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Water depth and lake-wide water level fluctuation influence on α- and β-diversity of coastal wetland fish communities

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ABSTRACT

Coastal wetlands in the Laurentian Great Lakes are critical habitats for supporting fish diversity and abundance within the basin. Insight into the coupling of biodiversity patterns with habitat conditions may elucidate mechanisms shaping diverse communities. Within coastal wetlands, water depth as well as fluctuations in lake-wide water levels over inter-annual timescales, both have the potential to influence fish communities. Water level fluctuation can influence fish habitat structure (e.g., vegetation) in Great Lakes coastal wetlands, but it is unclear how water depth and lake-wide water level fluctuations affect fish community composition and diversity. Using β dissimilarity indices and multivariate ordination techniques, we assessed fish community structure among bulrush (*Schoenoplectus acutus*)-dominated wetlands in Saginaw Bay, Lake Huron, USA. We examined whether community structure was related to wetland water depth at the time of sampling and whether fish communities were more similar among years with similar Lake Huron water levels. Results suggested relatively high levels of both spatial (among wetlands) and temporal (among year) community dissimilarity that was driven primarily by species turnover. Thus, variability in water depths among wetlands and in Lake Huron water levels among years likely both contribute to regional fish diversity. Further, fish abundance and alpha diversity were positively correlated with wetland water depth at the time of sampling. Both climate change and anthropogenic water level stabilization may alter the magnitude and timing of water level fluctuations in the Great Lakes. Our data suggest that these changes could affect local fish community composition and regional fish diversity.

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Introduction

Laurentian Great Lake coastal wetlands (GLCW) are ecologically and economically important ecosystems, serving as buffers between terrestrial and open waters. Wetlands provide services such as nutrient cycling and retention, carbon sequestration, sediment entrapment, erosion reduction, and wildlife habitat (Mitsch and Gosselink, 2000). GLCW are also biodiversity hotspots within the basin supporting fish, invertebrate, amphibian, bird, and mammal communities (Burton et al., 2004; Jude and Pappas, 1992; Weeber and Vallianatos, 2000). Fish use these highly productive ecosystems for spawning, nursey habitat, shelter, and food (Jude and Pappas, 1992). GLCW form where protection from hydrologic energy and sediment conditions support vegetation growth (Albert et al., 2005); therefore, because changes in water level can alter hydrologic energy and sediment conditions, water levels can also influence the persistence and structure of GLCW ecosystems (Uzarski, 2009).

Water levels fluctuate within the Great Lakes on inter-annual (up to 2 m), seasonal (20–40 cm) and hourly (up to 10 + cm seiche) timescales. Differences in precipitation and evaporation drive changes in lake water level between years (Quinn, 2002). Seasonal water levels typically peak in mid to late summer after the basin becomes replenished from spring runoff. Climate change is expected to increase both precipitation and evaporation within the Great Lakes basin. There is currently uncertainty surrounding estimates of precipitation and evaporation under climate change scenarios, and thus some models predict increases in Great Lakes water levels while others predict decreases (Music et al., 2015; Notaro et al., 2015). Climate change may also alter seasonal variation in water levels as precipitation and evaporation patterns change (Music et al., 2015).

In addition to climate change, anthropogenic water level stabilization has altered GLCW hydrology. Humans have altered the hydrology of GLCW through the construction of dykes and ditching (Wilcox and Whillans, 1999). Further, lake-wide water levels are semi-regulated in Lake Superior through the Soo locks and in Lake Ontario by the Moses-Saunders Dam, which reduces both inter-annual and seasonal fluctuations in water level (Wilcox and Whillans,

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1999). Changes in water levels are associated with changes in macroinvertebrate community composition in the Great Lakes (Cooper et al., 2014; Gathman and Burton, 2011), but it is unclear how inter-annual variability in water levels at the lake scale and water depth at more immediate spatial (e.g., mean depth of wetland habitat) and temporal (e.g., the day of sampling) scales affect fish community composition. To understand how changing water levels could affect wetland fish, we investigated the influence of water level cycles and fluctuations on fish community composition in GLCW. We also examined how beta (β) diversity was influenced by wetland water depth.

β diversity describes the degree of community differentiation between sites or the ratio between regional (γ) and local (α) species diversity (Whittaker, 1960, 1972). Therefore, if sites contain different species, management efforts oriented toward promoting β diversity may enhance and preserve regional diversity within the Laurentian Great Lakes. β diversity indices partition overall community variation into turnover and nestedness structuring components (Baselga, 2010). Community variation structured by turnover indicates that unique species assemblages are present at different sites, and community variation structured by nestedness indicates that some sites are low quality and contain a subset of the species present elsewhere. The use of β diversity indices has allowed greater insight into the effects of both historical and current processes (i.e. biogeographical barriers) along with species dispersal and mobility limitations (i.e. widespread species introduction) on community variation (Angeler, 2013; Toussaint et al., 2014; Villèger et al., 2013). Understanding β diversity patterns and associated environmental mechanisms are fundamental to establishing effective biodiversity conservation and restoration initiatives.

Community assessments within GLCW have revealed patterns of β diversity and environmental mechanisms driving these patterns. Species turnover (replacement) has been shown as the dominant structuring process of fish and macroinvertebrate communities within the basin (Langer et al., 2016) indicating that wetlands differ in community composition through both space and time. Seasonal events (e.g. spawning), wetland geomorphology (e.g. protected embayment), system productivity, and dominant wetland vegetation stands (e.g. cattail zones) have been described as factors contributing to community differences (Cooper et al., 2012; Bhagat and Ruetz, 2011; Burton et al., 2004; Uzarski et al., 2004, 2005). Despite our understanding of many factors regulating community composition, the influence of wetland water depth remains an understudied mechanism potentially controlling community variation at seasonal (or shorter) time scales. Water depth strongly correlates with changes in wetland vegetation along gradients from terrestrial to open water habitats; but depth can also fluctuate temporally at any given point along this gradient as lake-wide water levels vary. Examining how water depths among wetlands and lake-wide water level fluctuations through time both influence α and β diversity will enhance our understanding of the mechanisms controlling coastal wetland fish diversity.

We sampled fish communities within bulrush (*Schoenoplectus acutus*) habitat in Saginaw Bay, Lake Huron wetlands from 2009 to 2014. A subset of sites was sampled multiple times to allow us to examine both spatial and temporal variation in wetland community diversity. We hypothesized that Lake Huron water levels would influence community composition at inter-annual timescales and years with similar water levels would have similar fish communities. We also hypothesized that wetlands with similar bulrush-stand water depths would have similar fish communities within years. While our study focused on wetlands in Saginaw Bay, the processes we examined are likely relevant to wetlands across the Laurentian Great Lakes basin as fluctuations in inter-annual and seasonal water levels occur basin-wide.

Methods

Site location

Study sites included 10 fringing wetlands located within the inner bay portion of Saginaw Bay in Lake Huron, MI (Fig. 1) and the surrounding land use within 10 km varied substantially among the sites (Electronic Supplementary Material (ESM) ESM Table S1. The inner bay was much shallower and more influenced by the Saginaw River relative to the outer bay which is more influenced by the open water of Lake Huron. Sampling occurred between mid-June and mid-July during each sampling year after spring spawning events ended and summer communities were established. Three sites served as reference wetlands in which sampling occurred multiple (4–6) times throughout the six-year period. The remaining seven wetlands were each sampled one to two times in the six-year period. All wetlands were sampled only once per year.

Data collection

Fish were collected via fyke nets in bulrush habitat within each wetland following the protocol of Uzarski et al. (2017); net placement may have varied within a given wetland from one year to the next. Nets were set perpendicular to the shoreline with the lead extending from the edge to the core of the habitat in order to sample fish using the edge as well as core of the bulrush habitat. Two sizes of fyke nets were used depending on water depth, with small nets fishing shallower waters (0.2–0.5 m) and large nets fishing deeper waters (0.5–1.0 m). Large-sized fyke nets consisted of a 7.62 m (length) × 0.91 m (height) lead extended from the opening of a 1.22 m (width) × 0.91 m (height) box frame. The box frame had 1.82 m (length) × 0.91 m (height) wings that extended on either side at an approximately 45° angle from the direction of the lead and was followed by five 0.76 m diameter hoops that terminated in a closable cod-end. The inner diameter of the mesh funnels on the first and third hoops were 0.17 m and the mesh funnels were oriented toward the cod-end. The small-sized fyke nets were similar in configuration to the large fyke nets, and consisted of a 7.62 m (length) × 0.46 m (height) lead, a 0.91 m (width) × 0.46 m (height) box frame with 1.73 m (length) × 0.46 m (height) wings, followed by five 0.10 m diameter hoop with 0.10 m inner mesh funnels on the first and third hoops. Leads and wings on both the large and small fyke

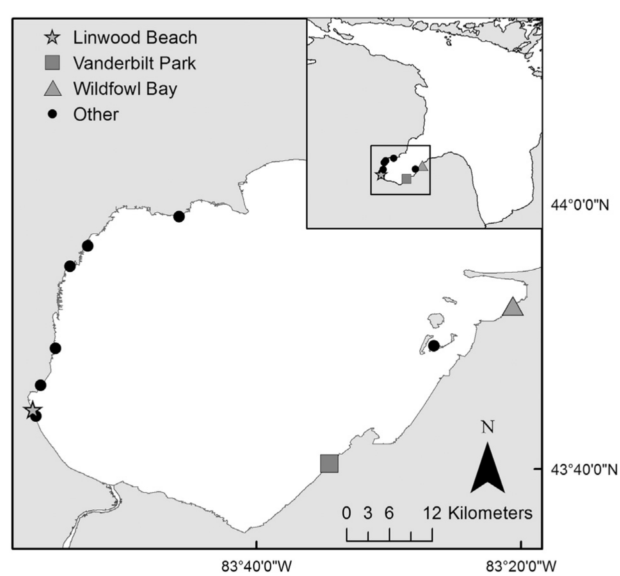

Fig. 1. Centroid locations of the 10 fringing wetland complexes we sampled within Saginaw Bay, Lake Huron. Gray shaded shapes represent reference locations repeatedly sampled during study period.