Fisheries and Oceans Canada | Pêches et Océans Canada
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Canadian Science Advisory Secretariat
Gulf Region | Science Response 2019/040

REVIEW OF ELEMENTS OF PROPONENT APPLICATION TO USE ROTENONE FOR THE PURPOSE OF ERADICATING SMALLMOUTH BASS (*MICROPTERUS DOLOMIEU*) FROM MIRAMICHI LAKE, NEW BRUNSWICK

Context

Smallmouth Bass (*Micropterus dolomieu*), a non-native fish species to New Brunswick, was confirmed in 2008 as introduced and established in Miramichi Lake, a headwater lake of the Southwest Miramichi River, of the southern Gulf of St. Lawrence (DFO 2009). A risk assessment concluded that there is a high likelihood of widespread establishment of Smallmouth Bass in the Southwest Miramichi River and in the Gulf Region rivers in general (DFO 2009). Physical barriers were considered to be the most effective immediate measure for containing the spread of Smallmouth Bass out of Miramichi Lake and this was actioned beginning in 2009 (Biron 2018). Control measures included intensive fishing in Miramichi Lake to remove adult and juvenile stages of Smallmouth Bass, which reduced the abundance of Smallmouth Bass but did not eradicate it from the lake (Biron 2018).

A non-government organization has submitted a request to the Minister of Fisheries and Oceans and the Canadian Coast Guard to authorize the deposit of a deleterious substance (rotenone) to eradicate an aquatic invasive species (Smallmouth Bass) in Miramichi Lake, New Brunswick. Pursuant to s. 19(3) of the Aquatic Invasive Species Regulations SOR / 2015-121 (AISR), fish toxicants could be authorized in New Brunswick by the Minister of Fisheries and Oceans to eradicate Smallmouth Bass because it is not an indigenous fish species to the Maritime provinces.

The Aquatic Invasive Species Regulations state that alternative measures and the impact on fish and fish habitat or use of fish must be taken into consideration before authorizing the deposit of a deleterious substance. To support the decision making process, the Fisheries and Oceans Canada (DFO) Gulf Region Aquatic Invasive Species National Core Program asked DFO Science to review specific elements of the proponent's application and advise on the adequacy of the information provided, the interpretation of the literature, and to identify gaps. This Science Response Report results from the Science Response Process of September 11, 2019 on the review of elements of proponent application to use rotenone for the purpose of eradicating Smallmouth Bass (*Micropterus dolomieu*) from Miramichi Lake, New Brunswick.

Background

The DFO Aquatic Invasive Species National Core Program Gulf Region asked DFO Science to review specific elements of the application to authorize the deposit of a deleterious substance (rotenone) to control an aquatic invasive species (Smallmouth Bass) in Miramichi Lake, New Brunswick and to advise on the adequacy of the information provided, the interpretation of the literature, and to identify gaps specific to the following considerations:

1. Impact of Smallmouth Bass on species diversity and abundance of aquatic organisms in Miramichi Lake and the Southwest Miramichi River, if no control efforts occur.
2. Effectiveness of the proposed eradication method inlcuding:
    - Consideration of alternate methods for control and eradication;
    - Feasibility of proposed project (i.e. risk of not achieving intended goal of eradication); including physical and anthropogenic concerns;
    - Risk of re-introduction of the targeted species into the waterbody / watershed;
    - Proposed monitoring protocol to quantify eradication effectiveness; and
    - Proposed contingency strategy if unsuccessful.
3. In terms of defining impacts of the deposit:
    - Resulting impact of loss of fish species in the lake in terms of ecosystem productivity;
    - Impact to invertebrate communities that support the food web/productivity of the system. This is linked to the re-establishment strategy (i.e. foods resource for fish species); and
    - Validity of proposed mitigation measures to “offset” the impacts described above (i.e. re-establishment strategy); in this case, the effectiveness of proposed re-establishment strategy.

The specific elements of the application to be reviewed were:

- Section 3: Rationale
- Section 4: Environmental impacts
- Section 5.1: Pesticide or drug impact
- Section 7: Re-establishment strategy
- Section 8: Monitoring.

Analysis and Response

The information presented in the proponent application is based on a more detailed and unpublished contract report (van den Heuvel, M.R., Pater, C., Finlayson, B., and Skaar, D. 2017. Exploring Options for Eradication of Smallmouth Bass in Miramichi Lake; A report prepared for the Working Group on Smallmouth Bass Eradication in Miramichi Lake: Atlantic Salmon Federation, Miramichi Salmon Association, Miramichi Watershed Management Committee, New Brunswick Salmon Council Inc., New Brunswick Wildlife Federation Inc., North Shore Micmac District Council Inc. July 2017. 61 pp.).

Consideration 1: Impact of Smallmouth Bass on species diversity and abundance of aquatic organisms in Miramichi Lake and the Southwest Miramichi River, if no control efforts occur.

Section 3 of the proponent application provides information relevant to this question.

The short period of time (since 2008) that Smallmouth Bass have been confirmed, monitored, and subjected to control measures in Miramichi Lake provide little information with which to judge the potential population size of Smallmouth Bass in Miramichi Lake nor the impacts on the fish community within Miramichi Lake should no control or eradication measures be conducted.

The most important ecological control on Smallmouth Bass recruitment in Miramichi Lake and in the Maritime provinces is considered to be overwinter survival of the young-of-the-year (Chaput and Caissie 2010). Chaput and Moore (2018) estimated that there may have been upwards of 6,700 (median estimate) young-of-the-year Smallmouth Bass in Miramichi Lake in 2010 with 2,500 removed by the end of 2010; i.e. about 40% of the median estimated abundance was removed. Despite the survival into the fall of the first year of potentially 5,000 + young-of-the-year, the realized cumulative catches of Smallmouth Bass aged one year and older of the 2010 yearclass during 2011 to 2017 (ages 1 to 6) totaled 19 fish (Biron 2018). The largest cumulative catch of age-1 and older Smallmouth Bass was from the 2008 yearclass, at 48 fish, whereas cumulative removals for earlier and more recent yearclasses have been in the order of 20 to 25 age-1 and older Smallmouth Bass.

Consequences to species diversity and abundance in Miramichi Lake

There is no expectation of any native species of fish in Miramichi Lake substantially benefitting from the presence of Smallmouth Bass; the expected consequences of Smallmouth Bass to abundance and productivity of native fish species are neutral or negative. The extent of the negative consequences is uncertain (DFO 2009).

The references in the application, including those reported in DFO (2009) as well as Chaput and Caissie (2010), are adequate to establish that there is the potential for Smallmouth Bass to have measurable negative effects on the fish community in Miramichi Lake if the abundance of Smallmouth Bass were to increase above levels that have occurred in Miramichi Lake.

There is no information provided in the proponent application on the actual or relative abundances of the different fish species in Miramichi Lake, particularly those species that support valued commercial, recreational and Indigenous people’s fisheries. Based on various DFO reports, the only species in Miramichi Lake that currently supports a fishery is gaspereau (*Alosa* sp.) (DFO 2009, 2013; Biron et al. 2014; Biron 2018; Chaput and Moore 2018).

There is no information presented in the application to support concerns that Smallmouth Bass will negatively impact gaspereau. Gaspereau is an abundant and seasonal migrant in the Miramichi River and the Maritime provinces overall. Gaspereau, mainly Alewife (*Alosa pseudoharengus*) but could include some Blueback Herring (*A. aestivalis*), migrate upstream to Miramichi Lake to spawn and most of the post-spawn gaspereau leave the lake in early summer. The young-of-the-year gaspereau rear in the lake until the late summer to early fall and migrate downstream to the sea. The gaspereau spawner abundance in Miramichi Lake was not documented, but qualitative estimates suggest tens of thousands of adult gaspereau spawn in Miramichi Lake and hundreds of thousands of young-of-the-year gaspereau migrate out of the lake annually (M. Biron, DFO Science, unpublished data).

There is no information on the contribution of Miramichi Lake as spawning habitat for Miramichi River gaspereau nor its contribution to total biomass landed in the fisheries. Based on the New Brunswick provincial database of lake area estimates, Miramichi Lake is the largest of the 45 lakes in the Southwest Miramichi drainage area (drainage code 02-04-*) and represents 18% (221 of 1,204 ha) of the total lake surface area of the 31 lakes with surface area estimates. The Northwest Miramichi drainage area (drainage code 02-05-*) includes 38 lakes at an estimated total surface area of 2,121 ha and gaspereau spawn in many of these lakes. Thus, Miramichi Lake represents at most 7% of the quantified surface area of lakes in the whole Miramichi River watershed.

Gaspereau are unlikely to be affected by the presence of Smallmouth Bass in Miramichi Lake. There are several examples in the Maritime provinces of sustained landings in gaspereau fisheries (Saint John River, Margaree River) despite the presence of established non-native predator fish including Smallmouth Bass in these river systems.

Atlantic Salmon (*Salmo salar*) do not utilize Miramichi Lake to any extent; during the most extensive sampling effort in 2010, only one Atlantic Salmon juvenile was captured (Chaput and Moore 2018). Atlantic Salmon juveniles were most abundant in the catches from Lake Brook including the upper portion of the brook near the lake outflow (Biron 2018). Consequently, the impact of Smallmouth Bass on Atlantic Salmon in Miramichi Lake is considered negligible.

American Eel (*Anguilla rostrata*) was frequently recorded in catches from fyke nets in Miramichi Lake (Chaput and Moore 2018). American Eel is a catadromous species broadly distributed throughout the Miramichi River and its occurrence in Miramichi Lake is the result of upstream migration from the sea. There is no information in the literature to assess the impact of Smallmouth Bass on American Eel.

Brook Trout (*Salvelinus fontinalis*) is relatively rare in Miramichi Lake; a total of 90 individuals were captured during intensive sampling in 2010, mostly from fyke nets but also in gillnets, and by boat electrofishing (Chaput and Moore 2018). There is, however, substantial fishing effort by recreational fishers.

The remaining fish species captured in Miramichi Lake (Biron 2018) are of limited interest to any fisheries nor unique to Miramichi Lake. Moreover, it is not clear whether Yellow Perch (*Perca flavescens*), Brown Bullhead (*Ameiurus nebulosus*), Golden Shiner (*Notemigonus crysoleucas*), and Common Shiner (*Luxilus cornutus*) are native to the Miramichi Lake although the extensive distribution of these species in other areas of the Miramichi River and the Maritime provinces indicates that they are if not native, then naturalized.

There is no information or evidence that Smallmouth Bass has negatively impacted the fish community in Miramichi Lake, however, fish removals during the control and reduction program may have limited or masked the impacts. The extensive fishing removal effort using large mesh gillnets has resulted in a major reduction in the abundance of the larger sizes of species such as White Perch (*Morone americana*), White Sucker (*Catostomus commersonii*), and Yellow Perch; however, the small size groups of these species remain abundant in the lake (Biron 2018).

Consequences to species diversity and abundance in the Southwest Miramichi River

There is no expectation that native fish species in the Miramichi River will benefit from the presence of Smallmouth Bass; the expected consequences on abundance and productivity of native fish species are neutral or negative. However, the magnitude of any potential negative consequence is highly uncertain (DFO 2009).

No new information is presented in the application on the potential negative effects of the presence of Smallmouth Bass on structuring or functioning of fish communities in large river systems in Atlantic Canada.

The risk assessment conducted by DFO (2009) focused on the risk to Atlantic Salmon of Smallmouth Bass establishment and spread in the Miramichi River and to rivers of DFO Gulf Region. DFO (2009) indicated: “As habitat in rivers is spatially more complex than in lakes, the impact of smallmouth bass on the ecosystem in rivers is expected to be less severe than in lakes.” The uncertainty was high because, when the risk assessment was conducted in 2009, there was very limited information on the interactions between Atlantic Salmon and Smallmouth Bass in riverine habitat.

There is no literature on the population level consequences of Smallmouth Bass presence on Atlantic Salmon productivity and abundance. The history of Smallmouth Bass establishment in many watersheds with Atlantic Salmon, and the few studies, do not support the statements in the application of consequences to Atlantic Salmon associated with the establishment of Smallmouth Bass in riverine habitat as devastating. Drawing from the broader Smallmouth Bass literature, impacts to other fish species including salmonids outside the Atlantic region show a range of response magnitudes from small to large. In some situations, impacts may depend on other environmental and anthropogenic (fish passage) factors that mediate the biological interactions of predation and competition. The application and the supporting consultant's report do not reference a review (Valois et al. 2009) and recent studies from the state of Maine on the habitat use and interactions between young-of-the-year Smallmouth Bass and Atlantic Salmon (Wathen et al. 2011, 2012).

Information that could be used to interpret the potential impact of Smallmouth Bass on riverine fish community structure is provided in Table 4b of Clarke et al. (2014). The results from electrofishing at 36 riverine sites throughout the Saint John River watershed show abundant catches of a diverse assemblage of freshwater and diadromous fish species at sites with or without Smallmouth Bass presence. After over 50 years of Smallmouth Bass presence in the Saint John River system, the catch data suggest a diverse abundance of native fish species although this information alone is insufficient to conclude that the fish community structure and function has not been changed by the introduction of Smallmouth Bass.

Effectiveness of proposed eradication method

The uncertainties associated with the effectiveness of rotenone for eradication of Smallmouth Bass in Miramichi Lake are understated in the application.

Reference is made in the consultant report, but not in the application, to a review by Halfyard (2010) on options for the containment, control, and eradication of Smallmouth Bass. Halfyard (2010) indicated that if eradication is the chosen management objective, chemical (rotenone or antimycin) treatment offered the highest probability of success. In a recent review of the effectiveness of control and eradication actions for non-native fish, Rytwinski et al. (2018) reported that when the management goal was eradication, chemical treatment with rotenone was only successful in 75% of the documented initiatives, even with multiple applications of rotenone, whereas electrofishing and passive removal approaches were successful in 58% of documented initiatives.

The eradication attempt of Round Goby from a stream in Ontario reported by Dimond et al. (2010) is a very relevant document that is not referenced in either the application or the consultant's report. There are substantial lessons learned from this initiative, including that the best laid plans for eradication with an assessed high likelihood of success do not always achieve their objective.

Consideration of alternate methods for control and eradication

The premise that application of a chemical piscicide for eradication of Smallmouth Bass is the most effective approach is consistent with the reviews of Halfyard (2010) and Rytwinski et al. (2018). Methods that involve combinations of electrofishing, angling, and netting have a lower success rate for eradication (Rytwinski et al. 2018); however, they are effective at suppressing Smallmouth Bass abundance.

Since 2009, one breach of the Miramichi Lake outlet barrier occurred due to debris and water discharge (Biron 2018). Moreover, the barrier is permeable to young-of-the-year Smallmouth Bass during annual activities to release young-of-the-year gaspereau (Biron 2018). As well, downstream escapement of Smallmouth Bass may have occurred before barrier installation in the spring or after removal in the fall. Whatever the cause, young-of-the-year and one-year-old Smallmouth Bass have been captured below the barrier in the upper stretch of Lake Brook which supports the premise that full containment of Miramichi Lake was not successful.

Intensive physical removal efforts during 2009 to 2014 succeeded in reducing the catches and presumed abundance of all Smallmouth Bass size/age groups (Biron 2018) but physical removal efforts were scaled back during 2015 to 2018; while maintaining barrier activities. The objective to prevent spawning and production of young-of-the-year was not achieved and an alternate to physical removal is needed if the goal is to eliminate Smallmouth Bass from Miramichi Lake.

Feasibility of proposed project (i.e. risk of not achieving intended goal of eradication); including physical and anthropogenic concerns

The application addresses concerns that the rotenone treatment may not be effective in eradicating Smallmouth Bass from Miramichi Lake. The assessment by experts familiar with application of rotenone consider the lake configuration for rotenone application to be of medium complexity without explaining how this level of complexity affects the probability of successful eradication.

Some physical characteristics and hydrological features of Miramichi Lake provided in the application are not consistent with values reported elsewhere.

- The application refers to an estimated mean annual flow of 0.45 m^3/s for Lake Brook, which does not concord with other estimates. According to Chaput and Caissie (2010), the mean annual lake outflow estimated using New Brunswick regional equations (Caissie and Robichaud 2009) is 1.06 m^3/s and the combined mean annual flow from Miramichi Lake and Lake Brook is 1.38 m^3/s.
- The volume calculation of Miramichi Lake needs to be verified. The estimated volume of Miramichi Lake is reported to be 11.492 million m^3. This estimate of volume appears in the Miramichi Lake bathymetry figures published in the various DFO documents (e.g. DFO 2013) and a variation of that figure is referenced as Figure 3 in the application. The source of the data is attributed to C. Connell and R. Jones (New Brunswick Department of Natural Resources) based on a depth survey conducted on May 27, 2009. For a surface area of 2.215 million m^2, a volume of 11.492 million m^3 equates to a mean depth of 5.19 m, which is not consistent with the depth profile of the lake and statements that the majority of the lake is < 4 m deep. The New Brunswick Department of Energy and Resource Development database, referenced to February 2017, reports that Miramichi Lake has a surface area of 2.24 million m^2 and a volume of 5.790 million m^3, which gives a mean depth of 2.59 m and is more consistent with the depth profile of the lake. The accuracy of the volume calculation of Miramichi Lake has important consequences on the quantity of product to be deposited in the environment and the required quantity of chemical may be much less than what is indicated in the application.

The applicant proposes to treat the lower 100 m of inlet streams with drip stations but this may be insufficient in many cases to cover potential Smallmouth Bass habitat.

- The characterization of the inlet tributaries as being intermittent (section 4.1, p. 7) is not consistent with the assessment of DFO field staff that have worked in Miramichi Lake. The first section of Four Mile Brook is swampy with minimal change in elevation up to the remains of a pond about 1 km upstream. The channel configuration of the lower section of several inlet brooks is complex; for example, the first 200 m of Five Miles Brook is composed of a series of channels and dead ends with dense overhanging vegetation and an abundance of Yellow Perch. All brooks would have to be properly surveyed to identify the most appropriate placement for the drip stations and block nets may be needed to prevent the upstream migration of fish above the drip stations.

The stated concentration of rotenone required to ensure killing of Smallmouth Bass in Miramichi Lake, 0.075 mg/L of rotenone, is not fully described nor justified. It is not clear which version of the chemical product is proposed to be used to treat Miramichi Lake.

- The 24 h LC50 for Smallmouth Bass is reported to be 0.0047 mg/L rotenone and referenced as Marking and Bills (1976). Marking and Bills (1976) reported toxicity tests using Noxfish (Noxfish®, an emulsifiable concentrate containing 5% rotenone).
- The minimum effective dose (MED) is set at twice the 24 h LC50 value, thus as proposed, 0.0093 mg/L rotenone (2 times 0.0047 mg/L rotenone). The standard operating procedures recommend that the treatment rate be at a minimum twice the MED or 0.0186 mg/L rotenone (4 times 0.0047 mg/L). The application states that the proposed dosage concentration for Miramichi Lake should be 0.075 mg/L based on specific conditions in Miramichi Lake that may render the compound less effective, including a lower toxicity to Smallmouth Bass associated with Miramichi Lake water, however using four times the standard operating procedure dosage is not adequately described.
- It is indicated in the application that a test conducted in 2017 on small bodied Smallmouth Bass in water of similar characteristics to Miramichi Lake resulted in a 24 h LC50 value of 0.0065 mg/L rotenone, suggesting that the toxicity of rotenone to Smallmouth Bass in Miramichi Lake water may be 40% less than that reported by Marking and Bills (1976). No information is presented on this experiment in terms of design, replicability, source of fish, and uncertainty. Note that Marking and Bills (1976) tested Noxfish whereas the test conducted in 2017 by the applicant used CFT Legumine. The consultant report has a table showing the chemical formulation for Noxfish and CFT Legumine; the striking difference is that the majority compound in Noxfish is naphthalene (80.5%) with some nonylphenol ethoxylates (2.6 – 3.2%) whereas in CFT Legumine, the dominant (50%) compound is diethylene glycol monoethyl ether and a large proportion (23%) is not specified. The difference in formulation may well explain some of the discrepancy in rotenone toxicity results reported by Marking and Bills (1976) and those reported in the application.
- It seems inappropriate to derive a specific LC50 value for Smallmouth Bass in Miramichi Lake based on a chemical that is not being proposed for the treatment and that is not registered for use in Canada. The application indicates that additional on-site toxicity tests will be conducted to confirm the toxicity of Noxfish to Smallmouth Bass. It would be critical to validate this as the concentration chosen affects the quantity of compound to be used in the Miramichi Lake treatment. The objective should be to use the minimum amount of product to ensure a high probability of successful eradication, a more rapid degradation to background concentration, and minimizing the effects on the receiving environment.
- The Noxfish formulation described in the consultant's report also contains nonylphenol ethoxylates (NPEs) which is toxic to aquatic organisms (Canadian Council of Ministers of the Environment 2002). NPEs degrade in the environment to more environmentally persistent nonylphenol (NP) which is bioaccumulative and extremely toxic to aquatic organisms (U.S. Environmental Protection Agency 2010).

A partial dewatering to lower the lake level and to reduce lake volume prior to rotenone application would improve the chances of successful eradication and reduce the quantity of the deleterious substance required for the treatment. If the lake water level is lowered to a point that is below the Lake Brook outflow, this may eliminate the need to use potassium permanganate in Lake Brook to neutralize the rotenone.

Risk of re-introduction of the targeted species into the waterbody / watershed

Miramichi Lake is a headwater lake of the Southwest Miramichi River and the risk of natural spread from Miramichi Lake and establishment into the Southwest Miramichi River is considered proportional to the abundance of Smallmouth Bass in Miramichi Lake. As long as there are Smallmouth Bass in Miramichi Lake, there is a risk of spread from Miramichi Lake and establishment into the Southwest Miramichi River and beyond.

The containment and control efforts in Miramichi Lake since 2009 may have reduced the risk of spread to the Southwest Miramichi, however the observed catches of Smallmouth Bass in Lake Brook (Biron 2018), and the recent documentation of Smallmouth Bass in the Southwest Miramichi River downstream of Lake Brook in 2019, indicate that the spread of Smallmouth Bass specifically from Miramichi Lake may have occurred, whether by natural means or human introduction. Treatment of Miramichi Lake with rotenone is expected to substantially reduce the risk of further spread from Miramichi Lake. However, even if complete eradication of the current Smallmouth Bass population from the lake is achieved, the risk of a future illegal introduction of Smallmouth Bass in Miramichi Lake and the Southwest Miramichi River remains. In the proximate Saint John River watershed, there is an established and valued Smallmouth Bass recreational fishery.

Proposed monitoring protocol to quantify eradication effectiveness.

The application (Section 8.1) proposes to assess rotenone concentrations in lake waters and the duration of toxicity using caged fish. There is limited description, however, on how the proponent will determine if total eradication of Smallmouth Bass has been achieved. The annual monitoring activities described in the application are mostly relevant to assessing the re-establishment of the aquatic community in the lake (see section Other Considerations).

To monitor toxicity, the applicant proposes to conduct 24 hour bioassays using fingerling Brook Trout placed in cages at three locations in the lake. There are two objectives with this bioassay monitoring: the first is to ensure that the rotenone concentrations in the lake are sufficient to kill Smallmouth Bass within 24 hours and the second is to determine when the rotenone has degraded to a level which would not be toxic to fish re-establishment. There are a number of issues that require clarification.

- The 24 h LC50 for Brook Trout is half that for Smallmouth Bass (Marking and Bills 1976). For the first objective, it would be better to use a native (or naturalized) fish model species, for example Yellow Perch or Brown Bullhead (Marking and Bills 1976), that has similar tolerance to rotenone as Smallmouth Bass.
- Once the 24 hour mortality rate of the model species in the lake is found to be equal to or less than the control mortality rates, the monitoring could switch to fingerling Brook Trout using the same monitoring design. When mortality rates of Brook Trout are less than or equal to the mortality rates of the controls, the lake water would be assessed as non-toxic to fish.
- Monitoring cages should be placed at different depths in the lake and should include the deep holes in Miramichi Lake to ensure that the rotenone has been adequately distributed at depth.

The proposal does not specify how Smallmouth Bass eradication success will be determined.

> "Monitoring includes a pre-rotenone monitoring period followed by at least annual monitoring for up to five years, or until the system recovers to a stable or pre-application state... As biota will vary seasonally, most monitoring efforts should be restricted to the time of the year at which application takes place (fall)... Fish surveys serve the dual purpose of monitoring recovery and examining for the presence of bass. For the examination of bass presence, netting efforts described below are only part of the solution. The use of eDNA should also be used as confirmation with monitoring for a period of three years." p. 33.

- Demonstrating absence of fish using fishing catches will be challenging, as described by Chaput and Moore (2018), however, demonstrating incomplete eradication only requires the capture of one live Smallmouth Bass post-treatment. Minimally, boat electrofishing at various locations around the lake edge should be conducted, prior to rotenone treatment, within one-week post-rotenone application, immediately after when the lake water is assessed to be non-toxic to fish, and most importantly prior to any re-introduction of fish to the lake by natural or artificial means.
- The suggestion to use eDNA to assess species presence is supported, with sampling before and after rotenone treatment. The non-detectable level of Smallmouth Bass in Miramichi Lake has not been defined. Fish and eDNA sampling prior to rotenone treatment with a quantification of the number and biomass of Smallmouth Bass killed by the rotenone treatment in Miramichi Lake would be an essential metric with which to partially calibrate the catch efficiency of the fishing gear and the eDNA detection level.

Proposed contingency strategy if unsuccessful

What constitutes a conclusion of successful eradication of Smallmouth Bass in Miramichi Lake needs to be defined. The absence of any catches of Smallmouth Bass in the lake for a period of two years post-treatment is proposed. The sampling effort required to achieve the desired level of certainty needs to be defined, some guidance on this is provided by Chaput and Moore (2018). Until it is concluded that eradication is likely (>75% chance for example) to have been achieved, the containment and control activities conducted to date in Miramichi Lake should be maintained.

The proposal indicates that a second treatment could be applied if total eradication was not achieved. The same considerations for monitoring effectiveness and assessing success would apply. A second treatment could be conducted in the same season if the initial treatment occurred earlier in the summer. An earlier treatment however could result in kills of gaspereau adults and juveniles that would otherwise be lower for a September treatment after the gaspereau have migrated from the lake. Failure to achieve eradication in the first treatment would be informative of the likely chance of success of a subsequent treatment.

Impacts of the deposition of rotenone in Miramichi Lake

Resulting impact of loss of fish species in the lake in terms of ecosystem productivity

There is little in the proposal that speaks to productivity (rate at which energy or carbon are converted to biomass per unit area) per se. The loss of species to ecosystem productivity is hard to quantify and predict. The number of fish expected to survive rotenone treatment is not known. If the proposed rotenone treatment kills all fish in the lake then fish production will be zero. In the absence of colonization from feeder streams or from downstream, fish production will be zero until fish are present in the lake and growing. The sources of fish food are also disrupted, a factor in calculating ecosystem-level production. Populations of many planktonic and macrobenthic invertebrate species will be greatly reduced or temporarily eliminated. However, because the information provided in the proposal is data poor in terms of species presence and abundances, and general relationships of ecosystem components, it is impossible to assess possible short-term and long-term outcomes. Biomass and productivity of lake fauna will certainly be greatly reduced in the short-term.

The native and naturalized fish species in Miramichi Lake are widely distributed in the Miramichi River and tributaries. No fish species in Miramichi Lake are currently listed under Schedule 1 of the Species at Risk Act. American Eel in eastern Canada has been assessed as threatened by COSEWIC. In the general status of wildlife species in Canada report of 2015, all fish species found in Miramichi Lake are listed as apparently secure or secure (Canadian Endangered Species Conservation Council 2016).

Impact to invertebrate communities that support the food web/productivity of the system

There is no baseline information presented on the species composition or abundances of the invertebrate community of Miramichi Lake. The invertebrate community composition would be expected to be similar to that in similar habitat in New Brunswick.

Many benthic invertebrate species are killed by concentrations of rotenone sufficient to kill fish. In general, aquatic insects are more sensitive than non-insect taxa to rotenone and important fish prey (e.g., Ephemeroptera, Plecoptera and Trichoptera) are among of the most sensitive (Vinson et al. 2010). It is not known whether crustaceans (amphipods, mysids, and crayfishes) are important components of the Miramichi Lake faunal community. In the short-term, most species of aquatic invertebrates are expected to suffer substantial reductions in abundance, including complete eradication from the lake.

Compared to the large body of literature on rotenone toxicity to aquatic macroinvertebrates, there is scant mention or discussion of peer-reviewed studies in the application and those provided do not necessarily support the interpretations in the report. Only one study is mentioned, Hobbs et al (2006), and LC50 values demonstrate that invertebrates vary with respect to their tolerance to rotenone. The effects of rotenone application on freshwater aquatic invertebrates have been studied for more than 70 years (e.g., Brown and Ball 1943; Hoffmann 1956); however, the precise toxicity levels have been determined for relatively few species (Dalu et al. 2015). While toxicity of rotenone varies widely among aquatic invertebrates, most are killed at the concentrations needed to kill fish (Mangum and Madrigal 1999; Vinson et al. 2010; Dalu et al. 2010).

No information is presented on the species composition or abundances of the zooplankton community, and in particular those that support the fish community. There are numerous studies not referenced in the application that document the post-rotenone demise and recovery of cladoceran, copepods, rotifers and other invertebrate taxa (Anderson 1970; Kjaerstad et al 2016), and the studies referenced in the application do not unambiguously support the statement that these taxa will survive treatment and recover rapidly. The study by Byrnildson and Kempinger (1973) only supports the recovery of *Daphnia* taxa following rotenone application (Figures 5 and 11 therein).

It is misstated in the application that a fall rotenone treatment will enhance the recovery of young-of-the-year gaspereau forage. The planktonic organisms that are forage of gaspereau larvae and juveniles have resting stages in the substrate that may offer some resistance to rotenone (Naess 1991; Dalu et al. 2015). In the best case, rotenone treatment will have no negative consequences to the emergence of these planktonic organisms post application or in the spring.

The summary in the application regarding species at risk is consistent with published information in the provincial databases of status of wildlife species (Canadian Endangered Species Conservation Council 2016) and COSEWIC assessments; there are no invertebrate species of concern in Miramichi Lake.

Validity of proposed mitigation measures to "offset" the impacts described above, in particular the effectiveness of proposed re-establishment strategy

> "There are three overall options for native species re-introduction: 1) capture and hold fish from Miramichi Lake and re-introduce once toxicity has dissipated; 2) collect fish from other New Brunswick waterways for restocking Miramichi Lake; or 3) let Miramichi Lake recolonize naturally. The third option would potentially take decades and has no guarantee of similar fish diversity being reached so is not considered a viable option. The option of capturing, holding and re-introducing species from Miramichi Lake itself is the preferred option." p. 29

The applicant proposes to temporarily capture and isolate select species of fish from Miramichi Lake and to re-introduce these fish into the lake in order to shorten the timeline for re-establishment of the native and naturalized fish community in Miramichi Lake, absent Smallmouth Bass. There are three considerations for the re-establishment strategy:

1. Feasibility of successful capture, holding, re-introduction, and survival of fish;
2. Acceptable timelines for re-establishment of a fish community in Miramichi Lake; and
3. Fisheries management or biodiversity objectives for Miramichi Lake.

The proposal by the proponent to remove a small number (1,000 or less) of fish of selected priority species, holding these fish in shore-based tanks, and returning the fish to the lake a few weeks later is presented with a high certainty of success whereas it is expected to be challenging. A number of issues were identified:

- There is no explanation for the priority species scoring in the application and the priority species identified as high, with exception of Brook Trout, are not of any particular fishery value.
- The survival of wild fish in captivity will depend on a number of factors.
- It is not indicated if the fish will be fed during the two weeks or more of captivity required for the rotenone to degrade to non-toxic levels and how successful this will be.
- The use of shore-based tanks requires accessing inlet water and managing outflow.
- While it is expected that zooplankton and aquatic invertebrate species will recover and recolonize naturally, some taxa may show signs of recovery in a few months (Anderson 1970), a year (as cited in proposal) or longer (Beal and Anderson 1993). Although the single study cited in the application found that invertebrate density returned to "normal" within a year post-application in a New Zealand stream, the reality for a temperate lake is likely somewhat different with respect to time for recovery and the metric chosen to measure the recovery. Previous studies have found nearly complete recovery of invertebrate communities within 6 months, however, return to a pre-rotenone state may take 2 to 5 years and some taxa may not re-colonize the affected area even within that timeframe (summarized by Vinson et al. 2010). This may leave the fish that are re-introduced, or those species that through tolerance survive the rotenone treatment, without adequate food supply

to survive during the recovery time of the lake ecosystem. Autumn feeding may be critical to over-winter survival of some species while others, e.g. Yellow Perch, feed year-round.

- The proposed re-introduction of fish into Miramichi Lake immediately post-treatment complicates the monitoring program to determine the effectiveness of the eradication effort. In the absence of re-introduction the expectation is that no fish, with possible exception to Brown Bullhead and Golden Shiner that may be tolerant to the concentration required to kill Smallmouth Bass, would be alive in the lake and the capture of any other fish species post-treatment would suggest that the eradication of Smallmouth Bass may not have been complete. This conclusion is precluded if fish are re-introduced into the lake.

If the objective is to re-establish a naturalized lake ecosystem post-treatment, a reasonable option is to allow the recolonization to occur naturally. Most species are expected to re-colonize the treated area. The timelines for recolonization will likely be affected by the proximity of a nearby source-population as well as the species' dispersal ability. Most fish species in Miramichi Lake will likely be re-established through immigration from Lake Brook and the inlet streams. Any recovery of the fish community will be controlled by the rate at which the prey community (in terms of numbers and species composition) re-establishes. Freshwater mussels could recolonize by transport of their glochidia on fish migrating to Miramichi Lake but it would take many years for population numbers and size structure to attain pre-treatment levels. Aquatic flying insects should recolonize from nearby waterbodies but abundance increases to levels needed to support fish populations at levels pre-invasion by Smallmouth Bass may take years. Recolonization by macroscopic crustaceans, if any are present in the lake, may be problematic unless they are present in non-treated inlets to the lake. Crayfishes, with their multi-year lifespan, may take many years to re-establish. In the absence of a prescribed timeframe for re-establishment of native aquatic organism communities, treating this eradication activity as a re-establishment experiment would provide useful information to assist in management decisions of future eradication actions.

Miramichi Lake is relatively large, accessible, and still holds interest for the recreational fishery. Based on the fish inventory and abundance data summarized by Biron (2018), there is currently limited recreational fisheries potential in Miramichi Lake; there is a small population of one sport fish (Brook Trout) and larger numbers of panfish (Yellow Perch, Brown Bullhead, and White Perch). The fish community of Miramichi Lake contains no unique or particularly iconic fish species of conservation concern. Re-introducing a small number of fish temporarily isolated from the lake during treatment, or allowing the fish community to re-establish post-treatment from downstream immigration or lake inlet emigration, will produce the same fish community that has the same limited fishery interest. An alternate management objective could consider taking advantage of the eradication of the lake community to stock Brook Trout for the purpose of establishing a more productive trout recreational fishery. This would not preclude a recolonization of the previous fish community and gaspereau will naturally migrate to Miramichi Lake in the spring.

Other Considerations

The purpose of the multi-year monitoring program outlined in Section 8 of the applicant report is not clear. It appears to be a combination of confirming the absence of Smallmouth Bass post-rotenone treatment and monitoring the re-establishment of the aquatic community in the lake. There would be an opportunity to use the Miramichi Lake initiative to learn about eradication of non-native species while considering the impacts on and re-establishment rates of native faunal communities post-piscicide treatment. A detailed review of an appropriate study design is outside the scope of this review.

Conclusions

This review was conducted in response to a request from DFO Gulf Region Aquatic Invasive Species National Core Program to advise on elements of an applicant's proposal to deposit rotenone for the purpose of eradicating the non-native Smallmouth Bass (*Micropterus dolomieu*) in Miramichi Lake and the upper section of Lake Brook, Southwest Miramichi River, New Brunswick.

In the case of Miramichi Lake and the Southwest Miramichi River, there will not be any substantive positive benefits to native species from the presence of Smallmouth Bass. The expected consequences of Smallmouth Bass to abundance and productivity of native fish species are neutral or negative. The extent of the negative consequences is uncertain both in scale and the timelines.

The short period of time, since 2008, that Smallmouth Bass have been confirmed and monitored in Miramichi Lake, and the control measures undertaken to date, provide little information with which to judge the potential population size of Smallmouth Bass in Miramichi Lake nor the impacts on the fish community in Miramichi Lake in the absence of control or eradication measures.

The citations in the proposal, including those reported previously, are adequate to establish that there is the potential for Smallmouth Bass to have measurable effects on the fish community in Miramichi Lake including undesirable impacts on native fish species if the abundance of Smallmouth Bass were to increase above levels that have occurred in Miramichi Lake. There is no information or evidence that Smallmouth Bass have negatively impacted the fish community in Miramichi Lake, however, the control and reduction program to date may have limited or masked these impacts.

No new information is presented in the application on the effects of Smallmouth Bass on communities in large river systems in Atlantic Canada. The risk assessment conducted by DFO (2009) was focused on the risk to Atlantic Salmon by Smallmouth Bass establishment and spread in the Miramichi River and to rivers of DFO Gulf Region. The uncertainty was high because when the risk assessment was conducted in 2009, there was limited information on the interactions between Atlantic Salmon and Smallmouth Bass in riverine habitat. There is also no literature on the population level consequences of Smallmouth Bass to Atlantic Salmon productivity and abundance. The history of Smallmouth Bass establishment in many watersheds with Atlantic Salmon and the limited studies and literature reviews do not support the statements in the application of presumably devastating consequences to Atlantic Salmon associated with the establishment of Smallmouth Bass in riverine habitat. However, the broader literature on impacts of non-native Smallmouth Bass to other fish species including salmonids in lakes and riverine environments outside the Atlantic region show a range of responses, from small to large, that are difficult to predict due to diverse environmental and anthropogenic factors that mediate the biological interactions of predation and competition.

The premise that application of a chemical piscicide for eradication of Smallmouth Bass is the most effective approach is consistent with the reviews of Halfyard (2010) and Rytwinski et al. (2018). However, the uncertainties associated with the effectiveness of rotenone for eradication of Smallmouth Bass in Miramichi Lake are understated in the application. The assessment by experts familiar with application of rotenone consider the configuration of Miramichi Lake for rotenone application to be of medium complexity. There is no explanation of how this assessment of medium complexity affects the probability of successful eradication nor if multiple treatments would be required.

Some physical characteristics and hydrological features of Miramichi Lake provided in the application are not consistent with the bathymetric profile of the lake and values reported elsewhere. The volume calculation of Miramichi Lake needs to be verified as this has important consequences on the quantity of product to be deposited into the environment. The stated concentration of rotenone required to ensure killing of Smallmouth Bass in Miramichi Lake, 0.075 mg/L of rotenone, is not fully described nor justified. A combination of partial dewatering to lower the lake level and to reduce lake volume prior to rotenone application could improve the chances of successful eradication as well as reduce the quantity of the chemical required for the management action.

The risk of spread into the Southwest Miramichi River from Miramichi Lake is considered proportional to the abundance of Smallmouth Bass in Miramichi Lake. Miramichi Lake is a headwater lake of the Southwest Miramichi River and as long as there are Smallmouth Bass in Miramichi Lake, there is an ongoing risk of spread and establishment into the Southwest Miramichi River and beyond. The recent documentation of Smallmouth Bass in the Southwest Miramichi River downstream of Lake Brook in 2019 indicates that the spread of Smallmouth Bass from Miramichi Lake may have already occurred. Treatment of the lake with rotenone is expected to substantially reduce the risk of further spread from Miramichi Lake. However, even if complete eradication of the current Smallmouth Bass population from the lake is achieved, the risk of future illegal introductions of Smallmouth Bass to Miramichi Lake or to the Miramichi River remains, in particular due to the proximity of established Smallmouth Bass populations in the adjacent Saint John River watershed.

There is limited information in the application on how the proponent will determine if total eradication of Smallmouth Bass has been achieved. The annual monitoring activities described in the application are mostly relevant to assessing the re-establishment of the aquatic community in the lake. Demonstrating absence of fish using fishing catches and eDNA will be challenging. Efforts to recover and enumerate species killed in Miramichi Lake, including number and biomass of Smallmouth Bass which is an essential element of monitoring the management action, is not described in the application.

There is little in the proposal that speaks to productivity per se. The proposed rotenone treatment will kill fish and fish productivity will be zero if all fish are killed. Much of the invertebrate food supply for fish, a vital component of fish habitat, will be temporarily (months to years) eliminated. Because the structure and functioning of the food web is a major consideration of ecosystem productivity and the information provided in the application is scant (in some cases non-existent), it is difficult to assess what the outcome will be.

There is no baseline information presented on the species composition or abundances in the plankton and macro-invertebrate communities of Miramichi Lake. In the short-term, most species of aquatic organisms will suffer major reductions (including eradication) in abundance, which will greatly reduce the taxonomic richness of the prey community. Considering the large body of literature describing the effects of rotenone, there are few references in the application that unambiguously support the statement in the application that these organisms will survive treatment and recover rapidly.

The applicant proposes to temporarily capture and isolate select species of fish from Miramichi Lake and to re-introduce these fish into the lake post-treatment in order to shorten the timeline for re-establishment of the native and naturalized lake fish community, absent Smallmouth Bass. This is presented with a high certainty of success whereas it is expected to be challenging. The re-introduction of fish into Miramichi Lake post-treatment complicates the monitoring program to determine the effectiveness of the eradication effort. Most species are expected to re-colonize the treated area naturally over time and the timelines for recolonization will be affected by a number of factors related to colonization including the proximity of a nearby source-population as well as the species' dispersal ability. The recovery of fish abundance will also depend on the recovery time of sufficient food to support the fish in the lake. In the absence of a defined timeframe for re-establishment of native aquatic organism communities, treating this eradication management action as a re-establishment experiment would provide useful information to assist in management decisions of future eradication actions.

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October 21, 2019

Sources of information

This Science Response Report results from the Science Response Process of September 11, 2019 on the review of elements of proponent application to use rotenone for the purpose of eradicating Smallmouth Bass (*Micropterus dolomieu*) from Miramichi Lake, New Brunswick.

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ISSN 1919-3769

Correct Citation for this Publication:

DFO. 2019. Review of elements of proponent application to use rotenone for the purpose of eradicating Smallmouth Bass (*Micropterus dolomieu*) from Miramichi Lake, New Brunswick. DFO Can. Sci. Advis. Sec. Sci. Resp. 2019/040.

Aussi disponible en français :

MPO. 2019. Examen des éléments de la demande du promoteur d'utiliser de la roténone dans le but d'éradiquer l'achigan à petite bouche (Micropterus dolomieu) dans le lac Miramichi (Nouveau-Brunswick). Secr. can. de consult. sci. du MPO, Rép. des Sci. 2019/040.