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Great Lakes coastal fish habitat classification and assessment

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ABSTRACT

Basin-scale assessment of fish habitat in Great Lakes coastal ecosystems would increase our ability to prioritize fish habitat management and restoration actions. As a first step in this direction, we identified key habitat factors associated with highest probability of occurrence for several societally and ecologically important coastal fish species as well as community metrics, using data from the Great Lakes Aquatic Habitat Framework (GLAHF), Great Lakes Environmental Indicators (GLEI) and Coastal Wetland Monitoring Program (CWMP). Secondly, we assessed whether species-specific habitat was threatened by watershed-level anthropogenic stressors. In the southern Great Lakes, key habitat factors for determining presence/absence of several species of coastal fish were chlorophyll concentrations, turbidity, and wave height, whereas in the northern ecoprovince temperature was the major habitat driver for most of the species modeled. Habitat factors best explaining fish richness and diversity were bottom slope and chlorophyll *a*. These models could likely be further improved with addition of high-resolution submerged macrophyte complexity data which are currently unavailable at the basin-wide scale. Proportion of invasive species was correlated primarily with increasing maximum observed inorganic turbidity and chlorophyll *a*. We also demonstrate that preferred habitat for several coastal species and high-diversity areas overlap with areas of high watershed stress. Great Lakes coastal wetland fish are a large contributor to ecosystem services as well as commercial and recreational fishery harvest, and scalable basin-wide habitat models developed in this study may be useful for informing management actions targeting specific species or overall coastal fish biodiversity.

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Introduction

Approaches such as spatial classification frameworks (e.g., Riseng et al., 2018; Wang et al., 2015) that allow consistent mapping and classification of ecological attributes can greatly advance our ability to predict species and functional guild distributions, estimate sensitivity of biota to anthropogenic impacts, and prioritize management and conservation efforts. Fish distribution and assemblage composition are structured by biotic and abiotic factors which can be viewed as a series of nested filters including broad-scale biogeographic processes and local-scale physical and chemical factors (e.g., Tonn, 1990). Most of these factors have been modified by anthropogenic activities at spatial scales ranging from regional (e.g., land use, species introductions, climate change affecting gross physiological tolerance) to local (e.g., hydrologic modification, habitat alteration, degradation of water quality). Spatial classification frameworks allow us to consistently classify important fish habitat and assess the degree to which it may be threatened by specific stressors (e.g., classification of Great Lakes tributaries by the level of impairment, Riseng et al., 2010).

In the Great Lakes, many studies have focused on developing models of fish habitat use for offshore (e.g., Arend et al., 2011; Höök et al., 2003, 2008; Wittmann et al., 2017), nearshore (McKenna and Castiglione, 2010), and coastal species (Schoen et al., 2016; Uzarski et al., 2005). These studies ranged widely in their spatial and temporal scope as well as the species or traits considered from detailed, fine-scaled, temporally intensive (Bhagat and Ruetz, 2011; Webb, 2008) to large lake- or basin-wide scales (Trebitz et al., 2009; Wittmann et al., 2017). Several studies considered hierarchical importance of regional and local scale factors for structuring fish assemblages (e.g., Brazner et al., 2007). However, in most cases models were not scalable to the entire basin and were not applied in a predictive mode, limiting their use for basin-wide assessment. This lack of predictive basin-wide models of coastal fish habitat may be particularly important for the Great Lakes where nearshore and coastal habitats are used by the majority of fish species at some point in their life cycle (Jude and Pappas, 1992; Trebitz and

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Hoffman, 2015; Vadeboncoeur et al., 2011; Wei et al., 2004). Lacking broad-scale assessment of fish habitat in the Great Lakes nearshore system limits the ability to prioritize for effective management and restoration actions.

Improving our understanding of preferred fish habitats in the Great Lakes is one of the objectives of the current project conducted as a part of the National Fish Habitat Partnership (NFHP), which more generally focuses on “increasing the quality and quantity of fish habitats that support a broad natural diversity of fish”. The NFHP mission is approached by setting fish habitat conservation goals and measuring the status of fish habitats in rivers and lakes across the U.S. (http://www.fishhabitat.org/). In the Great Lakes, the partnership focuses on two distinct habitat zones; coastal habitat that ranges from 0 to 3 m depth and nearshore defined as extending from 3 to 30 m in depth. Coastal fish habitat is strongly affected by fluctuations in physical (e.g., water level, bottom slope, submerged macrophytes and other types of habitat complexity) and water quality variables and responds to multiple local-scale factors (e.g., Cvetkovic et al., 2010; Seilheimer and Chow-Fraser, 2006; Trebitz et al., 2007). However, since these fine-scale factors are constrained by broad-scale factors (Bailey, 1989), models of coastal fish habitat associations using basin-wide data, such as temperature, wave energy and bottom slope, should be able to capture the main factors structuring coastal fish habitat and facilitate basin-wide management (Riseng et al., 2018; Wang et al., 2015). If successful, these models can result in more precise basin-wide habitat assessment for fish species and community metrics of interest which can then be used to enhance the NFHP mission to protect and/or restore critical coastal fish habitats or at least serve as the first step in habitat assessment standardization.

Our goal was to implement predictive modeling of coastal fish habitat associations across the Great Lakes basin, with particular focus on physical and water quality habitat predictors available basin-wide, and then use these habitat models to assess status for a suite of fish species that use Great Lakes coastal systems. Our objectives were to: 1) identify key habitat factors associated with highest probability of occurrence for several societally or ecologically important coastal fish species as well as ecologically significant fish community metrics, and 2) assess the degree to which optimal habitat may be threatened by watershed-level anthropogenic activities affecting coastal waters. In addition, we discuss the importance of these results in the context of coastal fish management and conservation, with an emphasis on native biodiversity and presence of invasive species.

Methods

We first developed habitat classification models for coastal fish based on habitat data integrated into the Great Lakes Aquatic Habitat Framework (GLAHF), a hierarchical spatial framework and database for the entire Laurentian Great Lakes including Canadian waters (Wang et al., 2015). We then assessed overlap between predicted habitats and integrated measures of watershed-based anthropogenic stress across the basin. We developed species-specific presence/absence Random Forests models for the two climatically distinct ecoprovinces of the Great Lakes, northern Great Lakes (NGL) and southern Great Lakes (SGL, Bailey, 1989). The SGL or the Eastern Broadleaf Forest, encompasses all of Lake Erie, southern Lake Michigan, southern Lake Huron, and western Lake Ontario, and has greater population densities and more intense agricultural land use. The NGL, or the Laurentian Mixed Forest is less developed with less productive soils, and includes Lake Superior and the northern parts of Lakes Huron and Michigan.

Fish data

We used fish data from two large-scale monitoring projects that sampled coastal areas across the Great Lakes (Fig. 1a): the Great Lakes Environmental Indicators (GLEI) project (2002–03; Niemi et al., 2007) and Coastal Wetland Monitoring Program (CWMP; 2002–03; Uzarski et al., 2005). The GLEI project sampled fish in both wetland and non-wetland coastal sites using two sets of large and small fyke nets (4 nets total) set overnight at 0.5–1 m depth, just offshore of the two dominant shoreline types and land uses, to most fully represent habitat diversity within a wetland (Brady et al., 2007). Sampling locations were selected using a stratified random approach designed to cover the entire stressor gradient (Danz et al., 2005). The CWMP sampled coastal wetlands only and used 3–9 fyke nets per wetland set overnight in the dominant habitats present within each wetland (Uzarski et al., 2005). For both projects, small nets were 0.9-m wide × 0.5-m tall and large nets were 1.2-m wide × 1.0-m. All nets had 0.5 cm (bar) mesh. Individual fyke net catch per unit effort (individual species abundance) data were averaged across all fyke nets at each site. We combined fish data from the two projects, and in cases when both GLEI and CWMP data were available for the same site, we retained GLEI data only. In total, there were 139 wetland and 39 high energy sites. For each site, we established a coastal polygon in GIS and linked averaged site data to the centroid of our sampling polygon, which was then associated with 30 m raster cells and associated habitat data in GLAHF.

For species-specific models, we selected species that had a minimum occurrence of 12 sites per ecoprovince. Overall, we modeled 13 species for NGL region including alewife (*Alosa pseudoharengus*), burbot (*Lota lota*), common carp (*Cyprinus carpio*), johnny darter (*Etheostoma nigrum*), ninespine stickleback (*Pungitius pungitius*), northern pike (*Esox lucius*), northern rock bass (*Ambloplites rupestris*), round goby (*Neogobius melanostomus*), spottail shiner (*Notropis hudsonius*), troutperch (*Percopsis omiscomaycus*), walleye (*Sander vitreus*), white sucker (*Catostomus commersonii*), and yellow perch (*Perca flavescens*), and 20 species for SGL region, including alewife, banded killifish (*Fundulus diaphanous*), black or brown bullhead (*Ameiurus melas* or *Ameiurus nebulosas* or hybrid), black crappie (*Pomoxis nigromaculatus*), bluegill sunfish (*Lepomis macrochirus*), bluntnose minnow (*Pimephales notatus*), common carp, emerald shiner (*Notropis atherinoides*), gizzard shad (*Dorosoma cepedianum*), largemouth bass (*Micropterus salmoides*), northern rock bass, pumpkinseed (*Lepomis gibbosus*), round goby, smallmouth bass (*Micropterus dolomieu*), spottail shiner, white bass (*Morone chrysops*), white perch (*Morone americana*), white sucker, yellow bullhead (*Ameiurus natalis*), and yellow perch. Total number of sites were 105 for NGL and 73 for SGL region models.

We also developed habitat models for several fish community metrics that may be of interest from a management and assessment perspective. These metrics included: native fish species richness, overall Shannon diversity, predator richness; abundance-based proportion of silt-intolerant, longer-lived (>5 years), intolerant (based on Barbour et al., 1999, App. C), piscivorous and nestguarding fish, presence of intolerant fish and presence as well as abundance-based proportion (relative dominance) of invasive fish. For community metrics, we relied only on GLEI fish data and models were developed basin-wide (n = 136).

Habitat data

We selected GLAHF basin-wide habitat factors likely to affect fish communities in the coastal zone (e.g., excluding off-shore water quality variables) and representing key physical attributes of coastal habitat given the available data. We excluded predictors that did not have sufficient resolution or a range of values in the coastal zone (e.g., bottom ruggedness and substrate type resolution were insufficient for the coastal margin). This data reduction step resulted in selection of 10 predictors used in the final models: chlorophyll *a* (chl *a*), bottom slope, turbidity, suspended minerals, wave height, wave energy, relative exposure index (Keddy, 1982), cumulative surface water degree-days, distance to spawning reef, and distance to river mouth (Table 1). Chlorophyll *a*, suspended minerals, and turbidity were remote-sensing interpreted images (Shuchman et al., 2013). Cumulative degree-days were the sum of all days above 0 °C from January 1 through December

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