Spawning Habitat Suitability for Walleye and Lake Sturgeon

in the Missisquoi River

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ABSTRACT

The Missisquoi River has long been identified as providing important spawning habitat for walleye and lake sturgeon in Lake Champlain. Unfortunately, like most northeastern rivers, the Missisquoi River has a history of anthropogenic modifications that limit access to historical spawning sites. Under the current hydrological conditions, the limit to fish migration upstream from Lake Champlain is Swanton Dam, although the falls at Highgate Dam were the historical limit. The purpose of this study was to locate and compare spawning areas above Swanton Dam to the currently available spawning habitat below Swanton Dam. We accomplished this using a modified Habitat Suitability Index (HSI) (McMahon *et al*. 1984) and the Vermont Agency of Natural Resources Phase 2 Stream Geomorphic Assessment protocal. These two modeling tools allowed us to quantify the six locations targeted in this study, two below Swanton Dam and four above. Our study indicated that the amount of spawning substrate was not a limiting factor in this river. However, it did indicate that the qualities of the spawning locations varied. For instance, in the locations below Swanton Dam, the amounts of suitable spawning substrate ranged from 112,860 ft^2 to 198,222 ft^2. However, when depth of substrate and average velocity over the spawning material were calculated, the suitable spawning habitat below Swanton Dam dropped to a range of 21 ft^2 to 78 ft^2 for walleye and from 686 ft^2 to 722 ft^2 for lake sturgeon. The substrate with the appropriate flows, depth and substrate measured above Swanton Dam ranged from 11,596 ft^2 to 25,420 ft^2 for walleye and from 218,927 to 235,404 ft^2 for lake sturgeon. This study indicated that suitable spawning habitat would increase by 65 to 1,210 times what is currently available for lake-run spawning walleye. Additionally, an increase of 303 to 342 times the current level could be realized by lake sturgeon. Therefore, providing access to the habitat above Swanton Dam would substantially increase the available suitable spawning habitat in the Missisquoi River for both walleye and lake sturgeon during normal spring flow conditions. Additionally, access to the habitat above Swanton Dam would insure successful spawning over a wider variety of river conditions and gage heights.

INTRODUCTION

The walleye (*Stizostedion vitreum vitreum*) is one of the most sought-after sportfish in the United States and Canada, making it an economically valuable species (Scott and Crossman, 1979; Werner, 1980; Smith, 1985; Sternberg, 1986; Gilbert, 1999). Walleye are found in freshwater as far north as Quebec and the arctic coast in the McKenzie River, south to northern Texas, Alabama, and Georgia, east to western New Hampshire, and west to North Dakota (Scott and Crossman, 1979; Werner, 1980; Smith, 1985).

Lake sturgeon (*Acipenser fulvescens*) habitat often overlaps walleye habitat. Like walleye, lake sturgeon are found in large rivers and lakes across southern Canada and northern United States, from the St. Lawrence drainage west to Alberta. They are found in the Mississippi and Arkansas drainages, as far south as Arkansas and as far west as the eastern Dakotas (Scott and Crossman, 1979).

Walleye and sturgeon overlap in their spawning requirements. Walleye spawn in the spring (April-June) just after the ice breaks in lakes and tributaries at temperatures ranging between 42^{o}-52^{o}F (5.6^{o}-11.1^{o}C) (Scott and Crossman, 1979; Werner, 1980; Smith, 1985). Lake sturgeon also spawn in the spring, but at slightly warmer temperatures 43.9^{o}-60.8^{o}F (6.6^{o} - 16 ^{o}C) (Scott and Crossman, 1979; LaHaye and Branchaud, 1992; Bruch and Binkowski, 2002).

The spawning substrate of walleye includes coarse gravel mixed with cobble, gravel, and sometimes sand in streams and shoals of lakes with good water flow (Scott and Crossman, 1979; Werner, 1980; Smith, 1985). Walleye generally spawn in water between 1-5 feet (0.3- 1.5 m) deep with a moderate current (Sternberg, 1986). Lake sturgeon spawn in depths of 2 to 15 feet (0.6 - 4.6 m) (Scott and Crossman, 1979) over a mixture of coarse substrates (Bruch and Binkowski, 2002; Seyler, 1997). Both walleye and lake sturgeon spawn in moderate velocities between 1.5 and 3.5 ft/sec. Table 1 compares the preferences of the two fish species regarding temperature, depth, velocity and substrate.

Both walleye and lake sturgeon are broadcast spawners. The eggs are adhesive and bond to stable substrate. Once the eggs hatch, the fry drift into the crevices between rocks and plant matter. Therefore, suitable spawning substrate, water velocities, and temperatures are important in the spawning success for each species. (Scott and Crossman 1979, Werner 1980, Smith 1985).

The Missisquoi River is an important spawning location for the northern part of Lake Champlain (Johnson 1998). Our objective was to measure the habitat conditions where walleye and lake sturgeon successfully spawn on the Missisquoi River downstream of the Swanton Dam, and compare that habitat to potential spawning habitats above Swanton Dam. The upstream limit to our study was Highgate Dam, the historical limit to the lake-run spawning fish. We hypothesized that the habitat above the Swanton Dam is suitable for walleye and lake sturgeon spawning and, if it were made accessible to the lake fish community, would substantially increase the currently available spawning habitat in the Missisquoi River.

Table 1: Comparison of spawning habitat requirements for walleye and lake sturgeon. The red rectangles with crosshatching indicate preferences.

WALLEYE											
TEMPERATURE (^{O}C)	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
STURGEON											

WALLEYE										
DEPTH (ft)	**1**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**15**	**16**
STURGEON										

WALLEYE							
VELOCITY (ft/sec)	**1-1.5**	**1.6 - 2**	**2.1 -2.5**	**2.6 - 3**	**3.1- 3.5**	**3.6 - 4**	**4.1- 5**
STURGEON							

WALLEYE						
SUBSTRATE (mm)	**SILT/CLAY** 0-0.06	**SAND** 0.06-2	**GRAVEL** 2 - 64	**COBBLE** 65-256	**BOULDER** 257-4096	**BEDROCK** >4096
STURGEON						

STUDY AREA

The Missisquoi River is ranked as the second major river in the Lake Champlain basin by main stem length. Its drainage area is 767,312 acres (310,527 hectares) (New England Interstate Pollution Control Commission 1999). The river begins in Lowell, Vermont and flows north into Canada, where it loops back to the south/southeast into Vermont in East Richford, then to Highgate and finally to Swanton, Vermont. The river empties into the Missisquoi Bay on the northeast end of Lake Champlain (Mitro 1995) and forms a large wetland/floodplain delta in the northeast corner of Lake Champlain (Howland 1981).

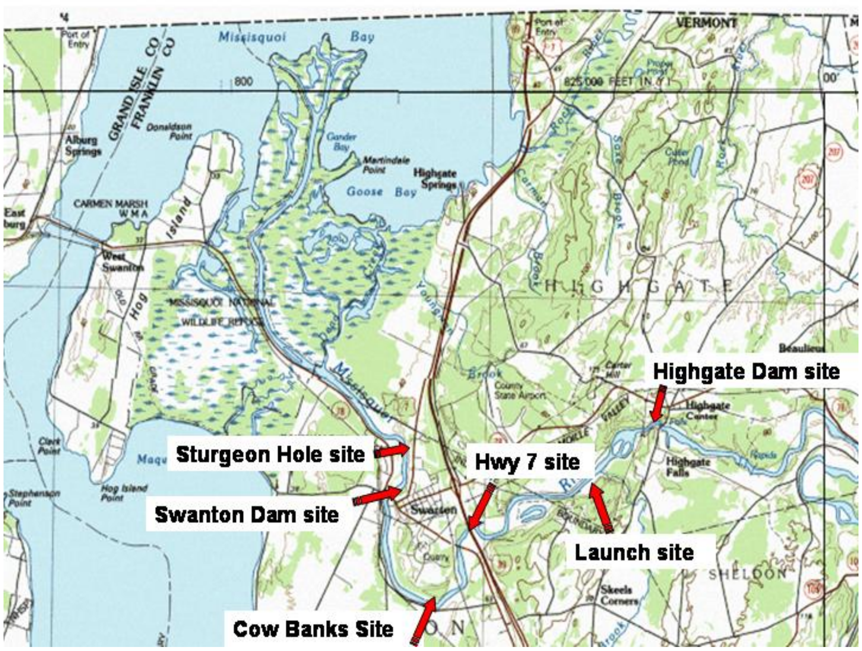
The river is 74 miles long in Vermont and contains seven dams. Spawning runs of several different fish species that originate in Lake Champlain frequent the river in the spring. However, the fish are limited to an eight mile reach below Swanton Dam. Swanton Dam, located just south the Vermont Route 78 bridge, is currently not used for hydropower generation, navigation, or flood control. The first dam was built on the site in 1789.

Highgate Dam, located seven and a half river miles upstream from the Swanton Dam, was built on a natural barrier to fish passage and is currently used as a hydroelectric power supply for the region. Figure 1 shows an aerial view of the Missisquoi River from Highgate Dam to Missisquoi Bay.

METHODS

Habitat Suitability Indices (HSI's), are modeling tools that quantify available habitat for a specific fish for its different life stages (McMahon *et al.*1984, Terrell *et al.* 1982, Schamberger *et al.* 1982). For instance, the McMahon *et al.* (1984) walleye HSI calculates the required habitat parameters for spawning, juvenile survival, growth and recruitment. There is currently no HSI available for lake sturgeon. However, as indicated on Table 1, the parameters required for successful walleye and lake sturgeon spawning are similar. Temperature and depth were more restrictive for walleye spawning. Walleye can tolerate slightly higher velocities. Spawning substrate differs for the two fish in that walleye preferred slightly finer material. With this information, we were able to expand the data collected for the walleye HSI to make inferences on spawning habitat quality for lake sturgeon.

Figure 1: Topographic map highlighting the Missisquoi River from Highgate Dam to Missisquoi Bay. It also indicates the six sites used in this study.



To satisfy the data requirements of the McMahon *et al*. (1984) model, we collected data in the Missisquoi River on temperature, dissolved oxygen, velocity, and substrate composition. We used the typical gage heights and discharges to evaluate the sites' flow regimes, cross sectional areas, and percentages of habitat between water depths of 1-5 feet during these normal flows. The data were collected between the months of May and September of 2003. We began by surveying the reach from the Missisquoi Bay to the Highgate Dam (River mile 14.5) for possible walleye/sturgeon spawning substrate. An underwater camera (Aqua-vu®) or a depth finder

(Humminbird 100SX®) was used to search for uneven substrate patterns on the river bottom. When we found uneven patterns, we probed the bottom with a plastic pole to verify if the substrate was rock. We did not include bank stabilizing rocks used to protect roads or bridges in this study. Using these techniques, we attempted to identify all potential spawning areas greater than approximately 500 ft^2.

Once we identified the potential spawning areas based on substrate, we marked the substrate boundaries with numerous floats. We then multiplied the length of a spawning substrate by the mean width of the channel to determine the total area at each location, and to establish the percentage of suitable spawning habitat for each area. For example, if the spawning substrate completely covered the substratum for the length and breadth of a site, the percent substrate would be calculated at 100%. However, if the suitable habitat covered only 2/3 of the substratum in that section, then the percentage would be less (66%).

Temperature and Dissolved Oxygen

Dissolved oxygen readings were taken with a Hach® Dissolved Oxygen kit below Swanton Dam and Highgate Dam during a range of flow and temperature conditions between the dates of May 28 through June 9, 2003. Water temperature was monitored with Onset ® temperature meters below Swanton Dam and below Highgate Dam. These meters went on-line below Swanton Dam on April 10 and below Highgate Dam on April 29 and recorded the water temperature every hour until mid-September. Temperatures above and below Swanton Dam were compared using the statistical program Systat 10®.

Field data temperatures taken during the Vermont Department of Fish and Wildlife spring walleye spawning catches were used to estimate the dates the walleye and lake sturgeon spawn in the Missisquoi River. Once the range of dates was identified, we obtained historic flow and gage information from the USGS gage located at Swanton Dam. These sources provided information on the water conditions during walleye spawning for eight consecutive years.

Velocity

Cross sectional transects were measured at each spawning location with a Spectra LL600® precision laser level (Rosgen 1993). A permanent bench mark was placed at each transect. The benchmark allowed us to measure water elevations during different flow conditions with a CST/berger® sight level and a surveying rod. One transect was selected for each spawning location that best represented the available substrate conditions. Water and substrate elevations were taken along each transect every ten meters or at depth changes that would be missed by using only uniformed measurements. Portions of the shoreline that were probably under water during common spring flows were included in these measurements. This provided a cross-sectional map of the spawning area. The Vermont River Morphology Workbook v. 4-9 spread sheet (Vermont Agency of Natural Resources, 2002) was used to calculate the wetted perimeter and depths changes at different flow conditions. A regression curve was developed to estimate the areas of suitable spawning habitat during walleye and lake sturgeon spawning by correlating water elevations with the gage and discharge readings from the USGS (Appendix 1). The same regression lines were used for the Sturgeon Hole and the Swanton Dam sites and the Highgate Dam and Launch sites because of their close proximities.

The velocities (ft/sec) for each spawning site at various flow conditions were calculated by dividing the stream discharge (cfs) obtained from the USGS gage by the cross-sectional area (ft^2) of the river during April 5 through May 4 at each spawning location. The cross-sectional area was calculated by manipulating the water elevation on the Vermont Stream Geomorphic Assessment Data Management Spreadsheet. This spreadsheet also gave the width of the river cross section (ft) in each sample location. This information was used to calculate the actual size of the spawning substrate at different water elevations that is reported in Appendix 2.

Substrate Composition

The substrate composition at all sites was measured using a modified Wolman (1954) pebble count (Table 2). In the four smaller potential spawning locations two swimmers collected the substrate for the pebble count data. Each swimmer started on a riverbank and randomly collected samples of substrate while moving toward the opposite bank. Substrate material found on the river's edge was incorporated in the count if the area would be submerged during spring flows. One hundred substrate samples from each of the four smaller locations were collected. This information was used to calculate the percentages of silt/clay, sand, gravel, cobble, boulder, and bedrock at each potential spawning area. In the two larger sites (Highgate and Swanton Dam sites), the pebble count data were obtained in randomly placed transects perpendicular to the flows, because the potential spawning substrate completely crossed the width of the river. The Highgate Dam site had seven transects and the Swanton Dam site had nine. At each transect, we collected data from ten stations spaced equidistant from each other.

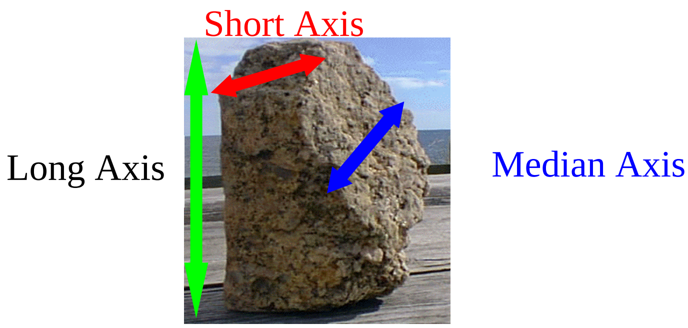
Table 2: Classification of substrate sizes.

Material	Size range (mm)
Silt/clay	0-0.06
Fine sand	0.061-0.25
Medium sand	0.26-0.5
Course sand (pea gravel)	0.51-2
Gravel	2-64
Cobble (rubble)	65- 256
Boulder	257-4096
Bedrock	>4096

The data included depth and substrate sample sizes. Substrate samples where collected by randomly selecting three samples of rock and gravel material that occurred at each station. The median axis of the rock or gravel was measured (Figure 2). In the case of sand, silt, and bedrock we simply noted the type and not the size. These data were incorporated into the McMahon *et al*. (1984) Substrate Indices (SI) formula [2(%gravel + %coble) = (%boulder + % bedrock) + 0.5(%sand) + 0.5(%dense vegetation) + 0(%silt/detritus)].

The Spawning Habitat Index (SHI) was calculated by multiplying the substrate SI by the portion of the water body composed of suitable substrate between 0.3 m and 1.5 meters (1 to 5 ft) of water depth for each spawning area.

Figure 2: Picture depicting the three axes of a rock.



RESULTS AND DISCUSSION

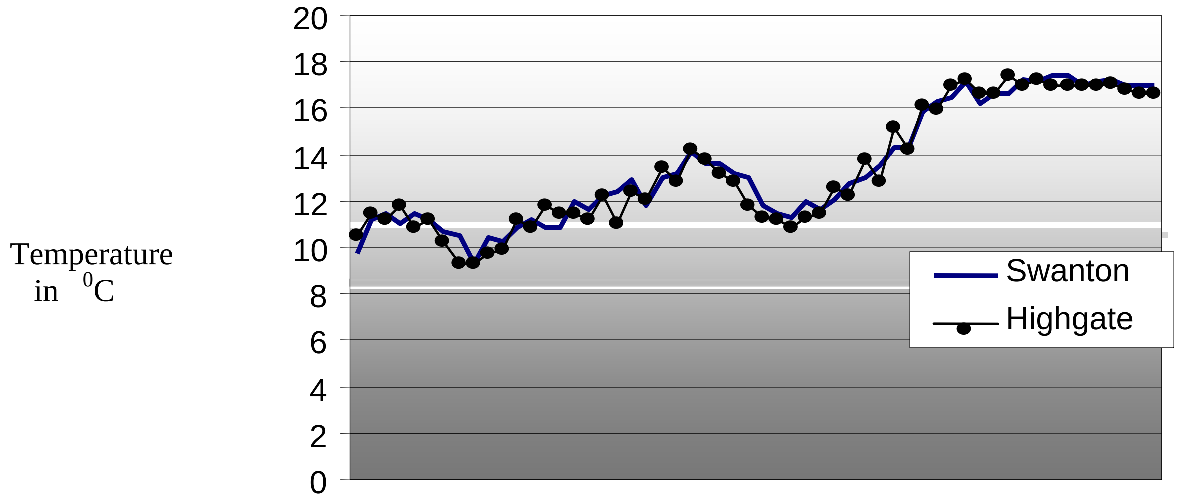
Dissolved Oxygen and Temperature

Dissolved oxygen (DO) readings were taken in conditions of low flow and warm temperatures. That is, our readings would be lower than would be expected during walleye spawning. Nevertheless, our DO readings ranged from 8 to 11 mg/l below Swanton and Highgate Dams, well above suitable levels for walleye spawning.

The temperature meters placed below Swanton and Highgate Dams indicated that the temperatures between the dates of April 30 to May 28, 2003 were not significantly different ($P=0.132$) when compared using a pared t-test. The temperatures recorded indicated that by early May, the temperatures were at the upper-limit for walleye spawning (Figure 3). However, the temperatures would not limit lake sturgeon until late May.

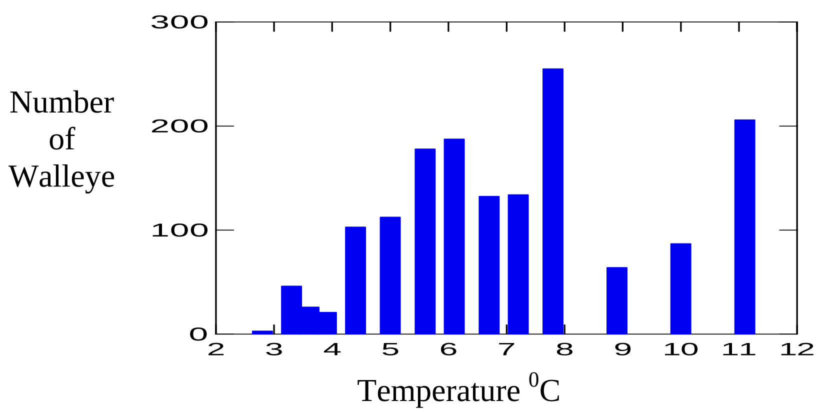
Once we determined that there were no significant differences in temperature between the Swanton and Highgate Dam sites, we obtained temperature data from Vermont Department of Fish and Wildlife's walleye sampling for the eight consecutive years (1994-2002). Vermont conducted their surveys below Swanton Dam between the dates of April 5 and May 4. The water temperatures below Swanton Dam ranged from 3 – 10 ^{o}C with a mean temperature of 6 ^{o}C (sd = 5.02, n = 34) (Figure 4).

Figure 3: Graph showing the variation in temperatures at locations below Swanton and Highgate Dams on the Missisquoi River between the dates of April 30 and May 28, 2003.



Temperature is one of the major factors that influence the success of walleye and lake sturgeon spawning (LaHaye et. al. 1992, Folz and Meyers, 1985, Scott and Crossman, 1973). For walleye, spawning occurs in a temperature range from 5-11^{o} C. Temperatures taken during the eight years of walleye sampling indicate that the Missisquoi River walleye fall into this predicted range.   LaHaye *et al*'s (1992) work on two Quebec rivers noted that lake sturgeon deposited their eggs in the temperature range of 11.6 to 15.4^{o} C. The egg deposition was irregular, with peaks occurring at 11.6 and 14.7^{o} C. Scott and Crossman (1973) reported optimal spawning temperatures for lake sturgeon between 13 and 18^{o} C. Both indicate that lake sturgeon spawning would be after the peak egg deposition of walleye

Figure 4: The number of adult walleye sampled in the Missiquoi River, below Swanton Dam, by the Vermont Department of Fish and Wildlife at different temperatures (C^{0}) over an eight year period.



Velocity

Once the spawning dates were established from the Vermont Department of Fish and Wildlife walleye survey data, we obtained mean gage and discharge levels from the USGS web site. The average gage readings between April 5 and May 4 over a thirteen year time period (1990 – 2002) ranged from 2.2 to 3.4 with the corresponding discharges ranging from 2,507 cfs to 6,290 cfs (Table 3). This information was used to calculate the average velocities (ft/sec) for different gage readings at each potential spawning (Table 4).

When we incorporated velocity into our model, the percentage of suitable habitat decreased substantially for both walleye and lake sturgeon. McMahon *et. al.*'s 1984 model identifies the spawning velocity range between 2 ft/sec to 3.5 ft/sec with 2.5 to 3 ft/sec being best (100% suitability) for walleye spawning.

Table 3: Average gage reading and discharge rates based on thirteen years of data obtained from USGS gage information for Swanton Dam Gage, Missisquoi River.

Day/ Month	Average Gage Reading	Average Discharge (cfs)
5 April	2.87	4465
6 April	2.81	4261
7 April	2.84	4349
8 April	2.89	4541
9 April	2.98	4857
10 April	3.19	5582
11 April	3.28	5933
12 April	3.12	5330
13 April	3.08	5172
14 April	3.21	5645
15 April	3.23	5746
16 April	3.30	6001
17 April	3.34	6147
18 April	3.14	5396
19 April	2.86	4417
20 April	2.76	4054
21 April	2.92	4628
22 April	3.19	5573
23 April	3.38	6290
24 April	3.37	6271
25 April	3.16	5504
26 April	2.93	4641
27 April	2.77	4197
28 April	2.63	3562
29 April	2.43	3028
30 April	2.27	2596
1 May	2.33	2743
2 May	2.41	2989
3 May	2.37	2851
4 May	2.24	2507

Table 4: Average velocities (ft/sec) at each of the spawning sites at different gage readings.

	gage = 1.3	**1.9**	**2.5**	**3.1**	**3.7**	**4.3**	**4.9**	**5.4**
Sturgeon Hole	.44	1.04	1.68	2.30	2.90	3.30	3.70	4.00
Swanton Dam	4.16	4.45	4.95	5.54	5.98	6.23	6.46	6.47
Cow Bank	.29	.77	1.36	2.03	2.67	3.27	3.81	4.28
Hwy 7	.29	.75	1.29	1.87	2.41	2.86	3.31	3.36
Launch	1.00	2.20	3.60	4.40	5.90	6.70	7.40	7.80
Highgate Dam	.24	.64	1.09	1.61	2.11	2.54	2.92	3.24

According to Mion *et al.* (1998) river discharge has a strong negative correlation with the survival of larvae after hatching. This can substantially limit the spawning success in a specific area. For instance, although the spawning area below Swanton Dam was not limited by substrate or depths, the average velocities were not suitable even at the lowest gage readings. We know, based on information obtained during field sampling, that this area is the primary spawning location for both walleye and lake sturgeon, suggesting that microhabitats provide at least some suitable velocities The Highgate Dam site, in contrast, does not have the velocity barriers at the rage of gage readings between 2.2 and 3.4 that occur during spring spawning.

Substrate Composition

All sites for this study were selected based on substrate type. All six sites were compared for walleye spawning suitability using the Substrate Index (SI) formula McMahon *et al.* (1984). A SI score of greater than 40 is considered appropriate spawning substrate for walleye. The SI was suitable for walleye spawning in all the locations included in our study (Table 5).

Lake sturgeon require larger spawning substrate then walleye. LaHaye et al's study showed that lake sturgeon did not utilize homogenous substrates dominated by silt, sand, or bedrock. Manny and Kennedy (2002) reported that lake sturgeon used course gravel, cobble, and coal cinders. The substrate selected by lake sturgeon in their study had large interstitial spaces that could protect the eggs and fry. Table 5 shows that none of our study sites had homogenous materials and they were comprised predominate of gravel, cobble and boulder size substrate. Based on these finding, we conclude that the substrate was suitable for lake sturgeon spawning.

Table 5: The Substrate Index (SI) for the spawning substrate found in six locations in the Missisquoi River in 2003. The Substrate Index = 2 (%gravel+ cobble) + (%gravel + %boulders) + 0.5 (%sand) + 0(%silt+ %clay) + 0.5% (dense vegetation).

Transect	% dense vegetation	% silt/clay	% sand	% gravel	% cobble	% boulder	% bedrock	SI
Sturgeon Hole	0	0	22	11	22	37	7	121
.Swanton Dam	0	0	7	7	38	19	30	143
Cow Bank	0	0	6	0	28	64	0	123
Hwy 7 bridge	0	6	31	11	30	23	0	121
Launch Area	0	10	50	20	15	5	0	100
Highgate Dam	0	0	14	59	3	1	23	155

The HSI model (McMahon's *et al*. 1984) categorized suitable walleye spawning habitat as being between .3 to 1.5 meters in depth. For lake sturgeon the suitable substrate depth is between .3 to 4.6 meters (Scott and Crossman, 1979). McMahon's model calculated the Spawning Habitat Index (SHI) by multiplying the portion of the site (% area) with the appropriate depths for walleye by the SI. We expanded his model by multiplying the SI by the percentage of spawning habitat with depths suitable for lake sturgeon. Appendix 2 shows the total spawning area and the SHI for walleye and lake sturgeon for each study site. When depth was incorporated into the model, the percentage of suitable habitat in most of the potential spawning areas dropped substantially for walleye.

Site Comparisons

Sites below Swanton Dam Barrier:

Based on depth of substrate, less than 18% of the total habitat available for walleye spawning in the Sturgeon Hole site is suitable at water gage readings greater than 3 ft. The average flow during spring spawning was calculated to be between the gage heights of 2.2 to 3.4 ft. When the gage is 3 ft there is 126 ft^2 of suitable habitat. However, because sturgeon may spawn at greater depths, 100% of the habitat (698 ft^2) is suitable for sturgeon spawning. Velocities at the Sturgeon Hole were not limiting for either walleye or sturgeon spawning except at the highest water gage readings (> 4.9 ft).

Unlike the Sturgeon Hole, the majority of the substrate at the Swanton Dam site did not exceed the depth requirements for spawning walleye. However, the average velocity, even at the lowest water gage readings, exceeded the suitability range of flows for spawning walleye and sturgeon. The suitable velocity range for spawning walleye and lake sturgeon is between 1.6 and 3.5 ft/sec. At the lowest water gage height calculated in this study (gage=1.3ft), the average velocity at the Swanton Dam site was calculated at 4.16 ft/sec. Historically, the average gage reading during the spawning in the Missiquoi River exceeds 2.5ft. This equates to greater than an average velocity of 4.95 ft/sec at the Swanton Dam site. Based on McMahon *et al.* (1984) model, when the water velocity exceeds 3.5 ft/sec a suitability of 0 is assigned for walleye. We assigned the same score for lake sturgeon based on the overlap in this habitat requirement between the two species.

McMahon's model indicates that velocity is the limiting factor for walleye and sturgeon spawning just below Swanton Dam. It is possible that spawning occurs in areas of the river channel with lower velocities, such as behind a stable structure or in deeper waters. Multiple field observations over several years have shown that walleye and lake sturgeon do spawn at the Swanton Dam site (Vermont Department of Fish and Wildlife 1998, Mitro 1995). However, according to the model, the success of such spawning activity would be limited due to the water velocities.

Sites above Swanton Dam Barrier

Cow Banks, the site closest to the Swanton Dam, had suitable substrate material (SI= 123) but inappropriate depths for spawning walleye. Less than 2% of the total 1,486 ft^2 habitat area was suitable for walleye spawning at the lowest calculated spring spawning gage reading of 2.4 ft. (Appendix 2). Any gage reading above 2.4 ft rendered the area not suitable for walleye spawning due to excessive depths. However, 100% of the habitat could be suitable for lake sturgeon at the entire range of spring flows (2.3-3.9 ft/sec). The average velocities during spawning would not limit either walleye or lake sturgeon. Based on our findings, the Cow Banks area has suitable substrate, depths, and velocities for lake sturgeon spawning,
The Hwy 7 site totaled 2,368 ft^2 of suitable spawning substrate. However, less than 7% was suitable for spawning walleye at gage readings of 2.5ft or higher. This was also one of the few locations that had depths that exceeded the range used by lake sturgeon. At gage readings of 4ft or higher, the amount of spawning habitat for sturgeon dropped by 38%. Velocity was limiting only at the higher flows (gage >4.9 ft). Therefore, although this site had appropriate spawning substrate and velocities for both walleye and lake sturgeon, depth would limit the amount of suitable substrate for both fish species.

The Launch Site spawning substrate was approximately 5,662 ft^2 in size and located approximately half way between the Hwy 7 site and the Highgate Dam site. The majority of the substrate was suitable for spawning but depths at gage readings greater than 3.7 ft limited walleye spawning by >90%. Depths were limiting for lake sturgeon spawning in the lowest flows (gage <1.3 ft). Velocities at this site were inappropriate at gage readings greater then 2.5 ft for both walleye and lake sturgeon. Therefore, velocity was the limiting factor at the Launch Site.

The uppermost site, Highgate Dam, had the largest amount of available spawning substrate (224,532 ft^2). Depths limited the availability for spawning walleye at gage readings greater than 2.5ft. Despite this, even at a gage reading of 3.1 ft, the amount of suitable spawning substrate for walleye was calculated to be 21,190 ft^2. For lake sturgeon, depth did not limit potential spawning at any of the calculated gage readings. Velocities would not be limiting for either spawning walleye or lake sturgeon. The velocity at the highest gage reading of 5.4 ft was calculated to be a velocity of 3.2 ft/sec, which is within the suitability rage of both fish species.

SUMMARY

The water depths over spawning substrate substantially lowered the suitability of spawning habitat for walleye in four of the six sites. Only Swanton Dam and Highgate Dam sites were not impaired by inappropriate water depths. Sturgeon, however, have been reported to spawn in water deeper than 15 feet (4.6 m) (Scott and Crossman, 1979). For sturgeon, depth limits spawning habitat only at the Hwy 7 site.

Highgate Dam was constructed on a natural barrier to spawning fish. Swanton Dam, however, currently impedes the historic run of walleye and sturgeon from Lake Champlain (Howland 1981). Access upstream of Swanton Dam would increase the quantity of spawning habitat for walleye from 171,930 ft^2 to 195,955 ft^2 and for lake sturgeon from 167,348 ft^2 to 387,324 ft^2 at the average spring flow gage reading of 3.1 ft based on substrate type and depth alone. However, when velocity limitations are taken into account, spawning habitat for Lake Champlain migratory fish, would be increased by 99% if access was provided upstream of the Swanton Dam barrier. Figures 5 A and B illustrate, the amount of habitat available at the three gage readings that fall within the velocity parameters for both walleye and lake sturgeon spawning.

The location of the existing barrier, Swanton Dam, has been identified in both figures. The floating bars represent the range of suitable spawning habitat, taking velocity into account, that occur between the gage readings of 2.5 ft., 3.1 ft, and 3.7 ft for each study site. The smaller the box, the less variance there is on the size of the available habitat. Note the Swanton Dam site.

The amount of habitat that is available, based on velocity between the gage readings of 2.5 and 3.7 equates to 0. At the Highgate Dam site, there is also little variance in the amount of substrate available for lake sturgeon between the three gage readings. However, the Highgate Dam site was markedly different than the Swanton Dam site in the total amount of available habitat. A higher range of water elevations suitable for walleye and lake sturgeon spawning occurs above Swanton Dam. Based on the parameters identified in McMahon's model, the Highgate Dam site was the most suitable Missisquoi River location for spawning walleye from Lake Champlain

Removal of the spawning barrier at the Swanton Dam site would increase the distance a larvae must drift to feeding sites by 7 miles. A fish can survive for approximately 5 days after hatching on the nutrients in its yolk sac (Li and Mathias, 1982). Increasing the amount of spawning area, without considering fry survival, would not benefit the walleye or the lake sturgeon in Lake Champlain. However, based on our calculated flows and distance, the time of drift for fry would increase an additional 3-8 hours if they hatched at Highgate Dam. Therefore, we can conclude that the fry from the Highgate Dam site would have essentially the same probability of getting to the Lake Champlain's food source (Hawes *et al.*, 1998) as fry hatching at the Swanton Dam site

This study evaluated the benefits of spawning substrates above the Swanton Dam, primarily in the location below the Highgate Dam. We focused on the historic range of migration for spawning Lake Champlain walleye and lake sturgeon. This study did not address the physical or biological changes that would be associated with modifications that would allow fish to bypass the existing Swanton Dam barrier. It is conceivable that removal of the barrier could affect flows, temperature, and substrate deposition patterns. In addition, the introduction of new organisms above the dam, such as sea lamprey, could reduce the benefits of the habitat improvements. Future studies should be conducted to examine the biotic and abiotic factors involved before future actions are conducted.

Figure 5A: The range of available spawning habitat for walleye in six locations in the Missisquoi River. The amount of habitat is based on USGS gage levels from 2.5 to 3.7 ft which are correlated to velocities suitable for walleye spawning.

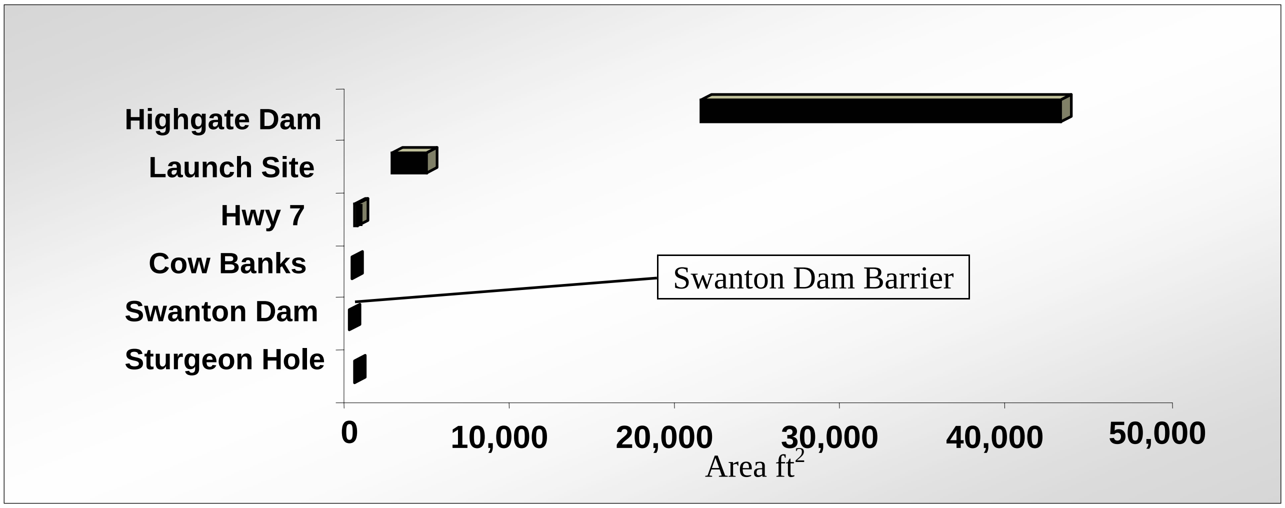
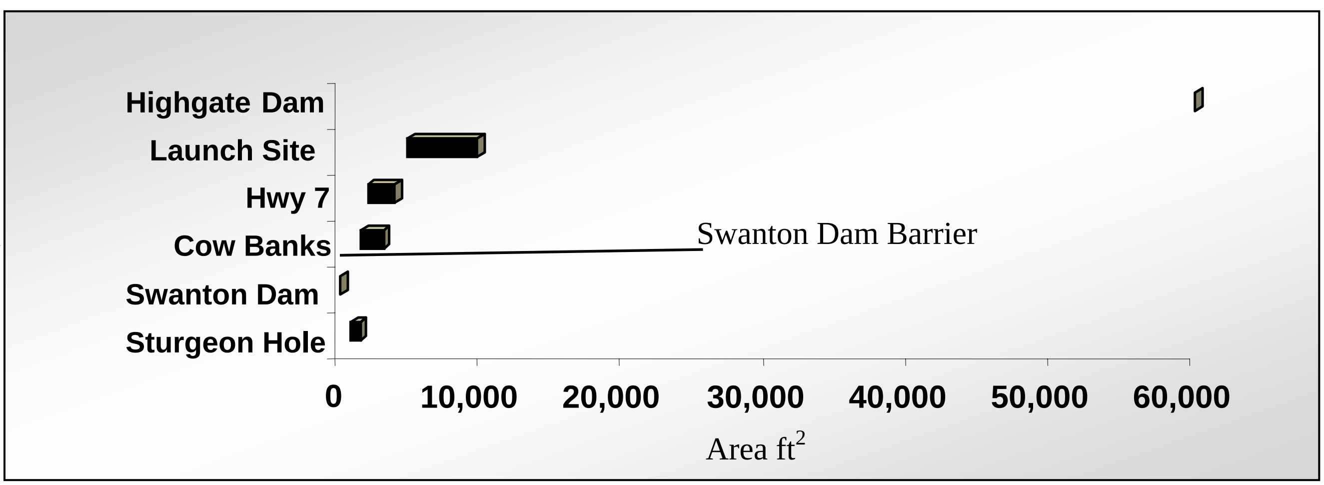


Figure 5B: The range of available spawning habitat for lake sturgeon in six locations in the Missisquoi River. The amount of habitat is based on USGS gage levels from 2.5 to 3.7 ft which are suitable for lake sturgeon spawning.



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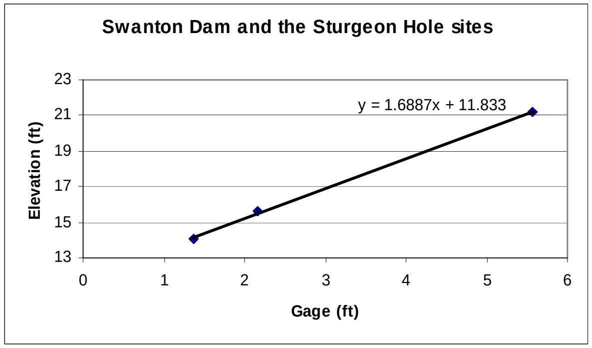
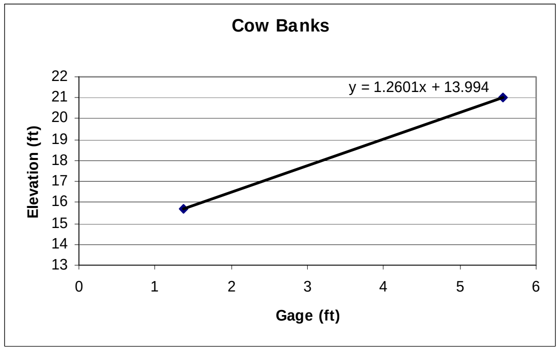
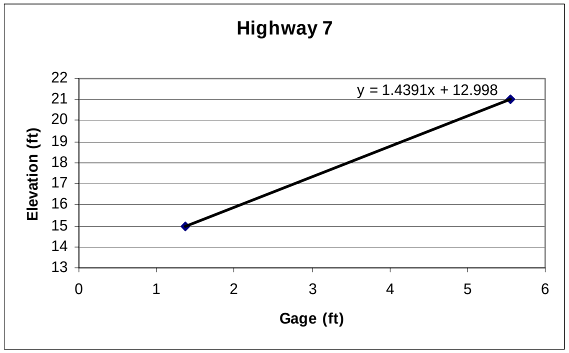
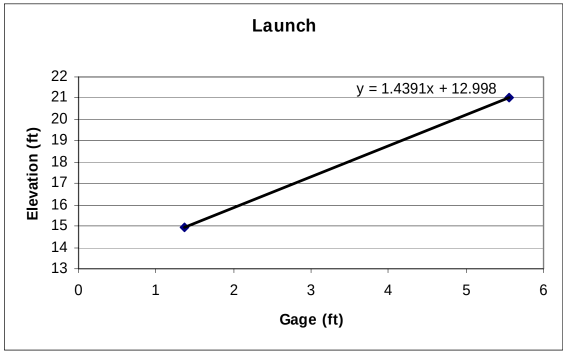
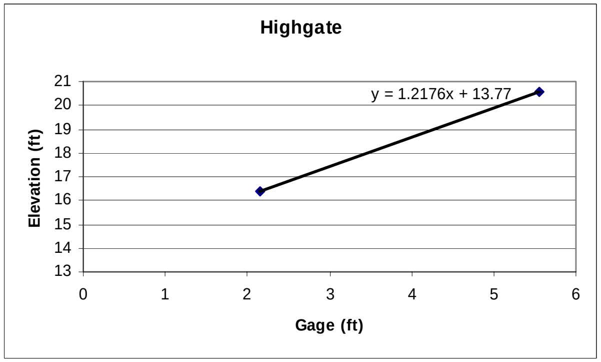
Appendix 1: Regression curves for the potential walleye and lake sturgeon spawning locations in the Missisquoi River. The regressions were formulated by correlating water elevations at various flow conditions with the gage and discharge readings from the USGS.











Appendix 2: Comparison of available spawning substrate for six locations in the Missisquoi River, VT.

Sturgeon Hole site: The available spawning habitat at different gage levels based on substrate, depths and average velocities. The suitability of the spawning habitat is based on substrate, depth, and flows.

Gage (ft)	spawning substrate (ft^2)	Walleye spawning Area (ft^2) based on depth and substrate.	Lake Sturgeon Spawning Area (ft^2) based on depth and substrate.	Total area (ft^2) for walleye with appropriate substrate, depths and flows.	Total area for lake sturgeon with appropriate substrate, depths, and flows.
1.3	660	455	660	0	0
1.9	672	410	672	0	0
2.5	686	178	686	178	686
3.1	698	126	698	126	698
3.7	710	21	710	21	710
4.3	722	29	722	29	722
4.9	722	22	722	22	0
5.4	722	22	722	22	0

Swanton Dam site: The available spawning habitat at different gage levels based on substrate, depths and average velocities. The suitability of the spawning habitat is based on substrate, depth, and flows.

Gage (ft)	Spawning substrate (ft^2)	Walleye spawning area (ft^2) based on depth and substrate	Lake sturgeon spawning area (ft^2) based on depth and substrate.	Total area (ft^2) for walleye with appropriate substrate, depths and flows.	Total area for lake sturgeon with appropriate substrate, depths, and flows.
1.3	112,200	54,978	112,200	0	0
1.9	147,950	109,483	147,950	0	0
2.5	159,500	145,145	159,500	0	0
3.1	166,650	171,804	166,650	0	0
3.7	179,300	164,956	179,300	0	0
4.3	185,900	76,219	185,900	0	0
4.9	191,400	49,764	191,400	0	0
5.4	197,450	41,465	197,450	0	0

Cow Bank site: The available spawning habitat at different gage levels based on substrate, depths and average velocities. The suitability of the spawning habitat is based on substrate, depth, and flows.

Gage (ft)	Spawning substrate (ft^2)	Walleye spawning area (ft^2) based on depth and substrate	Lake sturgeon spawning area (ft^2) based on depth and substrate.	Total area (ft^2) for walleye with appropriate substrate, depths and flows.	Total area for lake sturgeon with appropriate substrate, depths, and flows.
1.3	1,435	158	1,435	0	0
1.9	1,458	29	1,458	0	0
2.5	1,470	15	1,470	0	0
3.1	1,485	15	1,485	15	1,485
3.7	1,505	30	1,505	30	1,505
4.3	1,515	45	1,515	45	1,515
4.9	1,535	15	1,535	15	1,535
5.4	1,545	15	1,545	0	0

Hwy 7 site: The available spawning habitat at different gage levels based on substrate, depths and average velocities. The suitability of the spawning habitat is based on substrate, depth, and flows.

Gage (ft)	Spawning substrate (ft^2)	Walleye spawning area (ft^2) based on depth and substrate	Lake sturgeon spawning area (ft^2) based on depth and substrate.	Total area (ft^2) for walleye with appropriate substrate, depths and flows.	Total area for lake sturgeon with appropriate substrate, depths, and flows.
1.3	2,100	1,617	2,100	0	0
1.9	2,148	1,289	2,019	0	0
2.5	2,184	939	1,878	0	0
3.1	2,214	244	1,904	244	1,904
3.7	2,232	246	1,875	246	1,875
4.3	2,292	183	1,421	183	1,421
4.9	2,382	238	1,405	238	1,405
5.4	2,400	192	1,296	192	1,296

Launch site: The available spawning habitat at different gage levels based on substrate, depths and average velocities. The suitability of the spawning habitat is based on substrate, depth, and flows.

Gage (ft)	Spawning Substrate (ft²)	Walleye spawning area (ft²) based on depth and substrate	Lake sturgeon spawning area (ft²) based on depth and substrate.	Total area (ft²) for walleye with appropriate substrate, depths and flows.	Total area for lake sturgeon with appropriate substrate, depths, and flows.
1.3	4,032	3,145	3,790	0	0
1.9	4,242	3,182	4,242	3,182	4,242
2.5	4,452	2,449	4,452	2,449	4,452
3.1	4,683	2,576	4,683	0	0
3.7	4,893	2,055	4,893	0	0
4.3	5,166	1,705	5,166	0	0
4.9	5,397	1,673	5,397	0	0
5.4	5,544	1,275	5,544	0	0

Highgate Dam site: The available spawning habitat at different gage levels based on substrate, depths and average velocities. The suitability of the spawning habitat is based on substrate, depth, and flows.

Gage (ft)	Spawning Substrate (ft²)	Walleye spawning area (ft²) based on depth and substrate	Lake sturgeon spawning area (ft²) based on depth and substrate.	Total area (ft²) for walleye with appropriate substrate, depths and flows.	Total area for lake sturgeon with appropriate substrate, depths, and flows.
1.3	201,498	86,644	201,498	0	0
1.9	203,863	46,888	203,863	0	0
2.5	207,647	24,918	207,647	0	0
3.1	211,904	21,190	211,904	21,190	211,904
3.7	215,688	21,569	215,688	21,569	215,688
4.3	219,472	21,947	219,472	21,947	219,472
4.9	223,729	8,949	223,729	8,949	223,729
5.4	227,513	18,201	227,513	18,201	227,513