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FreshLanDiv: A Global Database of Freshwater Biodiversity Across Different Land Uses

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ABSTRACT

Motivation: Freshwater ecosystems have been heavily impacted by land-use changes, but data syntheses on these impacts are still limited. Here, we compiled a global database encompassing 241 studies with species abundance data (from multiple

biological groups and geographic locations) across sites with different land-use categories. This compilation will be useful for addressing questions regarding land-use change and its impact on freshwater biodiversity.

Main Types of Variables Contained: The database includes metadata of each study, sites location, sample methods, sample time, land-use category and abundance of each taxon.

Spatial Location and Grain: The database contains data from across the globe, with 85% of the sites having well-defined geographical coordinates.

Major Taxa and Level of Measurement: The database covers all major freshwater biological groups including algae, macrophytes, zooplankton, macroinvertebrates, fish and amphibians.

1 | Introduction

Freshwater ecosystems cover only 0.8% of Earth's surface but play an outsized role in maintaining biodiversity, which in turn provides valuable ecosystem functions and services (Cardinale et al. 2012; Dudgeon et al. 2006). However, intensive anthropogenic pressures can reduce freshwater biodiversity and shift species composition (Feio et al. 2023; Feld et al. 2016; Petsch et al. 2021; Tickner et al. 2020). Therefore, it is urgent to improve our understanding of how freshwater biodiversity responds to anthropogenic changes. Such knowledge would be invaluable for freshwater ecosystem restoration and conservation (Barouillet et al. 2023; Maasri et al. 2022; Reid et al. 2019; Rumschlag et al. 2023).

Land-use is widely regarded as one of the major anthropogenic drivers of biodiversity loss (Dudgeon et al. 2006; Jaureguiberry et al. 2022; McKeon et al. 2023). However, large-scale to global biodiversity assessments have primarily focused on terrestrial ecosystems (Hudson et al. 2014; Newbold et al. 2015), with limited attention given to freshwater ecosystems (Budnick et al. 2019; Tickner et al. 2020; Wilkinson et al. 2018). Land-use practices involving activities such as agriculture, urban expansion, logging and mining (Allan et al. 2015; Foley et al. 2005) can have major effects on freshwater ecosystems, changing flow patterns, water temperature, river morphology and water chemistry, which in turn can alter freshwater biodiversity (Allan, Erickson, and Fay 1997; Cooper et al. 2012; Dala-Corte et al. 2020; Feld et al. 2016; Foley et al. 2005; Petsch et al. 2021).

Many small-scale studies showed that different land-use practices have demonstrable effects on freshwater biodiversity. For example, insect communities in urban and agricultural streams tend to experience transitions from disturbance-sensitive taxa to more disturbance-tolerant taxa (Kasangaki, Chapman, and Balirwa 2008; Rumschlag et al. 2023). Fish communities can also be affected by changes in water quality and other habitat disturbances caused by urbanisation and agricultural runoff (Januchowski-Hartley et al. 2016). Other biological groups, such as freshwater algae (Heino et al. 2009) and macrophytes (Bomfim et al. 2023) can be strongly influenced by changes in land-use, such as forestry. Likewise, mining activities can alter patterns of species richness and abundance of invertebrates, fish and amphibians (Giam, Olden, and Simberloff 2018).

Here, we develop a globally distributed database of species-level data from freshwater assemblages. We compile from existing studies on land-use effects on freshwater biodiversity to provide a comprehensive resource for uncovering general patterns and their variation across systems, geographic regions and biological groups. A comparable database is already available for the effects of land use on terrestrial biodiversity (Hudson et al. 2014, 2017), and has led to a number of important insights (Leclère et al. 2020; Millard et al. 2021; Newbold et al. 2015). Providing species-level data (rather than derived metrics) in a comprehensive database will allow the calculation of multiple metrics of biodiversity (e.g., richness, evenness, abundance), determination of species composition and measurement of their changes across spatial scales (Chase et al. 2018). This is necessary for achieving a deeper understanding of the response of ecological communities in response to changes in land use. Our database explicitly includes species-level abundance data across different land-use categories, encompasses studies on all major freshwater biological groups and ecosystems, and will facilitate the investigation on freshwater biodiversity change in the Anthropocene.

2 | Methods

2.1 | Data Acquisition

We conducted a systematic literature search to identify primary studies on land-use effects on freshwater systems in November 2021. We started with 25 studies compiled by Petsch et al. (2021) to address a similar question of land-use effects on freshwater biodiversity. We then employed 'Litsearchr' (Grames et al. 2019), an R package designed to complete the search term coverage, to generate the search terms (refer to Supporting Information) related to 'land-use effects on freshwater using data from "Web of Science"'. This search identified 10,453 potentially useful articles.

For refining these results, we scanned through the title, abstract and full-text to filter the papers based on two criteria: (1) the title and abstract indicated that the study was on freshwater biodiversity across different land-use categories; (2) the data incorporated species abundance of multiple species within a consistent sampling method in each study. In all, our search resulted in 100 studies fitting our criteria. We next used the R package 'citationchaser', and by performing forward and backward citation chasing from these 100 studies (Haddaway, Grainger, and Gray 2022), we identified an additional 40 studies that met our criteria. We also obtained 22 studies that were originally not in our search results from the recommendations of our co-authors. For each study, we extracted data from tables, figures and/or supplemental documents and repositories.

When data were not available in the publication or associated repositories (met the criteria 1 only), we contacted authors to determine whether the data were available and could be included in this compilation. In total we contacted authors of 227 potentially relevant studies, and received 54 studies, which we make public for the first time here. In total, we compiled 241 studies with metadata regarding data source, site information, land-use categories and species-level information (further described in the database); the complete list can be found in the Supporting Information. The database is accessible on Dryad, saved in xlsx format.

2.2 | Quality Control

2.2.1 | Land-Use Categories

We recorded the land-use information used by the authors of the paper, which we then grouped into five broader categories: natural vegetation, forestry, agriculture, urban and mining. Most of the studies had a comparison to reference land use, which we defined as natural vegetation. We also included areas adjacent to dams due to their significant impact on freshwater ecosystems (Table 1) (Grill et al. 2019).

If the author provided several land-use categories for a given site, we chose the dominant land-use category. All the author-defined land-use information is available in the database, along with the land-use categories we defined.

2.2.2 | Taxonomy

We standardised all taxon names using the 'bdc' (v. 1.1.4) and 'rgbif' (v.3.7.7.2) packages in R (Chamberlain 2017; Ribeiro et al. 2022), which used the GBIF (Global Biodiversity Information Facility) taxonomic backbone (Secretariat 2023) to match the scientific name, and obtain the scientific classification. Names without a match in GBIF were checked for potential spelling errors, corrected when needed and checked again against GBIF. We maintained the original name as there is still no match in GBIF. Whenever a species name was modified, the original name was also kept to ensure name traceability.

2.2.3 | Geographical Coordinates

For most studies, we obtained geographical coordinates from the paper or directly from the authors. For some studies where geographical coordinates were not immediately available, we were able to extract geographical coordinates from published maps using WebPlotDigitizer (version 4.6). We transformed geographical coordinates into the World Geodetic System 1984 (WGS84) geographical coordinate reference system. When the authors did not report geographical coordinates in the paper, or we could not otherwise obtain them, these values were considered missing in the database, and omitted.

2.2.4 | Sampling Methods

We recorded the specifics of the sampling method and the sample area, followed by standardisation in accordance with the author's instructions.

3 | Results

The database consists of 200,124 records from 4716 sites, covering all major freshwater biological groups, including algae, macrophytes, zooplankton, macroinvertebrates, fish and amphibians, across both lotic and lentic ecosystems. These records are from 241 studies spread across 42 countries, from 1972 to 2019. The spatial distribution shows a sampling bias towards South America (58% studies), with the lowest proportion in Oceania (3%); the remaining continents contain 8%–14% of the data (Figure 1, Figure S1).

The database includes 138 studies on macroinvertebrates, 77 on fish, 12 on algae, 7 on zooplankton, 4 on amphibians and 3 on macrophytes. Our database includes 6078 species from 2464 genera, 710 families and 216 orders. In our database, 45% of the species are macroinvertebrates, 22% are fish and 24% are algae. All other biological groups comprised < 5% of the species in the database (Table 2, Figure 2A).

TABLE 1 | Land-use categories and definitions.

Land-use	Definition
Natural vegetation	Little evidence of disturbance on the vegetation, including forest, grassland or what the author simply called 'vegetation'
Forestry	Defined as managed (human-impacted) forest, including deforestation, tree plantations and reforestation
Agricultural	Agricultural activities (sometimes mixed with some human settlement). This category included cropland, pasture, rural and mixed agricultural activities
Urban	Sites located in cities. Impervious surfaces were also regarded as urban
Mining	Mining activities in or near water bodies
Impounded	Reservoir or impounded water bodies
Unimpounded	Unimpounded water bodies or control sites (upstream of reservoir/dam and control streams)
Downstream	Downstream of the dam

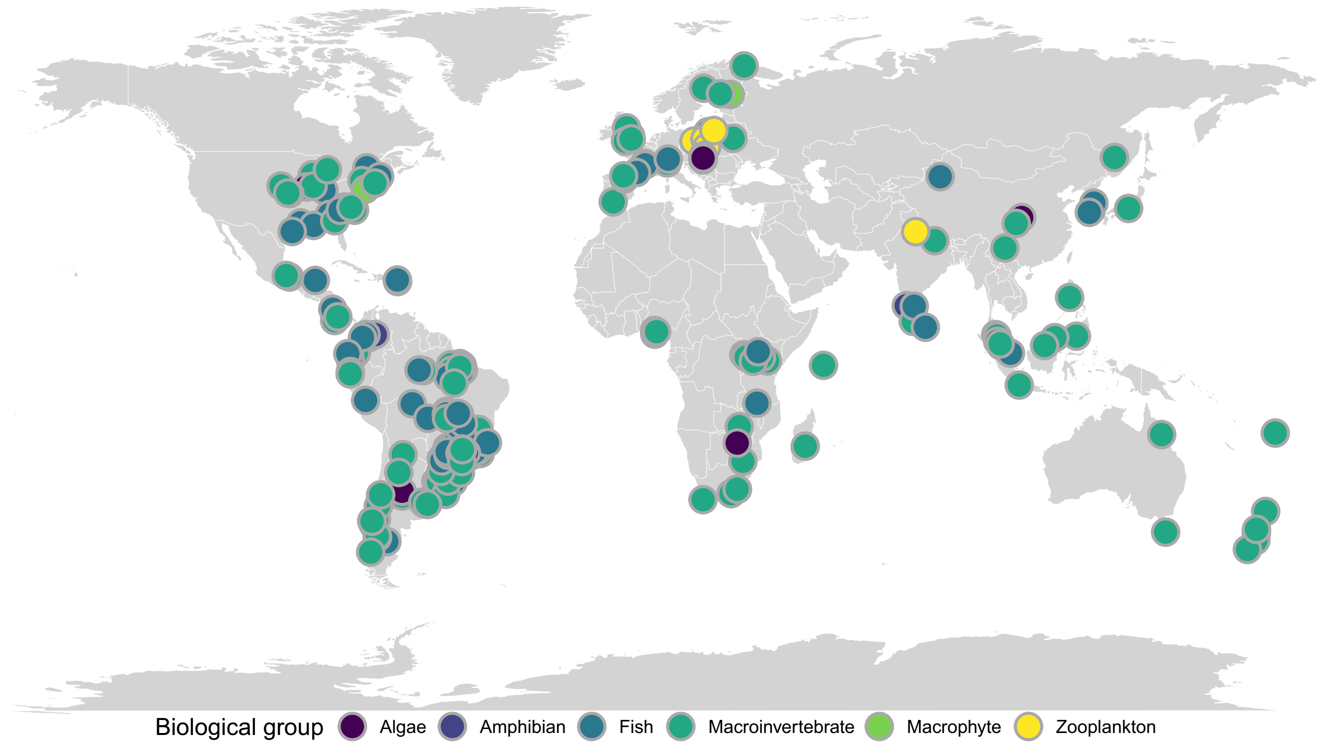

FIGURE 1 | Geographical distribution of studies by biological group. The study locations represent the central geographical coordinates (average latitude and longitude) of their sites. In cases of missing geographical coordinates, we placed studies at the geographical centre of their respective province/state or country, based on the most detailed information we had.

TABLE 2 | Number of taxa and records estimated by biological groups.

Biological group	Orders	Families	Genera	Species	Records
Macroinvertebrates	85	392	1466	2782	122,106
Fish	30	99	502	1314	24,850
Algae	55	100	253	1438	46,368
Zooplankton	14	48	105	295	2791
Macrophytes	30	56	97	171	3387
Amphibians	2	15	41	78	622

Our literature search included both lotic and lentic ecosystems, with 93% being from lotic systems (streams and rivers) and 7% from lentic systems (wetlands, ponds and lakes). Within lotic systems (224 studies), 163 studies were on streams (Figure 2B). The ecosystem type was recorded according to the author's description.

Each study encompassed a minimum of two land use or land cover categories. Most studies provided comparisons between water bodies adjacent to natural vegetation with water bodies adjacent to agriculture (117 studies), forestry (47) or urban (46). Other frequent comparisons include comparisons between agricultural and urban sites (51 studies; Figure 3) (dams are not included in this comparison).

Diverse sampling methods, land-use buffers, taxonomic precision and the measure of 'abundance' were used across studies, but they remained consistent within each study. Each site in a study was labelled with details of sampling methodology, including sampled area. The term 'land-use buffer' denotes the size of the identified land-use category surrounding each site, with the buffer size of each study being recorded in the database. Precision in species identification varied among taxa, particularly for macroinvertebrates, with certain studies identifying individuals only to family or genus. The measure of 'abundance' varied across studies, alongside diverse sampling and recording methodologies. It could mean the total number of individuals and mean density. The majority of studies (73%) use total abundance.

4 | Discussion

Our database is the largest compilation to incorporate the abundance data of freshwater biota across different land-use

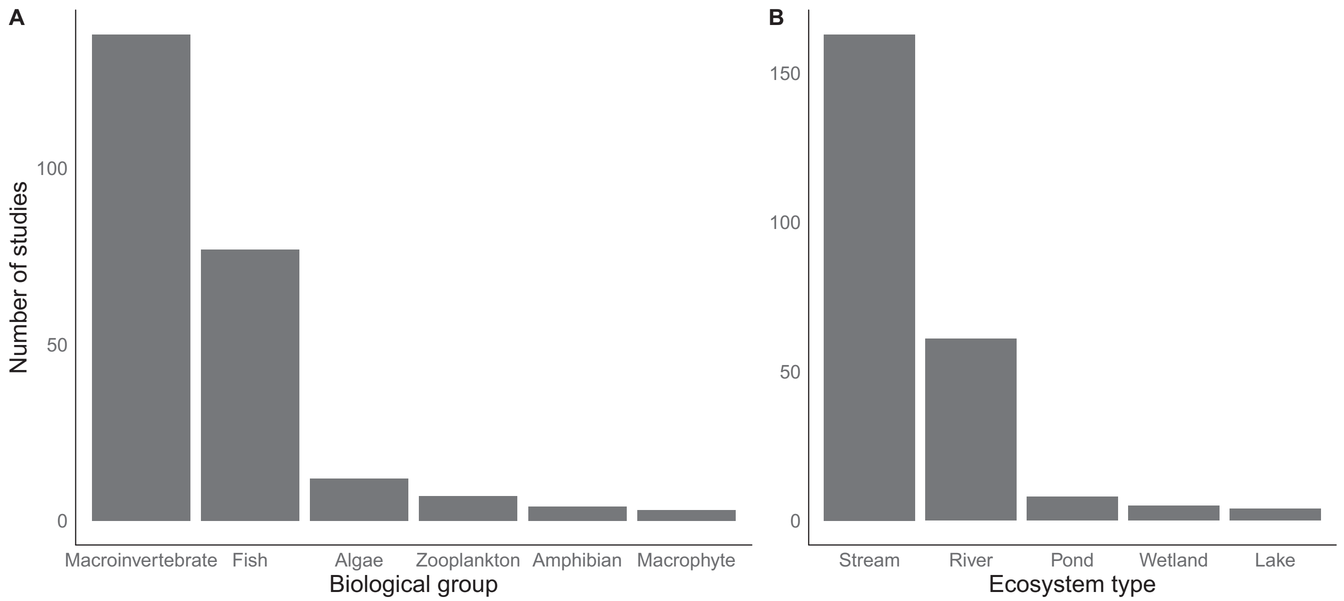

FIGURE 2 | Number of studies per biological group (A) and ecosystem type (B).

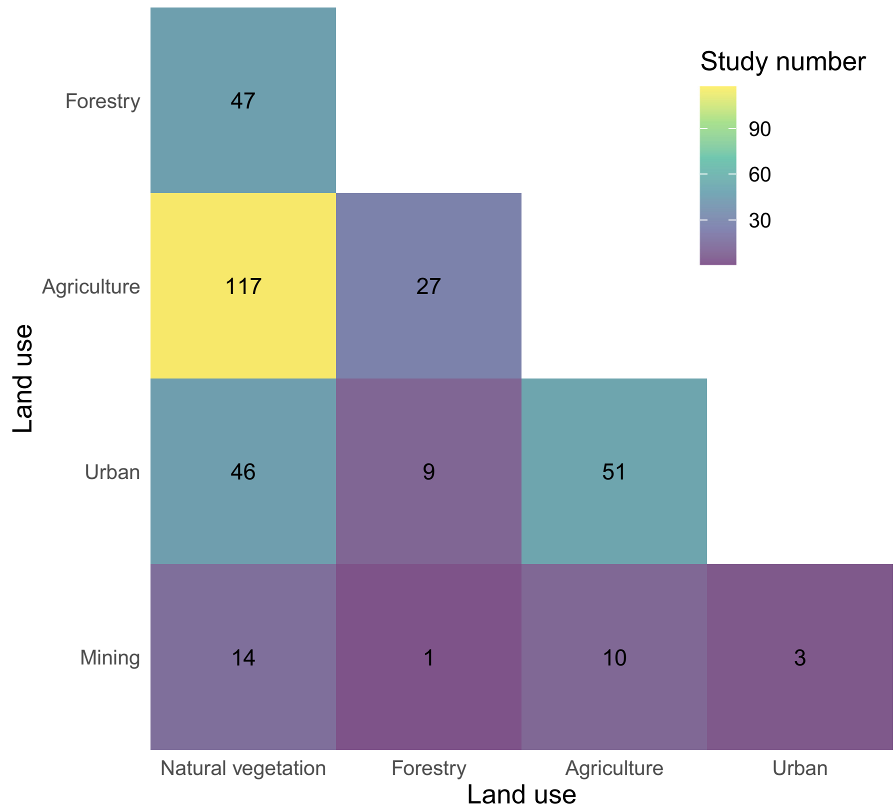

FIGURE 3 | Cumulative land-use comparisons recorded in the database. Each number within the grid indicates the count of study occurrences for the comparison of two land-use categories plotted on the respective axes.

categories. It builds on previous efforts (Petsch et al. 2021), but includes six times more data. By compiling all major freshwater biological groups and ecosystems in the database, this collation will facilitate the exploration of numerous aspects of freshwater ecology and land-use impacts, including changes to species abundance distributions (Blowes et al. 2022; McGill et al. 2007), biodiversity across scales (Chase et al. 2018), shifts in species composition (Blowes et al. 2024; Rumschlag et al. 2023) and related questions. As such, this data compilation can support both basic and applied ecological research (Spake et al. 2022).

About one-half of the studies in our database originate from South America, encompassing all of the biodiversity hotspots in this continent. This bias may suggest South America has growing scientific activities on this topic, particularly concerning vast freshwater resources threatened by land-use changes driven by economic development (Barletta et al. 2010; Campuzano et al. 2014). Conversely, other continents show a comparatively lower number of studies, showing an important knowledge gap. For example, regions in southwest Australia and the Horn of Africa are under-represented in our database, are currently experiencing rapid urbanisation (Güneralp et al. 2017; Myers et al. 2000; Pettit et al. 2015). Further work is needed to expand access to studies concerning the response of freshwater biodiversity to land-use change in these regions.

The biases regarding biological groups and ecosystem types largely reflect known patterns in ecological research globally. Macroinvertebrates comprise approximately 60% of our database and are widely used as indicators in stream and river monitoring. Different macroinvertebrate groups exhibit diverse responses to changes in habitat and water quality, and particularly sensitive taxa are useful for gauging the effects of land use on freshwater ecosystems (Chang et al. 2014; Juvigny-Khenafou et al. 2021). Among freshwater ecosystems, lotic systems—particularly streams—emerge as the most extensively studied within our records. As our database requires land-use data across varying intensities, most studies have utilised 'natural vegetation' as reference, which is more prevalent in headwater streams (Colvin et al. 2019; Encalada et al. 2019).

In conclusion, our database stands as the largest and most comprehensive compilation on the distribution and abundance of a broad range of freshwater biological groups across various land-use categories. Data on freshwater ecosystems need to be accessible, understandable, unambiguous and available to all those working on practical conservation projects (Barouillet et al. 2023). As such, this database can help in the development and implementation of effective management plans. Such plans require recognition of the vast diversity of freshwater habitats and species, as well as a systematic assessment of how scientific information can be translated into action at local, regional and global scales.

Author Contributions

M.S., R.v.K., J.M.C. contributed to project design. M.S. collected the data with support from R.v.K. and J.M.C. Data were validated by M.S. and A.S. All authors contributed their data to the database except M.S., R.v.K., A.S. and J.M.C. M.S. wrote the first draft of the manuscript. All authors contributed to revisions.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

FreshLanDiv can be downloaded from Dryad https://doi.org/10.5061/dryad.nvx0k6f06 and the code associated with the data paper is available at https://doi.org/10.5281/zenodo.13866691.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.