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A spatial classification and database for management, research, and policy making: The Great Lakes aquatic habitat framework

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ABSTRACT

Managing the world's largest and most complex freshwater ecosystem, the Laurentian Great Lakes, requires a spatially hierarchical basin-wide database of ecological and socioeconomic information that is comparable across the region. To meet such a need, we developed a spatial classification framework and database — Great Lakes Aquatic Habitat Framework (GLAHF). GLAHF consists of catchments, coastal terrestrial, coastal margin, nearshore, and offshore zones that encompass the entire Great Lakes Basin. The catchments captured in the database as river pour points or coastline segments are attributed with data known to influence physicochemical and biological characteristics of the lakes from the catchments. The coastal terrestrial zone consists of 30-m grid cells attributed with data from the terrestrial region that has direct connection with the lakes. The coastal margin and nearshore zones consist of 30-m grid cells attributed with data describing the coastline conditions, coastal human disturbances, and moderately to highly variable physicochemical and biological characteristics. The offshore zone consists of 1.8-km grid cells attributed with data that are spatially less variable compared with the other aquatic zones. These spatial classification zones and their associated data are nested within lake sub-basins and political boundaries and allow the synthesis of information from grid cells to classification zones, within and among political boundaries, lake sub-basins, Great Lakes, or within the entire Great Lakes Basin. This spatially structured database could help the development of basin-wide management plans, prioritize locations for funding and specific management actions, track protection and restoration progress, and conduct research for science-based decision making.

Introduction

The Laurentian Great Lakes comprise the largest freshwater ecosystem in the world. Their immense surface area (about 246,000 km^2) and water volume (about 23,000 km^3) support diverse physical, chemical, and biological components that exhibit complex ecosystem functions and processes (USEPA and Government of Canada, 1995; Wehrly et al., 2013). The Great Lakes drainage basin (about 765,000 km^2) spans a large geographic extent that encompasses a diversity of climatic conditions, soils and vegetation types, streams, inland lakes, wetlands, and wildlife. The Great Lakes waters exhibit diverse habitats from

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shallow water in bays/estuaries in Western Lake Erie to deep waters of Lake Superior, freshwater spawning reefs, extensive length of coastlines, and complex physical processes such as circulation and upwelling patterns. The Great Lakes and their drainage basin provide water and other natural resources for urban, industry, agriculture, transportation, fisheries, and other recreational needs for more than 33.5 million people in the basin (U.S. Census Bureau, 2000; Statistics Canada, 2002).

Managing such a large and complex ecosystem is challenging. Management authority of the Great Lakes is spread across multiple organizations including the federal governments of the U.S. and Canada, eight U.S. states, two Canadian provinces, and many local entities. Current management efforts are hampered by the lack of consistent information that can be shared and easily accessed by federal, state, and local organizations (Wehrly et al., 2013). The development of a basin-wide database of comparable ecological and socioeconomic data information across the region is, therefore, highly desirable. A consistent database could be used to develop basin-wide management plans, prioritize locations for funding and specific management actions, and to conduct research for science-based decision making. In addition, managers and policy makers are faced with the challenge of making management decisions at multiple spatial scales from an individual beach to a particular lake sub-basin, and from a specific lake to the entire Great Lakes Basin (McKenna and Castiglione, 2010a,b). Consequently, there is a need to organize information in a hierarchical spatial framework that allows managers and policy makers to apply information and make decisions at a variety of spatial scales.

The need for consistently managed and spatially comprehensive Great Lakes data and information has long been recognized and many efforts and resources have been invested in data collection and synthesis, database development, information delivery, habitat classification, and mapping. For example, the Great Lakes National Program Office (GLNPO) has coordinated with Environment Canada and the Province of Ontario, and the U.S. Great Lakes states to collect physical, chemical, and biological data from open waters of the Great Lakes since the 1960s and to manage those and other sampled environmental data in the Great Lakes Environmental Database (GLENDA) since 2003 (http://www.epa.gov/glnpo/monitoring/data_proj/glenda/). The Great Lakes Observing System (GLOS) provides access to near real-time and archived observations and modeled forecasts for water levels, wave heights, air and water temperatures, and other lake conditions (http://glos.us/). The Great Lakes Environmental Assessment and Mapping (GLTranslated by Susanne and Hans Ulrich RollEAM) project synthesized basin-wide coarse level anthropogenic data and assessed the Great Lakes health conditions (Allan et al., 2013; http://greatlakesmapping.org/). Great Lakes Environmental Indicator (GLEI; Niemi et al., 2007) and the Great Lakes Wetlands Consortium (GLWC) projects have developed environmental indicator data and assessed condition of much of the Great Lakes coastal wetlands (Niemi et al., 2007). Several efforts also have been devoted to the development of Great Lakes habitat and ecological classification systems (Johnson et al., submitted for publication; Rutherford and Geddes, 2007; McKenna and Castiglione, 2010a,b).

These efforts have met many critical information needs and helped answer management questions that could not be answered otherwise. However, each of these efforts had specific objectives and focused on particular aspects of information needs related to those objectives. For example, most Great Lakes data collection programs (e.g., offshore focused GLNPO, coastal focused GLEI) have collected physicochemical and biological point data at selected locations. Extrapolation of those data or inferences made from those data to unsampled areas is difficult due to the lack of spatial linkage (how a spatial unit connects to, and is influenced by other spatial units) and a common spatial framework. Extrapolation of information from sampled data to unsampled areas is important because scientists and managers lack the time or resources to sample all areas of the Great Lakes ecosystem. Many of the existing databases and data delivery systems serve as data downloading sources for geographic information system (GIS) data layers that are either available for one side of the U.S.–Canadian border or available for both sides but lack data consistency (e.g., the Institute for Fisheries Research's Great Lakes GIS [http://ifrgis.snre.umich.edu/projects/GLGIS/] and the Great Lakes Commission's Information Network [http://www.great-lakes.net/]). Other existing databases and data delivery systems serve as data portals for locally synthesized data to provide links to other web-based databases and information (e.g., GLOS). These portals may be limited by database sources that are discontinued, out of date, or haven't been linked by a common spatial framework. Few of the databases mentioned above provide the ability to scale spatial data as management needs dictate. Although those efforts serve well for their specific purposes, they do not satisfy the increasing need for a Great Lakes basin-wide integrated database and information system with a mechanism that allows spatial information linkage and hierarchical stratification.

The need for Great Lakes basin-wide information integration and spatial linkages has been widely recognized. The Protocol of Great Lakes Water Quality Agreement (GLWQA) of 2012 identified a need for an integrated approach to managing information to achieve adaptive management objectives for nearshore health improvement, nonpoint source pollution reduction from urban and agricultural sources, aquatic invasive control and prevention, species and habitat restoration and protection, nutrient load and concentration reduction, and climate change prediction and adaptation (GLWQA, 2012). Emerging issues, such as record low water levels for Lakes Huron and Michigan in December 2012 and January 2013 (Clites et al., 2014), the dramatic changes in offshore productivity and food web composition likely related to aquatic invasive species in lakes Huron and Michigan during the last decade (Fahnenstiel et al., 2010; Cha et al., 2011; Barbiero et al., 2012; Bunnell et al., 2013), the extraordinarily high nuisance algal blooms in Lake Erie during 2011 (Michalak et al., 2013), and the Lake Erie algal toxins that resulted in more than 400,000 people without tap water for two days in 2014 (http://ecowatch.com/2014/08/03/toxic-algae-bloom-500000-without-drinking-water-ohio/), require basin-wide and lake-wide binational strategies and management actions.

To address these ongoing and emerging challenges, both Canadian and U.S. governments need a spatial framework and database that provides basin-wide information on the location, characterization, status, and quantity of Great Lakes physical, chemical, biological, and human ecosystem components (e.g., GLWQA 2012 Annex 2 — Lakewide Management Plans and Annex 10 — Science). Ideally a basin-wide spatial framework and database would: (1) incorporate an integrated, objective standard for basin-wide and lake-wide condition comparison; (2) provide access to key available data and spatial information to decision makers to enable rapid identification of high priority, cost-effective locations for protection, enhancement, and rehabilitation; and (3) provide a spatial framework for reporting that allows the priority activities and progress of multiple government agencies to be synthesized, assessed, and reported at regional and basin-wide scales. Such a spatial framework and database is the foundation for the most efficient allocation of resources and management actions by binational government agencies (Riseng et al., 2008; Wang et al., 2011).

In 2010, a research team was formed to address the need for Great Lakes basin-wide information integration and spatial linkages. The team was composed of Great Lakes researchers and managers with extensive experience in collecting and synthesizing Great Lakes regional data, conducting regional assessments, or developing basin-wide habitat classifications. The goal of this team was to develop an operational, integrated basin-wide database and a hierarchical spatial classification framework with basic spatial mapping units for the entire Great Lakes Basin and their associated catchments in both Canada and U.S. The resulting geospatial classification framework and database, the Great Lakes Aquatic Habitat Framework (GLAHF), has a common spatial framework attributed with sampled, calculated, and modeled data and a flexible nested structure that enables aggregation of data into larger units characterized by specific criteria or constraint. This hierarchical structure allows data to be synthesized, utilized, and reported at any