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Hierarchical multi-scale classification of nearshore aquatic habitats of the Great Lakes: Western Lake Erie

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ABSTRACT

Classification is a valuable conservation tool for examining natural resource status and problems and is being developed for coastal aquatic habitats. We present an objective, multi-scale hydrospatial framework for nearshore areas of the Great Lakes. The hydrospatial framework consists of spatial units at eight hierarchical scales from the North American Continent to the individual 270-m spatial cell. Characterization of spatial units based on fish abundance and diversity provides a fish-guided classification of aquatic areas at each spatial scale and demonstrates how classifications may be generated from that framework. Those classification units then provide information about habitat, as well as biotic conditions, which can be compared, contrasted, and hierarchically related spatially. Examples within several representative coastal or open water zones of the Western Lake Erie pilot area highlight potential application of this classification system to management problems. This classification system can assist natural resource managers with planning and establishing priorities for aquatic habitat protection, developing rehabilitation strategies, or identifying special management actions.

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Introduction

Coastal aquatic organisms of the Great Lakes reside within ecosystems that are physically and biologically complex, consisting of many continua of environmental and biological conditions and interactions (Christie, 1974; Mills et al., 2003; Munawar, 2003). Benthic substratum and attached structure are tied to fixed locations in space, but water of various condition and organisms move through that space. Peterson (2003) has described these two basic aspects of aquatic environments as stationary (i.e., structural) and dynamic (i.e., physicochemical). Physical and chemical influences occur across a range of spatial and temporal scales and can significantly affect different processes at different scales (Ricklefs and Miller, 2000; Wetzel, 2001; Schertzer, 2003). For example, the distance over which wind blows (i.e., fetch) can determine the wave energy at any particular location, the depth to which waters are well mixed, and generate currents and upwelling zones (Li et al., 1975; Pickett, 1977). Turbidity and benthic substratum conditions can be strongly influenced by the size and location of rivers flowing into the coastal zone (Allen, 1995; Wetzel, 2001). Organisms and water (along with its suspended load) move freely throughout nearshore areas and interact with deeper offshore waters as well as mixing with waters and organisms entering from coastal tributary systems. Ecological problems (e.g., habitat modification and water quality degradation) in the Great Lakes vividly illustrate the connected nature of coastal systems and the problems that can arise (Christie, 1974; Mills et al., 2003). This complexity of aquatic environments has been recognized by the National Fish Habitat Action Plan (NFHSDC, 2008) and is an integral part of the foundation for the national strategy for assessment and management of aquatic ecosystems.

Nearshore habitats are critical to aquatic biodiversity and Great Lakes fish populations; more than 120 native or established fish species use coastal habitats as spawning and nursery grounds (Goodyear et al., 1982). Some of these species range widely and migrate through many different habitats annually (Scott and Crossman, 1973). The complex and dynamic coastal environment makes it difficult to determine which set of habitat conditions significantly affect aquatic organism survival and movement. In addition, increasing evidence that many local ecological problems stem from conditions at larger spatial scales highlights the need for tools to effectively address multi-scale problems (Matthews, 1998; Wetzel, 2001; Gido et al., 2006).

Classification is a tool that helps us simplify complex systems into sets of discrete units with known characteristics and relationships to each other, summarizing the essence of what is pertinent to a particular problem. Hierarchical classification systems also allow for determination of relationships among classified elements and may be applied to habitats, biota, or both. Several classification systems have been developed for coastal areas to address various needs (Cowardin et al., 1979; Busch and Sly, 1992; Hudson et al., 1992; Olson et al., 2001; Connor et al., 2004; Madden et al., 2005; Spalding et al., 2007)

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and numerous researchers have discussed important aspects of habitat within the context of landscapes (e.g., Davis and Henderson, 1978; Kotliar and Wiens, 1990; Seelbach et al., 2006; Riseng et al., 2008). An effective aquatic habitat classification system should function to (1) generate multiple classifications, because classification is needed for a wide variety of problems; (2) both generate hypotheses about the natural world and serve as a practical tool; (3) provide a basis for cataloging habitat status and making spatial comparisons; (4) provide a framework for developing management strategy; and (5) communicate knowledge and experience about aquatic habitat. In order to perform these functions, a coastal classification system should (1) be inclusive of all space and habitat types; (2) include both nearshore and tributary influences; (3) include hydrologic regime; (4) account for the mosaic of habitat patches on the landscape; (5) be a nested hierarchy of scale to address issues at a variety of scales; (6) be ecological in nature, including both biotic and abiotic features; (7) be mappable and use new technologies for organization and analysis (e.g., geographic information systems); and (8) be readily buildable for an entire region. Many different systems accommodate one or a few of these features, but there remains a need to effectively characterize, compare, and contrast coastal habitat units with a practical system that accommodates the range of scales and scale-dependent processes that significantly affect fish and other aquatic resources. In this paper, we describe a classification system that incorporates all of these characteristics, including practical instructions and data requirements for coastal aquatic habitats of the Great Lakes. The Great Lakes Regional Aquatic Gap Analysis Coastal Project Classification System (C_Gap) improves on existing classifications by providing a flexible, multi-scale framework for construction of organism- or habitat-specific classifications (or ecological hybrids) that are appropriate for different needs and situations in coastal ecosystems.

Our objectives were to describe the C_Gap hydrospatial framework and demonstrate the development of a habitat classification using a fish-based example. We discuss application of the fish-based classification to important aquatic resource issues. Effective prediction of organism occurrence and abundance within a lakescape is integral to an effective biologically based spatial classification and analysis tool. Therefore, we begin with an explanation of our spatial data and predictive model development. We deal first with the stationary aspect of aquatic habitat and show how the resulting framework may be used to deal with the multitude of dynamic factors that determine the character of a given unit of habitat at any particular time. Our focus is on western Lake Erie, where extensive fish data are available from survey work of the Ohio Environmental Protection Agency (OEPA) and Ohio Department of Natural Resources (ODNR).

Methods

The Western Lake Erie Demonstration Area

Western Lake Erie is a 4100-km^2, shallow (typically <10 m deep) system with a coastline that includes two major embayments, two large peninsulas, and numerous islands and shoals. Prevailing winds blow from the southwest and the fetch can be as large as 70 km. Western Lake Erie receives most water from the Detroit River (80%) and a smaller amount from the Maumee River (5%) and a number other tributaries (Bolsenga and Herdendorf, 1993). These coastal tributaries deliver varying amounts of dissolved and particulate materials and are themselves habitat for fish and other aquatic organisms. Benthic substratum ranges from rock to fine mud (Environment Canada, 1997) and submerged aquatic vegetation (SAV) grows in some areas. Extensive coastal wetlands exist along the southern and western shores (Herdendorf, 1992). Western Lake Erie is roughly bounded on the east by two major peninsulas, Point Pelee on the north shore and Scott Point on the south shore. We chose to use a line extending from just east of Point Pelee south to the Huron River, Ohio (approximately 82° 33' W longitude), as the eastern boundary of our study area because it allowed us to include Sandusky Bay and adjacent habitat to the east (Fig. 1). Due to the great complexity of deep water systems (e.g., upwelling and circulation, and weaker coupling of pelagic and benthic systems), we chose not to extend our scope beyond the nearshore zone, except in the small pockets that intruded into the western Lake Erie study area.

Habitat data

Energy in large lentic systems like the Great Lakes is generally provided by wind and waves and differential exposure creates areas of high or low energy. The wave regime of a particular coastline determines to what depth of water bottom sediments are physically reworked. We defined this depth as the offshore boundary of nearshore zones, calculated as:

$$Z_\mathrm{n} = ((\surd(g \cdot h) \cdot T) / 2), \quad \text{or} \quad Z_\mathrm{n} = 10\,\mathrm{m}, \tag{1}$$

whichever was deeper, where Z_n is the depth of the offshore boundary (m), g is the acceleration due to gravity (9.8 m/s^2), h is wave height (m), and T is wave period (Knauss, 1978). The alternative criterion of 10 m was chosen because in typically calm areas of the lakes, the dynamic definition of the nearshore zone becomes impractically small (<1 m in many cases). The SAV is an important aspect of nearshore zone habitats (Wetzel, 2001) and the band of waters ≤10 m usually encompasses the areas where light in Lake Erie penetrates close enough to bottom sediments to allow for SAV growth (when other conditions permit). In the case of western Lake Erie, the limited fetch distances and shallow waters define nearly all of it as nearshore habitat (≤10 m).

Locations within the study area were represented in raster form (i.e., simply as an array of equally sized cells) in a Geographic Information System (GIS) using ArcGIS 9.2 (ESRI, Inc., Redlands, California). The 270-m cell (0.07 km^2) was chosen as the best compromise among data spatial resolutions and computational capacity and is the basic unit of space containing all habitat and biotic information in this study.

Twenty-two georeferenced habitat variables were available to describe summer habitat conditions at each local cell (Table 1). Two basic data sets describe the nearshore zone in this work, (1) the lake shoreline, which provides spatial reference to coastal features, and (2) the lake bathymetry, from which bottom slope, aspect, and other physical geometry characteristics are derived. In addition to lentic geometry, the values of areal habitat characteristics, such as bedrock geology, bottom sediments, and water temperature, were determined for each spatial cell. These variables have different inherent spatial scales. For example, identity of the major circulation gyre and bedrock geology type are the same at all points throughout the western Lake Erie pilot area (>80 km range). Exposure varies with orientation and effective fetch (1–80 km range). Geomorphology is an indication of the structure and shape of the coastline and how it has been modified (0.1–10 km range). Local variables (e.g., water temperature and bottom sediment) indicate conditions in and on the bottom and in the overlying water column (0.1 km range). These data were acquired from publicly available, georeferenced databases, with the exception of bottom sediment (Environment Canada, 1997) (Table 1).

No complete spatial coverage of SAV was available for our pilot areas. Therefore, we applied a modification of an algorithm developed by Minns et al. (1995) that uses available habitat features of bottom sediment type (substrate as sand or finer), effective fetch (<2 km), and bottom slope (<15%) to estimate where SAV is expected to cover more than 50% of the bottom (Fig. 1).