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Geographic distribution of smallmouth bass, *Micropterus dolomieu*, in Nova Scotia: history of early introductions and factors affecting current range

Distribution géographique de l'achigan à petite bouche, *Micropterus dolomieu*, en Nouvelle-Écosse : historique des premières introductions et facteurs déterminants de son aire de distribution présente

Jason LeBlanc
Nova Scotia Department of Fisheries and Aquaculture
Inland Fisheries Division
PO Box / C.P. 700
Pictou, NS / N.-É.
B0K 1H0

leblanje@gov.ns.ca

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ABSTRACT

Since the first introduction of smallmouth bass (*Micropterus dolomieu)* into Nova Scotia in 1942, the number of occurrences in lakes and rivers increased to 188 by 2008 due to accidental and illegal transfers and dispersal within watersheds. Smallmouth bass are present in all but five counties but are more concentrated in Halifax, Lunenburg and Yarmouth counties. The majority of smallmouth bass in Nova Scotia occupy lakes and the prevalence in and utilization of riverine habitat is not well understood. Lake morphology appears to be a good predictor of the probability of establishment and shorter aquatic growing seasons in certain regions may function to prohibit, reduce or delay establishment. Smallmouth bass were confirmed in Lake Ainslie, Inverness County in 2003 and by 2007 had limited reproductive success but show evidence of young of the year winter survival. All new occurrences of smallmouth bass, as reported by anglers, are assigned a confidence ranking and subsequently followed up on by field staff. Waterbodies are only added to the distribution list once the presence is confirmed.

RÉSUMÉ

Depuis la première introduction de l’achigan à petite bouche (*Micropterus dolomieu)* en Nouvelle-Écosse en 1942, les occurrences de l’espèce dans les lacs et rivières ont augmenté et atteint 188 localités en 2008. Cette augmentation parmi les bassins versants s’explique par des transferts accidentels et illégaux. On retrouve présentement l’achigan à petite bouche dans tous les comtés de la Nouvelle-Écosse, sauf cinq, et l’espèce est particulièrement abondante dans les comtés de Halifax, Lunenburg et Yarmouth. On retrouve l’espèce principalement dans les lacs mais sa distribution et son utilisation d’habitat riverain sont très peu connus. Les caractéristiques des lacs semblent être des facteurs prédictifs de la probabilité d’établissement de l’espèce. Une saison de croissance raccourcie dans certaines régions de la province pourrait ralentir sinon prévenir l’établissement de l’espèce. La présence de l’achigan à petite bouche a été confirmée dans le lac Ainslie, comté Inverness en 2003. Par 2007, on a eu des indications de succès de reproduction limité mais les jeunes de l’année semblent avoir un bon succès de vie durant l’hiver. Les rapports de nouvelles occurrences de l’achigan à petite bouche provenant des pêcheurs sportifs sont premièrement assignés une cote de fiabilité en attendant d’être confirmés. Les cours d’eau sont ajoutés à la liste de distribution géographique que lorsque la présence de l’espèce est confirmée par les agents de terrain.

INTRODUCTION

The intentional or accidental movement of non-native smallmouth bass (*Micropterus dolomieu*) has contributed substantially to the current geographic distribution of this species in Nova Scotia. It is illegal to release live fish into the waters of the province without a permit because of the potential threat to local fish populations (ex. trophic alterations, competitive exclusion, predator-prey relationships, changes in littoral zone fish assemblages). However, since the original authorized introductions in Nova Scotia in the 1940s, the number of documented occurrences of smallmouth bass has increased to 188 water bodies by 2008 (Table 1, Fig. 1) and supports a significant recreational fishery. Smallmouth bass angling in Nova Scotia contributes an estimated $ 7 million to the economy annually. Smallmouth bass have become an important species within the recreational sport fishery and have been in the top five preferred species in Nova Scotia, by resident anglers, for the last 15 years (Nova Scotia Department of Fisheries and Aquaculture 2005). However, there continues to be a polarization of opinions about smallmouth bass in the province; within the angling community, and fisheries science and management.

Educational materials designed to inform about the potential negative consequences of illegal transfers have been widely utilized but unsuccessful in reducing the number of unauthorized introductions in recent years. Since the mid-1980s the number of documented occurrences of smallmouth bass has increased (Fig. 2). Ineffective legislation continues to be an impediment to reducing the threat even further. The main vectors of transfer in Nova Scotia, apart from the original government introductions, are illegal transfers, natural dispersal within watersheds and to a lesser extent, accidental releases; ex. live bait releases. New introductions documented during the development of this publication are not included. Data represents a complete data set up to and including May 2009 (i.e. Blacketts Lake, Cape Breton County).

The purpose of this report is to review the early introductions of smallmouth bass in Nova Scotia, in the context of range expansion since the 1940s and discuss the current status of this species. Nova Scotia has 6674 lakes of 1 hectare or greater in surface area (Alexander et al. 1986) and smallmouth bass currently occupy less than 3% of these. However, this represents approximately 9.5% of the total surface area (21,530 ha) of lake habitat in the province. There are several lake morphological characteristics, such as lake surface area and mean depth, that lead to an increased probability of smallmouth bass occupancy as well as regional differences in thermal regimes that seemingly limit, prohibit or delay establishment.

HISTORICAL RANGE

The native range of smallmouth bass (*Micropterus dolomieu*) has been shown to be limited to areas of the Mississippi and Great Lakes basins in North America (MacCrimmon and Robbins 1975) during the late Pleistocene glaciation. During this period a wide range of fluvial conditions facilitated re-colonization of coldwater species and co-existence with warmwater fishes during glacial retreat (Radforth 1944). Post glacial water levels, topography and mean summer temperatures (Coleman 1922) likely facilitated localized movements but smallmouth bass were unable to exploit dispersal opportunities throughout New England and were therefore constrained by the Appalachian mountain range. In 1825 smallmouth bass were reported to have accessed the Hudson River valley when the Erie Canal was opened and soon dispersed throughout New England and the Middle Atlantic states (Bain 1993).

INTRODUCTIONS INTO NOVA SCOTIA AND CURRENT DISTRIBUTION

In the Maritime provinces, smallmouth bass first occurred in New Brunswick during 1870 (Arndt 1996; MacCrimmon and Robbins 1975) and in Nova Scotia in Bunkers Lake, Yarmouth County in 1942 (Catt 1949). It was a sanctioned introduction by Government to develop new recreational fisheries where traditional fisheries for speckled (brook) trout were diminished due to over harvesting, habitat alterations, poor land use practices, eutrophication and acidification. Additionally, a general warming trend has limited the seasonal availability of cool water habitat for salmonid species in many areas of Nova Scotia (MacMillan et al. 2005). Early introductions in Nova Scotia (Table 2) from established populations in New Brunswick lakes were both successful and unsuccessful and occurred using varying numbers of individuals (n=16 to 108 individuals) but no records indicate that any introductions occurred using fish from their indigenous range (McNeill 1995). McNeill (1995) provides a detailed account of early introductions in Nova Scotia:

> "The first successful planting occurred in 1942 when 107 adults were taken from Wheatons Lake, New Brunswick, to Bunker Lake, Yarmouth County, Nova Scotia (Catt, 1949). During 1944-1953, 10 lakes in Nova Scotia were stocked with smallmouth bass, 6 of which developed sustaining populations (Catt, 1949; Gilhen, 1974). After 1953 government-sanctioned stocking of smallmouth bass ceased until 1967. During that interim, lake survey records and angler reports revealed that unauthorized introductions and natural dispersal within watersheds increased the number of lakes inhabited by smallmouth bass."

In 1954, Norwood Clearwater Lake in Digby County was illegally stocked with bass. By 1966 there were 23 known occurrences of smallmouth bass inclusive of the six original introductions that became established: Bunkers Lake (1942), Yarmouth County, Micmac Lake (1944), Halifax County, Lily Lake (1948), Hants County and Elliot Lake (1950), Annapolis County. However, the distribution in Yarmouth and Halifax counties was limited to lakes in the vicinity of the original introductions and remained isolated to Elliot Lake, Annapolis County and Lily Lake, Hants County. The next known occurrences were not documented until 1982 in Hants County with an additional 11 lake populations and not until 1992 in Annapolis County where there are currently seven other lake populations and one stream occurrence.

> "In 1967 and 1968, the Nova Scotia Department of Lands and Forests, with the approval of the Federal Department of Fisheries and Oceans (DFO) and the Nova Scotia Light and Power Co. Ltd., introduced smallmouth bass into Lumsden Pond, Black River Lake, Gaspereau Lake, and Methals Lake in Kings County (Bain, 1993). These and other lakes, by virtue of a hydroelectric power development, form what is known as the Gaspereau- Black River Complex and have developed into the premier smallmouth bass fishery in the province. " (McNeill 1995).

The Gaspereau – Black River Complex, Kings County provided recreational angling opportunities by 1982 (Sabean 1984) and continues to support one of the most important smallmouth bass fisheries in the province. Length of bass caught in tournaments has increased since 1995 and growth and relative weight is near the Nova Scotia average of 77 (LeBlanc and Halfyard 2008a) typical of stable populations in the province. Since 1970 there have been nine new occurrences of bass in Kings County, likely the result of migration within the hydroelectric development and illegal transfers. Murphy Lake, Kings County was stocked in 1984 with 124 adult bass from Black River Lake by the Nova Scotia Department of Natural Resources with permission from the Federal government. This was the last authorized smallmouth bass introduction in the province and continues to provide quality angling opportunities. In 1971,

Spectacle Lake, Digby County, was stocked by the Government of Canada and a successfully reproducing population was established in coexistence with chain pickerel (*Esox niger*) (McNeill 1995). There have been 18 subsequent occurrences of smallmouth bass in Digby County since 1971 several of which have developed into viable smallmouth bass fisheries. The majority of new populations, regardless of the vector of transfer, occur in Halifax and Lunenburg Counties (Fig. 3). These two counties combined represent approximately 44% of the known smallmouth bass occurrences in the province. Smallmouth bass exist in 14 of 18 counties in Nova Scotia. They first occurred in Colchester County in 1988 and Cumberland County in 1999. Other attempts were made in Blair Lake (1950) and Laytons Lake (1945-46) in Cumberland County but were unsuccessful. An earlier introduction of 300 fingerlings is believed to have occurred (Catt 1949) into Layton's Lake, Cumberland County from Lockharts Lake, New Brunswick in 1908 and thought to have not established due to a large resident perch population. This was the only time on record that bass at this stage were introduced. All other introductions were adult fish. No smallmouth bass were collected during field sampling of Laytons Lake (gill nets and angling) in 2003. The first confirmation of smallmouth bass in Queens County was 1989, in Shelburne County in 1997, and Pictou County in 2002. The first documented occurrence of smallmouth bass on Cape Breton Island occurred in Lake Ainslie, Inverness County in 1999 or 2000 and then in Blacketts Lake, Cape Breton County in 2009.

Although habitat modeling and predicting potential bass occurrences using suitability indices can be useful (Vander Zanden et al. 2004; Bozek et al. 2002) and certainly preventing illegal transfers and establishment are important policy goals, the occurrence of new populations from illegal transfers is difficult to monitor and prevent. Additionally, dispersal within watersheds is equally difficult to track given the complexities of fish movement and biological issues surrounding invasion. The intricacy of forecasting accidental or even intentional transfers results in reactionary monitoring. Since 1990 the Nova Scotia Department of Fisheries and Aquaculture has adopted a ranking system to record new reports of smallmouth bass, chain pickerel (*Esox niger*) and common carp (*Cyprinus carpio*). A single report from a non-angler source (ex. land owner, researcher, anonymous) is assigned a confidence level of 0, a single report from an angler is assigned a confidence level of 1, and multiple reports from anglers for the same location are assigned a confidence level of 2 (Table 3). It is important to note that no greater or lesser value is assigned to an angler report based on how knowledgeable or experienced the angler is because observations of an angler may be equally as valid as survey data (McNeill 1995). All reports on potential occurrences of smallmouth bass are subsequently followed up on by fisheries staff in an effort to confirm distributional data. There are currently 52 reported locations that have not been followed up completely to date. Occasionally new populations of bass are found during regular lake survey gill and trap netting as was the case with the 2009 occurrence of smallmouth bass in Blacketts Lake, Cape Breton County.

IMPEDIMENTS TO ESTABLISHMENT

In Nova Scotia smallmouth bass primarily inhabit lakes but are found to occur in various other waterbodies throughout their range (Coble 1975) from cool, clear lakes with rocky shoals and gravel or cobble substrates to slow moving streams with deep pools that have cover features such as logs, boulders and overhangs. Using the Fisheries Inventory of Nova Scotia (FINS) database with smallmouth bass distributional data, two sample t-tests assuming equal variances suggests the presence of smallmouth bass is significantly correlated with lake surface area, mean depth, maximum depth and the shoreline development index. Secchi disk was not a good predictor of smallmouth bass presence (Table 4). It may be possible to predict the potential occurrence of smallmouth bass within watersheds based on some of these lake

morphological features. Conversely, this data suggests that the probability of bass establishing populations in small, shallow lakes is lower than large, deeper lakes.

The length of an agricultural growing season may be a useful predictor of the presence of smallmouth bass whereby a minimum of 95-100 frost free days (FFD) might be required for establishment (Hubert, 1988). Additionally, the length of the aquatic growing season is a major factor affecting growth rate and age at maturity (Coulant 1975). These requirements were thought to potentially restrict establishment in areas of Cape Breton (Hebda et al. 1990) and some regions of mainland Nova Scotia. Although coastal Nova Scotia experiences relatively mild winters, there are regions where the mean daily temperature only decreases to 0 ^{o}C or below for short periods of time, effectively extending the growing season in both spring and fall or the total number of FFD. Conversely, there are regions of the province that have a substantial number of days that drop to at least 0 ^{o}C and have a higher probability of frost. Coastal areas tend to have low probability of frost and interior regions within Inverness County (Lake Ainslie), Cumberland, Colchester, Pictou, Guysborough and Halifax counties have a 90% chance of having frost after May 28 (Figure 4) which could restrict colonization, have negative effects on spawning success and result in poor year class strength and subsequent recruitment. Relating the current smallmouth bass distribution for the province to areas with a shorter growing season (fewer FFDs) illustrates that there are no known bass populations in what will be referred to as the “temperature exclusion zones”. The exact boundaries of what would represent the temperature exclusion zones have not been determined, however for the purposes of this discussion would include the interior of Inverness County from Cheticamp south to Port Hastings, northeastern Halifax County where it intersects Guysborough, Pictou and Colchester counties, the Cobequid mountain range and extending west to the New Brunswick border. Layton’s Lake, Cumberland County, in which smallmouth bass were unsuccessfully introduced on three separate occasions, is located within this zone. Lake Ainslie is within this zone, currently has an established population of smallmouth bass and represents an interesting exception.

Lake Ainslie Population

Inland Fisheries confirmed the presence of smallmouth bass in Lake Ainslie, Inverness County on September 23, 2003 following an angler report. Lake Ainslie is the largest natural freshwater lake in Nova Scotia and empties into the Southwest Margaree River. Documented introductions of smallmouth bass throughout northern Nova Scotia and in rivers draining into the Gulf Region have been limited. This Lake Ainslie occurrence represented the first documented introduction of smallmouth bass on Cape Breton Island. Since that time smallmouth bass and chain pickerel have been found in the Sydney River watershed.

Many aspects of the biology of smallmouth bass are influenced by natural variations in water temperature, including the timing of reproduction and reproductive success (Armour 1993). It has also been shown that instability in water temperature has the potential to affect spawning adults and young differently, ultimately affecting aspects of parental care, timing of spawning, offspring development and brood survival (Cooke et al. 2003). Nest abandonment can occur when water temperatures dip below 15 ^{o}C (Latta 1963) and several studies have reported that thermal variations as small as 2 ^{o}C may result in nest abandonment (Rawson,1945 ; Henderson and Foster 1957). It was thought that the potential for smallmouth bass establishment in Lake Ainslie could be limited by the high likelihood of frost events during the normal spawning period and the area’s propensity for shorter growing seasons as discussed previously. The last frost in spring at the Margaree Forks, Nova Scotia weather station (near Lake Ainslie) is generally not until June 16 or later and has occurred as late as July 10. The first frost in the fall is generally

September 16 or earlier and has occurred as early as August 19 (Environment Canada 1980). A 20 year data set for this station reveals that Lake Ainslie averages 91 FFD (range 65-124). Given that nest building would be delayed 9 out of 10 years and feeding declines drastically below 6 ^{o}C further restricting seasonal growth potential, smallmouth bass predictably could have difficulty becoming established in Lake Ainslie and young of the year could experience high first winter mortality. Overwinter mortality of young of the year has been shown to be influenced by size, energy reserves and temperature (Oliver and Holeton 1979). In New Brunswick populations post-winter collections of age-0 bass indicated high winter mortality of fish less than 5.0 cm (Curry et al. 2005). Longer winters, relative to other areas of Nova Scotia would therefore require maximum age-0 size to survive the starvation period. Age-0 bass collections to assess the size of young of the year bass heading into the first winter should be conducted to determine if year class strength could be comprised by winter survival.

Following the first angler report from Lake Ainslie in 2003 annual catch assessments were conducted to monitor catch per angler hour or catch per unit effort (CPUE). Angler creel surveys were limited and highly variable and white perch were often reported as bass so only catch by fisheries staff is presented here. From 2003 -2008 bass catch increased from 0.3 bass/hr to 1.63 bass/hr (Table 5; Figure 5). Speckled trout catch decreased from 1.5 trout/hr to 0.11 trout/hr during the same time period. However, it is too preliminary to conclude that declining speckled trout catch rates is attributed to increases in smallmouth bass abundance. Natural variation in wild trout abundance, influenced by fall fingerling enhancement from the Margaree Fish Hatchey and trout harvest from the recreational fishery could all influence trout CPUE during this survey. Seasonal variation in CPUE shows a decline in trout catch from May 26 to July 16 from 1.6 trout/hr to 0 trout/hr (range 0-1.71 trout/hr) which for this waterbody has been typical as the lake warms and trout seek out cooler water in tributaries (Figure 6). Inversely, CPUE for bass increased during the same time period from 0 bass/hr to 1.5 bass/hr (range 0-1.73 bass/hr). This is typical of bass lakes in other areas as water temperature increases and bass shift from spawning to feeding behaviour.

Until 2008, sample sizes were too small to assess length at age data. Length at age data for 143 bass caught in 2008 is presented in Figure 7. Smallmouth bass as old as 9 years implies that they could have been present in Lake Ainslie as early as 2000 with low enough abundance to be undetected by the current level of angling. Contrary to expectations based on a limited growing season, bass in Lake Ainslie reach 22.3 cm by age 3, 34.0 cm by age 6 and 40.3 cm by age 9. This growth is similar to bass in Ogden, Parr and Petes lakes, Yarmouth County, at their most southern distribution in Nova Scotia (LeBlanc and Halfyard 2008b). High prey item abundance during key feeding periods and developmental stages may compensate for any thermal restrictions discussed earlier. Little data is available for smallmouth bass younger than age 2, however in many populations in Nova Scotia bass of ages 1, 2 and 3 exhibit growth rates similar to the North American average (Dunlop and Shuter 2004). This may also be important when assessing winter survival.

Littoral zone water temperatures in Lake Ainslie do not tend to reach 15 ^{o}C for a sustained period until mid-June (Figure 8) whereas in established smallmouth bass populations in mainland lakes nest building is typically well under way by May 20-24 (LeBlanc and Heighton 2008, unpublished). Shoreline surveys of approximately 90% of available spawning habitat from 2003-2005 did not confirm reproductive success or any spawning activity at all. In 2006 nest building was documented on June 12 and June 13 in five locations. None of these nests received eggs nor was male guarding behaviour observed during what would be considered the spawning period. Subsequent captures of age 2+ bass caught in 2008, however, strongly suggest that successful spawning and first winter survival occurred and that life cycle closure

occurred in 2006 but was missed by researchers. Year-class strength in northern populations of smallmouth bass is strongly influenced by winter starvation of young-of-the-year (Shuter et al., 1989). During the 2007 field season 2 smallmouth bass nests were documented yet no eggs were deposited during that spawning period either. In 2008 at least 6 nests were documented by July 16 of which 3 produced swim-up fry and male guarding behaviour was observed. Nests in which the guarding male is able to protect the brood up to the swim-up fry stage are considered successful (LeBlanc and Heighton, 2008, unpublished). It can be assumed that there were other successful nests in 2008 as swim-up fry were observed in 3 other locations, however the nests and guarding male bass were not observed. Additional nesting and population density index surveys are planned for subsequent years.

Preliminary assessment of smallmouth bass stomach samples from Lake Ainslie suggest a diet dominated by insects however additional sampling is required to assess the degree to which bass feed on salmonids (particularly speckled trout), juvenile gaspereau, white perch and littoral zone fishes.

USE OF RIVERINE HABITAT IN NOVA SCOTIA

Consistent with populations throughout the northern part of their range, and unlike southern populations where they are primarily a riverine species, smallmouth bass in Nova Scotia are found primarily in lakes. In rivers and streams elsewhere, bass can often be found near undercuts and deeper pools (Rankin 1986) and just outside of the river current's direct flow. They also utilize the downstream side of fallen logs, trees, and stumps and prefer adjacent weed beds.

Riverine populations in Nova Scotia are not well documented, however, there are smallmouth bass throughout the lower Mersey River (series of impoundments), Carleton, Shubenacadie, Sackville and LaHave river drainages. Smallmouth bass in the LaHave River watershed utilize large pools and backwaters below lake populations but it is unclear what biological function the river provides (ex. feeding, over-wintering, spawning).

DISCUSSION

The limited North American distribution of smallmouth bass, post Pleistocene glaciation, appears much different now following decades of introductions within North America and subsequent global transfers to Africa, Asia, Europe, Central America and South America. Nova Scotia has had established populations since 1942 and has smallmouth bass populations and occurrences in most regions of the province. Although the documented number of bass populations is 188, the probability that additional populations exist is high given the extent to which angler reports can be investigated. It is clear that the introduction of a non-native species, particularly a top level predator has the potential for negative interactions with fauna in the recipient water body. Gozlan (2008) suggests that the risk of ecological impact after an introduction of a freshwater fish species is less than 10% for the majority of introduced fish. For Centrarchids, the family to which smallmouth bass belong, the likelihood of ecological impact is thought to range from 0 to 27% (Kolar and Lodge 2002). For consideration is that not all introductions become established as is evident in the history of smallmouth bass in Nova Scotia. Seven out of seventeen (41%) of historically attempted and authorized introductions established populations. This is substantially higher than the suggested establishment rate of

the “tens rule” whereby only 10% of introductions become established and only 10% of those have impacts on organisms in the donor environment (Williamson 1996). Following this rule there could have been as many as 1,880 attempts at establishment (cumulative of illegal transfers, authorized introductions and dispersal events) in waterbodies in Nova Scotia, however this seems unlikely and not to be the case. Application of the “tens rule” to the current list in Table 3 suggests an additional five locations would have established populations. However, the historical successes of authorized introductions in Nova Scotia implies that there could be an additional 22 lakes. The predicted number of established smallmouth bass populations in Nova Scotia could range from 193 to 211. The utility of this tool for Nova Scotia could be tested when investigating new reports of smallmouth bass.

Contrary to the temperature exclusion theory proposed earlier, smallmouth bass have established in Lake Ainslie and exhibit similar population characteristics to young populations in other areas of Nova Scotia and demonstrate growth rates similar to the North American average for fish less than age 4 (Dunlop and Shuter 2004). It is expected that given the substantial prey availability in Lake Ainslie bass growth will continue to be high at least at current abundance levels. This is substantiated by high relative weight measurements near 100 and far greater than the Nova Scotia mean value of 77 (LeBlanc and Halfyard 2008a). Higher relative weights seems to be typical of new smallmouth bass populations in Nova Scotia but is an area that requires additional attention. Big Mushamush Lake, Lunenburg County, thought to have had bass introduced in 1994 continues to exhibit high growth rates and arguably maintains a stable predator-prey balance. However, Ten Mile Lake, Queens County, which exhibited fast growth during the early stages of population development may now be showing signs of an imbalance between predator and prey abundances.

Climate change and the subsequent propensity for incremental warming could further reduce the availability of summer thermal refugia habitat in Nova Scotia for cold water species such as speckled trout and increase available habitat for species more tolerant of temperature fluctuations such as smallmouth bass, chain pickerel and yellow perch. For example, a $2^{o}C$ increase in summer mean water temperature could result in a 50% loss of cool water stream habitats and a dramatic increase in warm water habitats (MacMillan et al. 2005; Sharma et al. 2007). This could facilitate establishment where prior to temperature increases conditions were unsuitable for smallmouth bass establishment.

Lake morphological characteristics such as surface area and mean depth can be useful in predicting the potential for smallmouth bass to establish in a particular waterbody. However, no known threshold values for lake morphological features which exclude smallmouth bass were evident, rather an inference to more suitable lacustrine habitat features. Additionally, a significant vector for new occurrences is illegal transfers. Consideration must be given to angler activity and preferences and the proximity of newly documented populations to established ones. Other lake parameters that should be considered are pH, the area of the lake that has depths less than 6 m, chlorophyll a, and colour. Experimental results considering interactions of low pH and starvation on body weight of young of the year smallmouth bass suggest that at pH < 5.0 changes in tissue composition related to starvation were accentuated (Cunningham and Shuter 1986). Several other studies indicate that smallmouth bass have a low tolerance to acidic conditions (Rahel and Magnuson 1983; Beamish 1976). In Nova Scotia, poor condition during the winter starvation period could reduce the tolerance bass may have to low pH. Several regions of Nova Scotia experience seasonal acidic conditions during spring run-off periods which could result in high young of the year mortality as Snucins and Shuter (1991) reported for many Ontario lakes. However smallmouth bass populations persist in some acidic areas in Nova Scotia and exhibit average or above average growth (MacMillan and Robinson

1999). Further research in this area is important to predicting establishment in acid stressed regions.

River and stream usage of smallmouth bass is not clearly understood but have provided mechanisms for dispersal within watersheds. Biological aspects of riverine habitat utilization related to feeding behaviour, over wintering and spawning functions need to be addressed in order to provide evidence based commentary as to any potential impacts on riverine species assemblages. Investigating some of these questions may provide pertinent data for assessing potential impacts of smallmouth bass in the Margaree and Miramichi watersheds.

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Table 1. Known distribution of smallmouth bass in Nova Scotia in 2009. (A) denotes authorized introductions which established populations.

Water Body	County	First Known Occurrence	Latitude (Deg Min)	Longitude (Deg Min)
Elliot Lake[(A)]	Annapolis	1950	4456	6511
Paradise Lake	Annapolis	1989	4446	6510
Youngs Lake	Annapolis	1992	4449	6526
Grand Lake Flowage	Annapolis	1993	4439	6528
Nictaux River	Annapolis	1997	4456	6504
Waterloo Lake	Annapolis	2000	4444	6459
Molly Upsim Lake	Annapolis	2000	4440	6503
McGill Lake	Annapolis	2000	4442	6500
Lambs Lake Outflow	Annapolis	2006	4440	6528
Blacketts Lake	Cape Breton	2009	4607	6030
Shortts Lake	Colchester	1988	4512	6319
Round Lake	Colchester	1999	4539	6327
Big Lake	Cumberland	1998	4555	6344
Mattatall Lake	Cumberland	2001	4542	6328
Angevine Lake (Dewar Lake)	Cumberland	2001	4544	6331
Randalls Lake	Cumberland	2002	4540	6404
Clearwater (Norwood) Lake	Digby	1954	4405	6603
Spectacle Lake[(A)]	Digby	1971	4417	6607
Lac D'en Bas	Digby	1973	4416	6604
Cornings Lake	Digby	1975	4403	6605
Lower Cornings Lake	Digby	1976	4403	6605
Indian Pond	Digby	1976	4403	6605
Churchills Lake	Digby	1981	4404	6604
Doucette Lake	Digby	1988	4404	6608
Wentworth Lake	Digby	1992	4411	6556
Privilege Lake	Digby	1992	4411	6555
Lac a Victor	Digby	1994	4419	6602
Salmon River Lake	Digby	1995	4411	6604
Oakleaf Lake	Digby	1995	4415	6602
Cranberry Lake	Digby	1996	4409	6606
Weaver Lake	Digby	1998	4422	6559
Johnson Lake	Digby	1998	4421	6559
Grifiths Lake	Digby	1998	4421	6559
Midway Lake	Digby	1999	4432	6603
Spider Lake	Digby	2002	4413	6557
Micmac Lake[(A)]	Halifax	1944	4441	6333
Banook Lake	Halifax	1946	4440	6333
Charles Lake	Halifax	1954	4443	6333
William Lake	Halifax	1959	4446	6335
Thomas Lake	Halifax	1960	4448	6337
Shubenacadie Grand Lake	Halifax	1961	4455	6336
Fletcher Lake	Halifax	1961	4450	6336
Fish Lake	Halifax	1961	4455	6335

Table 1 (continued).

Water Body	County	First Known Occurrence	Latitude (Deg Min)	Longitude (Deg Min)
Powder Mill Lake	Halifax	1965	4446	6337
Penhorn Lake	Halifax	1965	4440	6333
Oathill Lake	Halifax	1965	4440	6333
Maynard Lake	Halifax	1965	4440	6333
Rocky Lake	Halifax	1966	4500	6318
Three Mile Lake	Halifax	1970	4447	6338
Third Lake	Halifax	1970	4447	6338
Kinsac Lake	Halifax	1971	4450	6339
Second Lake	Halifax	1975	4446	6339
Morris Lake	Halifax	1975	4439	6330
First Lake (Lower Sackville)	Halifax	1975	4450	6239
First Lake (Spry Harbour)	Halifax	1978	4446	6339
Loon Lake	Halifax	1984	4442	6330
Duck Pond	Halifax	1984	4448	6341
Albro Lake	Halifax	1984	4441	6334
Porters Lake	Halifax	1988	4445	6318
Hatchet Lake	Halifax	1988	4434	6343
Sackville River	Halifax	1990	4450	6347
McCabe Lake	Halifax	1990	4447	6345
Beaverback River	Halifax	1994	4451	6340
Tucker Lake	Halifax	1995	4450	6341
Russell Lake	Halifax	1996	4439	6331
Miller Lake	Halifax	1996	4449	6336
Beaverbank Lake	Halifax	1996	4451	6340
Sandy Lake (Lucasville)	Halifax	2000	4446	6342
Webber Lake	Halifax	2002	4447	6344
Kearney Lake	Halifax	2002	4442	6342
Egmont Lake	Halifax	2002	4500	6318
North River	Halifax	2006	4451	6354
Big Indian Reservoir	Halifax	2006	4447	6355
Lily Lake[A]	Hants	1948	4505	6405
Maitland Mill Pond	Hants	1982	4518	6330
Panuke Lake	Hants	1983	4450	6406
Pigott Lake	Hants	1994	4456	6353
Zwicker Lake	Hants	1996	4449	6414
Mockingigh	Hants	1996	4451	6415
Cogmagun Pond	Hants	1996	4509	6358
Uniacke Lake	Hants	2001	4453	6354
Murphy Lake	Hants	2002	4451	6413
Falls Lake	Hants	2002	4451	6415
Cockscomb Lake	Hants	2002	4456	6351
Big St. Margarets Bay Lake	Hants	2002	4447	6405

Table 1 (continued).

Water Body	County	First Known Occurrence	Latitude (Deg Min)	Longitude (Deg Min)
Lake Ainslie	Inverness	2000	4603	6107
Methals Lake[(A)]	Kings	1967	4458	6426
Lumsden Pond[(A)]	Kings	1967	4501	6423
Little River Lake[(A)]	Kings	1967	4459	6428
Gaspereau Lake[(A)]	Kings	1967	4448	6433
Four Mile Lake[(A)]	Kings	1967	4456	6437
Dean Chapter Lake[(A)]	Kings	1967	4453	6427
Black River Lake[(A)]	Kings	1967	4458	6424
Trout River Pond	Kings	1970	4456	6431
Moosehorn Lake	Kings	1970	4459	6427
Lake George	Kings	1972	4456	6442
Loon Lake	Kings	1975	4454	6440
Aylesford Lake	Kings	1975	4457	6440
Halfmoon Lake	Kings	1978	4458	6442
Murphy Lake[(A)]	Kings	1984	4455	6432
South Twin Lake	Kings	1994	4451	6443
North Twin Lake	Kings	1994	4452	6443
Midconner Lake	Kings	2002	4451	6444
Lake Paul	Kings	2002	4452	6441
Steverman Lake	Lunenburg	1952	4429	6436
Cantelope (Lilydale) Lake[(A)]	Lunenburg	1952	4424	6421
Pernette Lake	Lunenburg	1986	4419	6428
Blysteiners Lake	Lunenburg	1986	4425	6429
Becks Lake	Lunenburg	1986	4421	6425
Wallace Lake	Lunenburg	1994	4422	6422
Rhodenizer Lake	Lunenburg	1994	4441	6425
Big Mushamush Lake	Lunenburg	1994	4430	6433
Shingle Lake	Lunenburg	1995	4423	6420
Hunts Lake	Lunenburg	1995	4447	6431
Sucker Lake	Lunenburg	1996	4428	6425
Crouse Lake	Lunenburg	1996	4422	6424
Sherbrooke Lake	Lunenburg	1997	4425	6448
Moose Lake	Lunenburg	1997	4417	6434
LaHave River	Lunenburg	1997	4416	6420
Fancy Lake	Lunenburg	1997	4428	6451
Branch Lake	Lunenburg	1997	4415	6433
Wentzells Lake	Lunenburg	1998	4431	6455
Indian Lake	Lunenburg	1998	4434	6438
Round Lake	Lunenburg	1999	4428	6441
Randall Lake	Lunenburg	1999	4423	6429
Peter Lake	Lunenburg	1999	4435	6439
New Canada Lake	Lunenburg	1999	4429	6441
Little Mushalush Lake	Lunenburg	1999	4431	6428

Table 1 (continued).

Water Body	County	First Known Occurrence	Latitude (Deg Min)	Longitude (Deg Min)
Langille Lake	Lunenburg	1999	4427	6427
Pleasant River	Lunenburg	2000	4427	6431
Minamkeak Lake	Lunenburg	2000	4417	6436
Milipsigate Lake	Lunenburg	2000	4420	6436
Hebb Lake	Lunenburg	2000	4421	6434
Dares Lake	Lunenburg	2000	4424	6422
Andrew Lake	Lunenburg	2000	4421	6439
William Lake	Lunenburg	2002	4436	6439
Wagner Lake	Lunenburg	2002	4416	6432
Sefferns Lake	Lunenburg	2002	4440	6436
Lewie Lake	Lunenburg	2002	4421	6440
Church Lake	Lunenburg	2002	4433	6436
Big Otter Lake	Lunenburg	2002	4447	6417
Middle River Reservoir	Pictou	2002	4539	6244
Lansdowne Lake	Pictou	2003	4526	6249
Ten Mile Lake	Queens	1989	4410	6451
Little Ten Mile Lake	Queens	1989	4409	6451
Eight Mile Lake	Queens	1989	4410	6448
Mersey River	Queens	1995	4402	6443
Scott Lake	Queens	1999	4422	6505
Herring Cove Lake	Queens	1999	4408	6443
PonHook Lake	Queens	2001	4419	6453
Molega Lake	Queens	2001	4422	6451
Annis Lake	Queens	2001	4420	6450
West Horseshoe Lake	Shelburne	1997	4402	6529
Deception Lake	Shelburne	1999	4354	6523
George Lake	Shelburne	2000	4348	6518
Clamshell Lake	Shelburne	2002	4402	6529
Churchover Lake	Shelburne	2002	4342	6523
Bunkers Lake[(A)]	Yarmouth	1942	4355	6605
Second (Middle) Lake	Yarmouth	1947	4352	6606
Milo Lake	Yarmouth	1947	4352	6606
Doctors Lake	Yarmouth	1947	4353	6606
Brenton Lake	Yarmouth	1952	4358	6604
Two Island Lake	Yarmouth	1976	4402	6604
Cedar Lake	Yarmouth	1978	4401	6607
Killams Lake	Yarmouth	1981	4400	6605
Spectacle Lake	Yarmouth	1989	4402	6606
Petes Lake	Yarmouth	1989	4404	6552
Parr Lake	Yarmouth	1989	4405	6554
Odgen Lake	Yarmouth	1989	4403	6554
Peters Brook	Yarmouth	1990	4359	6549
Upper Crawleys Lake	Yarmouth	1994	4403	6553

Table 1 (continued).

Water Body	County	First Known Occurrence	Latitude (Deg Min)	Longitude (Deg Min)
Mink Lake	Yarmouth	1994	4401	6554
Lower Crawleys Lake	Yarmouth	1994	4402	6554
Harris Lake	Yarmouth	1994	4354	6600
Fanning Lake	Yarmouth	1994	4401	6555
Carleton River	Yarmouth	1994	4356	6556
Carleton Back Lake	Yarmouth	1994	4401	6556
Raynards Lake	Yarmouth	1995	4358	6555
Lake Vaughan	Yarmouth	1998	4355	6558
Kempt Back Lake	Yarmouth	1998	4404	6551
Hoopers Lake	Yarmouth	2000	4357	6559
Agard Lake	Yarmouth	2000	4355	6600

Table 2. Early known introductions of smallmouth bass in Nova Scotia (Bain 1993; Catt 1949; McNeill 1995). YOY refers to Young of the Year. All other introductions were adults.

Year	Waterbody	County	Number	Source	Agency	Status	Principle Bass Fishery
1951	Elliot Lake	Annapolis	34	Darlings Lake & Hammond River, NB	DFO	Present	No
1950	Blair Lake	Cumberland	60	Lake Utopia & Wheatons Lake, NB	DFO	Not present	
1908	Laytons Lake	Cumberland	108 (YOY)	Lockharts Lake, NB	DFO	Not present	
1945	(second introduction)		53	Lake Utopia, NB	DFO		
1946	(third introduction)		37	Lake Utopia, NB	DFO		
1971	Spectacle	Digby	Unknown	Unknown	NSDNR	Present	Yes
1952	Fishermans Harbour Lake	Guysborough	16	Lake Utopia & Spectacle Lake, NB	DFO	Not present	
1944	Micmac Lake	Halifax	61	Lake Utopia, NB	DFO	Present	Yes
1946	(second introduction)		37	Lake Utopia, NB	DFO		
1948	Lily Lake	Hants	44	Lake Utopia, NB	DFO	Present	No
1967	Black River System (Includes: Black River Lake, Dean Chapter, Four Mile, Gaspereau, Little River, Methals and Lumsden lakes)	Kings	748	Micmac, Lily & Elliot lakes, NS	DFO / NSDNR	Present	Yes
1984	Murphy Lake	Kings	124	Black River Lake, NS	NSDNR	Present	Yes
1953	Awalt Lake	Lunenburg	Unknown	Spruce Lake, NB	DFO	Not present	
1952	Cantelope Lake	Lunenburg	17	Lake Utopia & Spectacle Lake, NB	DFO	Not present	
1953	(second introduction)		Unknown	Lake Utopia & Spectacle Lake, NB	DFO		
1947	Victoria Lake	Queens	39	Wheatons Lake[1], NB	DFO	Unknown	
1942	Bunkers Lake	Yarmouth	107	Wheatons Lake[1], NB	DFO	Present	No

[1] Wheatons Lake, NB is also known as Bocabec Lake.

Table 3. Potential occurrences of smallmouth bass in Nova Scotia that have not been investigated and confidence in angler reports. Confidence: Non-angler report (0), single angler report (1) and multiple anglers reports (2).

Water Body	County	Year	Topo Map	Latitude (Deg Min)	Longitude (Deg Min)	Confidence	Source
Scragg Lake	Annapolis	2000	21A/15	4447	6459	1	Angler logbook (caught 4)
Shannon Lake	Annapolis	2000	21A/11	4445	6500	1	Angler
Upper Mersey River	Annapolis	2001	21A/06	4427	6511	1	Researcher at MTRI
Shannon River	Annapolis	2002	21A/11	4443	6500	2	Angler logbook (caught 3)
Third Lake *	Digby	1995				2	Angler logbook (caught 57)
Swallow Lake	Digby	2000	21B/01	4411	6601	1	Angler logbook (caught 1)
Clearwater Lake *	Digby	2003				1	RFAC meeting
English Lake	Digby	2003	21B/01	4410	6603	2	Personal conversation
Barrett Lake	Halifax	1988	11D/13	4449	6341	2	Angler logbook (caught 33)
Bayer Lake	Halifax	1994	11D/14	4448	6309	2	Angler logbook (caught 5)
Long Lake	Halifax	1994	11D/12	4437	6338	2	Angler
Scraggy Lake	Halifax	1994	11D/15	4458	6253	1	RFAC
Big Indian Lake	Halifax	1995	11D/12	4436	6343	1	Angler logbook (caught 7)
Bissett Lake	Halifax	1995	11D/11	4439	6328	2	Angler
Fourth Lake *	Halifax	1995				1	Angler logbook (caught 13)
Govenor Lake	Halifax	1995	11E/02	4513	6240	2	Angler
Wilson Lake	Halifax	1995	11D/13	4449	6342	2	Angler
Lake Echo	Halifax	1996	11D/11	4443	6324	1	Angler logbook (caught 29)
Papermill Lake	Halifax	1997	11D/12	4443	6341	2	Angler logbook (caught 10)
Pot Lake	Halifax	1997	11D/14	4454	6310	1	Angler logbook (caught 1)
DeSaid Lake	Halifax	2000	11D/11	4438	6329	1	Angler logbook (caught 5)
Brown Lake *	Halifax	2004				1	Angler
Ragged Lake *	Halifax	2004				1	Angler
Red Bridge Pond	Halifax	2004	11D/12	4441	6333	1	Angler

Table 3 (continued).

Water Body	County	Year	Topo Map	Latitude (Deg Min)	Longitude (Deg Min)	Confidence	Source
Dollar Lake *	Halifax		11D/14	4455	6319	1	Angler
Shields Lake	Hants	1982	11E/04	4510	6348	2	Angler
White Rock Pond	Kings	1972	21H/01	4503	6424	2	Angler
Silver Lake	Kings	1992	21H/02	4507	6436	2	Angler
Black Duck Lake	Kings	1995	21A/10	4443	6443	1	Angler
Crooked Lake	Kings	1996	21A/15	4454	6433	1	Angler
Baptist Lake *	Kings		21A/16	4452	6426	2	Unknown
Lilydale (Cantelope) Lake	Lunenburg	1994	21A/08	4424	6421	2	Angler logbook (caught 9)
Grimms Brook	Lunenburg	1995	21A/08	4420	6420	2	Angler logbook (caught 57)
Rhodes Lake	Lunenburg	1995	21A/08	4422	6424	1	Angler logbook (caught 2)
Little Beaver Lake	Lunenburg	1997	21A/14	4416	6433	1	Angler
Card Lake	Lunenburg	2002	21A/09	4445	6417	1	Angler
Island Lake	Lunenburg	2004	21A/02	4415	6435	1	Angler
Centre Lake *	Lunenburg					1	Angler
Lake Rossignol	Queens	1995	21A/03	4410	6507	1	Angler
Unnamed Caledonia Lake	Queens	1999	21A/06	4421	6502	0	Unknown
Beech Lake	Queens	2002	21A/06	4427	6503	0	Unknown
Bar Pond	Queens	2003	21A/02	4410	6443	1	Angler
Cannon Lake	Queens	2008	21A/06	4521	6509	1	Angler
Turtle Lake	Queens	2008	21A/06	4422	6508	1	Angler
Alvins Lake	Shelburne	2002	20P/11	4343	6524	1	Angler
Halfmoon Lake	Yarmouth	1994	21A/04	4402	6555	1	Angler logbook (caught 5)
Spar Lake	Yarmouth	1994	20P/13	4353	6540	1	Angler
Allen Lake	Yarmouth	1997	20O/16	4357	6609	1	Angler
Darlings Lake	Yarmouth	1997	20O/16	4358	6608	1	Angler
Sunday Lake *	Yarmouth	1998				1	Angler
Beaverhouse Lake	Yarmouth	2002	21A/04	4403	6548	1	Angler logbook (caught 13)
Great Pubnico Lake	Yarmouth	2002	20P/12	4342	6543	1	Angler

Table 4. Two-sample t-test for lake morphological parameters thought to influence occurrence of smallmouth bass in Nova Scotia.

Lake	Bass Present			Bass Absent						
Parameter	N	Mean	Variance	N	Mean	Variance	t-stat	P	z-score	Significant
Surface Area	100	215.3	n/a	907	65.59	n/a	-6.05	0.00000	2.37	Yes
Mean Depth	87	3.42	4.21	814	2.67	3.87	-3.35	0.00083	3.24	Yes
Maximum Depth	100	10.65	38.86	907	7.94	44.64	-3.87	0.00012	4.09	Yes
Shoreline Development Index	100	2.17	0.85	894	1.85	0.66	-3.76	0.00018	3.38	Yes
Secchi Disk	81	2.73	1.63	681	2.91	8.03	0.58	0.56248	1.03	No

Table 5. Smallmouth bass and speckled trout angling catch per unit effort (CPUE), 2003-2008.

Year	Effort (hours)	Number of trout	CPUE (trout / hr)	Number of bass	CPUE (bass / hr)
2003	10	15	1.50	3	0.30
2004	10	12	1.20	3	0.30
2005	10	2	0.20	5	0.50
2006	48	41	0.85	14	0.29
2007	15	9	0.60	6	0.40
2008	85.5	10	0.12	140	1.64

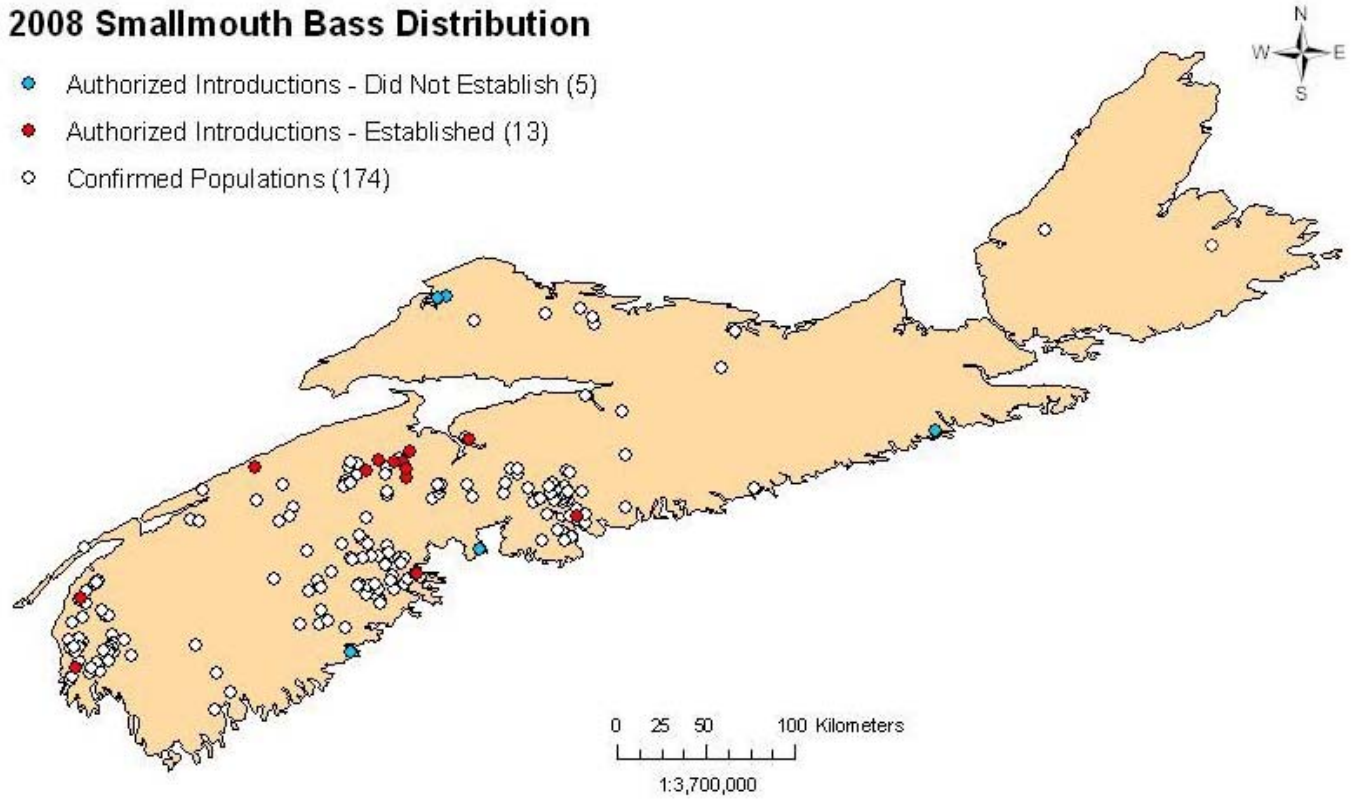

Figure 1. Known distribution of smallmouth bass in Nova Scotia showing locations of authorized introductions that did not establish populations (blue), authorized introductions that successfully established populations (red) and established populations resulting from natural dispersals or illegal transfers (white).

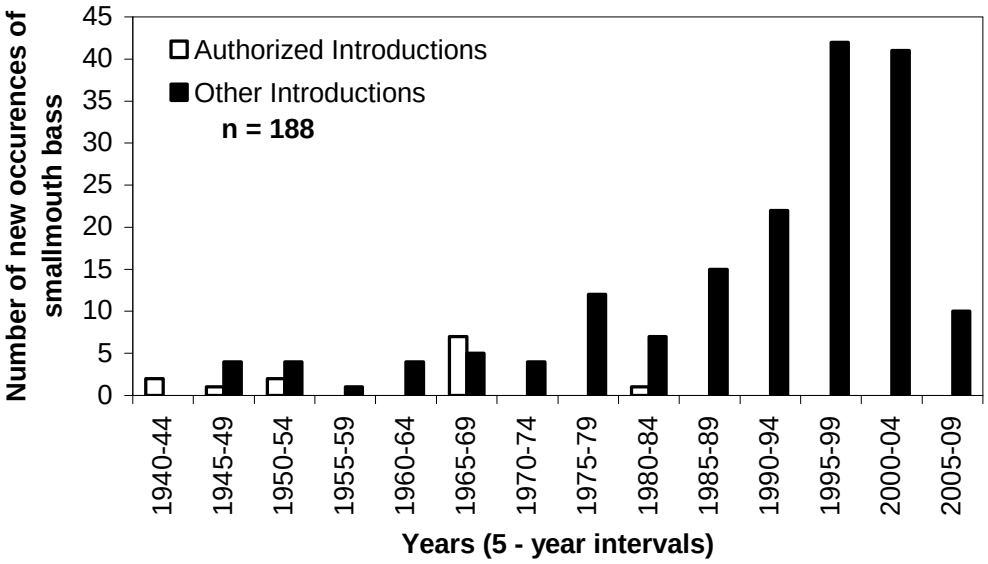

Figure 2. Increase in new occurrences of smallmouth bass from 1942-2009. The 2005-09 interval is under-represented and does include documented populations found after April 2009.

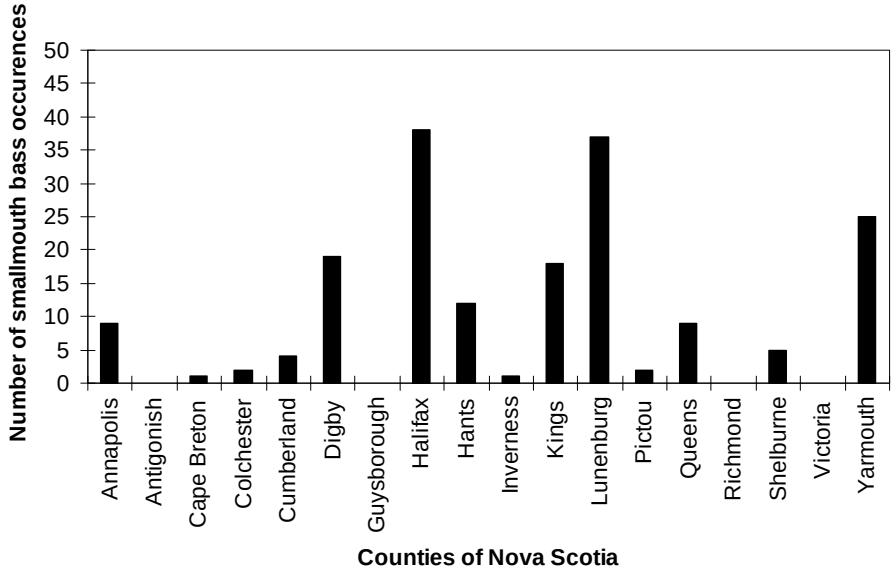

Figure 3. Smallmouth bass occurrences by County in Nova Scotia, April 2009.

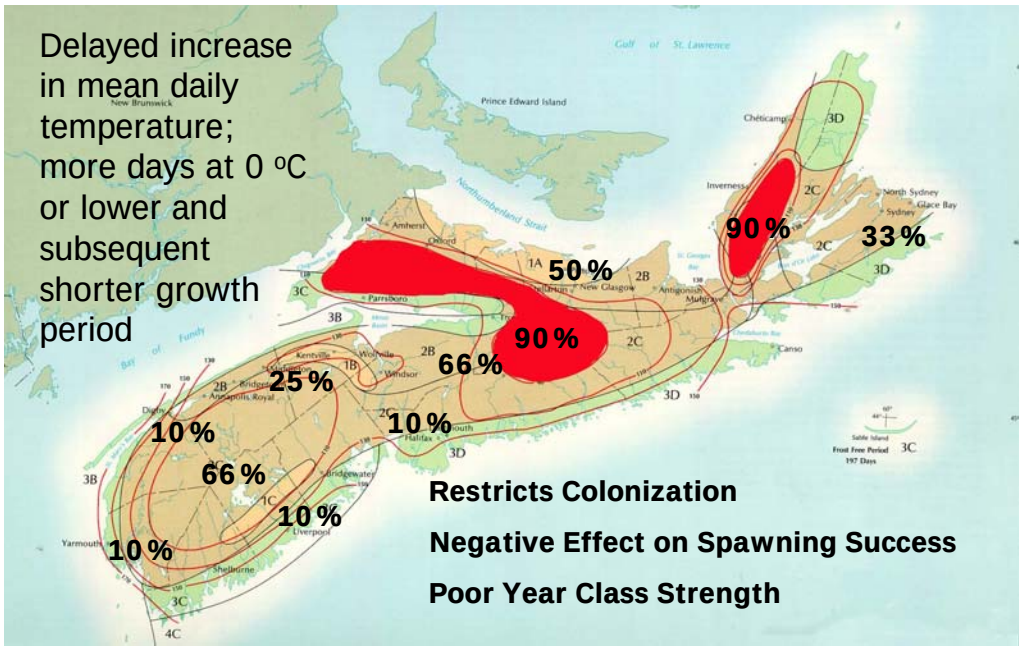

Figure 4. Smallmouth bass temperature exclusion zones in Nova Scotia showing the probability of frost occurring after May 28.

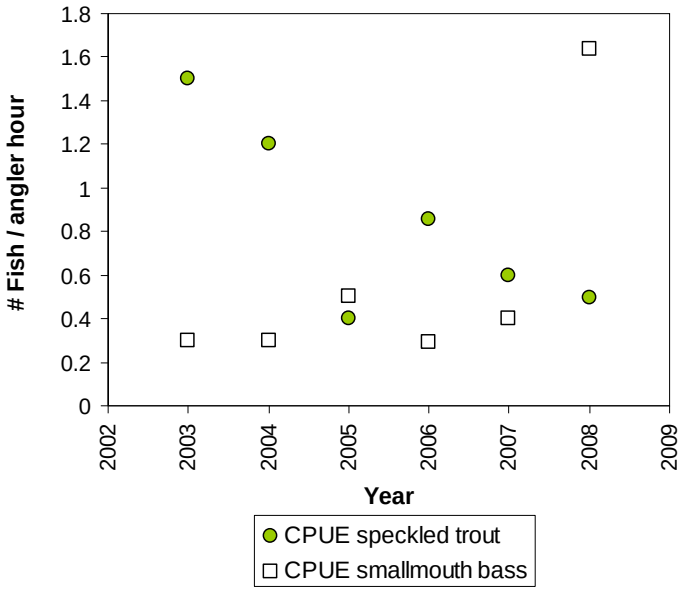

Figure 5. Catch per angler hour for speckled trout (r^2 = 0.61) and smallmouth bass (r^2 = 0.47) in Lake Ainslie from Inland Fisheries angling surveys during May through July, 2003-2008.

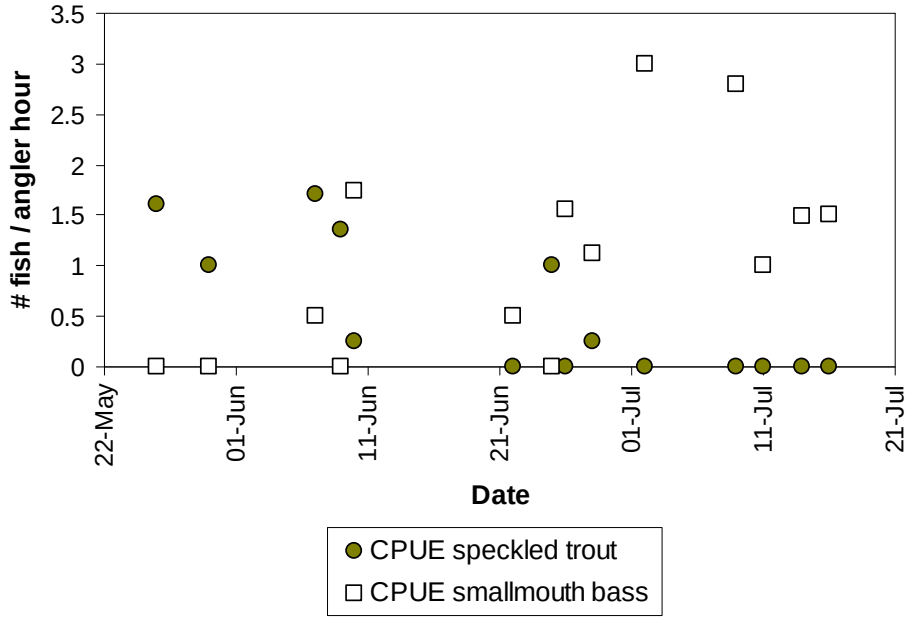

Figure 6. Seasonal variation in catch per angler hour for speckled trout (r^2 = 0.38) and smallmouth bass (r^2 = 0.63) in Lake Ainslie from Inland Fisheries angling surveys during May through July, 2008.

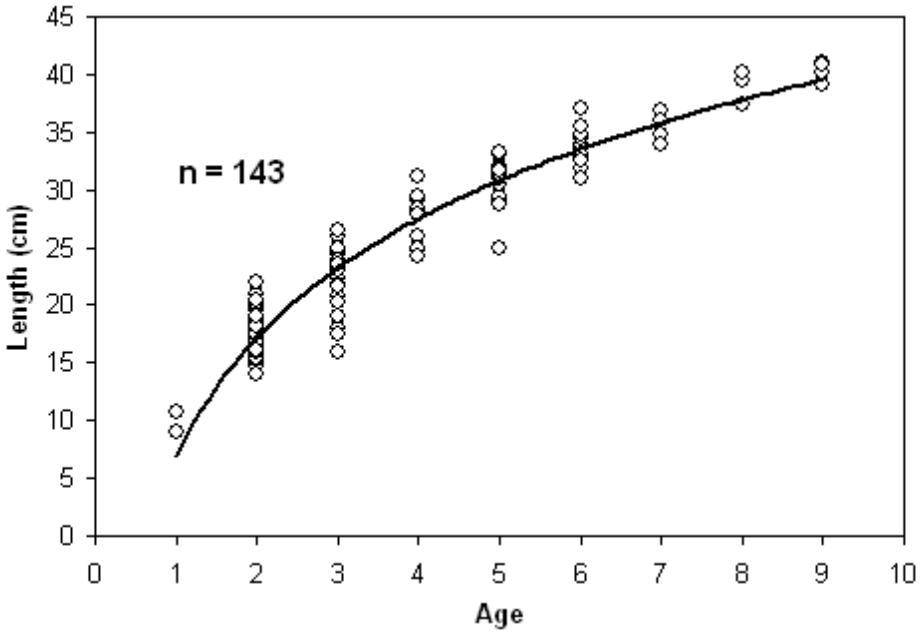

Figure 7. Length at age for smallmouth bass from Lake Ainslie (2008) from angling and gill netting surveys (n=143).

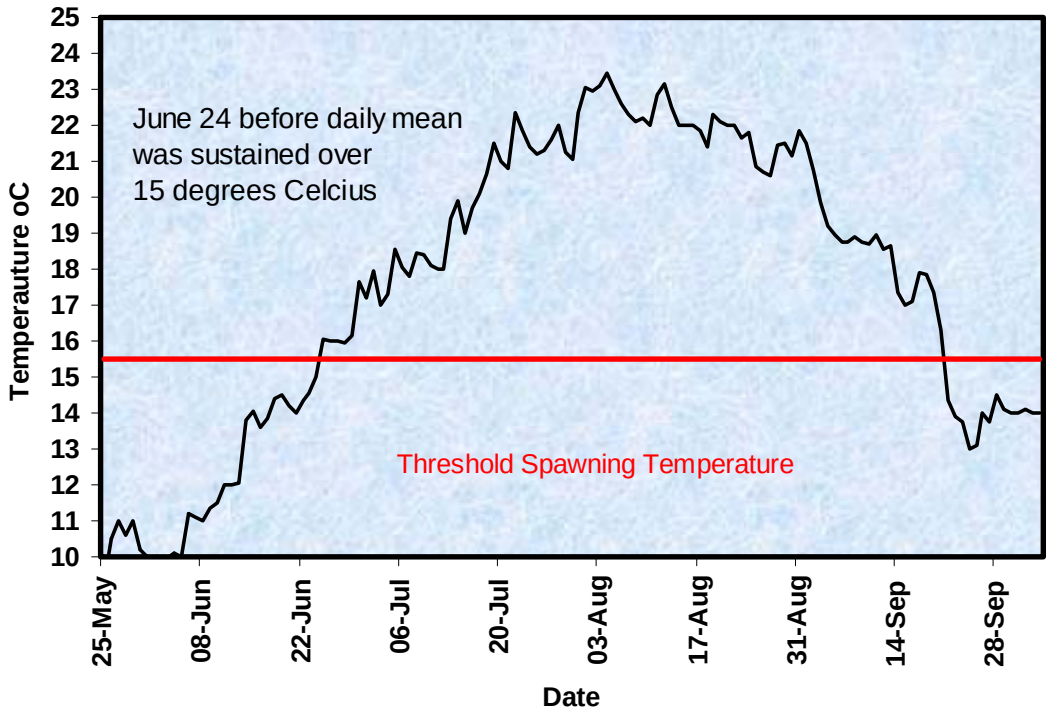

Figure 8. Mean daily water temperature in Lake Ainslie (2004) showing late June start of days with adequate spawning temperatures.