Great Lakes Site Prioritization Methods

A systematic spatial prioritization method was developed to attribute a weighted "index of invasion pressure" across the US waters of the Great Lakes Basin (**Figure 1.)**.

Spatial framework

We used the Great Lakes Aquatic Habitat Framework (GLAHF) 9,000-meter grid (Wang et al. 2015), covering the Great Lakes basin, as our underlying spatial framework. The original raster grid was converted to a polygon layer and cells (9 km per side) were attributed with country, state/province, and lake basin based on the location of cell centroids. This grid was subsequently attributed with surrogate variables thought to influence risk of AIS invasion from potential pathways of introduction.

We selected surrogates that account for all the major vectors that have been associated with the introduction of non-indigenous species into the Great Lakes (**Table 1**; sensu Mills 1993, Ricciardi 2010). Grid cells were attributed according to features occurring locally in the grid cell, while coastal cells were also attributed by features in the inland contributing watersheds. The grid was restricted to waters of the Great Lakes, connecting channels, and inland streams up to the first major barrier. The first major barrier was identified using a draft version of the FishWerks hydrography and barriers data layers (Moody et al. 2017; https://greatlakesconnectivity.org/).

Surrogate data and processing steps

The surrogate data were attributed to grid squares as follows: Most point datasets originated as tabular data and were converted to geospatial layer points using latitude and longitude coordinates contained in the data using ArcGIS version 10.3 (ESRI 2015). Census population data and land cover data for the Great Lakes Basin were acquired from GLAHF. We used the Dasymetric Mapping Toolbox tools (from EPA EnviroAtlas) to apportion the census unit population data to appropriate land covers to get a more precise spatial representation of population across the basin. This population data was then attributed to GLAHF watersheds and coastal grid squares. The Chicago metropolitan area is situated mostly outside of the basin, but because of the artificial connections created by the Chicago Area Waterway System, much of the population is effectively connected to the basin. We therefore included the population within two 8-digit hydrologic units (07120003 & 07120004) that are hydrologically connected to Lake Michigan to more accurately account for the risk in the Chicago area.

To create risk indices that did not over emphasize a single pathway, we combined the rescaled data for marina size and boat launch size (surrogates for both the dispersed and bait release pathway) into a single variable. The shipping surrogate data layer is a

combination of the number of ship visits to a given port and open water discharged events with the latter being treated as equivalent to a ship visit.

Data located within the boundaries of a Great Lake or along the coastline were simply assigned to the grid cell in which they occur and attributed with a count of the feature in that grid cell (e.g., population size) or a total amount of an attribute of the feature (e.g., total number of marina boat slips). Data located inland were first attributed to watershed polygons developed as part of the GLAHF, and then transferred to the appropriate grid cell using the outlet pour point of those watersheds that intersected the grid. After all data were attached to the grid, each variable was divided by the maximum value for that variable of any grid square and multiplied by 100 to rescale from zero (none) to 100 (maximum).

AIS risk weighting indices

An average of two models that weighted surrogate data layers based on either historic or future predicted patterns of invasion was used to develop a measure of predicted invasion risk after testing various approaches.

1. Future invaders (Watch List) index: In this approach each surrogate was weighted based on the proportion of predicted future invaders likely to be in a given pathway based on a "Watch List" of potential future invaders and range expansion species (see Great Lakes Surveillance Framework Watch List Methods).

   Pathway weightings were based on the relative proportion of "Watch List" species considered to be in present in each pathway (**Table 2 & Table 3**).

2. Historic invasion patterns: In this approach, a pathway of introduction was assigned for every established nonindigenous aquatic species (NAS) including range expander species in the Great Lakes (see http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html). Pathways were assigned per the pathway categories defined by GLANSIS (e.g. aquaculture, aquarium release, bait release, canals, etc., and see **Table 2**). Pathway weightings were then derived from the relative proportion of all established NAS and range expanders that are in each pathway.

We computed the average of the above two risk weighting indices to serve as the final index; separate indices were developed for fish, invertebrates, and plants. All sites (i.e., grids) were then ranked based on the average AIS risk scores.

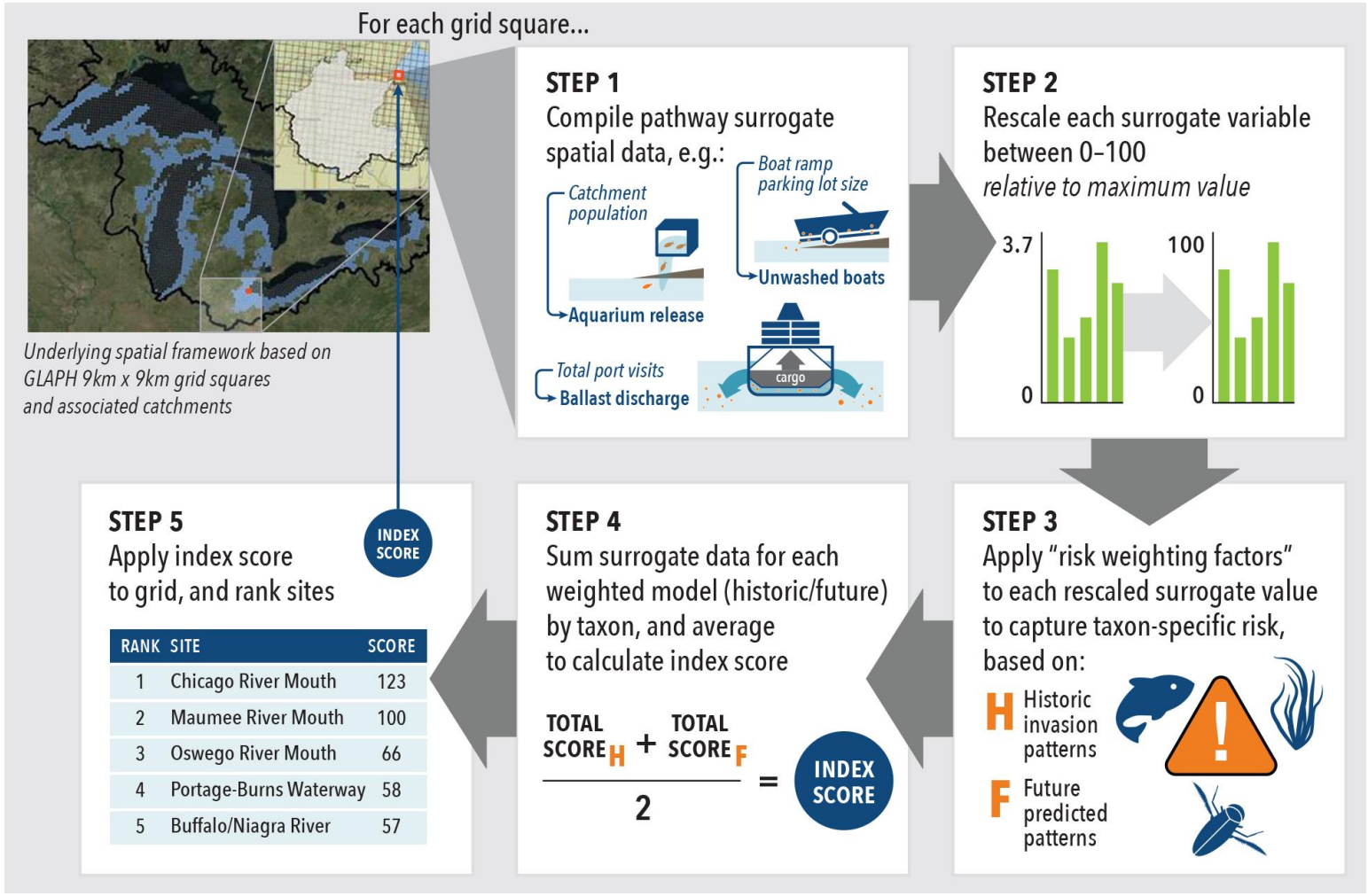

Figure 1. Conceptual diagram showing the systematic spatial prioritization method for attributing a weighted "index of invasion pressure" for each 9 x 9 km grid cell.

Table 1. Data sets, data type, and data source for all pathway surrogates used for determining the "index of invasion pressure".

Data Set	Data Type	Source	Associated AIS vector categories
9,000-meter grid	Raster converted to polygon	Great Lakes Aquatic Habitat Framework (GLAHF) glahf_9000m_grid GLAHF_spatial_framework_v1d1.gdb http://glahf.org/framework/	n/a
Great Lakes Basin Population (2010/2011)	Polygon	Great Lakes Aquatic Habitat Framework (GLAHF) US/Canadian integrated census data. Credits: U.S. Census Bureau 2010 Census Demographic Profile 1; Statistica Canada 2011 Census Profile. Apportioned to GLAHF US/Canadian land cover using Dasymetric Mapping Toolbox from EPA EnviroAtlas.	Organisms in trade pathways including, aquarium release and accidental release (e.g. ornamental escape)
Great Lakes Basin GLAHF Land Use (2010/2011)	Raster	Great Lakes Aquatic Habitat Framework (GLAHF) glahf_glb_land_cover_11_12_00_nlcd_solris_plo glahf_land_cover_11_12_00_nlcd_solris_plo.gdb http://glahf.org/data/	n/a
Shipping vessel trips to port (2004–2013)	Point	Data provided by: Elon O'Malia and Dr. Joel Hoffman (EPA). Data gathered by E. O'Malia, University of Minnesota Duluth/EPA — (2014) from National Ballast Water Clearing House (NBIC) (http://invasion.si.edu./nbic).	Ballast and hull fouling
In-lake discharge events (2004-2009)	Point	Data provided by: John Bossenbroek (University of Toledo).	Ballast
Marina size (# of boat slips)	Point	Data provided by Caitlin Dickinson at the Great Lakes Environmental and Mapping Project. Allan JD. et al. 2013. Joint analysis of stressors and ecosystem services to enhance restoration effectiveness. Proceedings of the National Academy of Sciences 110(1):372–377. Digital data.	Recreational boating and associated activities including, attachment to hulls, entanglement of fishing gear or anchor chains, and transport of standing water (e.g. live wells, bilge, bait buckets)
Boat launch size (# of parking spaces)	Point	Data provided by Caitlin Dickinson at the Great Lakes Environmental and Mapping Project. Allan JD. et al. 2013. Joint analysis of stressors and ecosystem services to enhance restoration effectiveness. Proceedings of the National Academy of Sciences 110(1):372–377. Digital data.	Recreational boating and associated activities including, attachment to hulls and trailers, entanglement of fishing gear or anchor chains, and transport of standing water (e.g. live wells, bilge, bait buckets)

Ponds	Polygon converted to point	National Wetlands Inventory (NWI) “excavated” freshwater ponds. U.S. Fish and Wildlife Service. 2015. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC. FWS/OBS-79/31. Publication date: 2015-05-01. Digital data.	Deliberate release associated with cultivation or stocking
Major canals	Point	Chicago Area Waterway System and Erie Canal. Internally developed.	Natural dispersal
Interbasin Headwater Connections	Point	Great Lakes and Mississippi River Interbasin Study. Internally developed using information provided in GLMRIS reports.	Natural dispersal
GLAHF watersheds	Polygon	Great Lakes Hydrography Dataset Version 1 (GLHDv1.0). 2014. Watersheds and pour point features. Digital data. Forsyth et al. 2015. A consistent binational watershed delineation and synthetic network dataset for the Great Lakes Basin. In review.	n/a

Table 2. Risk weighting factors applied to each re-scaled spatial surrogate value and used to derive invasion risk index scores based on historic invasion patterns (per the GLANSIS "Nonindigenous + Range Expanders" list). These were calculated as the proportion of species in each taxonomic group for which introduction has been assigned to a given pathway (s). When more than one pathway was indicated, the weighting is the sum of all pathways combined.

Spatial surrogates	**GLANSIS "Nonindigenous + Range expanders" pathways**	**All taxa**	**Fish**	**Inverts**	**Plants**
U.S. Population (2013)	Aquarium release Pet release Stocked Planted	0.37	0.68	0.13	0.47
Shipping vessel trips to port (2004–2013)	Shipping	0.43	0.16	0.67	0.24
Marina size (# of boat slips)	Dispersed Bait release	0.42	0.51	0.27	0.66
Boat launch size (# of parking spaces)					
Ponds	Aquaculture Planted Stocked	0.29	0.61	0.04	0.39
Canals	Canals	0.17	0.40	0.13	0.12

Table 3. Risk weighting factors applied to each re-scaled spatial surrogate value and used to derive invasion risk index scores based on future predicted patterns of invasion (per Davidson et al. 2017). These were calculated as the proportion of species in each taxonomic group that is predicted to arrive by the specified pathway(s). When more than one pathway was indicated, the weighting is the sum of all pathways combined.

Spatial surrogates	Davidson et al. 2017 pathways	All taxa	Fish	Inverts	Plants
U.S. Population (2013)	Unauthorized intentional release (INT) Escape from recreational culture (ESC)	0.67	0.57	0.14	0.98
Shipping vessel trips to port (2004–2013)	Shipping (SH)	0.31	0.33	0.74	0.09
Marina size (# of boat slips)	Hitchhiking/Fouling (HF)	0.59	0.33	0.40	0.84
Boat launch size (# of parking spaces)					
Ponds	Unauthorized Intentional release (INT) Escape from recreational culture (ESC) Escape from commercial culture (COMM)	0.74	0.67	0.14	1.08
Canals	Dispersal (D)	0.44	0.43	0.34	0.49

References:

Davidson AD, Fusaro AJ, Sturtevant RA, & Kashian DR (2017). Development of a risk assessment framework to predict invasive species establishment for multiple taxonomic groups and vectors of introduction. Management of Biological Invasions. 8(1), 25-36.

Moody AT, Neeson TM, Wangen S, Dischler J, Diebel MW, Milt A, Herbert M, Khoury M, Yacobson E, Doran PJ, Ferris MC, O'Hanley JR and McIntyre PB (2017). Pet Project or Best Project? Online Decision Support Tools for Prioritizing Barrier Removals in the Great Lakes and Beyond, Fisheries, 42:1, 57-65,

ESRI 2015. ArcGIS Desktop: Release 10.3. Redlands, CA: Environmental SystemsResearch Institute.

Mills EL, Leach JH, Carlton JT, and Secor CL (1993). Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. J. Gt. Lakes Res. 19: 1ñ54.

Ricciardi A (2006) Patterns of Invasion in the Laurentian Great Lakes in Relation to Changes in Vector Activity. Divers Distrib 12: 425–433

Wang L, Riseng CM, Mason LA, Wehrly KE, Rutherford ES, McKenna JE, Castiglione C, Johnson LB, Infante DM, Sowa S, Robertson M, Schaeffer J, Khoury M, Gaiot J, Hollenhorst T, Brooks C, Coscarelli M (2015). A spatial classification and database for management, research, and policy making: The Great Lakes aquatic habitat framework. Journal of Great Lakes Research, 41 (2) 584-596.