REVIEW OF CONTROL AND ERADICATION ACTIVITIES IN 2010 TO 2012 TARGETING SMALLMOUTH BASS IN MIRAMICHI LAKE, NEW BRUNSWICK

Context

In August 2008, the presence of the non-native Smallmouth Bass (*Micropterus dolomieu*) was confirmed in Miramichi Lake, in the headwaters of the Southwest Miramichi River in New Brunswick. A risk assessment of the possible impact of this non-native species introduction on the Miramichi River system, and on Atlantic Salmon in particular, concluded that the overall risk to aquatic species in Miramichi Lake was considered to be high with low uncertainty whereas the risk of potential impacts to the ecosystem of the Miramichi River and other rivers of the Gulf Region was moderate with high uncertainty (DFO 2009). Following on the risk assessment, the Department of Fisheries and Oceans (DFO) in collaboration with the watershed groups and the province of New Brunswick initiated a three-year containment, control and eradication program beginning in 2010. Following on the completion of the third year of the program, a review of the activities, results, and advice on the next steps was requested by DFO Science Branch and DFO Ecosystems and Fisheries Management Branch. The total abundance of Smallmouth Bass adults in Miramichi Lake was low and was further reduced in each year of the program. While successful spawning occurred in all three years of the program, the abundance of young of the year decreased substantially in each year. As the abundance of Smallmouth Bass was reduced, it has become more difficult to assess the presence of adult bass in Miramichi Lake. Preferred spawning locations have been identified which can be used to focus future activities with the objective of preventing spawning and ultimately recruitment to the lake. This Science Response Report results from the Science Special Response Process of March 7 2013 which reviewed the control and eradication activities of 2010 to 2012 that targeted Smallmouth Bass in Miramichi Lake, New Brunswick.

Background

Smallmouth Bass, *Micropterus dolomieu* Lacepède (1802), is a member of the Order Perciformes, Family Centrarchidae. The original Canadian distribution of Smallmouth Bass (SMB) was restricted to the Great Lakes / St. Lawrence River system. SMB were transplanted into the New England states in the late 1800s and spread into New Brunswick from Maine around 1869 (DFO 2009). Sanctioned and unsanctioned introductions in the first half of the 20th century and unsanctioned introductions to the present contributed to the expanded range of SMB in the Maritime provinces. SMB have been reported from eight lakes in the Gulf of St. Lawrence drainages; one in New Brunswick (Miramichi Lake, Southwest Miramichi River) and seven in Nova Scotia, all confirmed since 1998 (DFO 2009).

SMB is a medium body-sized fish with fork length of the largest animals typically less than 50 cm and whole weights typically less than 2 kg. The maximum age reported for the Maritimes is 22 years. Sexual maturity is reached typically at ages > 5 years but mature 3 year old fish have been recorded in some growth-stunted populations in Nova Scotia. Reproduction occurs in spring and male bass provide a large degree of parental care. Females produce from a few thousand up to 20,000 (depending on female body size) adhesive demersal eggs released in

nests constructed by males. Males guard the nests as well as embryos and swim-up fry until the latter disperse from the nest. By the end of the first growing season, young of the year (YOY) bass can attain lengths of 40 to 100 mm. Adults prefer the inshore rocky or large woody debris habitat areas of lakes and in areas of moderate current over rocky or gravel substrates in rivers. SMB consume a wide range of invertebrate and vertebrate prey, prey type being influenced by fish length, age and prey availability. They are also known to be cannibalistic.

The Miramichi River has the largest run of Atlantic Salmon (*Salmo salar*) in eastern Canada. Direct competitive interactions between juvenile SMB and juvenile Atlantic Salmon in streams is likely because river habitat used by juveniles of both species overlap. Juvenile salmon as fry or parr are the most vulnerable stages to predation by SMBs. Minimal interactions are expected between SMB and adult salmon and most likely as competition for space in holding pools between salmon and large SMB (DFO 2009).

DFO (2009) concluded that the overall risk to the aquatic ecosystem of SMB was high in the lake environment and moderate in the riverine. Although the overall risk to Atlantic Salmon was considered moderate in the riverine environment, none of the consequences of SMB introductions were positive for Atlantic Salmon or other native fish species in the watershed. The highest probability of controlling or eradicating non-native species was through the use of multiple approaches and the likelihood of success is reduced when control and eradication actions are delayed (DFO 2009).

The initial response in 2008 was to install a containment barrier with fine meshed nets at the single outlet of Miramichi Lake to prevent SMB from escaping the lake. This barrier was in place until ice up, and the area immediately below the barrier was electrofished weekly in an attempt to remove any bass which may have escaped from the lake. In 2009, two containment barriers were operated in the outlet of the lake to prevent dispersal of this species to other tributaries of the Miramichi River. A rotary screw trap was operated in the main branch of the Southwest Miramichi River below the mouth of Lake Brook to monitor any potential Smallmouth Bass migrants from the lake. Removal efforts using a number of physical removal methods were conducted, to remove bass and to obtain better information on the abundance of SMB in Miramichi Lake. Efforts in 2009 resulted in the capture and removal of 64 SMB including 26 YOY. The 2008 and 2009 sampling efforts confirmed the successful spawning and recruitment of SMB in Miramichi Lake in those two years.

DFO, in partnership with the Miramichi Watershed Management Committee, the Miramichi Salmon Association, and the New Brunswick government, developed a three-year plan to control and remove SMB with the intention of eradicating the species from Miramichi Lake. The use of chemical piscicides was excluded as a management tool due to regulatory constraints and concerns over the ecosystem in Miramichi Lake. Containment and physical removal methods were undertaken in 2010 to 2012 with the objective of depleting the SMB population and preventing spawning and recruitment of future spawners. Other objectives of the program were to estimate the population size and age structure of SMB in the lake in order to assess the effectiveness of the removal and eradication program.

Analysis and Response

Miramichi Lake is located in the headwater of the Southwest Miramichi River basin in New Brunswick. It is approximately 2.8 km in length by 0.8 km in width with an estimated surface area of 2.21 km^2 (221 ha). Relatively shallow, the majority of the lake is less than 3.75 m deep and has two deep holes with maximum depth less than 7.65 m (Fig. 1). Miramichi Lake drains into its only outlet, Lake Brook, a 4.5 km tributary of the Southwest Miramichi River. The lake was divided into 16 sectors to facilitate localization on the lake during fishing effort (Fig. 1).

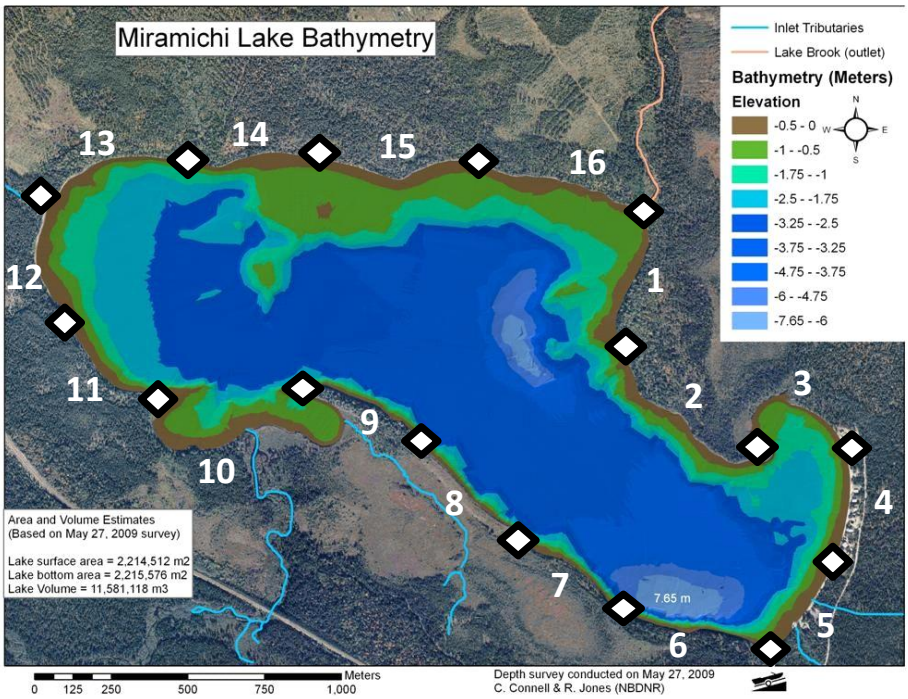


Figure 1. Bathymetry of Miramichi Lake and location of sectors and sector boundaries. Bathymetric data and profiles were provided by C. Connell and R. Jones, New Brunswick Department of Natural Resources.

SMB prefer water temperatures in summer of 17-28ºC with an upper lethal temperature of 35ºC. They may not feed actively until temperature reaches about 8.5ºC and cessation of feeding typically occurs when temperatures drop below 7-10ºC although there is evidence of feeding activity at colder temperatures in the Maritimes and northeast US (SMB are reportedly caught by ice fishermen). The weight of evidence indicates that the northern distribution of SMB is limited by temperature. In other populations in the Maritimes, spawning activity is initiated when the mean daily water temperature is sustained at or above 15ºC. Mean temperature in Miramichi Lake generally exceeded 15ºC after May 18, 2010, May 29, 2011, and May 20, 2012 (Fig. 2).

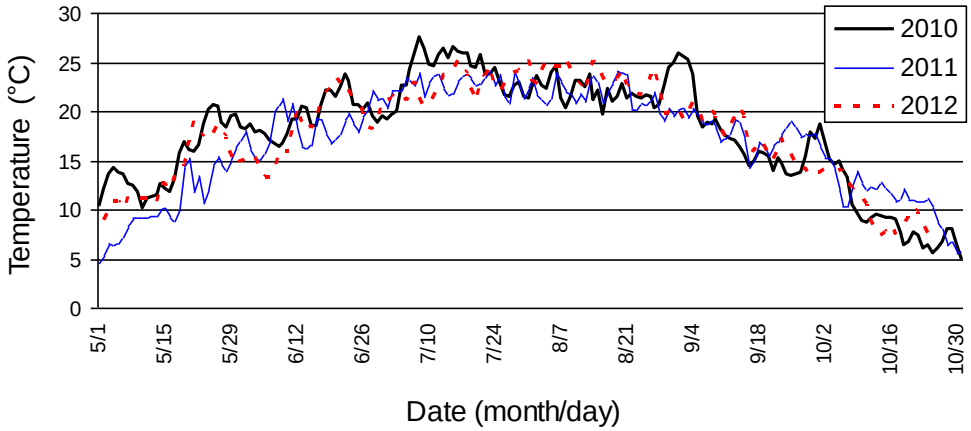


Figure 2. Mean daily water temperature in Miramichi Lake, May to October 2010 to 2012.

Containment and Fishing methods

Soon after the ice cover disappeared from the lake in 2010, 2011 and 2012, the containment barrier was installed in the outlet of Miramichi Lake, where it enters Lake Brook. The containment barrier consisted of two fences: the first one made of steel bars installed at half inch intervals and lined with a 12 mm mesh net, while the second fence (or debris fence) was installed a few meters upstream of the first fence and was constructed with rebar spacing at two foot intervals and lined with a 12 mm mesh net. The containment barrier was maintained and operated 7 days per week. To allow movement of fish in and out of the lake, the upstream or downstream barrier was opened to trap fish between the two fences. Beach seining was then conducted between the two barriers to capture and manually transport fish either upstream or downstream of the barriers. All fish captured between the two barriers were carefully examined to ensure that no SMB were released. The process of moving fish downstream was modified in 2011 and 2012 to reduce the mortality from manipulating YOY gaspereau. When large numbers (thousands) of YOY gaspereau gathered upstream of the barrier, a small section of the barrier net was lifted to let the fish go through without manipulation. A certain control was kept on the species and size of fish going through by making the fish travel over shallow areas, while being actively monitored by a crew member, ready to block the route if required.

Several fishing methods were used to capture and remove SMB from Miramichi Lake during 2010 to 2012. Boat electrofishing, backpack electrofishing, gillnetting, fyke-netting, beach seining and opportunistic angling were conducted throughout the open water season. The amount of fishing effort was not available for all sampling methods in 2011 and 2012 except for boat electrofishing, gillnetting and fyke-netting (Table 1).

Two electrofishing boats were used to sample shallow waters (depth less than 2 m) along the littoral zone of Miramichi Lake. Generally, boat electrofishing was conducted in late evening or after dark. The entire near shore of the lake was electrofished at least once a week to identify the distribution of SMB along the littoral zone of the lake. Two nights with favorable conditions were required to sample the entire near shore of the lake. During the remainder of the week, electrofishing effort was focused on areas where SMB were captured previously in the week. During the spawning period (late May - June), increased electrofishing efforts were directed toward the inferred spawning areas (sectors 1 and 16) to capture spawning adults or males guarding nests. Boat electrofishing effort began in May and continued into October (May 11-

Oct. 20, 2010; May 11-Oct. 19, 2011; May 01-Oct. 25, 2012). A total of 82 hours of electrofishing effort in 2010, 183 hours in 2011 and 125 hours in 2012 was conducted in the lake (Table 1).

Gillnets were fished from April to October. Gillnets were constructed of grey, white or green multifilament, with mesh sizes of 2, 2.25, 2.5, 2.75, 3, 3.25, 3.5, 4, and 5 inch stretched mesh. Most nets were 30 m in length and 2 m deep. Deployed nets were anchored at both ends with steel anchors or cinder blocks and floated with buoys at the surface. Gillnet fishing effort was focused on areas of the lake known to support adult SMB from previous years and were mostly installed near the two deep holes of the lake and near shore in sectors 1, 4, 5 and 16 (Fig. 1). In 2011, a 20-day random sampling program was initiated to spread the gillnet fishing effort throughout the lake. The lake was divided into a grid of 22 squares of 250 m^2 each. Twelve individual gillnets were assigned randomly to twelve different fishing squares. On each day, all gillnets were fished and reset in a new random location. A total of 233 net-days were applied in a randomized fashion throughout the lake and resulted in no catch of SMB.

Fyke nets were deployed in late April – early May until late October, and were fished intermittently throughout the season in all sectors of Miramichi Lake. Daily fyke-netting effort varied between four and eight nets and was concentrated in areas known to support SMB along the shallow shorelines of the lake.

Table 1. Comparison of the fishing effort and catches of Smallmouth Bass, by life stage, in Miramichi Lake, 2010 to 2012. YOY are young-of-the-year; juvenile are age 1 and 2; adult are age 3 and older.

Fishing method		2010	2011	2012
Boat electrofishing				
Effort (hours)		81.7	183.4	125.2
Catch of Smallmouth Bass	YOY	1,285	302	12
	Juvenile	6	6	4
	Adult	3	12	2
	Total	1,294	320	18
Gillnets				
Effort (net-days)		1,150	2,732	2,613
Catch of Smallmouth Bass	YOY	0	0	0
	Juvenile	5	6	0
	Adult	20	5	0
	Total	25	11	0
Fyke nets				
Effort (net-days)		487	988	868
Catch of Smallmouth Bass	YOY	190	32	2
	Juvenile	3	4	2
	Adult	9	1	0
	Total	202	37	4

Backpack electrofishing was used to sample Lake Brook, below the barrier, and the shoreline of Miramichi Lake. Lake Brook was electrofished from the barrier to a riffle located approximately 400 m downstream of the barrier. In 2010 and 2011, electrofishing was also regularly conducted up to 1,500 m downstream of the barrier to search for SMB. Special attention was paid to structures in the brook, especially along the shoreline in slow moving water at depths of 30 to 100 cm. Backpack electrofishing was also conducted in Miramichi Lake and mainly targeted the YOY in the shallow near shore area of the lake.

Beach seining was mostly conducted in August and September in most sectors around the lake in 2010. In 2011 and 2012 beach seining was mostly conducted during July and August in sectors 1, 3, 4, 5, 15 and 16 (Fig. 1). These sectors had suitable depth and substrate for beach seining and were known to support YOY SMB.

Sporadic angling effort around large boulders and other structures often known to be utilized by SMB resulted in the capture of two adult SMB in 2010, six adults in 2011 and one adult in 2012. All but one adult SMB were caught in sectors 1, 15 and 16 and all but one bass were caught in June and July.

All SMB captured were killed and sampled before shipment to the DFO Gulf Fisheries Center where they are currently preserved in freezers. Bass were sampled for fork length (nearest 1 mm) and weighed (nearest 0.1 g). Juveniles and adults were scale sampled for interpretation of age and sex was determined by dissection.

Containment of Smallmouth Bass in Miramichi Lake

The main barrier was not breached during any high water events and no SMB were captured in the enclosure between the main barrier and the debris fence during any sweep and sorting process.

Over 52% of all the SMB captured in the Miramichi Lake since 2009 were caught in the shallow areas of the lake in sectors bordering the outlet to Lake Brook (sector 16, and part of sectors 1 and 15) from May to October. YOY and juvenile SMB were captured against the front of the barrier, either by hand while cleaning the debris fence or during boat and backpack electrofishing. In 2009 (n=10), 2010 (n=1) and 2011 (n=1), YOY SMB were captured in the upper section of the Lake Brook in August and September. It is believed that some of the one-year old juvenile bass captured downstream of the barrier in 2011 moved into Lake Brook prior to the installation of the containment barrier.

Although the barrier may have become permeable to YOY for short periods of time, particularly during the process of moving YOY gaspereau downstream, it seems to have successfully prevented the passage of larger bass. No SMB 2-years of age or older were captured in the upper section of Lake brook. No SMB of any size were observed in the lower section during repeated backpack electrofishing in 2009, 2010 and 2011 or angling in 2012. No SMB were captured at the lower barrier near the mouth of Lake Brook or at the rotary screw trap operated in 2009. It should be noted that the upper section of Lake Brook acted more like an extension of Miramichi Lake from 2009 until 2011 due to the slowing of the water by a debris dam below the barrier. The debris dam washed out prior to the season in 2012 and that section of the brook became fast flowing. It is therefore possible that the null catch behind the barrier in 2012 may be the result of SMB being harder to find and capture in rapid water compared to the relatively calmer water of 2009 to 2011. Different habitat in the upper section of Lake Brook combined with a lower density of SMB in Miramichi Lake could have reduced the likelihood of bass moving out of the lake. No SMB has been observed or reported from other parts of the Miramichi watershed.

Catches of Smallmouth Bass and other aquatic species

A diverse fish fauna was sampled in Miramichi Lake; the most abundant species tabulated, in decreasing order of abundance, were Yellow Perch (*Perca flavescens*), White Sucker (*Catostomus commersoni*), White Perch (*Morone americana*), Fallfish (*Semotilus corporalis*) and numerous cyprinid species (Table 2). Anadromous species enumerated from Miramichi

Lake included Sea Lamprey (*Petromyzon marinus*), gaspereau (*Alosa sp*), Atlantic Salmon (*Salmo salar*), and American Eel (*Anguilla rostrata*) (Table 2). Large spawning runs of gaspereau and post-spawn adults (tens of thousands) were passed into and out of Miramichi Lake in all three years and unquantified large numbers of YOY gaspereau were guided through the fence and downstream in late July and August in all three years.

Table 2. Summary of enumerated catches by species and fishing methods in Miramichi Lake in 2010. Only SMB captured from backpack electrofishing or in beach seines were enumerated. No new species were identified in 2011 and 2012.

Species	Backpack electrofisher	Boat electrofisher	Gillnet	Fyke net	Beach seine
Yellow Perch		10,129	993	19,566	
White Sucker		1,405	3,541	23,171	
White Perch		2,302	1,968	5,073	
Fallfish		598	146	3,825	
Smallmouth Bass	183	1,294	25	202	816
Common Shiner		532		1,648	
Gaspereau		477	69	1,005	
Golden Shiner		369	16	550	
Brown Bullhead		55	75	648	
Banded Killifish		517		41	
American Eel		8		153	
Brook Trout		2	12	76	
Creek Chub		8		13	
Lake Chub		6		1	
Sea lamprey				1	
Atlantic Salmon				1	
Pearl Dace		1			
Tadpole		416		1,059	

A total of 3,153 SMB were captured and removed during 2010 to 2012. Of these, 97% (3,051 fish) were YOY from spawning in 2010, 2011 and 2012 (Table 3). The largest number of YOY were captured by boat electrofishing followed by beach seining (Table 3). The largest number of juvenile SMB (age-1 and 2) was captured by fyke netting and boat electrofishing (Table 3). Adult SMB (age-3 and older) were mostly captured with gillnets and by boat electrofishing followed by fyke netting and angling (Table 3). The largest (477 mm) SMB captured was in a fyke net in 2010 and most of the SMB greater than 200 mm in fork length were captured with gillnets.

Table 3. Catch of SMB by fishing method and overall in Miramichi Lake, 2010 to 2012. YOY are young-of-the-year; juvenile are age 1 and 2; adult are age 3 and older. Other methods include by snorkeling and with dipnets.

Year	Fishing method	Catch by life stage			
		YOY	Juvenile	Adult	Total
2010	Boat electrofishing	1,285	6	3	1,294
	Backpack electrofishing	179	4	0	183
	Gillnets	0	5	20	25
	Fyke nets	190	6	6	202
	Beach seines	815	0	0	815
	Angling	0	0	2	2
	Barrier	5	0	0	5
	Other	58	0	0	58
	All methods	2,532	21	31	2,584
2011	Boat electrofishing	302	6	12	320
	Backpack electrofishing	53	0	0	53
	Gillnets	0	0	11	11
	Fyke nets	32	4	1	37
	Beach seines	96	0	0	96
	Angling	0	0	6	6
	Barrier	0	0	0	0
	Other	0	0	0	0
	All methods	483	10	30	523
2012	Boat electrofishing	12	4	2	18
	Backpack electrofishing	9	0	0	9
	Gillnets	0	0	0	0
	Fyke nets	2	2	0	4
	Beach seines	13	0	0	13
	Angling	0	0	1	1
	Barrier	0	1	0	1
	Other	0	0	0	0
	All methods	36	7	3	46
All years	All methods	3,051	38	64	3,153

Life history characteristics of Smallmouth Bass

The two oldest SMB captured in Miramichi Lake were 10 and 11 years old, belonging to the 2000 year class, and were captured in 2010 and 2011 (Table 4). No SMB from the 2001, 2003 and 2004 year classes were captured in Miramichi Lake.

The fork length of the juveniles (age 1 and 2) varied between 72 and 240 mm, whereas the fork length of the adults (≥ age 3) varied between 201 and 477 mm (Table 5). Overall, the sex ratio was close to one when combining all the catches except for the 4 year old age group for which twice as many females than males were captured over all years (Table 5).

Table 4. Total number and year class of SMB captured and removed from Miramichi Lake during 2009 to 2012. Data for 2009 are from O'Donnell and Reid (unpublished data).

Year class	Year of capture				Total
	2009	2010	2011	2012	
2000		1	1		2
2001					0
2002		3	1		4
2003					0
2004					0
2005	10	6	2		18
2006	11	8	3		22
2007	4	13	6		23
2008	13	16	17	2	48
2009	26	5	1	1	33
2010		2,532	9	3	2,544
2011			483	4	487
2012				36	36
Total	64	2,584	523	46	3,217

Table 5. Biological characteristics of SMB captured in Miramichi Lake in 2009 to 2012.

Age (years)	Sex			Fork length (mm)				Whole weight (g)			
	Female	Male	Un-known	Mean (CV%)	Min	Max	N	Mean (CV%)	Min	Max	N
0				58 (25%)	28	110	3,055	4 (68%)	0.5	13	446
1	3	4	24	130 (26%)	72	174	31	46 (54%)	5	85	25
2	11	12	1	197 (16%)	131	240	24	133 (44%)	28	221	21
3	18	18	6	257 (11%)	201	313	40	287 (36%)	115	483	41
4	17	8	1	303 (11%)	239	350	26	499 (37%)	218	799	24
5	4	4	1	340 (6%)	317	375	9	641(20%)	507	850	8
6	1	1		391	365	416	2	1,015	680	1,349	2
7											
8	1	2		419 (4%)	409	438	3	1,463 (20%)	1,162	1,750	3
9		1		425			1	1,378			1
10	1			477			1	1,853			1
11		1		460			1	1,758			1
Total	56	51	33								

Length of the growing season determines the size of juvenile SMB entering their first winter which is positively correlated with over-winter survival. Achieving a minimum body size is critical for first winter survival and it was reported that 50 mm is the minimum length for SMB in the Maritimes. Summer water temperatures in Miramichi Lake encompass the preferred growth temperatures for SMB. The fork lengths at age of the SMB in Miramichi Lake were similar to those from other introduced populations in Nova Scotia. From 2010 to 2012, the majority (>96%) of YOY SMB captured in Miramichi Lake were larger than 50 mm in October, ranging in size from 47 to 110 mm fork length and averaging 71 mm (12.3 mm std. dev.). The five one-year old bass captured in May (2010 to 2012), survivors of the previous winters, measured 72 to 85 mm fork length (mean 78 mm and std. dev. 5.3 mm) and are within the range of sizes of YOY sampled in the previous years. The YOY gained on average 30.6 mm fork length during their first growing season. Most of the growth occurred in August and September (Fig. 3).

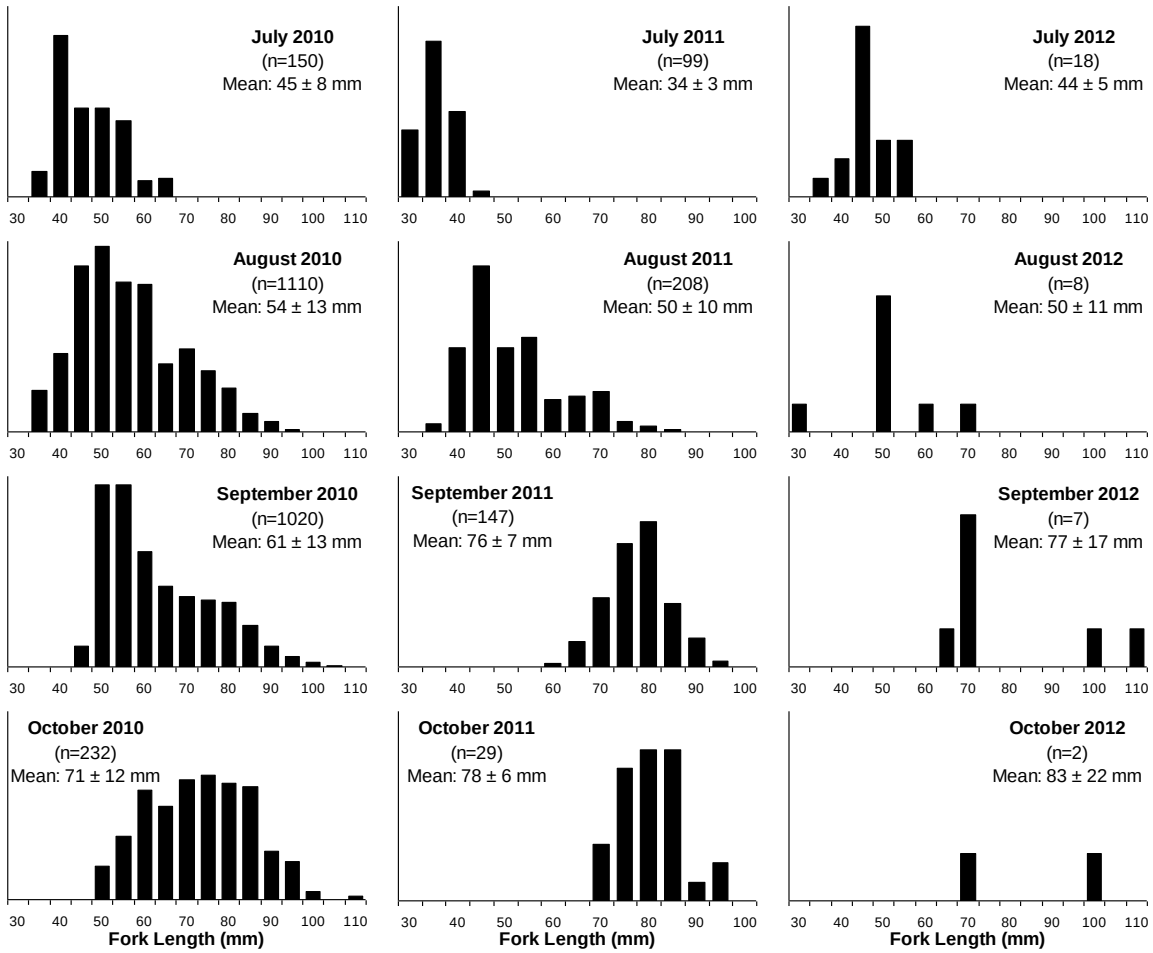


Figure 3. Relative fork length distribution of young-of-the-year SMB by month and year captured by all fishing methods in Miramichi Lake, 2010 to 2012. (n = number of SMB sampled for fork length.

Habitat utilization of Smallmouth Bass

In its native range, SMB inhabit primarily larger (> 40 ha) mesotrophic (clean, clear) lakes with average depths > 9 m. Shallow, cobble to gravel substrate in littoral zones are important for both spawning and rearing.

Most captures of adult SMB in gillnets and fyke nets occurred in sectors near the two deep holes (sectors 1 and 5) whereas the captures by electrofishing boat were on what is believed to be the prime spawning grounds (sectors 1 and 16).

In 2011, 94% of the adults (N = 17 fish) captured in May and June were caught in sectors 1, 15 and 16, and 76% of all adults caught during the entire season (22 of 30 bass) were from these same sectors (Fig. 1). This is similar to 2010 where the majority of the adult SMB were captured in sector 1, and to 2012 where all three adults were captured in sectors 1 and 16. The location and timing of capture of YOY provides strong evidence that the preferred spawning sites are located in sectors 1 and 16, more specifically along the shallow grounds between the shoreline and the deep hole located in that area (Fig. 4).

In 2011 YOY were first captured in the shallow waters on each side of the demarcation line between sectors 1 and 16, and then progressively further from this area as they dispersed along the near shore of the lake each week (Fig. 4). This suggests that adults aggregated in sectors 1 and 16 during the spawning period (late May – early June). In 2012, YOY were first caught in the same area as 2011, and also dispersed along the near shore of the lake each week, but were never captured outside of sectors 1 and 16. The first captures of YOY in 2010 were in sectors 1, 2, 4, 5 and 16, with the majority of the catch that week (76%) coming from sectors 1 and 16. The substrate, depths and water temperature in sectors 1 and 16 are most consistent with the spawning habitat favored by SMB. In 2011 and 2012, YOY appeared to have distributed themselves from the spawning area in sectors 1 and 16.

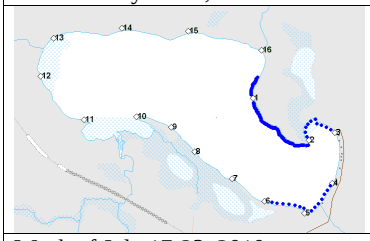
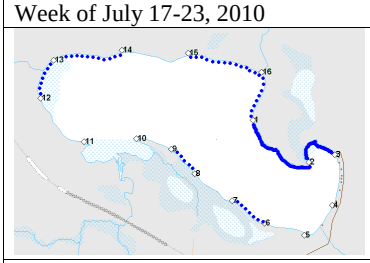
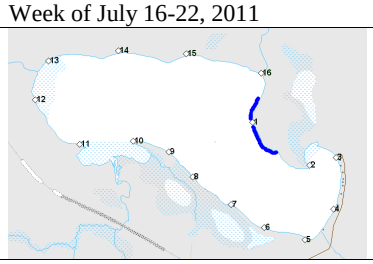
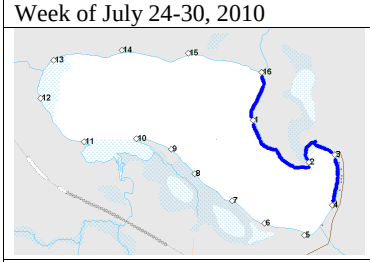
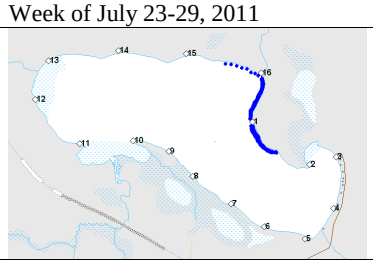
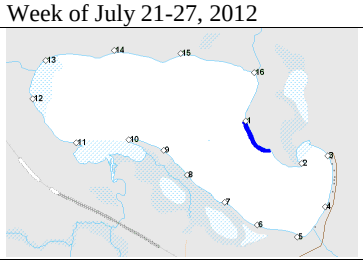
The only juvenile bass captured by backpack electrofishing were in Lake Brook in 2009 (n=1) and 2010 (n=4). In 2010 and 2011, juveniles were mostly captured near the deep hole in sector 5 from May to September, and in sectors 1 and 16 before (early May) and after (late July to October) the spawning period, as well as the area near the outlet (part of sectors 15 and 16) and Lake Brook. In 2012, all seven juveniles were captured in sectors 1 and 16 from May to July, which may be another indication that spawning grounds were less occupied by territorial spawning adults than in previous years.

Estimates of Abundance of Smallmouth Bass

The total number of SMB captured and removed declined by 5-fold in 2011 (523 fish) compared to 2010 (2,584 fish), and by 11-fold in 2012 (46 fish) compared to 2011 (Table 3).

Boat electrofishing effort doubled in 2011 relative to 2010 and was lower in 2012 relative to 2011 due to inclement weather conditions (Table 6). The catch-per-unit-effort (CPUE) for boat electrofishing was 15.84 SMB per hour of boat electrofishing effort (all life stages combined) in 2010, 1.74 SMB per hour in 2011 and 0.14 SMB per hr in 2012 (Table 6). From 2010 to 2012, CPUE decreased by 99% for YOY and by 60% for juveniles. However, the CPUE for adult, although low in all three years, increased in 2011. This could be attributed to an increase in capture efficiency in 2011 due to a better knowledge of the habitat utilization of the species and improved capture technique compared to 2010. When combining all life stages, the total CPUE declined by 99% in 2012 compared to 2010 (Table 6).

Gillnetting effort more than doubled in 2011 and 2012 compared to 2010 (Table 6). The total number of SMB captured declined by 56% in 2011 compared to 2010, and by 100% in 2012 compared to 2011 (Table 1). In 2011, a total of 11 SMB were captured with gillnets, resulting in a CPUE of 0.004 fish per net-day, an 86% decrease in CPUE (all life stages combined) compared to 2010 (Table 6). In 2009, gillnets were not always fished overnight and the unit of effort is not comparable with those in 2010 to 2012. Nonetheless, in 2009, an estimated total of 2,515 hours of gillnetting resulted in the capture of 21 adult SMB (3 and 4 year old) and a CPUE much higher compared to 2011, where 2,732 net-days (over 65,500 hours) resulted in the capture of six juvenile and five adult SMB. No SMB were captured with 2,613 net-days of effort in 2012.

Week of July 10-16, 2010		
		
Week of July 17-23, 2010	Week of July 16-22, 2011	
		
Week of July 24-30, 2010	Week of July 23-29, 2011	Week of July 21-27, 2012
		
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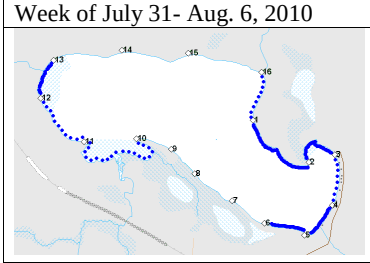	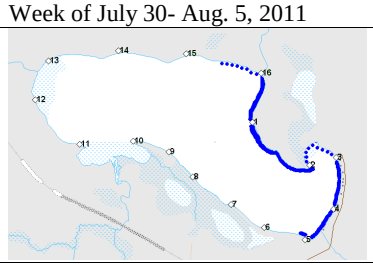	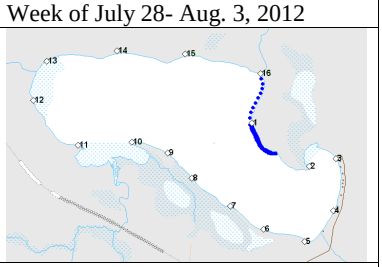
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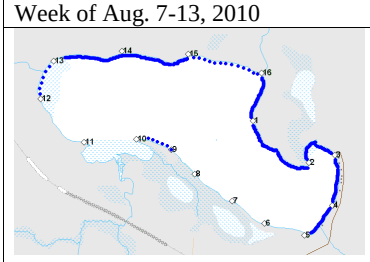
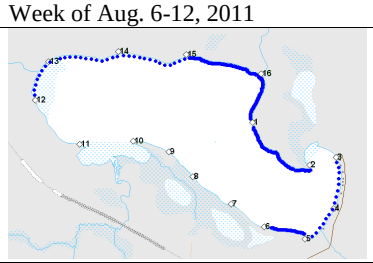
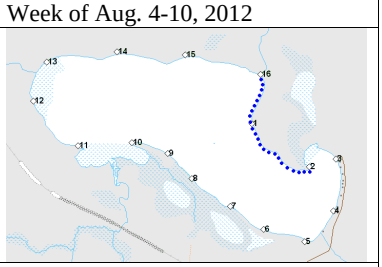
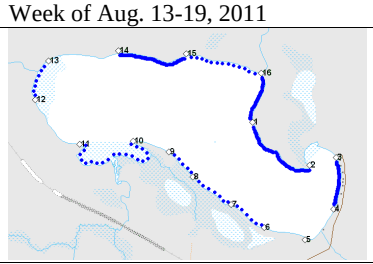
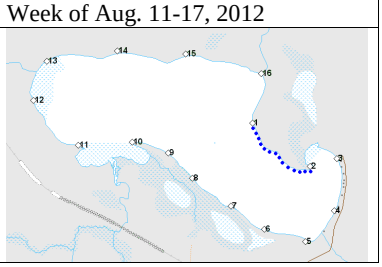
		
Week of Aug. 14-20, 2010	Week of Aug. 13-19, 2011	Week of Aug. 11-17, 2012
		

Figure 4. In-season distribution (presence) of catches of YOY Smallmouth Bass in Miramichi Lake by week of sampling during mid-July to mid-August, 2010 to 2012. The catches are tabulated over all methods of capture each week. Dotted lines along the shore represent sectors where 1 or 2 YOY were

captured in the week sampled; solid lines along the shore delineate the sectors with captures of 3 or more YOY in the week sampled.

Table 6. Comparison of the catch per unit of effort (catch per hour of boat electrofishing, catch per net-day for gillnets and fyke nets) of SMB by life stage, in Miramichi Lake during 2010 to 2012. YOY are young-of-the-year; juvenile are age 1 and 2; adult are age 3 and older.

Fishing method		2010	2011	2012
Boat electrofishing				
Effort (hours)		81.7	183.4	125.2
Catch per unit effort of Smallmouth Bass	YOY	15.73	1.65	0.10
	Juvenile	0.07	0.03	0.03
	Adult	0.04	0.07	0.02
	Total	15.84	1.74	0.14
Gillnets				
Effort (net-days)		1,150	2,732	2,613
Catch per unit effort of Smallmouth Bass	YOY	0	0	0
	Juvenile	0.004	0.002	0
	Adult	0.02	0.002	0
	Total	0.02	0.004	0
Fyke nets				
Effort (net-days)		487	988	868
Catch per unit effort of Smallmouth Bass	YOY	0.390	0.03	0.002
	Juvenile	0.010	0.004	0.002
	Adult	0.020	0.001	0
	Total	0.410	0.040	0.005

Fyke-netting effort doubled in 2011 and 2012 compared to 2010 and the total number of SMB captured declined by 98% in 2012 compared to 2010 (Table 6). In total, 202 SMB were captured in 2010, 37 SMB in 2011 and 4 SMB in 2012 (Table 1), the majority (83%) were YOY SMB. The CPUE from fyke-nets was 0.41 fish per net-day (all life stages combined) in 2010, 0.04 SMB per net-day in 2011 and 0.005 SMB per net-day in 2012. Compared with 2010, CPUE declined by 90% in 2011, and by 99% by the end of 2012 (Table 6).

The total abundance of SMB in Miramichi Lake in 2009 to 2012 is unknown. Observations since 2009 have shown that SMB are not randomly distributed in Miramichi Lake. Over the three years, and over each sampling season, fishing efforts were deployed in locations where the probability of catching bass was greatest based on previous observations, such as: gillnetting and fyke-netting mostly around the deep holes and spawning grounds; or beach seining and backpack electrofishing where YOY have been captured in the past and their presence was detected by boat electrofishing that year. The only age group in Miramichi Lake for which a population estimate could be derived was for YOY SMB in 2010. The population estimate was very uncertain, a coefficient of variation of greater than 100%, but there was a high probability (>90%) that the population size of YOY was less than 15,000 fish in 2010. The estimated probability of capture by boat electrofishing was very low (0.0125 per 10,000 seconds of effort). To achieve a probability of capture of 50% of the population in a sampling period of 3 to 4 days, the sampling intensity required was in the order of 111 hours.

Although the total population size of adult SMB in Miramichi Lake is unknown, an index of the number of adults available for spawning during 2009 to 2012 was derived from the cumulative catches of adult SMB (Table 7). The minimum number of adult spawners in May of year y was calculated as the cumulative catch of adult spawners age 3 years and older in June to October

of year y and the catches of adult SMB aged year 3+i and older in year y + i for i = 1 to 3 (2010 to 2012). In 2009, it was estimated that there were at least 46 spawning adults in Miramichi Lake, of which 24 were females (Table 7). The number of adults in May was estimated to have been 45 in 2010 of which 18 were females, and declined to 27 in 2011 with 15 females, and to 3 adult SMB in 2012 with two females (Table 7).

Table 7. Catches of male and female adult (age 3 years and older) SMB in May (pre-spawning and spawning period) and in June to October (post-spawning) from all fishing methods, 2009 to 2012. Also shown are the minimum abundances of adult bass age 3 years and older in May of each year based on cumulative catches of adult fish in subsequent years.

Year	Sex	May	June to October	Minimum adults (3+) present in May	Catch of YOY (number)
2009	Female		14	24	
	Male		5	18	
	All adults		21	46	
2010	Female	0	12	18	
	Male	1	17	23	2,532
	All adults	1	30	45	
2011	Female	1	13	15	
	Male	3	8	8	483
	All adults	5	25	27	
2012	Female	0	2	2	
	Male	0	1	1	36
	All adults	0	3	3	

The catches of YOY from all fishing methods in 2010 to 2012 declined in parallel with the estimated index of adult spawners from the lake; YOY index to total spawner (adults 3+) ratios were 56, 18 and 12 for 2010 to 2012, respectively (Table 7).

Results of Eradication Efforts

There is strong evidence of depletion of SMB in Miramichi Lake since 2010. The low catch rates in 2012 are interpreted as low abundance of these fish in Miramichi Lake. Overall, boat electrofishing and beach seining were the most successful methods at capturing YOY (representing 70 to 85% of their catch each year), followed by backpack electrofishing and fyke-netting (Fig. 5). Juvenile SMB were successfully captured by boat electrofishing and fyke-netting (with 60 to 100% of their catch each year), while adult SMB were mostly captured by gill-nets (all ages) and boat electrofishing (3 and 4 year old), followed by fyke-netting and angling (Fig. 5).

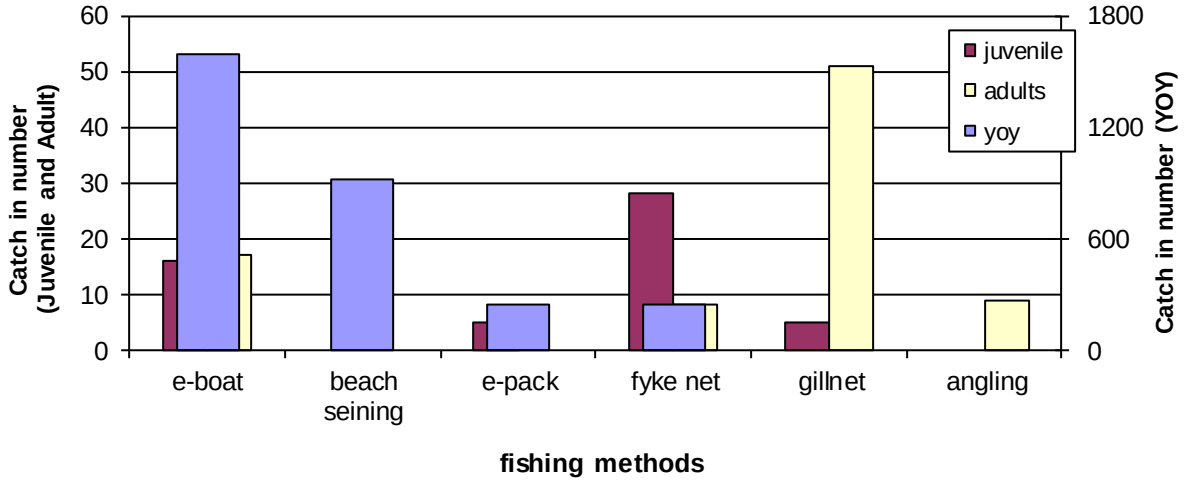


Figure 5. Total catches of SMB by life stage (YOY, juvenile, adult) for each fishing method (electrofishing boat, beach seining, backpack electrofishing, fyke nets, gillnets and angling) in Miramichi Lake during 2010 to 2012.

One of the strategies to control and eradicate SMB from Miramichi Lake was to target and remove the adults prior to spawning. The location and timing of first capture of YOY provides strong evidence that the preferred spawning grounds are located in sectors 1 and 16. Despite the extensive fishing efforts in the three years, SMB successfully spawned in 2010 to 2012. From 2010 to 2012, CPUEs for YOY SMB dropped by more than 99% for the electrofishing boat (from 15.73 to 0.14 fish per hr) and fyke nets (from 0.71 to 0.002 fish per net-day), and by more than 88% for backpack electrofishing (from 6.68 to 0.79 fish per hr). Studies reported that electrofishing can also induce elevated mortality rates in embryos, particularly during the early developmental phase. High voltage (1,000 V) and intensive fishing effort of about 25 hours of electrofishing was applied in sectors 1 and 16 during the potential incubation period of the embryos (May and June) in 2011 and 2012 compared to only four hours in 2010. Although the effects of electrofishing on SMB embryo survival was not quantified, it is possible that the elevated amount of electrofishing effort applied on the deposited eggs along with reduced adult spawner abundance contributed to the reduction in YOY production.

The extent of the adult SMB reduction is unknown, but the decline from the relatively higher annual catch of 30 adults in 2010 and 2011 to 3 in 2012 is important. Juvenile SMB (ages 1 and 2 years old) catches over the three years have been low, despite high abundance of YOY in the lake in 2010 and 2011. Total juvenile catches were 21 in 2010, 10 in 2011 and 7 in 2012 (Table 3). Juvenile bass captured by backpack electrofishing were in Lake Brook in 2009 (n=1) and were mostly captured near the deep hole in sector 5 from May to September, and in sectors 1 and 16 before (early May) and after (late July to October) the spawning period, as well as the area immediately upstream of the barrier (part of sectors 15 and 16) and in Lake Brook. In 2012, all seven juveniles were captured in sectors 1 and 16 from May to July. The few juvenile SMB captured over the years (relative to the other life stages of the population) may indicate that overwintering survival of YOY SMB is low in Miramichi Lake or that this life stage is difficult to capture with the sampling methods currently employed.

Impacts of Control Measures on Other Species

With the exception of the gillnets, fish captured with the other gears were captured alive and could be returned to the water. Several species were captured in gillnets with the largest numbers and proportions of total catches in the small mesh gillnets (< 3 inches) (Table 8). In 2010 when these catches were enumerated, 79% of the SMB were captured in gillnets with mesh size ≥ 3 inches, whereas about 20% of the catch of white perch and white sucker and 10% of the catches of yellow perch were taken in these large meshed gillnets (Table 8). In 2011 and 2012, only gillnets with a mesh size ≥ 3 inches were used in order to reduce the bycatch and mortality on small bodied fish. In 2012, minimal bycatch was recorded from the gillnets. The extensive use of these large meshed nets resulted in an important reduction in the abundance of the larger sizes of the bycatch species in the lake although the small size groups of these species remained abundant in the lake.

Table 8. Summary of enumerated catches by species in gillnets with mesh size < 3 inches and in gillnets with mesh size ≥ 3 inches in 2010. After July, catches of species other than SMB were not completely enumerated.

Species	Gillnet mesh size (inches)		Proportion of total in mesh size ≥ 3
	< 3	≥ 3	
Smallmouth Bass	4	15	0.79
Brown Bullhead	16	5	0.24
Brook Trout	6	4	0.40
Fallfish	59	59	0.50
Gaspereau	43	16	0.27
Golden Shiner	8	0	0.00
White Perch	1,057	284	0.21
White Suckers	1,921	487	0.20
Yellow Perch	190	20	0.10
Total	3,304	890	0.21

Conclusions

The containment of SMB in Miramichi Lake between 2009 and 2012 was deemed successful as far as it can be demonstrated that few SMB were captured downstream of the barrier. Over 52% of all the life stages of SMB captured in the Miramichi Lake since 2009 were caught in the vicinity of the lake outflow (where the barrier is located). The barrier may become permeable to YOY for short periods of time, but has precluded the passage of larger juvenile and adult SMB during its period of operation. A reduction in bass density in the lake during the last three years may have contributed in further decreasing the likelihood of fish escaping from the lake. No SMB have been observed or reported from any other part of the Miramichi watershed.

The reduction in numbers of the SMB in Miramichi Lake between 2009 and 2012 was deemed successful as demonstrated by the population reduction. Although the total population size of adult SMB in Miramichi Lake remains unknown, the number of adult SMB in 2010 was estimated to have been less than 50 fish. The extent of the adult SMB reduction is unknown but it has been reduced to very few individuals by the end of the 2012 field season (Table 7).

Adult SMB were mostly captured by gillnets and boat electrofishing. The decline from the relatively higher annual gillnet catch of 30 adults in 2010 and 2011 to 3 in 2012 is important.

The index of abundance based on CPUE in gillnets decreased by 86% in 2011 relative to 2010 and no adult SMB were captured in 2012 despite considerable gill netting effort (2,613 net-days).

SMB successfully spawned each year between 2008 and 2012. Spawning success in 2012 is considered to have been very limited based on the very low numbers of YOY captured and their limited distribution in the Lake.

Boat electrofishing and beach seining were the most successful methods for capturing YOY SMB. Juvenile SMB were successfully captured by boat electrofishing and fyke-netting.

The containment barrier at the outflow of the lake appears to have been effective at preventing the passage of larger juvenile and adult SMB from Miramichi Lake, however the desire of SMB to leave the lake and enter the stream or riverine environment is unknown. Over 50% of all SMB captured in Miramichi Lake since 2009 were caught in sectors 1 and 16 and in close proximity to the outflow into Lake Brook. The barrier may become permeable to YOY SMB for short periods of time when allowing the downstream movement of other fish through it. The reduction of SMB in Miramichi Lake between 2009 and 2012 may contribute to further decreasing the likelihood of fish escaping from the lake.

Substantial new knowledge on SMB in Miramichi Lake has been gained from the work conducted during 2009 to 2012. A preferred spawning area has been inferred which can be used to focus future activities with the objective of preventing spawning and ultimately recruitment to the lake. Based on the location and timing of capture of adult and YOY SMB, there is strong evidence that the favoured spawning area is situated in sectors 1 and 16, more specifically along the shallow grounds between the shoreline and the deep hole located in that area (Fig. 1).

Sustained sampling efforts with the electrofishing boat and with large mesh gillnets as conducted in 2011 and 2012 during the potential spawning and incubation period could be an effective means of achieving the objective of preventing spawning and removing adult SMB from the lake. Targeted boat electrofishing may be effective at disrupting the guarding males and negatively affecting the development of the eggs. YOY SMB are easily captured with the electrofishing boat and evidence of spawning success could be obtained by targeted sampling with this gear at the end of July and August.

Further knowledge on habitat utilization by juveniles and adults is required to target all areas of Miramichi Lake that may be supporting SMB. To date, only SMB in shallow areas around the perimeter of the Lake have been targeted because the central area of the lake could not be fished adequately with the available gear and methods. Gillnets set at the water's surface resulted in conflicts with recreational boating activities throughout the summer. The use of sinking gillnets should be considered in the future, as well as the use of smaller mesh sizes, which have been effective at sampling SMB elsewhere. Targeted electrofishing activities in the shallow nearshore areas in late fall could also be used to remove YOY SMB as they are known to seek overwintering refuge in coarse substrate.

The control program had impacts on other species in the lake. The extensive fishing effort with large meshed gillnets resulted in a detectable reduction in the abundance of the larger sizes of the bycatch species in the lake, in particular of white perch, white sucker and yellow perch. The small size groups of these species remain abundant in the lake.

The complete removal of SMB from Miramichi Lake may be difficult to prove regardless of the control technique. As the population declines in abundance, more and more effort will be required to capture the few remaining individuals. Simulations with the data collected in 2010 indicated that it would take a very large sampling effort to be reasonably confident (90% certainty) that the failure to catch any SMB was indicative of eradication of the species in Miramichi Lake.

Contributors

Name	Affiliation
Gérald Chaput (chairperson of the meeting)	DFO Science, Gulf Region
Michel Biron	DFO Science, Gulf Region
Cindy Breau	DFO Science, Gulf Region
Kathryn Collet	Province of New Brunswick
Chris Connell	Province of New Brunswick
Scott Douglas	DFO Science, Gulf Region
David Drolet	University of Prince Edward Island
Wayne Fairchild	DFO Science, Gulf Region
Mark Hambrook	Miramichi Salmon Association
Marc Lanteigne	DFO Science, Gulf Region
Jason LeBlanc	Province of Nova Scotia
Debbie Norton	Miramichi Watershed Management Committee
Pam Seymour	Province of New Brunswick

Approved by

Ghislain Chouinard
Regional Director Science Branch
Gulf Region

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Sources of Information

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Brown, T.G., Runciman, B., Pollard, S., Grant, A.D.A., and Bradford, M.J. 2009. Biological synopsis of smallmouth bass (*Micropterus dolomieu*). Can. Manuscr. Rep. Fish. Aquat. Sci. 2887: v + 50 p.

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Center for Science Advice (CSA)
Gulf Region
Fisheries and Oceans Canada
P.O. Box 5030
Moncton, NB E1C 9B6

Telephone: 506 851 6253
E-Mail: csas-sccs@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs

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