

Information Management**Interactive mapping of nonindigenous species in the Laurentian Great Lakes**

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Abstract

Nonindigenous species pose significant risks to the health and integrity of ecosystems around the world. Tracking and communicating the spread of these species has been of interest to ecologists and environmental managers for many years, particularly in the bi-national Laurentian Great Lakes of North America. In this paper, we introduce the Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) Map Explorer. The Map Explorer provides access to records of documented nonindigenous species and their spatial distributions. Users may view the distributions of well-known nonindigenous species (such as zebra mussels) as well as perform custom queries. Additional map layers allow users to compare the distribution of nonindigenous species to environmental conditions. This tool serves to communicate knowledge to diverse stakeholder groups and to enable further in-depth research on nonindigenous species.

Key words: invasive species, education, outreach, species monitoring, interface, species distributions, mapping application

Introduction

The Laurentian Great Lakes of North America are home to thousands of native fish, plants, invertebrates, and other species that provide the region with rich ecological, economic, and recreational value. However, the Great Lakes basin is also considered one of the most heavily invaded aquatic systems in the world, with over 180 documented aquatic nonindigenous species and an invasion rate estimated at 1.3–1.8 species per year (Mills et al. 1993; Ricciardi 2006; Aquatic Nuisance Species Task Force 2018). Although a number of these nonindigenous species pose negligible risks to

the ecosystem, others may become invasive when “their introduction does or is likely to cause economic or environmental harm or harm to human health” (E.O. 13112 1999) and subsequently damage the region’s ecological and socio-economic value (Sturtevant et al. 2014). To document these species, the Great Lakes Aquatic Nonindigenous Species Information System (NOAA GLANSIS 2018), in partnership with the U.S. Geological Survey (USGS), performs information assimilation for all nonindigenous species in the Laurentian Great Lakes, and also employs experts to verify and confirm these reports to ensure reliability.

Tools that integrate standard reporting methods along with compelling visualizations of compiled data are needed to address this ongoing threat to the health of the Great Lakes, as well as the rest of North America. Since 2005, the Center for Invasive Species and Ecosystem Health at the University of Georgia has developed and maintained the Early Detection and Distribution Mapping System (EDDMapS, Barger and Moorhead 2007), which assimilates and independently verifies reports of invasive species from organizations and volunteers across North America. Verification for EDDMapS species is performed by experts familiar with specific geographic areas and taxonomic groups (Wallace et al. 2016). Other applications, such as iMapInvasives (Dean 2010), the Midwest Invasive Species Information Network (MISIN 2018), and a collection of tools from the Great Lakes Indian Fish and Wildlife Commission (GLIFWC 2018) perform similar functions at a regional scale. Comparable and global-scale data assimilation and verification on invasive species have been performed by the Global Invasive Species Database (GISD, see Westphal et al. 2008 for example usage).

The wealth of ecological survey data and historical records that exist for species in the Great Lakes region allows scientists to track the spread of introduced species over time and space. However, a single, user-friendly information portal for comprehensive regional research and management use is necessary to avoid redundancy, gaps in data, and to further enable exploratory data analyses. We designed the GLANSIS Map Explorer (<https://www.glerl.noaa.gov/glansis/mapExplorer.php>) to address this need, and to serve as an interactive tool for displaying comprehensive records of nonindigenous species in the Laurentian Great Lakes. The GLANSIS database itself includes in-depth species profiles for hundreds of established species as well as those on a “watchlist” that are likely to be introduced. GLANSIS also includes information on species identification, ecology, anticipated or realized environmental impacts, and best practices for management. The Map Explorer further leverages this database, providing an interactive mapping feature that retrieves the specimen records and geographical coordinates available for each species in the database, displaying their geospatial distribution on a map. Additionally,

the Map Explorer allows the display of lake features (surface water temperature and depth, for example) to compare with species distributions.

Materials and methods

Source data

Data for GLANSIS Map Explorer are available from two sources as of this publication: the USGS's Nonindigenous Aquatic Species Database (USGS NAS 2018) and the Great Lakes Aquatic Habitat Framework (GLAHF, Wang et al. 2015).

The USGS NAS Database is designated as a central repository of data and information on discovered freshwater species nonindigenous to the United States. Identified as a need via the Nonindigenous Aquatic Nuisance Species Control and Prevention Act of 1990 (PL 101-646 1990) and the resulting Aquatic Nuisance Species Task Force (2018), its data and information include reports, maps, and geospatial data developed from sightings of nonindigenous aquatic plants and animals throughout the United States. The inclusion of a species in the database is independent of residence time, and thus species that ultimately could not become established within U.S. freshwater ecosystems are still included. GLANSIS data form a subset of the overall USGS NAS database, and provide additional Great Lakes-specific information for the species that are discovered, established, or anticipated to become established in the Great Lakes basin.

GLAHF has produced a comprehensive suite of spatial information and tools for the entire Great Lakes basin to support management, research, and policy-making. Products available from GLAHF include 1) a geospatial framework which defines aquatic zones throughout the basin, 2) an extensive geospatial database composed of chemical, physical, and biological data layers harmonized across the basin, and 3) a classification of aquatic ecosystems (Riseng et al. 2018), with mapping and visualization applications (Goodspeed et al. 2016). Development of GLAHF was funded by the Great Lakes Fishery Trust with ongoing support from the Michigan Department of Natural Resources and the University of Michigan.

Software

We developed the GLANSIS Map Explorer using client-side JavaScript and additional libraries including jQuery (<https://jquery.com/>) for user event processing, Leaflet (<https://leafletjs.com/>) for mapping, and the Esri Leaflet extension (<https://esri.github.io/esri-leaflet/>) to utilize Esri basemaps and ArcGIS service layers from GLAHF (2018). To query and retrieve geospatial and attribute data from the USGS NAS Database, we used its accompanying application programming interface (API, USGS NAS API 2018).

For Great Lakes basin-specific searches for nonindigenous species, we incorporated two arrays into the JavaScript for GLANSIS Map Explorer. The first array contains a list of the eleven states in the U.S. that border the Great Lakes and St. Lawrence River basins. A second array contains a compiled list of all eight-digit hydrologic unit codes (HUC8s) from the Watershed Boundary Dataset (WBD, U.S. Geological Survey et al. 2013) identifying sub-basins within the Great Lakes basin. We additionally wrote functions to compile state-based or HUC-based queries for the USGS NAS API.

Results and discussion

The GLANSIS Map Explorer comprises three interrelated components, each of which is described below: 1) the map interface, where nonindigenous species occurrences can be visualized alongside Great Lakes physiochemical data; 2) the query interface, where users can search for species occurrence data using a combination of taxonomic, temporal, or spatial filters, and 3) a data download section, providing users with occurrence data and associated bibliographic data in a human- and machine-readable text format.

Map interface

The top of the GLANSIS Map Explorer's interface contains the application-defining map and several controls. Nonindigenous species distributions across the Great Lakes basin and Great Lakes surface and shoreline data layers can be plotted in the map to compare species distributions to their surrounding environment (see Figure 1). Users are provided with drop-down menus of GLAHF surface (geomorphology, spring and summer surface temperatures, cumulative degree-days, ice duration, and upwelling) and shoreline (sinuosity and classification) layers for the Great Lakes, as well as the desired basemap. Basemap label visibility may be toggled with a checkbox. Labels for each of the mapped species contain the names of the mapped species and their year range (if applicable), with label colors corresponding to the color of the points plotted on the map. To remove all plotted species, users may click on the "Start Over" button beneath the colored boxes. Additionally, links to each species' informational profile in the USGS NAS database and GLANSIS database are provided. We have built in the capacity to simultaneously map up to three distinct sets of nonindigenous species occurrence data (i.e., current distributions of three different species, three temporal slices of occurrence data, or any combination thereof; see the next section, "Query interface").

Query interface

We have enabled users to query for species in the GLANSIS Map Explorer in a variety of ways. "Hot buttons" allow users to quickly map the distribution of well-publicized or species of otherwise great interest. These

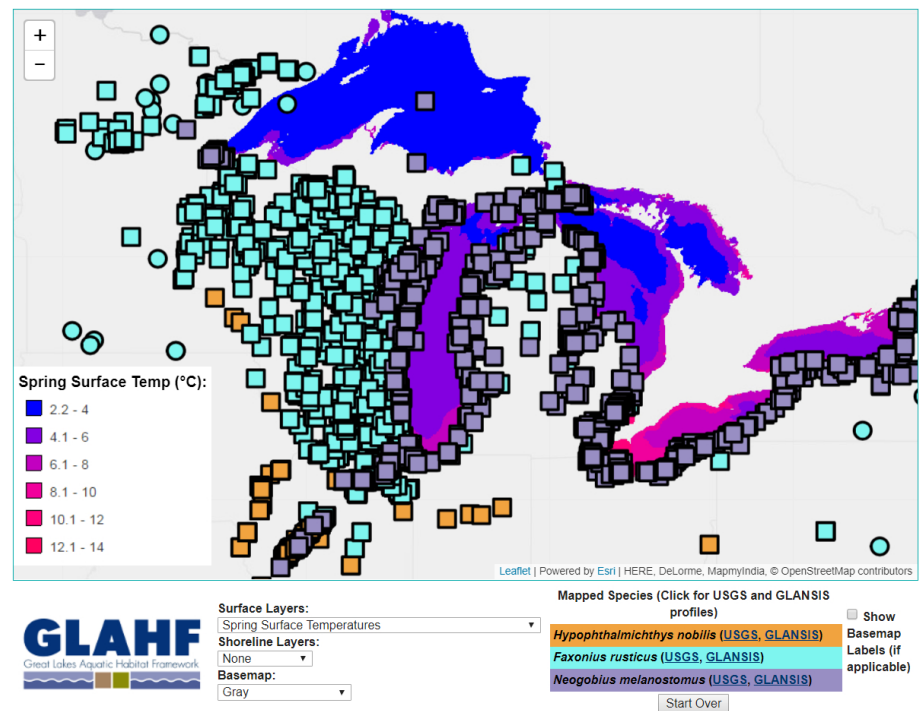


Figure 1. Map interface and menu of the GLANSIS Map Explorer displaying three different species' spatial distributions as provided by the USGS NAS database and average spring (April 1 – May 31 for the years 2006–2012) surface water temperatures in degrees Celsius from GLAHF. Listed from top to bottom in the “Mapped Species” list are, by common name, bighead carp, rusty crayfish, and round goby. These results are from “hot button” default queries throughout all of the Great Lakes states in the US. The shape of a map point for a particular species represents its status for that location. Square (\square) shapes indicate the species is established at that location, while circles (\circ) indicate the species was stocked, cultivated, or collected.

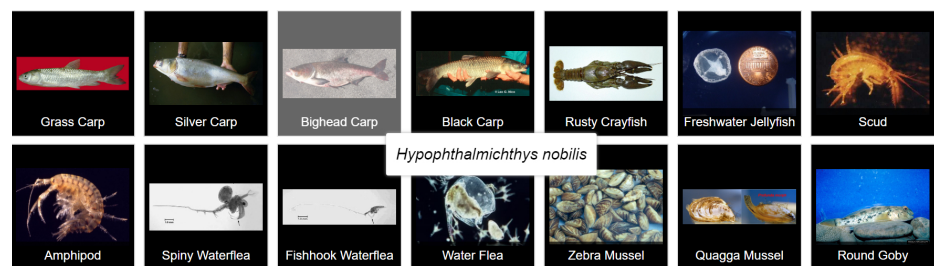


Figure 2. “Hot button” species menu, with the scientific name of the bighead carp shown in the mouse-over text.

include grass, silver, bighead, and black carp, rusty crayfish, quagga and zebra mussels, and round goby, among others. Hovering the mouse cursor over each button containing the common name for the species reveals its scientific name (Figure 2). Drop-down menus and search fields enable users to refine a “hot button” search or otherwise search for a particular species (Figure 3). Specifying a species can be done directly or via taxonomic search, wherein the Map Explorer queries the USGS NAS API for applicable families, genera, and species as users descend through the taxonomic tree. Within the Great Lakes hydrologic basin (HUC region 04) alone, GLANSIS Map Explorer allows users to search through 10 taxonomic groups, totaling at least 77 families and 138 genera as of this publication. To refine the geographic scope of a search, we created a “Region to search” drop-down

Specific Species Search

Query for species, **one-at-a-time**, in the NAS database below. Results will be mapped above, and you may map up to **3** species at once, which will be indicated in the 'Species slot's above. Clear the map with the 'Start Over' button.

Each submitted query will generate its own set of tabulated results below. Copy and paste your tabulated results for each query to save your work.

Taxonomic Group:

Enter the name of one species directly ('genus [space] species'):

Region to search:

8-digit hydrologic unit codes, separated by a comma (','):

2-Letter State Abbreviations, separated by a comma (','):

Year(s) collected (enter either a list of years separated by commas, e.g. 1997,2002; or a range with a dash '-', e.g. 1997-2008):

Figure 3. The detailed query interface for the Map Explorer. Species searches may be performed directly by name or by traversing the taxonomic tree. Results can be narrowed by region, HUC, US State, and year(s) discovered.

menu, with options including the Great Lakes bordering states, Great Lakes hydrologic basin, and specific states or HUC regions, to be listed in the fields below. Lastly, users may specify a year, list of years, or year range in which a species was discovered in a particular region.

Data download

Users may download text-based tables for each query submission at the bottom of the GLANSIS Map Explorer page. We provide two large text fields for *comma*-delimited tables of nonindigenous species observations, as well as *tab*-delimited tables of references for the queried species, which users may copy and paste to their preferred text editor. Saving the text files with the extensions “.csv” and “.txt”, respectively, enables users to open the files in their preferred spreadsheet program. We provide the first three potential entries of data and references in Figure 4, given a “hot button” default query for the round goby throughout all of the Great Lakes and St. Lawrence River basin containing states in the US.

Discussion

The GLANSIS Map Explorer provides a simple interface for querying and visually displaying detailed records on the history of aquatic invasions throughout the Great Lakes region and the ability to view these records in the context of existing physical and environmental data. This free online tool is not limited to use by research scientists alone—environmental managers, students in science courses, concerned citizens, and other stakeholders can use this simple interface to gain more in-depth knowledge of particular species or overall invasion patterns in the region.

Georeferenced Report Data

NAS ID, Group, Family, Scientific Name, Common Name, State, County, Latitude, Longitude, HUC8 Name, HUC8 Number, Year, Month, Day, Status, Record Type
 33563, Fishes, Gobiidae, *Neogobius melanostomus*, Round Goby, Illinois, Cook, 41.647983551, -87.6005859375, Chicago, 7120003, 1996, 10, 29, established, Specimen
 33579, Fishes, Gobiidae, *Neogobius melanostomus*, Round Goby, Illinois, Will, 41.550442, -88.078728, Des Plaines, 7120004, 1999, 10, 20, established, Personal communication
 33580, Fishes, Gobiidae, *Neogobius melanostomus*, Round Goby, Illinois, Cook, 41.6678848267, -87.5613937378, Little Calumet-Galien, 4040001, 1996, 10, 20, established, Personal communication

Associated References

Reference Type	Year	Author(s)	Title	Publisher	Publisher Location
Report	2000	Hintz, A.	Lake Huron exotic fish surveillance in 1999.	US Fish & Wildlife Service, Fishery Resources Office	Alpena, MI
Report	2000	Czypinski, G.D., A.K. Hintz, M.T. Weimer, A. Dextrase.	Surveillance for ruffe in the Great Lakes, 1999.	US Fish and Wildlife Service, Ashland, WI.	
Report	2002	Czypinski, G.D., A.K. Bowen, M.T. Weimer, and A. Dextrase.	Surveillance for ruffe in the Great Lakes, 2001.	US Fish and Wildlife Service, Ashland, WI.	

Figure 4. The first three potential entries of data and associated references for a “hot button” default query for the round goby throughout all of the Great Lakes and the St. Lawrence River basin containing states in the US.

Internally, the GLANSIS Map Explorer provides data-entry staff with quality assurance and control tools to verify newly-entered records into the database. Immediate feedback is provided by the mapping feature showing new locations where species have been discovered. Further quality assurance is achieved by viewing the provided text-based observation and reference data. Researchers using this tool will find utility in the ability to display species distributions along with shoreline, surface, water column, and geological data layers. Such displays enable scientists to explore hypotheses about the environmental factors that may influence nonindigenous species occurrence, survival, and establishment. Future data layers may include data indicating habitat suitability or environmental niches for select species, such as grass carp (Wittmann et al. 2017), Eurasian ruffe (Beletsky et al. 2017), and rainbow trout (Höök et al. 2004). As species records continue to be added to and displayed in the GLANSIS Map Explorer, a more complete picture of the state of the Great Lakes is provided.

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