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Factors influencing macrophyte growth and recovery following shoreline restoration activity

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ABSTRACT

Macrophytes are increasingly being used worldwide for assessing aquatic ecological condition. Because their growth is influenced by physical habitat conditions, such as sediment quality and near-shore gradient, macrophytes may also be valuable indicators of shoreline restoration efforts. An extensive shoreline restoration project in a lake with a history of industrial activity provided the opportunity to examine macrophyte and sediment status as metrics of aquatic ecosystem health and response.

We surveyed macrophyte beds in Muskegon Lake, Michigan over a 4-year period to assess the ecological benefits of the restoration project. Macrophyte biomass was affected strongly by the physical features of the individual sites, including hydrologic exposure (i.e., wind and wave action) and sediment organic matter, which contributed to a large degree of variability among the sites. Declines in macrophyte biomass the year following restoration suggested a short-term negative impact on macrophyte communities. Recovery to at least pre-restoration biomass was evident two years following restoration. However, concurrent changes at the reference sites, though to a lesser degree, also suggested a possible overriding environmental cause (i.e., water level, air temperature, precipitation) for the observed changes in macrophyte growth.

Lake restoration projects are usually designed to improve water quality and enhance the fishery. Although both goals are influenced by macrophytes, the plants themselves are rarely a focal point of restoration. Our study allowed us to address this information gap; even after 4 years of sampling, it appears the timeline is too short to detect a definitive response to restoration, but our results provide important baseline information and lessons learned for future studies.

1. Introduction

Lakes throughout the world that serve as industrial ports are at particular risk for loss of macrophyte communities because of dredging, hardened shorelines, and pollution (Whittier et al., 2002). This is especially true in the Laurentian Great Lakes, where saw mill, foundry, and industrial activities have resulted in considerable impairment to river mouth and near-shore ecosystems (Allan et al., 2013; Larsen et al., 2013). Approximately three-quarters of the coastal wetlands in heavily developed areas of the Laurentian Great Lakes have been lost, and the wetlands that remain often suffer from degraded quality (Jude and Pappas, 1992). Much of this loss has been the result of activities associated with industrialization and urbanization that have hardened the shoreline and altered the sediments (Albert and Minc, 2004). This can lead to macrophyte loss through changes in shoreline gradient and substrate quality (Gabriel and Bodensteiner, 2012), resulting in reduced ecosystem services provided by macrophytes, including sediment stabilization, nutrient cycling, and essential habitat for fish, invertebrates, and breeding marsh birds (Jude and Pappas, 1992; Wei et al., 2004; Sierszen et al., 2012).

Macrophyte abundance and community composition can be useful indicators of aquatic ecological health, as they reflect the quality of both physical and chemical habitat conditions (Lougheed et al., 2001; Madsen et al., 2001; Cvetkovic et al., 2010; Søndergaard et al., 2010; Grabas et al., 2012). Macrophytes are used as indicators of aquatic ecological status across Europe as part of the European Water Framework Directive (Stelzer et al., 2005; Penning et al., 2008; Hansen and Snickars, 2014) and in the Laurentian Great Lakes, macrophytes have been used successfully to indicate the status of coastal wetlands (Albert and Minc, 2004; Croft and Chow-Fraser, 2007; Cvetkovic et al., 2010; Grabas et al., 2012). Because macrophyte growth is affected, in part, by sediment quality (Barko and Smart, 1986; Barko et al., 1991; Squires and Lesack, 2003) and

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near-shore gradient (Duarte and Kalff, 1986; Barko et al., 1991; Partanen et al., 2009; van Leeuwen et al., 2014), macrophytes may also prove to be valuable indicators of shoreline restoration efforts (Grabas et al., 2012).

Despite the growing number of aquatic habitat restoration projects worldwide, most studies fail to evaluate the ecological outcome of restoration efforts. This deficiency has been particularly noted for streams (Bernhardt et al., 2005; Palmer et al., 2007), but it applies to other aquatic ecosystems as well (Spears et al., 2013). Evaluation and documentation of the ecological outcome of habitat restoration is critical for guiding adaptive management, demonstrating restoration benefits to funding agencies and the public, and improving the collective knowledge of restoration techniques and monitoring strategies (Palmer et al., 2007).

An extensive shoreline restoration project in Muskegon Lake, Michigan, provided the opportunity to evaluate the ecological outcome of habitat restoration using macrophyte metrics. Muskegon Lake is an important deep water port that connects directly to Lake Michigan. The lake provides a wide array of ecosystem services but has experienced years of environmental abuse. Approximately 315 ha of near-shore habitat have been filled by past industrial activities along the lake's south shore (MLWPHC, 2008); broken concrete, foundry slag, sheet metal, slab wood, saw dust, and other materials in shallow water areas further degrade habitat. Human-altered near-shore geomorphology, including steep drop-offs and unsuitable substrate, created unfavorable habitat conditions that threaten fish and wildlife populations.

We conducted both pre- and post-restoration surveys of macrophyte beds in Muskegon Lake over a 4-year period, and compared changes to reference sites in the lake. We anticipated that restoration activities would have a short-term negative impact on macrophytes because of physical disturbance, but that macrophyte growth and abundance would recover over time, with more protected sites exhibiting greater recovery.

2. Methods

2.1. Site description

Located in west-central Michigan, Muskegon Lake is a ~17 km^2 drowned river mouth lake that serves as the receiving water body for the 7060 km^2 Muskegon River watershed. Although the lake's entire shoreline is 65% hardened (Steinman et al., 2008), the southern shoreline is hardened to a greater degree (78%), as this part of the lake experienced a disproportionate share of industrial activity and urban development. In contrast, the north shore has more residential development and natural areas, and is only 45% hardened.

Macrophyte surveys were conducted at 4 restoration locations along the south shore of the lake: Grand Trunk, Amoco, Kirksey, and Heritage Landing (Table 1 and Fig. 1). In addition, two reference sites were located along the north shore of the lake to represent the macrophyte community associated with more natural habitat conditions. Reference sites were chosen by dividing the north shore into two reference zones (i.e., east and west) and randomly selecting one reference site within each zone: Northwest Reference and Northeast Reference (Table 1 and Fig. 1). Restoration activities took place in 2010 and 2011 and included: (1) the removal of unnatural fill materials (i.e., sawmill waste; industrial and/or commercial demolition material, such as broken concrete) at (shoreline) or below (underwater) the ordinary high water mark; (2) shoreline vegetation planting, and (3) shoreline wetland restoration (Table 1). At two of the restoration areas (Heritage Landing and Amoco) underwater fill removal occurred directly within the macrophyte survey transects; restoration activities at the other two sites (Grand Trunk and Kirksey) occurred either on shore or immediately adjacent to the transects (Table 1).

2.2. Field protocols

Macrophyte surveys took place in August 2009, 2010, 2011, and 2012. Transects were established perpendicular to shore, with transect points located every 5 m from 0 to 10 m from shore, every 10 m from 10 to 100 m from shore, every 25 m from 100 to 300 m from shore, and every 50 m from 300+ m from shore. Transects extended to the farthest point of macrophyte growth, as determined by (1) 2 consecutive transect points with no growth, or (2) the absence of macrophytes at a point greater than 4.5 m deep, which is the depth beyond which macrophytes can grow in Muskegon Lake. A transect width of 10 m was chosen to reflect our ability to visually assess the macrophyte community within approximately 5 m of the boat in any direction. Water depth was measured at each transect point.

At each point along the transect, overall plant cover was assigned one of the following ranks: 0 = Bare; 1 = 1–25%; 2 = 26–50%; 3 = 51–75%; or 4 = 76–100%. When plants were too deep to be easily distinguished from the water surface, a double-headed weighted rake was tossed three times to aid in assigning cover rank and estimating percent abundance.

Plant biomass and sediment organic matter (OM) were sampled at one randomly selected transect point within each of the following distance-from-shore categories: 0–20 m, 20–50 m, 50–100 m, 200–300 m, 300–400 m, 400–500 m, etc. Plant biomass was harvested using two garden rakes attached to each other at a pivot point near the middle of each rake's handle. The teeth of the rakes faced each other in order to cut and secure the plants when the handles were pulled together. A chain connected to the rakes fixed the sampling area at 0.6 m^2. A total area of 1.8 m^2 (3 scoops) was sampled at each point along the transect; where biomass was very high, only 0.6 or 1.2 m^2 (1 or 2 scoops, respectively) was sampled. One sediment core was collected (4-cm diameter, 10 cm deep) using a hand-held gravity corer (Davis and Steinman, 1998) for sediment OM determination. Field sampling was performed by the same personnel during each survey year to exclude interpersonal variation.

2.3. Laboratory processing

Plant biomass and sediment samples were kept refrigerated until laboratory processing, within 60 days of collection. Plant biomass samples were cleaned of sediment, *Dreissena* mussels, and filamentous green algae. Samples were dried at 85 °C for 96 h and weighed. Sediment samples were homogenized by hand and three 5-g subsamples were dried for 24 h at 105 °C, weighed, ashed at 550 °C for 4 h, and re-weighed. Sediment OM was calculated as the difference between pre- and post-combustion weights, expressed as a percentage of sediment dry weight. Values for each of the three subsamples were averaged for each sampling point.

2.4. Data analysis

To better facilitate comparisons among sites, macrophyte data analysis was limited to submergent and floating taxa. The Northwest Reference site included ~90 m of wet meadow habitat that supported dense emergent vegetation. Grand Trunk was the only other site with similar habitat (~10 m). While wet meadow areas provide important habitat, inclusion of emergent taxa made meaningful comparisons among sites problematic. Taxa richness (submergent and floating) was determined for each transect and survey year. Macrophyte density (g/m^2) within each transect (excluding wet meadow habitat) was calculated by summing the dry mass (g) of plants collected along a transect and dividing