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[Article]

Management Perspectives on Coaster Brook Trout Rehabilitation in the Lake Superior Basin

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Abstract.—Coaster brook trout are a migratory form of brook trout *Salvelinus fontinalis* that spend part of their lives in the Great Lakes. Over the last century the abundance of coaster brook trout in Lake Superior has declined dramatically, and only remnant stocks remain. Recently, the rehabilitation of coaster brook trout in Lake Superior has become a goal of fish management agencies. The specific goal agreed upon by all of the agencies involved is to maintain widely distributed, self-sustaining populations in as many of the historical habitats as practical. We discuss realistic expectations for rehabilitation and emphasize the need for management agencies, academia, and angling organizations to work cooperatively. We first present a brief history of coaster brook trout in Lake Superior, then discuss habitat requirements and protection, the regulations required for rehabilitation, stocking, species interactions, and the role that human dimensions play in rehabilitation. The management issues that must be addressed are implementation of a basinwide survey to identify remnant stocks and critical habitat, restrictive harvest regulations, watershed rehabilitation, critical biological review, and the formulation of expectations before experimental stocking programs are initiated, along with coordinated, basinwide information sharing and cooperative management among agencies similar to that undertaken during the rehabilitation of lake trout *Salvelinus namaycush* in Lake Superior. Future research needs include basic coaster biology and life history, habitat use in streams and the lake, interaction with other species in the Lake Superior fish community, and interaction between stream-resident and coaster brook trout. Successful rehabilitation will require a shift from a harvest fishery to one with minimal or no harvest of coaster brook trout in the Lake Superior basin. Coaster brook trout rehabilitation will take time and will proceed at different rates at different locations, depending on the presence of remnant stocks, quality of habitat, angling pressure, and political will.

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The rehabilitation of coaster brook trout *Salvelinus fontinalis* has become a high priority among many anglers, environmentalists, and fish management agencies in the Lake Superior basin. Coaster brook trout are loosely defined as "those spending part of their lives in the Great Lakes" (Becker 1983). A more explicit definition might include all of the complex life strategies that the brook trout populations in Lake Superior exhibit, such as migratory behavior, use of estuaries and embayments, and shoal or shore spawning in the lake (Huckins et al. 2008, this issue). Research has been conducted to determine whether coasters are genetically distinct from resident brook trout or are simply a brook trout ecotype (life history variant). Presently, genetic studies support the hypothesis that coasters are not a genetically distinct strain (Burnham-Curtis 1996, 2001; D'Amelio 2002; Wilson et al. 2008, this issue).

Once the most abundant native salmonid in Lake Superior tributaries, coaster brook trout have declined to extremely low levels and now occur in only a few isolated areas. Overfishing was probably the initial cause of the decline, as many populations were heavily exploited even before railways and roads allowed easy access to the resource (Roosevelt 1865). Habitat degradation, barriers to migration, and competition from other fish species also contributed to the overall decline and must be overcome if rehabilitation is to be successful (Newman et al. 2003). Even though coaster brook trout are not considered a genetically distinct strain, much genetic diversity has been lost and maintaining the genetic attributes of remnant populations in different regions of the lake is important for rehabilitation. The genetic implications of rehabilitation strategies such as stocking should be thoroughly considered before implementation so that they will not negatively impact rehabilitation (Wilson et al. 2008).

Over the past century, a number of fish management agencies have made unsuccessful attempts to rehabilitate coaster brook trout (Newman and DuBois 1996). Most attempts involved stocking a non–Lake Superior strain of hatchery-reared brook trout. Early efforts were not coordinated among the agencies and lacked long-term goals and strategies. Since the 1960s, the Great Lakes Fishery Commission (GLFC), working with fish management agencies on the Great Lakes (GLCF 1992), has given high priority to the rehabilitation of lake trout *Salvelinus namaycush* and the control of sea lamprey *Petromyzon marinus* (Hansen 1996; Bronte et al. 2003; Horns et al. 2003). Based on their experience with lake trout rehabilitation in Lake Superior, management agencies recognized that if coaster brook trout rehabilitation were to be successful, they would need to cooperate and implement coordinated basinwide management efforts targeting the major impediments to rehabilitation. As in the case of lake trout, these efforts include harvest restrictions, habitat protection and restoration, protection of remnant stocks, reducing interactions with other species, and judicious stocking.

Restoration of native fish species in Lake Superior was identified as a major management objective and given a high priority in both the 1990 and 2000 fish community objectives for Lake Superior (Busiahn 1990; Horns et al. 2003). The coaster brook trout was identified as a species that required rehabilitation. In 1990, the Lake Superior Committee, a group of senior staff biologists representing all of the management agencies with jurisdiction over Lake Superior, approved the formation of the brook trout subcommittee to investigate coaster brook trout rehabilitation. This group developed a status report on coaster brook trout (Newman and DuBois 1996) and in 1998 a plan for rehabilitation that was subsequently published by the GLFC (Newman et al. 2003). Since development of the plan, biologists working with various angling and environmental groups have developed a variety of rehabilitation strategies that reflect the different philosophies and missions of the agencies.

Critical to the successful rehabilitation of coaster brook trout is a common vision and a set of guiding principles that will direct rehabilitation activities into the future. In an effort to synthesize current information and philosophies on coaster brook trout rehabilitation in Lake Superior, a conference involving biologists from management agencies, academia, and angling organizations was held in October 2003. This paper is a product of that conference; it builds on the strategies described in the coaster brook trout plan (Newman et al. 2003) and outlines a shared vision for coaster restoration in Lake Superior. It is based on the experience of biologists working on coaster rehabilitation and does not specifically represent the philosophies or missions of the various fish management agencies on the lake.

There are a number of management questions with respect to rehabilitation: What types of habitat change will be required? How will angling regulations need to change? What, if any, stocking strategies might best be applied? How do other fish species affect coaster brook trout? What are the human dimension issues that must be addressed for rehabilitation to be viewed as successful by diverse user groups? And lastly, what management and research needs must be met to advance restoration? In this paper we briefly summarize the relevant history and provide a general overview of coaster brook trout management in Lake Superior, giving specific responses to these questions.

Management History

Before the early 1900s, coaster brook trout populations were locally abundant in areas along the shoreline of Lake Superior and near stream mouths with good spawning habitat. Overharvest of coasters began with subsistence fishing by European settlers around the Lake Superior basin in the mid-1840s and increased rapidly in the late 19th century, when sportfishing for coasters became popular. Early reports of successful brook trout angling along Lake Superior's shore are given by R. B. Roosevelt, a noted naturalist and uncle of President Theodore Roosevelt (Roosevelt 1865). Worldwide attention was brought to this unique fishery in 1915, when the world-record brook trout was caught at Rabbit Rapids in the upper Nipigon River, an Ontario tributary to Lake Superior (Scott and Crossman 1973). The fish weighed 6.58 kg and was 86.4 cm in length. Angling pressure greatly increased in the late 1800s and early 1900s as new roads and logging trails allowed greater access to remote streams and areas where coaster brook trout were concentrated. On the lake, larger and more seaworthy powerboats enhanced anglers' opportunities to reach stream mouths or shoreline areas that had not been accessible before then. The rapid expansion of the sport fishery quickly resulted in overharvest, which caused the initial decline of coasters in Lake Superior by the early 1900s. Logging and pollution from industry in rapidly expanding communities began in the 1850s, degrading stream habitat and further reducing brook trout abundance.

Before 1930, the management of coaster brook trout consisted mainly of stocking and implementing harvest regulations; however, most of these efforts were ineffective in curtailing the decline. Liberal sportfishing regulations offered little protection for coasters, and management for a long-term sustainable fishery was not yet being considered. In U.S. waters, there was extensive stocking of fry, fingerlings, and yearlings. These stockings were made with domestic-strain brook trout with no concern for genetic viability. One early management strategy in Minnesota involved transferring brook trout found below natural barriers to above-barrier sites where they did not originally occur (Waters 1977). Overharvest, habitat degradation, and inappropriate stocking all contributed to the general decline of Lake Superior coaster stocks.

In the 1960s, most state and provincial management agencies began to implement restrictive harvest regulations to curtail brook trout sport harvest. These regulations resulted in shorter fishing seasons, lower bag limits, and size limits. The first attempts to specifically manage coaster brook trout began in the 1970s. The states of Wisconsin (1970) and Michigan (1975) attempted to restore coaster fisheries by means of stocking at various locations. Michigan personnel set nets at Isle Royale National Park to capture coasters but failed to catch sufficient quantities to develop a broodstock. Ontario established the Nipigon strain in 1976, with augmentation from wild stocks in 1977 and 1978 (Newman et al. 2003). Wisconsin and Minnesota experimented with stocking Nipigon strain coasters in the 1980s, with minimal success. Unfortunately, by the late 1980s most agencies still did not have harvest regulations that were restrictive enough to protect coasters and coordinated coaster management was not yet a high priority among the agencies.

Management agencies turned their resources and attention to the rehabilitation of other native species once the rehabilitation of lake trout in Lake Superior had been judged successful (Schreiner and Schram 1997). Guided by the fish community objectives for Lake Superior (Busiahn 1990; Horns et al. 2003) and using the status report and lakewide plan developed by the brook trout subcommittee, coaster brook trout rehabilitation efforts increased dramatically. Since 1995 coaster rehabilitation projects have been undertaken and progress has been made in coordinating management among the various agencies (Figures 1, 2). Individual agencies have also developed internal operational plans with input from interested anglers and citizens to advance coaster restoration in their jurisdictions (Schreiner 1995; Wisconsin Department of Natural Resources 2005). It is anticipated that the collaborative efforts of the various agencies will advance coaster brook trout rehabilitation much more effectively than in the past.

General Overview

The goal for coaster brook trout rehabilitation in Lake Superior is to "maintain widely distributed, self-sustaining populations in as many of the original native habitats as practical" (Newman et al. 2003). We discuss some of the important questions that must be answered, the challenges that must be overcome, and the information required to achieve that goal.

The large size of Lake Superior and the widely different habitats that characterize the numerous streams found around the basin dictate that different rehabilitation strategies be developed for different areas of the lake. Although some recommendations may seem inconsistent, different strategies are necessary because environmental conditions and the health of remnant populations vary geographically. For example, where remnant populations exist in relatively undisturbed areas of the Ontario shoreline, stocking and habitat improvement may be unnecessary and restric-

Number	River system/area	Population status [a]	Habitat management activities [b]
1	Ontario north shore streams	R	HS, HU, HI, HP
2	Nipigon River, Ontario	R	HS, HU, HI, HP, RF
3	Nipigon Bay, Ontario	R	HS, HU, HI, HP
4	Thunder Bay and streams, Ontario	RE	HS, HI
5	Isle Royale National Park, Michigan	R	HS, HU, HP
6	Grand Portage Reservation streams, Minnesota	RE	HS, HU, RC
7	Minnesota north shore streams	PR/RC	HS, HU, HI, BC, RC
8	Brule River, Wisconsin	PR/RC	HS, HU, HI, BC
9	Bayfield Peninsula streams, Wisconsin	PR/RC	HS, HU, HI, HP, BC
10	Apostle Islands National Lakeshore, Wisconsin	PR/RC	HS, HU
11	Whittlesey Creek National Wildlife Refuge, Wisconsin	RE	HS, HU, HI, HP
12	Graveyard Creek, Wisconsin	PR/RC	HS, HU, HI, BC
13	Little Carp River and 9 local streams, Michigan	PR/RC	HS, HU, HI
14	Gratiot River, Michigan	RE	HS, HU
15	Salmon Trout River, Michigan	R	HS, HU, HP, RC
16	Pictured Rocks National Lakeshore streams, Michigan	RE	HS, HU
17	Eastern Lake Superior streams, Ontario	PR/RC	HS, HU

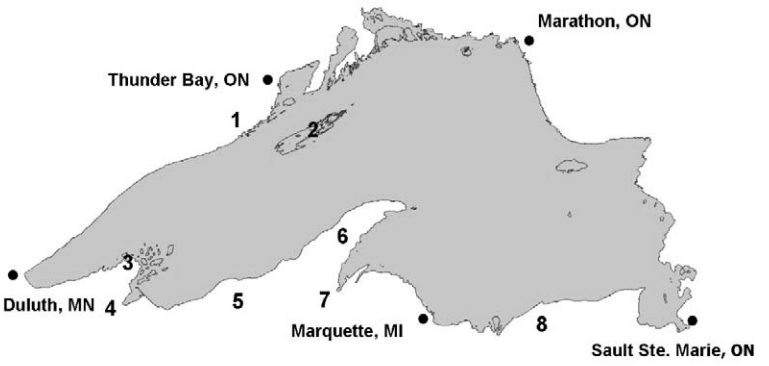
[a] R = remnant population, RE = reintroduction experiment, and PR/RC = potential reintroduction or recovery site.

[b] HS = habitat survey, HU = habitat use by brook trout, HI = habitat improvement benefiting brook trout, HP = specific habitat plans benefiting brook trout, BC = beaver control, RC = addressing fish passage issues at road crossings, and RF = attempts to modify flows that benefit brook trout.

FIGURE 1.—Locations of habitat management activities benefiting coaster brook trout in the Lake Superior basin.

tive angling regulations may be all that is required to protect the population. However, in some Wisconsin watersheds, where few or no remnant populations exist and stream habitat has changed greatly owing to logging, agriculture, and general development, a very different set of strategies may be appropriate, including not only restrictive regulations but also a well-devised stocking program and watershed improvement.

A major impediment to the rehabilitation of coaster brook trout in Lake Superior is a lack of quantitative information. Coaster brook trout were extirpated throughout much of Lake Superior before management agencies were established. Much of the early information is anecdotal. Even early management efforts by agencies were not well documented and mostly involved stocking hatchery fish with little or no evaluation. It has only been within the last 10 years that managers and biologists have started to employ formally designed experiments with rigorous evaluation. This paper is not intended to be a detailed technical analysis that justifies specific management strategies based on quantitative data. In formulating the strategies discussed in this paper, we draw heavily on the historical anecdotal observations, results of studies on other salmonids in the Lake Superior basin, more recent brook trout work in different habitats, and our



Number	River system/area	Jurisdiction	Strain [a]
1	Grand Portage Reservation streams	Grand Portage Band, Minnesota	N, TH, S
2	Siskiwit Bay, Isle Royale National Park	Michigan DNR and Isle Royale National Park	S
3	Red Cliff Reservation, streams and shoals	Red Cliff Band, Wisconsin	N
4	Whittlesey Creek	USFWS and Wisconsin DNR	TH, S
5	Little Carp River	Michigan DNR	N
6	Gratiot River	Michigan DNR	N
7	Keweenaw Bay Reservation streams	Keweenaw Bay Band	TH, S
8	Pictured Rocks National Lakeshore streams	NPS and Michigan DNR	TH

[a] N = Nipigon, TH = Tobin Harbor, S = Siskiwit Bay.

FIGURE 2.—Stocking locations and strains of coaster brook trout currently being used for experimental stocking by various management agencies in the Lake Superior basin. Abbreviations not explained in the figure are as follows: DNR = Department of Natural Resources, USFWS = U.S. Fish and Wildlife Service, and NPS = National Park Service.

general knowledge, intuition, and experiences gained from working with the Lake Superior fish community. We advocate that over the next 10 years studies addressing coaster restoration be well documented and have rigorous experimental design, so that the science of coaster restoration will advance.

Habitat

What types of habitat changes will be required to rehabilitate coaster brook trout? This is an important and difficult management question because if quality habitat is not available, none of the other strategies will be worth pursuing. Brook trout are normally associated with high-quality aquatic habitat and have finite habitat needs at each phase in their life cycle. Movement studies of coaster brook trout in Lake Superior have indicated that adult fish generally stay within 150 m of shore or in water less than 7 m deep (Newman 2000; Mucha and Mackereth 2008). When sexually mature, most coasters return to their natal streams in the fall to spawn. However, a few coaster stocks have been reported to spawn on shoals or along shorelines (Quinlan 1999; Swainson 2001). Successful reproduction is particularly dependent on the groundwater flowing into streams and the availability of clean gravel substrate over upwellings in lakes (Kondolf and Wolman 1993; Curry and Devito 1996). Juveniles and adults utilize overhead cover and pools for protection from predation and a mixed variety of substrates and stream reaches for food sources. Based on the evidence that most Lake Superior coaster populations spawn in streams, we conclude that streams are the highest-priority habitats to protect, particularly those with major inflows of groundwater.

The Lake Superior basin historically offered brook trout a multitude of varied and healthy habitats. Although overexploitation by sport fisheries may have been the primary cause for the original declines, the cumulative impact of habitat degradation in streams is a threat to the self-sustainability of existing stream-spawning populations and probably constitutes a major impediment to the expansion of the populations once found in those streams. Nearshore areas (those less than 10 m in depth) in the lake are also susceptible to anthropogenic changes. The affect of nearshore habitat alteration on shoal- and shore-spawning coaster brook trout populations is largely unknown, although the Lake Superior shoreline is in better condition than many streams. Despite the relatively high quality of habitat near shore, coaster populations have also declined in these areas.

Until the mid-1800s, the conditions in streams tributary to Lake Superior were much better than they are today (Greene 1935). From the mid-1800s to the early 1900s, forests of red pine *Pinus resinosa* and white pine *Pinus strobus* were logged. Many stream channels were cleared of all obstructions in order to drive the logs from inland areas to Lake Superior for distribution (Larson 1949; Rector 1951; Curtis 1959). This activity destroyed large woody cover, eroded stream channels, and deposited heavy sediment loads, covering productive brook trout habitats (Harmon et al. 1986; Bassett 1987; Newman and DuBois 1996; Inter-Fluve and Brian Graber Water Resource Consulting 2003). In Michigan and Wisconsin, many acres were then burned, cleared, and drained for agriculture by early European settlers. Other factors that impacted habitat include wildfires (which burned over most portions of the Lake Superior watershed in the decades following the cutover), road building, and land use changes associated with increasing human populations (Holbrook 1943; Brasch et al. 1982). In the 1900s, mining activity impacted thousands of acres in the Lake Superior watershed and discharged more than 1×10^9 tons of tailings along Lake Superior shorelines (Kerfoot et al. 1999). Many streams have been impounded over the last 150 years, altering the hydrology and affecting brook trout migration and spawning and general habitat availability. The best-known example is the Nipigon River, where a series of hydroelectric dams were built beginning in the 1920s, destroying much of the prime brook trout habitat (Swainson 2001). Other major rivers impacted by hydropower include the St. Mary's, Ontonagon, Sturgeon, Black Sturgeon, Dead, Au Train, Iron, Michipicoten, Pic, and Kaministiqua.

The legacy of these activities persists, and in many places groundwater, the stream channels, and the processes that form and maintain in-stream habitat have all been fundamentally altered. Geomorphic studies of Fish Creek in Wisconsin have documented increased floods and sedimentation after the forests were cleared and the land converted to cropland and pasture. Specific impacts on the stream include major downward erosion of the streambed, a marked increase in channel capacity, much higher peak flows, and large increases in sedimentation rates. Today, erosion and flooding rates are still appreciably higher than they were before large-scale land clearing activities (Fitzpatrick et al. 1999). Groundwater flow and hydrological attributes have been modeled on Whittlesey Creek in Wisconsin under various land use scenarios and have shown that returning the landscape to a forested condition may decrease flooding, contributing to more stable stream habitat conditions (Lenz et al. 2003).

Given the enormous size of the Lake Superior basin, the amount of habitat degradation that has already occurred and the multiple stressors that continue to negatively impact habitat, prioritization of habitat improvements will be required. Habitat restoration in watersheds is extremely expensive and takes time to produce results. Most agencies will want to consider a formal benefit-cost analysis before implementing large-scale watershed projects. In some Lake Superior locations where watersheds are generally healthy, in-stream habitat enhancement activities such as beaver dam removal, bank stabilization, sediment removal, culvert modification, and addition of large woody debris may be used to achieve coaster brook trout rehabilitation more quickly and less expensively than entire watershed restoration. Agencies will have to decide what strategies or combinations of strategies work best for their specific location.

We suggest that the highest priority for habitat management be given to those watersheds and tributary and lake areas where there are remnant, self-sustaining populations of coaster brook trout. Protection of critical habitats in these areas should be the primary strategy. Management efforts should focus on protecting spawning redds, riparian zones, headwater reaches, estuary habitat, lake habitat, groundwater recharge zones, and other important areas. Most of the known remnant populations are located in areas that have avoided the widespread disturbances of the last 150 years. Isle Royale National Park and the Salmon Trout River in Michigan are two such areas. Both are relatively remote, have limited access, and still possess large expanses of mature and stable forests (Bullen 1988; Quinlan 1999).

The second priority for habitat management should be to restore watersheds and habitats where there are remnant coaster brook trout populations limited by an identifiable stressor. Much of this habitat type in the Lake Superior basin is within "protective ownership," including conservation reserves, parks, wildlife refuges, and land trust reserves. These areas offer more protection against development and other potentially damaging land uses. County, state, provincial, and national forests usually offer more protection than private lands but are not considered to be under protective ownership because they are actively managed for timber harvest. Even with the implementation of best management practices, streams may not have adequate protection from increased runoff, sedimentation, erosion, and instability (Inter-Fluve and Brian Graber Water Resource Consulting 2003).

The Nipigon River system in Ontario is an example of an area where the remnant coaster brook trout population has benefited from concerted efforts to improve flow regimes and protect and restore critical spawning and rearing habitat by working with the hydropower industry (Swainson 2001). Coaster restoration efforts in these types of systems require a watershed-based ecosystem approach to protect and restore healthy channel formation, groundwater regimes, and damaged instream habitat (Wang et al. 2002). Strategies for watershed restoration include improving forestry and other land use practices to protect riparian zones, minimize runoff and erosion, preserve groundwater recharge areas, and improve connectivity by modifying ineffective culverts and removing dams.

A third priority might be to protect areas with high-quality habitat where few or no coaster brook trout currently exist. These habitats may be appropriate for reintroduction stocking or adult transfers. A number of habitat restoration efforts are ongoing across the basin (Figure 1).

Regulations

Species that have experienced a decline in range and abundance as a result of multiple factors (e.g., exploitation, habitat loss, and competition) often respond to decreased exploitation more quickly than to other management strategies. Large harvests of coaster brook trout in the late 19th and 20th centuries are well documented and have been considered a primary reason for their extirpation in most of their natural range (Goodier 1982; MacCallum 1989). Restrictive regulations that will support self-sustaining populations are essential for the rehabilitation of coaster brook trout and should be implemented immediately to protect remnant stocks. Restrictive regulations should also be considered where populations have been extirpated and other rehabilitation initiatives are being implemented.

The regulatory tools available to reduce the harvest of coaster brook trout include the creation of fish sanctuaries and the imposition of season closures, possession (bag) limits, size restrictions, catch-and-release regulations, and gear and bait restrictions (Newman et al. 2003). Angling seasons were recognized early as a tool for decreasing exploitation, and catch limits for recreational fishing were first imposed in the early 1900s. Before 1995, brook trout regulations were relatively liberal in most state and provincial jurisdictions, and low minimum size limits and large possession limits contributed to excessive harvests. Since that time, all agencies around the lake have recognized the need to protect remnant stocks through harvest reduction. Current Lake Superior brook trout regulations are much more uniform among jurisdictions and are now some of the most restrictive among the fish species managed in Lake Superior (Table 1). Lake Superior tributary regulations are less restrictive and are difficult to standardize because each jurisdiction has different geographical features that make setting regulations for coasters versus resident brook trout problematic. Streams with natural barriers, like many of those in Ontario and Minnesota, provide natural boundaries for the application of coaster-specific regulations. The lack of natural barriers in Wisconsin and Michigan tributaries makes the determination of boundaries much more difficult.

Catch-and-release regulations and seasonal sanctuaries decrease harvest and protect brook trout during spawning but can significantly restrict angling opportunities for other species. Hooking mortality is a major concern because brook trout are such aggressive feeders. Required changes in terminal tackle should be considered not only for anglers targeting brook trout but also for all anglers fishing in waters where brook trout are targeted for rehabilitation. Implementation of regulations that reduce hooking mortality or permit only a minimal harvest of trophy-size fish will require a focused commitment to pubic education. The implementation of restrictive regulations in 1989, along with habitat rehabilitation, creation of spawning sanctuaries, and water management improvements in the Nipigon River, Ontario, have significantly improved that fishery (Swainson 2001). Similarly, in Minnesota the size distribution in some streams appears to have shifted to slightly larger fish after 5 years of restrictive regulations (Prankus and Ostazeski 2003).

There are numerous issues associated with implementing and enforcing angling regulations that restrict traditional harvest. For example, splake (brook trout × lake trout) and brook trout often utilize the same habitat and exhibit similar physical characteristics. Because these two species are difficult for anglers to differentiate, the same regulations should apply to both. The remoteness of much of the Lake Superior coast makes enforcement of regulations difficult. Reduction of subsistence harvest is problematic, as harvesting fish is associated with aboriginal culture and protected through traditional rights. Brook trout are considered a

TABLE 1.—Summary of general Lake Superior and tributary fishing regulations for brook trout.

Jurisdiction	Area	Season	Catch and possession limit	Size restriction
Ontario	Lake Superior and tributaries below identifiable landmark	Last Saturday in Apr–Labor Day	One per day	Minimum size of 22 in (559 mm)
Michigan	Isle Royale: within 4.5 mi (7 km) and tributaries	Open all year	Catch and release	
	Lake Superior	Open all year	One per day	Minimum size of 20 in (508 mm)
	Tributaries of Lake Superior	Last Saturday in Apr–Sep 30	Five per day; no more than three >15 in (381 mm)	Varies from 7–15 in (178–381 mm)
Wisconsin	Lake Superior	Open all year	One per day	Minimum size of 20 in (508 mm)
	Tributaries of Lake Superior below barrier or landmark	May 1–Sep 30	Five per day	Minimum size of 8 in (203 mm)
Minnesota	Lake Superior and tributaries below posted boundaries	Mid-Apr–Labor Day	One per day	Minimum size of 20 in (508 mm)
First Nations (Ontario)	Lake Superior and tributaries	Open all year	No limit	
1836 Treaty Area (eastern Wisconsin)	Lake Superior and tributaries	Open all year	100 lb (45.4 kg) daily in aggregate for all species	
1842 Treaty Area (central Michigan, eastern Wisconsin)	Lake Superior	Open all year	No limit	
	Tributaries of Lake Superior	First Saturday in May–Sep 30	Ten per day	Minimum size of 6 in (152 mm)
1854 Treaty Area (Minnesota)	Lake Superior and tributaries below posted boundaries	Open all year	Ten per day	

recreational species by all agencies and cannot be harvested or sold as a commercial species. However, bycatch in commercial gill nets is difficult to control and can ultimately result in the destruction of substantial numbers of brook trout.

We feel that conservative lakewide implementation of coaster brook trout regulations is the first step in successful rehabilitation, and all management agencies have made significant progress in this regard since the mid-1990s. Efforts are required to shift angler expectations toward catching fewer but larger fish rather than maintaining large daily possession limits. Having the opportunity to catch a trophy fish is becoming more acceptable to most recreational anglers. Continuing this trend will only be accomplished through extensive education and consultation with the angling community.

Stocking

The stocking of brook trout in Lake Superior and its tributaries has occurred basinwide since the late 1800s. During most of this period, stocking provided a put-grow-and-take recreational fishery. More than 27 million brook trout were stocked, including at least 15 different domesticated strains that originated in the eastern United States and Canada (Goodier 1982; GLFC 2006). These domesticated strains were not behaviorally or evolutionarily adapted to the environment in which they were stocked, circumstances that are known to greatly reduce survival and reproductive success (Ryman and Utter 1987; Brannon 1993).

Stocking continues to be used by some agencies as a rehabilitation strategy for coaster brook trout (Figure 2), but it should not automatically be the first strategy employed. Current information on remnant stocks and habitat quality must be critically reviewed before stocking programs are initiated. Much has been published over the last two decades on the use of stocking to rehabilitate depleted fish populations (Stroud 1986; Krueger and May 1991; Hallerman 2003). Major genetic problems can occur when high numbers of hatchery fish are stocked into waters with remnant wild populations (Ferguson 1990; Evans and Willox 1991; Utter 2003). More recently, research exploring the restoration of native species by stocking has been conducted (Krueger and Ihssen 1995; Hallerman 2003; Nickum et al. 2004).

The genetic aspects of coaster brook trout behavior have been debated at length (Wilson et al. 2008; Huckins et al. 2008). A number of studies indicate that coasters are a migratory life history variant of stream-resident brook trout and that these migratory populations may develop if provided adequate protection and suitable habitat (Burnham-Curtis 2001; D'Amelio 2002; and Wilson et al. 2008). Contrary to these findings, preliminary results from the Salmon Trout River suggest that coasters and stream-resident fish may be reproductively segregated. This segregation may indicate behavioral and genetic differences between coaster and resident fish. Our understanding of coaster life history in Lake Superior is still incomplete, and the studies described above will undoubtedly stimulate further and more in-depth genetic and life history analysis.

Lake Superior fish management agencies have described the use of judicious, scientifically based stocking as an option for rehabilitating fish community structure in Lake Superior (Horns et al. 2003). All agencies have agreed to use Lake Superior strain brook trout in rehabilitation efforts and to mark all stocked fish (Newman et al. 2003). Analyses of mitochondrial DNA and microsatellite loci have found that genetic variation and reproductive interaction in Lake Superior brook trout is greater within than between populations (Burnham-Curtis 1996, 2001; Sloss et al. 2008). Importantly, these same analyses provide no evidence that introgression among stocked and wild brook trout has occurred in Lake Superior. These results suggest that for purposes of conservation and rehabilitation, Lake Superior basin brook trout populations should be managed as unique entities (Burnham-Curtis 2001; Wilson et al. 2008).

One of the major decisions managers must make is to determine whether there is a justifiable need for stocking. Despite the limitations of stocking as a rehabilitation strategy, it has become an easy short-term solution promoted by many anglers and agencies alike. If self-sustaining coaster brook trout populations exist, there is no need to stock; other management options, such as regulatory protection, habitat improvement, and the reduction or elimination of management practices that benefit competitors may be all that is required for populations to increase. If remnant populations are heavily depleted or nonexistent, the limiting factors must first be identified and addressed. If stocking is considered, managers must weigh the potential risks of stocking against the chance of successfully creating coasters. Finally, any stocking program will require a rigorous evaluation plan that includes criteria by which to judge the success or failure of the program. As an example, we suggest that the use of stocking be reevaluated if the percent return to the stocking site is less than 1% for three consecutive years; if two or fewer year-classes are established from 5 years of stocking; or if stocking is discontinued after 10 years and reproduction is undetected or so low that the population cannot sustain itself. We suggest that each agency develop its own criteria based on the characteristics of their resource before any stocking program is implemented.

If stocking is chosen as a rehabilitation strategy, factors such as strain, life stage, type of mark, location, and time of stocking can be critical. A small number of experimental stocking trials are taking place in the Lake Superior basin to determine the most appropriate life stage, location, time, and optimal density of fish (Figure 2). Unfortunately, few studies are being rigorously evaluated and in most cases the results have not yet been determined. Many studies of salmonines have shown that imprinting occurs at early life stages. Thus, to improve imprinting and increase the potential for adults to return to the stocking site, we recommend experimental stocking of early life stages. To aid in analysis we also recommend the use of genetic marks on all early life stages proposed for stocking (Wilson et al. 2008). Initially, the experimental use of various life stages, strains, and densities will be necessary to establish recommendations for reintroductions.

At this time few wild coaster brook trout populations are sufficiently abundant to be used as a source of gametes. To meet experimental stocking requests in U.S. waters, three captive Lake Superior broodstock strains have been established. They are the Tobin Harbor and Siskiwit Bay strains from Isle Royale, Michigan, and the Lake Nipigon strain from Ontario. Development of locally adapted broodstock strains taken from Lake Superior and comparative studies between these strains are recommended (Wilson et al. 2008). To increase the probability that stocked fish will successfully contribute to rehabilitation efforts, strategies should include maintaining genetic variability and using best management practices for creating broodstock in all hatcheries (Allendorf and Ryman 1987; Miller and Kapuscinski 2003; Cooper 2004).

Interaction with Other Species

There is little documentation as to the interactions between the present Lake Superior fish community and coaster brook trout. Before European settlement, Lake Superior had a relatively simple and stable fish community. Lake trout, lake whitefish *Coregonus clupeaformis*, cisco *Coregonus artedi*, and brook trout were the prominent nearshore species. The principal migratory species using the tributaries for spawning included coaster brook trout, burbot *Lota lota*, lake sturgeon *Acipenser fulvescens*, suckers (family Catostomidae), and walleye *Sander vitreus*. The resident species in coldwater streams consisted mainly of brook

TABLE 2.—Potential for various types of interaction between coaster brook trout and other sport fish species found in the Lake Superior fish community (L = likely, P = possible, U = unlikely).

Species	Spawning habitat	Nursery habitat	Stream food web	Predation in Lake Superior	Lake food web	Interbreeding
Brown trout	L	L	L	L	P	P
Chinook salmon	L	L	L	P	U	U
Coho salmon	L	L	L	L	U	U
Rainbow trout	U	L	L	L	P	U
Lake trout	U	U	U	L	U	U
Splake	P	P	P	L	L	P

trout, sculpins (family Cottidae), and a variety of cyprinids (Lawrie 1978).

Throughout the 1900s, a variety of fish species were introduced, both intentionally and unintentionally, which resulted in extensive changes to the native fish community. Most of the unintentional introductions in the Great Lakes occurred through the shipping industry (Mills et al. 1993). Intentional introductions took place to provide a nearshore recreational fishery after coaster brook trout populations were depleted. Examples of intentionally introduced species include brown trout *Salmo trutta*, rainbow trout *Oncorhynchus mykiss* (and its anadromous form, steelhead), Chinook salmon *O. tshawytscha*, coho salmon *O. kisutch*, and the splake. A few of the prominent unintentionally introduced species include sea lamprey, pink salmon *O. gorbuscha*, ruffe *Gymnocephalus cernuus*, and rainbow smelt *Osmerus mordax*. These introductions resulted in major changes to native fish communities, and only recently have the nearshore and deepwater fish communities of Lake Superior begun to resemble the more stable, historic communities found before sea lampreys invaded (Bronte et al. 2003; Horns et al. 2003).

Relatively little is known about the interactions between coaster brook trout and sympatric fish species. Reports by Fausch and White (1986), Peck et al. (1994), and Newman et al. (2003) speculate that introduced nonnative species may impact coaster and resident brook trout populations and hinder rehabilitation efforts. However, no studies specifically addressing the interactions among introduced salmonines and coaster brook trout in Lake Superior tributary streams have been undertaken.

Given the extremely low productivity in many Lake Superior tributaries, the number of nonnative salmonines present, and the limited amount of spawning substrate in many U.S. streams (Bronte et al. 2003), it is likely that competition between brook trout and other species occurs in some streams. Inferences drawn from interactions between other migratory stream-spawning fish in Lake Superior suggest that brook trout compete for food, space, and spawning substrate with a variety of introduced salmonids (Table 2). Rainbow trout spawn in the spring but utilize similar habitats in the stream. Fall-spawning species such as Chinook, coho, and pink salmon and brown trout could all compete for redd space when spawning sites are limited, which is the case in many Lake Superior tributaries. Also, Chinook and coho salmon and rainbow and brown trout spend time in the stream as juveniles and could prey on brook trout fry or compete with brook trout for food and space. There is also the potential for interbreeding between brook trout and brown trout and between brook trout and splake. Interbreeding of brook and brown trout was documented through genetic analysis in the Sucker River, Michigan (Burnham-Curtis 1996), and there is evidence that backcrosses between splake and brook trout are present near Munising, Michigan (Wendylee Stott, U.S. Geological Survey, Great Lakes Science Center, personal communication).

Along the Ontario and Minnesota shoreline, high numbers of lake trout pose a potential predatory threat to juvenile coaster brook trout as they enter Lake Superior from tributaries. There is little evidence of lake trout predation on brook trout, but brook trout numbers are so low that finding the rare occurrence of predation would be highly unlikely. However, stocked lake trout and emigrating rainbow trout are commonly found in lake trout diets (Ray 2004), and one can infer that if brook trout were available to feeding lake trout they could easily be consumed.

Little is known about sea lamprey predation on coaster brook trout in Lake Superior, as coasters had declined dramatically before the sea lampreys invaded. However, the Ontario Ministry of Natural Resources has hypothesized that brook trout could avoid sea lamprey attacks better than lake trout because brook trout utilize very nearshore habitats and have a propensity for more rapid and constant movement. Recognizing these traits, Ontario began a splake program in Lake Huron as a means to restore a fishery similar to the historic lake trout fishery in the presence of sea lampreys (Berst and Spangler 1972). Although a few lamprey wounds have been reported on coaster brook trout, overall wounding appears to be low in the Lake Superior basin.

Human Dimensions Considerations

Rehabilitation of Lake Superior's coaster brook trout requires not only resolving critical ecological challenges but also addressing key human dimensions challenges (Hewitt et al. 2008, this issue). Successful rehabilitation will require cooperation among a diverse group of fish management agencies and support from a wide variety of user groups, each with its own values and perspectives toward the fishery (Ripp 1999).

Participatory decision making is needed to integrate public input into coaster brook trout rehabilitation strategies (Harding 1998; Decker and Krueger 1999). Forming advisory groups with diverse stakeholders early in the management planning process and facilitating discussion among individuals may help to build a consensus on what rehabilitation strategies to implement. It is also important that all stakeholders agree on what successful coaster rehabilitation is. Many of the management recommendations for rehabilitating coaster brook trout will require action through a social and political process. The awareness and support of the general public will generate the political commitment necessary for these initiatives.

Lake Superior fish management agencies have a long and successful history of working together, as evidenced by the successful rehabilitation of lake trout (Hansen et al. 1995; Schreiner and Schram 1997; Bronte et al. 2003), and collaboration in rehabilitating coaster brook trout has begun (Newman et al. 2003). Public outreach efforts by individual agencies have recently evolved into a coordinated basinwide outreach strategy. This effort highlights rehabilitation activities through a Web site dedicated to coaster rehabilitation, fact sheets, brochures, and outreach meetings around the basin. It is important that outreach information promote reasonable expectations for coaster rehabilitation based on sound science. The rate at which coaster rehabilitation might progress is a good example. Given the complexity and scope of the management activities required, it may take several decades to realize significant progress (Francis and Regier 1995).

Management and Research Recommendations

We propose the following general priority of management strategies to rehabilitate coaster brook trout in Lake Superior. The simplest and most immediate strategy is to reduce or eliminate harvest of any remnant populations through restrictive regulations. Habitat protection, restoration, and enhancement of areas currently or historically used by coasters will be necessary if range expansion and general population increases are to occur. If habitat is suitable and fish are protected from overexploitation and competition, reintroduction of appropriate Lake Superior strain brook trout may enhance rehabilitation efforts. The influence of other species on coaster populations is unknown and must be quantified to determine its importance. Lastly, the cooperation and coordination of Lake Superior management agencies, acceptance by diverse user groups, and continued support by the general public are critical if coaster rehabilitation is to be successful.

Restrictive regulations will have to be implemented in areas where rehabilitation is being attempted. Managers must deliver the message that coasters will not support the traditional "harvest" type of fishery but only have the potential to create a trophy or "memorable experience" type of fishery. In some cases this may be the only management action necessary for rehabilitation to proceed. The management of coasters may be controversial in some areas of Lake Superior, as the regulation changes required to accommodate coaster rehabilitation may affect anglers targeting other species. Large-scale coaster restoration efforts could divert agency resources away from other programs. Straightforward facilitated discussions among competing user groups of the regulation options and redistribution of agency resources may resolve some of the controversy.

We suggest that the protection of quality habitat that currently supports remnant coaster brook trout populations be given a high priority. Although watershed restoration and improvement is expensive, complex, and time-consuming, in some cases it may be the only alternative for coaster restoration. In most cases this activity will benefit other stream-dwelling organisms as well. Agencies will have to look closely at other factors that influence coaster rehabilitation before major watershed restoration is attempted. Forming partnerships among private landowners and local, state, and federal agencies will be required if watershed restoration efforts are to be successful. In some cases, less expensive instream habitat improvements may be sufficient to tip the balance in favor of coaster rehabilitation and should be considered a viable alternative.

Stocking is a management tool that might be considered for coaster rehabilitation, but habitat, the presence of remnant stocks, and gamete source should all be critically reviewed before a stocking program begins. We recommend that all stocked fish originate from a Lake Superior source and be marked for assessment so that agencies can evaluate the success of stocking projects. The percent return to a stocking site, the number of year-classes established, and ultimately the number of years before self-sustaining populations become established can all be used as criteria to evaluate a stocking program.

To minimize the effects of other species on coaster brook trout rehabilitation efforts, we suggest that managers cease introductions of new migratory fish species into the Lake Superior basin; discontinue stocking other salmonids in streams where coaster rehabilitation is of high priority; evaluate the abundance and success of other salmonids in streams targeted for coaster brook trout rehabilitation; and select stocking locations with favorable stream and lake habitat to minimize overlap with potential predators. Research is needed to quantitatively document instream interactions between brook trout and other migratory salmonids. This information would further our understanding of the impacts of the fish community on coaster rehabilitation efforts.

We suggest that fishery managers continue to work within their own agencies to better align management efforts across the basin. Increasing support for coaster brook trout rehabilitation will require a continued public outreach campaign that provides various mechanisms for citizen input and involvement.

Monitoring and reporting the results of management strategies such as stocking, restrictive regulations, and habitat manipulation will require that each agency put more emphasis on assessment. Realistic objectives must be adopted and measurable criteria established to determine whether the objectives have been achieved, and the results must be shared with other agencies and the public to demonstrate that rehabilitation is achievable. We suggest the following criteria as evidence that a population is rehabilitated: it is composed of five or more year-classes, it is self-sustaining, and reproduction can be documented in 1 of every 2 years. We fully expect annual fluctuations in abundance and variations in population size among streams of different sizes.

Where possible, all agencies should adopt standardized assessments to adequately evaluate progress toward coaster brook trout rehabilitation on a basin-wide scale, as with the protocols in place for lake trout assessment (Hansen 1996). However, standardization of assessment and monitoring approaches may not always be practical lakewide owing to geographic differences. On smaller scales, such as within a jurisdiction or geographic region, standardization would allow direct comparison of the results from one stream or embayment with those from others. Creel surveys provide the broadest geographic coverage around Lake Superior and are beneficial for monitoring changes in angler effort, catch, catch rate, and size structure. Data from standardized creel surveys can be used to monitor the results of the various management strategies implemented.

In most cases we propose taking an adaptive management approach to future rehabilitation efforts. Agencies should structure management actions as planned experiments to discriminate between alternative hypotheses about how the system may react to different treatments (Walters 1986). Other evaluations may simply be a comparison of alternative methods. In either case, agencies that are experimenting with coaster brook trout rehabilitation techniques must share their results in a formal scientific manner.

There is a critical need for more and improved information on coaster brook trout life history, ecology, and distribution. Additional biological surveys targeted at coasters in all jurisdictions will be necessary to determine their location and abundance. Information on migratory behavior patterns between lake and river environments is required to determine the regulations, stocking strategies, and habitat manipulations that will best protect and enhance coaster brook trout stocks. Recent work on the movement and distribution of brook trout within Nipigon Bay has been extremely valuable (Mucha and Mackereth 2008) but is limited in scope, and similar studies should be conducted in other areas of the lake. Experimentation with specific regulations (terminal gear, bait types, seasons, and sanctuaries) to address unique concerns at discrete sites may be required for rehabilitation in those areas. Studies to determine the location and abundance of groundwater are critical for coaster restoration. Initial studies have been conducted along the Minnesota shoreline and in a few tributaries located in Wisconsin, Minnesota, and Ontario. This information must be developed basinwide to enable managers to protect and monitor important groundwater sources. In addition, new cost-effective techniques to restore impacted watersheds for the benefit of all stream-dependent species must be developed (Williams et al. 1997; Roni 2005). Both anglers and biologists are concerned about the extent and impacts of hypothesized interactions between coasters and other salmonid species (Huckins et al. 2008). Research on interactions in streams and in the lake is needed.

In summary, we have identified a number of key management issues that must be addressed if coaster rehabilitation is to continue and we have indicated areas for future research. Agencies have begun collaborating on a number of projects, obstacles have been identified, and rehabilitation strategies have been outlined. Realistic expectations for the rate of rehabilitation must be conveyed to the public, so that both supporters and opponents of this effort do not become impatient and view rehabilitation as unattainable.

Supporters of coaster restoration must recognize that the Lake Superior fish community has changed dramatically since the early 1800s and that the abundance and range of coasters may never approach the levels that occurred historically. Managers and anglers must also recognize that the restoration of coaster brook trout will take time and will proceed at different rates in different locations around the basin, depending on the presence of remnant stocks, quality of habitat, angling pressure, and political will. In a stream with quality habitat, few competitors, and little or no angling pressure, a coaster reintroduction may start to show positive results in 10 years or less. Conversely, a stream that historically produced high numbers of coaster brook trout but that needs major watershed restoration (tree plantings, wetland restoration, and erosion control) may require up to 100 years before coaster brook trout will again be self-sustaining. Although progress will vary by location, the knowledge and confidence gained from initial successes in one area of the basin will carry forward into other areas.

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