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Five-year evaluation of habitat remediation in Thunder Bay, Lake Huron: Comparison of constructed reef characteristics that attract spawning lake trout

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ABSTRACT

Degradation of aquatic habitats has motivated construction and research on the use of artificial reefs to enhance production of fish populations. However, reefs are often poorly planned, reef design characteristics are not evaluated, and reef assessments are short-term. We constructed 29 reefs in Thunder Bay, Lake Huron, in 2010 and 2011 to mitigate for degradation of a putative lake trout spawning reef. Reefs were designed to evaluate lake trout preferences for height, orientation, and size, and were compared with two degraded natural reefs and a high-quality natural reef (East Reef). Eggs and fry were sampled on each reef for five years post-construction, and movements of 40 tagged lake trout were tracked during three spawning seasons using acoustic telemetry. Numbers of adults and spawning on the constructed reefs were initially low, but increased significantly over the five years, while remaining consistent on East Reef. Adult density, egg deposition, and fry catch were not related to reef height or orientation of the constructed reefs, but were related to reef size and adjacency to East Reef. Adult lake trout visited and spawned on all except the smallest constructed reefs. Of the metrics used to evaluate the reefs, acoustic telemetry produced the most valuable and consistent data, including fine-scale examination of lake trout movements relative to individual reefs. Telemetry data, supplemented with diver observations, identified several previously unknown natural spawning sites, including the high-use portions of East Reef. Reef construction has increased the capacity for fry production in Thunder Bay without apparently decreasing the use of the natural reef. Results of this project emphasize the importance of multi-year reef assessment, use of multiple assessment methods, and comparison of reef characteristics when developing artificial reef projects. Specific guidelines for construction of reefs focused on enhancing lake trout spawning are suggested.

1. Introduction

Loss of critical habitat is widely recognized as one of the most important variables affecting stability of natural populations (National Research Council, 1992; Benaka, 1999). In aquatic environments, critical habitat is often associated with nearshore areas that are vulnerable to on-shore pollution and sediment deposition resulting from human activities such as agriculture and industry. The attraction of fishes to coral or rocky habitat, whether for feeding, shelter, or spawning, and damage to habitats in coastal waters has motivated the use of artificial reefs to replace these habitats and to restore fish populations (Bassett, 1994; Benaka, 1999; Baine, 2001; McLean et al., 2015).

Artificial reefs can be used as a management tool to solve the problem of a reduction in the amount or quality of essential habi-

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tats (Baine, 2001). Artificial reefs may increase abundance of fishes through improved recruitment and survival, or increased growth. However, poor reef design or planning can result in under-use or have undesirable consequences such as aggregating fish in a way that makes them more vulnerable to predators or fishery harvest (Carr and Hixon, 1997; Grossman et al., 1997; Bortone, 1998; Pickering and Whitmarsh, 1997). Reef construction should be based on prior data on habitat characteristics that will benefit the target fish species, either by providing refuge for adults, eggs, or larvae, or habitat for their prey. If these characteristics are not well understood, then the reef design should include first an evaluation of different reef habitat characteristics of natural reefs before construction (Bassett, 1994; Baine, 2001). Reefs must also be located where the target species is likely to find them, such as near existing migratory corridors or nearby natural habitats. Artificial reefs are usually constructed to help one particular species, but are likely to provide benefits to non-target species, and consequently have community-level effects.

In freshwater lakes, rocky substrates with interstitial spaces are particularly valuable habitats, as they provide a three-dimensional structure and refuge for benthic organisms and the eggs and larvae of spawning fishes (McLean et al., 2015). Interstitial spaces provide protection from the physical forces associated with wave and ice action and from large-bodied predators and, if free of decomposing organic material, provide ideal habitat for incubation of eggs of benthic-spawning fishes. Among species that use such habitats in the Laurentian Great Lakes, lake trout (*Salvelinus namaycush*) are of particular concern.

Lake trout were extirpated from the main basins of the lower four Great Lakes by the 1960s, largely due to overfishing and predation by sea lamprey (*Petromyzon marinus*; Krueger and Ebener, 2004; Muir et al., 2014). U.S. and Canadian federal, provincial, state, and tribal agencies are committed to restoring self-sustaining populations of lake trout to the Great Lakes (e.g., GLFC, 2011). These efforts began with sea lamprey control in the late 1950s, extensive basin-wide stocking of hatchery-reared juvenile lake trout in the 1960s, and regulation of commercial and sport harvest. Evidence of spawning by stocked fish has been extensive in most of the lakes, but until recently little evidence of sustained recruitment to age-1 and older has been observed except in Lake Superior, western Lake Michigan, and at three sites in Lake Huron—South Bay, Parry Sound, and Thunder Bay (Anderson and Collins, 1995; Cornelius et al., 1995; Elrod et al., 1995; Eshenroder et al., 1995; Hansen et al., 1995; Hanson et al., 2013; Holey et al., 1995; Johnson and VanAmberg, 1995; Reid et al., 2001). Because lake trout stocked as fingerlings or yearlings survive and grow well to maturity, the impediments to successful lake trout reproduction likely occur between spawning in fall and emergence of fry from spawning reefs in spring (Bronte et al., 2007).

The role of habitat degradation or loss in the failure of lake trout restoration in the Great Lakes is not clear. Lake trout spawn on cobble-rubble substrates with deep interstitial spaces; locations adjacent to a steep drop-off appear to be particularly attractive, likely because Venturi-effect currents reduce sediment deposition that may suffocate eggs (Ellrott and Marsden, 2004; Fitzsimons and Marsden, 2013; Marsden et al., 1995a,b). Deep, offshore spawning habitats are distant from sedimentation sources and human influences, but nearshore habitats, where most documented lake trout spawning historically occurred (Marsden et al., 1995b), are vulnerable to deposition processes such as silt or sawdust as a result of changes in nearby landscapes. For example, the collapse of lake trout populations in Lake Champlain by 1900, in the absence of commercial fishing pressure, may be attributed to massive deforestation and subsequent lake-wide siltation in the 1800s (Ellrott and Marsden, 2004). Stocked lake trout use nearshore constructed habitats such as breakwalls extensively for spawning (Fitzsimons, 1996; Marsden and Chotkowski, 2001; Marsden et al., 1995a,b; Peck, 1986). Whether this habitat use is a consequence of some combination of limited natural habitat, loss of habitat due to degradation, or simply attraction to available good substrates, the intentional addition of cobble substrates as spawning sites (Marsden et al., 1995a) or unintentional addition as breakwalls in harbor areas (Peck, 1986) has effectively increased the amount of available spawning habitat. However, the relative contribution of natural versus artificial reefs to recruitment of lake trout or other harvestable species such as lake whitefish (*Coregonus clupeaformis*) in the Great Lakes has not been evaluated. Likewise, the characteristics of artificial reefs that make them attractive to spawning lake trout and result in successful egg incubation have not been quantitatively assessed. In this study, we evaluated whether spawning lake trout were attracted to different designs of constructed rock reefs and compared spawning activity and fry production at those reefs to high quality and degraded natural reefs, over five years post-construction. If the quantity or quality of spawning habitat is limiting recruitment in the Great Lakes or elsewhere, then a better understanding of optimal reef configurations will enhance reef habitat design, construction and evaluation.

The project was focused in the northwestern portion of Thunder Bay, Lake Huron (Fig. 1). Past collection of unclipped (wild) young-of-year and post-yearling fish indicated natural reproduction by lake trout in Thunder Bay has occurred since at least as early as 1984 (Johnson and VanAmberg, 1995). Aggregations of spawning lake trout, including unclipped fish, were found at Mischley Reef near the entrance to Thunder Bay in 1991–1993 (Johnson and VanAmberg, 1995). Suppression of sea lamprey (*Petromyzon marinus*) populations and increased control of fisheries harvests substantially improved lake trout survival to maturity after 2000, and collapse of alewife (*Alosa pseudoharengus*) after 2004 increased survival and recruitment of lake trout fry (Riley et al., 2007; Johnson et al., 2015). As of 2012, over 50% of lake trout less than age-8 in western Lake Huron were wild origin. Continued progress toward rehabilitation of lake trout populations in Lake Huron depends on maintenance and improvement of natural reproduction.

The goal of the reef construction project was to increase recruitment of lake trout in Thunder Bay by mitigating the putative degradation and loss of spawning habitat. The goals of our post-construction monitoring study were to (1) determine whether lake trout would use the newly constructed reefs and, if they did, how long it would take for the fish to find and use the reefs, (2) identify characteristics of the new reefs that attract lake trout (height, orientation, and size), and (3) compare spawning on the new reefs relative to the natural (degraded and unaffected) reefs nearby. Specifically, our objectives were to (1) evaluate changes in the density of lake trout eggs and fry on 29 newly constructed reefs over five years, relative to two natural, low-quality reefs, and one natural, high-quality reef (East Reef), and (2) evaluate relative attraction of constructed reef characteristics (height, orientation, size, and age) to spawning lake trout. We hypothesized that

(1) lake trout will recognize the constructed reefs as suitable spawning habitat and colonize them within five years of construction;
(2) the degree to which the constructed reefs are used by spawning lake trout will depend on the physical characteristics of the reefs (e.g., total area, height, and orientation); and
(3) the addition of constructed reefs will increase overall fry production in Thunder Bay, as opposed to simply attracting spawners away from existing spawning areas.

Our approaches provide useful lessons for those assessing other large-scale aquatic restoration projects and inform the construction