

The Great Lakes aquatic tissue analysis repository (GLATAR)[☆]

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ABSTRACT

Empiricists and modellers use information on energy density, proximate composition, stable isotopes, fatty acids, thiamine, and bioaccumulative tracers (e.g., PCBs and mercury) to understand the state and inter-relationships of aquatic food webs. Data exist in many published and unpublished sources, but are not consolidated in an easily accessible database that would serve as a vital resource to i) provide basic estimates of these diet-derived measures of body composition, ii) understand sources of variation in the underlying data, iii) facilitate exploration and development of data proxies, and iv) assist in study design. We designed GLATAR (Great Lakes Aquatic Tissue Analysis Repository, glatar.org) to address this need. GLATAR is an open-access, searchable database linked to a web-based toolbox to visualise and generate user-defined summaries on diet-derived ecological metrics, with a focus on taxa of importance to the Great Lakes. GLATAR currently contains over 50,000 records on energy density, chemical tracers, and proximate body composition from 67 species of fish and 72 invertebrate taxa. We hope this user-friendly interface will entice others to upload their published and unpublished data to the repository, enriching the breadth of data accessible to researchers. In this way, GLATAR will become a 'living' and interactive resource for empiricists and modellers working in freshwater ecosystems as they make critical decisions related to growth, production, and consumption across a diverse group of economically and ecologically important aquatic species.

1. Introduction

The Laurentian Great Lakes (hereafter Great Lakes) support extensive recreational, commercial, and subsistence fisheries valued at > \$5 billion USD annually, in addition to supporting many other ecosystem services and ecological benefits (Council of the Great Lakes Region,

2017; Great Lakes Fishery Commission (GLFC), 2020). The lakes, however, are plagued with numerous stressors, including invasive species, contamination, and habitat loss among other factors, which compromise their health and ability to sustain productive fisheries (Allan et al., 2013; Lynch et al., 2017). Resource managers rely on assessment and monitoring programs to interpret the state of the lake, and biologists and

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scientists use these data to perform analyses and develop models to understand potential impacts of stressors, including forecasting probable future states (Bunnell et al., 2014; ECCO and US-EPA, 2022; Hecky and DePinto, 2020). Food web and bioenergetic models are key tools used by fishery managers, the former reflecting our understanding of linkages among interacting food web members (e.g., multi-species, predator-prey interactions), while the latter quantifies growth rate potential, production and consumption under differing scenarios (Deslauriers et al., 2017; Fitzpatrick et al., 2022). Inherent to both types of models is a solid understanding of the connections (i.e., predator-prey interactions) and the related quality (i.e., energy, nutrition) of those connections. Stomach content analyses and stable isotopes are frequently used to identify interacting species, while energy density (Joules per gram) data are required to estimate the energy budget (and contaminant transfer) for predators and prey. With over 140 established fishes and countless invertebrate prey in the Great Lakes, accessing suitable data to parameterize models is challenging (Chipps and Wahl, 2008; Johnson et al., 2017; Ney, 1993). Creating a web-based, open-access, searchable database containing data on energy and body composition would be of tremendous benefit to the Great Lakes scientific community and beyond.

One of the most cited sources for energy density data is Cummins and Wuycheck (1971), a now more than 50-year-old publication that includes data for only nine fish species resident in the Great Lakes (among other marine and brackish water species). Since then, information on the energy density of freshwater fishes has expanded significantly (e.g., Hartman and Brandt, 1995; Johnson et al., 1999; Johnson et al., 2017; Rand et al., 1994; Rottiers and Tucker, 1982). Data also exist for invertebrate prey, although often not originating from the Great Lakes (James et al., 2012). Further, energy density of aquatic animals is known to vary among taxa, life stages, body sizes, seasons, and geographic regions. Capturing these metadata in a large, accessible database will contribute to increased accuracy of modelled outputs. Data exist in publications, reports, and theses, with many additional records unpublished and thus undiscoverable. Data from multiple published and unpublished sources need to be brought together in an open-access, searchable, and downloadable database to ensure scientists and managers are using the most accurate information in their analyses and decisions.

Bomb calorimetry remains the gold standard for estimating energy density, but the procedure requires specialized equipment and is very time-consuming (Glover et al., 2010). As such, researchers have sought to develop proxies for energy density using indirect methods such as water content, proximate composition of biochemical constituents (e.g., protein, lipid, and ash), or elemental composition (e.g., carbon, nitrogen, and hydrogen; Breck, 2014; Gnaiger and Bitterlich, 1984; Hartman and Brandt, 1995). Each of these proximate techniques are prone to error, largely attributable to variation in proximate composition with body size and taxon (Breck, 2014) and energy density of lipids (Johnson et al., 2017). Further, biochemical approaches are both time-consuming and use large quantities of dangerous chemicals (Schmidt and Hesselberg, 1992; Syamittra et al., 2014). Although considerable research has revealed a strong relationship between water content and energy density (Hartman and Brandt, 1995; James et al., 2012; Love, 1970), and between ash (incombustible inorganic matter) and energy density (Weil et al., 2019), an extensive consolidation of data would permit more robust (multi-species, including covariates of body size, life stage, maturation, season, etc.) analyses to elucidate better relationships from patterns and trends (Brey et al., 2010; Hrycik et al., 2024). Greater confidence in proxy measures of energy density may provide estimates for taxa with no direct calorific data and ultimately reduce the amount of time and laboratory-intensive analyses needed to address data gaps.

In developing our vision for this project, we realised that many additional diet-derived metrics were co-reported or used in mass-balance approaches to ecological analyses related to fish energetics. Principle among these are stable isotopes which are routinely collected

by many aquatic researchers to estimate trophic position and interactions among multiple co-occurring species (e.g., predator-prey dynamics; Mumby et al., 2018; Peterson and Fry, 1987; Turschak et al., 2014). More recently, fatty acid analyses have informed diet characterization serving as tracers of food web dynamics, in addition to their fundamental importance in energy storage, cell structure, neural development, immune response and reproduction (Budge et al., 2006; Happel et al., 2016). Thiamine deficiency complex, a disorder resulting from the inability to acquire or retain thiamine (vitamin B1), has been documented in aquatic organisms throughout the northern hemisphere and may be related to high levels of thiaminase (Harder et al., 2018) and/or the ratio of thiamine to fat in prey (Keinänen et al., 2012). Finally, contaminants, principally polychlorinated biphenyls (PCBs) and mercury (or more specifically methyl mercury for higher trophic levels), have been used as tracers of food consumption and active metabolism in wild-ranging fishes (Madenjian et al., 2000; Rennie et al., 2005). As with energy density, a growing body of science is exploring the effects of body size, season, geographic location, lake characteristics, etc. on the absolute value of these additional diet-derived ecological metrics, resulting in considerable sampling and laboratory analyses archived in largely discrete databases.

Our objective was to consolidate the large amount of recorded published and unpublished data on diet-derived ecological metrics used to inform our understanding of freshwater energetics, with a focus on taxa of importance to the Great Lakes. Unlike some database projects that summarise information constrained by date and search criteria (Brey et al., 2010; Hermann et al., 2025), we instead focused on creating an easily discoverable, open-access framework that would facilitate query and data exploration but also entice others to upload and share data. Large volumes of data are not well documented (e.g., existing in agency reports, university theses, unpublished data, etc.) or easily discoverable (e.g., data used in modelling analyses are difficult to find using conventional search engines because the data are not often the principal topic of the study). At the time of publication, we have sought only to enter our own previously unpublished data (~29,500 records, excluding any data originating from USGS), and limited queries for the metrics described above (~169 published sources) to illustrate what we hope is the utility of this 'living' and interactive resource for empiricists and modellers working in freshwater ecosystems. We expect the Great Lakes Aquatic Tissue Analysis Repository (GLATAR) to become an important reference for aquatic biologists and managers as they make critical decisions related to growth, production, and consumption of and by a diverse flock of economically and ecologically important aquatic species.

2. Development of GLATAR

GLATAR—the Great Lakes Aquatic Tissue Analysis Repository (glatar.org)—is an R-based application containing information on energy density, proximate composition, stable isotopes, fatty acids, amino acids, thiamine / thiaminase, and bioaccumulative contaminant tracers (mercury and PCBs) (Table 1). GLATAR combines multiple technologies to seamlessly allow users to interface with the data. These technologies are broken in two main components: i) a PostgreSQL database and ii) a

Table 1
Number of records by data type and organism.

Data type	Fish	Invertebrate
Calorimetry	12,834	424
Proximate composition	20,291	315
Stable isotope	8346	687
Lipids	178	36
Fatty acids	5781	658
Amino acids	0	136
Thiamine	858	15
Contaminants	95	6

web-based toolbox that interfaces with the database. This toolbox was developed in R v4.5.3 using {renv} (Ushey and Wickham, 2026) and {shiny} (shiny-app; Chang et al., 2025) along with multiple packages for database interfacing ({DBI}; R Special Interest Group on Databases (R-SIG-DB) et al., 2024), data manipulation ({dplyr} and {dplyr}; Wickham et al., 2026a, Wickham et al., 2026b), plotting ({ggplot2} and {ggtext}; Wickham, 2016; Wilke and Wiernik, 2022), and uploading and validating user submitted data ({validate}; Van der Loo and de Jonge, 2021). All source code is publicly available on GitHub (benjaminhlna/glatar-app) allowing for community-based enhancement. For easy server deployment and community development, the shiny-app is built in a Docker container that uses “rocker/shiny:latest”. By using “rocker/shiny:latest” the shiny-app regularly updates to the newest version of R (currently v4.5.3) and will re-deploy the application on a shiny-server making the application self-contained. The container is built whenever the source code changes using GitHub actions (GHA) which register the built container in GitHub's Container Registry (GHCR). Once the shiny-app has been built in GHCR, another GHA uses Docker Composer to combine a nginx and certbot container (i.e., to allow reverse proxying and HTTPS certification of the site) with our shiny-app to seamlessly deploy GLATAR onto a server. All shiny-app source code has been modularized to ensure easy deployment, and all functions are called directly using “::” instead of loading all the required packages with each activation of the application.

3. GLATAR – A new tool for study of freshwater food webs

Multiple aquatic taxa representative of freshwater ecosystems of North America (from algae to amphibians; most at species-level) are included in GLATAR, with a particular focus on fish and invertebrates of the Great Lakes. Our preliminary efforts to populate the database resulted in 56,660 records representing 67 fish and 72 invertebrate

species being incorporated into GLATAR (Table 1). Approximately 29,500 records, that did not include unpublished, USGS data, came from our own original research, with the remaining 18,000 records extracted from a Web of Science literature search targeting published data relevant to GLATAR (conducted on 15 January 2026). For this search, we used the following search string – TOPIC: (“proximate composition” OR isotop* OR calor* OR “energy densit*” OR “energetic condition” OR lipid OR “fatty acid*” OR FAME) AND (fish OR fishes OR “invert*” OR “aquatic plant*” OR alga* OR amphibian* OR reptile*) AND (“North America” OR “Great Lake*” OR “Lake Superior” OR “Lake Michigan” OR “Lake Huron” OR “Lake Erie” OR “Lake Ontario”) AND (freshwater OR lake OR river OR stream OR wetland)). This literature search identified 1028 potentially useful publications, of which 348 have been screened for relevancy to identify those containing data of interest. To date, we have included data from 169 of the screened publications and will continue to extract data from the remaining studies to be added to GLATAR during the next few months. Ultimately, we hope the user-friendly interface of GLATAR will encourage others to upload their published and unpublished data, enriching the breadth of data for use by researchers for a broad range of applications.

GLATAR is much more than a database in that it contains built-in tools to visualise and generate user-defined summaries of data of interest (Fig. 1). Modules consist of a documentation pane, tools to search by taxonomy and source (author), a map, a scatter plot, a summary tool, a means to upload data, and a report feature (Fig. 2). The documentation pane provides brief narratives on each of the primary data types: calorimetry, proximate composition, stable isotopes, fatty acids, amino acids, thiamine / thiaminase, and contaminants used as ecological tracers (PCBs and mercury). The search tools allow the user to quickly scan if their species of interest (as either scientific or common name) or higher taxonomic organisation, including the taxonomic serial number (TSN, itis.gov), is contained within the database. Likewise, the user can

Great Lakes Aquatic Tissue Analysis Repository

Explore database components

Get Started

Use the sidebar to:

- Visualize sampling locations on a map.
- View and download summary statistic tables.
- View visualizations of energy density, proximate composition, stable isotope, thiamine, fatty acid, mercury and PCB data.
- Upload new data into the repository (i.e., if you're a contributing member).
- View and filter your uploaded raw data (i.e., if you're a contributing member).

About the Repository

The Great Lakes Aquatic Tissue Analysis Repository (GLATAR) contains data on energy density, proximate composition, stable isotopes, thiamine, fatty acid, mercury, and PCBs for fish and aquatic invertebrates collected across the Great Lakes and North America. The data and this repository helps researchers and managers understand ecosystem health, bioenergetics, energy transfer, and food web dynamics.

- The basic data entry template has fields to collect energy density, proximate composition, and stable isotope data.
- The extended data entry template has additional fields to collect thiamine, fatty acid, mercury, and PCB data.
- Both data entry templates can be found in the [documentation pane](#).
- If you would like to contribute to this repository, please create a username using your email address on the data upload pane and wait for registration code to be sent to you.
- Any questions can be directed to the GLATAR manager at: benjamin.hlna@gmail.com

Fig. 1. The Great Lakes Aquatic Tissue Analysis Repository (GLATAR) landing page showing the menu, infographic linking to background information on the GLATAR components, and general user guidance.

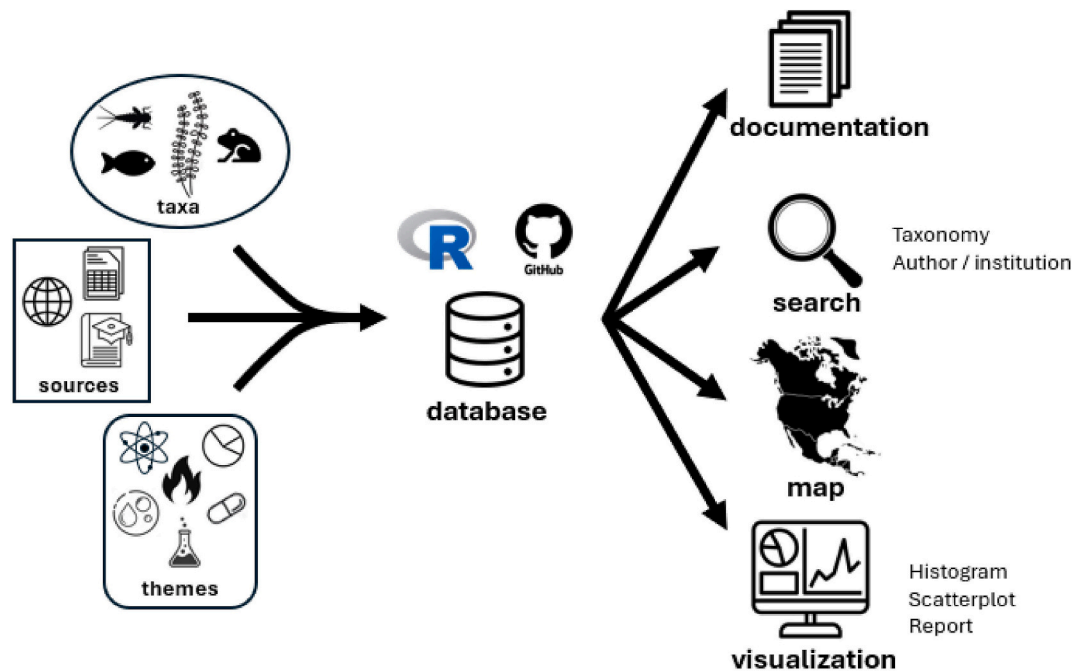


Fig. 2. A conceptual diagram for Great Lakes Aquatic Tissue Analysis Repository (GLATAR) illustrating how different elements are connected and output.

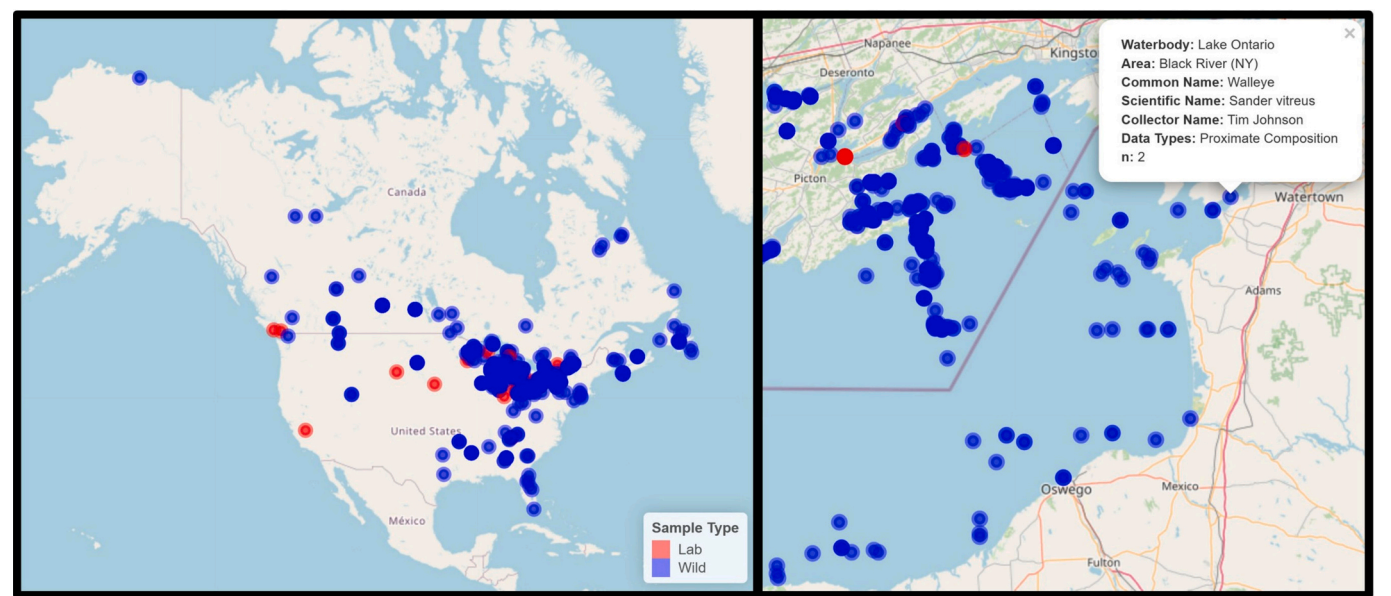


Fig. 3. Map showing current distribution of data contained within Great Lakes Aquatic Tissue Analysis Repository (GLATAR). Presently GLATAR focused on freshwater taxa and has a geographic emphasis on the Laurentian Great Lakes. The left pane shows the data availability for all North America, while the right pane shows the eastern portion of Lake Ontario revealing the broad spatial distribution (distance from shore / depth). Users can click on a data point, and a message box describes the underlying data.

Table 2
User selected filters to customise queries.

Category	Fields
Taxonomic	scientific name, common name, genus, family, order, class, ITIS code
Spatial	latitude / longitude, waterbody (e.g., Lake Ontario), regional descriptor (e.g., Bay of Quinte), local descriptor (e.g., Hay Bay), depth where sample was collected
Temporal	year, month, season
Biological	sex, life stage, age, length, mass, tissue type
Analytical	PCB congener, thiamine vitamers, specific fatty acid, type of lipid

search by author surname or institution to see which data have been captured within GLATAR. The map is a scalable display of the geographic locations where data originated, allowing the user to zoom in on an area of interest to see which data are present (Fig. 3). The scatter plot feature allows users to select up to four variables of interest (e.g., species, geographic location, life stage, season; Table 2) and display available data in bivariate space (Fig. 4). The scatter plot also provides a convenient way for the user to explore proxies (e.g., water vs. energy density, C:N ratio vs. lipid) which may provide useful support for estimating critical information indirectly from other, more readily available data types. The summary tool generates basic descriptive statistics (i.e.,

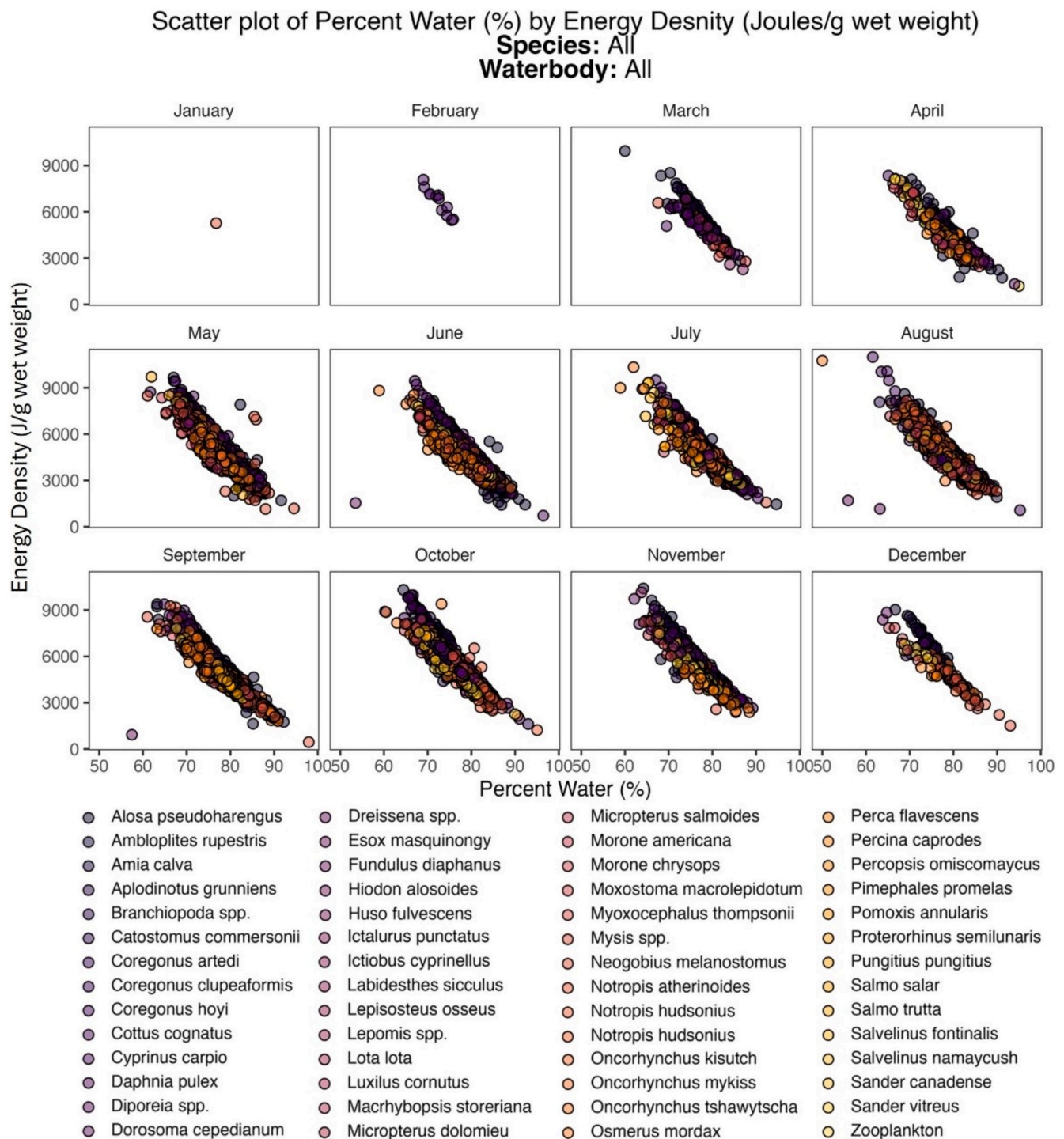


Fig. 4. Sample output (scatterplot) from Great Lakes Aquatic Tissue Analysis Repository (GLATAR) showing the relationship between water content and energy density (J/g wet weight) faceted by month of the year and showing all 50 species currently contained within the database.

sample size, mean, and standard deviation) for selected data based on user-defined filters (Fig. 5). GLATAR also contains different formats for data upload, including basic error-checking on the front end upon data upload (e.g., correct spelling of species names, data falling within expected ranges) and database schemas on the backend. Finally, the report feature generates a one-page PDF summarising data contained within GLATAR based on the user defined criteria (Fig. 6). The report: i) specifies any selection criteria (filters) used, ii) provides mean, standard deviation, and sample size for the species but also for increasing levels of taxonomic resolution (e.g., species, genus, family, order and class)

which may be informative in estimating a value in the absence of data at a particular taxonomic level, iii) displays a frequency histogram of a user defined variable (e.g., energy density or total thiamine), and iv) displays a bivariate plot with fitted regression based on user selected x- and y-variables. This report serves as a reference for common criteria the user may wish to refer back to.

4. Applications of GLATAR

GLATAR is intended to facilitate the sharing of data on energy and

Summary Statistics

This panel displays summary statistics and histograms for your selected data. Use the dropdowns to filter your results by either clicking and select a choice or choices from dropdowns or by typing directly into the dropdown to search for specific options. To clear selections, click on the dropdown and press Backspace which will clear a selected choice. All dropdowns can have multiple selections, except when selecting the desirable variable used for the histogram and when the filters are set to 'All'.

Summary Table

Show entries

Search:

	Organism Type	Data Type	Waterbody	Scientific Name	n	$\delta^{15}\text{N}$ (mean)	$\delta^{15}\text{N}$ (sd)
1	Fish	Composite	Lake Erie	Perca flavescens	46	14.01	1.47
2	Fish	Individual	Deux Montagnes	Perca flavescens	636	11.89	0.9
3	Fish	Individual	Lake Erie	Perca flavescens	328	14.01	1.47
4	Fish	Individual	Lake Michigan	Perca flavescens	87	12.61	1.84
5	Fish	Individual	St.francis	Perca flavescens	989	14.2	0.81
6	Fish	Individual	St.louis	Perca flavescens	1031	13.33	0.71
7	Fish	Mean	Lake Erie	Perca flavescens	24	14.01	1.47

Showing 1 to 7 of 7 entries

Previous Next

Summary Histograms

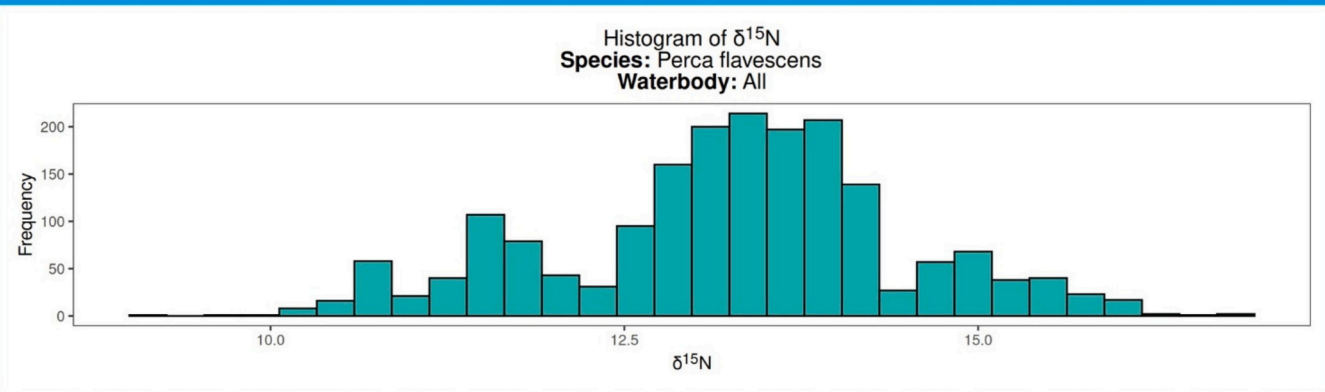


Fig. 5. The data summary pane, showing the sample size by waterbody containing stable isotope data for yellow perch, with the frequency histogram (all water bodies combined) in the lower panel. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

body composition of freshwater taxa. Over time, more published and unpublished sources will be uploaded, and we hope the community of researchers recognise the utility of GLATAR and begin to upload data of their own. We envision many uses for GLATAR: i) as a source of information, ii) to facilitate exploration and development of data proxies, iii) to understand sources of variation in the underlying data, and iv) to assist in study design. We elaborate on each of these potential uses below.

Sources of data

- What is the energy density [or other GLATAR variable] for my species of interest?
- What are reasonable estimates of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for organism X and Y to inform my isotope mixing model?
- I cannot find thiamine concentration data [etc.] for my species, but how much variation is there if I generate an estimate from higher levels of taxonomic aggregation (e.g., genus, family)
- What PCB or Hg data are available / from what date are data available when considering my contaminant tracer study? How do

these bioaccumulation rates compare among sites / species / time periods?

Proxy development

- I have percent water data for my species of interest. What would be appropriate estimates of energy density based on this information?
- Can I estimate elemental composition from the C:N ratio for my species?
- More broadly, by bringing multiple data types together, we anticipate numerous opportunities to investigate previously unexplored or preliminary relationships among variables (e.g., Breck, 2014; Brey et al., 2010)

Understanding sources of variation

- How much seasonal [or spatial, or allometric, or long-term] variation is there in lipid concentration [etc.] for my species?



Great Lakes Aquatic Tissue Analysis Repository

Report generated Mar 23, 2026

Salvelinus namaycush

Total Thiamine

Data filters applied:

Spatial	Lake Ontario
Temporal	fall
Biological	adult, female
Analytical	egg

Summary statistics:

	Taxonomic level	Mean	Std. dev.	N
Species	<i>Salvelinus namaycush</i>	3.12	1.42	15
Genus	<i>Salvelinus</i> spp.	3.12	1.42	15
Family	Salmonidae	5.18	2.01	52
Class	Teleostei	5.54	2.55	64

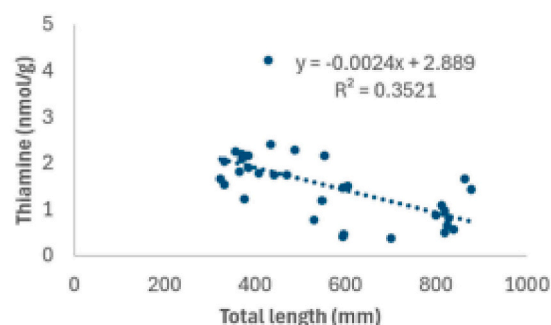
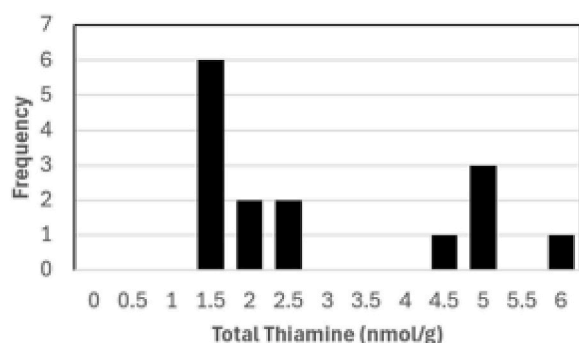


Fig. 6. A sample report that the user can export (pdf) based upon user-defined criteria.

- Is there evidence for latitudinal or lake area differences in GLATAR variables?
- Exploration of depth, ecotype (e.g., wetland vs open-coastal), land use factors, etc. on variation of GLATAR variables may help elucidate underlying mechanisms to inform management (e.g., [Hlina et al., 2026](#); [Wegher et al., 2025](#))

Study design

- What is an appropriate isotopic baseline for my lake / region / season? By extension, comparison of systems or even regions within large lakes such as the Great Lakes requires data normalisation by adjusting for isotopic baseline (e.g., [Nawrocki et al., 2022](#)).
- Pre-study understanding of spatial and temporal variation (at regional or Great Lakes scales) can help inform researchers develop the level of sampling intensity that is needed to appropriately characterise their study system to avoid bias and erroneous conclusions.
- Are key diet-derived metric data not available for my proposed study? If so, where will I need to focus my efforts to fill in these important data gaps?

5. Conclusion

GLATAR is an open-access resource for freshwater researchers and managers seeking information and streamlined data summaries for frequently sought energy and body composition metrics for fish and other aquatic taxa. GLATAR adheres to Findable, Accessible, Interoperable, and Reusable (FAIR) data principles ([Wilkinson et al., 2016](#)), has been developed using multiple technologies (i.e., PostgreSQL, R, Docker), and is hosted on GitHub to promote community practices to ensure it remains relevant and informative. Already containing over

46,000 records on energy density, proximate composition, stable isotopes, fatty acids, thiamine and contaminant tracers, GLATAR is a valuable reference. Further, GLATAR's user-friendly interface should entice others to upload their published and unpublished data, enriching the breadth and usefulness of information contained within the repository. In this way, GLATAR will become a 'living' and interactive resource for empiricists and modellers working in freshwater ecosystems as they make critical decisions related to growth, production, and consumption across a diverse group of economically and ecologically important aquatic species.

CRediT authorship contribution statement

Timothy B. Johnson: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **James E. Breck:** Writing – review & editing, Validation, Resources, Methodology, Data curation. **Steven R. Chipps:** Writing – review & editing, Validation, Resources, Methodology, Data curation. **David Deslauriers:** Writing – review & editing, Validation, Resources, Methodology, Data curation. **Mark W. Kershner:** Writing – review & editing, Validation, Resources, Methodology, Data curation. **Charles P. Madenjian:** Writing – review & editing, Validation, Resources, Methodology, Data curation. **Steven A. Pothoven:** Writing – review & editing, Validation, Resources, Methodology, Data curation. **Michael D. Rennie:** Writing – review & editing, Validation, Resources, Project administration, Methodology, Data curation. **Benjamin L. Hlina:** Writing – review & editing, Software, Methodology, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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