Status and recovery of round whitefish (*Prosopium cylindraceum*) in New York, USA

Final report

to

State Wildlife Grant T-3-1
NYSDEC, Bureau of Wildlife, Albany NY

Submitted by:
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Executive summary

Below is a summary of the important findings from our investigations into the status and recovery potential for round whitefish in the Adirondack Park, New York.

1. We reviewed early state reports, which revealed that over 75 million round whitefish were stocked into various waters from 1895-1918. Stocking was reported in several lakes not recorded as having contained round whitefish, bringing the total number of historical waters containing round whitefish to 86. But, **widespread stocking also suggests that many extirpated populations may have been the result of failed introductions** (we estimated that 25 populations were likely failed introductions) and that the number of endemic populations might have been lower than previously thought.
2. Using multiple techniques, it is apparent that the decline in round whitefish was likely caused by a combination of low pH (13 lakes), non-indigenous species (31 lakes), and failed introductions. **Round whitefish were extirpated from all lakes experiencing low pH (< 5.5)**. While some round whitefish populations were able to cope with non-indigenous species, **the appearance of smallmouth bass, rainbow smelt, and yellow perch often accompanied a decline or disappearance of round and lake whitefish**.
3. Data from Little Moose Lake suggest that **smallmouth bass can reduce round whitefish recruitment and round whitefish growth might be limited by intraspecific competition**. Following the start of a smallmouth bass removal program, catch rates of small round whitefish have increased exponentially in Little Moose Lake. At the same time, the overall condition, or plumpness, of round whitefish has been decreasing. Likewise, the general trend from our field sampling of other endemic round whitefish populations suggests that those with the highest densities of round whitefish also have low plumpness.
4. **We determined that short (60 min) gill net sets were effective for sampling round whitefish populations**. Short sets allowed for high spatial coverage with frequent relocations and reduced round whitefish mortality. Our gill nets consisted of six 8 ft by

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50 ft panels of 1.5 in stretch sinking monofilament mesh (purchased from Redden Net, www.redden-net.com). Nets were set perpendicular to shore, starting at a depth where the entire net was below water. By comparing our catch rates with estimated round whitefish densities, from known stocking densities and an estimated annual mortality, we developed an equation to estimate round whitefish densities after determining catch per unit effort: round whitefish per ha = 14.764 × CPUE + 17.675.

5. **We captured round whitefish in all stocked waters except Eighth Lake, Fulton Chain**, which had an unusually low stocking density. However, **we did not observe any sign of natural reproduction in the three lakes where we expected to catch naturally-reproduced age-1 fish**. In general, all stocked fish appeared to grow faster and were plumper than the parental stock from Lower Cascade Lake.
6. Using multiple logistic regression, we explored lake characteristics that are conducive to supporting round whitefish. The most important environmental variables were pH, growing degree-days, and surface area to depth ratio (a surrogate for summer stratification). The most important biologic variable was the number of warm water predators (*Micropterus* spp., yellow perch, rainbow smelt, *Sander* spp., *Esox* spp.). The fish community was such an important factor for round whitefish abundance, that the most parsimonious model included only pH and warm water predators. **An ideal round whitefish lake meets the following criteria: no more than one warm water predator and the minimum pH should exceed 5.5**. For lakes that do not contain any warm water predators, thus only considering environmental variables, it is preferable to consider pH, growing degree-days, and surface area to depth ratio.
7. Data collected during this project (Fall 2004-Spring 2006) has been submitted for inclusion in the New York State Department of Environmental Conservation statewide database. Ongoing related work includes genetic and morphometric analyses of differences among endemic round whitefish populations in New York. In addition, a draft round whitefish recovery strategy is presented in Appendix 4.

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Introduction

Round whitefish (*Prosopium cylindraceum*), also called frost fish, once were found in over 80 lakes in New York. Early fisheries reports commented on the importance of round whitefish to humans, calling them "a small species of whitefish greatly prized by the public" (1906) and "Give any of the…guides…his choice between a trout and a frost fish and the chances are 9 out of 10 that he will choose the frost fish" (1913). Round whitefish were also seen as an important component of native food webs: "The frost fish is valuable not only for human food, but also for feeding the large trout and other game fishes" (1906) and "important for the food of lake trout and other good fish" (1913). But, many round whitefish populations have been extirpated so that by 1979 they were found in fewer than 15 lakes and by 2000 there were only four known native populations. The dramatic decline in round whitefish abundance led to their listing as a New York endangered species in 1983 and prompted the New York State Department of Environmental Conservation (NYSDEC) to begin a recovery program.

In 2004, the NYSDEC and researchers at Cornell University began an investigation in to the status and recovery of round whitefish in New York. This report describes our findings regarding the objectives outlined by the NYSDEC (paraphrased below, but see Appendix 1):

1) Provide details of the species life history that would likely be useful in implementing a recovery program
2) Identify the probable factors that have contributed to the decline of round whitefish in Adirondack lakes
3) Develop a field sampling protocol and conduct field surveys on at least 25 lakes formerly known to support round whitefish populations
4) Assess the outcome of experimental stockings implemented within Adirondack waters stocked in 1999-2005
5) Develop a framework for environmental conditions conducive to round whitefish and develop a prioritized list of Adirondack lakes suitable for restoration of round whitefish through re-introduction

Objective 1: Round whitefish life history

We completed a thorough literature search and found that round whitefish have rarely been studied in depth. However, there is a wide body of literature regarding studies of closely related *Coregonus* spp. from which some parallels might be drawn. We had previously prepared and submitted to the NYSDEC a summary of round whitefish biology and ecology (Appendix 2). As part of this exploration, we contacted numerous researchers from other institutions and agencies (Appendix 3).

Through our field sampling (Objectives 3 and 4), we also learned more about round whitefish growth (presented in Objectives 3 and 4), diet, and maturation. We analyzed the diet of 139 round whitefish from 11 different lakes. Round whitefish were generalist feeders: eating everything from zooplankton to macroinvertebrates to snails and mollusks. The dominant prey by biomass were *Daphnia* spp (Figure 1). Overall, zooplankton made up 52% of the diet. Diptera larvae and pupae were the most abundant macroinvertebrates in the diet, followed by caddisflies and mayflies. While diets were highly variable when pooled, individual fish often contained predominantly one prey item suggesting that they had distinct, albeit variable, search

images. On the same sampling date in Buck Pond, for example, there were three round whitefish that ate exclusively daphnia, three that ate predominantly caddisflies, two that ate mostly damselflies, one that ate almost entirely dragonflies, and one that ate a little of all prey types.

Another interesting phenomenon was the difference in diets between Upper and Lower Cascade Lake round whitefish. Fish in Lower Cascade Lake ate more pelagic prey (mites and diptera pupae) than did round whitefish in Upper Cascade Lake. The only exceptions were six round whitefish captured during spring in the shallow end of Upper Cascade Lake that ate mostly benthic snails and diptera larvae. We believe that the round whitefish in Upper Cascade Lake may, at times, be denied access to benthic resources by a combination of high temperatures at the surface (prohibiting access to benthos in the shallow waters) and low dissolved oxygen preventing access to the benthos in deep water (T. Langen, Clarkson University, personal communication).

In the Adirondacks, round whitefish appear to mature at age-3. Fish begin developing gonads at age-1, and some fish, especially males, may mature at age-3, but most fish do not mature until their third year. Our data on maturation is somewhat limited, however, because much of our sampling occurred prior to spawning. In addition, even when we did sample while fish were ripe, we had limited mortality where we could obtain otoliths for accurate ageing or we lacked immature fish (e.g., trapnetting in the Cascade Lakes). Still, data from Little Moose Lake and Lower Cascade Lake suggest that most fish do not mature until age-3. This is comparable to the timing of maturation in the Great Lakes (Armstrong et al. 1977; Bailey 1963; Mraz 1964).

Objective 2: Factors contributing to the decline of round whitefish

The steep decline in round whitefish distribution in upstate New York likely was caused by a combination of factors. Since the early 1900's, records indicate that round whitefish were present in at least 86 lakes (Table 1), but by 1979 fewer than 15 lakes contained round whitefish (Figure 2). We hypothesized the decline was most likely due to a combination of low pH caused by acid deposition and from the introduction of various non-indigenous fishes. To test these hypotheses, we used multiple approaches. First, we assigned a "best guess" cause for round whitefish extirpation in each lake by reviewing available data. Next, we used multiple logistic regression to predict round whitefish presence/absence. Finally, we used a detailed 50-year data set from one lake where round whitefish have persisted to look for factors that affected round whitefish growth and recruitment.

We used chemical, physical, and descriptive data from the NYSDEC (and earlier Commissioners of Fisheries, Game, and Forests reports), the Adirondack Lake Survey Corporation (ALSC), the Environmental Protection Agency (EPA), and Cornell University's Adirondack Fishery Research Program (AFRP). There are many limitations to these data, primarily that sampling was somewhat infrequent during the period that most round whitefish populations disappeared. In addition, round whitefish and many other non-game species were rarely targeted during sampling prior to the work done by the ALSC. Still, these data represent the best available information on Adirondack lakes.

Assigning causes for failures

Given our hypotheses, we focused on pH and the fish community when assigning possible causes for the disappearance of round whitefish. Specifically, we assumed that if a lake

experienced a pH less than 6.0, it was considered too acidic to support round whitefish. In addition, anecdotal information from NYSDEC reports (e.g., Lake Lila, Lake Clear, Little Green Pond) and from other states (J. Viar, New Hampshire Fish and Game, personal communication) suggests that round whitefish are incompatible with some non-native species. Smallmouth bass, yellow perch, and rainbow smelt have all been mentioned as potentially harmful to whitefish populations and, therefore, their presence was considered a possible cause for round whitefish extirpation.

In reviewing early reports from the Commissioners of Fisheries, Game, and Forests, we discovered that round whitefish were heavily stocked in New York waters during the late 1800's and early 1900's. The peak of stocking occurred in the late 1890's and declined steadily until the program was largely abandoned due to World War I (Figure 3). During this period of widespread stocking, there were several lakes that had been stocked with round whitefish but which were not previously listed as historical round whitefish waters. Many of the lakes where round whitefish were introduced did not contain round whitefish at the time of the lake surveys conducted in the 1920's and 1930's. Therefore, we believe that many of the early stocking efforts may have, in fact, been introductions that did not establish a naturally reproducing population.

After reviewing the data for each of 75 lakes where round whitefish were extirpated, we tallied the number of lakes with round whitefish stocking, low pH, and non-indigenous fishes. But, we also looked more closely at the timing of each possible factor to assign our best guess explaining round whitefish extirpation. When round whitefish were never recorded in a lake, except for a stocking record, we assumed a failed introduction. Next we differentiated between low pH or the appearance of non-indigenous species (NIS) by assigning the factor that most closely matched with the date when round whitefish were last captured or recorded.

The most common potential causes (allowing multiple causes per lake) were the possibility of failed introductions and presence of at least one non-indigenous fish (Figure 4, Table 2). When we assigned our best guess for extirpation, the presence of smallmouth bass, rainbow smelt, and/or yellow perch was the most common explanation (Figure 5). Furthermore, 29 of the 31 NIS lakes had at least two of the three NIS species present. In addition to a number of possible failed introductions, four lakes were reclaimed while round whitefish were still present and in two lakes conflicting reports suggest that confusion about early synonyms for various species may have resulted in an erroneous record of round whitefish.

Modeling round whitefish presence

We used multiple logistic regression to predict round whitefish presence/absence in 77 historical round whitefish lakes in New York. Although the main objective of the modeling was to prioritize restoration efforts (see Objective 5 for a complete description of the modeling), it also identified variables that were not conducive to round whitefish and, therefore, could be important factors in their decline. Physical parameters included for each lake in the model were: mean annual growing degree-days, perimeter, maximum depth, pH, and surface area to depth ratio (a surrogate for summer stratification, Demers and Kalff 1993). Fish community parameters included presence/absence of various fish species, alone or in logical combinations (e.g., number of warm water predator species).

The most parsimonious model contained only pH and the number of warm water predators, both of which were negatively related to the probability of finding round whitefish in the lake.

In fact, the model predicted that any lake with more than two warm water predators (*Micropterus* spp., yellow perch, rainbow smelt, *Sander* spp., *Esox* spp.) would not contain round whitefish, even when other conditions were suitable. Lakes affected by acid deposition would not be predicted to support round whitefish when pH was less than 5.5. *Coregonus* spp. embryos exposed to pH below 5.5 experienced increased mortality and impaired development (Vuorinen et al. 2004b). In addition, ovulation and maturation in Coregonus spp. can be delayed when pH drops below 6.0 (Vuorinen et al. 2004a, 2004b; Appendix 2).

Case study: Little Moose Lake

Of the ten lakes on the Adirondack League Club (ALC) that once contained round whitefish, Little Moose Lake is likely the only lake where round whitefish were native. An extensive database from Little Moose Lake provides some insight into the dynamics of round whitefish. From 1952-1956 there was an effort made to drastically reduce the population size of round and lake whitefish in Little Moose Lake (Neth 1955, 1959). It was believed that whitefish were so abundant that their growth was stunted. Therefore, the goal of thinning the population was to increase growth rates. A total of 2,751 round whitefish were removed over 5 years of trap netting. Although many fish were removed, there was no consistent increase in size or condition, nor a decrease in abundance based on catch rates (Neth 1959). However, there also were many lake whitefish removed from Little Moose Lake, and their population did show an increase in growth and condition. Furthermore, lake whitefish have, for the most part, been extirpated. Lake whitefish were extremely rare in sampling conducted during the 1990's and 2000's (AFRP data). It has been shown that round and lake whitefish compete for food resources (Sandercock 1964), so round whitefish growth may have benefited from the removal of lake whitefish.

Around the time of the whitefish removal program, smallmouth bass became established in Little Moose Lake. Smallmouth bass became so abundant they were seen as an impediment to successful minnow recruitment and, subsequently, brook trout and lake trout growth and survival (Weidel 2004). Beginning in 2000, the AFRP began a smallmouth bass removal program in Little Moose Lake.

Two important observations about round whitefish were made following the start of the smallmouth bass removal. First, the abundance of young (< 200-mm total length) round whitefish has been increasing exponentially since the start of the smallmouth bass removal (Figure 6). This implies that smallmouth bass may indeed have negative effects on round whitefish, as suggested by our modeling results. Whether the interaction is due to competition or predation is unknown; however, round whitefish were not found in juvenile smallmouth bass diets (Weidel 2004). Second, the condition of round whitefish has declined since the start of the smallmouth bass removal (Figure 7). We assessed condition by looking at changes in residual wet weight (RWW), which is the difference of an individual's actual weight from its predicted weight. A high RWW indicates that a fish is plumper than the sample population, while a negative RWW means the fish is light for its length. Before the smallmouth bass removal, mean RWW was 48.4, while after the removal the mean RWW declined to -10.7 (df=97, t=6.13, p<0.0001). The change in RWW could be due to increased intraspecific competition from the increasing number of young round whitefish.

Objective 3: Round whitefish field sampling

Development of a round whitefish sampling technique

We have made targeted sampling efforts for round whitefish since spring 2004 and have determined that short gill net sets are the most effective sampling method for round whitefish in the Adirondacks. Gill nets are relatively portable compared to trap nets and, thus, are more easily used in remote lakes. We also tried sampling with boat electrofishing, backpack electrofishing, seines, and trap nets. Boat electrofishing caught more small round whitefish (<300-mm) than did gill netting, but it is unrealistic to launch a large electrofishing boat in many Adirondack lakes. Backpack electrofishing, from a boat or from shore did not yield any round whitefish in Little Moose Lake, Little Green Pond, or Deer Pond. Seining was ineffective in Little Green Pond and Lower Cascade Lake. Trap nets have historically been useful when the fish are congregating, for example, during the spawning season. Because it takes prior knowledge of a system to know where to set a trap net, they are not very efficient as exploratory sampling equipment. Although we know where round whitefish spawn in Little Moose Lake, we were not very successful catching them in trap nets during fall 2004. Therefore, gill nets appear to be the best sampling method for quickly assessing the presence or absence.

The gill netting technique we now recommend for sampling for round whitefish is a variation on a method developed by the Ontario Ministry of Natural Resources to estimate lake trout abundance. Spring littoral index netting, or SLIN, uses 90 min sets of sinking monofilament gill nets (purchased from Redden Net; www.redden-net.com), set perpendicular to randomly selected stretches of shoreline. We determined that 1.5-in stretch mesh nets were more effective at catching round whitefish than smaller mesh nets (3/4 in or 1 in). We decided on using shorter sets, 60 min versus 90 min, to allow more sets to be made in a shorter period and to reduce mortality. Net mortality averaged 36% and was lower in fall sampling than during spring sampling. While SLIN sampling is supposed to occur in spring when water temperatures are below 12.7˚C, we were successful at catching round whitefish during spring and fall and in all temperatures we sampled (up to 15˚C).

Our procedure for gill netting started by dividing a lake's shoreline into approximately 500-ft sections. Netting sections were randomly selected, without repetition, before sampling began. We set nets in different sites based on ease of sampling (e.g., sites were not necessarily on opposite ends of a lake), but never in adjacent sections. In addition, we sometimes repeated sampling in particular sections in small lakes (e.g., Deer Pond). When our main objective was to capture fish for sampling purposes, we sometimes targeted known spawning areas (e.g., in Little Moose Lake) to maximize our catch. Each net consisted of six panels, each 8-ft high by 50-ft long, making an 8 by 300 ft net. The nets were set perpendicular to shore, at locations free of snags within each section, starting in water approximately 8-ft deep. We attached small anchors to both ends of the net. When using an outboard motor, three nets were run simultaneously, set at 20-min intervals. When rowing, two nets were used, set 30-min apart. Using these methods, it is possible to set up to 15 nets per day with an outboard motor and 10 nets per day when rowing.

In lakes where we ultimately captured round whitefish, we caught our first round whitefish by the third net set (average 1.5 net sets to capture the first round whitefish) and 69% of our net sets contained at least one round whitefish. In other words, there was a 0.31 probability of <u>not</u> catching a round whitefish in a single net set, when round whitefish were present. This means

that if after three net sets no round whitefish were captured, the probability that round whitefish actually were present in the lake is only 0.03 (0.31^3). Despite the high frequency of round whitefish catches in gill nets, their distribution can be patchy and some of our net sets were targeting areas where round whitefish were known to congregate. Therefore, we recommend that sufficient net sets be made to ensure good spatial coverage when sampling to determine the presence of round whitefish.

SLIN was developed as a technique to estimate lake trout abundance and it might be capable of estimating round whitefish abundance. Toward this goal, we analyzed our gill net catch per unit effort (CPUE) data to look for relationships between round whitefish density and CPUE. Although we did not have exact estimates of round whitefish density or population size from conventional methods, we did have CPUE data from eight lakes with known stocking densities. But to compare density with CPUE, we first needed to estimate density on our sampling date by assuming a mortality rate. To estimate mortality, we used two approaches. First, for stocked lakes with multiple sampling efforts in consecutive years, we calculated the relative change in CPUE from one sample period to the next. Using this method, we estimated an annual mortality rate of 32%. Second, we calculated an average annual mortality of 27% based on age distributions from native populations in Little Moose Lake (29%), Lower Cascade Lake (24%), Moose Pond (21%), Newcomb Lake (44%), Upper Ausable Lake (21%), and Upper Cascade Lake (21%). Therefore, for estimating density of round whitefish in introduced populations, we assumed an annual mortality of 30%. Our estimated mortality was much lower than the 63% mortality reported by Neth (1959) for Little Moose Lake, however it represents our best estimate given our limited age data.

Next, using the known stocking density, annual mortality, and the fact that our sampling is only effective for age-1+ fish, we estimated the actual density of vulnerable fish at the time of sampling. This was done separately for both NYSDEC and AFRP sampling efforts. The NYSDEC used multiple mesh sizes, so there were actually fewer net-feet of 1.5-mesh, and longer net sets. We scaled the NYSDEC data to only include the 1.5-in mesh. We found a significant relationship between round whitefish CPUE and estimated round whitefish density (Figure 8), but owing to differences in sampling technique, we believe that the estimate using Cornell University's AFRP data is the better model (round whitefish per ha = 14.764 × CPUE + 17.675, r^2=0.64, df=8, F=12.26, p=0.01). Using this equation, it was possible to estimate the population size of other round whitefish populations (Table 2).

Because round whitefish CPUE was correlated with round whitefish density, CPUE should be considered when deciding stocking rates to ensure enough fish are present to assess their success. We believe a catch rate of one fish per net hour is sufficient and would require stocking fish at a density of 45 fish ha^{-1} (18 fish $acre^{-1}$) when assessment happens 1 yr post-stocking, 65 fish ha^{-1} (26 fish $acre^{-1}$) when assessment happens 2 yr post-stocking, 90 fish ha^{-1} (36 fish $acre^{-1}$) when assessment happens 3 yr post-stocking, and 190 fish ha^{-1} (76 fish $acre^{-1}$) when assessment happens 5 yr post-stocking. These estimates assume similar mortality rates and should be adjusted upwards if it is believed that predation may be high. In practice, recently stocked lakes were stocked with a mean density of 53 fish $acre^{-1}$ (range: 3.3-84.2).

Field sampling

Sampling for this project began in spring 2004 (using Cornell University resources) and continued through spring 2006. Existing AFRP data and ongoing AFRP sampling provided

additional sampling data. From the above sampling efforts, we have data from 31 round whitefish lakes: 25 historical lakes and 8 lakes following recent stocking (Table 3). These data include 1,014 gill net sets, plus additional electrofishing and trap net data from Little Moose Lake.

Of the historical round whitefish lakes, we found endemic populations in only six lakes: Little Moose Lake, Moose Pond, Newcomb Lake, Lower Cascade Lake, Upper Ausable Lake, and Upper Cascade Lake. Round whitefish also were found in Cat Pond, which was stocked with round whitefish in the 1970's. We did not find any round whitefish in Hoel Pond (last round whitefish caught in 2003), Chapel Pond (1999), or West Canada Lake (1975). Given the success of our gill netting technique, we are confident that these lakes do not contain significant populations of round whitefish, despite the recent catch records. In Hoel Pond, the disappearance of round whitefish is fairly recent: 6 fish were captured in 1975 (mean 398-mm TL, range 350-429), 3 fish in 1984 (mean 400-mm TL, range 257-485), but the last, a large individual, was captured in 2003. The apparent extirpation of round whitefish from Hoel Pond is likely due to the presence of numerous exotic species: rainbow smelt, largemouth and smallmouth bass, and yellow perch.

Our highest catch rates were in Upper and Lower Cascade Lakes and Upper Ausable Lake, while the lowest catch rate was in Cat Pond (Figure 9). Catch rates were not directly comparable to population size (Table 4) because the lakes varied greatly in size and Upper and Lower Cascade Lakes are relatively small compared to the other endemic round whitefish lakes.

All round whitefish captured were weighed and measured. In addition, we collected scales or, when fish died in our nets, otoliths to determine ages. We then estimated the von Bertalanffy growth parameters using length at age data and found that round whitefish in Little Moose Lake grew faster and larger than other populations (Figure 10). Lower Cascade Lake had the smallest adult fish and were generally slow growing, although round whitefish in Upper Ausable Lake also grew slowly.

In addition to growth, we also examined residual wet weight, a measure of a fish's condition. We estimated residual wet weight (RWW) by first calculating the mean weight at a given length for all endemic populations. Round whitefish in Little Moose Lake had high RWW, and only Lower Cascade Lake and Upper Ausable Lake fish had negative mean RWW (Figure 11). These data suggest that growth conditions are most favorable in Little Moose Lake, despite the increase in juvenile abundance, and that growth may be limited in Lower Cascade and Upper Ausable Lakes.

Objective 4: Assessing recent round whitefish introductions

We assessed the success of experimental stockings in eight Adirondack lakes: Buck Pond, Deer Pond, Eighth Lake Fulton Chain, Evergreen Lake, Little Green Lake, Little Trout Pond, Rock Pond (P424), and Trout Pond. We captured round whitefish in all lakes except Eighth Lake (Figure 12). Our failure to catch round whitefish in Eighth Lake may have been due to the low stocking density (only 8 fish ha^{-1}) or due to high predation from a combination of yellow perch and salmonids. Only Evergreen Lake had a round whitefish CPUE that was much higher than would have been predicted given our assumptions about mortality rates and estimated density (Objective 3, Figure 8). Rock Pond (P424) and Trout Lake had CPUE's that were lower than would have been predicted, but the difference was not terribly large.

In all stocked lakes, the fish captured were stocked fish: there was no sign of natural reproduction. There is some evidence that introduced populations in Cat Pond and Chapel Pond did reproduce successfully. Cat Pond was stocked in 1970 and 1974, but round whitefish were captured during our sampling in spring 2004. Although we do not have ages from these fish, it is highly unlikely that they were 30-year old fish despite their large size (mean length 412 mm). Likewise, Chapel Pond was stocked with adult round whitefish around 1976 and round whitefish were captured as recently as 2000 (mean length in 1990 was 320 mm). We have never aged a round whitefish beyond 15-years old, so it is improbable that the fish captured in Chapel in 2000 was one of the original stocked fish.

It may be too early to rule out the possibility of natural reproduction in the recently stocked populations. Assuming first spawning occurs at age-3 and that age-1 fish are vulnerable to our nets (as observed in Little Green and Rock (P424) Ponds), the only lakes sampled where we would have expected to find naturally reproduced offspring (all age-1) were Trout Pond, Little Trout Pond, and Deer Pond. By 2012, however, if natural reproduction is occurring in these waters, we would expect three generations of fish in Trout, Little Trout, Deer, and Buck Ponds and Evergreen Lake. Little Green Pond, Rock Pond (P424), and Bug Lake would be expected to have two generations each.

As with the endemic lakes, all round whitefish captured were weighed and measured and we calculated residual wet weight. We estimated residual wet weight by first calculating the mean weight at a given length for all stocked populations and the parental stock from Lower Cascade Lake. The introduced populations all were plumper than round whitefish from Lower Cascade Lake (Figure 13) and had larger mean length at age. Little Trout Pond was the only introduced population where growth was close to growth rates from Lower Cascade Lake, but we only captured two fish in Little Trout Pond.

Objective 5: Prioritizing restoration efforts

We used data from both Ontario and New York (Table 5) to generate models predicting the probability of round whitefish presence in lakes. We analyzed the data separately for each location, in case their were other factors that differed between the regions or data sets (e.g., we were not as familiar or trusting of the quality of the Ontario data). Our approach was to use multiple logistic regression and Akaike's Information Criterion (AIC) to evaluate a set of models chosen *a priori*. The environmental variables included in the 17 physical factor models tested were: pH, growing degree days (cumulative from 5°C), lake area (ha), lake perimeter (km), maximum depth (m), and surface area to depth ratio. Once we determined the top five physical factor models, we added different measures of the fish community composition (e.g., presence/absence of lake whitefish, brook trout, lake trout, smallmouth bass, yellow perch, rainbow smelt, northern pike, walleye; number of salmonid species, number of cyprinid species, number of warm water predator species, number of smallmouth bass, yellow perch, and rainbow smelt species, and number of all fish species). We ranked the models based on their AIC weight, which takes into account not only the fit of the model, but also seeks to minimize the number of parameters by identifying the most parsimonious model.

In both Ontario and New York, physical parameters that best predicted round whitefish presence were pH, growing degree-days, and surface area to depth ratio. Olden and Jackson (2002), using the same Ontario dataset, found lake size (surface area and volume), summer stratification, and pH were the most important variables predicting round whitefish distribution

using four different modeling methods. In addition, growing degree days were found to be important when predicting round whitefish distributions using artificial neural networks (Olden 2003). In our models, the variable that appeared in the most high-ranking models was pH, indicating that pH was the most important variable in determining the presence or absence of round whitefish. When only considering physical variables, the best predictor of round whitefish presence/absence in New York lakes was:

$$\text{Log odds ratio} = 5.31 - 2.055\times\log(\text{SA:D}) - 0.011\times\text{GDD} + 1.855\times\text{pH}$$

where SA:D is the surface area to depth ratio, GDD is the growing degree-days. To calculate the probability of round whitefish presence, one uses the following equation:

$$\exp(\text{Log odds ratio}) / (1 + \exp(\text{Log odds ratio}))$$

When using this equation to predict round whitefish presence or absence, it is commonly assumed that a probability greater than 0.5 indicates presence of a species.

For some unknown reason, the presence of other fish species affects round whitefish distributions differently in Ontario and New York. When we included the fish community variables, results from the two datasets disagreed. In Ontario, the only significant outcome was a positive association between round whitefish and lake whitefish. In New York, however, round whitefish were negatively associated with the number of warm water predator species, smallmouth bass, and the number of smallmouth bass, yellow perch, and rainbow smelt species. The results from modeling the New York data agree with our observations from the field, which is not surprising given that our hypothesis about the effects of NIS species like smallmouth bass, yellow perch, and rainbow smelt were based on years of data and observations coming from the data set. When fish variables were included with the physical factors, the most parsimonious model contained only pH and the number of warm water predators. The model results suggest that any lake with more than two warm water predators (*Micropterus* spp., yellow perch, rainbow smelt, *Sander* spp., *Esox* spp.) would not contain round whitefish, even when other conditions were suitable. Lakes affected by acid deposition would not be predicted to support round whitefish when pH was less than 5.5.

To develop a prioritized list of lakes for reintroduction, we used the best physical factor model and added the number of warm water predators. Technically, by adding warm water predators to this model, it became "worse" than the simple warm water predator and pH model because we added more variables. We believe, however that it was important to include all the physical factors along with the warm water predators. We used the following equation:

$$\text{Odds ratio of round whitefish} = 0.505 - 0.233\times\log(\text{SA:D}) - 0.015\times\text{GDD} + 3.873\times\text{pH} - 2.344\times\text{WWP}$$

where WWP is the number of different warm water predator species in the lake, to generate lists of lake most likely to support round whitefish under two different scenarios. First, we calculated ranks using historical low pH for all lakes (Table 6). But, because some lake may be recovering from the effects of acid deposition, we also calculated rankings assuming a neutral pH (pH=7.0) for all lakes (Table 7). The results suggest that low pH is indeed important in Adirondack lakes. Only nine lakes were likely to support round whitefish using historical pH values: four were

surviving endemic populations, two were introduced populations, and two were reclaimed while round whitefish were present. When we assumed a neutral pH, however, there were 28 lakes that were likely to support round whitefish. For example, Pico Pond (P832) was the 24th ranked lake given a historical low pH of 4.3, but was ranked 3rd if we assumed a current pH of 7. When assuming a neutral pH, most of the top candidate waters are located on the ALC property. Other notable candidate waters were: Brandereth Lake, Dart Lake, Limekiln Lake, Massawepie Lake, South Lake, and West Canada Lake.

The model predictions were, and will be, only as good as the data that were used to generate the probability of round whitefish. Because the model was built using many lakes, the overall model form and values were sound. Testing individual lakes may, if the data are biased or lacking, yield erroneous probabilities. For example, if the fish community data were limited (e.g., gill net sampling only, which may not be effective for smallmouth bass), then the model may have predicted a higher probability of round whitefish presence than was expected given the actual conditions in the lake. Furthermore, our choice of variables (e.g., presence/absence of species as opposed to density) is somewhat limiting. It is very likely that the mere presence of a few predators or competitors will not eliminate round whitefish, but high densities of NIS species could. We have used the best available data, from the NYSDEC statewide database, Adirondack Lake Survey Corporation, Adirondack Fishery Research Program, and U.S. Environmental Protection Agency for the 77 lakes we tested with the model. Still, the data could have been lacking or biased for some of these lakes. Therefore, we recommend that a group of NYSDEC staff carefully review each candidate water before final stocking decisions are made.

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Table 1. List of all known historical round whitefish waters in New York.

1st Bisby Lake (P977)	Hemlock Lake (P44)	Nelson Lake (P718)
1st Lake, Fulton (P782D)	Hoel Pond (P161)	Newcomb Lake (P694)
2nd Bisby Lake (P976)	Honnedaga Lake (P877)	Panther Lake (P809)
2nd Lake, Fulton (P787A)	Jones Pond (P123)	Pico Pond (P832)
3rd Bisby Lake (P975)	Lake Bonaparte (P24)	Piseco Lake (P234)
3rd Lake, Fulton (P782C)	Lake Champlain (P1)	Rainbow Lake (P66)
4th Lake, Fulton (P782B)	Lake Clear (P199)	Raquette Lake (P293)
6th Lake, Fulton	Lake Colby (P106)	Rock Pond (P807)
7th Lake, Fulton (P787)	Lake George (P367)	Round Pond (P687)
8th Lake, Fulton (P790)	Lake Lila (P541)	Sacandaga Lake (P314)
Big Moose Lake (P752)	Lake Ontario	Schroon Lake (P374)
Big Tupper Lake (P109)	Lake Placid (P254)	South Pond (P245)
Big Wolf Pond (P97)	Lake Pleasant (P313)	Spitfire Lake (P264)
Blue Mountain Lake (P307)	Lake Rondaxe (P739)	Stillwater Reservoir (P493)
Brandereth Lake (P277)	Limekiln Lake (P826)	Thirteenth Lake (P540)
Brantingham Lake (P689)	Little Clear Pond (P191)	Trout Lake (P293)
Bug Pond (P789)	Little Forked Lake (P279)	Turtle Pond (P160)
Canachagala Lake (P838)	Little Green Pond (P192)	Upper Ausable Lake (P277)
Cat Pond (P139)	Little Moose Lake (P808)	Upper Cascade Lake (P271)
Chapel Pond (P274)	Little Tupper Lake (P120)	Upper Chanteaugay Lake (P2)
Chazy Lake (P20)	Loon Lake (P48)	Upper Saranac Lake (P114)
Clear Pond (P70)	Lower Cascade Lake (P270)	Upper St. Regis (P265)
Crystal Lake (P595)	Lower Saranac Lake (P104)	Utowana Lake (P304)
Crystal Pond (P590)	Lumber Lake	Warm Pond (P285)
Dart Lake (P750)	Massawepie Lake (P369)	West Canada Lake (P931)
Eagle Lake (P306)	Meacham Lake (P179A)	White Lake (P958)
Forked Lake (P276)	Mirror Lake (P250)	Woodhull Lake (P982)
Gilman Lake (P281)	Moose Pond (P221)	
Green Lake (P812)	Mud Lake (P231)	

Table 2. Lakes where round whitefish were extirpated and predicted reason(s) for extirpation. Through review of old reports and data, we assigned reasons for extirpation based on the time round whitefish were last seen in each water. Potential reasons for round whitefish extirpation included: failed introductions (INT), appearance of non-indigenous species (NIS), low pH (pH), misidentified or recorded fish (MIS), and reclaimed while round whitefish still present (REC).

Lake	Reason	Lake	Reason	Lake	Reason
1st Bisby Lake	pH	Gilman Lake	NIS	Mud Lake	INT
1st Lake, Fulton	NIS	Green Lake	INT	Nelson Lake	INT
2nd Bisby Lake	pH	Hemlock Lake	INT	Panther Lake	INT
2nd Lake, Fulton	NIS	Honnedaga Lake	pH	Pico Pond	INT
3rd Bisby Lake	pH	Jones Pond	INT	Piseco Lake	NIS
3rd Lake, Fulton	NIS	Lake Bonaparte	INT	Rainbow Lake	INT
4th Lake, Fulton	NIS	Lake Champlain	NIS	Raquette Lake	MIS
6th Lake, Fulton	NIS	Lake Clear	NIS	Rock Pond (P807)	INT
7th Lake, Fulton	NIS	Lake Colby	NIS	Round Pond	pH
8th Lake, Fulton	NIS	Lake George	INT	Sacandaga Lake	NIS
Big Moose Lake	pH	Lake Lila	NIS	Schroon Lake	INT
Big Tupper Lake	INT	Lake Placid	NIS	South Pond	pH
Big Wolf Pond	MIS	Lake Pleasant	NIS	Spitfire Lake	INT
Blue Mountain Lake	NIS	Lake Rondaxe	pH	Stillwater Reservoir	NIS
Brandereth Lake	pH	Limekiln Lake	REC	Thirteenth Lake	INT
Brantingham Lake	NIS	Little Clear Pond	REC	Trout Lake	NIS
Bug Pond	REC	Little Forked Lake	INT	Turtle Pond	INT
Canachagala Lake	pH	Little Green Pond	REC	Upper Chanteaugay Lake	NIS
Chazy Lake	NIS	Little Tupper Lake	INT	Upper Saranac Lake	NIS
Clear Pond	INT	Loon Lake	INT	Upper St. Regis	NIS
Crystal Lake	INT	Lower Saranac Lake	NIS	Utowana Lake	NIS
Crystal Pond	NIS	Lumber Lake	INT	Warm Pond	INT
Dart Lake	pH	Massawepie Lake	NIS	West Canada Lake	pH
Eagle Lake	NIS	Meacham Lake	INT	White Lake	NIS
Forked Lake	INT	Mirror Lake	NIS	Woodhull Lake	pH

Table 3. Summary of round whitefish sampling by Cornell University researchers during 2003-2006. All lakes were sampled with gillnets, while some lakes also were sampled with boat electrofishing, backpack electrofishing, seining, and/or trap nets.

Lake	Dates sampled (S = Spring, F = Fall)	Net sets	RWF present	Notes
Buck Pond	F 2005	6	Yes	Stocked in 2001-02
Bug Pond	S 2005	18	No	Stocked in 2006
Brandereth Lake	S 2004, D 2004	30	No	Last seen in 1969
Canachagala Lake	F 2005, S 2006	49	No	Introduced in 1902
Cat Pond	S 2004	15	Yes	Introduced in 1970's
Chapel Pond	S 2004, S 2006	37	No	Introduced in 1970's
Deer Pond	F 2004, S 2005	31	Yes	Stocked 2001
Eighth Lake, Fulton	F 2005, S 2006	27	No	Stocked in 2005
Evergreen Lake	S 2006	7	Yes	Stocked in 2000, 2002
First Bisby Lake	S 2003-05, F 2005	94	No	Last seen in 1956
Green Lake	F 2005	16	No	Introduced in 1902
Hoel Pond	S 2004, F 2004	81	No	Last seen in 2003
Honnedaga Lake	S 2004-06	87	No	Introduced in 1891
Limekiln Lake	S 2004	18	No	Last seen in 1959
Little Green Pond	S 2005	6	Yes	Stocked in 2004-05
Little Moose Lake	S and F 2003-2006	176	Yes	Endemic
Little Trout Pond	F 2005	6	Yes	Stocked in 2000
Lower Cascade Lake	S 2004-05, F 2004	11	Yes	Endemic
Moose Pond	S 2005	11	Yes	Endemic
Newcomb Lake	S 2005	11	Yes	Endemic
Panther Lake	S 2005	15	No	Introduced in 1902
Piseco Lake	F 2005	19	No	Last seen in 1932
Rock Pond (P807)	S 2005-06, F 2005	40	No	Introduced in 1897
Rock Pond (P424)	S 2006	9	Yes	Stocked in 2005
Second Bisby Lake	S 2003-05, F 2005	97	No	Last seen in 1973
Third Bisby Lake	S 2003, 2005, F 2005	51	No	Last seen before 1962
Trout Pond	F 2005	8	Yes	Stocked in 2000-01
West Canada Lake	S 2006	12	No	Last seen in 1979
Woodhull Lake	S 2003	30	No	Introduced in 1902
Upper Ausable Lake	S 2005	8	Yes	Endemic
Upper Cascade Lake	S 2005	3	Yes	Endemic

Table 4. Estimated population size for endemic round whitefish populations in New York waters. Population size was calculated from a relationship developed between round whitefish catch per unit effort and estimated population size from known stocking numbers.

Lake	Estimated population size (minimum-maximum)	
Cat Pond	461	(30-1,715)
Little Moose Lake	12,463	(2,419-73,264)
Lower Cascade Lake	2,451	(589-19,009)
Moose Pond	3,027	(539-17,116)
Newcomb Lake	9,727	(2,100-61,003)
Upper Ausable Lake	10,284	(2,907-77,603)
Upper Cascade Lake	2,442	(606-18,752)

Table 5. Adirondack lakes (*n*=77) included in modeling simulations. All lakes have historical records of containing round whitefish.

Lake	Pond #	Lake	Pond #
Big Moose Lake	P752	Lake Pleasant	P313
Big Tupper Lake	P109	Limekiln Lake	P826
Big Wolf Pond	P97	Little Clear Pond	P191
Bisby First	P977	Little Forked Lake	P279
Bisby Second	P976	Little Green Pond	P192
Bisby Third	P975	Little Moose Lake	P808
Blue Mountain Lake	P307	Little Tupper Lake	P120
Brandereth Lake	P277	Lower Cascade Lake	P270
Brantingham Lake	P689	Lower Saranac Lake	P104
Bug Pond	P789	Massawepie Lake	P369
Canachagala Lake	P838	Meacham Lake	P179A
Cat Pond	P139	Mirror Lake	P250
Chapel Pond	P274	Moose Pond	P221
Chazy Lake	P20	Newcomb Lake	P694
Clear Pond	P70	Panther Lake	P809
Crystal Lake	P595	Pico Pond	P832
Crystal Pond	P590	Piseco Lake	P234
Dart Lake	P750	Rainbow Lake	P66
Eagle Lake	P306	Raquette Lake	P293
Forked Lake	P276	Rock Pond	P807
Fulton Eighth	P790	Rondaxe Lake	P739
Fulton First	P782D	Round Pond	P687
Fulton Fourth	P782B	Sacandaga lake	P314
Fulton Second	?	Schroon Lake	P374
Fulton Seventh	P787	South Pond	P245
Fulton Sixth	?	Spitfire Lake	P264
Fulton Third	P782C	Stillwater Reservoir	P493
Gilman Lake	P281	Thirteenth Lake	P540
Green Lake	P812	Trout Lake	P293
Hoel Pond	P161	Upper Ausable Lake	P277
Honnedaga Lake	P877	Upper Cascade Lake	P271
Jones Pond	P123	Upper Chanteaugay Lake	P2
Lake Bonaparte	P24	Upper Saranac Lake	P114
Lake Champlain	P1	Upper St. Regis	P265
Lake Clear	P199	Utowana Lake	P304
Lake Colby	P106	West Canada Lake	P931
Lake George	P367	White Lake	P958
Lake Lila	P541	Woodhull Lake	P982
Lake Placid	P254		

Table 6. Adirondack lakes ranked based on their probability of supporting round whitefish populations, Pr(RWF). Ranks are based on the model predictions using the lowest recorded pH value for each lake and the best available data for fish community composition around round whitefish disappearance (for extirpated populations) or current community structure. Lakes with a Pr(rwf) greater than 0.5 are considered as suitable for supporting round whitefish populations.

Lake	County	Pond #	RWF history	Rank	Pr(RWF)
Bug Lake	Hamilton	P789	Present / Stocked	1	1.00
Upper Ausable Lake	Essex	P227	Present / Endemic	2	0.99
Chapel Pond	Essex	P274	Extirpated?	3	0.95
Upper Cascade Lake	Essex	P271	Present / Endemic	4	0.85
Cat Pond	Franklin	P139	Present / Stocked	5	0.84
Moose Pond	Essex	P221	Present / Endemic	6	0.80
Little Green Pond	Franklin	P192	Present / Stocked	7	0.62
Lower Cascade Lake	Essex	P270	Present / Endemic	8	0.54
Rock Pond	Herkimer	P807	Extirpated	9	0.52
Lake Colby	Franklin	P106	Extirpated	10	0.46
Newcomb Lake	Essex	P694	Present / Endemic	11	0.44
Little Clear Pond	Franklin	P191	Present / Immigrated	12	0.43
West Canada Lake	Hamilton	P931	Extirpated	13	0.22
Canachagala Lake	Herkimer	P838	Extirpated	14	0.29
Massawepie Lake	St. Lawrence	P369	Extirpated	15	0.24
Limekiln Lake	Hamilton	P826	Extirpated	16	0.20
Green Lake	Herkimer	P812	Extirpated	17	0.19
Utowana Lake	Hamilton	P304	Extirpated	18	0.13
Little Moose Lake	Herkimer	P808	Present / Endemic	19	0.06
First Bisby Lake	Herkimer	P977	Extirpated	20	0.02
Lake Clear	Franklin	P199	Extirpated	21	0.02
Third Bisby Lake	Herkimer	P975	Extirpated	22	0.02
Gilman Lake	Hamilton	P281	Extirpated	23	0.01
Pico Pond	Herkimer	P832	Extirpated	24	0.01
Honnedaga Lake	Herkimer	P877	Extirpated	25	0.01
Second Bisby Lake	Herkimer	P976	Extirpated	26	0.01
Rainbow Lake	Franklin	P66	Extirpated	27	<0.01
Mirror Lake	Essex	P250	Extirpated	28	<0.01
Stillwater Reservoir	Herkimer	P493	Extirpated	29	<0.01
Lake Rondaxe	Herkimer	P739	Extirpated	30	<0.01

Table 7. Adirondack lakes ranked based on their probability of supporting round whitefish populations, Pr(RWF). Ranks are based on the assumption that pH levels are now suitable for round whitefish (in practice, pH greater than 6.0, but for the model simulations we assumed that all lakes had a pH of 7.0). In other words, this list contains those lakes most likely to support round whitefish provided pH levels are currently suitable for round whitefish survival. An asterisk marks lakes that were predicted to not contain round whitefish (Pr(rwf) less than 0.5, see Table 6) using the historic low pH. In other words, if pH has improved, these lakes might now be considered candidates for reintroduction. Lakes marked with a † indicates lakes were low pH was the assigned cause for round whitefish extirpation.

Lake	County	Pond #	RWF history	Rank	Pr(RWF)
Rock Pond	Herkimer	P807	Extirpated	1	1.00
Green Lake*	Herkimer	P812	Extirpated	2	1.00
Pico Pond*	Herkimer	P832	Extirpated	3	1.00
Panther Lake*	Herkimer	P809	Extirpated	4	1.00
Canachagala Lake*†	Herkimer	P838	Extirpated	5	1.00
Chapel Pond	Essex	P274	Extirpated?	6	1.00
Upper Cascade Lake	Essex	P271	Present / Endemic	7	0.99
Upper Ausable Lake	Essex	P227	Present / Endemic	8	0.99
Cat Pond	Franklin	P139	Present / Stocked	9	0.99
West Canada Lake*†	Hamilton	P931	Extirpated	10	0.98
Honnedaga Lake*†	Herkimer	P877	Extirpated	11	0.98
Moose Pond	Essex	P221	Present / Endemic	12	0.98
Newcomb Lake*	Essex	P694	Present / Endemic	13	0.97
Bug Lake	Hamilton	P789	Present / Stocked	14	0.97
Limekiln Lake*	Hamilton	P826	Extirpated	15	0.96
Lower Cascade Lake	Essex	P270	Present / Endemic	16	0.95
Little Green Pond	Franklin	P192	Present / Stocked	17	0.89
Little Clear Pond*	Franklin	P191	Present / Immigrated	18	0.88
Massawepie Lake*	St. Lawrence	P369	Extirpated	19	0.87
Third Bisby Lake*	Herkimer	P975	Extirpated	20	0.75
First Bisby Lake*†	Herkimer	P977	Extirpated	21	0.74
Little Moose Lake*	Herkimer	P808	Present / Endemic	22	0.71
Second Bisby Lake*†	Herkimer	P976	Extirpated	23	0.71
Woodhull Lake*†	Herkimer	P982	Extirpated	24	0.70
Mirror Lake*	Essex	P250	Extirpated	25	0.60
Dart Lake*†	Herkimer	P750	Extirpated	26	0.57
South Pond*†	Hamilton	P245	Extirpated	27	0.55
Brandereth Lake*†	Hamilton	P277	Extirpated	28	0.55
Lake Lila	Hamilton	P541	Extirpated	29	0.36
Lake Clear	Franklin	P199	Extirpated	30	0.36
Gilman Lake	Hamilton	P281	Extirpated	31	0.33
Round Pond†	Hamilton	P687	Extirpated	32	0.26
Eagle Lake	Hamilton	P306	Extirpated	33	0.11
Lake Rondaxe†	Herkimer	P739	Extirpated	34	0.10
Utowana Lake	Hamilton	P304	Extirpated	35	0.10

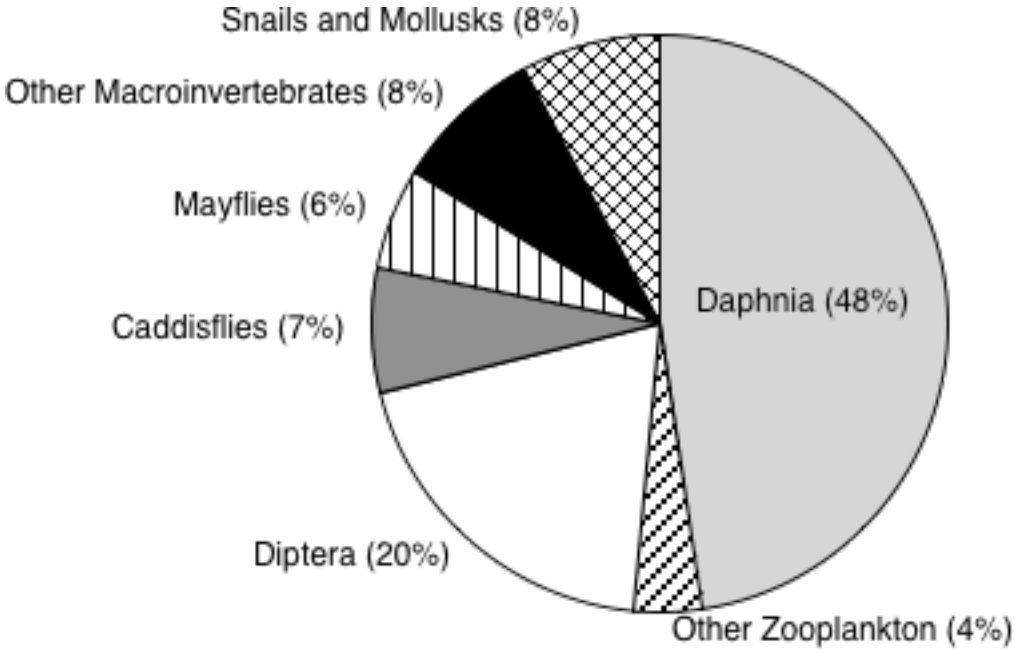

Figure 1. Diet composition (percent by weight) of all round whitefish (*N*=139, from 11 lakes) sampled in New York waters during 2004-2005.

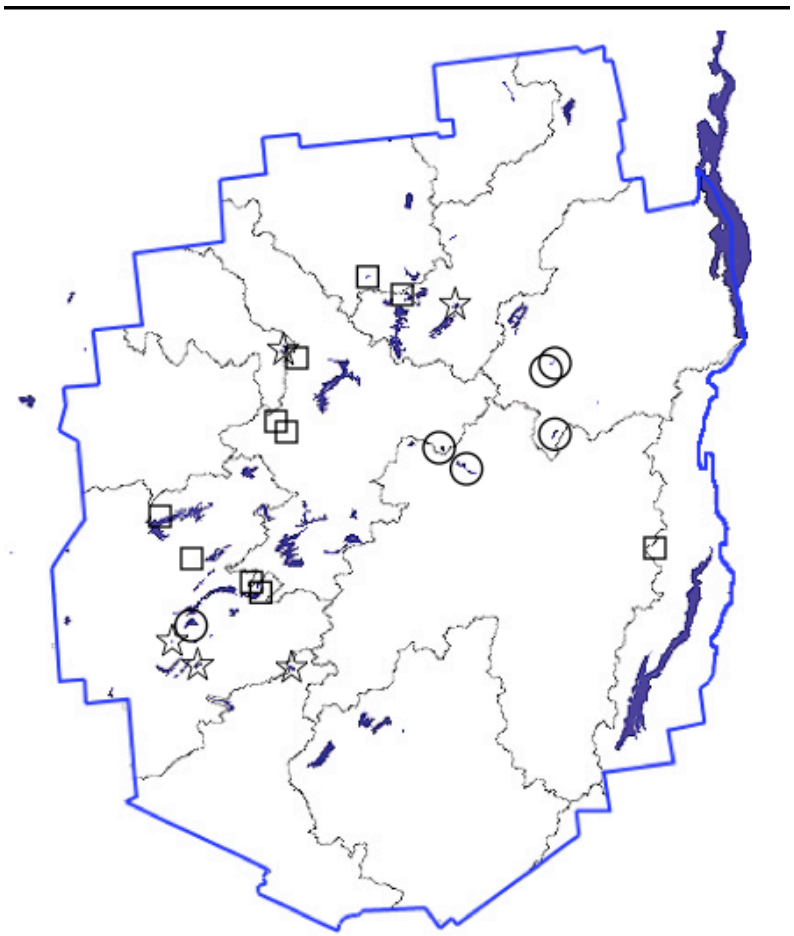

Figure 2. Map of historical and current round whitefish waters in New York. Circles mark the six remaining endemic populations; rectangles mark the ten recently introduced populations that are still present; stars indicate the top five candidates for reintroduction (based on the modeling results presented in Table 6). The thick outline indicates the Adirondack Park boundary and the thin black lines are watershed boundaries.

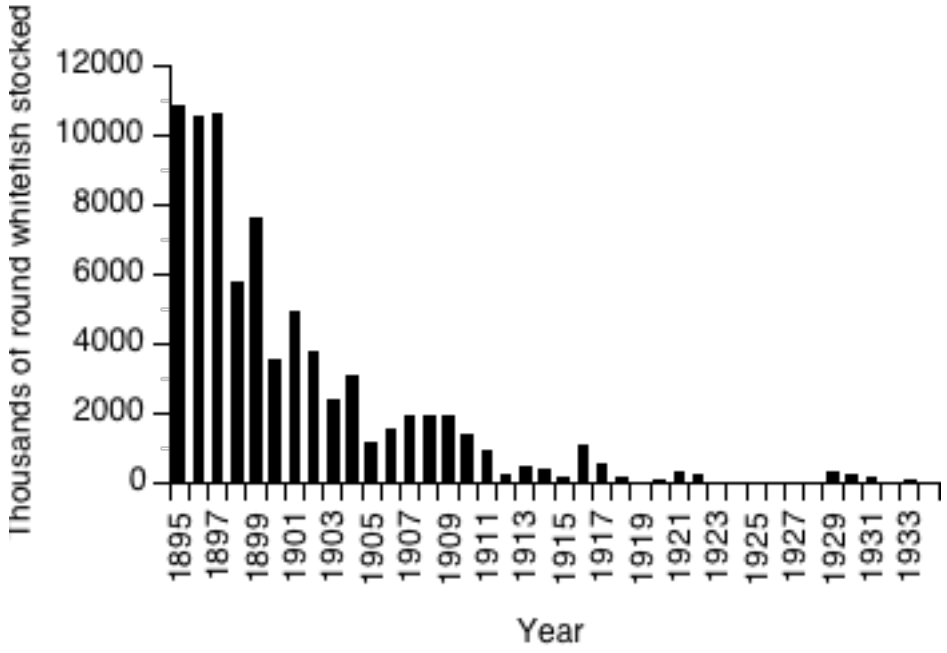

Figure 3. Number of round whitefish fry stocked in New York waters from 1895-1934.

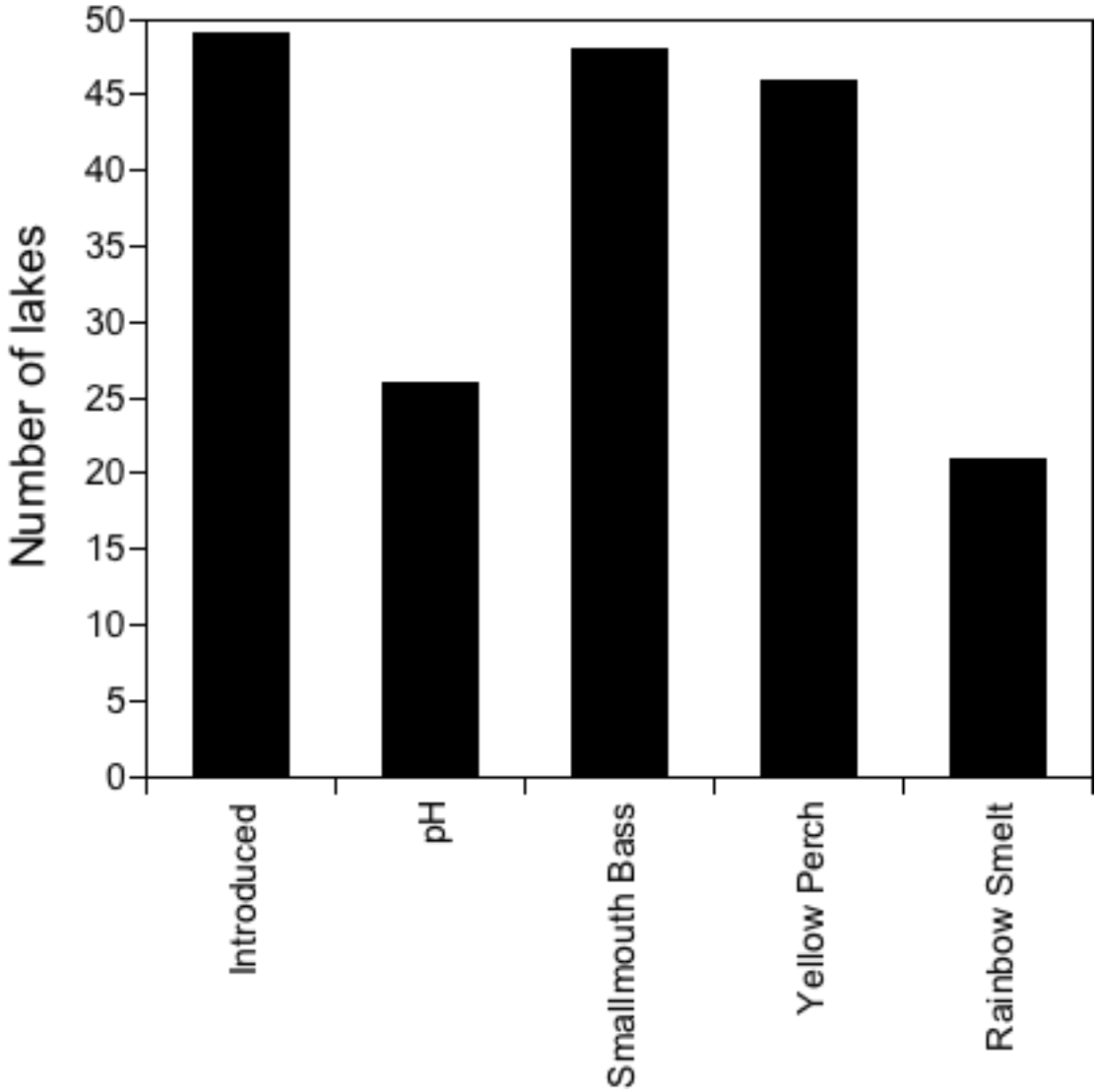

Figure 4. Number of lakes (*N*=75) possessing different impediments for the persistence of round whitefish in New York waters. Round whitefish were extirpated from each lake and each lake may have had more than one impediment.

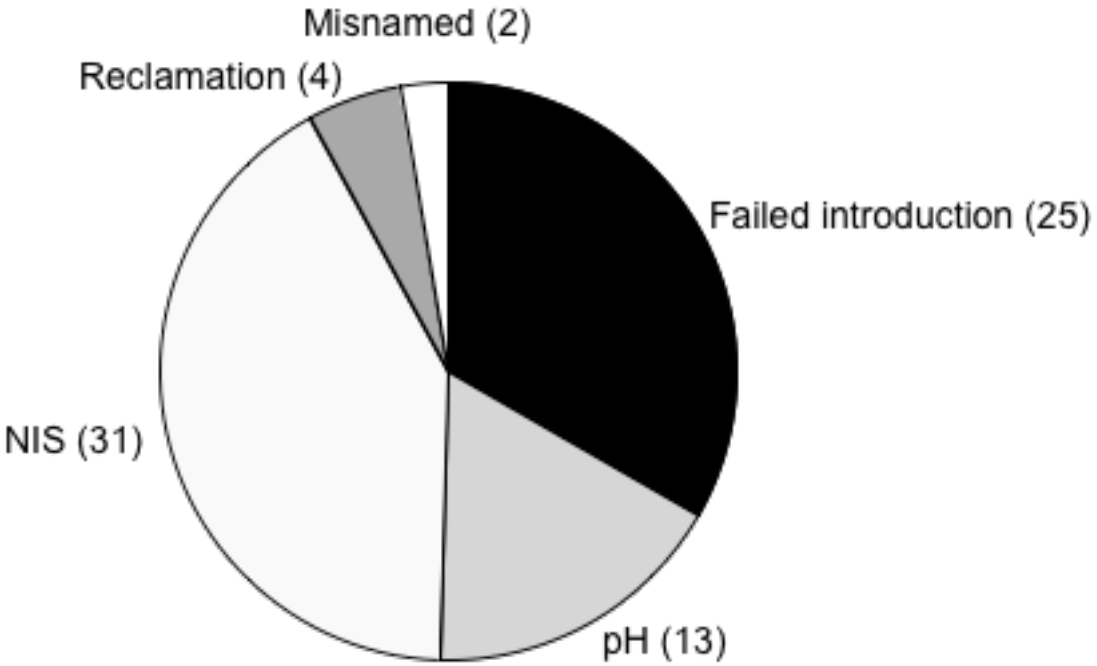

Figure 5. Presumed cause for the extirpation of round whitefish in New York lakes (*N*=75).

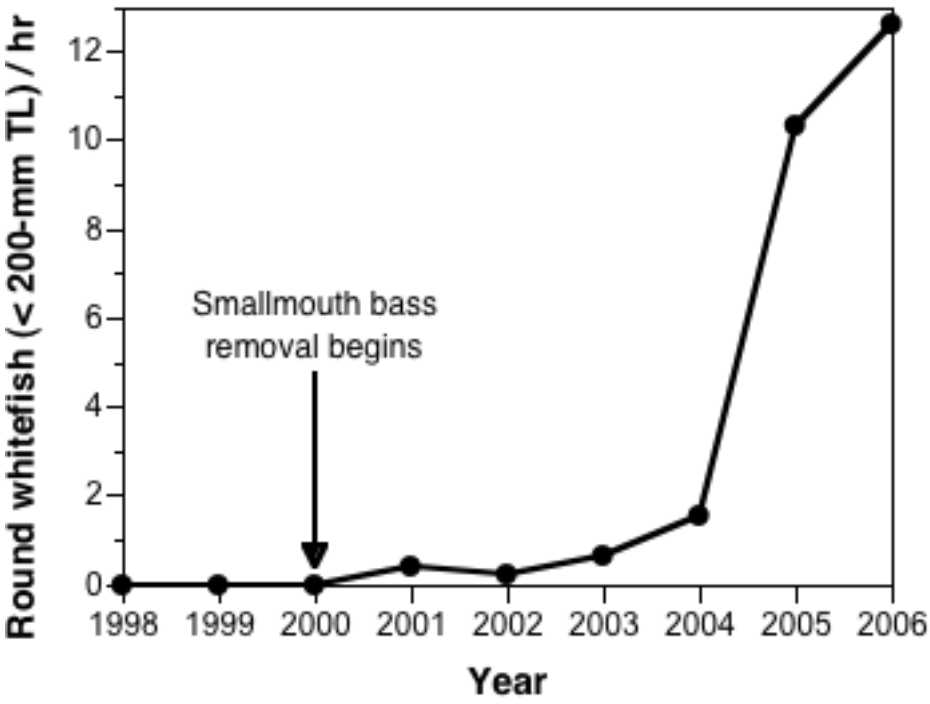

Figure 6. Catch of juvenile round whitefish per hour of spring nighttime boat electrofishing in Little Moose Lake, New York, during 1998-2006.

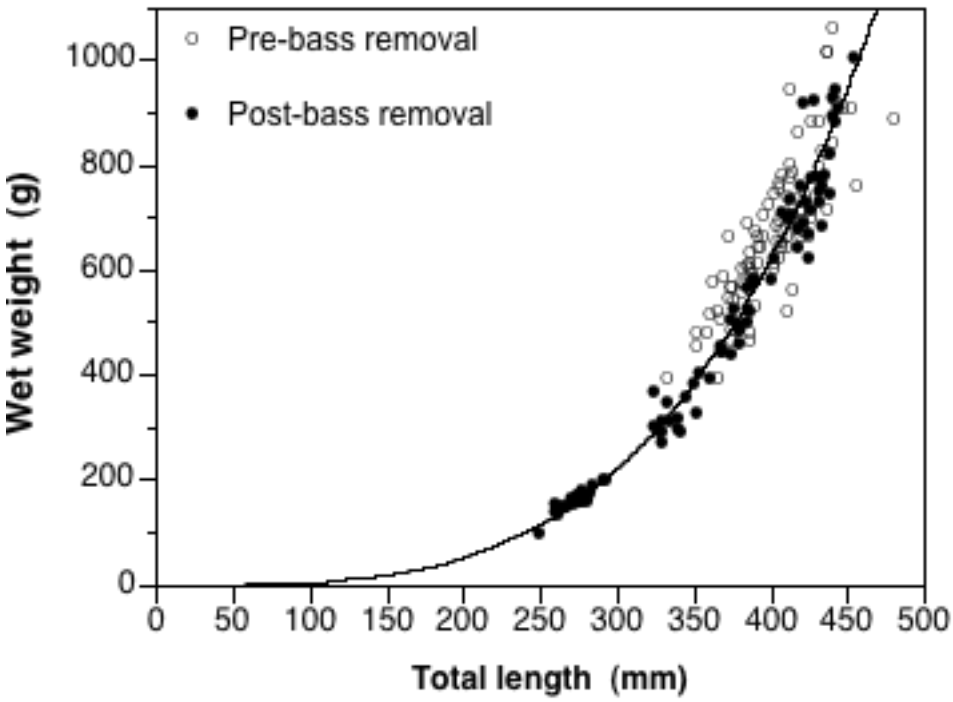

Figure 7. Length and weight of round whitefish captured in Little Moose Lake before and after the implementation of a smallmouth bass removal program. Round whitefish residual wet weight (a measure of condition, or plumpness) declined after the removal started (df=97, t=6.13, p<0.0001).

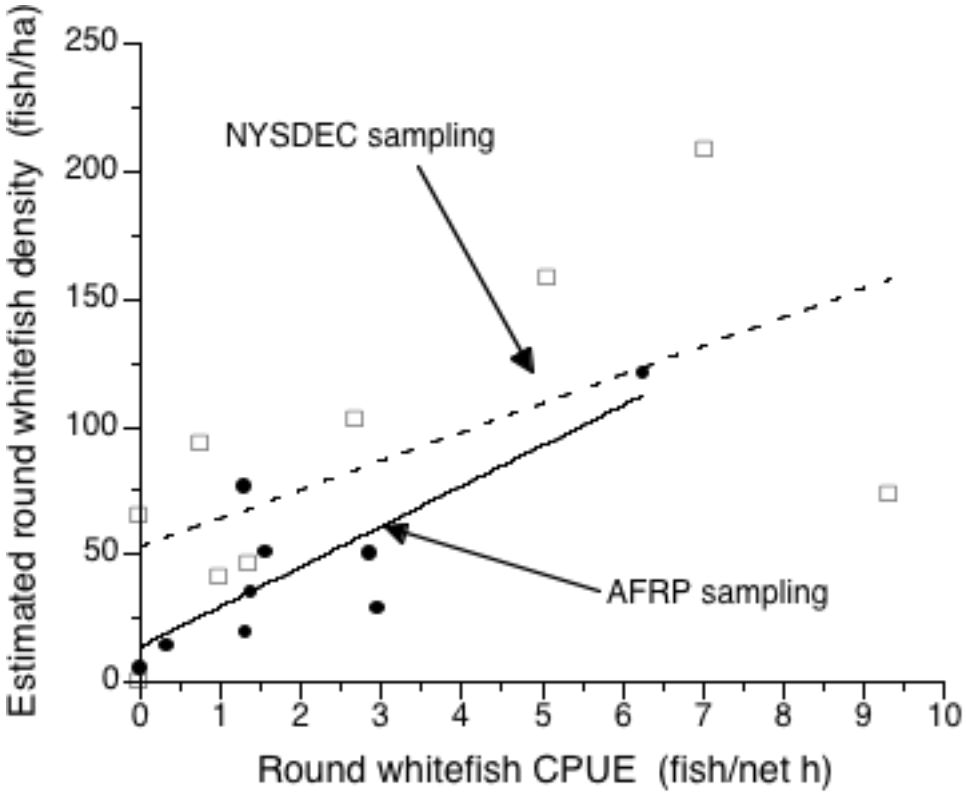

Figure 8. Relationship between catch per unit effort and estimated round whitefish density for lakes with known stocking densities. The AFRP sampling technique is described in the text and the regression equation is: round whitefish per ha = 14.764 × CPUE + 17.675 (r^2=0.64, df=8, F=12.26, p=0.01).

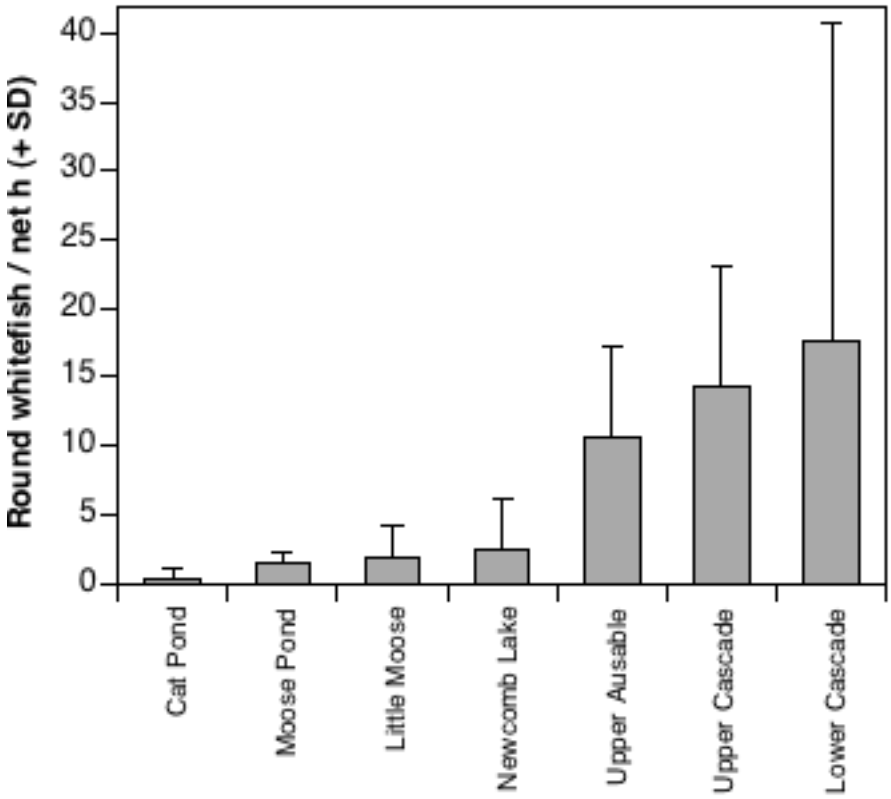

Figure 9. Round whitefish catch per unit effort for lakes with endemic populations in New York.

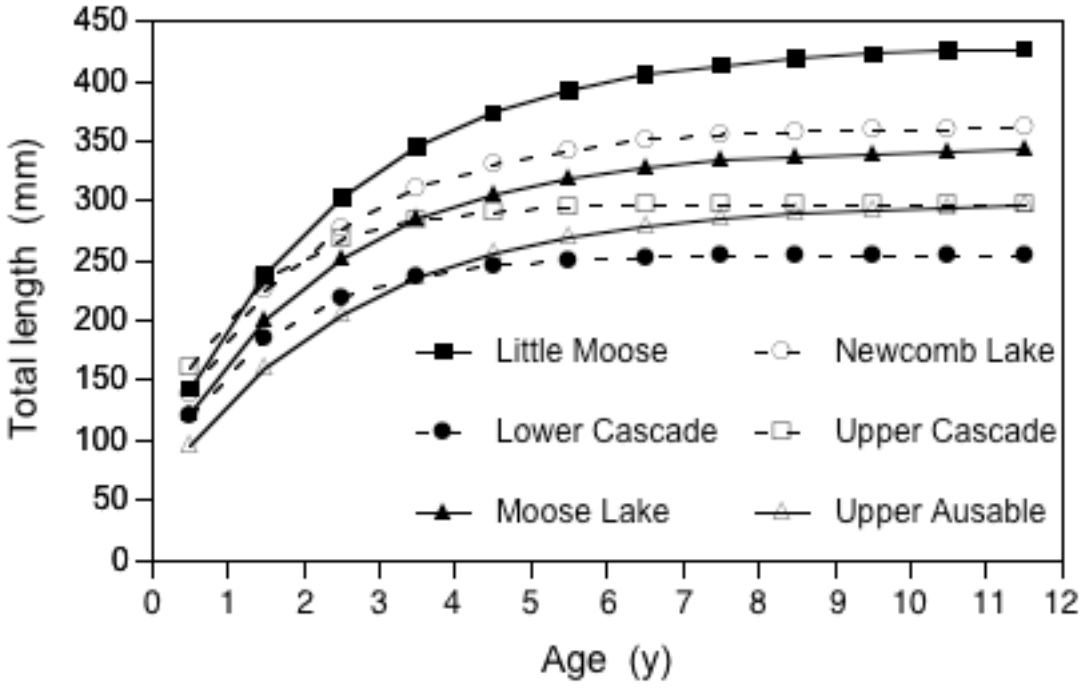

Figure 10. Estimated length at age for different endemic populations of round whitefish in New York. Length at age was estimated using the von Bertalanffy growth equation based on measured lengths and ages from scales or otoliths.

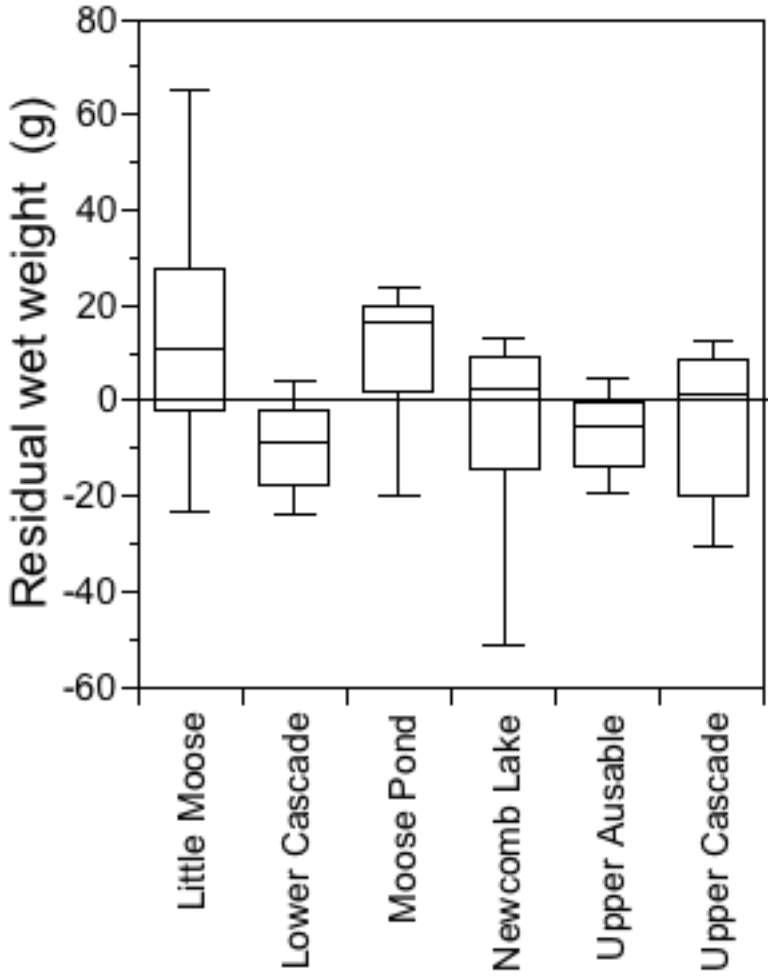

Figure 11. Residual wet weights of round whitefish from endemic populations in New York. Whiskers indicate the 10th and 90th percentiles, the box indicates the 25th and 75th percentiles, and the bar indicates the 50th percentile.

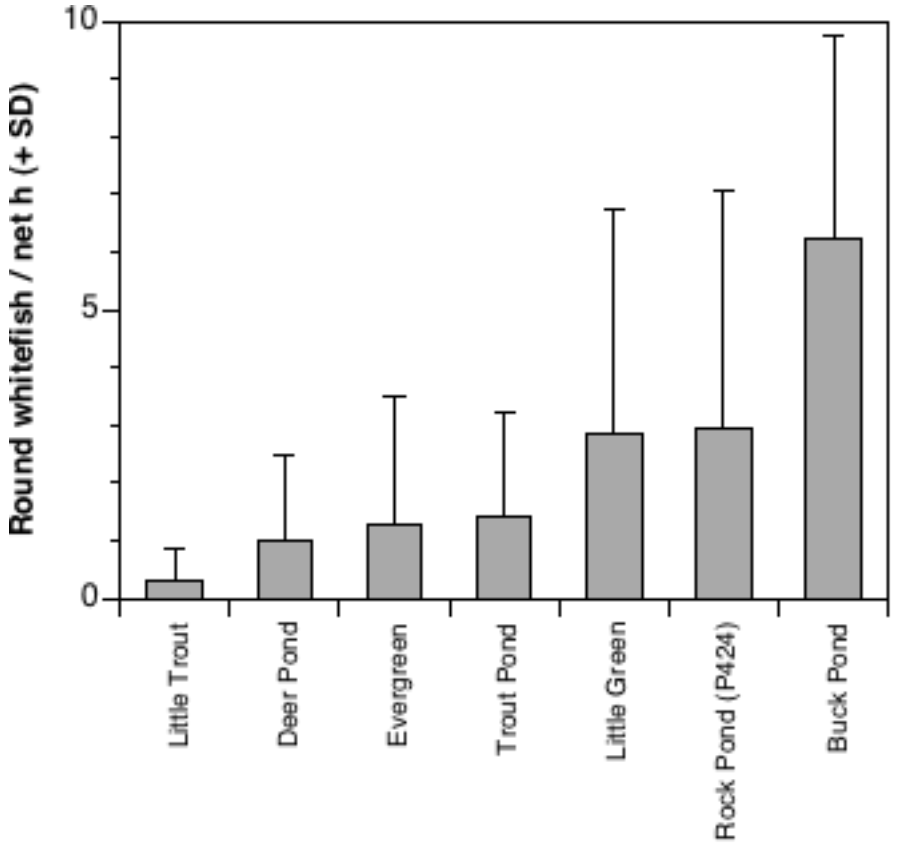

Figure 12. Round whitefish catch per unit effort for lakes with recently stocked populations in New York.

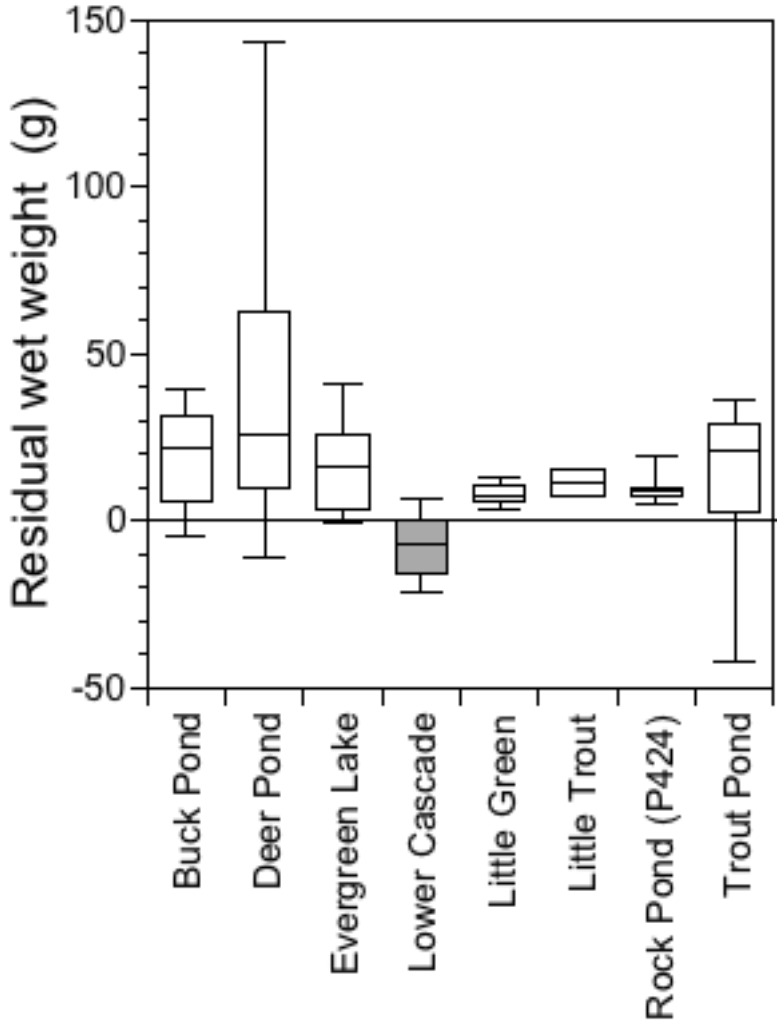

Figure 13. Residual wet weights of round whitefish from endemic populations in New York. For comparison, the broodstock source, Lower Cascade Lake, is shown in grey. Whiskers indicate the 10th and 90th percentiles, the box indicates the 25th and 75th percentiles, and the bar indicates the 50th percentile.

Appendix 1: Memorandum of Understanding

Adirondack Round Whitefish Investigation

Identify Causes for Historic Population Declines and Candidate Lakes for Restoration Efforts

Objectives

1) Identify the probable factors that have contributed to the decline of round whitefish in Adirondack lakes and throughout it's native range by completing:
    a. A thorough literature review of the species.
    b. Interviews with agency staff and university researchers, primarily from Maine, Quebec, and Ontario.
    c. A summary report that incorporates review comments by DEC staff.

2) Develop a field sampling protocol for various gear types (eg.g., trapnets, gillnets, electro-fishing) and conduct field surveys. Field surveys will be conducted on at least 25 lakes formerly known to support round whitefish populations; including all lakes that have received recent experimental stockings of round whitefish. Specific field measurements of physical, chemical, and biological parameters will be determined based upon the literature review and interviews. A summary report describing the sampling protocol, fish catch records and preliminary findings will be prepared.

3) Based on the results of objectives 1 and 2,
    a. Develop a framework for environmental conditions (biotic and abiotic) necessary to support round whitefish populations, and apply these criteria to Adirondack lakes, using available information from DEC and Adirondack Lakes Survey Corporation (ALSK) staff and databases:
    b. Develop a prioritized list of Adirondack lakes suitable for restoration of round whitefish through re-introduction (i.e., stocking). Lakes without prior record of round whitefish population may be considered for stocking to develop refugia populations.
    c. Assess the outcome of experimental stockings implemented within Adirondack waters stocked in 1999-2003.
    d. Provide details of the species life history that would likely be useful in implementing a recovery program, including: description of spawning habitat, sexual dimorphism (relevant to brood stock selection), growth rate (by gender), expected maximum age, variability in age at maturity, and other life history features relevant to egg-take, propagation and understanding the role of this species in the lake community.

Appendix 2: Notes on the round whitefish (*Prosopium cylindraceum*)

Prepared by Geoffrey B. Steinhart
Cornell University
6 December 2005

1. Systematic notes

Family: Salmonidae; Genus: *Prosopium*

Other *Prosopium* spp.
Prosopium abyssicola (Bear Lake whitefish)
Prosopium coulteri (Pygmy whitefish)
Prosopium gemmifer (Bonneville cisco)
Prosopium spilonotus (Bonneville whitefish)
Prosopium williamsoni (Mountain whitefish)

2. Physical description

Round whitefish have a slender, elongate, almost cylindrical in cross section, body. Average total length of individuals is 200-300 mm total length, with the largest reported individual reaching 564 mm and 2000 g. Gill rakers are generally shorter and more widely spaced than *Coregonus* spp., possibly making round whitefish inferior competitors for zooplankton prey (Sandercock 1964; Scott and Crossman 1998). Round whitefish are generally more colorful than other coregonids: silvery with a brown, bronze, or green tinge on the dorsal side (Scott and Crossman). Scales have a distinctive dark, pigmented border. During spawning, the fins acquire an orange hue. Tubercles, or pearl glands, develop prior to spawning. There is typically one tubercle per scale for five rows above and below the lateral line. Tubercles are more pronounced on males than females, but are not a tell tale sign of sex. Young round whitefish have two or more rows of latitudinal black spots and larger red or purple tinged "parr" marks along the side. Complete physical descriptions of round whitefish are provided in (Becker 1983; Normandeau 1963; Scott and Crossman 1998). Descriptions of larval round whitefish, with drawings, can be found in Faber (1970), Normandeau (1963), and Shestakov (1991).

3. Geographical distribution

Round whitefish are widely distributed in North America and Russia (Becker 1983; Scott and Crossman 1998). In the United States round whitefish are found in Alaska, Maine, New Hampshire, Connecticut, Vermont, and New York. In addition, round whitefish are present in all Great Lakes except Lake Erie. Round whitefish are present in Labrador, Quebec, Ontario, Manitoba, Alberta, Saskatchewan, British Columbia, Northwest Territories, and Nunavut. There is a discontinuity in round whitefish distributions in Canada with few populations found from northern Ontario to northern Manitoba. The disjoint distribution of round whitefish in North America could be indicative of two morphological types. The northwestern populations tend to have higher mean gill raker counts than the eastern populations (McPhail and Lindsey 1970). In

Asia, round whitefish are found predominantly in Arctic drainages in the northeast and the Kamchatka Penninsula, but some populations are found west to the Yensei River, Siberia (Becker 1983; Hale 1981; Scott and Crossman 1998).

4. Physical tolerances and preferences

Depth

Round whitefish inhabit a wide range of depths depending on season, age, and other species present. In general, round whitefish are considered a demersal species (Merrick et al. 1992; Sandercock 1964). Round whitefish spawn in shallow water during the late fall. At this time, the may be found in depths of only a few cm, with the most common spawning depths between 15-60 cm (Normandeau 1963; Normandeau 1969). In other studies, round whitefish have been found spawning as deep as 15 m (Neth 1955; Scott and Crossman 1998). Because they typically spawn in very shallow water, incubating round whitefish eggs may be especially susceptible to lake drawdown, which may expose offspring to desiccation, currents, increased predation, or other harsh conditions, as was reported for Bonneville cisco (Bouwes and Luecke 1997).

Young-of-the-year (YOY) round whitefish start their lives in shallow water. Catching YOY round whitefish has proven difficult, so it is unknown what depths they occupy after leaving the spawning areas. Age-1 round whitefish were caught near the bottom in depths from 9-27 m in Lake Superior (Bailey 1963). Adult round whitefish have been frequently been reported in depths up to 45 m in large lakes (Scott and Crossman 1998), but with the majority of fish caught shallower than 10 m or deeper than 26 m in Great Slave Lake (Rawson 1951). A single individual was captured at 218 m in Lake Superior (Scott and Crossman 1998). In lakes smaller than the Great Lakes and Great Slave Lake, round whitefish have been reported in depths up to 25 m (Sandercock 1964). Round whitefish tend to inhabit a shallower depth range than sympatric with lake whitefish (Sandercock 1964).

Temperature

Little information on temperature preferences is available, except for spawning temperatures (Section 7). In Moosehead Lake, Maine, the maximum temperature where round whitefish were observed was 17.5°C (Hale 1981). On the North Slope of Alaska, round whitefish were found in 3-16°C waters, but the maximum available temperatures were not reported (Hale 1981).

Dissolved Oxygen

Little information is published on oxygen tolerances for round whitefish, but they have been captured in waters with oxygen concentrations as low as 2.6 ppm and 49% saturation (Hale 1981).

Salinity

Round whitefish are generally tolerant of high salinities. In fact, some round whitefish populations in James Bay, Quebec, migrate from freshwater to estuaries as juveniles, only to return to freshwater to spawn (Jessop and Power 1973; Mackay and Power 1968; Morin et al. 1982).

pH and Aluminum

There is no information published on pH tolerances or aluminum toxicity for the round whitefish. Below are some of the findings from other whitefish species of the genus *Coregonus*. In general, low pH can affect fertilization, embryonic development, maturity, and survival (Keinänen et al. 1998; Keinänen et al. 2003; Rask et al. 1992; Vuorinen et al. 2004a; Vuorinen et al. 2004b). Physiologically, pH and AL can act in concert to disrupt ion regulation (Vuorinen et al. 2004a; Vuorinen et al. 2004b). In addition, low pH can cause behavioral differences, such as sluggishness and slow growth (Vuorinen et al. 2004a).

In laboratory studies, fertilization and embryonic development of *C. lavaretus* was impaired when pH droped below 5.5 or when AL exceeded 250 μg/L (Keinänen et al. 2003). Fertilization rates were below 50% when pH was less than 5.0 or AL exceeded 250 μg/L and no fertilization was seen at pH 4.0. Embryonic mortality increased when pH dropped below 5.5 and all embryos died at pH 4.5. Deformed offspring were seen at pH values below 5.5. Keinanen et al. (2003) noted that *C. l. pallasi* were more acid tolerant than *C. l. lavaretus*, but provided no details.

Experimental stocking of six acidified lakes (pH range 4.1-6.4; AL range 18-387 μg/L) with *C, pallasi* resulted in three failed introductions (lakes with pH less than 5.0 and AL greater than 50 μg/L; Rask et al. 1992). Surprisingly, introduced whitefish survived in a lake with pH 4.3-4.9 and 159 μg/L AL; however, these fish showed signs of acid stress and the lake was previously fishless (i.e., no competition or predation). Rask et al. (1992) did not determine if any introduced populations successfully reproduced. In highly acid lakes whitefish growth is often retarded (Raitaniemi et al. 1999).

Vuorinen et al. (2004b) describe the response of whitefish (*C. l. pallasi*) when an acidified lake was divided and one side limed. After treatment, the limed side ranged from pH 6.3-8.3, while the acidic side ranged from 5.4-5.6. Growth was more rapid on the limed side, probably due to decreased stress and better ion regulation (Vuorinen et al. 2004b). On the limed side, 80% of males were ready to spawn (no data on females), but on the acidic side, only 20% of males and no females were ready to spawn. In addition, a survey of Finnish lakes found that whitefish growth was more rapid when pH exceeded 5.5 and ovulation was delayed at pH of 5.75 and inhibited at pH of 4.75 (Vuorinen et al. 2004b). There were no apparent negative effects of liming on the whitefish. In subsequent work, these authors reported that in pH 4.5-5.2 male whitefish have a low frequency of maturity (54%) and some females (18%) had degenerated or resorbed oocytes (Vuorinen et al. 2004a).

Aluminum levels greater than 50 μg/L, in the presence of pH values below 5, are considered toxic to *Coregonus* spp (Rask et al. 1992).

UV Radiation

In laboratory studies of embryonic and larval whitefish (*C. lavaretus*) and vendace (*C. albula*), a 34% increase in UV-B levels caused a 30% increase in melanin pigment, but with no effect on survival (Häkkinen et al. 2002).

Toxicants

There is little information on how various toxic chemicals influence whitefish. Contamination levels in Saginaw Bay, Lake Michigan, were ten times lower in round whitefish tissue than in Chinook salmon for PCB's, PBB's, DDT, MeHg, and dieldrin (Miller and Jude 1984). While several consumption advisories are in place for whitefish in the Great Lakes, at least their contaminant levels were lower than in piscivorous salmonids. Work on lake whitefish

in Lake Simcoe found that PCB, DDT, MeHg, and dieldrin levels were low enough to be of no concern (Evans et al. 1988).

Climate Change

Eutrophication can have negative effects for whitefish populations. Increased algal productivity can result in oxygen depletion that limits cool water refugia during warm summers and can suffocate eggs and embryos (Evans et al. 1988). In addition, if certain algal species become abundant (e.g., *Cladophora*), they can interfere with egg deposition by suffocating eggs and preventing the eggs from falling into crevices that protect the eggs from predation (Evans et al. 1988). The potential effects of climate warming have received little attention, but it has been suggested that warm springs may result in earlier zooplankton blooms that, in turn, may increase growth and survival of larval whitefish (Gerdeaux 2004).

5. Age and growth

Because of their wide distribution, resulting in dramatically different growth conditions, round whitefish growth rates are highly variable across their range (Table 1). The highest reported length at age was for Little Moose Lake, New York (ages 0-3 y), Lake Michigan (ages 3-8 y), Great Bear Lake, NWT (age 9 y), and the Chara River, Russia (ages 10-14 y). In general, the growth was higher in southern populations (e.g., Little Moose Lake, Newfound Lake, and Lake Michigan) than in more northern populations (e.g., Quebec). Latitude seems more important than whether the population is riverine or lacustrine. Another trend from these data are that individuals from more northern populations appear to have a longer lifespan than those from southern systems (Table 1).

Length weight relationships also vary across systems (Figure 1). Round whitefish from Great Slave Lake, Chara River, Russia, and the Kokasoak River, Quebec, were clearly heavier for their length, while individuals from the Apostle Islands, Lake Superior, were the lightest. A number of round whitefish populations fell between these extremes, near the Little Moose Lake population, but are not shown on the graph.

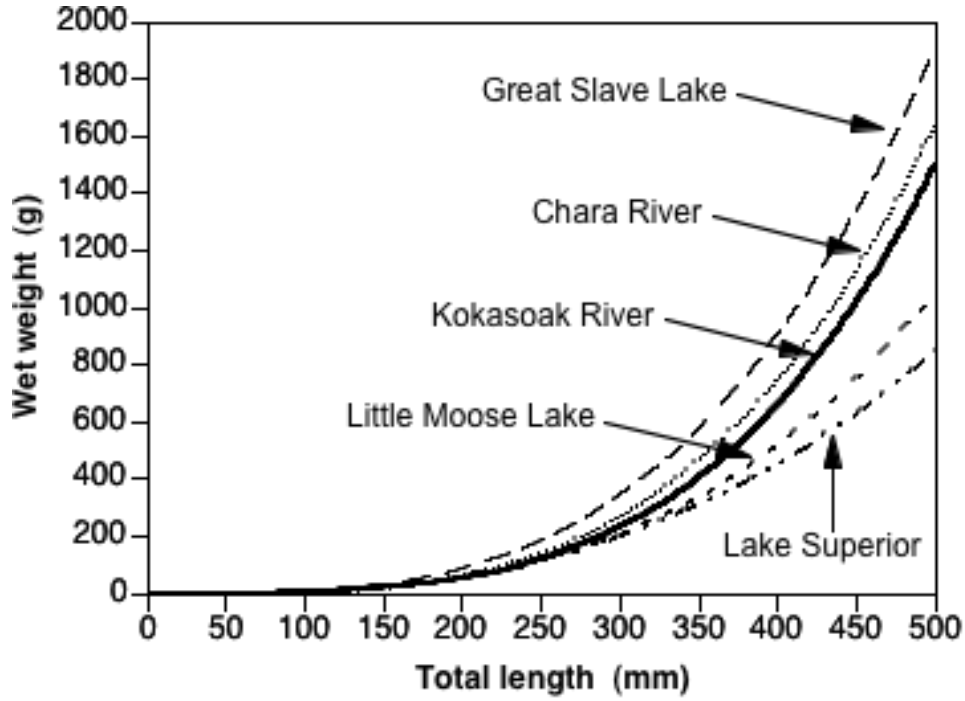

Figure 1. Length weight relationship for five round whitefish populations around the world.

Parameters for the total length (mm, TL) to wet weight (g, W) relationships for various round whitefish populations is shown below. Equations are of the form $W = aTL^b$. Because most studies used different units or measured fork length, the equations were calculated using corrected data. For the purpose of comparing data from other sources, the conversion from fork length to total length for round whitefish is:

$$\text{total length} = 0.05 + 1.085 \times \text{fork length}$$

Site	*a*	*b*	Reference
Chara River, Russia	7.000×10^{-7}	3.473	(Zyus'ko et al. 1993)
George River, Quebec	9.378×10^{-6}	2.966	(Mackay and Power 1968)
Great Slave Lake, NWT	1.542×10^{-6}	3.371	(Rawson 1951)
Koksoak River, Quebec	1.707×10^{-7}	3.684	(Mackay and Power 1968)
Lake Michigan, Ludington	3.016×10^{-6}	3.163	(Armstrong et al. 1977)
Lake Michigan, Sturgeon Bay	1.265×10^{-6}	3.294	(Mraz 1964)
Lake Superior, Apostle Islands	3.265×10^{-5}	2.749	(Bailey 1963)
Lake Superior, Isle Royal	2.477×10^{-6}	3.197	(Bailey 1963)
Little Moose Lake, New York	3.332×10^{-6}	3.152	(Neth 1959)
Paxson Lake, Alaska	2.593×10^{-6}	3.184	(Peck 1964)
Summit Lake, Alaska	1.503×10^{-6}	3.276	(Peck 1964)

6. Maturity

Round whitefish typically become mature when they are 4-6 years old, but age of maturation can be highly variable. In general, southern populations mature at a younger age than northern populations. In Lake Michigan, round whitefish may mature as early as age 2 and all are mature by age 4 (Armstrong et al. 1977; Mraz 1964). A little further north, in lake Superior, round whitefish mature at age 3, one year later than in Lake Michigan (Bailey 1963). In northern Quebec, round whitefish first mature at age 4, with all fish mature by age 6 (Jessop and Power 1973; Mackay and Power 1968). In two Alaskan lakes, round whitefish do not become mature until at least age 4 and some do not mature until age 8 (Peck 1964). Despite the age differences, southern populations mature at a larger size than northern population owing to their higher growth rates. In Lake Michigan, round whitefish mature at 380-400 mm (Armstrong et al. 1977; Mraz 1964), while in northern Quebec, they mature at 240-250 mm (Jessop and Power 1973; Mackay and Power 1968). In lake whitefish (*C. clupeaformis*), populations with high early growth rates have lower age at maturity than populations with slow early growth rates (Beauchamp et al. 2004).

Once mature, round whitefish were presumed to spawn every year (Hale 1981). Several studies, however, suggest that individuals may skip some years (Jessop and Power 1973; Zyus'ko et al. 1993). In Little Moose Lake, New York, round whitefish might not spawn every year and only 68% of lake whitefish spawned in consecutive years (Neth 1955; Neth 1959).

Table 1. Mean total length (mm) of round whitefish by age (y) from various locations throughout their range. Numbers in bold indicate the largest size across sites for a particular age.

Site	Mean total length (mm) of round whitefish by age (y)															Reference
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Beau Lake, Maine			201	226	267	279	297	305	335	356	373					(Basley 2001)
Chara River, Russia				270	306	349	384	407	443	449	**462**	**482**	**505**	**526**	**564**	(Zyus'ko et al. 1993)
George River, Quebec			127	163	220	242	267	283	307	369	377					(Mackay and Power 1968)
Great Bear Lake, NWT						357	368	384	401	**459**						(Kennedy 1949)
Koksoak River, Quebec			165	190	218	240	262	289	319	331	347	382	402			(Mackay and Power 1968)
La Grande River, Quebec		76	138	188	229	262	288	310	327	341	353	362	370			(Morin et al. 1982)
Lake Michigan, Ludington		139	255	**346**	**396**	**436**	**460**	**481**								(Armstrong et al. 1977)
Lake Michigan, Sturgeon Bay		117	229	312	361	399	447	475	**500**							(Mraz 1964)
Lake Superior, Apostle Islands		109	180	229	272	305	330	356	381	394						(Bailey 1963)
Lake Superior, Isle Royal				211	264	312	348	356	381	404	406	452				(Bailey 1963)
Leaf River, Quebec	44	101	147	204	228	259	292	305	327	337	362	365	371	384	406	(Jessop and Power 1973)
Little Moose Lake, New York	**169**	**263**	**308**	331	348	353	362									(Neth 1959)
Moosehead Lake, Maine				259	274	292	312	312	363	376						(Carlander 1696)
Newfound Lake, New Hampshire		189	257	307	354	367	389	407	415	412						(Normandeau 1969)
Paxson Lake, Alaska		118	162	202	225	263	290	318	332	354	370	383	367			(Peck 1964)
Summit Lake, Alaska	58	106	153	204	224	264	305	332	347	361	375	393				(Peck 1964)

7. Reproduction

Round whitefish typically spawn in October through December, depending on latitude and water temperature (Bryan and Kato 1975; Neth 1955; Neth 1959; Normandeau 1963; Normandeau 1969; Zyus'ko et al. 1993). Reported spawning temperatures range from nearly 0°C (Rybnaya River, Russia, Hale 1981), 1-2°C (Aishihik Lake, Yukon Territory, Bryan and Kato 1975), 2.5°C (Chara River, Russia, Zyus'ko et al. 1993) to 4.5°C (Lake Superior, Scott and Crossman 1998). Spawning occurs after lake trout and before (Neth 1955; Neth 1959) or after (Bryan and Kato 1975) lake whitefish spawning. Males arrive on the spawning grounds before females (Normandeau 1963; Normandeau 1969). Prior to spawning, males and females develop breeding tubercles, or pear organs, on their lateral scales (Bryan and Kato 1975; Normandeau 1963; Zyus'ko et al. 1993). The tubercles are more pronounced in males. Large fish turn pale orange to red on their belly and fins (Normandeau 1963; Zyus'ko et al. 1993).

Spawning often occurs at night (Bryan and Kato 1975). Round whitefish are broadcast spawners and their eggs have no adhesion (Bryan and Kato 1975; Zyus'ko et al. 1993). They often spawn in groups (Bryan and Kato 1975) or pairs (Normandeau 1963; Normandeau 1969). There is no feeding during spawning (Normandeau 1963; Normandeau 1969).

Spawning substrate is almost always gravel or rubble and must be clean (Hale 1981; Normandeau 1963; Normandeau 1969; Scott and Crossman 1998). Spawning often occurs in shallow water, but has been reported as deep as 15 m (Scott and Crossman 1998). Bryan and Kato (1975) reported round whitefish spawning on gravel 2-50 mm in diameter in shallow (0.7 to 2.5 m), fast water (31 to 63 cm/s). In the Chara River, Russia, round whitefish spawned at depths of 1.0 to 1.5-m deep over large and small pebbles (Zyus'ko et al. 1993). In lakes, round whitefish often spawn on shallow reefs on gravel, rubble, and sometimes sand (Normandeau 1963; Normandeau 1969). These reefs or shallow areas are often exposed to wind (Normandeau 1963; Normandeau 1969). There is no evidence that round whitefish favor areas with high ground water discharge. Spawning round whitefish sometimes use the same spawning areas as lake trout (Normandeau 1963; Normandeau 1969). In some lakes, round whitefish spawn in the same areas as lake whitefish (Neth 1959), but in other systems, lake whitefish may spawn over vegetation or silt, which round whitefish avoid (Bryan and Kato 1975). *C. lavaretus*, when stocked into new waters, do not spawn when introduced into "small" lakes (Raitaniemi et al. 1999).

Some round whitefish migrate to spawn (Hale 1981; Normandeau 1963; Normandeau 1969). In James Bay, Quebec, there are anadromous populations of round whitefish that spawn in freshwater streams (Jessop and Power 1973; Mackay and Power 1968; Morin et al. 1982). In the Chara River, Russia, some round whitefish migrate into smaller streams to spawn while others remain in the main branch (Zyus'ko et al. 1993). In Aishihik Lake, Yukon Territory, round whitefish spawned in both the lake and the river outlet (Bryan and Kato 1975).

8. Habitat

Little information is available on habitat use by round whitefish, except for depth distribution (Section 4) and spawning habitat (Section 7). It has been reported that juvenile round whitefish use the same habitats as adults, only shallower (Hale 1981). The use of shallower waters may be to exploit warmer water temperatures (Peck 1964). In streams, round whitefish are generally

found in rivers with gradients greater than 0.5 m/km and currents range from 24 to 274 cm/sec (Hale 1981). However, the critical velocity for round whitefish (mean 30.4 cm fork length) was only 42.5 cm/sec (Hale 1981). Round whitefish prefer low turbidity waters (Hale 1981).

9. Fecundity

Reported fecundities for round whitefish range from 2,200-9,445 eggs per individual (ages 3-8) in Newfound Lake, New Hampshire (Normandeau 1963) and 1,076-11,888 (ages 3-9) eggs per round whitefish in Lake Superior, with an average of 5,330 eggs per fish and 12 eggs per gram of wet weight (Bailey 1963). Fully developed round whitefish eggs are approximately 2.4-2.9 mm when released and they swell to at least 4 mm in water (Normandeau 1963; Zyus'ko et al. 1993). Morin et al. (1982) reported that anadromous round whitefish in eastern James Bay, Quebec, appeared to be "K-selected:" their fecundity was lower and egg size larger than sympatric cisco and lake whitefish.

10. Behavior

Other than the behaviors discussed in other sections, the most interesting behavior was noted in Newfound Lake, New Hampshire. In this lake, round whitefish moved into the tributaries after ice-out. The fish remained in the streams for only a few weeks to feed on insect larvae (Normandeau 1963).

11. Diet

Round whitefish are best described as opportunistic feeders. They consume mainly zooplankton and benthic invertebrates (Armstrong et al. 1977; Normandeau 1963; Rawson 1951; Sandercock 1964). Among the benthic invertebrates consumed are: caddisflies (Normandeau 1963; Rawson 1951; Sandercock 1964; Zyus'ko et al. 1993), mayflies (Sandercock 1964; Zyus'ko et al. 1993), chironomids (Armstrong et al. 1977; Merrick et al. 1992; Normandeau 1963; Rawson 1951; Sandercock 1964; Zyus'ko et al. 1993), chaoborus (Normandeau 1963), craneflies and blackflies (Zyus'ko et al. 1993). Molluscs and gastropods are sometimes consumed in large numbers by certain inviduals, but rarely make up a significant portion of the diet at the population level (Armstrong et al. 1977; Sandercock 1964) with the exception of in Toolik Lake (Merrick et al. 1992) and Great Slave Lake (Armstrong et al. 1977). Some round whitefish occasionally consume some terrestrial insects (Normandeau 1963).

Many people believe that round whitefish may consume significant numbers of fish eggs. Some studies conducted during the fall, when whitefish and some other salmonids spawn, confirm this notion (Neth 1955; Normandeau 1963). Other studies, however, found few or no fish eggs in round whitefish diets (Armstrong et al. 1977; Nester and Poe 1984; Zyus'ko et al. 1993). Overall, it appears the round whitefish will consume eggs when presented with the opportunity, but that they do not actively seek eggs at times distant from their own spawning. Large whitefish sometimes become piscivorous; for example, nearly all Bonneville whitefish (*P. spilonotus*) greater than 300-mm consumed other fish (Tolentino and Thompson 2004).

Round whitefish diet selection does vary in the presence of other species. Sandercock (1963) reported that in the absence of lake whitefish, round whitefish consumed mostly zooplankton.

But when lake and round whitefish were sympatric, round whitefish consumed predominantly benthic invertebrates (see Section 12).

Zooplankton can make up a significant portion of round whitefish diets (Normandeau 1963) and zooplankton abundance during early life is important for whitefish survival. In lab experiments, zooplankton densities below 20 individuals/l resulted in larval whitefish (*C. zugensis*) mortality that was 20-60% higher than when zooplankton densities exceeded 20 individuals/l (Rellstab et al. 2004).

12. Ecological interactions

Egg predators

Round whitefish have been observed consuming conspecific eggs (Neth 1955; Normandeau 1963). In Lake Huron, longnose suckers consumed many lake whitefish eggs (Nester and Poe 1984) and presumably would eat round whitefish eggs when possible. White suckers and bullhead ate round whitefish eggs in Little Moose Lake, New York (Neth 1959). Martin and Fry (1973) reported that no round whitefish eggs were ever found in smallmouth bass diets in Lake Opeongo. For Bonneville cisco fewer than 4% of the spawned eggs survived 30 d, with the majority of egg losses attributed to predation by sculpins (Bouwes and Luecke 1997). Normandeau (1963) noted that some round whitefish eggs were likely lost to a combination of predators, suffocation, and fungal infection.

Predators

There have been few confirmed reports of predation on round whitefish. In Newfound Lake, New Hampshire, a single round whitefish was found in the stomach of a chain pickerel in and two of four Atlantic salmon (*Salmo salar*) captured contained 200 and 25 round whitefish fry (Normandeau 1963). Normandeau (1963) also suggested that yellow perch and cisco may be important predators on round whitefish, but failed to find evidence of predation. Smelt (*Osmerus mordax*) have been implicated in recruitment failures of lake whitefish in Twelve Mile Lake, Ontario (Loftus and Hulsman 1986). Models suggested that smelt could consume 100% of the larval lake whitefish produced in any given year. Likewise, in Lake Simcoe, rainbow smelt appeared to have a negative impact on lake whitefish recruitment (Evans et al. 1988). In Europe, perch (*P. fluviatilis*) have been implicated in the decline of vendace (*C. albula*; Bohn and Amundsen 2004).

Competition

Round whitefish may compete for food, and possibly other resources, with other whitefish species. In Ontario lakes, round whitefish ate more zooplankton and grew faster in the absence of lake whitefish than when the species were found in sympatry (Sandercock 1964). It was hypothesized that lake whitefish gill morphology conferred an advantage in foraging on zooplankton. In large lakes (greater than 5 mi^2), both species were able to coexist; however in small lakes (less than 0.5 mi^2) only one of the two species was found (Sandercock 1964). In Lake Simcoe, competition among lake whitefish led to slower growth when their population was small than when they were abundant (Evans et al. 1988). In Little Moose Lake, New York, it was hypothesized that both intra and interspecific competition with lake whitefish may have been retarding round whitefish growth (Neth 1955; Neth 1959). A mass removal of both whitefish species suggested that subsequent growth did indeed increase. High densities of

whitefish (*C. lavaretus*) experienced reduced growth due to intraspecific competition in Finland (Raitaniemi et al. 1999). Round whitefish and lake whitefish spawn in the same areas in Little Moose Lake (Neth 1955; Neth 1959) but because they are both broadcast spawners, there is no competition for spawning sites. In fact, it could be argued that having more eggs present may dilute the effects of predation.

Whitefish also may compete for food with other species. Whitefish (*C. lavaretus*) in Finland grew slower when zooplanktivorous roach (*Rutilus rutilus*), smelt (*O. eperlanus*), or vendace (*C. albula*) were abundant than when their densities were low (Bohn and Amundsen 2004; Raitaniemi et al. 1999). A biomanipulation that removed many roach increased whitefish growth. In Paxson Lake, Alaska, growth of round whitefish was lower than nearby Summit Lake, possibly due to competition with either sockeye salmon (*Oncorhynchus nerka*) or lake whitefish (Peck 1964).

13. Methods of capture

Most studies reported catching round whitefish using variable mesh gill nets set horizontally on the lake bottom. The most commonly cited mesh sizes that caught many round whitefish ranged from 1.5 to 3.0-in stretch mesh (Armstrong et al. 1977; Bailey 1963; Jessop and Power 1973; Mackay and Power 1968; Normandeau 1969; Peck 1964; Rawson 1951; Sandercock 1964). Vertical gill nets caught few round whitefish in Algonquin Park, Ontario (Sandercock 1964). Normandeau (1963) tried various sampling techniques for round whitefish. Fyke nets, pound nets, otter trawls, seines, dip nets were largely ineffective. Trap nets were successful in Newfound Lake, but only when round whitefish were congregating to spawn and relied on prior knowledge of where fish were spawning (Normandeau 1963). In Little Moose Lake, where the location of spawning aggregations was well known, trap nets were effective during spawning (Neth 1955; Neth 1959). Normandeau (1969) concluded that gill nets were the best sampling technique for capturing round whitefish.

Many researchers have had difficulty catching YOY round whitefish. In known spawning areas of Lake Huron, swimming surveys, seines, and towed nets did not catch any YOY round whitefish, although they did catch many YOY lake whitefish (Faber 1970). In Alaskan lakes, beach seines caught age 1, 2, and 3 individuals, but no YOY we captured (Peck 1964). Beach seines and rotenone successfully caught round whitefish, including YOY, in rivers of Ungava, Quebec (Jessop and Power 1973; Mackay and Power 1968).

14. Known parasites

The only reported parasites from round whitefish in the Adirondacks were *Acanthocephala* and *Schistocephalus* in Chazy Lake (State of New York 1930). In lakes of Algonquin Park, Ontario, Canada, Sandercock (1964) reported finding round whitefish infested with *Crepidostomum farionus*, *C. cooperi*, and *Prtocephalus bruei*. In Great Slave Lake, Northwest Territories, Canada, two round whitefish were found with cysts of the tapeworm *Triaenopherus crassus*. Round whitefish in Newfound Lake, New Hampshire, were parasitized by *Azygia sebago* (Normandeau 1963).

Appendix 3: Log of discussions with researchers outside of New York

D. Bruce Stewart (stewart4@mts.net)
Last contacted February 2007.
Head of Arctic Biological Consultants. Contacted me about round whitefish research. He mentioned that in Manitoba, round whitefish eat more benthic prey when they live with lake whitefish and they eat more zooplankton when lake whitefish are absent. He is trying to secure some genetic samples from round whitefish in northern Canada.

Tom Langen (tlangen@clarkson.edu)
Last contacted January 2007
Associate Professor at Clarkson University. Provided data, with Michael Twiss, on the benthic communities and temperature and oxygen profiles in Upper and Lower Cascade Lakes.

Jud Kratzer (Jud.Kratzer@state.vt.us)
Last contacted December 2006
Fish and Wildlife Scientist for the Vermont Fish and Wildlife Department. Provided tissue samples for genetic analysis for round whitefish from Lake Wiloughby. Did not have much data on current status of round whitefish in Vermont, but is willing to share data in the future.

Benjamin Nugent (Benjamin.nugent@wildlife.state.nh.us)
Matt Carpenter (matt.carpenter@wildlife.state.nh.us)
Last contact December 2006
Fisheries biologists for New Hampshire Fish and Game. Recently started working on species of concern in NH, including round whitefish. They sampled Newfound Lake did his work) in fall 2005. They caught only 5 round whitefish (3 females, 2 males, mean length=432 mm and weight = 840g). One fish had a tumor. Provided tissue samples from round whitefish caught in Newfound Lake.

Wendylee Stott (wstott@usgs.gov)
Last contacted December 2006
Fishery Biologist For the USGS Great Lakes Science Center. Provided advice and suggested primers for round whitefish genetic analyses.

Nicholas Mandrak (mandrakn@dfo-mpo.gc.ca)
Last contacted August 2006
Research Scientist with Canada's Department of Fisheries and Oceans. Provided a detailed database of fish presence/absence and abiotic factors for nearly 300 lakes in or near Algonquin Park. These data were used for the modeling described in this report.

Julian Olden (olden@wisc.edu)
Last contacted April 2006
Post-doctoral researcher at the University of Wisconsin-Madison. Has worked extensively with the data provided by Dr. Mandrak. Identified some errors in the data set, provided his own data and discussed modeling strategies.

John Viar (jviar@nhfgd.org)
Contacted December 2004.
Fisheries biologist for New Hampshire Fish and Game. He said NH has little data on round whitefish. Anecdotally, it appears that whitefish abundance may be negatively correlated with smelt abundance. Historical NH RWF lakes are 1st Connecticut Lake, Lake Winnepasaki, and Newfound Lake.

Nigel Lester (nigel.lester@mnr.gov.on.ca)
Contacted July 2005
Fisheries biologist with OMNR. Provided a dataset of Ontario lakes with various biotic and abiotic parameters. Dataset will be used to predict round whitefish distribution.

Mark Ridgway (mark.ridgway@mnr.gov.on.ca)
Last contact October 2005
Fisheries biologist with OMNR. Upon request, can provide age and growth data for round whitefish in Lake Opeongo. Did not know of any recent research on round whitefish in Ontario.

Mark Ebener (mebener@lighthouse.net)
Contacted June 2005
Fisheries biologist with Chippewa-Ottawa Resource Authority (MI). Provided RWF samples from Lake Huron and Lake Michigan for genetic analysis.

Paul Ripple (prippleh2o@yahoo.com)
Contacted June 2005
Fisheries biologist with Bay Mills (MI), now a teacher at Bay Mills Community College. Provided RWF samples from Lake Superior for genetic analysis.

Julie Turgeon (Julie.Turgeon@bio.ulaval.ca)
Contacted June 2005
Geneticist at University of Laval. Knowledgeable about genetic techniques and whitefish genetics. Willing to provide samples from Lake Nipigon, possibly elsewhere, and to advise on genetic analyses.

David Basely (david.basely@maine.gov)
Last contact January 2006.
Research biologist for Maine Department of Inland Fisheries and Wildlife. Provided an update that there are now 65 RWF lakes (up from 56) and said that Maine is more concerned about lake whitefish than RWF.

Merry Gallagher (merry.gallagher@maine.gov)
Contacted February 2005
Research biologist for Maine Department of Inland Fisheries and Wildlife. Database biologist who provided me with a list of Maine round whitefish lakes (and presence absence of smallmouth bass).

Appendix 4: Draft recovery plan for round whitefish, *Prosopium cylindraceum*, in New York

Summary

Round whitefish (*Prosopium cylindraceum*), also called frost fish, once were found in over 80 lakes in New York. But, most round whitefish populations have been extirpated. By 1979 they were found in fewer than 15 lakes and by 2006, there were only six known endemic populations. The New York State Department of Environmental Conservation (NYSDEC) classified round whitefish as endangered in 1983. The dramatic decline in round whitefish abundance and their listing eventually resulted in the actions of: 1) introducing round whitefish into nine new waters from 1999-2006 and 2) a research study into the status and potential recovery of round whitefish. The research study was a collaborative effort between NYSDEC and Cornell University and was completed in 2006, with the products including a scientific report and this recovery plan.

Herein, we outline the goals and objectives for round whitefish recovery in New York that includes establishing and maintaining at least 10 naturally reproducing populations, with sufficient genetic diversity, in protected waters. Because there are already six endemic populations, this plan suggests establishing four additional reproducing populations in various watersheds. While there are an additional nine recently stocked waters, evidence for natural reproduction following stocking is still lacking.

Background

From 1895-1918, over 75 million of round whitefish fry were stocked into various New York waters. Widespread stocking suggests that many extirpated populations may have been the result of failed introductions (we estimated that 25 of 75 populations examined were likely failed introductions). Other potential causes for the decline in round whitefish were low pH (13 lakes), non-indigenous species (31 lakes, due primarily to introduced smallmouth bass, yellow perch, and rainbow smelt), reclaimed waters (4 lakes), and misidentification or confusion about names (2 lakes). Round whitefish were extirpated from all lakes experiencing low pH (< 5.5). While some round whitefish populations were able to cope with non-indigenous species, the appearance of smallmouth bass, rainbow smelt, and yellow perch often accompanied a decline or disappearance of round whitefish (e.g., Lake Lila). Extensive research in Little Moose Lake has shown an increase in juvenile round whitefish abundance following the start of a smallmouth bass removal program.

Renewed artificial propagation efforts were planned in 1979, 1990, and 1994, but the plans were unable to be realized until stocking efforts began in 1999. The protocol for egg take was developed in 1999 and fingerlings were reared and stocked in 2000. Optimum size at stocking was expected to be larger, but rearing beyond mid-May was not possible at Oneida Hatchery and the resultant size of 30cm was sufficient. Annual production has been limited by choosing to take eggs from only about 50 females and this has resulted in fingerling production ranging from 2,000-18,800. These stocking efforts from 2000-2006 have been directed at nine new Adirondack waters (Table 1). In addition, round whitefish have naturally emigrated from Little Green Pond to Little Clear Lake. Unfortunately, there has been no observed natural reproduction by any of the introduced populations.

In an effort to reduce the strain on the Lower Cascade Lake population and to secure that stock in a refuge, Little Green Pond was reclaimed and stocked for three years to establish a broodstock water using progeny from Lower Cascade Lake. In fall 2006, an effort was made to

collect round whitefish gametes, but there were not a sufficient number of mature fish as they were only 2-years old. In addition, expanding the source of progeny has been explored including disease testing of round whitefish from Little Moose Lake, another endemic population. Disease testing from 2004 and 2005 found no evidence of diseases or pathogens, including bacterial kidney disease, whirling disease, and testing in 2006 found no evidence of viral hemoragic septasemia. In fact, no diseases or pathogens were found in round whitefish samples from various lakes collected during 1998-2006.

Recovery Plan

Goal

To secure and maintain at least 10 naturally reproducing round whitefish populations in New York waters. These populations must preserve genetic diversity and be established in lakes that are relatively secure from invading fish species and should be in several different watersheds. When this has been achieved, the species will be recommended for down listing to Threatened. After 10 naturally reproducing populations persist for a 15-year period, they can be down listed to Special Concern. For delisting from Special Concern, it is recommended that New York have 15 round whitefish populations that are stable for 20 years,

Objectives

1) Establish at least four additional naturally reproducing round whitefish populations by 2016.
2) Ensure that introduced and endemic populations are reproducing by monitoring the success of introduced populations. Success will be determined through gill net sampling 5-7 years after the first stocking.
3) Determine genetic variability in the remaining endemic round whitefish populations to determine if additional sources for broodstock are required.
4) Monitor chemistry and other biotic factor to assure habitats are not degraded. It might be determined that habitat restoration might be needed; for example, liming.

Implementation

Round whitefish will be introduced into new waters using primarily brookstock from Little Green Pond. Should there be significant differences in the genotypes of the various endemic populations, however, it will be increasingly important to diversify the source populations for stocking. Other potential sources of round whitefish broodstock include Lower Cascade Lake or Little Moose Lake.

The choice of candidate waters involves many variables. A good round whitefish lake should consistently have pH levels exceeding 6.0. In addition, candidate waters should not contain smallmouth bass, yellow perch, or rainbow smelt and the lakes should have some security from their invasion or introduction. That is, the lakes could be on remote or private land, or have existing or new barriers to migrating non-indigenous species.

In addition to the waters where round whitefish have recently been stocked, we believe the current top candidate waters include West Canada Lake, Massawepie Lake, and Brandereth Lake Table 2). These lakes were chosen based on modeling results that predicted the probability of round whitefish presence (Table 2) and their relative security from introduced species. That is, some of these lakes are private or remote, thus decreasing the probability of smallmouth bass, yellow perch, or rainbow smelt introductions. Massawepie Lake does contain smallmouth bass,

but it also has lake whitefish, suggesting that smallmouth bass densities may not be too high to limit whitefish populations. By introducing round whitefish into Massawepie Lake, we also will gain some insight into the generality that smallmouth bass are incompatible with round whitefish. Stocking into Eighth Lake, Fulton Chain, is recommended both as a follow up to the 2005 stocking (Table 1) and as another test of whether round whitefish introductions into diverse fish communities can be successful (Eighth Lake contains lake trout, brook trout, rainbow trout, Atlantic salmon, white sucker, brown bullhead, rock bass, yellow perch, and some smallmouth bass). In addition, stocking is suggested in Bug Lake (to follow the 2006 introduction) and Little Green Pond may need some restocking to augment the population (Table 2). The desire to achieve some degree of restoration to each of the 7 watersheds where this species formerly occurred is achieved with this plan (Table 3) for all but the Oswegatchie watershed.

There are many other high-ranking lakes, many of them on the Adirondack League Club (Table 3; see the Steinhart et. al report on the Status and recovery of round whitefish). Other candidate waters may arise due to reclamation efforts or once they are evaluated with the following model:

$$\text{Log odds ratio of round whitefish} = 0.505 - 0.233\times\log(\text{SA:D}) - 0.015\times\text{GDD} + 3.873\times\text{pH} - 2.344\times\text{WWP}$$

where SA:D is the surface area (km2) divided by maximum depth (m), GDD is the growing degree days (cumulative from 5°C), and WWP is the number of different warm water predator species in the lake (*Micropterus* spp., yellow perch, rainbow smelt, *Sander* spp., *Esox* spp.). The probability of round whitefish presence should exceed 0.5 to be considered a candidate, and is calculated as follows:

$$\text{probability of round whitefish} = \exp(\text{Log odds ratio}) / (1 + \exp(\text{Log odds ratio}))$$

Based on our evaluation technique and observation from other introductions, we suggest a stocking density of at least 50 fish ha^{-1} (20 fish $acre^{-1}$). This density should result in density that could reasonably be detected using gill nets and is similar to other recent stocking efforts. The proposed stocking densities take into account future evaluation, but also are scaled down as needed to be realistic about egg take numbers (Table 3).

We believe that of the past introductions, Bug Lake and Rock Pond are the two most likely populations to become naturally reproducing. The other water might not contain suitable rocky spawning habitat. If these two waters establish naturally reproducing populations, even if no other past introductions become established, it means that only two more must be successful to meet our management objective. This goal could be from those already stocked (Table 1) or from West Canada Lake, Brandereth Lake or Massawepie Lake.

Evaluation

Evaluation should take place in 2011 and 2016. We have yet to observe any successful reproduction of introduced round whitefish, but given their maturity schedules (most mature at age 3), it is premature to say that none of the introduced populations will reproduce. In addition, on going stocking efforts will need to be evaluated. Sampling in 2011 should target introduced populations in Trout Pond, Little Trout Pond, Buck Pond, Deer Pond, Evergreen Lake, Rock Pond, and Bug Lake. Sampling could be less intensive than recent efforts and should take no

more than 7-14 field days (1-2 days per lake, see below). If round whitefish are reproducing in these waters, there should be at least several year classes and at least two generations in each of these lakes. In 2016, any of the previously mentioned waters may be sampled. In addition, we would expect at least to see signs of natural reproduction in both Brandereth Lake and West Canada Lake. This effort would be of a larger scale and might also examine the finer details of successful spawning and measure water chemistry at various locations and depths.

Evaluating the success of round whitefish introduction should use techniques comparable to past research to provide suitable comparisons. Specifically, assessment should use 60 min sets of sinking monofilament gill nets (1.5-in stretch mesh, six joined 8 by 50-ft panels, purchased from Redden Net; www.redden-net.com), set perpendicular to shore in randomly selected 500-ft stretches of shoreline. Sampling should occur in spring or fall while water temperatures are below 13˚C. It is recommended 8-15 net sets be made in each lake. But, before the final decision that round whitefish are not present, there should be at least 15 net sets of 60 min. and 3 nets set overnight. Although past efforts have been successful at finding round whitefish in large lakes, if a lake is over 200 acres sampling effort should consist of 30 sets before a final determination is reached. Length, weight, scale, and fin samples should be collected from all fish. Any fish that die in the nets should be saved for otolith extraction. Scales, fin rays, and/or otoliths can be used to determine the age of captured fish.

Table 1. Recent stocking history of New York waters receiving round whitefish. Parenthetical values indicate NYSDEC pond numbers and watershed codes. All fingerlings were progeny of round whitefish captured in Lower Cascade Lake.

Lake	Years stocked (number of fingerlings)
Trout Pond (P146 SL)	2000 (6,250)
	2001 (1,200)
Little Trout (P145 SL)	2000 (3,750)
Buck Pond (P540 B)	2001 (1,600)
	2002 (1,600)
Deer Pond (P372 R)	1999 (<30 adults)
	2001 (1,600)
Evergreen Lake (P500 B)	2000 (7,500)
	2002 (2,000)
Lower Cascade Lake (P270 Ch)	2002 (2,330)
Little Green Pond (P192 Ch)	2004 (2,000)
	2005 (1,600)
	2006 (1,000)
Rock Pond (P424 UH)	2005 (1,000)
	2006 (1,300)
Eighth Lake, Fulton Chain (P790 B)	2005 (1,000)
Bug Lake (P789 B)	2006 (1,700)

Table 2. Proposed broodstock and stocking activities for the recovery of round whitefish in New York during 2008-2012.

Year	Lakes	Number of fingerlings stocked	Estimated number of eggs required	Estimated number of females required
2008	Bug Lake	2,000	21,000	100
	West Canada Lake	6,000		
2009	Brandereth Lake	14,000	37,000	175
2010	Little Green Pond	1,500	37,000	175
	West Canada Lake	6,000		
	Eighth Lake, Fulton Chain	6,500		
2011	Brandereth Lake	14,000	37,000	175
2012	Massawepie Lake	14,000	37,000	175

Table 3. Adirondack lakes ranked based on their probability of supporting round whitefish populations, Pr(RWF). Ranks are based on the assumption that pH levels are now suitable for round whitefish (assuming all lakes had a pH of 7.0). Lakes that once contained introduced populations are marked with an asterisk (i.e., there are historical records of stocking and the round whitefish may not have been endemic). Codes for watersheds are B=Black, Ch=Champlain, SL=St. Lawrence, M=Mohawk, UH=Upper Hudson and R=Raquette.

Lake	County	Pond #	WS	RWF history	Rank	Pr(RWF)
Rock Pond*	Herkimer	P807	Bl	Extirpated	1	1.00
Green Lake*	Herkimer	P812	Bl	Extirpated	2	1.00
Pico Pond*	Herkimer	P832	Bl	Extirpated	3	1.00
Panther Lake*	Herkimer	P809	Bl	Extirpated	4	1.00
Canachagala Lake*	Herkimer	P838	Bl	Extirpated	5	1.00
Chapel Pond*	Essex	P274	Ch	Extirpated?	6	1.00
Upper Cascade Lake	Essex	P271	Ch	Present / Endemic	7	0.99
Upper Ausable Lake	Essex	P227	Ch	Present / Endemic	8	0.99
Cat Pond*	Franklin	P139	SL	Present / Stocked	9	0.99
West Canada Lake	Hamilton	P931	M	Extirpated	10	0.98
Honnedaga Lake*	Herkimer	P877	Bl	Extirpated	11	0.98
Moose Pond	Essex	P221	UH	Present / Endemic	12	0.98
Newcomb Lake	Essex	P694	UH	Present / Endemic	13	0.97
Bug Lake	Hamilton	P789	Bl	Present / Stocked	14	0.97
Limekiln Lake	Hamilton	P826	Bl	Extirpated	15	0.96
Lower Cascade Lake	Essex	P270	Ch	Present / Endemic	16	0.95
Little Green Pond	Franklin	P192	Ch	Present / Stocked	17	0.89
Little Clear Pond	Franklin	P191	Ch	Present / Immigrated	18	0.88
Massawepie Lake	St. Lawrence	P369	SL	Extirpated	19	0.87
Third Bisby Lake*	Herkimer	P975	Bl	Extirpated	20	0.75
First Bisby Lake*	Herkimer	P977	Bl	Extirpated	21	0.74
Little Moose Lake	Herkimer	P808	Bl	Present / Endemic	22	0.71
Second Bisby Lake*	Herkimer	P976	Bl	Extirpated	23	0.71
Woodhull Lake*	Herkimer	P982	Bl	Extirpated	24	0.70
Mirror Lake	Essex	P250	Ch	Extirpated	25	0.60
Dart Lake	Herkimer	P750	Bl	Extirpated	26	0.57
South Pond	Hamilton	P245	R	Extirpated	27	0.55
Brandereth Lake	Hamilton	P277	R	Extirpated	28	0.55