DATA PAPER

RivFishTIME: A global database of fish time-series to study global change ecology in riverine systems

Running title: Time-series database of riverine fish communities

Lise Comte[1,*], Juan Carvajal-Quintero[2,3], Pablo A. Tedesco[2], Xingli Giam[1], Ulrich Brose[4,5], Tibor Erős[6], Ana Filipa Filipe[7,8], Marie-Josée Fortin[9], Katie Irving[10,11], Claire Jacquet[12,13], Stefano Larsen[14,15], Sapna Sharma[16], Albert Ruhi[17], Fernando G. Becker[18], Lilian Casatti[19], Giuseppe Castaldelli[20], Renato B. Dala-Corte[21], Stephen R. Davenport[22], Nathan R. Franssen[23], Emili García-Berthou[24], Anna Gavioli[20], Keith B. Gido[25], Luz Jimenez-Segura[26], Rafael P. Leitão[27], Bill McLarney[28], Jason Meador[28], Marco Milardi[29], David B. Moffatt[30], Thiago V. T. Occhi[31], Paulo S. Pompeu[32], David L. Propst[33], Mark Pyron[34], Gilberto N. Salvador[35], Jerome A. Stefferud[36], Tapio Sutela[37], Christopher Taylor[38], Akira Terui[39], Hirokazu Urabe[40], Teppo Vehanen[37], Jean R. S. Vitule[41], Jaquelini O. Zeni[19,42], Julian D. Olden[43]

[1]Department of Ecology and Evolutionary Biology, University of Tennessee, Knoxville, Knoxville, TN 37996, USA

[2]Research Unit 5174, Laboratoire Evolution et Diversité Biologique, CNRS, Institut de Recherche pour le Développement, Université Paul Sabatier, F-31062 Toulouse, France

[3]Laboratorio de Macroecología Evolutiva, Red de Biología Evolutiva, Instituto de Ecología, A.C., El Haya, 91070 Xalapa, Veracruz, Mexico

[4]German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, 04103 Leipzig, Germany

[5]Institute of Biodiversity, Friedrich-Schiller-University Jena, 07743 Jena, Germany

[6]Centre for Ecological Research, Balaton Limnological Institute, Klebelsberg K. u. 3. 8237 Tihany, Hungary

[7]CIBIO/InBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos da Universidade do Porto, 4485-661 Vairão, Portugal

[8]Instituto Superior de Agronomia, Universidade de Lisboa, 1349-017 Lisboa, Portugal

[9]Department of Ecology and Evolutionary Biology, University of Toronto, Toronto, Ontario, M5S 3B2, Canada

[10]Department of Ecosystem Research, Leibniz Institute of Freshwater Ecology and Inland Fisheries, 12587 Berlin, Germany

[11]Department of Biology, Chemistry and Pharmacy, Freie Universität Berlin, 14195 Berlin, Germany

[12]Department of Aquatic Ecology, Swiss Federal Institute of Aquatic Science and Technology, Eawag, Dübendorf, Switzerland

[13]Department of Evolutionary Biology and Environmental Studies, University of Zurich, Zürich, Switzerland

[14]Department of Civil, Environmental and Mechanical Engineering, University of Trento, Trento, Italy

[15]Computational Biology Unit, Research and Innovation Centre, Fondazione Edmund Mach, San Michele all'Adige, Italy

[16]Department of Biology, York University, 4700 Keele Street, Toronto, Ontario, M3J 1P3, Canada

[17]Department of Environmental Science, Policy, and Management, University of California, Berkeley, Berkeley, CA 94720, USA

[18]Department of Ecology, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil

[19]Department of Zoology and Botany, UNESP – São Paulo State University, São José do Rio Preto, SP, Brazil

[20] Department of Life Sciences and Biotechnology, University of Ferrara, via Luigi Borsari 46, 44121 Ferrara, Italy

[21]Department of Ecology, Universidade Federal de Goiás, Goiânia, GO, Brazil

[22]New Mexico Fish and Wildlife Conservation Office, 3800 Commons NE, Albuquerque, NM 87109, USA

[23]U.S. Fish and Wildlife Service, 2105 Osuna Rd NE, Albuquerque, NM 87113, USA

[24]GRECO, Institute of Aquatic Ecology, University of Girona, 17003 Girona, Catalonia, Spain

[25]Division of Biology, Kansas State University, Manhattan, KS 66506, USA

[26]Instituto de Biologia, Universidad de Antioquia, Calle 67 No.53-108 Medellin, Colombia

[27]Laboratório de Ecologia de Peixes, Department of Genetics, Ecology and Evolution, Federal University of Minas Gerais (UFMG), 31270-901, Belo Horizonte, MG, Brazil

[28]Mainspring Conservation Trust, Franklin, NC 28734, USA

[29]Fisheries New Zealand - Tini a Tangaroa, Ministry for Primary Industries - Manatū Ahu Matua, 34-38 Bowen Street, Pipitea 6011, Wellington, New Zealand

[30]Department of Environment and Science, Ecosciences Precinct, Dutton Park QLD 4102, Australia

[31]Department of Ecology and Conservation, Federal University of Paraná, Jardim das Américas, 81530-900 Curitiba, Brazil

[32]Department of Ecology and Conservation, University of Lavras (UFLA), 37200-900 Lavras, MG, Brazil

[33]Department of Biology, Museum of Southwestern Biology, University of New Mexico, Albuquerque, NM 87131, USA

[34]Department of Biology, Ball State University, Muncie, IN 47306, USA

[35]Ecology and Conservation Laboratory (LABECO), Federal University of Pará (UFPA), 66075-110, Belém, PA, Brazil

[36]USDA Forest Service (Retired), Phoenix, AR 85012, USA

[37]Natural Resources Institute Finland, Latokartanonkaari 9, 00790 Helsinki, Finland

[38]Department of Biology and School of Earth, Environmental, and Marine Sciences, University of Texas Rio Grande Valley, Edinburg, TX 78539, USA

[39]Department of Biology, University of North Carolina at Greensboro, Greensboro, NC 27412, USA

[40]Salmon and Freshwater Fisheries Research Institute, Hokkaido Research Organization, Eniwa, Hokkaido, Japan

[41]Department of Environmental Engineering, Federal University of Paraná, Curitiba, Jardim das Américas, 81530-900, Brazil

[42]Department of Ecology, UNESP – São Paulo State University, Rio Claro, SP, Brazil

[43]School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98105, USA

[*] **Corresponding author:** Lise Comte, Department of Ecology and Evolutionary Biology, The University of Tennessee, Knoxville, TN, USA

lcgcomte@gmail.com

Running title: Time-series database of riverine fish communities

ABSTRACT

Motivation: We compiled a global database of long-term riverine fish surveys from 46 regional and national monitoring programs as well as individual academic research efforts upon which numerous basic and applied questions in ecology and global change research can be explored. Such spatially- and temporally-extensive datasets have been lacking for freshwater systems compared to terrestrial ones.

Main types of variables contained: The database includes 11,386 time-series of riverine fish community catch data, including 646,270 species-specific abundance records together with metadata related to geographic location and sampling methodology of each time-series.

Spatial location and grain: The database contains 11,072 unique sampling locations (stream reach), spanning 19 countries, 5 biogeographic realms, and 402 hydrographic basins worldwide.

Time period and grain: The database encompasses the period 1951–2019. Each time-series is composed of a minimum of two yearly surveys (mean = 8 years) and represents a minimum time span of 10 years (mean = 19 years).

Major taxa and level of measurement: The database includes 944 species of ray-finned fishes (Class Actinopterygii).

Software format: .csv

Main conclusion: Our collective effort provides the most comprehensive long-term community database of riverine fishes to date. This unique database should interest ecologists who seek to understand the impacts of human activities on riverine fish biodiversity, and model and predict how fish communities will respond to future environmental change. Together, we hope it will promote advances in macroecological research in the freshwater realm.

KEYWORDS: species abundance; biodiversity; conservation; freshwater streams and rivers; Actinopterygii; temporal trends; worldwide

1| INTRODUCTION

Increasing awareness of the ongoing biodiversity crisis has motivated global initiatives to compile large-scale datasets of population and community abundance records that have been consistently sampled through recent times (Pereira & Cooper, 2006). Included among these are the Global Population Dynamics Database (Inchausti & Halley, 2001), the Living Planet Index database (Loh *et al.*, 2005), and more recently, the BioTIME database (Dornelas *et al.*, 2018). These databases have proven extremely useful and allowed major advancements in ecological research (e.g. Kendall *et al.*, 1998; Sibly *et al.*, 2005; Butchart *et al.*, 2010; Dornelas *et al.*, 2014); however, they remain highly biased towards terrestrial and marine assemblages (e.g. only 0.50% of the records concern riverine fishes in BioTIME, the most recent of these initiatives). This is unfortunate as effective strategic plans for conserving water resources that support human well-being and ecosystem integrity rely on access to comprehensive, pertinent, quantitative information regarding the status and trends of riverine biodiversity over regional to continental scales (Tickner *et al.*, 2020).

Long-term studies of riverine species are limited because they require highly specialized and time-consuming sampling methods. Furthermore, rivers in remote areas are often difficult to access (Olden *et al.*, 2010; Radinger *et al.*, 2019). Nevertheless, over the past few decades, large-scale policies have been enacted in response to the rapid degradation of freshwater resources, such as the Water Framework Directive in the EU (Hering *et al.*, 2004) and the Clean Water Act in the USA (Paulsen *et al.*, 2008), which require countries to monitor and evaluate the biological integrity of surface waters through time to adopt quality standards that restore and maintain ecological integrity (Kuehne *et al.*, 2017). Beyond these official national and regional monitoring programs, the temporal dynamics of riverine systems and their fish communities have also been assessed through various independent, though often local in extent, academic research programs (e.g. Gido, 2017; Matthews & Matthews, 2017). All of these institutional and academic monitoring efforts have produced considerable freshwater fish temporal data that remain largely inaccessible to the broader scientific community due to the inherent difficulty in gathering and harmonizing field data from disparate institutions and sampling protocols (Buss *et al.*, 2015).

To fill this important gap, we here present RivFishTIME, a compiled and curated database of long-term (≥ 10 years) surveys of riverine fish communities at a fine spatial (stream reach) and taxonomic (species) resolution, using data mining approaches to harmonize existing but currently fragmented biomonitoring data sets. Riverine fish are extremely diverse in spite of the small surface they inhabit on Earth: they represent about 40% of all known fish species while occupying <1% of available aquatic habitat ("the freshwater fish paradox" sensu Lévêque *et al.*, 2008 and Tedesco *et al.*, 2017). However, they are also among the most threatened taxonomic groups on Earth because of the convergence between the high concentration of biodiversity and the many pressures resulting from human uses of freshwater resources and habitat change (Reid *et al.*, 2019; Tickner *et al.*, 2020). The RivFishTIME database provides a unique opportunity to understand the rate, magnitude, and geography of biodiversity trends, and to identify opportunities to mitigate human impacts on riverine systems (Pereira & Cooper, 2006; Anderson, 2018). Due to the paucity of spatially- and temporally-extensive datasets in freshwater compared to terrestrial systems (Heino, 2011), RivFishTIME should also help ecologists close the gap between these two systems and to address a wider range of taxa in unraveling large-scale spatio-temporal biodiversity patterns.

2| METHODS

2.1| Data acquisition

We gathered time-series of fish community abundance data for riverine (lotic) ecosystems, broadly defined as freshwater bodies that are continually or intermittently flowing. We tried to the extent possible to exclude wetlands and brackish habitats (salinity > 0.5 ‰). Note, however, that due to the complex nature of the datasets, we do not guarantee that sites are located on free-flowing river segments (i.e. natural condition without impoundment, diversion, or other modification of the waterway). We used the following criteria for data inclusion: (1) the location of the sampling sites is known and consistent through time, (2) the sampling protocol is known and consistent through time, (3) the sampling survey sought to quantify all species in the fish community according to well-established protocols, (4) species-specific abundances are available for each survey, (5) surveys at a given site were conducted over a period of at least 10 years, and (6) at least two yearly surveys with non-null abundance are available. We considered abundance measures derived from direct fish counts, catch-effort indexes such as relative abundances (%) and catch per unit effort (CPUE), abundance classes, as well as statistically estimated abundances (e.g. Leslie method; Ricker, 1975).

To identify potential datasets, we used Google Search, Google Scholar and Dataset Search with different combinations of the keywords “time series”, “fish”, “abundance”, “stream”, “river”, “freshwater”, “community”, “temporal”, and “monitoring” or “monitoring program”. We screened the scientific as well as the grey literature to identify studies involving temporal datasets of fish communities and conducted similar searches in data repositories such as Dryad (https://datadryad.org/stash) and FigShare (https://figshare.com/). We also conducted targeted searches for national and regional monitoring programs by adding country names to the previous keywords. For the European Union, we further used the EuMon database as a reference to identify fish monitoring databases (available at http://eumon.ckff.si/about_daeumon.php).

We contacted all the authors and monitoring program coordinators to request and obtain permission to publish the data and/or ensure that the license under which the data were publicly released allowed their inclusion in our global effort (e.g. Open Government License, CC0 1.0 Universal). We excluded the datasets for which we did not receive permission, unless the reusability of data was clearly stated on the online repositories where the data were released.

2.2| Quality control

Taxonomy. We validated species scientific names using the online database Fishbase (Froese & Pauly, 2019). We used the R package *rfishbase* (as of December 2019; Boettiger *et al.*, 2012) and confirmed names with no match manually using the Catalog of Fishes (Fricke *et al.*, 2018). We then selected only records involving ray-finned fishes (Class Actinopterygii), excluding rays and lampreys, and unidentified species.

Coordinates. We harmonized the coordinate system by projecting (if necessary) the coordinates of the individual datasets using the World Geodetic System (WGS84) as reference geographic coordinate system. We visually inspected the spatial distribution of the sites with respect to their respective country, region, or state borders as given in the original data sources and discarded sites with dubious coordinates (e.g. sites located in the ocean). We also removed sites whose coordinates were located outside of any hydrographic basin using the global major river basin GIS layer in HydroSHEDS (Lehner *et al.*, 2008).

Consistent sampling methods. We excluded surveys lacking information on sampling methods and selected only time-series collected using a consistent sampling protocol through time. The latter evaluation was dataset-specific as dictated by the complexity of the monitoring scheme and the available metadata. For instance, surveys were deemed consistent if they did not experience any major deviation in sampling protocol, and disregarded minor variations (e.g. number of anodes or traps, area sampled) due to survey-specific constraints (e.g. water depth, habitat complexity). By contrast, several monitoring programs implemented alternate sampling protocols to compare the efficiency of different gears (e.g. seining versus electrofishing) or sampling methods (e.g. continuous versus point electrofishing); these time-series conducted at the same sites but using different sampling protocols were kept separate in the database.

Duplicates. We removed duplicates within individual datasets based on the coordinates of the sites, date of the survey, and species collected (e.g. due to different name attribution for the same site). We also identified potential duplicates among datasets (e.g. overlap between state-level and national databases) based on the coordinates of the sites rounded to three digits to account for different post-processing of the individual datasets.

2.3| Database formatting

Each entry (species abundance record) was assigned a unique (1) site, (2) survey, and (3) time-series identifier. The site ID corresponds to a given pair of coordinates, the survey ID to a sampling campaign, and the time-series ID to a combination of site × sampling protocol. We extracted the names of the sampled water bodies (e.g. creek, stream, river) from the available metadata associated with each individual dataset, that we cross-referenced against several continental and national geospatial river networks in GIS (e.g. Australian Hydrological Geospatial Fabric, Ordnance Survey Open Rivers). Additionally, each site ID was assigned to a biogeographic realm following Olson *et al.* (2001), hydrographic basin following HydroSheds (Lehner *et al.*, 2008), and administrative units (country, region and province) based on its coordinates. For each sampling ID, we aggregated abundance records if they were given separately for individuals, size classes or sub-species for each validated species name or if different sampling passes, hauls, or sub-sampling areas were considered. We also converted time-series species abundances to densities or CPUE whenever possible. The different surveys were kept independent when conducted on different occasions within the same calendar year. We provided the year together with the quarter of the survey (1: January-March; 2: April-June; 3: July-September, 4: October-December). We also provided the associated unit (abundance class, count, CPUE, individuals/100m^2, Leslie index, relative abundance) for each species abundance record. Finally, we extracted basic information regarding the sampling protocol, including details on electrofishing (backpack, shore-based or boat mounted electrofishers), netting (dip nets, gill nets, beach or pelagic seines), trapping (minnow traps, fyke nets or hoop nets), and trawling techniques. Many survey protocols involve a combination of sampling approaches, rendering challenging the inclusion of detailed information about the sampling effort in a standardized way. We therefore encourage the data user to refer to each data source for more information on the sampling methods.

The database is organized in three tables (.csv format): the time-series table, the survey table, and the information source table. The tables can be linked using the unique dataset source

ID and time-series ID. The time-series table contains: (1) source ID, (2) site ID, (3) time-series ID, (4) sampling method, (5) latitude (WGS 84), (6) longitude (WGS 84), (7) biogeographic realm, (8) hydrographic basin, (9) country (ISO code), (10) region, (11) province, and (12) water body. The survey table contains: (1) time-series ID, (2) survey ID, (3) sampling year, (4) sampling quarter, (5) species scientific name, (6) abundance, and (7) abundance unit. The information source table contains the full citation(s), online link to the raw data when publicly available, as well as the name(s) and contact of the data responsible(s) for each individual dataset. Data curation was performed in the *R* (3.6.0) programming environment (R Core Team, 2019).

A list of the data sources is found in Appendix 1; for further information consult the metadata. We provide a static version of the database with this article (1951-2019), but we aim to continue interacting with data contributors to update and add new time-series datasets to be released through the iDiv portal (https://idata.idiv.de/idiv/Content/Databases) and the more specialized Freshwater Biodiversity Data Portal (https://data.freshwaterbiodiversity.eu/).

3| RESULTS

Our database includes 11,386 time-series of riverine fish compiled from 46 individual source datasets, representing a total of 106,785 surveys and 646,270 individual species abundance records at 11,072 unique sites. Survey-specific species richness across all time-series ranges from 1 to 50 species, and covers 944 ray-finned fish species. The surveyed sites display a wide distribution along longitudinal and latitudinal gradients, spanning 19 countries, 402 hydrographic basins, and 5 biogeographic realms (Fig. 1a). Despite broad geographical coverage, we note a clear spatial bias towards the Palearctic (European Union) and, to a lesser extent, Nearctic (North America) and Australasia realms. The abundance time-series are largely represented by individual counts, followed by densities (individuals/100m^2) and CPUE (Fig. 1b). Abundance classes, Leslie index and relative abundance represent < 1% of the time-series. Electrofishing is by far the main sampling technique used to record the time-series, although variations are noticeable among biogeographic realms (Fig. 1c). For instance, dipnetting sampling techniques are only represented in the Neotropics, whereas gillnetting is the most common gear in the Afrotropics.

The time-series cover a time period from 1951 to 2019 and are mainly concentrated over the last two decades (average first year = 1996; Fig. 2a). Surveys have been conducted primarily in the 3rd (July-September) and 4th (October-December) quarters of the year, especially in the Palearctic and Nearctic realms (corresponding to periods of low flows), but all quarters are represented in the different biogeographic realms (Fig. 2b). The mean time span of the time-series is of 19 years and ranges from 10 to 68 years, with the longest time-series located in the Palearctic (Fig. 2c). The sites were sampled from (non-necessarily consecutive) 2 to 52 years, with an average number of yearly surveys of 8 years (Fig 2d). Again, the highest number of yearly surveys was found in the Palearctic. The completeness of the time-series (i.e. ratio of number of yearly surveys to the overall time span) ranges from 4 to 100%, with a mean value of 45% (Figure 2e). Importantly, the degree of completeness is largely uncorrelated to the time span of the time-series ($r = 0.05$).

4| CONCLUSIONS

Our collective effort provides the most comprehensive long-term community database of riverine fishes to date, spanning large biogeographic, climatic and hydrographic gradients. Almost all biogeographic realms are represented but it is important to note that our database is not exempt from spatial bias. For instance, less than 1% of the time-series belong to the Afrotropic or Neotropic realms, whereas 84% belong to the Palearctic realm. These spatial gaps often present in biodiversity-rich regions (tropical areas, southeast Asia) are likely to mirror the current networks of freshwater monitoring programs (Buss *et al.*, 2015; Radinger *et al.*, 2019) as well as biodiversity research efforts (Martin *et al.*, 2012), and hence will be prioritized in future updates of RivFishTIME. We also warn data users that species abundance may not be directly comparable across sites without a full understanding of the specifics of sampling approach and effort, with respect to their selectivity and efficiency (Goffaux *et al.*, 2005; Portt *et al.*, 2006; Oliveira *et al.*, 2014; Benejam *et al.*, 2012), and refer to the original data sources for more information about the sampling protocols.

Despite these unavoidable limitations associated with secondary datasets collected for multiple purposes, we are confident that RivFishTIME will stimulate new research in the fields of global change ecology and macroecology. First and foremost, it will provide the needed baseline information for conservation and restoration efforts to bend the curve of freshwater biodiversity loss (Tickner *et al.*, 2020). For instance, the fish abundance time-series could be used to assess population or community trends in different rivers of the world, broadening the taxonomic and spatial representation of existing indicators of the status of global biodiversity (e.g. Living Planet Index). Coupled with high-resolution environmental time-series, this unique database could also help to decipher the underlying drivers of biodiversity changes in riverine systems, including (but not limited to) habitat fragmentation and destruction, invasive species, pollution, hydrologic alteration and climate change (e.g. Chen & Olden, 2020, Erős *et al.,* 2020). In turn, this knowledge could be integrated into ecological models used to forecast how fish communities will respond to future environmental change, paving the way to mitigate those impacts. RivFishTIME could also offer new macroecological insights into the implications of river network complexity on community structure and assembly processes across extensive environmental gradients (e.g. community composition, population persistence, spatial synchrony in community dynamics) – questions that have long fascinated ecologists but have been so far primarily explored through theoretical approaches.

REFERENCES

Anderson, C.B. (2018) Biodiversity monitoring, earth observations and the ecology of scale. *Ecology Letters*, **21**, 1572–1585.

Benejam, L., Alcaraz, C., Benito, J., Caiola, N., Casals, F., Maceda-Veiga, A., … García-Berthou, E. (2012). Fish catchability and comparison of four electrofishing crews in Mediterranean streams. *Fisheries Research*, **123-124**: 9–15.

Boettiger, C., Lang, D.T. & Wainwright, P.C. (2012) rfishbase: exploring, manipulating and visualizing FishBase data from R. *Journal of fish biology*, **81**, 2030–2039.

Buss, D.F., Carlisle, D.M., Chon, T.S., Culp, J., Harding, J.S., Keizer-Vlek, … Hughes, R.M. (2015) Stream biomonitoring using macroinvertebrates around the globe: a comparison of large-scale programs. *Environmental Monitoring and Assessment*, **187**.

Butchart, S.H.M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J.P.W., Almond, R.E.A., Baillie, J.E.M., … Watson, R. (2010) Global biodiversity: Indicators of recent declines. *Science*, **328**, 1164–1168.

Dornelas, M., Antão, L.H., Moyes, F., Bates, A.E., Magurran, A.E., Adam, D., Akhmetzhanova, A.A., … Zettler, M.L. (2018) BioTIME: A database of biodiversity time series for the Anthropocene. *Global Ecology and Biogeography*, **27**, 760–786.

Dornelas, M., Gotelli, N.J., McGill, B., Shimadzu, H., Moyes, F., Sievers, C. & Magurran, A.E. (2014) Assemblage time series reveal biodiversity change but not systematic loss. *Science*, **344**, 296–299.

Chen, K., & Olden, J.D. (2020). Threshold responses of riverine fish communities to land use conversion across regions of the world. *Global Change Biology*, **26**, 4952–4965.

Erős, T., Comte, L., Filipe, A.F., Ruhi, A., Tedesco, P.A., Brose, U., Fortin, M.-J., … Olden, J.D. (2020) Effects of nonnative species on the stability of riverine fish communities. *Ecography*, **43**, 1156–1166.

Fricke, R., Eschmeyer, W.N. & van der Laan, R. (eds.) (2018) Catalogue of fishes: Genera, species, references. http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp. Electronic version accessed December 2020.

Froese, R. & Pauly, D. (eds.) (2019) FishBase. World Wide Web electronic publication. Available at http://www.fishbase.org.

Gido, K. (2017) CFC01 Kings Creek long-term fish and crayfish community sampling at Konza at Konza Prairie [Data set]. *Environmental Data Initiative*.

Goffaux, D., Grenouillet, G. & Kestemont, P. (2005) Electrofishing versus gillnet sampling for the assessment of fish assemblages in large rivers. *Archiv für Hydrobiologie*, **162**, 73–90.

Heino, J. (2011) A macroecological perspective of diversity patterns in the freshwater realm. *Freshwater Biology*, **56**, 1703–1722.

Hering, D., Verdonschot, P.F.M., Moog, O. & Sandin, L. (eds.) (2004) *Integrated assessment of running waters in Europe*. Springer, Dordrecht.

Inchausti, P. & Halley, J. (2001) Investigating long-term ecological variability using the global population dynamics database. *Science*, **293**, 655–657.

Kendall, B.E., Prendergast, J. & Bjørnstad, O.N. (1998) The macroecology of population dynamics: taxonomic and biogeographic patterns in population cycles. *Ecology Letters*, **1**, 160–164.

Kuehne, L., Olden, J.D., Strecker, A., Lawler, J.J., & Theobald. D. (2017) Past, present, and future of ecological integrity assessment for fresh waters. *Frontiers in Ecology and the Environment,* 15, 197–205.

Lehner, B., Verdin, K. & Jarvis, A. (2008) New global hydrography derived from spaceborne elevation data. *Eos, Transactions American Geophysical Union*, **89**, 93.

Lévêque, C., Oberdorff, T., Paugy, D., Stiassny, M.L.J. & Tedesco, P.A. (2008) Global diversity of fish (Pisces) in freshwater. *Hydrobiologia*, **595**, 545–567.

Loh, J., Green, R.E., Ricketts, T., Lamoreux, J., Jenkins, M., Kapos, V. & Randers, J. (2005) The Living Planet Index: using species population time series to track trends in biodiversity. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **360**, 289–295.

Martin, L.J., Blossey, B. & Ellis, E. (2012) Mapping where ecologists work: biases in the global distribution of terrestrial ecological observations. *Frontiers in Ecology and the Environment*, **10**, 195–201.

Matthews, W.J. & Marsh-Matthews, E. (2017) *Stream fish community dynamics. A Critical Synthesis*, Johns Hopkins University Press, Baltimore, Maryland.

Olden, J.D., Kennard, M.K., Leprieur, F., Tedesco, P.A., Winemiller, K.O & García-Berthou, E. (2010) Conservation biogeography of freshwater fishes: past progress and future directions. *Diversity and Distributions,* **16,** 496–513.

Oliveira, A.G., Gomes, L.C., Latini, J.D. & Agostinho, A.A. (2014) Implications of using a variety of fishing strategies and sampling techniques across different biotopes to determine fish species composition and diversity. *Natureza & Conservação*, **12**, 112–117.

Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G.V.N., Underwood, E.C., … Kassem, K.R. (2001) Terrestrial Ecoregions of the World: A New Map of Life on Earth: A new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. *BioScience*, **51**, 933–938.

Paulsen, S.G., Mayio, A., Peck, D. V., Stoddard, J.L., Tarquinio, E., Holdsworth, S.M., Sickle, J. Van, … Olsen, A.R. (2008) Condition of stream ecosystems in the US: an overview of the first national assessment. *Journal of the North American Benthological Society*, **27**, 812–821.

Pereira, H. & Cooper, H.D. (2006) Towards the global monitoring of biodiversity change. *Trends in Ecology & Evolution*, **21**, 123–129.

Portt, C.B., Coker, G.A., Ming, D.L. & Randall., R.G. (2006) A review of fish sampling methods commonly used in Canadian freshwater habitats. *Canadian technical report of fisheries and aquatic sciences*, **2604**, 1–58.

R Core Team (2019) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Radinger, J., Britton, J.R., Carlson, S.M., Magurran, A.E., Alcaraz-Hernández, J.D., Almodóvar, A., … García-Berthou, E. (2019) Effective monitoring of freshwater fish. *Fish and Fisheries*, **20**, 729–747.

Reid, A.J., Carlson, A.K., Creed, I.F., Eliason, E.J., Gell, P.A., Johnson, P.T.J., … Cooke, S.J. (2019) Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews*, **94**, 849–873.

Revenga, C., Campbell, I., Abell, R., de Villiers, P. & Bryer, M. (2005) Prospects for monitoring freshwater ecosystems towards the 2010 targets. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **360**, 397–413.

Ricker, W.E. (1975) Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board of Canada*, **191**, 1–332.

Sibly, R.M., Barker, D., Denham, M.C., Hone, J. & Pagel, M. (2005) On the regulation of populations of mammals, birds, fish, and insects. *Science*, **309**, 607–610.

Tedesco, P.A., Paradis, E., Lévêque, C. & Hugueny, B. (2017) Explaining global-scale diversification patterns in actinopterygian fishes. *Journal of Biogeography*, **44**, 773–783.

Tickner, D., Opperman, J.J., Abell, R., Acreman, M., Arthington, A.H., Bunn, S.E., … Young, L. (2020) Bending the curve of global freshwater biodiversity loss: An emergency recovery plan. *BioScience*, **70**, 330–342.

Data Storage and Documentation

We provide a temporary link to the database at https://figshare.com/s/97c447c4f16d92baf254 (confidential; for review purposes only). The database and associated DOI will be made publicly available through the iDiv portal (https://idata.idiv.de/idiv/Content/Databases) upon publication.

ACKNOWLEDGMENTS

The data compilation is the result of a joint effort of the international working group “sYNGEO - The geography of synchrony in dendritic networks” kindly supported by sDiv, the Synthesis Centre of the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, funded by the German Research Foundation (FZT 118). We thank the iDiv Biodiversity Informatics unit and Jitendra Gaikwad for the support received to prepare, upload and scrutinize dataset integrity. We also would like to thank Angelo Agostinho, Agencia Catalana del Agua, Agencia Vasca del Agua, Jammes Gammon, Iowa Department of Natural Resources, William Matthews, Edie Marsh-Matthews, Minnesota Pollution Control Agency, Montana Fish, Wildlife & Parks, Murray-Darling Basin Authority, North Carolina Department of Environmental Quality, Okavango Research Institute, Oklahoma Water Resources Board, Office Français de la Biodiversité (OFB), Parks Canada, Vincent Resh, John Rinne, Swedish University of Agricultural Sciences, Toronto and Region Conservation Authority, U.K. Environmental Agency, Upper Midwest Environmental Sciences Center, U.S. Environmental Protection Agency, U.S. Geological Survey and Gerlinde Van Thuyne for making their monitoring data available. Data collection for the SourceID #2 was supported by Fapesp - São Paulo Research Foundation through the research grants to J.O.Z. (Processes Numbers: 2012/20280-5 and 2015/04366-5) and LC (Processes Numbers: 2001/13340-7, 2012/05983-0) and CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) through the research grant provided to LC (Process Number: 301877/2017-3). Data collection for the SourceID #3 was supported by

Convenio CT-2017- 001714 between University of Antioquia and Empresas Publicas de Medellin. Part of the data collection for the SourceID #4 was supported by the GINOP-2.3.2.-15-2016-00004 project. Data for the SourceID #6 were collected by the Queensland Department of Environment and Science in collaboration with Healthy Land and Water Limited. Data collection for the SourceID #10 was supported by the New Mexico Department of Game and Fish. We acknowledge CNPq for research grants provided to J.R.S.V. (Process Numbers:302367/2018-7 and 303776/2015-3) [SourceID #13], and the Japan Society for the Promotion of Science KAKENHI Grant 18K06404 to A.T. [SourceID #14]. We also acknowledge the assistance of Dr. Stefano Porcellotti, Dr. Simona Piccini (UTR Grosseto) and Dr. Lorena Di Iulio Chiacchia (UTR Prato), who kindly helped with original data retrieval for the SourceID #16. Data collection for the SourceID #17 (Ivory Coast) was supported by the World Health Organisation (WHO), Onchocerciasis Control Programme (OCP). Data collection for the SourceID #18 was supported by the United States Fish and Wildlife Service and Oklahoma Department of Wildlife Conservation through Endangered Species Act funding (Project E-12). Data collection for the SourceID #19 (Kings Creek watershed) was supported by the NSF Long-Term Ecological Research Program at Konza Prairie Biological Station. Data collection for the SourceID #20 (Upper Little Tennessee River Watershed) was supported by Brad Stanback, Janirve Foundation, Macon County Community Foundation, Merck Family Fund, National Fish and Wildlife Foundation, National Forest Foundation, NC Division of Water Quality, NC Wildlife Resources Commission, Norcross Foundation, River Network, Southern Appalachian Man and the Biosphere Foundation, Tennessee Valley Authority, World Wildlife Fund, and Z. Smith Reynolds Foundation. Data collection for the SourceID #29 was supported by the Companhia Energética de Minas Gerais (P&D ANEEL/CEMIG GT-487 and GT-599), Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and CNPq. Data collection for the SourceID #35 (Upper Paraná River) was supported by the Long-Term Research Program / CNPq-Sitio 6, carried out by Nupélia / UEM (Núcleo de Pesquisas em Limnologia, Ictiologia e Aquicultura/Universidade Estadual de Maringá). R.B.D.C. received a scholarship from CAPES and F.G.B. received a student scholarship from CNPq and financial support from WWF (Programa Natureza e Sociedade) for sampling done in 1999 [SourceID #37]. Data collection for the SourceID #40 was supported by the New Mexico Department of Game and Fish. Data collection for the SourceID #43 was supported by various town councils and the Catalan Water Agency through the "Observatori de la Tordera" project (led by Dr Martí Boada).

DATA AVAILABILITY

RivFishTIME is publicly available through the iDiv Biodiversity Portal: https://doi.org/10.25829/idiv.1873-10-4000. We kindly ask the users to cite this paper as well as the source of each primary dataset in any published material produced using these data. We encourage any potential data contributor to contact LC with possible datasets to expand the database. Updates of RivFishTIME will be curated through the iDiv Biodiversity Portal and also released through the more specialized Freshwater Biodiversity Data Portal (https://data.freshwaterbiodiversity.eu/).

BIOSKETCH

Lise Comte is a global change ecologist who is interested in the mechanisms shaping the (re)distribution of biodiversity in an era of global environmental change, with a special emphasis on freshwater fish. All co-authors share the common goal of advancing freshwater biodiversity conservation and hope that RivFishTIME will generate new knowledge to help bend the curve of global freshwater biodiversity loss.

FIGURES

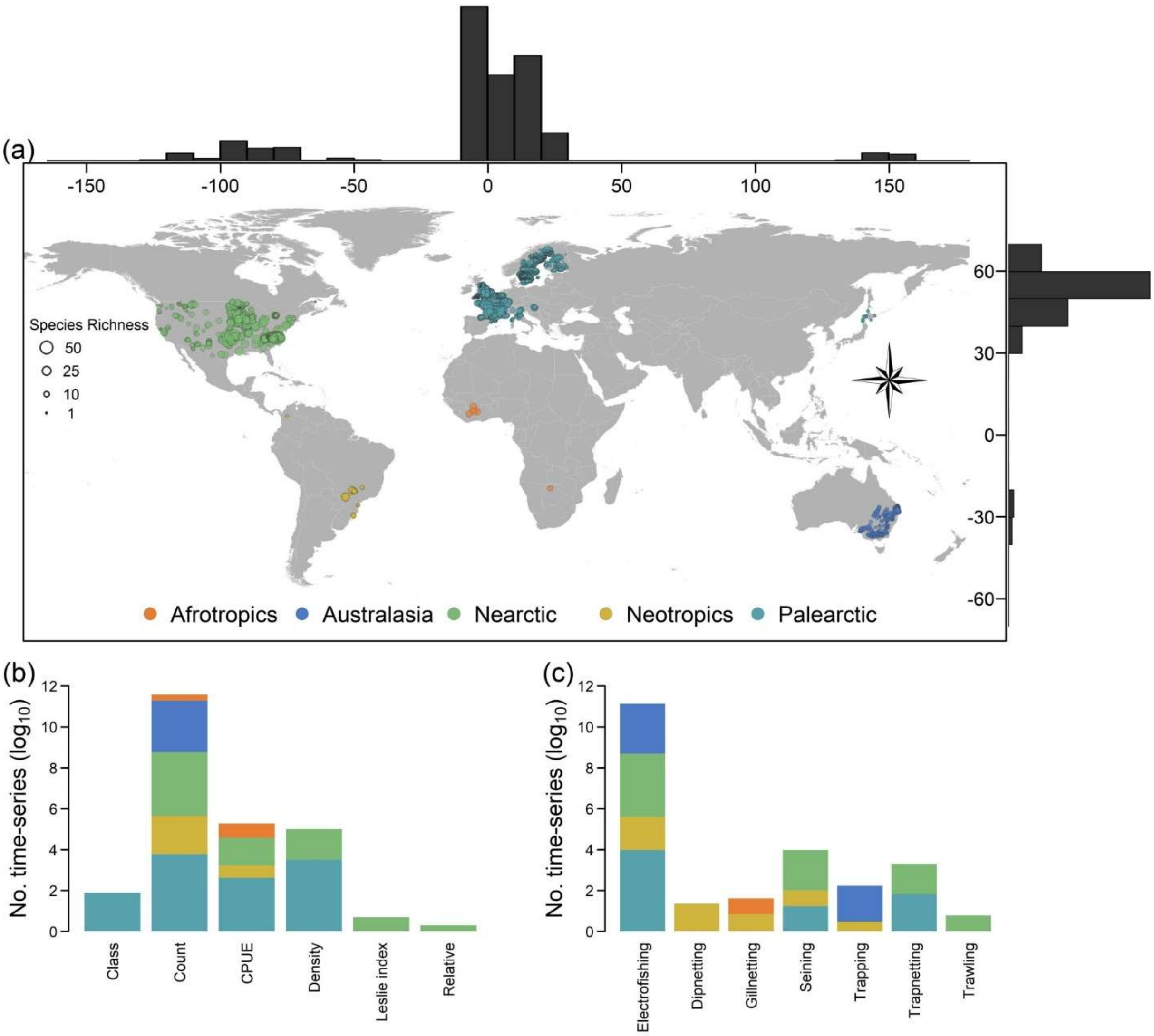

Figure 1. (a) Map showing the distribution of the time-series where each time-series is represented by a dot with colors indicating the biogeographic realm and size representing fish species richness (averaged across surveys). Inset histograms display the distribution of the time-series according to latitude and longitude. Barplots show the distribution of the time-series with respect to the (b) type of abundance, and (c) primary sampling method. Note the $\log_{10}(x+1)$ *y*-axes in (b)-(c).

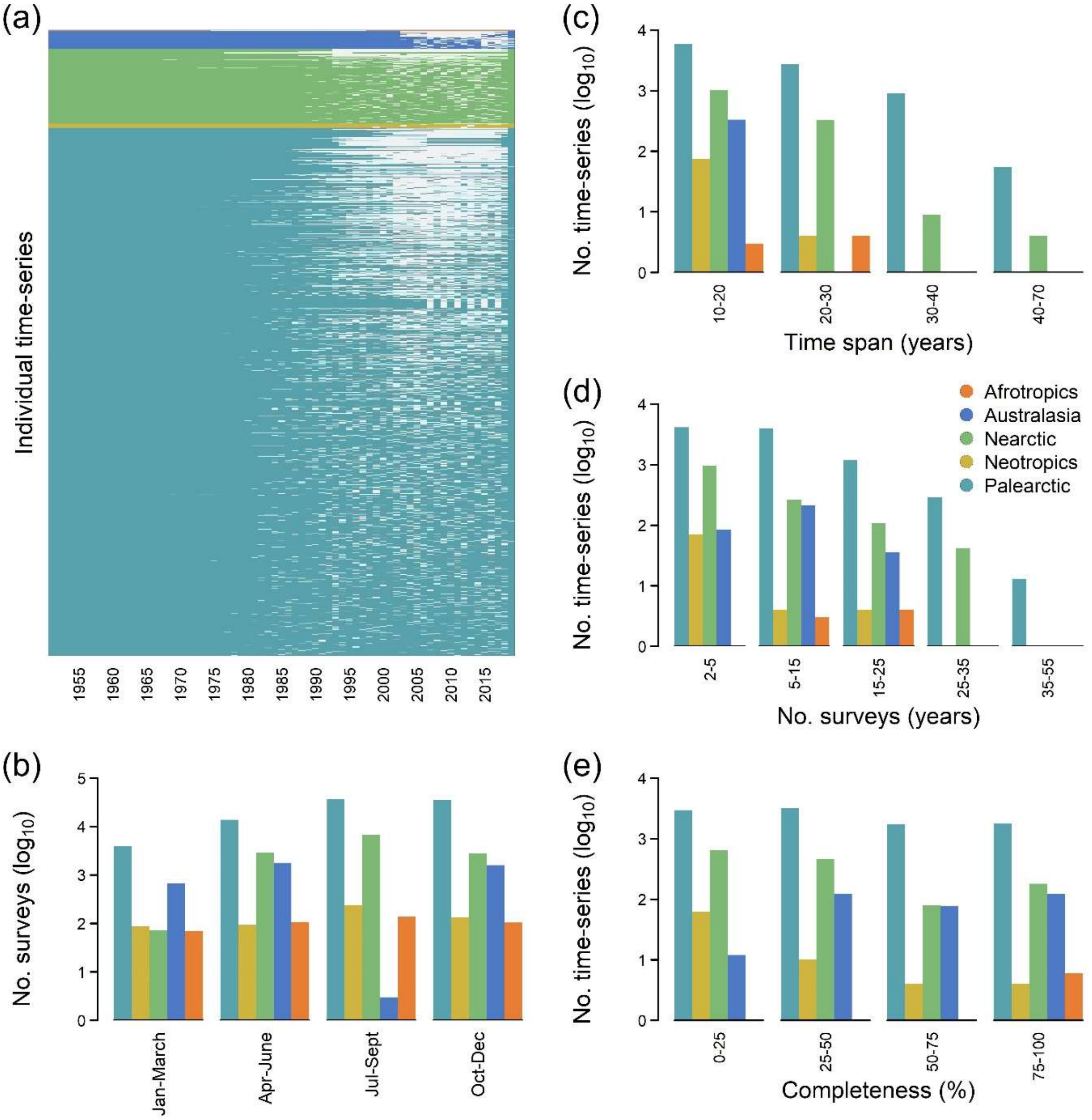

Figure 2. (a) Temporal distribution of the yearly surveys relative to the period covered by the database (1951-2019). Each time-series appears in rows where the background colors correspond to the biogeographical realms and white indicates sampled years. (b) Temporal distribution of the surveys with respect to the quarter of the year. Temporal characteristics of the time-series with respect to the (c) overall time span, (d) number of yearly surveys, and (e) completeness defined as the ratio between the number of yearly surveys and the overall time span (expressed in %). Note the $\log_{10}(x+1)$ *y*-axes in (b)-(e).

Appendix 1 - Data sources

SourceID	Citations	URLaccess
1	Agència Catalana de l'Aigua (2003); Agència Catalana de l'Aigua (2010); Agència Catalana de l'Aigua (2018)	http://aca.gencat.cat/
2	Zeni *et al.* (2017); Casatti *et al.* (2009)	_
3	Universidad de Antioquia-Empresas Publicas de Medellin (2019)	_
4	Erős *et al.* (2014)	_
5	Gammon (2013)	_
6	Ecosystem Health Monitoring Program Queensland (2019)	https://hlw.org.au/report-card/
7	Finnish electrofishing register Hertta (2019)	https://wwwp2.ymparisto.fi/koekalastus_sahko/yhteinen/Login.aspx?ReturnUrl=%2fkoekalastus_sahko
8	Sigouin (2017)	https://open.canada.ca/data/en/dataset/fe2441a6-8ae4-4884-b181-cd7ec53bd842
9	Whitney *et al.* (2016)	_
10	Gido *et al.* (2013); Gido *et al.* (2019)	_
11	Kesner and Marsh (2010)	https://www.rosemonteis.us/documents/kesner-marsh-2010
12	Griffith (2017); Griffith *et al.* (2018)	https://doi.org/10.23719/1376690
13	Occhi, V. T. & Vitule, J. R. S. (Unpublished data)	_

14	Terui *et al.* (2018)	–
15	Iowa DNR (2013)	https://data.iowa.gov/Environment/BioNet/e7yf-f5fs
16	Milardi *et al.* (2020)	–
17	Levêque *et al.* (2003)	–
18	Pyron *et al.* (1998)	–
19	Gido (2017)	https://doi.org/10.6073/pasta/150e218b069074a8ecede85a7406d43f
20	McLarney *et al.* (2013)	http://coweeta.uga.edu/dbpublic/personnel_bios.asp?id=wmclarney
21	Long Term Resource Monitoring Program (2016)	https://www.umesc.usgs.gov/data_library/fisheries/fish1_query.shtml
22	Matthews and Marsh-Matthews (2017)	https://doi.org/10.5061/dryad.2435k
23	Murray-Darling Basin Authority (2018)	https://data.gov.au/data/dataset/murray-darling-basin-fish-and-macroinvertebrate-survey
24	Minnesota Pollution Control Agency (2018)	https://cf.pca.state.mn.us/water/watershedweb/wdip/search_more.cfm?datatype=assessments
25	Montana, Fish, Wildlife & Parks (2019)	http://gis-mtfwp.opendata.arcgis.com/items/8192e75218c6460ba97ba3dd0a2fb3a5
26	U.S. Geological Survey (2019)	https://aquatic.biodata.usgs.gov/clearCriteria.action
27	U.K. Environmental Agency (2019)	https://data.gov.uk/dataset/d129b21c-9e59-4913-91d2-82faef1862dd/nfpd-freshwater-fish-survey-relational-datasets

28	North Carolina Department of Environmental Quality (2018)	https://deq.nc.gov/about/divisions/water-resources/water-resources-data/water-sciences-home-page/ecosystems-branch/fish-stream-assessment-program
29	Fagundes *et al.* (2015)	_
30	Winston *et al.* (1991); Taylor (2010)	https://onlinelibrary.wiley.com/doi/full/10.1111/fwb.13211
31	Mosie and Makati (2018)	https://www.gbif.org/dataset/77929c0a-7506-4b2d-a49d-10fc3312d50d
32	Office Francais de la Biodiversite (2019)	http://www.naiades.eaufrance.fr/acces-donnees#/hydrobiologie
33	Oklahoma Water Resources Board (2019)	http://home-owrb.opendata.arcgis.com/search?tags=fish
34	Agencia Vasca del Agua (2019)	http://www.uragentzia.euskadi.eus/informazioa/ubegi/u81-0003341/eu/
35	Ortega *et al.* (2015)	_
36	Davenport, S.R. (Unpublished data)	_
37	Dala-Corte *et al.* (2017)	_
38	Bêche *et al.* (2009); The Resh Lab (2019)	https://nature.berkeley.edu/reshlab/
39	Toronto and Region Conservation Authority (2018)	https://data.trca.ca/dataset/2018-watershed-fish-community
40	U.S. Fish and Wildlife Service (2017)	_
41	Stefferud, J. A. (Unpublished data)	_

42	Sers (2013)	https://www.slu.se/en/departments/aquatic-resources1/databases1/database-for-testfishing-in-streams/
43	Benejam *et al.* (2010); Merciai *et al.* (2017)	–
44	Miyazono and Taylor (2015)	https://bioone.org/journals/The-Southwestern-Naturalist/volume-60/issue-1/MP-02.1/Long-term-changes-in-seasonal-fish-assemblage-dynamics-in-an/10.1894/MP-02.1.short
45	Rinne & Miller (2006)	–
46	Van Thuyne *et al.* (2013); Brosens *et al.* (2015)	https://ipt.inbo.be/resource?r=vis-inland-occurrences

References

Agència Catalana de l'Aigua (2003) *Desenvolupament d'un índex d'integritat biòtica (IBICAT) basat en l'ús dels peixos com a indicadors de la qualitat ambiental dels rius a Catalunya*. Aplicació de la Directiva Marc en Política d'Aigües de la Unió Europea (2000/60/CE). 207 pages.

Agència Catalana de l'Aigua (2010) *Ajust de l'Índex d'Integritat Biòtica (IBICAT) basat en l'ús dels peixos com a indicadors de la qualitat ambiental als rius de Catalunya*. Departament de Medi Ambient i Habitatge, Generalitat de Catalunya. 187 pages.

Agència Catalana de l'Aigua (2018) ACORD GOV/139/2013, de 15 d'octubre, pel qual s'aprova el Programa de seguiment i control del Districte de conca fluvial de Catalunya per al període 2013-2018.

Agencia Vasca del Agua (2019) UBEGI. Información sobre el estado de las masas de agua de la CAPV. Available at http://www.uragentzia.euskadi.eus/informacion/ubegi/u81-0003341/es/ [Accessed 10/10/2019].

Bêche, L.A., Connors, P.G., Resh, V.H. & Merenlender, A.M. (2009) Resilience of fishes and invertebrates to prolonged drought in two California streams. *Ecography*, **32**, 778–788.

Benejam, L., Angermeier, P.L., Munné, A. & García-Berthou, E. (2010) Assessing effects of water abstraction on fish assemblages in Mediterranean streams. *Freshwater Biology*, **55**, 628–642.

Brosens, D., Breine, J., Van Thuyne, G., Belpaire, C., Desmet, P. & Verreycken, H. (2015) VIS – A database on the distribution of fishes in inland and estuarine waters in Flanders, Belgium. *ZooKeys*, **475**, 119-145.

Bunn, S.E., Abal, E.G., Smith, M.J., Choy, S.C., Fellows, C.S., Harch, B.D., … Sheldon, F. (2010) Integration of science and monitoring of river ecosystem health to guide investments in catchment protection and rehabilitation. *Freshwater Biology*, **55**, 223–240.

Casatti, L., Ferreira, C.P. & Carvalho, F.R. (2009) Grass-dominated stream sites exhibit low fish species diversity and dominance by guppies: an assessment of two tropical pasture river basins. *Hydrobiologia*, **632**, 273–283.

Dala-Corte, R.B, Becker, F.G. & Melo, A.S. (2017) The importance of metacommunity processes for long-term turnover of riffle-dwelling fish assemblages depends on spatial position within a dendritic network. *Canadian Journal of Fisheries and Aquatic Sciences*, **74**, 101–115.

Erős, T., Sály, P., Takács, P., Higgins, C.L., Bíró, P. & Schmera, D. (2014) Quantifying temporal variability in the metacommunity structure of stream fishes: the influence of non-native species and environmental drivers. *Hydrobiologia*, **722**, 31–43.

Fagundes, D.C., Leal, C.G., Carvalho, D.R., Junqueira, N.T., Langeani, F. & Pompeu, P.S. (2015) The stream fish fauna from three regions of the Upper Paraná River basin. *Biota Neotropica*, **15**, 1–8.

Finnish electrofishing register Hertta (2019) Available at https://wwwp2.ymparisto.fi/koekalastus_sahko/yhteinen/Login.aspx?ReturnUrl=%2fkoekalastus_sahko [Accessed on 04/09/2019].

Gammon, J. (2003) The fish communities of Big Raccoon Creek 1981-2002. Report for Heritage Environmental Services. Indianapolis, Indiana. 258 pages.

Gido, K. (2017) CFC01 Kings Creek long-term fish and crayfish community sampling at Konza Prairie. Environmental Data Initiative. Available at https://doi.org/10.6073/pasta/150e218b069074a8ecede85a7406d43f [Accessed on 11/18/2019].

Gido, K.B, Propst, D.L., Olden, J.D., & Bestgen, K.R. (2013) Multidecadal responses of native and introduced fishes to natural and altered flow regimes in the American Southwest. *Canadian Journal Fisheries and Aquatic Sciences*, **70**, 554–564.

Gido, K.B, Propst, D.L., Whitney, J.E., Hedden, S.C., Turner, T.F. & Pilger, T.J. (2019) Pockets of resistance: Response of arid-land fish communities to climate, hydrology, and wildfire. *Freshwater Biology*, **64**, 761–777.

Griffith, M. (2017) Combined Fish Data. U.S. EPA Office of Research and Development (ORD), doi: 10.23719/1376690.

Griffith, M., Zheng, L. & Cormier, S. (2018) Using extirpation to evaluate ionic tolerance of freshwater fish. *Environmental Toxicology and Chemistry*, **37**, 871–883.

Iowa DNR [Department of Natural Resources] (2013) BioNet - Iowa DNR Biological Monitoring and Assessment Database. Available at https://programs.iowadnr.gov/bionet/ [Accessed on 02/01/2018].

Kesner, B.R. & Marsh, P.C. (2010) Central Arizona project fish monitoring: Final report. Analysis of fish population monitoring data for selected waters of the Gila River Basin, Arizona, for the five year period 2005-2009. Contract No. R09PD32013. Submitted to U.S. Bureau of Reclamation. Tempe, Arizona: Marsh and Associates, LLC. 50 pages.

Levêque, C., Hougard, J.M., Resh, V., Statzner, B. & Yaméogo, L. (2003) Freshwater ecology and biodiversity in the tropics: what did we learn from 30 years of onchocerciasis control and the associated biomonitoring of West African rivers? *Hydrobiologia*, **500**, 23–49.

Long Term Resource Monitoring Program (2016) Available at https://www.umesc.usgs.gov/data_library/fisheries/fish1_query.shtml [Accessed on 06/09/2019].

Matthews, W.J. & Marsh-Matthews, E. (2017) Data from: *Stream fish community dynamics: a critical synthesis*, Dryad, Dataset, doi: 10.5061/dryad.2435k.

McLarney, W.O., Meador, J. & Chamblee, J. (2013) Upper Little Tennessee River biomonitoring program database. Coweeta Long Term Ecological Research Program. Available at: https://coweeta.uga.edu/dbpublic/dataset_details.asp?accession54045 [Accessed on 11/15/2019].

Merciai, R., Molons-Sierra, C., Sabater, S. & García-Berthou, E. (2017) Water abstraction affects abundance, size-structure and growth of two threatened cyprinid fishes. *Plos One*, **12**, e0175932.

Milardi, M., Gavioli, A., Soana, E., Lanzoni, M., Fano, E.A. & Castaldelli, G. (2020) The role of species introduction in modifying the functional diversity of native communities. *Science of the Total Environment*, **699**, 134364.

Minnesota Pollution Control Agency (2018) Surface water data. Available at https://cf.pca.state.mn.us/water/watershedweb/wdip/search_more.cfm?datatype=assessments [Accessed on 04/03/2019].

Miyazono, S. & Taylor, C.M. (2015) Long-term changes in seasonal fish assemblage dynamics in an adventitious desert stream. *The Southwestern Naturalist*, **60**, 72–79.

Montana, Fish, Wildlife & Parks (2019) Fish Survey Sites. Available at http://gis-mtfwp.opendata.arcgis.com/datasets/8192e75218c6460ba97ba3dd0a2fb3a5 [Accessed on 05/21/2019].

Mosie, I. & Makati, K. (2018) Long term time-series data on fish monitoring by Okavango Research Institute, Botswana. Version 1.2. Okavango Research Institute. Available at https://www.gbif.org/dataset/77929c0a-7506-4b2d-a49d-10fc3312d50d [Accessed on 05/11/2019], doi: 10.15468/4vvwzc.

Murray-Darling Basin Authority (2018) Murray-Darling Basin Fish and Macroinvertebrate Survey. Available at https://data.gov.au/data/dataset/7826d7c9-bcc5-48c0-832a-66aaedfe7b0f [Accessed on 10/15/2019].

North Carolina Department of Environmental Quality (2018) Fish Community Assessment Data. Available at https://deq.nc.gov/about/divisions/water-resources/water-resources-data/water-sciences-home-page/biological-assessment-branch/fish-community [Accessed on 02/06/2018].

Office Français de la Biodiversité (2019) Suivi des éléments biologiques 'POISSONS' des rivières françaises. Available at http://www.naiades.eaufrance.fr/acces-donnees#/hydrobiologie [Accessed on 07/08/2019].

Oklahoma Water Resources Board (2019) OWRB Open Data. Available at http://home-owrb.opendata.arcgis.com/search?tags=fish [Accessed on 10/16/2019].

Ortega, J.C.G., Dias, R.M., Petry, A.C., Oliveira, E.F. & Agostinho, A.A. (2015) Spatio-temporal organization patterns in the fish assemblages of a Neotropical floodplain. *Hydrobiologia*, **745**, 31–41.

Pyron, M., Vaughn, C.C., Winston, M.R. & Pigg J. (1998) Fish assemblage structure from 20 years of collections in the Kiamichi River, Oklahoma. *Southwestern Naturalist*, **43**, 336–343.

Rinne, J.N., & Miller, D. (2006) Hydrology, geomorphology and management: implications for sustainability of native southwestern fishes. *Reviews in Fisheries Sciences* **14**, 91–110.

Sers, B. (2013) Swedish Electrofishing RegiSter – SERS. Swedish University of Agricultural Sciences (SLU), Department of Aquatic Resources. Available at http://www.slu.se/elfiskeregistret [Accessed on 11/18/2019].

Sigouin, D. (2017) Fish Communities – Forillon, dataset fe2441a6-8ae4-4884-b181-cd7ec53bd842. Available at https://open.canada.ca/data/en/dataset/fe2441a6-8ae4-4884-b181-cd7ec53bd842 [Accessed on 05/07/2019].

Taylor, C.M. (2010) Covariation among plains stream fish assemblages, flow regimes, and patterns of water use. *In: Community ecology of stream fishes: concepts, approaches, and techniques.* American Fisheries Society Symposium, 2010.

The Resh Lab (2019) Hunting Creek and Knoxville Creek long-term data. Available at: https://nature.berkeley.edu/reshlab/data/HCKC_fish.xls [Accessed 05/19/2019].

Terui, A., Ishiyama, N., Urabe, H., Ono, S., Finlay, J. C. & Nakamura, F. (2018) Metapopulation stability in branching river networks. *Proceedings of the National Academy of Sciences*, **115**, E5963–E5969.

Toronto and Region Conservation Authority (TRCA) (2018) Watershed Fish Community. Available at https://data.trca.ca/dataset/2018-watershed-fish-community [Accessed on 09/18/2019].

U.K. Environmental Agency (2019) National Fish Populations Database (NFPD): Freshwater fish survey relational datasets. Available at https://data.gov.uk/dataset/d129b21c-9e59-4913-91d2-82faef1862dd/nfpd-freshwater-fish-survey-relational-datasets [Accessed on 10/15/2019].

Universidad de Antioquia-Empresas Publicas de Medellin. (2019) Monitoreo a la ictiofauna, su habitat y sus servicios ecosistemicos. Convenio CT 2017- 001714.

U.S. Geological Survey (2019) BioData - Aquatic Bioassessment Data for the Nation. Available at https://aquatic.biodata.usgs.gov/clearCriteria.action [Accessed on 10/15/2019], doi:10.5066/F77W698B.

U.S. Fish and Wildlife Service (2017) San Juan River basin recovery implementation program. Albuquerque, NM, 87113, USA. Data are available by contacting: https://www.fws.gov/southwest/sjrip/.

Van Thuyne, G., Breine, J., Verreycken, H., De Boeck, T., Brosens, D. & Desmet, P. (2013) VIS - Fishes in inland waters in Flanders, Belgium. Research Institute for Nature and Forest (INBO). Dataset/Occurrence. Available at https://www.gbif.org/dataset/823dc56e-f987-495c-98bf-43318719e30f [Accessed on 04/11/2017], doi:10.15468/gzyxyd.

Whitney, J.E., Gido, K.E., Martin, E.C. & Hase K.J. (2016) The first to arrive and the last to leave: colonisation and extinction dynamics of common and rare fishes in intermittent prairie streams. *Freshwater Biology,* **61**, 1321–1334.

Winston, M.R., Taylor, C.M. & Pigg, J. (1991) Upstream extirpation of four minnow species due to damming of a prairie stream. *Transactions of the American Fisheries Society*, **120**, 98–105.

Zeni, J.O., Hoeinghaus, D.J. & Casatti, L. (2017) Effects of pasture conversion to sugarcane for biofuel production on stream fish assemblages in tropical agroecosystems. *Freshwater Biology*, **62**, 2026–2038.