11-11-2020

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Recommended Citation

Comte, L, Carvajal-Quintero, J, Tedesco, PA, et al. RivFishTIME: A global database of fish time-series to study global change ecology in riverine systems. Global Ecol Biogeogr. 2020; 30: 38– 50. https://doi.org/10.1111/geb.13210

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Comte, L., Carvajal-Quintero, J., Tedesco, P. A., Giam, X., Brose, U., Erős, T., … Olden, J. D. (2021). RivFishTIME: a global database of fish time-series to study global change ecology in riverine systems. Global Ecology and Biogeography, 30(1), 38-50.
https://doi.org/10.1111/geb.13210

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

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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, Prendergast, & Bjørnstad, 1998; Sibly, Barker, Denham, Hone, & Pagel, 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, Verdonschot, Moog, & Sandin, 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, Olden, Strecker, Lawler, & Theobald, 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, Oberdorff, Paugy, Stiassny, & Tedesco, 2008 and Tedesco, Paradis, Lévêque, & Hugueny, 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 unless the reusability of data was clearly stated on the online repositories where the data were released (e.g., Open Government License, CC0 1.0 Universal). We excluded the datasets for which we did not receive the permission.

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, Lang, & Wainwright, 2012) and confirmed names with no match manually using the Catalog of Fishes (Fricke, Eschmeyer, & van der Laan, 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, Verdin, & Jarvis, 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. A static version of RivFishTIME is available through the iDiv Biodiversity Portal (Comte et al., 2020), but we aim to continue interacting with data contributors to update and add new time-series datasets as they become available (see *Data Availability Statement*).

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).

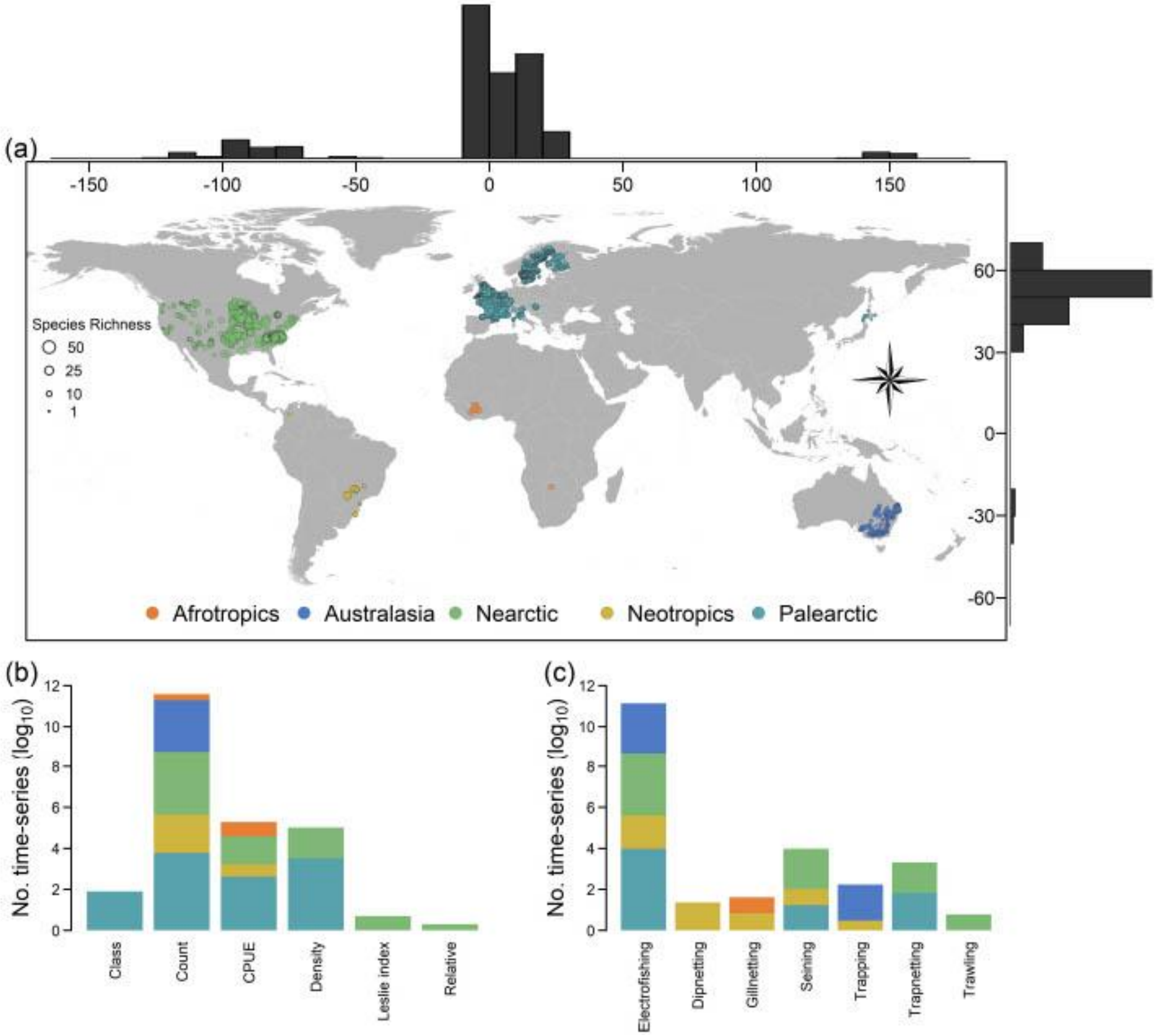

Figure 1. (a) Map showing the distribution of the time-series where each time-series is represented by a dot with colors indicating the biogeographic realm and size representing fish species richness (averaged across surveys). Inset histograms display the distribution of the time-series according to 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).

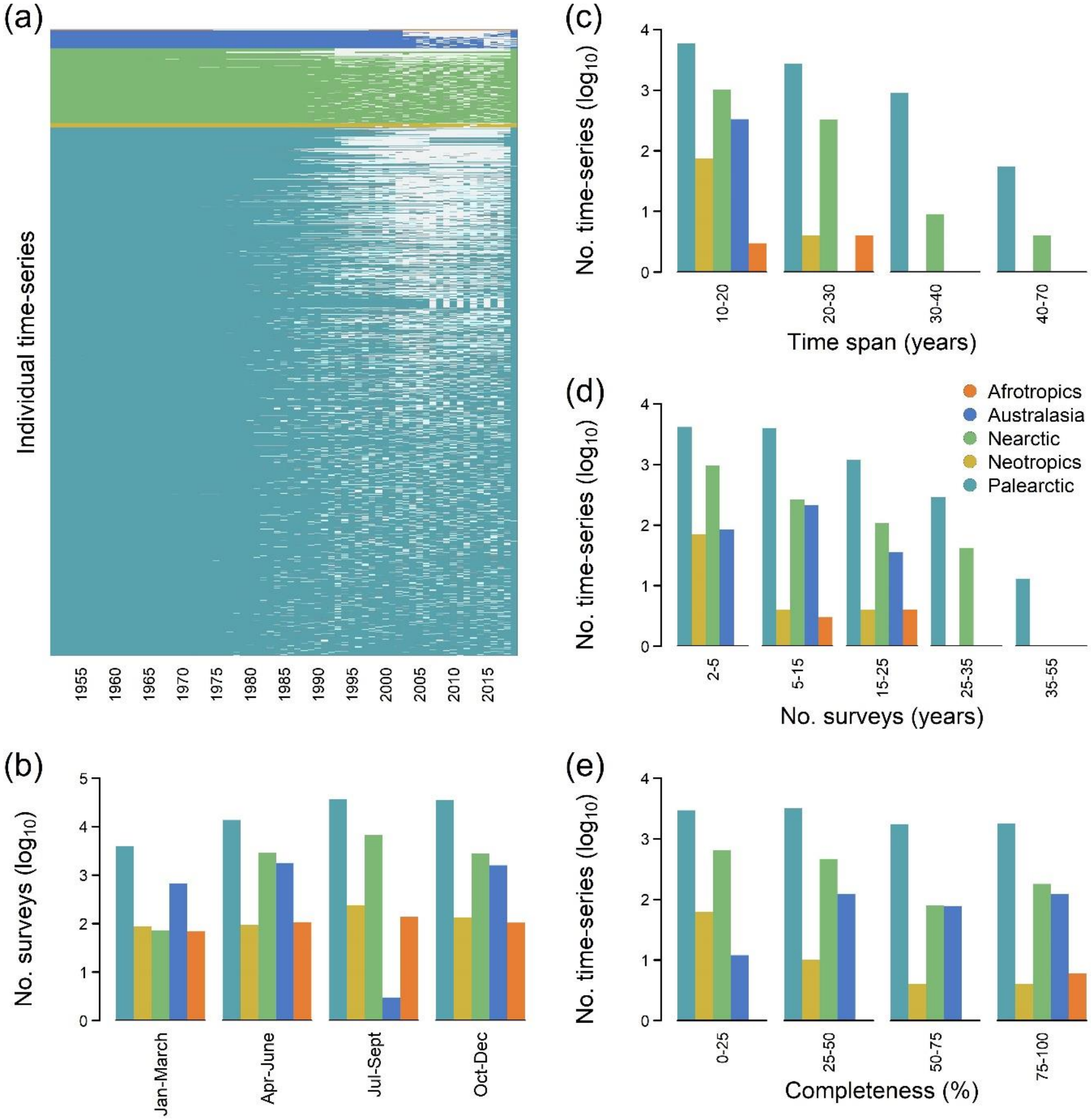

Figure 2. (a) Temporal distribution of the yearly surveys relative to the period covered by the database (1951-2019). Each time-series appears in rows where the background colors correspond to the biogeographical realms and white indicates sampled years. (b) Temporal distribution of the surveys with 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).

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, Blossey, & Ellis, 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, Grenouillet, & Kestemont, 2005; Portt, Coker, Ming, & Randall, 2006; Oliveira, Gomes, Latini, & Agostinho, 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.

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/).

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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, Hoeinghaus, & Casatti (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)	–
8	Sigouin (2017)	https://open.canada.ca/data/en/dataset/fe2441a6-8ae4-4884-b181-cd7ec53bd842
9	Whitney, Gido, Martin, & Hase (2016)	–
10	Gido, Propst, Olden, & Bestgen (2013); Gido et al. (2019)	–
11	Kesner & Marsh (2010)	https://www.rosemonteis.us/documents/kesner-marsh-2010
12	Griffith (2017); Griffith, Zheng, & Cormier (2018)	https://doi.org/10.23719/1376690
13	Occhi, V. T. & Vitule, J. R. S. (Unpublished data)	–
14	Terui et al. (2018)	–
15	Iowa Department of Natural Resources (2013)	https://data.iowa.gov/Environment/BioNet/e7yf-f5fs
16	Milardi et al. (2020)	–
17	Levêque, Hougard, Resh, Statzner, & Yaméogo (2003)	–
18	Pyron, Vaughn, Winston, & Pigg (1998)	–

19	Gido (2017)	https://doi.org/10.6073/pasta/150e218b069074a8ecede85a7406d43f
20	McLarney, Meador, & Chamblee (2013)	https://www.mainspringconserves.org/what-we-do/aquatic-monitoring/
21	Long Term Resource Monitoring Program (2016)	https://www.umesc.usgs.gov/data_library/fisheries/fish1_query.shtml
22	Matthews & 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://www.pca.state.mn.us/water/biological-monitoring-water-minnesota
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, Taylor, & Pigg (1991); Taylor (2010)	https://onlinelibrary.wiley.com/doi/full/10.1111/fwb.13211
31	Mosie & Makati (2018)	https://www.gbif.org/dataset/77929c0a-7506-4b2d-a49d-10fc3312d50d
32	Office Français de la Biodiversité (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, Dias, Petry, Oliveira, & Agostinho (2015)	–
36	Davenport, S.R. (Unpublished data)	–
37	Dala-Corte, Becker, & Melo (2017)	–
38	Bêche, Connors, Resh, & Merenlender (2009)	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, Angermeier, Munné, & García-Berthou (2010); Merciai, Molons-Sierra, Sabater, & García-Berthou (2017)	–
44	Miyazono & 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

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