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Effects of lake trout refuges on lake whitefish and cisco in the Apostle Islands Region of Lake Superior

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ABSTRACT

Lake trout refuges in the Apostle Islands region of Lake Superior are analogous to the concept of marine protected areas. These refuges, established specifically for lake trout (*Salvelinus namaycush*) and closed to most forms of recreational and commercial fishing, were implicated as one of several management actions leading to successful rehabilitation of Lake Superior lake trout. To investigate the potential significance of Gull Island Shoal and Devils Island Shoal refuges for populations of not only lake trout but also other fish species, relative abundances of lake trout, lake whitefish *(Coregonus clupeaformis)*, and cisco *(Coregonus artedi)* were compared between areas sampled inside versus outside of refuge boundaries. During 1982–2010, lake trout relative abundance was higher and increased faster inside the refuges, where lake trout fishing was prohibited, than outside the refuges. Over the same period, lake whitefish relative abundance increased faster inside than outside the refuges. Both evaluations provided clear evidence that refuges protected these species. In contrast, trends in relative abundance of cisco, a prey item of lake trout, did not differ significantly between areas inside and outside the refuges. This result did not suggest indirect or cascading refuge effects due to changes in predator levels. Overall, this study highlights the potential of species-specific refuges to benefit other fish species beyond those that were the refuges' original target. Improved understanding of refuge effects on multiple species of Great Lakes fishes can be valuable for developing rationales for refuge establishment and predicting associated fish community-level effects.

Introduction

Marine protected areas (MPAs) are a tool in conservation of biodiversity and management of marine ecosystems (Agardy et al., 2003; Halpern and Warner, 2002; NRC, 2001). From a fishery perspective, prohibiting harvest or disturbance of fish habitat in designated zones within MPAs (also known as marine reserves) can allow overfished stocks to recover and benefit yield in areas adjacent to reserves (Gell and Roberts, 2003; Halpern et al., 2010; Roberts et al., 2005; Russ and Alcala, 1996; Vandeperre et al., 2010). The same management approach can be applied in freshwater systems, but the extent of implementation and published evaluation of aquatic protected areas (APAs) is not as common as MPAs in marine environments (Abell et al., 2007; Hedges et al., 2010; Suski and Cooke, 2007). In the Laurentian Great Lakes, APAs have been implemented as management tools, and their use over several decades provides an opportunity to evaluate their long-term effects on freshwater species and local fisheries (Hedges et al., 2011).

Great Lakes APAs were established for various cultural and ecological purposes, ranging from protection of Great Lakes maritime heritage sites, such as shipwrecks, to restoration of fish populations (Hedges et al., 2010). Six APAs in lakes Superior, Huron, and Michigan are specifically closed to recreational and commercial harvest of lake trout (*Salvelinus namaycush*) to aid in recovery of local populations (MDNR, 2011; Stanley et al., 1987; WDNR, 2011). Stocks of this native piscivore collapsed across the upper Great Lakes by 1950 because of overexploitation, sea lamprey (*Petromyzon marinus*) predation, and possibly by habitat degradation of traditional near-shore spawning areas (Hansen, 1999; Krueger and Ebener, 2004; Krueger et al., 1995; Muir et al., 2012). Provincial, state, and tribal fishery management

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agencies collaborated with federal governments and the Great Lakes Fishery Commission to rehabilitate lake trout populations through fishery regulation, stocking, and sea lamprey control. The use of APAs in this process included establishment of areal fishery closures (referred to as refuges in this regulatory context) that were closed to year-round lake trout harvest and were sites of intensive stocking. These lake trout refuges were designed to encompass areas known to include lake trout spawning reefs because protection of spawning populations might increase recruitment and wild fish production (Hansen et al., 1995; Holey et al., 1995; Schram et al., 1995; Stanley et al., 1987; Swanson and Swedberg, 1980). While refuges in Lake Michigan and Lake Huron allow harvest of other species (MDNR, 2011), fishery restrictions in Lake Superior refuges generally extended to all fish species, except in designated areas for limited fisheries. Extensive long-term monitoring within and adjacent to these refuges has been used to assess progress toward lake trout rehabilitation goals (e.g., Schram et al., 1995). Previous analyses in Lake Michigan (e.g., Madenjian and DeSorcie, 1999) and Lake Huron (e.g., Madenjian et al., 2008) provided mixed conclusions regarding effectiveness of refuges in improving lake trout stock abundance, survival, growth, spawning success, and natural reproduction. In contrast, in Lake Superior, lake trout rehabilitation has been consistently associated with the role of refuges and evaluated based on establishment of self-sustaining populations (e.g., Bronte et al., 1995a; Hansen et al., 1995; Linton et al., 2007; Schram et al., 1995).

Within one of the Lake Superior refuges, Gull Island Shoal Refuge (Fig. 1), increased recruitment and lake trout abundance followed in the years immediately after refuge establishment (Swanson and Swedberg, 1980). This initial success was possibly further enhanced by low fishing effort in Michigan waters immediately east of the Gull Island Shoal Refuge during the 1970s and early 1980s, thereby increasing the total area with low fishing mortality (Schram et al., 1995). However, increased survival initially observed after refuge implementation continued into the 1990s (Pollock et al., 2007) despite late 1980s increases in commercial fishing pressure in these adjacent waters. Subsequent analyses further highlighted the value of the refuge's protection and role in the ongoing recovery of lake trout in the region (e.g., Johnson et al., 2015).

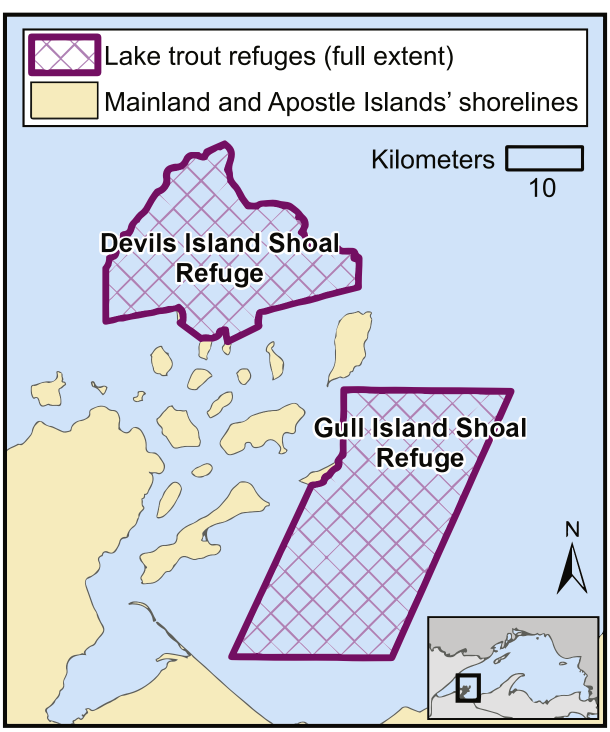

Fig. 1. Lake trout refuges in the Apostle Islands region of Wisconsin. (Inset: Lake Superior). Full refuge extent is indicated by the purple line surrounding cross-hatching. Detailed information about base layer data sources is available in Electronic Supplementary Material (ESM) Appendix A. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The population's recovery was supported by observations of density-dependent effects on growth, recruitment, and age at first maturity. By 1990, a truncated lake trout age structure with few old fish in non-protected inshore areas of the Apostle Islands contrasted with a much wider age distribution in offshore refuge-protected areas (Hansen et al., 1996). Faster growth of lake trout subject to exploitation in non-protected inshore areas than in the Gull Island Shoal Refuge suggested density-dependent growth, possibly due to changes in prey fish abundance (Hansen et al., 1996). This trend was accompanied by declines in recruitment from 1988 through 1995, potentially driven by intraspecific competition and limited food availability, which indicated a population whose recovery was approaching carrying capacity (Corradin et al., 2008). In later years, wild fish matured at a similar length, but older age, inside compared to outside the refuge during 2001–2010 (Johnson et al., 2015). These observations were all consistent with density-dependent feedback associated with dynamics reported in marine reserves (e.g., Sánchez Lizaso et al., 2000), thereby supporting a conclusion that the refuge had an effect on local population dynamics of lake trout. Recent assessments further demonstrated that the Gull Island Refuge afforded enough protection to sustain the lake trout population across a wide range of plausible fishing mortality rates and that removal of the refuge would risk population collapse at much lower fishing mortality (Akins et al., 2015).

Evaluation of Devils Island Shoal Refuge has also highlighted the refuge's role in past efforts to re-establish spawning lake trout populations at the site (Bronte et al., 2002). Increased wild lake trout abundance observed within this refuge during 1985–1997 was linked to age-classes arising from lake trout embryos planted in turf incubators on Devils Island Shoal (Bronte et al., 2002). This success was partially attributed to the protection from harvest provided by the refuge in addition to embryo stocking, thereby aiding in survival of recruits to spawning age (Bronte et al., 2002).

The two refuges' collective contribution to lake trout population recovery in the Apostle Islands region of Lake Superior raises the question of how refuges might affect other fish species of management priority in the region. Previous studies in marine areas have shown evidence that fishing closures can have indirect, and even trophic cascading effects (Babcock et al., 2010; Pinnegar et al., 2000; Salomon et al., 2002), as demonstrated through population shifts in invertebrates linked to protected fish species at higher trophic levels. Although less prevalent, isolated evaluations of no-take marine reserves have also suggested negative secondary effects on prey species that underwent increased predation by protected fishes (Graham et al., 2003). The focus on broad fish assemblages and multi-species models for MPAs (Baskett et al., 2007) highlights the need for inclusion of conspecific species in MPA or APA evaluations.

Lake Superior fishery managers have long worked toward achieving carefully developed fish community objectives that involve species in addition to lake trout (Horns et al., 2003). These management objectives allow for sustainable harvest of conspecific species, as well as for maintaining a forage base to support other species of importance for commercial and recreational fisheries. Two key species of focus in the objectives are the lake whitefish (*Coregonus clupeaformis*) and cisco (*Coregonus artedi*). In addition to dominating Lake Superior's commercial fishery since the late 1980s (Bronte et al., 2003), lake whitefish also support the largest contemporary commercial fishery in the Apostle Islands (Seider and Schram, 2011) and across the Great Lakes (Ebener et al., 2008a). Lake trout restoration management indirectly affected lake whitefish management because large-mesh gill-net fishing effort in the lake whitefish fishery was limited to reduce incidental lake trout bycatch (Ebener et al., 2008a; Hansen et al., 1995). In addition, cisco stocks (a native species) interacted with rainbow smelt (a non-