Update of the Strategic Plan for Management of the St. Lawrence River Muskellunge Population and Sportfishery Phase III: 2003-2010

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Executive Summary

The St. Lawrence River provides one of the few, large, self-sustaining populations of muskellunge (*Esox masquinongy* Mitchell) in North America. This population is thought to be genetically unique, and produced a world record, 69 pound 15 ounce muskellunge in 1957. The St. Lawrence River muskellunge is both an important ecological and economic resource to the State of New York and the Province of Ontario. The St. Lawrence River is also unique in that both muskellunge and northern pike (*Esox lucius* Linnaeus) are sympatric in this ecosystem.

The New York State Department of Environmental Conservation (NYSDEC) previously published the "Strategic Plan for the Management of the Muskellunge Population and Sportfishery of the St. Lawrence River" in 1980 (Panek 1980), and "Phase II" in 1991(LaPan and Penney 1991). These documents identified specific research goals and objectives, and outlined a tentative schedule for the completion of those objectives. The goals of the original management plan for the St. Lawrence River muskellunge population were, and continue to be:

> ***To perpetuate the muskellunge as a viable, self sustaining component of the fish community in the St. Lawrence River, and to provide a quality trophy fishery.***

In 1980, a St. Lawrence River Muskellunge Management Work Group was created within the Lake Ontario Committee of the Great Lakes Fishery Commission. This Work Group is comprised of fisheries research advisors from the SUNY College of Environmental Science and Forestry and fisheries management biologists from the NYSDEC and the Ontario Ministry of Natural Resources (OMNR). The responsibilities of this Work Group include identification of research needs and coordination of a cooperative research and management effort to protect and enhance the St. Lawrence River muskellunge population and sportfishery. Work Group progress is reviewed every 3-5 years or as needed.

The muskellunge fishery in the St. Lawrence River declined significantly during the late 1970s through the 1980s. Heavy fishing pressure, liberal angling regulations, increased human disturbance, and development of shoreline habitats likely contributed to this decline. A trophy muskellunge management strategy implemented by NYSDEC and OMNR included more restrictive harvest regulations and protection of spawning and nursery habitats. The actions have had positive impacts on muskellunge population trends and the abundance of larger fish. Public education and the "catch and release" fishing philosophy have also had a very positive impact of the quality of the fishery. A mail survey conducted in 1998 by NYSDEC indicated that the fishery has remained relatively stable over the previous decade.

A great deal of progress has been made in identifying biological characteristics of the muskellunge population and in development of methods for identifying critical habitats and movement patterns. Objectives and strategies for "Phase III" of the plan will continue to focus on habitat identification and protection, population monitoring, and conservation education. A summary of 1991-2001 research findings is provided in this report. Research and management objectives have been updated based on the most recent Work Group meeting in July 1999.

Table of Contents

1.0 Introduction

The muskellunge (*Esox masquinongy* Mitchell) is the largest piscivorous fish inhabiting the waters of the St. Lawrence River, and represents one of the few self-sustaining populations in North America. As a freshwater sport fish the musky has no rival, anglers annually catch fish in the 50-pound class. A world record muskellunge, 69 pounds 15 ounces (31.8 kg), was taken in the St. Lawrence River, near Clayton, in 1957. Its large size, unmatched aesthetic appearance, and secretive nature make the muskellunge one of the most revered and sought after freshwater game fish. Its value goes well beyond the fishery and into the historical and present appeal of maritime communities of the River.

Resource managers from the New York State Department of Environmental Conservation (NYSDEC) and the Ontario Ministry of Natural Resources (OMNR) recognized in the late 1970s that critical information for making management decisions regarding muskellunge was needed. The first comprehensive plan for the management of muskellunge in the St. Lawrence was published in 1980 (Panek 1980). A "Phase II Strategic Plan" (LaPan and Penney 1991) outlined research achievements from 1980-1990 and set directives for continued research on muskellunge behavior and biology for the next decade.

Phase II objectives and tactics addressed three primary areas: habitat protection and restoration, population quantification, and standardization of international regulations. Habitat protection incorporates needs for all life stages of muskellunge as well as habitat enhancement. Identification of spawning, nursery, and sub-adult habitat are key elements to understanding reproductive biology and variables associated with year class formation. Muskellunge habitat protection is critical to maintenance of a viable population. Habitat restoration may become an important tool in enhancing muskellunge reproduction at sites that have been degraded by human activities.

Population quantification has proven difficult in the past due to the nature of this low-density predator and the variability associated with catch. Adult muskellunge are at times very difficult to catch on spawning areas. A tremendous effort must be put forth to generate adequate numbers for tagging studies and abundance indices for adult muskellunge. Abundance indices, however, have been developed for YOY muskellunge in 12 nursery bays and will be useful in tracking reproductive success. Future modeling using these indices may yield insight into the population dynamics of this species.

Standardization of angling regulations within the international boundary of the St. Lawrence River has been a common goal of both NYSDEC and OMNR since 1980 and was realized in 1991. Consistency in regulations alleviates the potential for concentrating angling effort and exploitation in specific areas, reducing confusion among anglers, aids law enforcement officers by simplifying enforcement activities, and makes scientific evaluations of changes more feasible.

Public education has played a valuable role to date in management of the St. Lawrence River muskellunge. Although the muskellunge has an identifiable reputation, few people have ever seen a live specimen. Continued efforts in informing the angling public about the importance of proper identification, handling, and release of these fish will continue to pay dividends in the future. Partnerships, such as the Save The River Muskellunge Release Program, have been very successful in educating the public and promoting muskellunge conservation practices.

The purpose of this document is to highlight research and management progress, and to identify research and programmatic needs and strategies to guide management of the St. Lawrence River- Eastern Lake Ontario muskellunge into the next decade.

2.0 Biology of Muskellunge and Management of the Fishery

(1) Taxonomy and Identification

The muskellunge is a large freshwater predatory fish that reaches sizes over 50 pounds. It is one of four North American species in the single genus Esox, of the family Esocidae. Misidentification of muskellunge with other esocids, especially the northern pike (*Esox lucius*), continues to be a management problem. Characteristics, including coloration and markings, scale patterns, and sensory pores, are useful in field identification. Three general forms of muskellunge coloration are observed, including a light background with dark bars, spots, or a diffuse pattern of spots and bars (Crossman 1978). Adult muskellunge of the Great Lakes-St. Lawrence River form most frequently have dark spotted markings. For all forms, the lower half of the cheek is without scales, and there are six or more submandibular pores. Natural hybridization between northern pike and muskellunge occurs (although rarely) in the St. Lawrence River; hybrids typically have characteristics intermediate between northern pike and muskellunge.

Muskellunge eggs range in diameter from 3.1-3.4 mm (average 3.3) and are significantly larger than northern pike with some degree of overlap at 3.1 mm (Farrell et al. 1996).

Developmental characteristics of larval muskellunge were described in detail by Cooper (2000). Pigmentation of the yolk sac in muskellunge embryos is much less developed relative to northern pike. Young-of-the-year (YOY) muskellunge have a prominent mid-dorsal stripe with a yellow-gold coloration and large dark spots. The mid-dorsal stripe is retained through juvenile stages (ages 1-5) but is lost at adulthood (Farrell and Underwood 2003).

(2) Distribution and Habitat Use

The native range of muskellunge extends northeast along the St. Lawrence River to the Chaudiere River, Quebec, west to the Winnipeg River in Manitoba and south through Tennessee, including a small potion of western North Carolina (Crossman 1978). This management plan focuses on muskellunge in the International waters of Eastern Lake Ontario through Lake St. Lawrence of the St. Lawrence River, including tributaries upstream to the first impassable barrier.

(3) Muskellunge Spawning and Nursery

Muskellunge spawning studies have been completed for movements of radio-tagged adults during spawning (LaPan et al. 1996), the capture and tagging of adults on the spawning grounds (Farrell et al. 2002), and the distribution of naturally spawned eggs (Farrell 1991, Farrell et al. 1996, Cooper 2000, and Farrell 2001).

Muskellunge typically have a protracted spawning run in the St. Lawrence River occurring from early May to mid-June. Spawning occurs at different times of the year in different bays due to variation in thermal regimes. The main channel of the St. Lawrence is very slow to warm in springtime and spawning sites exposed to this cool water often exhibit later spawning runs; other more sheltered locations often warm earlier and exhibit early spawning runs. Spawning, based on trapnet captures of over 240 adults (from 1990-2000), was observed between 26 April and June 13. Spawning runs that continued beyond the second week of June were not recorded in this dataset because traps were pulled.

Based on collections of naturally spawned eggs at Point Marguerite Marsh, near Alexandria Bay, muskellunge spawning occurred from 13 May to 12 June 1989. Water temperatures ranged from 7-17 °C and spawning peaked at 10-13 °C. In Rose Bay, near Cape Vincent, spawning occurred from 23 May to 23 June 1994, and 23 May to 23 June 1995. Water temperatures during muskellunge spawning ranged from 13.2-18.1 °C in 1995.

Spawning distribution is generally restricted to shallow waters <1.5 m-depth, although a few deep-spawned eggs were collected at Rose Bay in 2.8 m-depth, on 23 June 1995. Patterns of muskellunge egg distribution following spawning have shown no statistical relationship with a specific set of vegetation variables, but vegetation has not been a limiting feature within the habitats studied. Muskellunge spawn over a variety of new submersed and emergent vegetation growth, and over several substrate types including those high in sand, silt and organic content (Farrell 1991). Radio-tagged muskellunge during spawning were shown to frequent a variety of emergent and submersed vegetation types but no selection was apparent (LaPan et al. 1996).

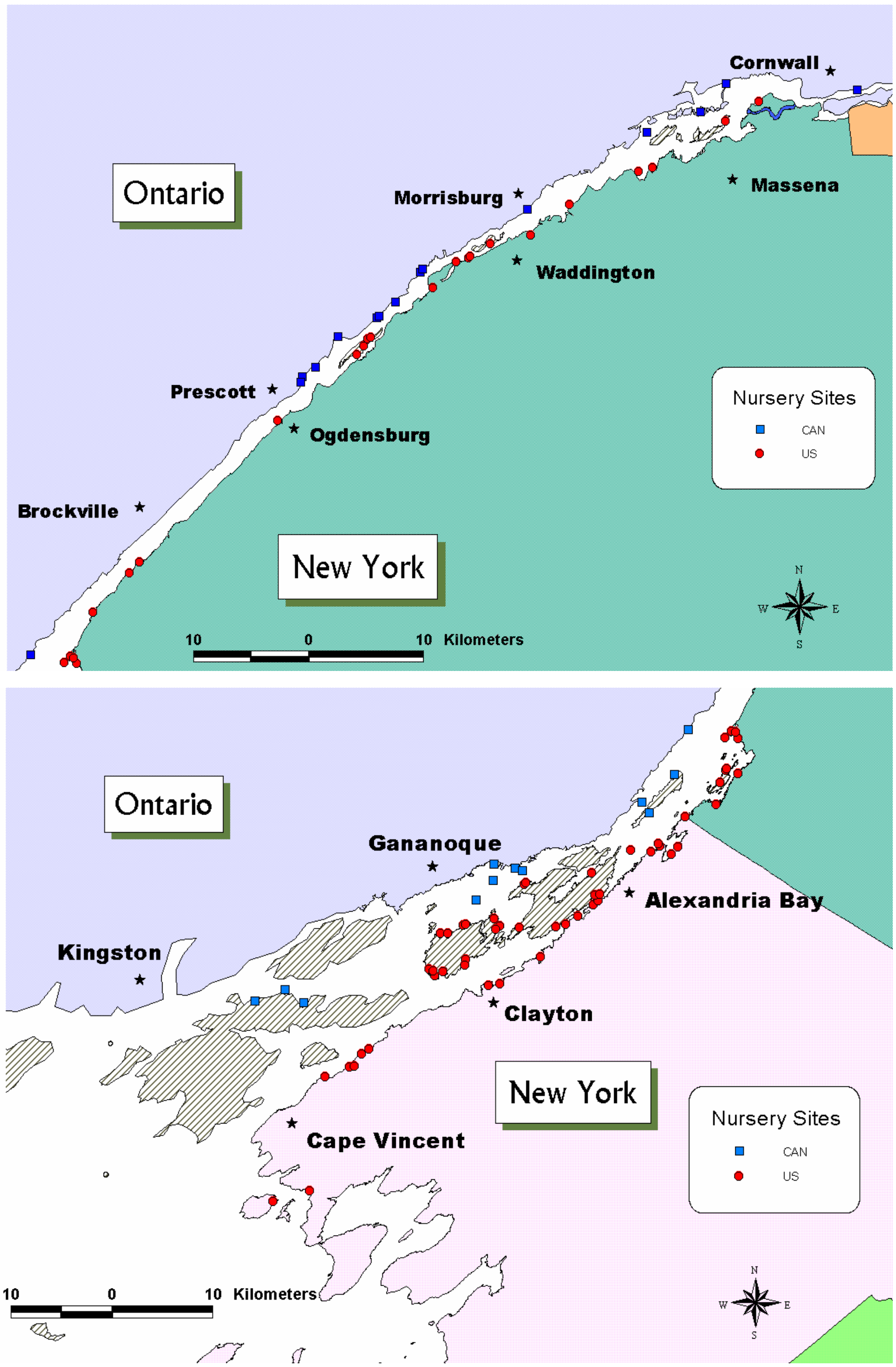
Muskellunge nursery is completed in the bays where spawning has occurred. Of 35 nursery areas identified in a 1983-1989 study, 27 were in locations frequented by radiotagged females or where spawning adult muskellunge had been captured (LaPan et al. 1996). In an international effort, 95 locations (68 US and 27 Canada) have been identified as muskellunge nursery sites (Figure 1; Appendix I).

Muskellunge use shallow littoral habitats <1.5 meters water-depth during nursery, although sampling generally does not occur in deeper habitats. Mean water depth at successful seine hauls taken within nursery habitats were significantly shallower (mean = 0.65 m) than at unsuccessful hauls (P = 0.0001; mean = 0.72 m) (Farrell and Werner 1999).

Data from the sampling program in Ontario waters showed a variety of submersed and emergent aquatic vegetation types were present in muskellunge nursery locations, but wild celery, *Vallisneria americanus*, was most prevalent found in 95% of the locations, followed by coontail, *Ceratophyllum demersum*, bulrushes, *Scirpus* sp., and water milfoil, *Myriophyllum* species (Bendig 1994).

A study of vegetative characteristics of muskellunge nursery habitat on the American side of the river had similar and more detailed findings (Werner et al. 1996). The presence of mixed aquatic vegetation that approaches the water surface, typical of the shallow littoral environment, has been shown to be an important habitat for YOY muskellunge during summer nursery (Jonckheere 1994). Vegetation species commonly occurring at nursery sites included muskgrass, *Chara vulgaris*, water milfoil, common waterweed, *Elodea canadensis*, and wild celery. Estimates of stem densities of these plant types indicated that muskgrass had significantly lower

Figure 1. Locations of muskellunge spawning and nursery areas in the International Eastern Lake Ontario and the St. Lawrence River from Cornwall, Ontario to Cape Vincent, New York.



densities in sites known as nursery areas. A study by Clapsadl (1993) suggested that dense mats of muskgrass might negatively influence survival of muskellunge eggs and sac fry.

In nursery sites, percent vegetative coverage increased from 9% (0 to 10 m offshore) to 59-73% (20-50 m offshore) due to a transition from emergent to submergent vegetation zones (Werner et al. 1996). Percentage cover of vegetation was high (77-89%) in sites with YOY muskellunge. Submersed vegetation height was 10 to 32 cm greater in successful seine hauls for YOY muskellunge compared to unsuccessful ones.

(4) Behavior

Muskellunge appear to demonstrate spawning site fidelity based on both tagging and radiotelemetry studies (Crossman 1990; LaPan et al. 1996; Farrell et al. 2002). Of 29 fish tagged and recaptured during spawning over multiple years, all were found at the location of original tagging. Whether this behavior represents a natal homing instinct remains uncertain (Farrell and Werner 1999).

Following spawning in shallow bays of the St. Lawrence, a portion of the adult muskellunge population makes an upstream migration to Eastern Lake Ontario. About one-half of 47 radio-tagged fish moved upstream to the Cape Vincent-Eastern Lake Ontario region. Migrations of nearly 100 km have been observed (LaPan et al. 1996). Migration is speculated to promote dispersal and maximize foraging opportunities.

Young-of-the-year muskellunge remain in the shallow littoral habitats of bays until fall emigration. Seasonal variability occurs within this habitat including changes to plant community composition and stem density, and fluctuations in water level and temperature. Temperature shifts, habitat changes, and individual fish size may be important in the timing of emigration from shallow nursery areas (Farrell 1998).

Following emigration little is known of habitat use or location of immature sub-adult stages (Farrell 1999; Farrell and Underwood 2003). A telemetry study on hatchery-reared fish indicated a preference for sandy substrates and emergent plant types (bulrush, *Scirpus validus*) for age-2 fish, but both intensive and extensive seining and trapnetting surveys have resulted in only rare catches of wild sub-adults (Farrell 2000).

During early fall, adult muskellunge make large movements again and tend to congregate in well known fall fishing locations. In late fall and winter, muskellunge move to staging areas near their respective spawning areas (LaPan et al. 1996).

(5) Food and Feeding

A great deal of information has been collected about the diet of YOY muskellunge. Cooper (2000) examined the timing of availability of forage fish for larval muskellunge based on prey cross-sectional area and gape limitations. The timing of spawning relative to the abundance peaks for suitable sized forage species was considered an important factor to muskellunge success. Muskellunge YOY (0.9 – 78.2 g) have been shown to be entirely piscivorus and focus feeding on tessellated darter (*Etheostoma olmstedi*), banded killifish (*Fundulus diaphanus*) and shiners (*Notropis sp.*) (Farrell 1998). YOY muskellunge are opportunistic and stomach analyses have shown they consume at least 16 different fish species during summer nursery. Increases in gape size allow consumption of larger prey items as YOY grow (up to 25 % of body weight), however, YOY will continue to feed on a range of prey sizes.

Adult muskellunge are known to consume a large variety of prey including birds, mammals, and amphibians, but primarily focus on fish of varying sizes (Bozek 1999). Hasse (1976) described fish in the gut of adult St. Lawrence River muskellunge, including yellow perch, alewife, white sucker and smelt, ranging in size from 4.5 to 17 inches. In 1995, a dead, emaciated 57 inch muskellunge with a half-digested 28 inch lake trout deeply lodged in its mouth was found in Flynn Bay, Clayton, NY by ESF researchers. There was a similar report of a large muskellunge “choked to death” on a common carp below the Sr. Lawrence FDR power project. Researchers observed an estimated 22 inch northern pike regurgitated by a muskellunge during spring spawning. Reports of muskellunge taking adult bass from anglers and being captured on bass minnows are relatively common and demonstrate their wide range in size selection of prey. Muskellunge guides seek schools of “baitfish” to locate muskellunge during fall fishing. Muskellunge are thought to be sit-and-wait predators but little is known about their foraging behavior during adulthood.

(6) Reproductive Success

Fertilization (76-97%) and egg viability (67-92%) rates of naturally spawned muskellunge eggs are relatively high (Farrell 2001) and are not currently perceived as an important issue regulating reproductive success in the upper St. Lawrence River. The percent survival of muskellunge from spawning to fall emigration of young-of-the-year was 0.034-0.105% over two years at Rose Bay. These levels of survival appear to support high YOY abundance of muskellunge in Rose Bay relative to other St. Lawrence River bays (Farrell and Werner 1999). In addition, these studies indicated that survival of stocked fry (fed two weeks post swim up) and small fingerlings were adequate to enhance abundance on the nursery grounds. Observed fry survival for 45 stockings ranged from 0 to over 3% and averaged 0.7%. Fingerling survival was greater (mean = 18%) but fry stocking contributed more to abundance within nursery bays, due to greater numbers stocked. Population densities were maintained at nearly 20 YOY muskellunge per hectare of nursery habitat at ten sites during 1990-1996 by both stocking and natural reproduction.

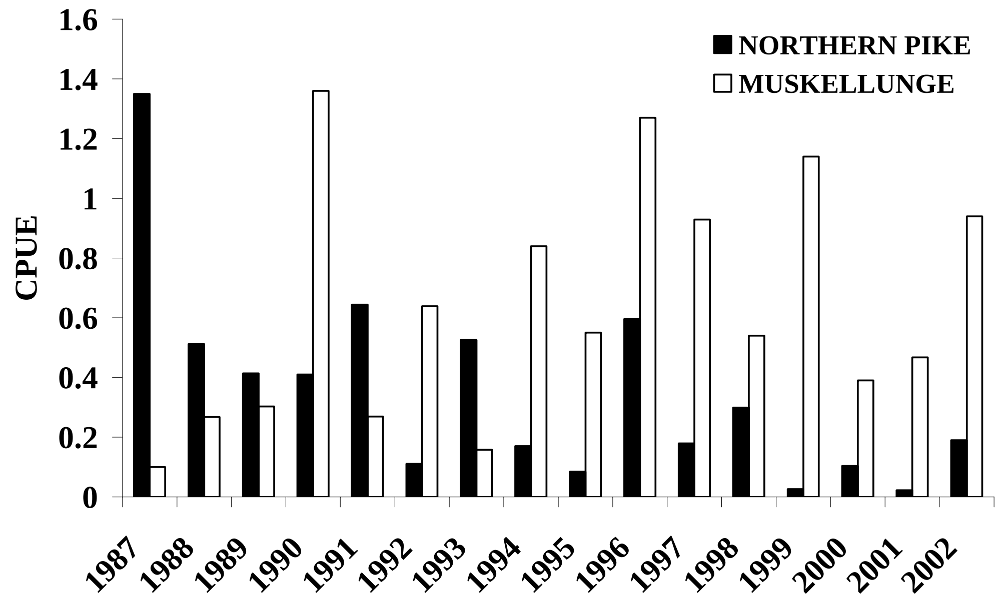
A monitoring program for muskellunge reproductive success, as indicated by patterns of YOY muskellunge abundance in eleven upper St. Lawrence River nursery bays, has been in effect for 1987-2002. Trends in wild YOY muskellunge catch-per-unit-effort (CPUE) indicated consistent reproductive success and an increase in YOY abundance on the nursery grounds throughout the region (Figure 2). High YOY abundance, especially 1990, 1994, 1996, 1997, 1999, and 2002 may have promoted strong year-classes. Northern pike, a potential competitor, has experienced declines in abundance in the muskellunge nursery bays.

(7) Age, Mortality, Recruitment, and Growth

Cleithra bones, obtained from taxidermists, fishing guides, muskellunge anglers, and a few from research studies have been collected from muskellunge in the Thousand Islands section of the St. Lawrence River. Historic samples were collected by John Casselman (OMNR) starting in the 1960s and more recently by Al Schiavone and Steve LaPan, (NYSDEC) and John Farrell (ESF). More than 250 cleithra have been assembled from trophy muskellunge throughout the Thousand Islands section of the St. Lawrence River. Early samples were archived by

J. Casselman, and more recent samples are archived by the above-mentioned contributors, and the Cleithrum Project, Royal Ontario Museum (ROM), and Crossman and Casselman coordinators. Additional samples sent to the Cleithrum project should, until further notice, be sent to: The Cleithrum Project, Attention: J. Casselman, Ontario Ministry of Natural Resources, Glenora Fisheries Station, R.R. 4, Picton, Ontario K0K 2T0.

Figure 2. Catch per unit effort of YOY northern pike and muskellunge captured in seine hauls in Upper St. Lawrence River nursery sites, 1987-2002.



Age estimates from cleithra range from 4 to 30 years, with a median age of 16 (1985-2000). Results indicate that trophy muskellunge harvested from the St. Lawrence River are older and larger than those from most other water bodies (Casselman et al. 1999).

The cleithra data provide considerable insights to assist in managing and understanding the dynamics of St. Lawrence River muskellunge. The age distribution of the harvested fish suggests that mortality rate is relatively low, possibly due to increased size limits and voluntary catch and release. Because of angler concern and education, handling mortality appears to be relatively low, despite high fishing pressure in some locations.

Mortality rate could be estimated from the data in hand, but would require special analysis due to the selected sample. Periods could be chosen where sample sizes would be adequate and comparable, given that cleithra samples exist from the 1960s to the present, a 40-year period. Total mortality rate, fishing and natural combined, indicates that over-exploitation is not an immediate concern. Current size limits are based on growth trajectories and have been increased over the years in unison in both Ontario and New York waters. These increased size limits are biologically based and support self-reproducing large-bodied trophy populations and fisheries.

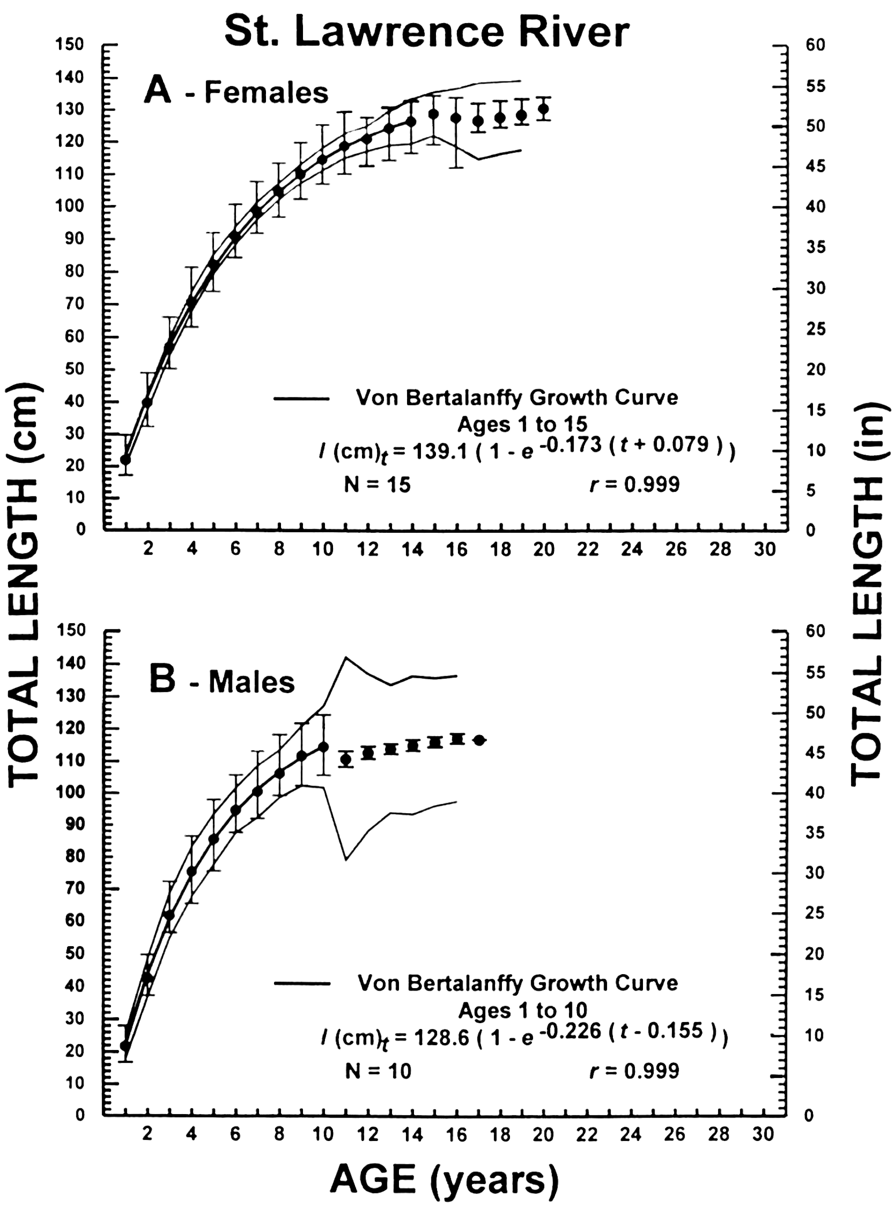
Muskellunge recruitment in the upper St. Lawrence River is positively correlated with summer temperatures (Casselman and Robinson, unpublished data). Extreme temperature conditions show the best correlations with year-class strength. Extremely warm El Niño years produced the strongest year-classes; for example, 1955, 1973, 1975, and 1983. The weakest year-classes came from the extremely cold La Nina years; for example, 1976-77. Recently, Casselman and Jason Dietrich (unpublished) have shown that temperatures in the upper St. Lawrence River have increased significantly over the past four decades. Increasing temperature conditions in the upper St. Lawrence River should continue to enhance muskellunge growth and production.

Cleithra samples provide good long-term information on growth of muskellunge (Figure 3). The ultimate size and growth trajectories indicate that St. Lawrence River muskellunge, both males and females, are very large-bodied fish, similar to those taken from the Ottawa River and Georgian Bay, and well above other Ontario populations (Table 1; Casselman et al. 1999).

Table 1. Summary of von Bertalanffy growth parameters for male and female muskellunge from the St. Lawrence River, Ottawa River, and Georgian Bay. Also, overall, equally weighted parameters are provided for 12 Ontario populations. (From Casselman et al. 1999)

	Females			Males		
Source	L_∞	K	$t_{(o)}$	L_∞	K	$t_{(o)}$
St. Lawrence River	139.1	0.173	-0.079	115.9	0.208	-0.146
Ottawa River	133.8	0.148	-0.684	106.8	0.228	-1.121
Georgian Bay	128.7	0.186	-0.494	117.3	0.210	-0.140
Overall	125.1	0.173	-0.312	106.0	0.218	-0.355

Figure 3. Length at age for female and male muskellunge from the Thousand Islands section of the St. Lawrence River. Means (back-calculated) are indicated by closed circles, ranges by bars, and 95% confidence limits by thinner lines. Von Bertalanffy growth curves calculated from the means are illustrated (thick lines), and the equations are provided. Number of ages used to construct the Von Bertalanffy growth curves are also indicated.



New size limits implemented on the St. Lawrence River follow the procedure of setting limits based on age at maturity and growth potential. Growth trajectories are calculated to estimate ultimate length based on mean body size with upper and lower 99% confidence limits (Table 2). The minimum ultimate size limit is the size that 99% of the fish would reach if they lived to their ultimate growth potential. Females from the St. Lawrence River, Ottawa River, and Georgian Bay have the same limit of 49 inches, well above 14 other populations from the province of Ontario (45 inches) (Table 2). Age predictions at this large size indicate that the youngest females harvested at this minimum ultimate size would be 10 to 19 years old, considerably older than at the age at maturity + 2 (age 7) that was formerly used in Canada (40 inches). Protecting females to this large size means that natural reproduction would be greatly enhanced.

Such large size limits, biologically based and set around minimum ultimate size, greatly enhance natural reproductive capacity of the population, ensuring that the population will be self-sustaining, and remain an important keystone feature of St. Lawrence River. Obviously, most males would not reach this size, hence would remain unharvested (Table 2). In the future, some consideration should be given to different male and female size limits since external sex determination is possible. Growth trajectories for the males are also provided, if future plans include implementing more progressive differentially sex-based size limits. The minimum ultimate size limit for male muskellunge would be 41 inches (Table 2). Although more complicated, the eventual harvest of males is an important prerequisite to sound resource use.

Age and growth of muskellunge from the upper St. Lawrence River provide important biological data, which have been taken into consideration in managing this trophy fishery. A general observation is that muskellunge are benefiting from these changes in regulations and increases in size limits, which are biologically based on growth trajectories and ultimate size. Long-term growth data extracted from growth increments in the cleithra gave some evidence that growth was increasing. The increase in growth appears were more definitive when the accumulated size at age 8 was examined, especially for the late 1960s (Robinson, unpublished data; Figure 4).

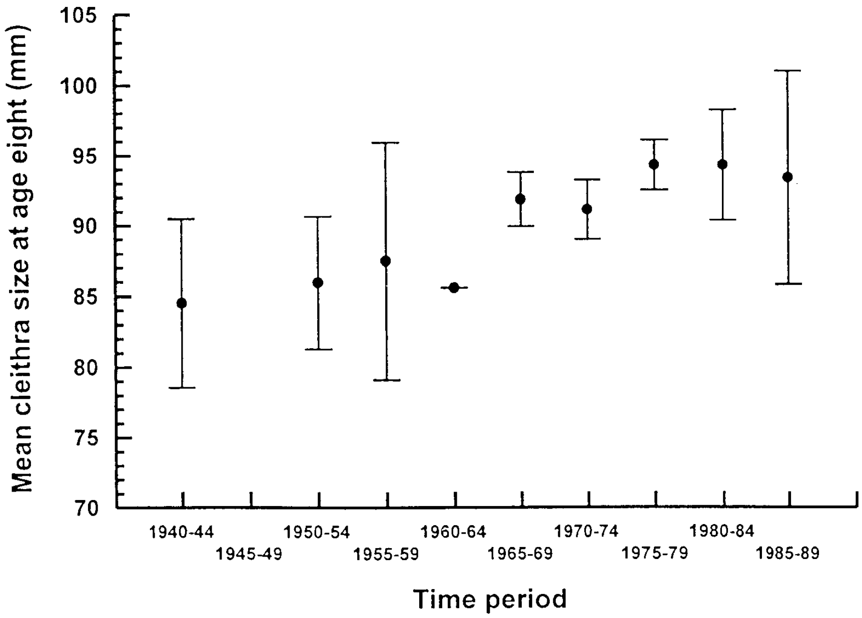
Compared with the 1940s, after the mid-1980s muskellunge and their cleithra have been significantly larger—slightly more than 10%. This reflects a substantial increase in growth rate over this time period. In fish populations, increases in growth rate have often been associated with over-exploitation; however, this would not be expected with muskellunge in the upper St.

Lawrence River due to their low abundance. The increasing growth rate may indicate a natural response to changes in the prey base and environmental conditions.

Table 2. Comparison of growth and ultimate length for male muskellunge from the St. Lawrence River, Ottawa River, and Georgian Bay. Minimum ultimate length is the L infinity at the lower 95% C.L. Weight and age data for this length are provided. Mean is for 14 Ontario populations. (Casselman and Robinson, unpublished data.)

	Ultimate length (in)				Minimum ultimate size limit				
		99% C.L.		Upper 99%		Estimated	Predicted age		
Sex and source	Mean	Upper	Lower	C.L. at age 7 (in)	Length (in)	weight (lb)	Youngest	Oldest	Oldest observed
Males									
St. Lawrence River	45	49.4	41.8	33.3	41	17.6	9	18	17
Ottawa River	42	44	40	33.7	40	16.3	8	31	17
Georgian Bay	43.5	48.6	39.6	34.1	39	15.1	9	17	20
Mean (14 populations)	41.1	45.7	37.3	31.7	37	13.5	8	20	16
Females									
St. Lawrence River	54.8	61.7	49.9	39.9	49	30.6	10	19	20
Ottawa River	52.7	55.4	49.9	37.9	49	30.6	14	26	17
Georgian Bay	52.8	58.5	49.6	37.7	49	30.6	13	24	30
Mean (14 populations)	48.4	52.8	45.2	36.3	45	24.4	12	23	19

Figure 4. Mean cleithral size (mm) at age-8 for five-year periods from 1940 to 1989. No data exist for the 1945 to 1949 period. Means and 95% confidence limits are illustrated. LSD test of paired differences is provided in Table 3 (Robinson, unpublished data). The one-in-ten rule of thumb is that the cleithral radius in millimetres is approximately equal to fish length (cm).



(8) ***The Past and Present Status of the Fishery***

The quality of the St. Lawrence River muskellunge fishery has been in question since ardent anglers and guides voiced their concerns in the 1940’s. No fishery data exists for the muskellunge population prior to these complaints. Attempts to obtain brood stock to enhance the muskellunge population in the 1950’s suggest that a problem existed (Anonymous 1953). New York diary participants required 32 hours to capture a legal sized muskellunge during 1969-1977 (Panek 1980). Data from the Clayton Muskellunge Derby (1969-1978) showed decrease in the mean size of muskellunge and a 25% harvest of immature fish along with a consistent decline in numbers of fish entered (LaPan and Penney 1990). Both Hasse (1976) and Schiavone (1986) reported difficulty in obtaining reliable catch and effort information from angler cooperators. The lack of basic biological and fishery data was cited as the single largest problem facing management of the muskellunge fishery (Panek 1980).

A mail survey of St. Lawrence River muskellunge anglers (who had purchased non-resident muskellunge stamps at Hill Island, Ontario) was conducted in 1990 (LaPan and Schiavone 1991). Of these 639 license sales, 285 surveys were completed and returned, 200 of these anglers indicated they fished for muskellunge in 1989. The muskellunge catch rate was 0.038 fish per hour (or 1 per 26 hours fished) for a total of 290 fish landed. Legal sized fish (44 inches) catch rates were 0.011 fish per hour and the mean length of the catch was 39 inches. Harvest was reported at 10% of all fish caught.

This survey was repeated eight years later in 1998 using a combined list from the 1992 non-resident muskellunge stamp list (the last year of the requirement), the NYSDEC statewide angler survey, lists compiled of active guides, and the Save The River Muskellunge Release Program. The survey questionnaire remained identical and 167 respondents indicated they fished for muskellunge. The muskellunge catch was 242 fish and the catch rate of 0.037 fish per hour (1 per 27 hours fished), and results were nearly identical to the 1989 survey. Legal sized catch rates were slightly higher at 0.015 fish per hour and the mean length of the catch was also greater at 41 ¼ inches. Harvest rates, despite the larger sizes of fish caught, were lower at 7.9%.

As expected, the results change considerably if only data from professional fishing guides are used. In 1989, four respondents account for 20% of the total catch with a 0.10 fish per hour catch rate. For 1998, twenty guides caught over 1/3 of the total catch with a 0.11 fish per hour rate. Harvest by guides was higher relative to other anglers but was reduced from 1989 at 15.3% to 9.8% for 1998.

An angler diary program of several guides and serious anglers has been maintained for the Thousand Island Region since 1997 in an attempt to monitor muskellunge fishery trends (Farrell et al. 2002). The catch per effort data is similar to that reported by guides for the mail surveys described above, ranging from 0.04-0.118 fish per hour (Table 3). The total annual catch in the program was near double all other years in 2000 at 102 fish. Mean length of the catch has ranged from 40 ½ to over 45 inches. A total of 712 anglers were present on the fishing trips, for the five-year period, despite having only 27 participant entries. This indicates a strong interest in the sport fishery despite a low success rate per angler.

Table 3. St. Lawrence River muskellunge angler diary program data summarized for 1997-2001.

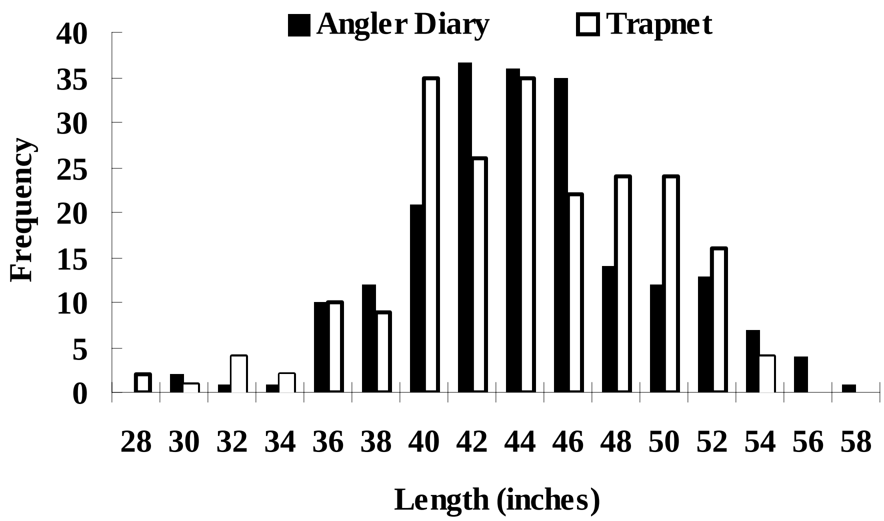
Metric	1997	1998	1999	2000	2001
Participants	5	6	4	7	5
Angler Trips	57	73	59	104	78
# Anglers	135	245	165	325	142
Total Hours Fished	468	564	450	899	1160.5
Total Catch	46	51	53	102	47
CPUE	0.098	0.090	0.118	0.113	0.040
# Harvested	19	15	10	7	0
% Harvested	41	27	19	7	0
Mean Length	45.3	44.7	43.7	40.5	42.5
Mean Length Harvested	49	50.2	47.9	51.7	-
Length Range	30-54	36-58	36-50	32-56	33-58.5

A comparison of the length frequency histograms for the angler diary program catch and spring trapnet surveys during the spawning runs 1990-2000 shows a similar increase in catch at the 36-37" size interval (Figure 5). Smaller fish are not fully represented in either the angler catch or in the spawning population. A decline in the angler catch of fish in the 48-51" size category is also evident relative to their frequency in trapnet catches.

Harvest rates of muskellunge show a remarkable change in the philosophy of anglers regarding exploitation on this fish population. During the Clayton Muskellunge Derby, 90% of fish captured in 1975 were harvested with over 1,000 fish removed from the population at the derby from 1969-1978. Hasse (1976) reported an 87% harvest (20 of 23 fish logged) for a voluntary creel program in 1975. Harvest rates have clearly declined in recent years with an estimated 10% in the 1989 mail survey and from 0 to 41% harvest during the angler diary program (1997-2001).

A comparison of the length frequency histogram for male muskellunge captured over two extended periods of spring trapnetting (1983-1991 and 1992-2000) in the upper River indicates a shift in the size distribution from smaller to larger individuals (Figure 6). Mean length in the catch has increased from 40" to 43"over the period. Female muskellunge have also shown an increase in size between the periods. The male distribution shows a normal bell-shaped curve

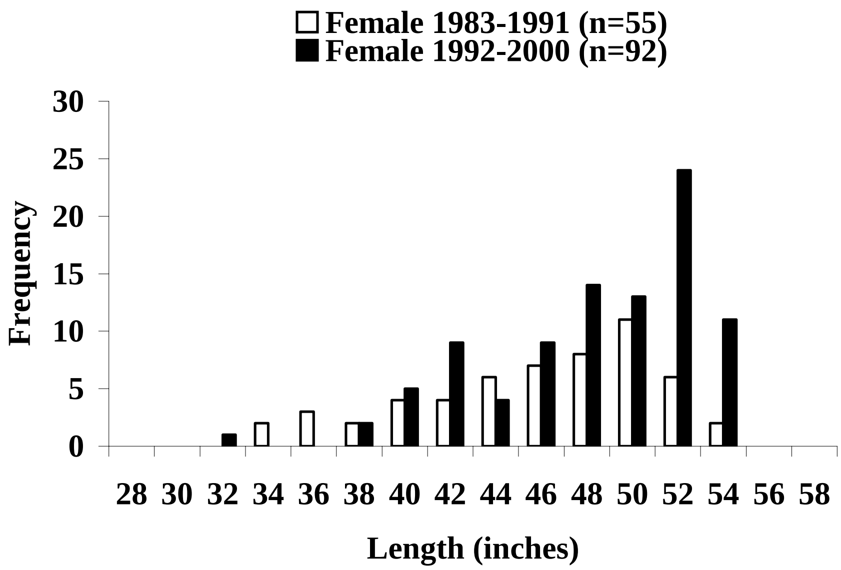
Figure 5. Length-frequency histogram of male and female muskellunge captured in the New York 1997-2001 St. Lawrence River angler diary program and in a New York trapnetting survey (1990-2000).

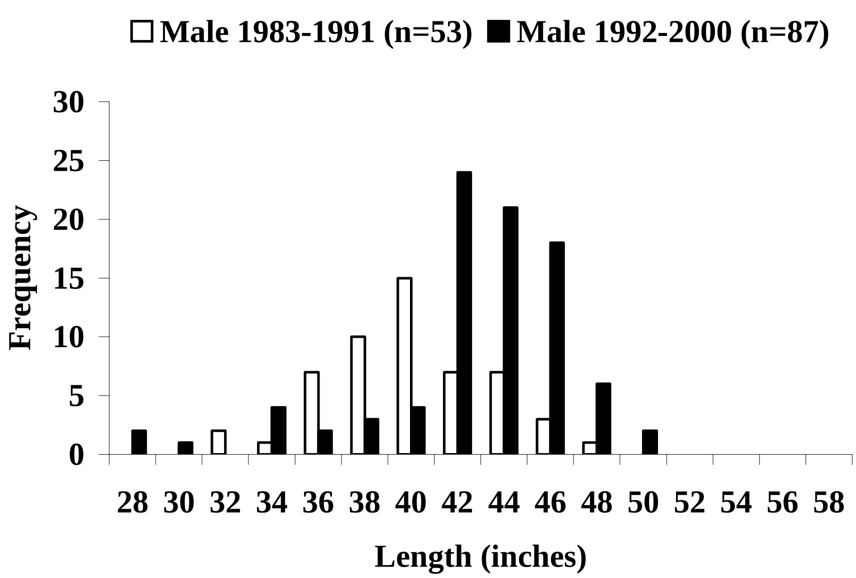


whereas the female distributions are skewed toward larger individuals. Female muskellunge also appear to have larger individuals in the recent period compared to the past. The changes in the size distributions are likely due to increasing size limits over these time periods. At Lake of the Woods, Ontario, an increase in the size limit from 28” to 44” in 1987, and to 48” in 1992 is believed to have caused an increase in average size of muskellunge (Mosindy 1995).

Sexually mature muskellunge generally first appear in trap net catches on the spawning grounds at approximately 35” total length. Since muskellunge fishing effort is concentrated in the fall (at the end of the growing season), many fish that reached 36” during the growing season probably had not yet spawned for the first time. With the support of professional muskellunge guides and angler cooperators, the minimum size limit for muskellunge was raised to 44” in 1987 in New York and in 1991 in Ontario waters of the St. Lawrence River. In addition, harvest rates have declined significantly. This added protection, discouraging the removal of smaller adults, has probably increased the abundance of large individuals. Potentially, regulation changes have protected males to a greater degree due to their smaller size relative to females. Another feature in the male muskellunge size distribution is the presence of fewer small muskellunge in the 36-40” size range in the recent period. Perhaps this represents poorer recruitment to these age classes or perhaps an increase in the size at first spawning due to increased growth rates.

Figure 6. Length-frequency histogram for female (Top) and male (Bottom) muskellunge captured in trapnet sets in New York waters of the Thousand Islands section of the St. Lawrence River during spring spawning runs over two eight year periods (1983-1991 and 1992-2000).





(9) *Regulation of the Fishery*

Management of the St. Lawrence River muskellunge began in New York State in 1909 and has since followed a trend from extremely liberal regulations with no biological basis to a more restrictive plan with a trophy management strategy. From 1909 to 1960, a 24" size limit was in place with no creel limit. In 1961-1962, the size limit was increased to 28"and from 1963 through 1977 the creel limit was 2 fish per day. Based on the recommendations of Hasse (1976), the size limit was increased to 36" in 1978 to allow females a minimum one-year opportunity to spawn, and the creel limit was reduced to one fish. Following recommendations of the Muskellunge Working Group, the size limit was increased to 44" in 1986 for New York waters and in 1991 for Ontario to allow females greater opportunity to spawn prior to being available for exploitation. In the fall of 2002, a 48" size limit was enacted for both Ontario and New York waters of the St. Lawrence River. This change is in part based on estimates of ultimate length and growth potential for St. Lawrence River muskellunge that provided a biological basis for setting higher size limits (Casselman et al. 1999).

(10) The St. Lawrence River Esocid Working Group

The Muskellunge Working Group was amended to become the Esocid Working Group in 1999 when it was recognized that the St. Lawrence River northern pike (*Esox lucius*) population and fishery showed declining trends and that issues regarding management of both northern pike and muskellunge should be considered mutually. The original Muskellunge Working Group was created as part of the Great Lakes Fishery Commission Lake Ontario Committee in 1980 (Panek 1980). Responsibilities of the Esocid Working Group continue with the same direction of identification of research needs and coordination of an international research and management effort to protect and enhance St. Lawrence River esocid fisheries. The working group is currently composed of fisheries management personnel from the New York State Department of Environmental Conservation, and the Ontario Ministry of Natural Resources, and scientists of the SUNY College of Environmental Science and Forestry and the Royal Ontario Museum. The working group meets on alternate years and on an ad hoc basis. The current representatives of the Esocid Working Group are the following members representing management agencies and serving as advisors:

Agencies

New York State Department of Environmental Conservation

Chief of Fisheries, Doug Stang

Supervisor of Inland Fisheries, Shaun Keeler

Great Lakes Section Head, Bill Culligan

Fisheries Manager, Region 6, Bill Gordon

St. Lawrence River Unit Biologist, Rodger Klindt

Lake Ontario Unit Leader, Steve LaPan

Ontario Ministry of Natural Resources

Lake Ontario Rob MacGreggor

Lake Ontario Fisheries Management Unit Assessment Supervisor, Bruce Morrison

District Biologist, Kemptville, Ontario, Anne Bendig

Advisors

Dr. John M. Farrell (Working Group Chair) – Director, SUNY College of Environmental Science and Forestry, Thousand Islands Biological Station

Dr. John M. Casselman – Fisheries Scientist, OMNR Research Branch, Glenora Field Station

Dr. Edward Crossman – Curator, Department of Ichthyology and Herpetology, Royal Ontario Museum, Toronto

3.0 Management Goals and Objectives for 2001-2010

The goals for management of the St. Lawrence River muskellunge are to (1) perpetuate the species as a viable, self-sustaining component of the River's fish community, and (2) provide a high quality trophy sport fishery.

The above stated management goals will be met by fulfillment of the following objectives:

(1) Protect all muskellunge spawning and nursery habitats from Eastern Lake Ontario through Lake St. Lawrence.

(2) Restore degraded muskellunge spawning and nursery habitats to enhance reproduction rates.

(3) Maintain a high quality trophy fishery with a minimum average catch rate by guides and ardent anglers of one adult muskellunge per 10 hours fished.

4.0 Strategies

(1) Identify all muskellunge spawning and nursery habitats from Eastern Lake Ontario downriver through Lake St. Lawrence.

(2) Monitor age-0 muskellunge populations in spawning and nursery sites and develop an index of reproductive success.

(3) Monitor adult muskellunge populations during spawning to develop an index of abundance, evaluate sex ratios, size structure, and spawning site fidelity.

(4) Maintain common US/Canadian minimum total length and creel restrictions.

(5) Monitor effort, catch rates, muskellunge age and growth, and catch composition of the fishery.

(6) Determine the feasibility of restoration/enhancement of degraded habitats to increase natural reproduction.

(7) Foster conservation of muskellunge through educations programs such as the Save The River Muskellunge Release Program.

5.0 Programmatic Needs for Management and Education

(1) Partnerships

Partnerships have become an integral part of fish and wildlife resource management. Direct contact with stakeholders offers insight into program needs and offers a pool of first hand knowledge of the resource. It would be beneficial to the muskellunge management program to support and work with organized groups interested in managing and utilizing this trophy fishery.

(2) Stocking Policies

It is recommended that no stocking program be instituted to increase population levels of the St. Lawrence River muskellunge population at this time. Stocking of early life stages (fry) to restore populations at specific locations could be considered, however, natural reproduction is currently adequate to sustain the muskellunge population. Serious concerns over the consequences of stocking to supplement natural reproduction outweigh its potential benefits. These concerns include potential effects on health of the St. Lawrence River muskellunge genetic strain, the unintentional introduction of diseases, maintenance of balanced predator-prey relationships, and impacts of hatchery fish on population dynamics of muskellunge (including age, growth, and recruitment). The St. Lawrence River muskellunge fishery is one of the finest trophy fisheries available and is best sustained through natural reproduction.

(3) Conservation Education

Conservation and education programs involving St. Lawrence River muskellunge are not new concepts. An identification guide for northern pike and muskellunge ("What's It", NY Sea Grant) and the Save the River Muskellunge Release Program are two examples of successful public outreach programs. Save the River's "Save The Muskie" tee-shirts and "Muskie Release!" hats have also been very popular in promoting conservation.

Muskellunge have been shown in the past to be vulnerable to casual angling, and are frequently taken by those targeting other warm water species. It is not unusual for juvenile muskellunge to be mistaken for northern pike and harvested. Little is known concerning habitat requirements and behavior of juvenile muskellunge in the St. Lawrence thus making their protection of utmost importance. An updated brochure outlining the identification characteristics of St. Lawrence River esocids would benefit the resource and enlighten the public to an important resource issue.

The Muskellunge Release Program, begun in 1987 by Save the River, has been instrumental in promoting catch and release fishing for muskies in the St. Lawrence. A limited edition print is offered as incentive for the release of a legally harvestable fish. Since its inception, this program has resulted in the release of over 500 adult fish. While these numbers are difficult to relate directly to a population estimate, they likely account for a significant portion of the spawning population. Continued support for this program is warranted. A publication outlining proper catch and release methods would be a useful addition to the Muskellunge Release Program.

(4) Evaluation of Angler Satisfaction

Angler satisfaction is a key component to the evaluation of a fishery management program. Regulations and restrictions are often balanced on both resource protection and stakeholder desires. Although an angler diary program does exist, active participation is limited and may possibly provide a biased indication of angler satisfaction. In the wake of recent regulation changes on both the Canadian and New York reaches of the river, it would be beneficial to the muskellunge management program to develop a methodology for periodic evaluation of angler satisfaction. New York's newly computerized license issuing system, DECALS, may provide an efficient way to identify and contact St. Lawrence River muskellunge anglers.

(5) Impacts of Development and Land Use

A key component to the management of muskellunge in the St. Lawrence River has been habitat protection. To date, protection of habitat has been based on the presence or absence of spawning and/or YOY muskellunge. Past research has focused on isolating variables that play an important role in spawning and nursery site selection. Although much has been accomplished, there is still much to learn in order to apply habitat protection over a broad scale.

Controlling direct impacts to spawning and nursery sites is accomplished through regulatory permitting for activities such as dredging and dock construction. Long-term changes in spawning and nursery bays related to development, increased boating activity, and changes in riparian land use have not been adequately assessed. Researching historic records of YOY abundance and correlating them to human use changes over time would potentially be valuable to future resource managers.

6.0 Programmatic Needs for Research

(1) Esocid Interactions and Role of Muskellunge in the Aquatic Community

Muskellunge YOY are sympatric in specific spawning and nursery habitats with two other esocids, the northern pike and the grass pickerel (*Esox americanus vermiculatis*). Studies have shown a considerable dietary overlap between northern pike and muskellunge and to a lesser extent grass pickerel, which show a greater preference for invertebrates (Farrell 1998). Northern pike typically attain the largest size during the first year of development among the esocids and are believed to be a superior competitor of muskellunge during early life (Inskip 1986). Northern pike in the upper St. Lawrence River, however, according to the NYSDEC Warmwater Assessment Database, have experienced a consistent decline from population highs in the early 1980’s. The Thousand Islands Biological Station seining database has documented a significant decline in YOY northern pike since a peak in 1987 (Figure 1). A decline in reproductive success in pike is thought to be linked to changes in access to spawning habitats and habitat change associated with water level stabilization of the upper St. Lawrence River due to its damming in 1959 (Farrell 2001).

The increase in abundance of muskellunge on the nursery grounds may be due to release from predation and prey resource competition with northern pike in the shared spawning and nursery areas. Empirical data showing reduced instantaneous growth rates of muskellunge in the presence of abundant northern pike at specific sites suggests that the northern pike interaction may play a role in regulation of muskellunge YOY success. Also, at one bay (Affluence), both northern pike and muskellunge were equally abundant in 1996 during early summer. A consistent decline in muskellunge was observed over the summer while northern pike remained abundant (Farrell 1998).

More research is needed to assess niche overlap of northern pike and muskellunge in nursery areas. Currently spawning habitat segregation of northern pike and muskellunge is well understood, but the differences in nursery habitat among the esocids are not well known. Attempts to perform population estimates for YOY muskellunge were very successful but failed for northern pike despite marking an equal number of individuals in some locations. Northern pike recaptures were extremely low in these studies and greater movement of YOY may have affected recapture rates.

Well-designed field experiments may elucidate the mechanisms of esocid interaction. This information will be very important for planning and implementation measures of northern pike population enhancement to prevent negative impacts on muskellunge YOY production.

(2) Develop Predictive Models and Monitoring of Esocid Habitat Dynamics

The effects of water level management of the Lake Ontario and St. Lawrence River system on the muskellunge population requires more attention. Shallow emergent habitats in coastal wetlands of the Upper River and Lake Ontario have changed dramatically over the period of regulation (Cooper 2000; Farrell 2001). Currently the International Joint Commission Water Levels Study is looking at possible modifications to the water level regulation plan 1958D. Current regulation and any proposed changes to the plan should be evaluated for how they will affect muskellunge habitat and reproductive success.

To accomplish this task it is necessary to understand how a variety of environmental factors (i.e. temperature, water levels, habitat, and biotic interactions) affect recruitment processes. As part of the water levels study, models for spawning and nursery habitat and the maximization of growth need to be developed. The models should be upgraded using long-term field data from nursery sites and experimental data to predict what conditions promote strong year-classes and maintain high quality habitat. Additional models are being developed to assess environmental and climatic conditions important to muskellunge population dynamics from data from the OMNR Cleithrum Project (John Casselman, OMNR Glenora Station, personal communication). Continued collection of cleithra bones from taxidermists is imperative to further development of the model. Both approaches will yield useful information affecting future management considerations.

(3) Muskellunge Imprinting on Spawning Locations

Muskellunge have demonstrated some form of reproductive homing where adults spawn in the same areas year after year. It is not known if this behavior represents a natal homing instinct or if spawning site selection occurs at adulthood. This is a question that is important to muskellunge management and was used as the basis of a spawning population restoration study (Farrell and Werner 1999). Reproductive homing behavior is valuable in distributing spawning across many locations in the system (95 locations have already been identified in the International waters). The two strategies could have very different impacts with respect to gene flow in the system and to maintenance of spawning populations. With natal imprinting and homing, muskellunge would likely persist in habitats that have promoted past reproductive success. The site fidelity following adulthood strategy could result in repeated spawning in poorer quality habitats. However, natal imprinted populations could receive less genetic mixing and would be at greater risk of loss to overexploitation regardless of habitat changes. Because muskellunge spread their gametes over considerable distances, sufficient mixing may occur making it difficult to identify either pattern.

(4) Genetic Variation among Geographic Locations

Future work should focus on individual and population level genetics for muskellunge within the geographic area of scope for this plan to establish large-scale reproductive strategies and the extent of genetic isolation. Currently the genetic markers do not exist to address these important questions. Most studies have focused on use of allozyme-based techniques that cannot provide the necessary information. In order to conduct the level of genetic analyses to test population level hypotheses related to the health of the muskellunge population, the useful primer pairs to obtain separation need to be identified.

(5) Muskellunge Migration Patterns

Patterns of muskellunge seasonal movements have been loosely identified. The processes of reproductive homing, upstream migration, and congregation at specific habitats in the fall are poorly understood. The mechanisms behind these behaviors needs further study for improved muskellunge management. Shifts in fishing effort are likely to correspond to seasonal and inter-annual changes in muskellunge distribution. An apparent shift in fishing effort has been observed in the upper River, from a focus on the Cape Vincent and the Carleton Island area during the 1980s through early 1990s, to the current focus on the Wolfe Island and Forty Acre Shoals area over the late 1990s to the present. Identifying the relationship of migratory patterns to angling effort will be important in understanding exploitation processes. Technological advancements with tagging systems may allow more information to be collected on adult muskellunge previously unavailable. Archival tags that collect a variety of information including fish position, depth and temperature simultaneously for long periods may prove to be useful in addressing difficult scientific questions regarding adult biology.

(6) Identification of Critical Habitats for Sub-Adult muskellunge (ages 1-5)

Information regarding the distribution and habitat use and dynamics of age classes of 1-5 year old muskellunge is greatly needed and continues to be problematic. Recent telemetry studies of hatchery-reared age-1 muskellunge indicated a preference for shallow emergent vegetation. Electrofishing surveys targeting emergent habitats during springtime are recommended. Future studies should use radio-telemetry with wild fish.

(7) Monitoring of Muskellunge Diseases

Diseases of muskellunge have had devastating impacts on populations in other waters such as Chautauqua Lake, New York. Recently muskellunge in Lake St. Clair have been infected with a rash-like disease named *Piscirickettsia*, and its effects on the population are unknown. Disease monitoring should become a regular part of current trapnetting and angler diary programs in the St. Lawrence River.

Literature Cited

Anon. 1953. Conservation Department Forty-third Annual Report for the year 1952. Legislative Document (1953), No. 27.

Bendig, A. 1996. 1994 St. Lawrence River muskellunge nursery habitat inventory. Pages 83-91 *In* Kerr, S. J. and C. H. Olver (eds.) Managing Muskies in the 90's. Workshop proceedings. OMNR, Southern Region Science and Technology Transfer Unit WP-007.

Bozek, M. A., T. M. Burri, and R. V. Frie. 1999. Diets of muskellunge in Northern Wisconsin Lakes. North American Journal of Fisheries Management 19:258-270.

Casselman, J. M., C. Robinson, and E. J. Crossman. 1999. Growth and ultimate length of muskellunge from Ontario water bodies. North American Journal of Fisheries Management 19:271-290.

Clapsadl, M. 1993. An examination of habitat characteristics influencing the survival of stocked muskellunge (Esox masquinongy) in four St. Lawrence River embayments. Master's Thesis, State University of New York, College of Environmental Science and Forestry, Syracuse, New York.

Cooper, J. E. 2000. Comparative development and ecology of northern pike (Esox Lucius) and muskellunge (Esox masquinongy) eggs and larvae in the Upper St. Lawrence River and the implications of changes in the historical spawning habitat. Doctoral Thesis, State University of New York, College of Environmental Science and Forestry, Syracuse, New York.

Crossman, E. J. 1978. Taxonomy and distribution of North American esocids. Pages 13-26 in R. L. Kendall, editor. Selected Coolwater Fishes of North America. American Fisheries Society, Special Publication 11, Washington, D.C.

Crossman, E. J. 1990. Reproductive homing in muskellunge, (Esox masquinongy). Canadian Journal of Fisheries and Aquatic Sciences 47:1803-1812.

Farrell, J. M. 1991. Spawning ecology of sympatric northern pike and muskellunge in the St. Lawrence River. Master's Thesis, State University of New York, College of Environmental Science and Forestry, Syracuse, New York.

Farrell, J. M. 1998. Population ecology of sympatric age-0 northern pike and muskellunge in the St. Lawrence River. Doctoral Thesis, State University of New York, College of Environmental Science and Forestry, Syracuse, New York.

Farrell, J. M., R. G. Werner, S. R. LaPan, and K. A. Claypoole. 1996. Egg distribution and spawning habitat of northern pike and muskellunge in a St. Lawrence River marsh, New York. Transactions of the American Fisheries Society 125:127-131.

Farrell, J. M., and R. G. Werner. 1999. Distribution, abundance, and survival of age-0 muskellunge in Upper St. Lawrence River nursery bays. North American Journal of Fisheries Management 19:310-321.

Farrell, J. M. 2000. Movements and Habitat Use By Sub-Adult Muskellunge in the St. Lawrence River. NYSDEC Final Report, Federal Aid in Sportfish Restoration FA-48-R, Job 103.

Farrell, J. M. 2001. Reproductive success of sympatric northern pike and muskellunge in an Upper St. Lawrence River bay. Transactions of the American Fisheries Society 130:796-808.

Farrell, J. M. and H. B. Underwood. 2003. Habitat use by sub-adult northern pike and muskellunge in the St. Lawrence River. North American Journal of Fisheries Management (submitted).

Farrell, J. M., M. A. Connerton, J. E. Cooper, B. A. Murry, and A. Bosworth. 2002. St. Lawrence River esocid management strategies. NYSDEC Annual Report. Federal Aid in Sportfish Restoration Project FA-5-R.

Hasse, J. J. 1976. A comparison of the St. Lawrence River muskellunge fishery to other muskellunge waters with a recommendation on regulation changes. NYSDEC report, Region 6 Sub-Office, Utica, 12 pages.

Inskip, P. D. 1986. Negative associations between abundances of muskellunge and northern pike: evidence and possible explanations. American Fisheries Society Special Publication 15:135-150.

Jonckheere, B. V. 1994. Production and survival of juvenile muskellunge (Esox masquinongy) in the St. Lawrence River, and the habitat characteristics affecting distribution. Master's Thesis. State University of New York, College of Environmental Science and Forestry, Syracuse, New York.

LaPan, S. R. 1985. Spawning and early life history of muskellunge and northern pike in the St. Lawrence River. Master's Thesis. State University of New York, College of Environmental Science and Forestry, Syracuse, New York.

LaPan, S.R. and L. Penney 1991. Strategic plan for management of the muskellunge population and sportfishery of the St. Lawrence River Phase 11: 1991-2000. New York State Department of Environmental Conservation, Albany, New York. 51 p.

LaPan, S.R. and A. Schiavone 1991. Angler survey, St. Lawrence River muskellunge. New York State Department of Environmental Conservation, Region 6, Watertown, New York. 18 pages.

LaPan, S. R., A. Schiavone, and R. G. Werner. 1996. Spawning and post-spawning movements of the St. Lawrence River muskellunge (Esox masquinongy). Pages 73-82 *In* Kerr, S. J. and C. H. Olver (eds.) Managing Muskies in the 90’s. Workshop proceedings. OMNR, Southern Region Science and Technology Transfer Unit WP-007.

Panek, F.M. 1980. Strategic plan for management of the muskellunge population and sport fishery of the St. Lawrence River. NYS Department of Environmental Conservation. Watertown, NY.

Werner, R. G., R. Klindt, and B. V. Jonckheere. 1996. Vegetative characteristics of muskellunge (Esox masquinongy) spawning and nursery habitat in the 1000 Islands section of the St. Lawrence River. Great Lakes Research Review 2:29-35.

Appendix I. International Eastern Lake Ontario and upper St. Lawrence River muskellunge nursery site locations. Coordinate information uses the Universal Transverse Mercator system. Basin codes: LO = Lake Ontario, SLR = St. Lawrence River, TI = Thousand Islands, MC = Middle Corridor, LSL = Lake St. Lawrence.

SITE	COUNTRY	BASIN	DESCRIPTION	ASSOCIATION	UTME	UTMN
1	US	LO	Grenadier Isl.	Grenadier Isl.	392478	4878137
2	US	LO	Fox Cr.	Mainland	396145	4879169
3	US	SLR-TI	Grass Bay	Mainland	397665	4890423
4	US	SLR-TI	Peos Bay	Mainland	400046	4891364
5	US	SLR-TI	Millens Bay	Mainland	400510	4891497
6	US	SLR-TI	Dodge Bay	Mainland	401279	4892696
7	US	SLR-TI	Rose Bay	Mainland	402013	4893173
8	US	SLR-TI	Flynn Bay	Grindstone Isl.	409270	4900713
9	US	SLR-TI	Lindley Bay	Grindstone Isl.	408497	4900328
10	US	SLR-TI	Red Boathouse Bay	Grindstone Isl.	407924	4900930
11	US	SLR-TI	Thurso Bay	Grindstone Isl.	409035	4904495
12	US	SLR-TI	Long Pt. Marsh	Grindstone Isl.	409763	4904450
13	US	SLR-TI	Grindstone Isl.	Grindstone Isl.	411273	4905279
14	US	SLR-TI	Grindstone Isl.	Grindstone Isl.	411521	4905397
15	US	SLR-TI	Whitehouse Marsh	Grindstone Isl.	414297	4905932
16	US	SLR-TI	Buck Bay	Grindstone Isl.	408367	4900814
17	US	SLR-TI	Pt. Angiers	Grindstone Isl.	414811	4905212
18	US	SLR-TI	Salisbury	Grindstone Isl.	414444	4904884
19	US	SLR-TI	Aunt Janes Bay	Grindstone Isl.	411535	4901940
20	US	SLR-TI	Boscobel Isl.	Grindstone Isl.	411462	4901321
21	US	SLR-TI	Frinks Bay	Mainland	413709	4899356
22	US	SLR-TI	Carrier Bay	Mainland	414822	4899498
23	US	SLR-TI	The Narrows	Murray Isl.	416788	4905007
24	US	SLR-TI	Blind Bay	Mainland	418844	4902139
25	US	SLR-TI	Cobb Shoal	Mainland	421378	4905386

26	US	SLR-TI	Swan Bay	Mainland	422584	4906134
27	US	SLR-TI	Pt. Vivian	Mainland	424096	4907296
28	US	SLR-TI	Garlock Bay	Mainland	424596	4907670
29	US	SLR-TI	Affluence Bay	Wellesley Isl.	420401	4905114
30	US	SLR-TI	Densmore Bay	Wellesley Isl.	424222	4908297
31	US	SLR-TI	Densmore Bay	Wellesley Isl.	424698	4908320
32	US	SLR-TI	State Park	Wellesley Isl.	417284	4909339
33	US	SLR-TI	State Park	Wellesley Isl.	417456	4909430
34	US	SLR-TI	Lake of the Isles	Wellesley Isl.	423901	4910464
35	US	SLR-TI	Deer Isl.	Deer Isl.	427781	4912677
36	US	SLR-TI	Pt. Marguerite Marsh	Mainland	429822	4912530
37	US	SLR-TI	Number 9 Isl.	Mainland	430703	4913071
38	US	SLR-TI	Birch Isl.	Birch Isl.	430555	4913320
39	US	SLR-TI	Goose Bay	Mainland	432457	4912993
40	US	SLR-TI	Chippewa Bay-Grant Isl.	Mainland	438411	4920206
41	US	SLR-TI	Little Hammond Pt.	Mainland	438427	4923700
42	US	SLR-TI	Chippewa Pt. (outer)	Mainland	437103	4923791
43	US	SLR-TI	Townline Bay	Mainland	433164	4916015
44	US	SLR-TI	Chippewa West	Mainland	436193	4917210
45	US	SLR-TI	Oak Island N	Oak Island	436649	4919316
46	US	SLR-TI	Owatonna Isl.	Oak Island	437216	4920544
47	US	SLR-TI	Brush Isl.	Oak Island	437300	4920684
48	US	SLR-TI	Chippewa Pt.	Mainland	437754	4924425
49	US	SLR-TI	Sheepshead Pt.	Mainland	438169	4924303
50	US	SLR-TI	Oak Pt.	Mainland	440251	4929145
51	US	SLR-TI	Point Comfort	Mainland	444198	4933367
52	US	SLR-TI	Jacque Cartier SP	Mainland	445236	4934509
53	US	SLR-MC	Oswegatchie R.	Mainland	460176	4949563
54	US	SLR-MC	Galop Isl.	Galop Isl.	468675	4956622

55	US	SLR-MC	Benedict Isl.	Galop Isl.	469472	4957448
56	US	SLR-MC	Big Bay W	Galop Isl.	469895	4958246
57	US	SLR-MC	Big Bay E	Galop Isl.	470218	4958410
58	US	SLR-MC	Iroquois E	Mainland	476924	4963631
59	US	SLR-LSL	Whitehouse Bay	Mainland	479310	4966395
60	US	SLR-LSL	Leishman Pt.	Mainland	480639	4966806
61	US	SLR-LSL	Waddington Beach	Mainland	480844	4966979
62	US	SLR-LSL	Ogden Isl.	Ogden Isl.	482999	4968329
63	US	SLR-LSL	Brandy Brook	Mainland	487349	4969266
64	US	SLR-LSL	Nichols Hill Isl.	Wilson Hill	491600	4972563
65	US	SLR-LSL	Wilson Hill E	Wilson Hill	499038	4976018
66	US	SLR-LSL	Sand Islands	Mainland	500557	4976506
67	US	SLR-LSL	Long Sault Isl.	Long Sault Isl.	508403	4981417
68	US	SLR-LSL	Barnhardt Beach	Barnhardt Isl.	512033	4983501
69	CAN	SLR-TI	E of McDonnell Bay	Wolfe Isl.	390695	4897757
70	CAN	SLR-TI	Oak Pt.	Wolfe Isl.	395478	4897588
71	CAN	SLR-TI	Holliday Bay	Wolfe Isl.	393621	4898826
72	CAN	SLR-TI	Sugar Isl.	Sugar Isl.	412411	4907682
73	CAN	SLR-TI	Stave Isl.	Stave Isl.	414102	4909639
74	CAN	SLR-TI	Halsteads Bay	Mainland	414191	4911240
75	CAN	SLR-TI	Lancaster Isl.	Lancaster Isl.	416326	4910796
76	CAN	SLR-TI	Owen Isl.	Owen Isl.	417008	4910558
77	CAN	SLR-TI	Near Van Buren Isl.	Van Buren Isl.	428812	4917320
78	CAN	SLR-TI	W of Fermans Pt.	Grenadier Isl.	432015	4920048
79	CAN	SLR-TI	W of Pitch Pine Pt.	Grenadier Isl.	429523	4916282
80	CAN	SLR-TI	E Mallorytown,	Mainland	433408	4924527
81	CAN	SLR-MC	Johnstown Provincial Park	Mainland	462739	4954154
82	CAN	SLR-MC	E of Johnstown Prov. Park	Mainland	464192	4955162
83	CAN	SLR-MC	McLachlan Creek	Mainland	466565	4958365

84	CAN	SLR-MC	Sawmill Creek	Mainland	470767	4960395
85	CAN	SLR-MC	E of Sawmill Creek	Mainland	471050	4960557
86	CAN	SLR-MC	Presquile Isl.	Presquile Isl.	472777	4962101
87	CAN	SLR-MC	Iroquois Marina	Mainland	475496	4965252
88	CAN	SLR-LSL	Hoasic Creek	Mainland	486971	4971964
89	CAN	SLR-LSL	E end Morrison Isl.	Morrison Isl.	499823	4980175
90	US	SLR-TI	Little Birch Isl., Goose Bay	Mainland	431773	4912248
91	CAN	SLR-LSF	Cornwall Marina	Mainland	522556	4984706
92	CAN	SLR-MC	Port of Prescott	Mainland	462566	4953567
93	CAN	SLR-MC	Bay W. of Iroquois	Mainland	475692	4965575
94	CAN	SLR-LSL	Hoople Isl.	Long Sault Parkway	505653	4982339
95	CAN	SLR-LSL	Mille Roche Isl.	Long Sault Parkway	508388	4985364