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Review

Artificial reefs and reef restoration in the Laurentian Great Lakes

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ABSTRACT

We reviewed the published literature to provide an inventory of Laurentian Great Lakes artificial reef projects and their purposes. We also sought to characterize physical and biological monitoring for artificial reef projects in the Great Lakes and determine the success of artificial reefs in meeting project objectives. We found records of 6 artificial reefs in Lake Erie, 8 in Lake Michigan, 3 in Lakes Huron and Ontario, and 2 in Lake Superior. We found 9 reefs in Great Lakes connecting channels and 6 reefs in Great Lakes tributaries. Objectives of artificial reef creation have included reducing impacts of currents and waves, providing safe harbors, improving sport-fishing opportunities, and enhancing/restoring fish spawning habitats. Most reefs in the lakes themselves were incidental (not created purposely for fish habitat) or built to improve local sport fishing, whereas reefs in tributaries and connecting channels were more frequently built to benefit fish spawning. Levels of assessment of reef performance varied; but long-term monitoring was uncommon as was assessment of physical attributes. Artificial reefs were often successful at attracting recreational species and spawning fish; however, population-level benefits of artificial reefs are unclear. Stressors such as sedimentation and bio-fouling can limit the effectiveness of artificial reefs as spawning enhancement tools. Our investigation underscores the need to develop standard protocols for monitoring the biological and physical attributes of artificial structures. Further, long-term monitoring is needed to assess the benefits of artificial reefs to fish populations and inform future artificial reef projects.

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Introduction

Habitat degradation is a global source of imperilment of fishes (e.g., Jelks et al., 2008; Munday, 2004; Powels et al., 2000), and restoration of physical habitat is often used to mitigate losses and degradation of natural habitat (Bassett, 1994; Palmer et al., 2005). In large aquatic systems such as the Laurentian Great Lakes, artificial reefs are often created to provide spawning and nursery habitat to benthic-spawning fishes (e.g., Fitzsimons, 1996; Gannon, 1990; NOAA, 2007). Artificial reefs have been used as a fishery management tool for over 40 years in the Laurentian Great Lakes and have often been championed as a successful means for improving recreational fisheries (Kelch, 2012). However, unequivocal evidence of improved fisheries resulting from habitat restoration projects is often lacking (Hughes et al., 2014; Jähnig et al., 2011; Whiteway et al., 2010). We conducted a literature review of Great Lakes reef projects to

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guide future habitat restoration and monitoring in the Great Lakes and other large aquatic systems.

Artificial reefs have been constructed in freshwater and marine systems (1) to attract fish (Creque et al., 2006; Kelch, 2012) and (2) to provide spawning, nursery, and adult habitats, and increase fish abundance (Brickhill et al., 2005; Dumont et al., 2011; Kuhl, 1992; Pickering and Whitmarsh, 1997). Artificial reefs have been proven to attract fish and increase catch rates in recreational fisheries (Bombace et al., 1994; Brickhill et al., 2005; Kelch, 2012), but the ability of reefs to increase fish abundance is not well documented in freshwater and marine systems (Baine, 2001; Pickering and Whitmarsh, 1997). Several reports reviewed artificial reef projects in marine and freshwater systems and determined that reefs seldom increased fish population abundance. Problems arose from flawed study design (Brickhill et al., 2005), lack of clear objectives for reef building (Baine, 2001; Claudet and Pelletier, 2004), and inadequate monitoring of reefs (Baine, 2001). Few studies concluded that artificial reefs can perform as well or better than natural reefs in terms of increasing fish abundance and richness at the reef site (Carr and Hixon, 1997; Koeck et al., 2014). From an ecological perspective, whether artificial reefs can function as well as natural reefs remains unclear (Perkol-Finkel et al., 2006). Some artificial reefs have produced fish communities that are different in composition from those in natural habitats (Ambrose and Swarbrick, 1989; Flopp et al., 2013).

Despite careful planning, artificial reefs can be damaged or degrade over time. Damage to reefs can be caused by navigation and channelization, sedimentation, intrusion of groundwater, and changes in water levels (Rutherford et al., 2004). Other potential threats to reef quality and function over time include redistribution of reef materials by wave action, fouling by invasive species (e.g., Dreissenidae), and algae accumulation (Marsden and Chotkowski, 2001). These factors often limit the effectiveness of both artificial and natural reefs by filling interstices in the reef that protect fish eggs until they hatch. Most of these stressors do not pose an immediate threat, but they can develop over time. In order to quantify the contribution of man-made reefs to fish populations and provide a basis for comparison with natural reefs, routine standardized long-term monitoring protocols should be implemented (Gannon, 1990).

Here we review available information about artificial reef projects in the Laurentian Great Lakes and synthesize information on reef construction, monitoring, and performance. Our objectives were (1) to inventory artificial reef projects in the Great Lakes and their connecting channels and tributaries, (2) to characterize the purpose and construction methods of artificial reef projects, (3) to determine the type and extent of physical and/or biological monitoring on Great Lakes artificial reefs, and (4) to determine whether artificial reefs have achieved their intended objectives.

Review of artificial reef projects in the Great Lakes

We conducted a literature search using Google (https://www.google.com/), Google Scholar (http://scholar.google.com/), the U.S. Geological Survey Library (http://rl3mq7xr4s.search.serialssolutions.com/), ISI Web of Knowledge (http://go.isiproducts.com/cgi-bin/MPL/2_0_1/User/Logon.cgi), and the online search function of the Journal of Great Lakes Research (http://www.sciencedirect.com/). We paired location keywords, including “Great Lakes,” “Lake Michigan,” “Lake Erie,” “Detroit River,” etc., with subject keywords such as “artificial reef”, “constructed reef,” and “spawning habitat restoration”. These terms were also searched without a specific location to obtain results for artificial reefs located outside of the Great Lakes. Lists of references in publications were searched forward (papers that cited the current paper) and backward (papers cited within) to find other relevant publications, including gray literature such as agency reports, theses, and news releases. For all relevant Great Lakes reef studies discovered, we obtained reef site name, location, year of construction, objectives for construction, materials used (Table 1), construction design, monitoring scope, and timing/duration of monitoring. We also determined whether the objectives of each project were achieved, based on published accounts and personal communications with agency scientists familiar with respective projects.

Purpose and design of artificial reefs in the Great Lakes

In our literature search, we found 38 artificial reefs constructed in the Great Lakes basin between the late 1800s and 2013. We found at least one project in each of the Great Lakes, as well as several in the Great Lakes connecting channels (St. Clair-Detroit rivers and St. Lawrence River) and tributaries (Fig. 1). Some projects consisted of multiple reefs, and unless individual reefs within a project were differentiated from one another by name, a project or site referred to all reefs constructed at that location. Lake Michigan (8 projects) and the connecting channels (9 projects) had the greatest number of reef projects, whereas Lake Superior had the fewest reef projects (2 projects; Fig. 2). About 62% of man-made reefs have been the focus of biological monitoring but not physical monitoring, 24% of the reefs had both physical and biological monitoring, and about 14% had not been monitored (Fig. 2). Size and design of artificial reefs also varied on a project specific basis. Sizes of constructed structures ranged from less than 95 m^2 (Marsden et al., 1995) to over 33,000 m^2 (Yauck, 2009). Physical designs also varied from a 3-m high wall of rock in East Tawas Bay, Lake Huron (Foster and Kennedy, 1995), to individual uniform beds of various materials to assess preference for rock type in the Detroit River (Roseman et al., 2011) and large piles of rock in Lake Ontario (Marsden et al., 1995).

The earliest artificial reefs were created incidentally, for purposes other than fish habitat (Fig. 3). For example, the coal cinder reef in the North Channel of the St. Clair River is thought to have been formed in the late 1800s when ships discarded coal cinders while moored at the site (Nichols et al., 2003). Other examples of incidental reefs include projects aimed at abating physical impacts of currents and waves, providing safe harbors, or to protect water intake pipes for industry and municipalities (i.e., Liston et al., 1985; Marsden and Chotkowski, 2001; Peck, 1986; Rutecki et al., 1985). Interest in building reefs to improve sport fishing and restore functional fish spawning habitat started after 1980 (Fig. 3). Structures designed to improve recreational fishing opportunities were most often placed near metropolitan areas where anglers could have access (Bader, 1985; Kelch, 2012; Kelch et al., 1999; Kevern et al., 1985; Stewart and Haynes, 1994; Vincent, 1995). For example, large reefs were built to attract fishes such as walleye and smallmouth bass near the cities of Cleveland, Ohio (Kelch, 2012) and Chicago, Illinois (Creque et al., 2006). These projects had social and economic objectives (i.e., increase angler effort and success) rather than to increase fish populations. Sport-fishing reefs have been constructed from natural materials, such as limestone and granite (Creque et al., 2006), and man-made materials, including cement, brick, and even old stadium rubble (Kelch et al., 1999) (Table 1). Hence, reefs aimed at improving recreational fisheries have often been sited to provide easy access to anglers and were constructed out of convenient, available materials, which may have limited the value of these reefs as fish spawning habitat.

More recently, the focus of artificial spawning habitat construction shifted to restoring and increasing functional spawning habitat in order to enhance fish populations (e.g., Dumont et al., 2011; Fitzsimons, 1996; Manny et al., 2010; Roseman et al., 2011) (Fig. 3). Emphasis of these projects was on spawning habitat for imperiled or important species, such as lake sturgeon (e.g., Dumont et al., 2011; Roseman et al., 2011), lake trout (Fitzsimons, 1996), and walleye (Geiling et al., 1996), or improving diversity of benthic-spawning fishes (Manny et al., 2010). Material used to construct fish spawning reefs has most frequently been broken limestone (Roseman et al., 2011) but has also included igneous rocks (Geiling et al., 1996) (Table 1). Substrate size also varied across artificial reef projects, ranging from boulders (Marsden et al., 1995) to cobble and gravel (Dumont et al., 2011). Recent projects used a large