Lake Champlain Lake Sturgeon Recovery Plan

February 2016

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Commissioner, Vermont Fish & Wildlife Department	3/6/16 Date
Secretary, Vermont Agency of Natural Resources	3-10-16 Date

Acknowledgements

This project was paid for in part by fishing license sales and matching Dingell-Johnson/Wallop Breaux funds available through the Federal Sportfish Restoration Act. Additional funding was provided through the State Wildlife Grant Program.

I'd like to thank the many people that made this plan possible. Special thanks to Angelo Incerpi, retired fisheries director for the Vermont Department of Fish and Wildlife, who gave me an opportunity to work with this unique fish and Dave Ravelin, a private landowner along the Winooski River, who allowed us to use his property as a staging area, saving hundreds of hours of travel time to and from sampling sites. Thanks to Michel LaHaye, who travelled from Quebec to Vermont to share his knowledge on sturgeon spawning habitat and the techniques used to collect lake sturgeon eggs and Micah Kiefer from the Conte Anadromous Research Lab (USGS) for demonstrating the surgical techniques used to implant tags in sturgeon.

Many people within the department, both permanent and temporary employees, should be acknowledged for their help on the project, including but not limited to John Claussen, Rich Kirn, Eric Palmer, Shawn Good, Dave Gibson, Joel Flewelling, Jill Oudman, Steve Doyle, Joe Burt, Andy Edmunds, Ryan Smith, Jon Piper, Jason Kain, Andy Edmunds, Jay Seals, and Stephanie Pierce. Special thanks to Madeleine Lyttle and Nick Staats of the USFWS for helping with the surveys in the Lamoille and Winooski rivers and in particular the sampling for adults and eggs in the Missisquoi River. Without the help of all the people listed above the project would not have been successful.

Thanks to Eric Palmer, Rich Kirn, Brian Chipman, Ken Cox, Susan Warner, and Rod Wentworth for providing comments and improvements to earlier drafts of this plan.

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Executive Summary

Lake sturgeon belong to an ancient family of fishes and have been described as living fossils. Lake sturgeon have life history traits that are unique when compared to more recently evolved fish species. They are long lived, slow to mature, spawn intermittently, and have high fecundity and low natural mortality. Lake sturgeon can live for 150 years and weigh up to 310 pounds. Lake sturgeon are the largest and longest living fish found in Vermont and are only present in Lake Champlain and its major tributaries.

Lake Champlain supported a small commercial fishery for lake sturgeon in the late 1800s and early 1900s. Annual harvest declined rapidly in the late 1940s and the commercial fishery was closed in 1967. The lake sturgeon was classified as endangered by Vermont in 1972. The decline in lake sturgeon abundance in Lake Champlain has been attributed to over fishing, habitat loss in the rivers that were used as spawning and nursery grounds, and the introduction of non-native species.

Lake sturgeon are now rarely seen during fisheries assessments on Lake Champlain and its tributaries. Sturgeon still migrate to the Missisquoi, Lamoille, and Winooski rivers to spawn although the number of spawning adults in each of the rivers is small. To ensure survival of Lake Champlain's lake sturgeon populations, the state has set a restoration goal of 2000 mature adults in the lake or 750 mature adults for each population spawning in the Missisquoi, Lamoille, and Winooski rivers.

Reducing mortality of sub-adult and adult sturgeon and protecting and restoring spawning habitat will be critical to restoration efforts. Ensuring lake sturgeon survive in Lake Champlain and recover to the point where they can support a unique recreational fishery will require a long-term commitment to the program. Restoring a healthy, abundant, lake sturgeon population could take 25 to50 years or longer.

Introduction

Lake sturgeon (*Acipenser fulvescens*) are widely distributed in North America and are the only sturgeon species native to Vermont. Lake sturgeon in Vermont are confined to Lake Champlain and they are the largest and longest living fish found in the state. Lake sturgeon can reach 150 years of age and weigh up to 310 pounds. (Scott and Crossman 1973).

Lake sturgeon belong to an ancient family of fishes and have been described as living fossils (Priegel and Wirth 1974). Lake sturgeon have life history traits that are unique when compared to more recently evolved fish species. They are long lived, slow to mature, spawn intermittently, and have high fecundity and low natural mortality

Delayed maturity, large size, intermittent spawning, and low natural mortality make lake sturgeon populations vulnerable to over-exploitation. Prior to 1860 lake sturgeon were considered a nuisance by commercial fisherman and discarded (Harkness and Dymond 1962, Priegel and Wirth 1974). After 1860, commercial fisheries for lake sturgeon flesh and caviar developed in the Great Lakes and elsewhere, leading to rapid declines in lake sturgeon abundance. Lake sturgeon populations in many locations are estimated to be 1 percent of their former abundance (Hay-Chmielewski and Whelan 1997).

Declines in sturgeon abundance have been attributed to overharvest, habitat alteration and fragmentation, flow regulation, pollution, and species invasions (Harkness and Dymond 1961; Auer 1996a; Patrick et al. 2009; Golder Associates 2011).

Lake sturgeon serve an important role as an indicator of ecosystem health and attract the public's attention because of their large size and prehistoric looks (Hayes and Caroffino 2012). Lake sturgeon can provide a unique fishery because of their large size and fighting ability.

Restoring lake sturgeon populations in Lake Champlain will take time due to the species' unique life history and environmental/ habitat challenges. Improving survival or recruitment of young fish today will not result in increases in spawning populations of sturgeon for 15 to 25 years. Restoring abundant, healthy, lake sturgeon populations in Lake Champlain will require a long-term commitment.

History in Lake Champlain

Lake Champlain supported a small commercial fishery that harvested from 50 to 200 sturgeon annually in the late 1800s and early 1900s (Halnon 1963). Annual harvest declined rapidly in the late 1940s, and the fishery was closed in 1967. Listed as an endangered species by the State of Vermont in 1972, lake sturgeon are rarely seen during fisheries assessments on Lake Champlain and its tributaries.

The decline in lake sturgeon abundance in Lake Champlain has been attributed to over fishing, habitat loss in the rivers that were used as spawning and nursery grounds, and the introduction of non-native species.

Halnon (1963) summarized the commercial fishing reports for the lake sturgeon fishery in Lake Champlain from 1896 to 1962 (Figure 1). A significant drop in sturgeon harvest did not become apparent until after 1950. Records from the commercial fishery are incomplete with no reports from 1914 to 1939 and it was suspected that commercial fishermen were under-reporting their catches. Additionally it is unclear if the reports Halnon summarized included catches by noncommercial anglers or from commercial fishermen fishing in the spawning tributaries. No lake sturgeon harvest was reported in 1900 but Stone (1900) reported examining more than one hundred sturgeon caught by "two gangs of sturgeon fishermen" in the Missisquoi River that spring. During the same time period fishermen were spearing sturgeon in the Missisquoi River just below the bridge in Swanton. Authorities stopped the fishing because the bridge was smeared with sturgeon eggs dropped by harvested fish and they wanted to avoid the stench from the rotting eggs (Stone 1900).

Historic spawning grounds for lake sturgeon from Lake Champlain were located in the Missisquoi, Lamoille, and Winooski rivers and Otter Creek (Stone 1900, 1901; Harkness and Dymond 1961). No record exists of lake sturgeon spawning in the New York tributaries to Lake Champlain. Historically sturgeon spawned at the base of Highgate Falls on the Missisquoi River but they are now restricted to the river below the dam in Swanton (Halnon 1963; Moreau & Parrish 1994). Sturgeon spawned upstream of Woods Falls on the Lamoille River until the Peterson Dam was constructed in the Sturgeon Hole in 1948, limiting spawning to the rapids below the dam (Stone 1901; Fellinger 2000). The upstream extent of sturgeon spawning runs in the Winooski River and Otter Creek were thought to be limited by falls before dams were constructed at those sites. Stone (1901) reported that sturgeon spawning activity was seen at a site along the shores of Lake Champlain just south of the mouth of the Lamoille River. Stone and others were able to collect ripe males and female sturgeon at the site but did not succeed in collecting any fertilized eggs.

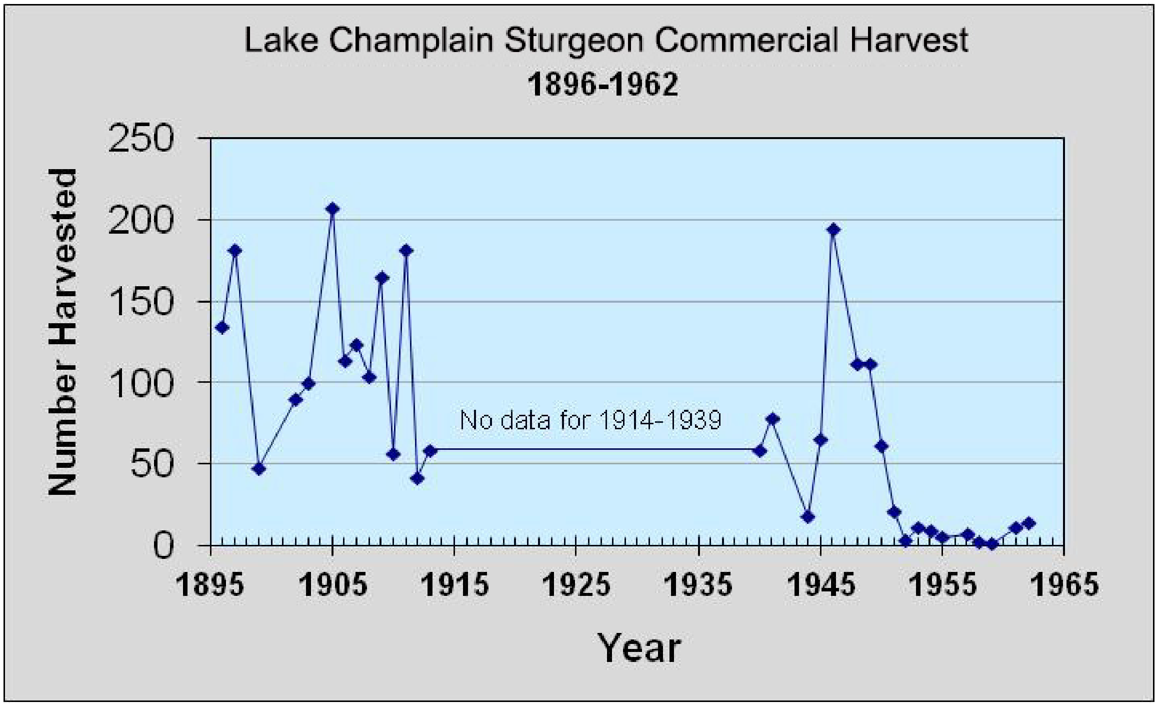


Figure 1: Lake sturgeon commercial harvest, Lake Champlain: 1896 to 1962.

Sturgeon spawning runs in the Missisquoi and Lamoille rivers were abundant enough in the early 1900s that these locations were used to capture ripe adults that were then used in early attempts to culture lake sturgeon eggs (Stone 1901; Carter 1904).

Life History and Habitat

The lake sturgeon is a cartilaginous fish with large bony plates, a heterocercal (shark-like) tail, and a pointed snout with barbells used to locate food (Harkness and Dymond 1961). Adult sturgeon are light brown to gray in color on the back and sides with a lighter-colored belly (Figure 2).

Lake sturgeon are a bottom-dwelling fish that require extensive areas of shallow water (under 30 feet) where they feed on a wide variety of benthic organisms including insect larvae, amphipods, leeches, mollusks (including non-native zebra mussels (*Dreissena polymorpha*)), crayfish, and fish (Scott and Crossman 1973; Jackson et al. 2002; Priegel and Wirth 1974). Juvenile lake sturgeon in the St Lawrence River system are generalist and opportunistic benthic feeders but their diet composition may only partially be determined by benthos availability as it appears they also select for drifting prey (Nilo et al. 2006).

Figure 2: Lake sturgeon adult captured from the Winooski River.

Males usually mature in 12 to 15 years and females mature in 20 to 25 years (Scott and Crossman 1973; Bruch and Binkowski 2002). Male lake sturgeon typically spawn every 2 or 3 years and females may only spawn once every 4 to 9 years (Roussow 1957; Scott and Crossman 1973).

Lake sturgeon migrate to spawning grounds in tributaries to Lake Champlain from late April to mid- June (Carter 1904, MacKenzie 2003, 2008). Males enter the rivers before females and remain near the spawning sites longer than females (Bruch and Binkowski 2002). Sturgeon prefer spawning in fast, shallow, water with rocky substrates (Harkness and Dymond 1961). They typically spawn in depths of 2 to 15 feet (Scott and Crossman 1973). Depth at spawning sites in the Big Manistee River in Michigan ranged from 4.9 to 9.8 feet with average water velocities of 1.12 to 4.33 ft/s (Chiotti et al. 2008). Minimum and maximum current velocities where sturgeon eggs were collected on spawning grounds in the Des Prairies and L'Assomption rivers in Quebec ranged from 0.07 to 4.56 ft/s (LaHaye et al. 1992). The maximum numbers of eggs were collected at sites with current velocities between 2.00 to 2.76 ft/s.

Spawning activity occurs during both night and day at water temperatures ranging from 48 to 60° F (Bruch and Binkowski 2002; Chiotti et al. 2008). Female sturgeon are usually surrounded by multiple males when spawning and adhesive eggs are broadcast over rock and rubble substrate. Females usually deposit several batches of eggs (Bruch and Binkowski 2002). Fecundity ranges from 50,000 to 885,000 eggs (Scott and Crossman 1973; Priegel and Wirth 1974). Some populations have two peaks of spawning activity (Auer and Baker 2002; Bruch and Binkowski 2002, Nichols et al. 2003).

Eggs incubate for 5 to 14 days depending on water temperature (Scott and Crossman 1973; Bruch and Binkowski 2002). Mortality of eggs and larvae is high with less than 1 percent estimated survival to the age-0 juvenile stage (Nichols et al. 2003; Caroffino et al. 2010). Yolk-sac larvae are negatively phototactic and hide in the interstitial spaces of the spawning substrate. After the yolk sac is absorbed the larvae begin a swim up phase.

Larvae swim up from the bottom at night and passively drift downstream with the current. The peak of fry movement occurs 10 to 18 days after hatching (LaHaye et al. 1992; Kempinger 1983, 1984). Total lengths (TL) of drifting larvae average 0.67 to 0.79 inches (LaHaye et al. 1992; Nichols et al. 2003). Larval drift is not uniform in space or time with the majority of larvae drifting between 2300 and 2400 hours and not in the main channel (Auer and Baker 2002).

Age-0 sturgeon prefer shallow (< 6.6 ft.), riverine areas with substrates of course sand or pea-sized gravel, low current velocity (< 1.97 ft/s), and no rooted vegetation (Kempinger 1996). Age-0 lake sturgeon appear to feed on drifting benthic organisms predominantly dipteran larvae and Baetidae nymphs (Benson et al. 2005; Kempinger 1996).

Current Status in Lake Champlain

Lake sturgeon are currently listed as endangered in Vermont and are rarely seen during fisheries assessments on the lake and its tributaries. In recent years increasing numbers of lake sturgeon are being caught by anglers fishing in tributaries to Lake Champlain. In 2012 more than twelve sturgeon were reported being caught by anglers fishing in the Winooski River. Most sturgeon have been caught by anglers fishing in the Winooski and Lamoille rivers but an occasional fish is reported from the Missisquoi River and Otter Creek.

A study on the feasibility of restoring lake sturgeon to Lake Champlain was completed in 1994 (Moreau and Parrish, 1994). The study concluded that suitable sturgeon habitat still exists in Lake Champlain and its tributaries but, based on the limited sightings of lake sturgeon, the likelihood of achieving restoration through the natural reproduction of existing sturgeon populations was extremely small. Moreau and Parrish (1994) recommended several stocking strategies for increasing lake sturgeon abundance in Lake Champlain.

In 1995, the Department decided to conduct a survey of adult sturgeon at spawning sites before deciding whether or not to stock sturgeon from other lakes into Lake Champlain.

Adult Sampling

Sampling with large mesh gillnets at historic spawning sites began in 1998 to determine if lake sturgeon were still present in Lake Champlain and, if they still existed, to gather information on populations. Sampling was focused near spawning sites in the Lamoille and Winooski rivers, where most of the recent sightings had been reported (MacKenzie 2003). Sampling was conducted in each river for five years. Sampling was expanded to include the Missisquoi River in 2003.

Three to four lake sturgeon were captured each year in the Lamoille River (Table 1). No sturgeon were captured in the Winooski River in 1998, one was captured in 1999, and three to seven sturgeon were captured each year during the last three years of the survey (Table 2). Several individuals were captured in multiple years and more than once in a year. A total of fifteen individual sturgeon captured by gillnetting were tagged with (passive integrated transponders (PIT) tags in the Winooski River. Two additional lake sturgeon captured by electrofishing while monitoring the walleye spawning run in the Winooski River were PIT-

Table 1: Dates of capture, lengths, weights, sex, ages and tag numbers of lake sturgeon captured in the Lamoille River, 1998 thru 2002.

Year	Date	Fork Length (inches)	Total Length (inches)	Weight (lbs)	Sex	Age	Tag Number	Gear
1998	5/07	52.6	56.7	59	M	-	A283 Disc	Gillnet
1998	5/07	51.6	55.8	40	M	-	A285 Disc	"
1998	5/07	62.2	66.1	70	M	29	4226250016	"
1999	5/03	65.0	66.5	78	"	-	"	"
	5/11	-	-	-	-	-	"	"
2000	5/08	62.0	66.5	72	-	-	"	"
	5/09	-	-	-	-	-	"	"
	5/15	-	-	-	-	-	"	"
	5/17	-	-	-	-	-	"	"
2002	5/24	61.6	65.5	70	-	-	"	"
	5/28	-	-	-	-	-	"	"
1999	5/11	50.2	54.3	26	M	23	4229015742	"
1999	5/11	60.0	65.0	65	M	39	4228751353	"
2000	5/17	57.3	72.8	58	M	-	"	"
1999	5/13	55.5	58.9	56	M	48	42257A334A	"
2000	5/08	52.4	56.1	60	-	-	"	"
	5/17	-	-	-	-	-	"	"
2001	5/09	53.1	56.5	56	-	-	"	"
	5/10	-	-	-	-	-	"	"
2002	5/30	53.0	56.6	56	-	-	"	"
2001	5/08	65.4	66.5	70	M	31	42261D4C1F	"
2002	5/07	61.8	66.0	78	-	-	"	"
	5/28	-	-	-	-	-	"	"
2001	5/10	56.7	61.2	52	M	45	4226183819	"
	5/11	-	-	-	-	-	"	"
	5/17	-	-	-	-	-	"	"
	5/18	-	-	-	-	-	"	"
2002	5/28	53.1	58.2	65	M	39	4229023A34	"

Table 2: Dates of capture, lengths, weights, sex, ages and tag numbers of lake sturgeon captured in the Winooski River, 1998 thru 2003.

Year	Date	Fork Length (inches)	Total Length (inches)	Weight (lbs)	Sex	Age	Tag Number	Gear
1999	5/06	50.0	53.9	31	M	11	4229001A50	Gillnet
2000	5/10	55.5	60.0	50	M	41	4225776853	“
2000	5/10	47.4	51.9	35	M	11	42261A120F[1]	“
2000	5/19	52.8	57.3	42	M	15	4226342908	“
2002	5/14	53.1	58.2	44	-	-	“	
2001	5/03	52.2	56.1	46	M	43	4228775179	“
	5/11	-	-	-	-	-	“	“
	5/15	-	-	-	-	-	“	“
2002	5/09	51.6	55.5	42	-	-	“	“
2001	5/10	53.5	58.0	40	M	49	4229023A34	“
2001	5/15	33.5	37.7	11	UNK	5	422635153D	“
2001	5/15	36.9	41.8	18	UNK	7	4228726328	“
2001	5/18	55.9	60.4	58	M	39	4225631A03	“
2001	5/18	44.9	49.8	24	M	13	4225786209	“
2002	5/01	42.6	47.2	30	M	7	41795C7715	“
2002	5/08	39.4	44.2	20	M	8	423B23782B	“
	5/23	“	“	“	“	“	“	“
2002	5/09	53.9	59.7	54	M	15	42343E3E1A	“
2002	5/09	46.1	51.5	30	M	9	423B337B50	“
2002	5/14	52.4	58.1	42	M	23	423B0E573B	“
2003	4/30	39.3	43.9	-	M	-	417947102A	e-fish
2003	5/01	47.2	48.0	-	M	-	422E0D205F	e-fish

tagged in 2003. Seven individual sturgeon were PIT- tagged in the Lamoille River and two other sturgeon caught in the Lamoille were tagged with external disc tags in 1998 before PIT tags were available. Gillnets were set near spawning sites in the Missisquoi River for three years (2001 to 2003) but no sturgeon were caught.

One sturgeon was tagged in the Winooski River in 2001 and recaptured during the spawning season in the Lamoille River one year later, indicating movement between these two spawning sites.

[1] This sturgeon was found dead in the lower Winooski River on June 8, 2000. No obvious cause of death.

Trotlines baited with nightcrawlers, squid, silver lamprey (*Ichthyomyzon unicuspis*), and golden shiners (*Notemigonus crysoleucas*) were set in the Lamoille and Winooski rivers in 2002 but no sturgeon were captured. Trotlines have been used to capture lake sturgeon in the St. Clair River, Michigan (Thomas and Haas 1998). A wide variety of baits were tested but nearly 99 percent of the lake sturgeon were caught using non-native round gobies (*Neogobius melanostomus*) as bait.

Sturgeon collected during the spawning runs in the Winooski and Lamoille rivers ranged in total length from 38 to 73 inches (958 to 1850 mm) and weighed from 11 to 78 pounds (Tables 1 and 2). All sturgeon were ripe males with the exception of two small sturgeon that could not be sexed (Table 1). Estimated ages, determined by viewing cross sections of pectoral fin spines, ranged from 5 to 49 years. Estimating age from pectoral fin spines may underestimate true ages beyond age 14 and errors in aging increase with increasing age of the fish (Bruch et al., 2009).

The number of fresh and healing lamprey wounds seen on adult sturgeon ranged from 0 to 11 wounds and averaged 2.5 wounds per fish (Figure 3). The number of healed scars from lamprey wounds was high on larger sturgeon indicating they survive multiple lamprey attacks. Photos of lake sturgeon collected during the spawning run on the Lamoille River in the early 1900's show no evidence of sea lamprey attacks (Figure 4 and 5) (Carter 1904).

In addition to the sturgeon captured in the Lamoille and Winooski rivers, a large dead sturgeon was found in Otter Creek in June 2000 and a dead adult and sub-adult sturgeon were recently found washed up on the lake shore in Colchester and Grand Isle. One juvenile lake sturgeon (6.7 inches TL) was collected in the Winooski River during August 2001 while seining for other species.

Figure 3: Scars from lamprey wounding seen on a lake sturgeon collected by gillnetting in the Winooski River during the spring spawning migration, 2002.

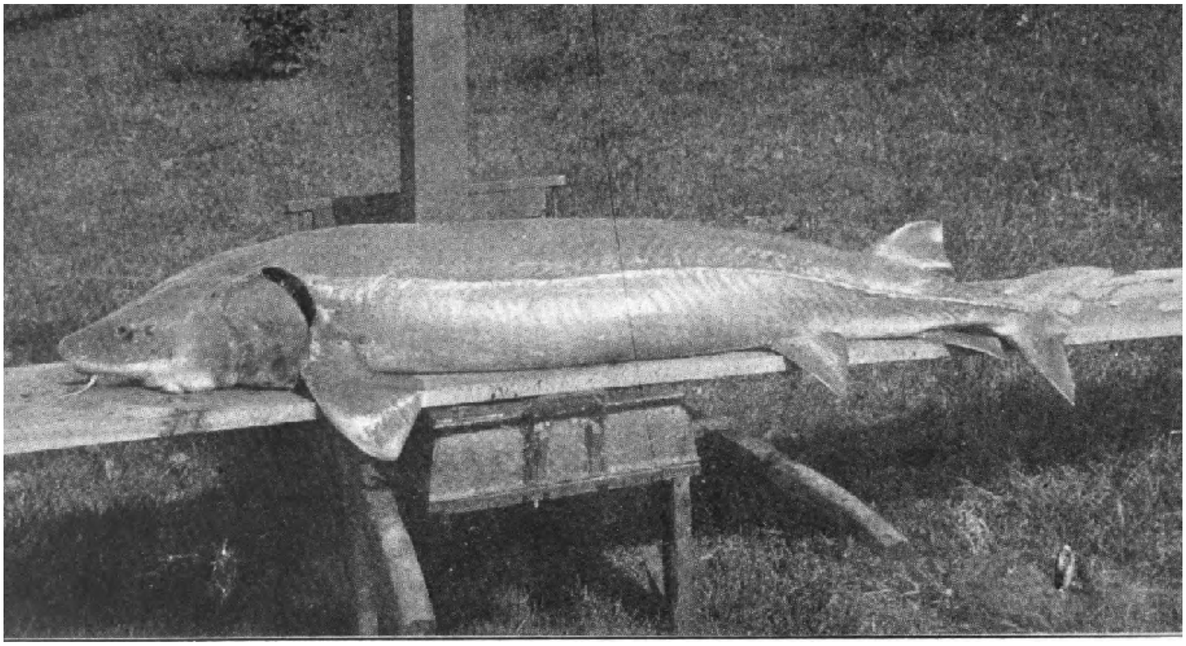


Figure 4: Lake sturgeon collected from the Lamoille River, 1904 (Carter, 1904).

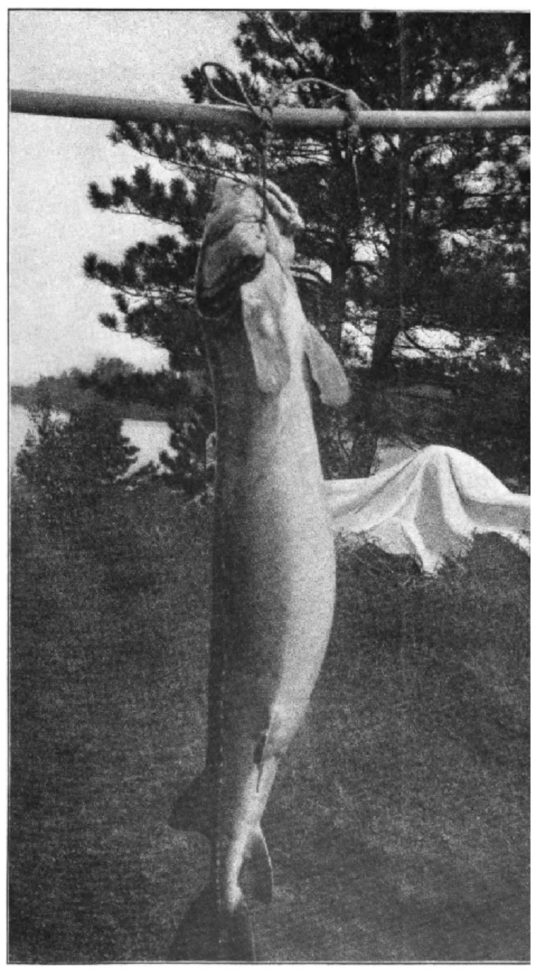


Figure 5: Lake sturgeon collected in the Lamoille River, 1904 (Carter 1904).

Egg Sampling:

After documenting the presence of ripe males at spawning sites the next step in the assessment was to sample for sturgeon eggs at spawning sites. Sampling for sturgeon eggs was conducted in the Winooski, Lamoille, and Missisquoi rivers and Otter Creek from 2003 to 2008 (MacKenzie 2008). Egg traps were placed in a grid pattern at suspected spawning sites. Sturgeon egg traps were constructed by wrapping mats of latex-coated hog hair filter fabric around concrete blocks (LaHaye et al. 2003) (Figure 5). Sturgeon eggs were collected in every year that traps were set in the Winooski River. Eggs were collected in 3 of the 5 years traps were set in the Lamoille and 4 of 5 years that traps were set in the Missisquoi. No sturgeon eggs were collected in Otter Creek. The number of eggs collected each year ranged from 14 to 234 (Table 3).

Figure 5: Placing sturgeon egg traps in the Winooski River, 2003.

Table 3: Numbers of sturgeon eggs collected on egg traps set in Vermont tributaries to Lake Champlain, 2003 to 2008.

River	Year	Sampling Period	Number of sturgeon eggs
Winooski	2003	May 6 to 27	22 (+ 1 prolarva)
	2004	May 6 to June 8	186
	2005	May 6 to 23	59
	2006	May 2 to June 6	8
	2007	May 9 to June 4	98
Lamoille	2003	May 5 to 26	7
	2004	May 11 to June 8	0
	2005	May 6 to 24	120
	2006	April 26 to June 2	12
	2007	May 8 to June 5	0
Missisquoi	2004	unknown	26
	2005	May 4 to 26	55
	2006	May 1 to June 6	42
	2007	May 7 to June 6	0
	2008	April 29 to May 29	14
Otter	2004	May 7 to June 4	0
	2005	April 28 to May 23	0
	2006	April 24 to June 2	0

Figure 6: Drift nets set in the Winooski River to sample for drifting larval lake sturgeon, 2004.

Larval Sampling:

Driftnets were used to sample for larval lake sturgeon in the Winooski River in 2004 and 2005, Otter Creek, and the Lamoille River in 2005 and in the Missisquoi River in 2008 (MacKenzie 2008) (Figure 6). Sturgeon larvae (Figure 7) were collected in both years that driftnets were set in the Winooski River. Eighty sturgeon larvae were collected in 2004 and one larvae was collected in 2005 (Table 4). A drift net was set for one night in the Lamoille River in 2005 and 30 sturgeon larvae were collected. No sturgeon larvae were collected in Otter Creek or the Missisquoi River.

Sampling at historic spawning sites from 1998 to 2008 documented that lake sturgeon ranging in age from 5 to 50 years continue to spawn in 3 tributaries to Lake Champlain. Eggs are hatching and larval lake sturgeon are surviving and drifting from spawning sites.

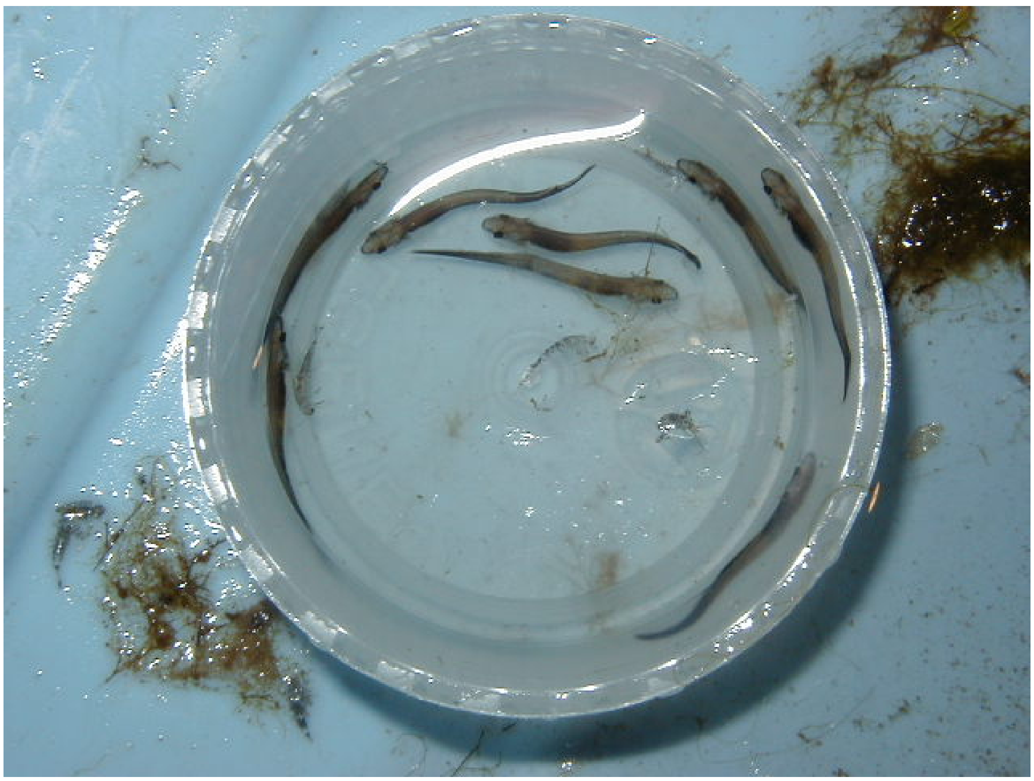


Figure 7: Larval lake sturgeon collected in the Winooski River, 2004.

Genetics:

Tissue samples were collected from sturgeon captured by gillnetting in the spawning tributaries to include in a genetic assessment of lake sturgeon in the Great Lakes Basin. Lake sturgeon from Lake Champlain were most closely related to sturgeon from the St. Lawrence River although they were genetically distinct (Welsh et al. 2008). Genetic diversity was relatively consistent among populations and heterozygosity was consistent with that observed for most freshwater fish species. Lake sturgeon populations have declined significantly but genetic diversity within populations has not been depressed and there is no sign of inbreeding (DeHaan et al. 2006; Welsh et al. 2008; Schueller and Hayes 2011).

Table 4: Numbers of sturgeon larvae collected in driftnets set in Vermont tributaries to Lake Champlain, 2004 to 2008.

River	Year	Date	Number of Larval Sturgeon
Winooski	2004	6/14	17
		6/15	54
		6/16	3
		6/17	5
		6/18 (am)	1
	2005	5/31	0
		6/02	1
		6/06	0
		6/07 (am)	0
Lamoille	2005	6/06	30
Otter	2005	5/31	0
		6/02	0
		6/07	0
Missisquoi	2008	5/27	0
		5/29	0
		6/02	0
		6/05	0
		6/10	0

Limiting Factors

Natural Mortality and Exploitation:

Lake sturgeon populations are particularly sensitive to changes in adult mortality rates because of the unique life history characteristics of sturgeon including delayed maturation, low natural mortality, longevity, and intermittent spawning. (Bruch 2009, Schueller and Hayes 2010, Sutton et al. 2003, Velez-Espino and Koops 2009). Adult mortality, particularly for young adults, may have greater impacts on population fitness than reproductive success (Velez-Espino and Koops, 2011).

Schueller and Hayes (2010) used an individual-based modeling approach to assess the sensitivity of various lake sturgeon population parameters on demographic characteristics, including rates of extinction and genetics. Post young-of-year (YOY) mortality was the most sensitive parameter affecting long-term population dynamics in lake sturgeon populations. Reducing post YOY mortality would have the largest impact on population persistence and maintenance of genetic integrity. YOY mortality was also a sensitive parameter in the model. Increasing the quality and quantity of rearing habitat by removing obstructions to spawning migrations, reducing pollution and the introduction of non-native species, and managing river flows in a more natural manner could all help reduce YOY mortality (Schueller and Hayes 2010). YOY mortality can also be reduced or offset by artificial propagation.

Total mortality of lake sturgeon is composed of natural mortality and exploitation. Annual natural mortality of age 1 and older lake sturgeon in the Lake Winnebago System, Wisconsin, is estimated to be around 5.4 percent (Bruch, 2009). Exploitation rates from the unique recreational spear fishery ranged from 2 to 5 percent from 1955 to 1969 (Priegel and Wirth, 1975). Priegel and Wirth (1975) recommended managing the recreational fishery for a harvest rate equal to the estimated recruitment rate of 4.7 percent to maintain the existing population of lake sturgeon. Exploitation rates above 4.7 percent would cause declines in adult abundance while lower exploitation rates would allow the population to increase. A 5 percent exploitation rate was also recommended for the lake sturgeon fishery in the Menominee River (Priegel, 1973). Estimated exploitation rates on the Winnebago population have averaged 3.4 percent since the mid-1960s, which has allowed adult abundance to increase (Bruch 2009). Simulation modeling of the Lake Winnebago sturgeon population indicated populations would go extinct at high exploitation rates of 20 percent although it could take hundreds of years (Bruch 2009). Time to extinction decreased rapidly for exploitation rates above 20 percent.

Angling Mortality:

There is limited opportunity to reduce fishing mortality in Vermont. The commercial fishery was closed in 1967 and sturgeon were listed as an endangered species in 1972. Sturgeon are occasionally caught by anglers, particularly near major spawning sites in the spring. Spawning areas on the Missisquoi, Lamoille, and Winooski rivers are closed to fishing from March 16 to May 31 primarily to protect spawning concentrations of walleye (*Sander vitreum*) from excessive harvest. This closure protects spawning concentrations of sturgeon in most years but there are years, particularly in the Winooski River, when spawning extends into early June (Carter 1904, MacKenzie 2008). In 2012, which was a cool spring, anglers reported catching twelve sturgeon in the Winooski River on the first weekend that fishing was allowed in the area of the river closed for the spring spawning season.

Reports of incidental catches have been increasing in recent years but it is unknown if this is due to increasing sturgeon abundance, increased awareness by anglers of the need to report sturgeon catches, or environmental conditions that have extended spawning into June when closed spawning areas are opened to fishing. Anglers have submitted photos of the sturgeon they have caught and it is apparent that some anglers do not know that they are required to release sturgeon immediately or how to handle the fish to minimize injury.

Illegal Harvest:

Illegal harvest can undermine restoration efforts. In recent years the department has responded to a few reports from anglers that they have seen sturgeon harvested illegally. Two anglers were convicted and fined for harvesting a 35-inch lake sturgeon from Otter Creek in

2011. The poaching was reported by a concerned angler fishing next to the two men**.** Cooperation between law enforcement staff and the general public reduced illegal harvest in Black Lake, Michigan and the Wolf River system in Wisconsin (Hayes and Caroffino, 2012). Illegal harvest could become a larger concern if sturgeon numbers increase in Lake Champlain and its tributaries.

Sea Lamprey Mortality:

Sea lamprey likely contribute to the mortality of lake sturgeon in Lake Champlain. Sixty- two percent of the adult sturgeon that were captured during the spawning assessment surveys on the Lamoille and Winooski rivers, conducted from 1998 thru 2002, had fresh or healing lamprey wounds. The average number of fresh and healing wounds was 2.5 wounds per fish.

While the extent of lamprey-induced mortality in Lake Champlain is unknown, Patrick et al. (2009) reported total mortality from a single lamprey attack ranged from 16 to 50 percent for sub-adult and young adult lake sturgeon (17.7 to 29.9 inches TL). Large adult lake sturgeon (> 37.4 inches TL) survived single attacks but may still be vulnerable to secondary infections. Sea lampreys are known to attack and possibly kill large lake sturgeon in the Great Lakes (Scott and Crossman 1973).

Controlling sea lamprey-induced mortality on lake sturgeon may be critical to recovery efforts in Lake Champlain. Exploitation rates as low as 5 percent can lead to declines in lake sturgeon abundance (Bruch 2009) and mortality from sea lamprey predation is likely greater (Patrick et al. 2009). Sea lamprey predation may have been as significant as overharvest and habitat loss in causing the decline in lake sturgeon in Lake Champlain in the late 1900s and could be an important factor affecting the population's recovery.

Sturgeon can also be affected by sea lamprey control efforts. Barriers constructed in streams to block the upstream movement of sea lamprey to spawning sites can prevent the upstream migration of lake sturgeon to spawning sites. Young-of–year (YOY) lake sturgeon were thought to be sensitive to the lampricide TFM (3-trifluoromethyl-4-nitrophenol) at concentrations typically used to control sea lamprey larvae in streams (Johnson et al. 1999, Boogard et el. 2003). Recent stream-side bioassays and in situ exposures of YOY lake sturgeon in Great Lakes streams indicated that survival is higher during field treatments than previous lab studies indicated (Pratt et al. 2012).

After reviewing the results of these studies and population modeling studies indicating that lake sturgeon populations are more sensitive to increases in adult mortality due to sea lamprey predation than to reductions in recruitment (Schueller and Hayes 2010, Sutton et al. 2004) the Great Lakes Fisheries Commission suspended the requirement to use lower concentrations of lampricide in streams with sturgeon populations because the risk to sturgeon populations from ineffective sea lamprey control is greater than the limited juvenile lake sturgeon mortality that would occur during lampricide treatments using higher concentrations (Adair and Sullivan 2004).

One dead juvenile lake sturgeon (9.1 inch TL) was collected during post treatment mortality surveys following the 2004 lampricide treatment of the Winooski River (Chipman 2005). No mortalities occurred among the 78 juvenile sturgeon held in cages exposed to lampricides during the same 2004 treatment. No other dead lake sturgeon have been seen during four other mortality surveys that occurred after the lampricide treatment of rivers in the Lake

Champlain basin where sturgeon spawning activity has been documented (Chipman 2009a, 2009b, 2010; Smith 2013a, 2013b).

Recommended Strategies

The lake sturgeon has potential for recovery in Lake Champlain and would benefit from several actions to reduce adult mortality from sea lamprey predation, reduce illegal harvest, and increase public awareness (Appendix 1). Highest priority actions are labeled accordingly. Actions include:

A. **Continue efforts to reduce sea lamprey numbers in Lake Champlain to reduce lamprey predation on sub-adult and adult lake sturgeon. (Highest)**

B. **Increase the angling public's awareness of the protected status of lake sturgeon in Lake Champlain and spawning tributaries. (Highest)**

C. **Educate anglers on the proper way to handle lake sturgeon when one is caught and encourage anglers to stop fishing or change tactics if they are catching sturgeon frequently.**

D. **Encourage the fishing and general public to report illegal sturgeon harvest to law enforcement.**

E. **Minimize impacts of lampricide treatments on lake sturgeon young-of-the- year in rivers where sturgeon presence has been documented.**

F. **Increase the general public's awareness and knowledge of lake sturgeon biology, population threats, and restoration efforts to garner public support of rehabilitation efforts, their role in species conservation, and contributions to data collection.**

G. **Support efforts to prevent the introduction or spread of non-native aquatic organisms or diseases.**

H. **Extend spawning water closures on the Missisquoi, Lamoille and Winooski rivers until June 15 to protect concentrations of spawning sturgeon.**

Habitat Restoration and Protection

Lake sturgeon utilize a variety of habitats in the Lake Champlain basin throughout their life cycle including shallow areas of the lake for feeding and over wintering habitat and rivers for both spawning and nursery habitat.

Habitat in Lake Champlain for juveniles and adults is not likely one of the major factors limiting the recovery of lake sturgeon. There are about 170 square miles of shallow water (< 30 ft.) in Lake Champlain that supports a benthic forage base for sturgeon (Moreau and Parrish 1994). Threats to physical habitat are minimal and water quality is adequate throughout the lake.

Currently the largest threat to lake sturgeon habitat conditions in the lake is most likely the introduction of non-native species such as round goby which may increase predation on eggs deposited on rock substrates (Chotkkowski and Marsden 1999; Nichols et al. 2003).

Loss of spawning and nursery habitat may be a major factor in the inability of some sturgeon populations to recover (Auer 1996b). Dams on tributaries can fragment populations and block migration to upstream spawning and nursery habitats. Dams obstructing migrations and dams built at the natural upstream limit of sturgeon migration can also reduce spawning habitat downstream of the dam by disrupting natural flow regimes and/or reducing the recruitment of rubble and cobble to spawning sites downstream of the dam.

Lake sturgeon were more abundant and spent less time at a spawning site below a hydroelectric facility on the Sturgeon River in Michigan when the facility was operated under a more natural run-of-river flow regime than when there were large daily fluctuations when the facility was operated in peaking mode. (Auer 1996a). In addition to changing adult behavior, daily peaking operations at hydroelectric facilities may increase mortality of eggs by dewatering or scouring eggs deposited during high or low flows, respectively.

Multiple dams have been built on all the tributaries to Lake Champlain used by lake sturgeon for spawning. The Missisquoi and Lamoille rivers have had dams built that block sturgeon migration to historic spawning sites resulting in substantial reductions in the amount of available spawning and nursery habitat. The dams on the Winooski River and Otter Creek are most likely built at the upstream extent of sturgeon migration but may still have impacts on sturgeon spawning success by altering flows and the recruitment of spawning substrate.

Missisquoi River:

The sturgeon migration on the Missisquoi River extended 15.5 miles upstream to Highgate Falls until a dam was built near Swanton Village in 1789 (Lyttle 2004). The dam in Swanton restricts sturgeon migrations to the lower 8 miles of the river. The dam is not currently used for electric generation, navigation, or flood control. The Missisquoi River downstream of Swanton Dam is made up predominantly of low gradient, slow-flowing habitat with sand and silt substrate. Much of this portion of the river is seasonally backwatered by Lake Champlain. Only a steeper gradient segment of the river immediately downstream of Swanton Dam provides the coarse substrate and water velocities required by sturgeon and a number of other fish species for spawning.

Estimated sturgeon spawning habitat below the Swanton Dam is about 56,400 square feet with 33 percent of that area rated as poor spawning habitat under typical spring flows (Moreau and Parrish 1994). A habitat study of the river upstream of the Swanton Dam and below Highgate Falls indicated there would be a 300-fold increase in available sturgeon spawning habitat if sturgeon had access to this reach (Lyttle 2004). Not only would the total area of spawning habitat increase but more quality spawning habitat would be available under a wider range of flows. Available nursery habitat for age-0 sturgeon would also be increased by providing access above the Swanton Dam.

Providing access to the reach between Highgate and Swanton could potentially be accomplished by providing passage over the dam or removing or breaching the dam. However, designing a fishway or lift to allow fish to pass upstream of barriers can be extremely difficult. A review of fish passage data on the Connecticut, Merrimack, and Susquehanna rivers indicated that few fish are able to use fish passage facilities to reach spawning habitat upstream of the dams (Brown et al. 2013). Fish that do manage to reach upstream spawning habitat must then pass downstream, often through turbines, which may increase mortality on both spawning adults and juveniles (Bell and Kynard 1985; Taylor and Kynard 1985; Mather et al. 1994).

Designing upstream fish passage facilities for large fish such as lake sturgeon is difficult. Most fishways have been designed to provide passage for salmonids or other jumping fish. Swimming abilities of lake sturgeon, particularly burst speeds, are less than salmonids (Peake et al. 1997). Only 30 percent of migratory lake sturgeon were able to successfully move upstream of a barrier through a vertical slot fishway on the Richelieu River (Thiem et al. 2011). Upstream passage of artificially reared juvenile lake sturgeon ranged from 40 to 73 percent in an experimental side-baffle fish ladder (Kynard et al. 2011).

The Swanton dam is also preventing walleye, suckers, redhorse, esocids, minnows and other fishes found in Lake Champlain from ascending the Missisquoi River to reach historical spawning habitat which is very limited downstream of the dam. Providing upstream fish passage facilities that are effective for sturgeon as well as these other species will be even more difficult.

Providing safe downstream passage for adults returning to the lake after spawning, juveniles, and drifting larvae should also be required when upstream passage is provided. Maintaining suitable flows over the limited lake sturgeon spawning habitat found immediately downstream of the dam should also be addressed during the design and operation of any fish passage facility built at the Swanton Dam.

There are five dams on the Missisquoi River and its tributaries above the Swanton Dam that are currently used to generate hydroelectric power. The Swanton and other dams prevent the recruitment of gravels and cobble to spawning sites. The two dams immediately upstream from Swanton, Highgate Falls and Sheldon Springs, have at times regulated river flows during the sturgeon spawning period, resulting in unnatural flow patterns that can impact spawning success.

In 1999, Sheldon Vermont Hydro Company, Inc. (SVHCI) entered into a voluntary agreement to operate its Sheldon Springs hydropower project in a run-of-river mode during April and May to improve habitat conditions for spawning walleyes and sturgeon in reaches of the Missisquoi River downstream of Highgate Falls. In 2006, the Agency of Natural Resources submitted a letter to SVHCI to request that it extend the run-of-river period through June 15 to further protect egg incubation conditions for lake sturgeon. SVHCI formally agreed to this request on May 12, 2006.

The Highgate Falls hydropower project is required by license to operate in a run-of-river mode from April 1 through May 31. In 1999, the Agency of Natural Resources submitted a letter to the Village of Swanton, owner of the project, to request that it extend the run-of-river period through June 15 to further protect lake sturgeon egg incubation and fry emergence. This request was declined, as was a similar request made in 2006.

Daily peaking at any facility in the watershed often cascades through downstream facilities and can impact spawning success. Daily peaking flows during the spawning seasons for sturgeon and walleye are a common event on the Missisquoi River. For example, the graph below (Figure 8) shows the flow regime that occurred in the Missisquoi River from June 1 to 15, 2012, as measured at the U.S. Geological Survey gage in Swanton. This gage is located about 6.5 river miles downstream of Highgate Falls and about 0.3 miles upstream of the Swanton dam. This graph illustrates hydropeaking with daily flow fluctuations well in excess of 1,000 cfs.

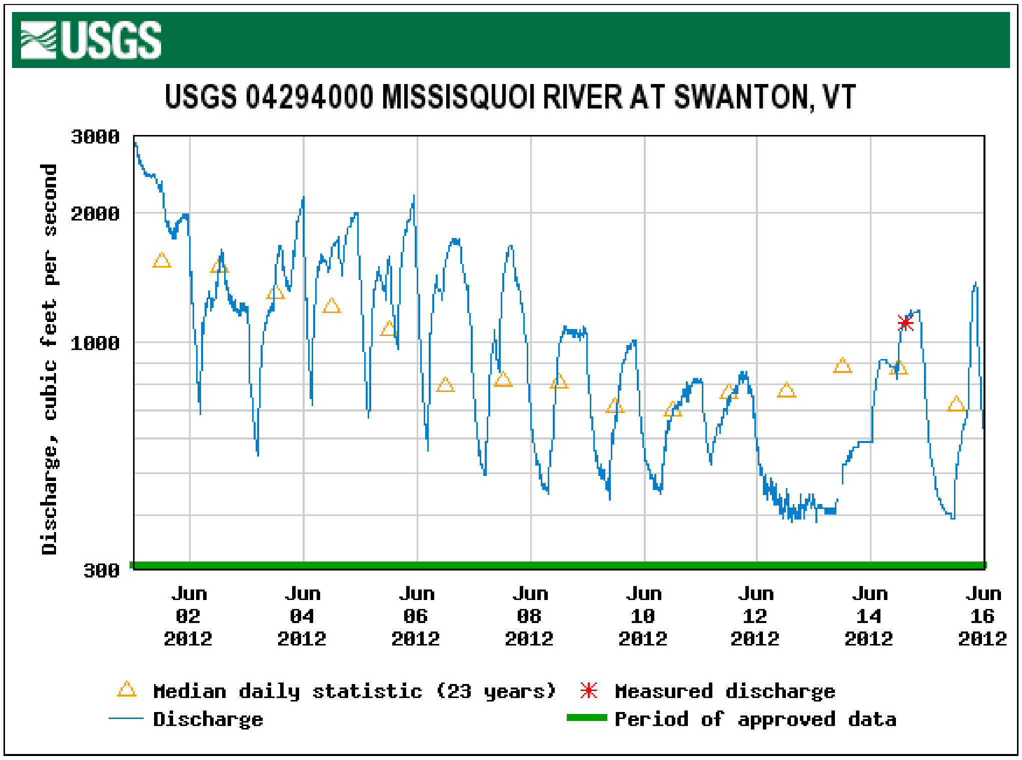


Figure 8: Discharge measurements, Missisquoi River, June 1 to 15, 2012.

Lamoille River:

Lake sturgeon historically migrated up the Lamoille River to spawn upstream of Woods Falls in West Milton (Fellinger 2000). Sturgeon congregated in the Sturgeon Hole at the base of Woods Falls before migrating upstream to spawn (Stone 1901). Sturgeon staging in the Sturgeon Hole were once so abundant that the U.S. Bureau of Fisheries used the site to collect ripe sturgeon for early experiments on the artificial rearing of lake sturgeon (Carter 1904: Stone 1901). In 1948, the Peterson Dam was built at the Sturgeon Hole preventing sturgeon from migrating upstream to spawn. It is unknown exactly how far upstream of the falls they migrated to spawn because a series of falls were inundated when Peterson Dam was built. Based on local residents' descriptions of the falls, it is believed sturgeon should have been able to migrate as far as Miners Falls, located about 1.65 miles upstream of Peterson Dam and currently inundated by the impoundment (Fellinger 2000, Wentworth 2001).

A short stretch of suitable spawning habitat is present in the rapids below the Peterson Dam downstream of the Sturgeon Hole. The estimated area of available spawning habitat is about 178,680 square feet with about 29 percent considered poor habitat during typical spring flows (Moreau and Parrish 1994). Wentworth (2001) estimated the quantity of suitable spawning habitat below the dam to be less than 100,104 square feet.

Eight dams have been built on the main stem of the Lamoille River and seven are used for hydroelectric generation. Spawning success for lake sturgeon can be negatively affected by peaking operations at these dams during the spawning season, which can extend into early June.

Winooski River:

The sturgeon spawning migration on the Winooski River was limited to the lower nine miles of river by the Winooski Falls even before the existing dam was built on the falls (Parrish and Moreau 1994). There is no estimate of available spawning habitat in the river today but the dam built at the falls may not have reduced the quantity of spawning or nursery habitat available in the Winooski River. There are fifteen hydroelectric dams operating in the watershed some of which can impact sturgeon spawning success by altering the natural flow regime during the spring spawning season

Otter Creek:

The sturgeon spawning migration in Otter Creek was limited to the lower 7.5 miles of the river by the falls in Vergennes. A hydroelectric dam was constructed at the falls in Vergennes which is thought to be the natural upstream barrier. While the dam may not be an obstruction to migration, Otter Creek was dredged from the falls in Vergennes to Lake Champlain to create a channel 8 feet deep and 100 feet wide. This dredging project, which was completed in 1900, likely removed most of the suitable spawning substrate for lake sturgeon from the river. The dam at the falls in Vergennes prevents recruitment of suitable spawning substrate to the base of the falls. Flow regulation in the watershed could also impact the success of sturgeon spawning.

Recommended Strategies:

The lake sturgeon has potential for recovery in Lake Champlain and would benefit from several actions to remove obstructions to historic spawning and nursery habitats or improve spawning habitat on tributaries to the lake (Appendix 1). These include:

A. **Restore connectivity for lake sturgeon to spawning and nursery habitats upstream of the Swanton Dam on the Missisquoi River. Removal of the dam is the preferred alternative because of the difficulty in providing safe and effective upstream and downstream passage for adults and juveniles. (Highest)**

B. **Ensure hydroelectric facilities operating on the Missisquoi, Lamoille, and Winooski rivers and Otter Creek watersheds provide instantaneous run-of-river flows during the lake sturgeon spawning and incubation seasons, April 1 to June 15. (Highest)**

C. **Investigate the potential for increasing suitable spawning habitat in Otter Creek and the Lamoille River.**

D. **Participate in the regulatory review of developments under FERC hydroelectric development or relicensing, Act 250 and Act 248, water withdrawals, or stream alteration projects to minimize impacts aquatic habitat and natural flow regimes.**

E. **Ensure adequate flow within bypassed river channels in river reaches containing lake sturgeon.**

F. **Ensure hydroelectric facilities provide safe downstream passage on river systems that have upstream lake sturgeon populations.**

Monitoring and Assessment

Recovery of depressed lake sturgeon populations in Lake Champlain could be very slow. Improved survival of sturgeon hatched this year will not be reflected in increases in the number of spawning adults for 15 to 20 years. Their offspring would not reach spawning age for another two decades. Recovery could easily take 50 to 100 years. Assuring recovery will require a long-term commitment to reducing sturgeon mortality and increasing reproductive success by protecting and restoring critical habitats. Developing methods for measuring progress towards achieving recovery objectives is also important.

Assessing progress towards achieving recovery objectives can be extremely challenging because of the depressed populations found in Lake Champlain today and the difficulty in sampling those populations. Adult abundance, age structure, annual spawning activity, hatching success, and juvenile abundance could all be useful metrics for measuring the impacts of management actions.

Assessments often focus on adult abundance because they are more likely to be captured when they concentrate in rivers during spawning and/or on information collected from recreational or commercial fisheries (Bruch 1999; Priegel and Wirth 1978; Dumont et al.1987). Sampling in rivers during the spring can be very challenging. Estimating size of spawning populations using mark recapture modeling is complicated if sampling is focused on spawning sites because of the unique life history of lake sturgeon. Sturgeon do not spawn every year and sampling must occur each year over at least a five-year period, since it may take this long for an individual sturgeon to return and spawn after it was originally captured and tagged. Sampling effectiveness in any given year will also vary because of differing flow conditions.

If adult sturgeon can be captured during times of the year when they are not concentrated at spawning locations then population size could be estimated in one year (Hayes and Caroffino 2012). However, in Lake Champlain, sturgeon numbers may be so low that capturing enough individuals to allow an accurate estimate of population size would be difficult. If areas where sturgeon congregate in the lake are identified in the future, it may allow the estimation of a lake wide population. However this will only be useful in measuring progress towards achieving the goals set for river-specific spawning stocks if they congregate at different locations in the lake.

Monitoring egg deposition with collection devices set on the substrate at spawning sites is an indicator of spawning activity but cannot be used as an index of adult abundance because of the clumped distribution of egg deposition. Sampling efficiency and the location of suitable spawning sites are also affected by varying river flows during the spring. Drift nets may be an alternative sampling method for collecting eggs and they could be evaluated to see if they reduce the impacts of the patchy distribution of eggs deposited during spawning events. The effectiveness of drift netting for eggs would also be affected by fluctuating flows during the spring spawning season.

Monitoring larval drift by drift nets can also be used to assess spawning activity and hatching success, but this is also not an indicator of adult abundance. The effectiveness of this technique is also affected by varying flows during the spawning and incubation season.

Developing a plan to assess changes in lake sturgeon abundance in Lake Champlain is a critical need. All the techniques described earlier for sampling lake sturgeon at different life stages have limitations because of the significant changes in sampling effectiveness that can occur because of rapidly changing river conditions during the spawning season. Another factor that impacts sampling for adults during the spawning migrations is that sturgeon numbers are low and an extensive sampling effort is required to capture fish. Sturgeon may be captured multiple times during the spawning season and this can increase the chance that a fish is injured or killed.

Remote sensing technologies could be used to monitor spawning stocks as they migrate upstream or concentrate in feeding or resting locations. Fixed location, split-beam sonar technology was used to identify adult lake sturgeon and estimate the population size of the spawning run on the Sturgeon River in Michigan (Auer and Baker, 2007). High-definition imaging sonar (DIDSON) is a newer technology that could be also used to count migrating sturgeon during a spawning run (Nelson et al. 2010). Side-scan sonar was used to detect Atlantic sturgeon (*Acipenser oxyrinchus*) in five of six rivers surveyed in North Carolina and South Carolina (Flowers and Hightower, 2013). Understanding the timing and duration of spawning runs could also aid in focusing netting during the time the greatest number of fish were present therefore reducing sampling effort.

Underwater video cameras have been used to characterize lake sturgeon spawning behavior and substrate preference (Nichols et al 2003; Chiotti et al. 2008). Cameras may have the potential to monitor behavior and habitat preferences if visibility is adequate.

Advances in electronic tagging have facilitated research on sturgeon habitat use and migratory behavior (Nelson et al.). Electronic tags can transmit data in real time to receivers or store information to an internal memory that can be transmitted later. Radio and acoustic tags transmit in real-time. Archival tags store data until they are collected when the fish is recaptured, transmit to a passive receiver or transmit at a pre-programmed time to a satellite. Archival tags can collect a variety of information including temperature, depth, and location. Electronic tagging could be used to determine habitat preferences, spawning activity, and migration patterns of lake sturgeon in Lake Champlain.

The Department will continue to keep records of all incidental sturgeon catches, because these records do provide some information about sturgeon presence and seasonal habitat use.

Recommended Strategies:

To determine trends in lake sturgeon abundance and habitat use research and monitoring techniques will need to be developed for Lake Champlain and its major tributaries (Appendix 1). Recommended actions include:

A. **Develop an electronic tagging project to monitor movements, habitat use, and migratory patterns of adult lake sturgeon both in rivers used for spawning and Lake Champlain. (Highest)**

B. **Evaluate the use of DIDSON or other remote sensing technologies for estimating abundance of migrating adult sturgeon returning to spawn in at least one of the tributaries to Lake Champlain. (Highest)**

C. **Develop a standardized reporting format and develop a centralized database to record lake sturgeon sightings in the Lake Champlain Basin. Include outreach efforts to inform the public of how to participate in the program.**

D. **Design and implement a gillnetting survey for sub-adult and adult lake sturgeon in Lake Champlain.**

E. **Investigate techniques for monitoring juvenile lake sturgeon in nursery habitat in tributaries where spawning activity has been documented.**

F. **Sample for eggs and/or drifting larvae on the Missisquoi, Lamoille, and Winooski Rivers to assess spawning activity. Sampling should occur for a minimum of three years on each of the rivers beginning in 2017 and should be repeated every fifteen years.**

Artificial Propagation and Stocking

Stocking has played a role in lake sturgeon management including restoration efforts in cases where it is not possible to address habitat limitations to spawning, reintroduction of sturgeon to waters where they were extirpated, and to provide recreational fishing opportunities (Hayes and Caroffino 2012; Welsh et al. 2010). Stocking should not be used to replace management actions taken to address factors that contributed to the decline of the population (Ontario Ministry of Natural Resources 2009; Welsh et al. 2010).

Genetic guidelines for stocking lake sturgeon in the Great Lakes basin emphasized maintaining the genetic diversity of existing populations and, if this is not possible, selecting appropriate donor stocks based on the premise that neighboring stocks are most likely to be genetically similar (Welsh et al. 2010). If a remnant population exists with evidence of recruitment and there is not a high likelihood of extinction then the guidelines recommend that a stocking program should not be implemented because stocking may compromise the genetic integrity of the existing population.

The genetic risks of stocking include outbreeding depression, a loss of genetic diversity, and/or artificial selection (Welsh et al. 2010). Outbreeding depression can occur when genetically distinct populations interbreed resulting in declines in genetic adaptation to a specific environment. Loss of genetic diversity can occur if a representative sample from the donor population cannot be collected. Artificial selection can occur if fish reared in a hatchery environment face differing selection pressures than sturgeon in the wild.

Another challenge faced by lake sturgeon stocking programs is that the fish should be reared with techniques that promote homing and minimize straying of stocked fish into other spawning populations. Streamside rearing facilities can be used to promote imprinting on the stocking location and may reduce artificial selection pressures (Holtgren at al. 2007).

Spawning activity by lake sturgeon has been observed in three of the four tributaries to Lake Champlain where spawning had occurred historically. Lake sturgeon in Champlain are most closely related to the St. Lawrence population of sturgeon but are genetically distinct from that population as well as the other populations surveyed in the Great Lakes Basin (Welsh et al. 2010). There was also no indication that lake sturgeon in Lake Champlain have lower than expected genetic diversity.

Recommended Strategies:

Given the spawning activity present in Lake Champlain tributaries and evidence of recruitment a cautious approach to stocking is recommended (Appendix 1). Recommendations include:

A. **Stocking lake sturgeon in Lake Champlain to augment existing populations or to establish spawning populations is not recommended at this time.**

B. **If lake sturgeon numbers decline after adult mortality and spawning and nursery habitat issues have been addressed, a stocking program should be reconsidered.**

C. **Any artificial propagation attempts should give highest priority to using native Lake Champlain genetic stocks before considering the use of non-native strains.**

D. **Sturgeon culture should follow best management practices for genetic conservation as outlined by Welsh et al. (2010).**

Recovery Goals

Recovery plans developed for lake sturgeon populations in North America have adopted a variety of management goals and objectives. Recovery goals typically include conserving or rehabilitating existing lake sturgeon populations, increasing abundance to allow sturgeon to be removed from threatened or endangered status, reestablishing lake sturgeon in their historic habitats and increasing population abundance to support recreational or tribal fisheries (Hayes and Caroffino 2012; Auer 2003; Golder Associates 2011; Missouri Department of Conservation 2007)

Specific objectives listed in recovery plans vary widely. The sturgeon rehabilitation plan for Lake Superior recommends maintaining, enhancing, or rehabilitating self-sustaining populations. Objectives for populations that use a common location for spawning include 1,500 mature adults, an equal sex ratio, 20 or more year classes of adult fish, evidence of annual reproduction and measurable recruitment of age 0 to age 5 fish (Auer 2003).

The Missouri Recovery Plan (Missouri Department of Conservation 2007) sets a goal for establishing a self-sustaining population of lake sturgeon in the Mississippi and Missouri rivers but does not include specific criteria to describe a self -sustaining lake sturgeon population. The plan suggests that the lake sturgeon population can be removed from the list of state endangered species when there is evidence of adequate recruitment and 15-20 % of the population is 50 inches TL or longer.

Michigan's lake sturgeon rehabilitation strategy uses two population characteristics in setting population objectives, adult abundance and the rate of change in abundance (population trajectory) (Hayes and Caroffino 2012). Populations are characterized as small (80 to 200 adults), medium (200 to 750 adults) or large (> 750 adults). Populations smaller than 80 adults are considered to be below the Minimum Viable Population[2] level (MVP) (Schueller and Hayes 2011). Population trajectory is classified as increasing, stable, or declining over a 15-year window. Populations below MVP are evaluated on a case-by-case basis to determine if recovery efforts are justified. Objectives for other populations include offsetting declines in populations that have been reduced by at least 30 percent during the last 15 years, encouraging expansion of stable populations, maintaining growth in populations that have increased during the last 15 years, and establishing new populations of lake sturgeon in areas of suitable habitat. Due to the low numbers of sturgeon in some populations and the inherent difficulty in sampling abundance, management decisions are sometimes based on best professional judgment and the precautionary principle (Hayes and Caroffino 2012).

Demographic sustainability modeling using stage-structured models and population viability analysis concluded that an average recovery target of 1,188 spawning females would be necessary for Canadian lake sturgeon populations to persist (Velez-Espino and Koops 2009**).** Model results indicated that lake sturgeon populations are most sensitive to changes in adult survival particularly for young adults. Velez-Espino and Koops's analysis indicated that changes to adult mortality (caused by fishing or other sources) would have greater impacts on population fitness than changes to reproductive success.

Schueller and Hayes (2011) estimated that the minimum viable population (MVP) size for a lake sturgeon population in the Great Lakes basin was 80 to 150 post young-of-year male and female sturgeon, which would reduce the risk of extinction over 250 years to 5 percent. They used an individual based model incorporating demographics and inbreeding effects and cautioned that the recommended MVP was based on the baseline parameters used in their model. Populations with differing baseline parameters such as higher mortality rates for adults and sub-adults may have a different minimum viable population size.

A restoration goal of at least 750 sexually mature adults was recommended for populations in the Great Lakes basin based on the minimum number of sturgeon thought to be present in Great Lakes populations that were considered to be stable or increasing (Welsh et al. 2010). A minimum population of 100 females and at least 100 males was recommended for reducing the risk of extinction.

Development of specific recovery targets for lake sturgeon populations can require extensive research and monitoring. Golder Associates (2011) recommended criteria that should be used to develop specific measurable recovery objectives for lake sturgeon populations in Ontario including annual spawning activity, hatching success, natural recruitment, age structure, population structure, stable genetic diversity, and suitable, connected habitat, including features meeting all life history requirements.

The historic abundance of lake sturgeon in Lake Champlain is unknown. Estimated population size, based on the commercial fishery data available from 1896 to 1962, was approximately 3,000 adults (Moreau and Parrish 1994). However records from the commercial fishery are incomplete and no information exists on non-commercial or subsistence harvest. Specific recovery targets cannot be developed for each population spawning in tributaries to Lake Champlain based on historic records.

Estimates of the minimum viable population size based on sustainability modeling of North American lake sturgeon populations ranged from 80 to 150 post-young- of-year adults to 1,100 adult females (Schueller and Hayes 2011; Velez-Espino and Koops 2009). Welsh et al.

[2] Minimum Viable Population level is defined as a population of sufficient size to persist with a given probability over a given time frame.

(2010) recommended a minimum population size of 100 mature females and at least as many males which increases the likelihood of maintaining low frequency alleles. However they also recommended setting a recovery goal of 750 adults for a population based on the size of existing lake sturgeon populations in the Great Lakes basin that are considered to be stable or increasing.

Based on the review of sustainability modeling and condition of lake sturgeon populations elsewhere in North America that are stable or increasing in abundance (Schueller and Hayes 2011; Velez-Espino and Koops 2009; Welsh et al. 2010) the recovery goal for each of the spawning populations migrating to the Winooski, Lamoille, and Missisquoi rivers is 750 adults or 2,000 mature adults lakewide.

Lake sturgeon are currently listed as endangered by the State of Vermont. Once population size has increased to 200 mature adults in each of the three spawning populations and populations are found to be stable or increasing, lake sturgeon should be reclassified to threatened status. A spawning population of 200 adults exceeds the minimum viable population size estimated from an individual-based sustainability model (Schueller and Hayes 2011). Once adult abundance in all three spawning populations has recovered to 750 adults or there is a lakewide population of 2,000 mature adults and there is evidence that populations are stable or increasing lake sturgeon should be removed from protected status (Appendix 2). Opening a limited recreational fishery can then be considered.

These goals may be modified as more information becomes available. More information on the lake sturgeon found in Otter Creek and available spawning habitat is needed before a restoration goal can be set.

Objectives:

The restoration plan for Lake Champlain includes the following objectives

A. **Develop a monitoring and assessment program to determine if the lake sturgeon population in Lake Champlain is declining, stable, or increasing. (Highest)**

B. **Increase the number of lake sturgeon spawning in the Missisquoi, Lamoille, and Winooski rivers to 200 sexually mature adults in each spawning population. Change designation to threatened when this objective is achieved**

C. **Increase the number of lake sturgeon spawning in the Missisquoi, Lamoille, and Winooski rivers to 750 sexually mature adults in each spawning population or 2000 mature sturgeon lakewide. Remove lake sturgeon from the threatened and endangered listing at this time and consider developing a limited recreational fishery.**

Future Directions

Restoring an abundant, self-sustaining, naturally reproducing population of lake sturgeon in Lake Champlain that will sustain a limited recreational fishery will require a longer time frame than is typically considered for fisheries management programs. Lake sturgeon biology and life history traits are unique when compared to other fish species found in Vermont. They are long lived (up to 150 years old), slow to mature (10 to 25 years), spawn intermittently, and have high fecundity and low natural mortality. Successfully restoring Lake Champlain's population of lake sturgeon could take 25 to 50 years.

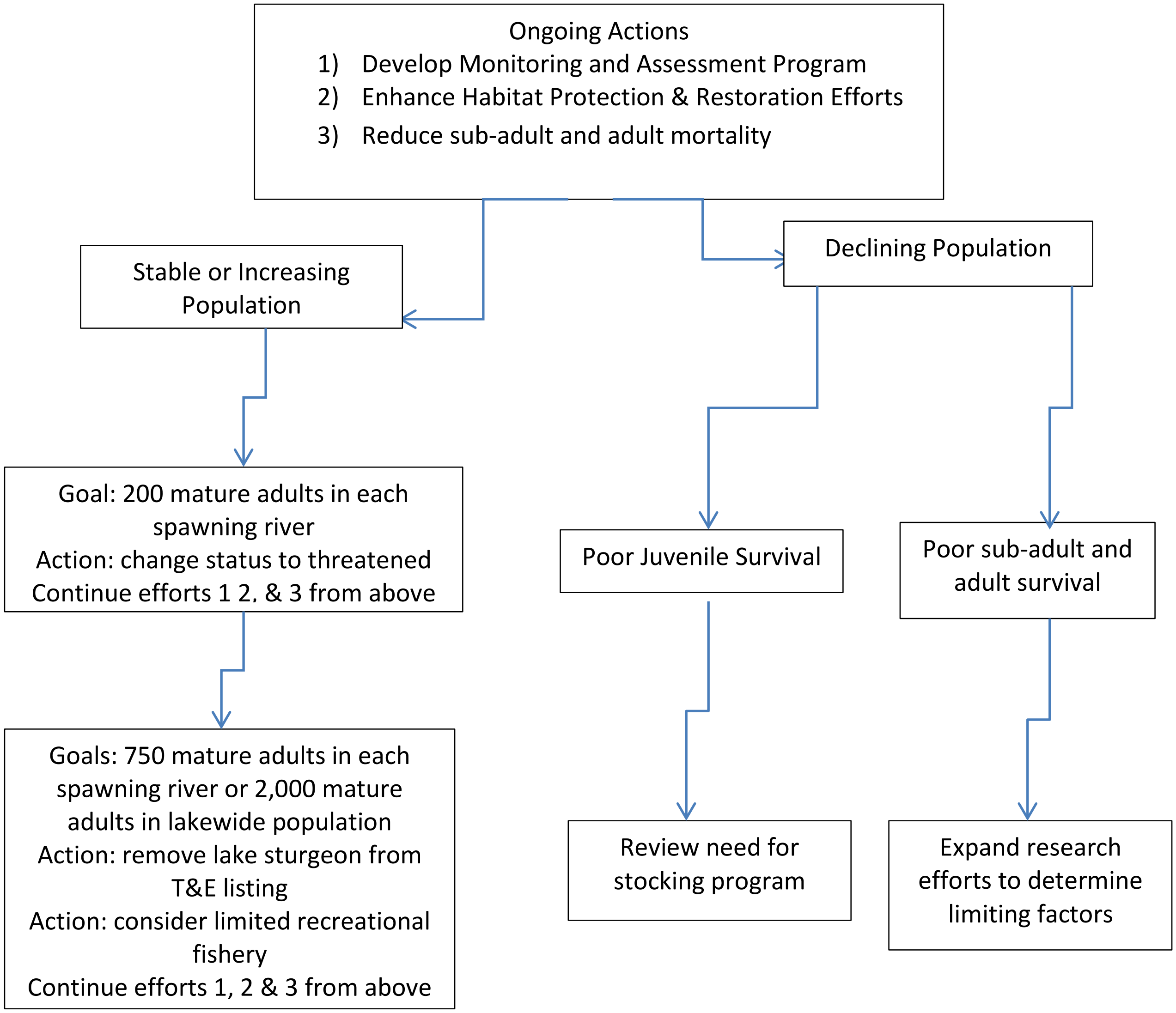
This plan identifies a framework for decision making that can be used to guide recovery efforts over the long term (Figure 9). This plan is a working document that will likely change as new information becomes available on lake sturgeon in Lake Champlain or other sturgeon populations in North America.

The highest priority identified in this plan is to develop assessment and monitoring techniques to determine if the sturgeon population in Lake Champlain is declining, stable, or increasing. Developing a monitoring program that will allow determination of the trend in sturgeon abundance could easily entail research for the next 5 to 10 years and implementation of the monitoring program for another 10 to 20 years before a trend in abundance could be determined. At the same time efforts should continue to reduce sub-adult and adult mortality by enhancing sea lamprey control, law enforcement efforts to minimize poaching, and outreach to anglers to reduce mortality from incidental catches. Efforts to improve spawning success by increasing available spawning habitat or spawning conditions are also a high priority of the plan. These priorities are important for the recovery program for lake sturgeon in Lake Champlain regardless of the population's trajectory: stable, declining, or increasing.

If the population is stable or increasing efforts to reduce sub-adult and adult mortality and improve spawning success should be continued. Once populations in the Lamoille, Winooski and Missisquoi River reach 200 mature adults the status of lake sturgeon in Vermont should be changed to threatened from endangered. Once spawning populations increase to 750 adults in each river or a total population size of 2,000 adults in the lake, sturgeon should be considered for removal from the endangered or threatened listing and a limited recreational fishery could be considered.

If the lake sturgeon population is declining or remains at a stable but very small population size (<200 adults, lakewide) than research on factors limiting sub-adult and adult survival should be expanded and a stocking program could be considered if juvenile survival is considered to be limiting the population recovery.

Figure 9: Framework for decision making for lake sturgeon restoration efforts, Lake Champlain.



References

Adair R. A. and R. J. Sullivan. 2004 (edited 2014). Standard operating procedures for application of lampricides in the Great Lakes Fishery Commission integrated management of sea lamprey (*Petromyzon marinus*) control program. U. S. Fish and Wildlife Service Technical Report. Special Report 92-001.3. U. S. Fish and Wildlife Service, Marquette Biological Station, Marquette, MI.

Auer, N. A. (Ed). 2003. A lake sturgeon rehabilitation plan for Lake Superior. Great Lakes Fishery Commission Miscellaneous Publication 2003-02.

Auer, N. A. 1996a. Response of spawning lake sturgeon to change in hydroelectric facility operation. Transactions of the American Fisheries Society 125: 66-77.

Auer, N.A. 1996b. Importance of habitat and migration to sturgeons with emphasis on lake sturgeon. Canadian Journal of Fisheries and Aquatic Science 53: 152-160.

Auer, N. A. and E. A. Baker. 2002. Duration and drift of larval lake sturgeon in the Sturgeon River, Michigan. In: Proceedings of the 4th International Symposium on Sturgeon. H. Rosenthal, (Ed.). Journal of Applied Ichthyology 18: 557-564.

Auer, N. A. and E. A. Baker. 2007. Assessment of lake sturgeon spawning stocks using fixed-location, split beam sonar technology. Journal of Applied Ichthyology 23: 113-121.

Bell, C. E. and B. Kynard. 1985. Mortality of adult shad passing through a 17-megawatt Kaplan turbine at a low-head hydroelectric dam. North American Journal of Fisheries Management 5: 33-38.

Benson, A. C., T. M. Sutton, R. F. Elliot, and T. G. Meronek. 2005. Seasonal movement patterns and habitat preferences of Age-0 lake sturgeon in the lower Peshtigo River, Wisconsin. Transactions of the American Fisheries Society 134: 1400-1409.

Boogard, M.A., T. D. Bills, and D. A. Johnson. 2003. Acute toxicity of TFM and a TFM/Niclosamide mixture to selected species of fish, including lake sturgeon (*Acipenser fulvescens*) and mudpuppies (*Necturus maculosus*) in laboratory and field exposures. Journal of Great Lakes Research 29 (Supplement 1): 529-541.

Brown, J. J., Limburg, K. E., Waldman, J. R., Stephenson, K., Glenn, E. P., Juanes, F. and Jordaan, A. (2013). Fish and hydropower on the U.S. Atlantic coast: failed fisheries policies from half-way technologies. Conservation Letters doi: 10.1111/conl.12000.

Bruch, R. M. 1999: Management of lake sturgeon on the Winnebago System – long term impacts of harvest and regulations on population structure. Journal of Applied Ichthyology 15: 142-152.

Bruch, R. M. 2009. Modeling the population dynamics and sustainability of lake sturgeon in the Winnebago System, Wisconsin. Doctoral dissertation. University of Wisconsin. Milwaukee.

Bruch, R. M. and F. P. Binkowski. 2002. Spawning behavior of lake sturgeon (*Acipenser fulvescens*) In: Proceedings of the 4th International Symposium on Sturgeon. H. Rosenthal, (Ed.). Journal of Applied Ichthyology 18: 57- 579.

Bruch, R.M., S.E. Campana, S.L. Davis-Foust, M.J. Hansen, and J. Janssen. 2009. Lake sturgeon age validation using bomb radiocarbon and known- age fish. Transactions of the American Fisheries Society 138: 361-372.

Caroffino, D.C., T.M. Sutton, R.F. Elliot, and M.C. Donofrio. 2010. Early life stage mortality rates of lake sturgeon in the Peshtigo River, Wisconsin. North American Journal of Fisheries Management 30: 295-304

Carter, E.N. 1904. Notes on sturgeon culture in Vermont. Transactions of the American Fisheries Society 33: 60-75.

Chiotti , J. A., J. M. Holtgren, N. A. Auer, and S. A. Ogren. 2008. Lake sturgeon spawning habitat in the Big Manistee River, Michigan. North American Journal of Fisheries Management 28: 1009-1019.

Chipman, B. D. 2005. Lake Champlain sea lamprey control program, chemical treatment summary: Winooski River, Vermont, 2004. Vermont Department of Fish and Wildlife, Essex Junction, VT.

Chipman, B. D. 2009a. Lake Champlain sea lamprey control program, chemical treatment summary: Winooski River, Vermont, 2008. Vermont Department of Fish and Wildlife, Essex Junction, VT.

Chipman, B. D. 2009b. Lake Champlain sea lamprey control program, chemical treatment summary: Missisquoi River, Vermont, 2008. Vermont Department of Fish and Wildlife, Essex Junction, VT.

Chipman, B. D. 2010. Lake Champlain sea lamprey control program, chemical treatment summary: Lamoille River, Vermont, 2009. Vermont Department of Fish and Wildlife, Essex Junction, VT.

Chotkowski, M. A., and J. E. Marsden. 1999. Round goby and mottled sculpin predation on lake trout eggs: field predictions from laboratory experiments. Journal of Great Lakes Research 25:26-35.

DeHaan, P. W., S.T. Libants, R.F. Elliott, and K.T. Scribner. 2006. Genetic population structure of remnant lake sturgeon populations in the upper Great Lakes basin. Transactions of the American Fisheries Society 135: 1478-1492.

Dumont, P., R. Fortin, G. Desjardins, and M. Bernard. 1987. Biology and exploitation of lake sturgeon (*Acipenser fulvescens*) on the Quebec waters of the Saint-Laurent River. pp 57-76. In: Olver, C.H.(editor). Proceedings of a workshop on lake sturgeon (*Acipenser fulvescens*). Ontario Fisheries Technical Report Series No. 23.

Fellinger, J. 2000. Lower Lamoille River History. Vermont Natural Resources Council, Barre, VT. 54 pp.

Flowers, H.J. and J.E. Hightower. 2013. A novel approach to surveying sturgeon using side-scan sonar and occupancy modeling. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 5(1): pp 211-223.

Golder Associates LTD. 2011. Recovery strategy for Lake Sturgeon *(Acipenser fulvescens)* – Northwestern Ontario, Great Lakes – Upper St. Lawrence River and Southern Hudson Bay – James Bay populations in Ontario. Ontario Recovery Strategy Series. Prepared for the Ontario Ministry of Natural Resources, Peterborough, Ontario. vii + 77 pp.

Halnon, L. C. 1963. Historical survey of Lake Champlain's fishery. Vermont Fish and Game Service, Federal Aid Fish and Wildlife Restoration Project F-1-R-10, Job 6.

Harkness, W. J. K. and J. R. Dymond. 1961. The lake sturgeon: the history of its fishery and problems of conservation. Fish and Wildlife Branch, Ontario Department of Lands and Forests, Toronto.

Hay-Chmielewski, E., and G. Whelan. 1997. State of Michigan lake sturgeon rehabilitation strategy. Michigan Department of Natural Resources, Special Report no. 18, Lansing, MI.

Hayes, D. B. and D. C. Caroffino, editors. 2012. Michigan's lake sturgeon rehabilitation strategy. Michigan Department of Natural Resources, Fisheries Special Report No. 62. Lansing, MI.

Holtgren, J.M., S.A. Ogren, A.J. Paquet, and S. Fajfer. 2007. Design of a portable streamside rearing facility for lake sturgeon. North American Journal of Aquaculture 69: 317-323.

Jackson, J.R. and A.J. VanDeValk, T.E. Brooking, O.A. vanKeeken, and L. G. Rudstam. 2002. Growth and feeding dynamics of lake sturgeon, *Acipenser fulvescens*, in Oneida Lake, New York: results from the first five years of a restoration program. Journal of Applied Ichthyology 18: 439-443.

Johnson, D.A., J.W. Weisser, and T.D. Bills. 1999. Sensitivity of lake sturgeon (*Acipenser fulvescens*) to the lampricide 3-trifluoromethyl-4-nitrophenol (TFM) in field and laboratory exposures. Technical Report 62, Great Lakes Fishery Commission, Ann Arbor, MI.

Kempinger, J.J. 1983. Early life history of lake sturgeon. Progress Report, Study No. 227, Bureau of Research. Wisconsin Department of Natural resources, Madison, WI.

Kempinger, J.J. 1984. Early life history of lake sturgeon. Progress Report, Study No. 502, Bureau of Research. Wisconsin Department of Natural resources, Madison, WI.

Kempinger, J.J. 1996. Habitat, growth, and food of young lake sturgeons in the Lake Winnebago System, Wisconsin. North American Journal of Fisheries Management 16: 102-114.

Kynard, B., D. Pugh, and T. Parker. 2011. Passage and behaviour of cultured lake sturgeon in a prototype side-baffle fish ladder: I. ladder hydraulics and fish passage. Journal of Applied Ichthyology 27: 77-86.

LaHaye, M., A. Branchaud, M. Gendron, R. Verdon, and R. Fortrin. 1992. Reproduction, early life history, and characteristics of the spawning grounds of the lake sturgeon (*Acipenser fulvescens)* in Des Prairies and L'Assomption rivers, near Montreal, Quebec. Canadian Journal of Zoology 70:1681–1689.

LaHaye, M. S. Desloges. C. Cote, J. Deer, S. Philips, B. Giroux, S. Clermont, and P. Dumont. 2003. Location of lake sturgeon (*Acipenser fulvescens*) spawning grounds in the upper part of the Lachine rapids (St. Lawrence River). Study carried out on behalf of the Societe de la faune et des parcs du Quebec, Direction de l'amenagement de la faune de Montreal, de Laval et de la Monteregie, Longueuil, Technical Report 16-15E, ix + 43 p.

Lyttle, M. 2004. Spawning habitat suitability for walleye and lake sturgeon in the Missisquoi River. U.S. Fish & Wildlife Service, Lake Champlain Fish and Wildlife Resources Office, Essex, VT.

MacKenzie, C. 2003. Restoration of lake sturgeon. Vermont Fish and Wildlife Department. Federal Aid in Fish Restoration. Project No. F-34-R-5, Study No. VI, Job Performance Report, Rutland, VT.

MacKenzie, C. 2008. Restoration of lake sturgeon. Vermont Fish and Wildlife Department. Federal Aid in Fish Restoration. Project No. F-35-R-10, Study V, Job Performance Report, Rutland, VT.

Mather, D., P. G. Heisey, and D. A. Robinson. 1994. Turbine-passage mortality of juvenile American shad at a low-head hydroelectric dam. Transactions of the American Fisheries Society 123: 108-111.

Moreau, D. A. and D. L. Parrish. 1994. A study of the feasibility of restoring lake sturgeon to Lake Champlain. Vermont Cooperative Fish & Wildlife Research Unit, University of Vermont.

Missouri Department of Conservation. 2007. A plan for the recovery of lake sturgeon in Missouri. Jefferson City. 24 pp.

Nelson, T. C., P. Doukakis, S. T. Lindley, A. D. Schreier, J. E. Hightower, L. R. Hildebrand, R. E. Whitlock, and M. A. H. Webb. 2012. Modern technologies for an ancient fish: tools to inform management of migratory sturgeon stocks. A report for the Pacific Ocean Shelf Tracking (POST) Project. Available: http://www.postprogram.org.

Nichols, S.J., G. Kennedy, E. Crawford, J. Allen, J. French III, G. Black, M. Blouin, J. Hickey, S. Chernyak, R. Haas, and M. Thomas. 2003. Assessment of lake sturgeon (*Acipenser fulvescens*) spawning efforts in the lower St. Clair River, Michigan. Journal of Great Lakes Research 29: 383-391.

Nilo P., S. Tremblay, A. Bolon, J. Dodosn, P. Dumont, and R. Fortin. 2006. Feeding ecology of juvenile lake sturgeon in the St. Lawrence River system. Transactions of the American Fisheries Society 135: 1044-1055.

Peake, S., F. W. H. Beamish, R. S. McKinley, D. A. Scruton, and C. Katopodis. 1997. Relating swimming performance of lake sturgeon, *Acipenser fulvescens*, to fishway design. Canadian Journal of Fisheries and Aquatic Sciences 54: 1363-1366.

Ontario Ministry of Natural Resources. 2009. The lake sturgeon in Ontario. Fish and Wildlife Branch. Peterborough, Ontario. 48 pp + appendices.

Patrick, H., T. Sutton, and W. Swink. 2009. Lethality of sea lamprey parasitism on lake sturgeon. Transactions of the American Fisheries Society 138: 1065–1075.

Pratt, T. C., L. M. O'Connor, L.M., T. B. Steeves, B. Stephens, M. Boogaard, and C. Kaye. 2012 In situ assessment of lampricide toxicity to age-0 lake sturgeon. Great Lakes Fishery Commission, Project Completion Report. Ann Arbor, MI.

Priegel G.R., 1973. Lake sturgeon management on the Menominee River. Wisconsin Department of Natural Resources Technical Bulletin No. 67, Madison, WI.

Priegel, G.R., and T.L. Wirth. 1974. The lake sturgeon, its life history, ecology and management. Wisconsin Department of Natural Resources, Publication 4-3600(74), Madison, WI.

Priegel, G.R., and T.L. Wirth. 1975. Lake sturgeon harvest, growth, and recruitment in Lake Winnebago, Wisconsin. Wisconsin Department of Natural Resources Technical Bulletin No. 83, Madison, WI.

Priegel, G.R., and T.L. Wirth. 1978. Lake sturgeon populations, growth, and exploitation in Lakes Poygan, Winneconne, and Lake Butte Des Morts, Wisconsin. Wisconsin Department of Natural Resources Technical Bulletin No. 107, Madison, WI.

Roussow, G. 1957. Some considerations concerning sturgeon spawning periodicity. Journal of the Fisheries Research Board of Canada 14: 553-572.

Schueller, A., and D. Hayes. 2010. Sensitivity of lake sturgeon population dynamics and genetics to demographic parameters. Transaction of the American Fisheries Society 139: 521-534.

Schueller, A., and D. Hayes. 2011. Minimum viable population size for lake sturgeon (Acipenser fulvescens) using an individual-based model of demographics and genetics. Canadian Journal of Fisheries and Aquatic Science 68: 62-73.

Scott, W. B. and E. J. Crossman. 1973. Freshwater fishes of Canada. Bulletin 184, Fisheries Research Board of Canada, Ottawa, Canada.

Smith, S.J. 2013a. Lake Champlain sea lamprey control program, chemical treatment summary: Winooski River, VT 2012. USFWS Lake Champlain Fisheries Resource Office, Essex Junction, VT.

Smith, S.J. 2013b. Lake Champlain sea lamprey control program, chemical treatment summary: Missisquoi River, VT 2012. USFWS Lake Champlain Fisheries Resource Office, Essex Junction, VT.

Stone, L. 1900. The spawning habits of lake sturgeon (*Acipenser rubicundus*). Transactions of the American Fisheries Society 29:118–128.

Stone, L. 1901. Sturgeon hatching in the Lake Champlain basin. Transactions of the American Fisheries Society 30:137–143.

Sutton, T., B. Johnson, T. Bills, and C. Kolar. 2003. Effects of mortality sources on population viability of lake sturgeon: a stage structured model approach. Great Lakes Fishery Commission, Final Project Report, Ann Arbor, Michigan.

Taylor, R. E. and B. Kynard. 1985. Mortality of juvenile American shad and blueback herring passed through a low-head Kaplan hydroelectric turbine. Transactions of the American Fisheries Society 114: 430-435.

Thiem, J. D., T. R. Binder, J. W. Dawson, P. Dumont, D. Hatin, C. Katapodis, D. Z. Zhu, and S. J. Cooke. 2011. Behavior and passage success of upriver-migrating lake sturgeon *Acipenser fulvescens* in a vertical slot fishway on the Richelieu River, Quebec, Canada. Endangered Species Research 15: 1-11.

Thomas, M. and Haas, R. 1998. Capture of lake sturgeon with setlines in the St. Clair River, Michigan. North American Journal of Fisheries Management 19: 610-612.

Wentworth, R.S. 2001. Ecological assessment of the Peterson Dam reach of the Lamoille River. Vermont Department of Fish and Wildlife report. Waterbury, VT.

Welsh, A., T. Hill, H. Quinlan, C. Robinson, and B. May. 2008. Genetic assessment of lake sturgeon population structure in the Laurentian Great Lakes. North American Journal of Fisheries Management 28: 573-591.

Welsh, A., R. Elliot, K. Scribner, H. Quinlan, E. Baker, B. Egghold, J. Holtgren, C. Krueger, and B. May. 2010. Genetic guidelines for the stocking of lake sturgeon (*Acipenser fulvescens)* in the Great Lakes basin. Great Lakes Fishery Commission Miscellaneous Publication 2010-01.

Velez-Espino, L. A. and M. A. Koops. 2009. Recovery potential assessment for lake sturgeon in Canadian designatable units. North American Journal of Fisheries Management 29: 1065-1090.

Appendix 1

Summary of Recommended Strategies for Restoring Lake Sturgeon in Lake Champlain

Recommended Strategies (Actions)

a. Reduce mortality of lake sturgeon

1. Continue efforts to reduce sea lamprey numbers in Lake Champlain to reduce lamprey predation on sub-adult and adult lake sturgeon.
2. Increase the angling public's awareness of the protected status of lake sturgeon in Lake Champlain and spawning tributaries
3. Educate anglers on the proper way to handle accidentally caught sturgeon and encourage anglers to stop fishing or change tactics if they are catching sturgeon frequently.
4. Encourage the fishing and general public to report illegal sturgeon harvest to law enforcement.
5. Increase the general public's awareness and knowledge of lake sturgeon biology, population threats, and restoration efforts to garner public support of restoration efforts, their role in species conservation, and contributions to data collection.
6. Minimize impacts of lampricide treatments on lake sturgeon young-of-year in rivers where sturgeon reproduction has been documented.
7. Support efforts to prevent the introduction or spread of non-native aquatic organisms or diseases that are or pose a threat to sturgeon populations and restoration.
8. Extend spawning water closures on the Missisquoi, Lamoille and Winooski rivers until June 15 to protect aggregations of spawning sturgeons.

b. Spawning and Nursery Habitats

1. Restore connectivity for lake sturgeon to spawning and nursery habitats upstream of the Swanton Dam on the Missisquoi River.
2. Require hydroelectric facilities operating on the Missisquoi, Lamoille and Winooski rivers and Otter creek watersheds to provide instantaneous run-of-river flows during lake sturgeon spawning and incubation seasons.
3. Investigate the potential for increasing suitable spawning habitat in Otter Creek and the Lamoille River.
4. Participate in the regulatory review of developments under FERC hydroelectric development or relicensing, Act 250 and Act 248, water withdrawals, or stream alteration projects to minimize impacts on waters containing lake sturgeon
5. Require adequate flow within bypassed river channels in river reaches containing lake sturgeon.
6. Require hydroelectric facilities to provide safe downstream passage on river systems that have upstream lake sturgeon populations.

c. Assessment and Monitoring

1. Develop an electronic tagging project to monitor movements, habitat use, and migratory patterns of adult lake sturgeon both in rivers used for spawning and Lake Champlain.
2. Evaluate the use of DIDSON or other remote sensing technologies for estimating abundance of migrating adult sturgeon returning to spawn in at least one of the tributaries to Lake Champlain.
3. Develop a standardized reporting format and develop a centralized database to record lake sturgeon sightings in the Lake Champlain Basin. Include outreach efforts to inform the public how to participate in the program.
4. Design and implement a gillnetting survey for sub-adult and adult lake sturgeon in Lake Champlain.
5. Investigate techniques for monitoring juvenile lake sturgeon in nursery habitat in tributaries where spawning activity has been documented.
6. Design a sampling program for eggs and/or drifting larvae on the Missisquoi, Lamoille and Winooski Rivers and Otter Creek to assess spawning activity.

d. Artificial Propagation and Stocking

1. Stocking lake sturgeon in Lake Champlain to augment existing populations or to establish spawning populations is not recommended at this time.
2. If lake sturgeon numbers do not increase after mortality and habitat limiting factors are addressed and results fall short of the restoration goal then a stocking program may be reconsidered.
3. Artificial propagation should give highest priority to using native Lake Champlain genetic stocks before considering the use of non-native strains.
4. Sturgeon culture should follow best management practices for genetic conservation as outlined by Welsh et al. (2010).

Appendix 2

Summary of Restoration Objectives for Lake Sturgeon in Lake Champlain

Restoration Objectives

a. **Goal:** Restore a self-sustaining wild population of lake sturgeon to Lake Champlain such that its historic ecological role in the lake system is re-established and sport fishing opportunities are provided.

   Objective 1: Develop a monitoring and assessment program to determine if the lake sturgeon population in Lake Champlain is declining, stable, or increasing.
   Objective 2: Increase the number of lake sturgeon spawning in the Missisquoi, Lamoille, and Winooski rivers to 200 sexually mature adults in each spawning population. Change designation to threatened when this objective is achieved
   Objective 3: Increase the number of lake sturgeon spawning in the Missisquoi, Lamoille, and Winooski rivers to 750 sexually mature adults in each spawning population or 2000 mature sturgeon in the lake. Remove lake sturgeon from the threatened and endangered listing at this time and consider developing a limited recreational fishery.
   Objective 4: Investigate sturgeon restoration opportunities in Otter Creek.