Great Lakes Fish and Wildlife Restoration Act

FINAL Project Report

***Project Title:** Poor Quality of Spawning Habitat: A Serious Impediment to Cisco Rehabilitation in the Great Lakes?

***Project Sponsor:** US Fish and Wildlife Service

***FWS Agreement Number:** # 30181-8-G016

***Principal Investigator(s):** Charles P. Madenjian and Edward S. Rutherford

***Report Author(s):** Charles Madenjian, Edward Rutherford, Jeff Elliott, Bryan Sederberg, and Marc Blouin

***Date Submitted: 03/29/11**

Study Objectives:

1. Measure water quality conditions in lower Green Bay and at the St. Marys River site during winter months.
2. Determine the duration and geographic extent of hypoxic conditions in lower Green Bay and at the St. Marys River site.
3. Compare overwinter survival of cisco eggs in replicated chambers in lower Green Bay with those at the St. Marys River site and under controlled laboratory conditions.
4. Determine whether sediment ATP concentration is an accurate predictor of winter DO conditions.

5. Map water quality and suitability of historic and current cisco spawning habitats in Green Bay and at the St. Marys River site.

Description of Tasks:

Task 1: Measure water quality conditions in lower Green Bay and at the St. Marys River site during winter months.

Task 2: Determine the duration and geographic extent of hypoxic conditions in lower Green Bay and at the St. Marys River site.

Task 3. Compare overwinter survival of cisco eggs in replicated chambers in lower Green Bay with those at the St. Mary's River site and under controlled laboratory conditions.

Task 4: Determine whether sediment ATP concentration is an accurate predictor of winter DO conditions.

Task 5: Map water quality and suitability of historic and current cisco spawning habitats in Green Bay and at the St. Marys River site.

Major findings and accomplishments:

Our major findings for Tasks 1-3 and 5 were reported earlier in annual project reports for 2009 and 2010, and are included in a separate manuscript intended for submission to a peer reviewed journal Freshwater Biology after internal review within USGS-Great Lakes Science Center and NOAA Great Lakes Environmental Research Laboratory. Below we summarize major findings and accomplishments by individual task.

Task 1: Measure water quality conditions in lower Green Bay and at the St. Marys River site during winter months.

Task 2: Determine the duration and geographic extent of hypoxic conditions in lower Green Bay and at the St. Marys River site.

We measured water quality conditions at several sites in lower Green Bay and at a site in St. Marys River from January through March 2009 and January-February 2010 (Figure 1). In lower Green Bay during winter 2009, we conducted water quality surveys monthly on 21-22 January, 20-21 February, and 14-15 March. In 2010, we conducted water quality surveys on 2 February and 24 February. Our trip to Green Bay to measure water quality in early March 2010 was aborted due to melting ice conditions. We sampled between 25 and 40 different sites in the lower bay during each one of these surveys in February and March of 2009 and February 2010. To sample a variety of bottom depths, we sampled sites using a zigzag pattern along the western and eastern sides of the lower bay. At each site, we drilled a hole through the ice using a gas-powered ice auger. We then slowly lowered a YSI model 6600 sonde by rope to the bottom, pausing for at least 10 s at 1-m depth intervals, and kept it at bottom for at least 60 s before retrieval. We programmed the sonde to record DO concentration (mg L^{-1}), water temperature (°C), specific conductivity (µS cm-1), pH and water depth (m) every 4 s. We used a GPS unit to mark the location of each sampling site. We used an airboat to conduct the first part of the survey on 20-21 February 2009. However, due to mechanical problems with the airboat, we opted to use snowmobiles to perform the remainder of the survey work during 2009 and both surveys during 2010. Due to a data recording problem with the sonde during 14-15 March 2009, water quality data were available for only the eastern side of lower Green Bay and just two sites on the western side for that particular survey of lower Green Bay. In addition to the above-mentioned survey work, on 22-23 January 2009 we also measured water quality conditions using the YSI model 6600 sonde at each of the six sites in lower Green Bay where we first introduced egg incubator chambers into lower Green Bay. We resampled water quality at these six sites during each of the winter water quality surveys in lower Green Bay and on 28 April 2009 when we removed the incubator chambers.

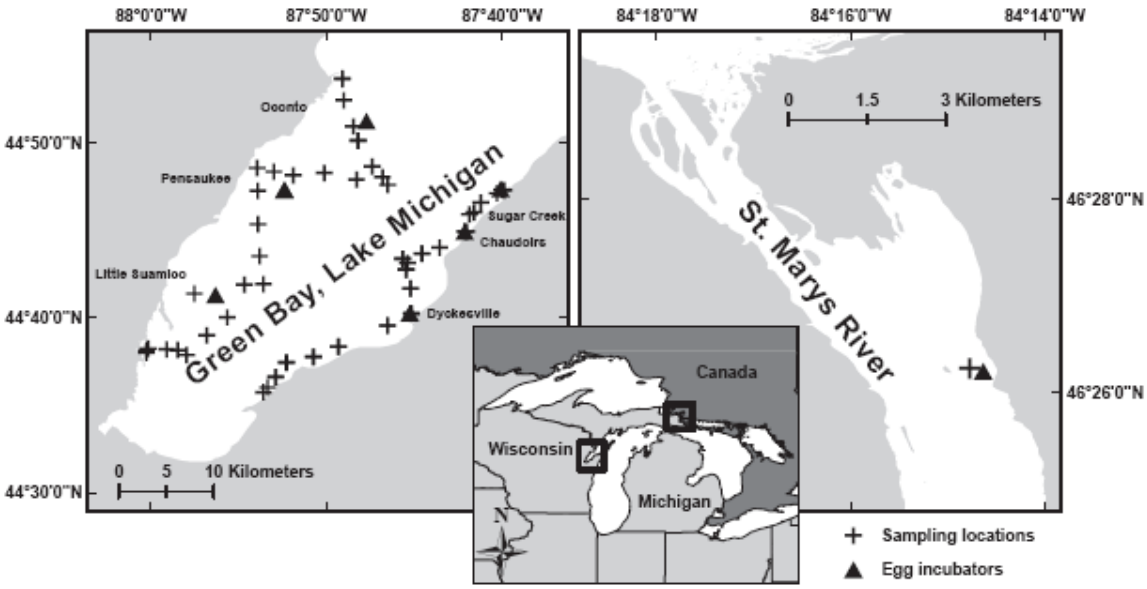

Figure 1. Study sites in Green Bay and St. Marys River for cisco (lake herring) egg survival experiments and water quality surveys during winter 2009 and 2010.

In the St. Marys River in 2009, we and our collaborator Dr. Geoffrey Steinhart (Lake Superior State University) measured water quality approximately every 2 weeks: 16 January, 29 January, 12 February, 26 February, 12 March, and 26 March. In 2010, Dr. Steinhart and his students measured water quality on 28 January, 12 February, and 22 February. At each site, we drilled a hole through the ice with an ice auger, and slowly lowered the YSI 6600 sonde by rope to measure dissolved oxygen (mg L^{-1}), temperature (° C), specific conductivity (μ-siemens/cm^2), and pH at several depths from surface to bottom. We kept the sonde at bottom for at least 60 s before retrieving it.

Results indicated water quality was relatively good in both the St. Marys River and lower Green Bay in winter of both years. The water column was well mixed at most sites, with surface temperatures and oxygen concentrations similar to values at bottom. Dissolved oxygen

concentrations remained high through winter in Green Bay and St. Marys River (Table 1, Fig. 2). In Green Bay, DO concentrations at bottom averaged from 13.8 to 15.7 mg L^{-1} and remained well above the 2 mg L^{-1} level known to affect cisco larvae survival in the laboratory (Brooke and Colby 1980). Water temperatures averaged below 2 °C in March, but increased rapidly to 8 °C after ice-out in late April (Table 1). Average water column values for pH values ranged from 6.0 to 8.9 (2009 average = 7.8 ± 0.1; 2010 average = 8.0 ± 0.03), and values for conductivity ranged from 188 to 536 μ-siemens/cm^2 (2009 average = 370 ± 10 μ-siemens/cm^2; 2010 average = 354 ± 7 μ-siemens/cm^2). In the St. Marys River, bottom oxygen concentrations remained above 12.6 mg L^{-1} through March. Water temperatures remained below 1 °C from January through March, then climbed rapidly after ice out in late April. In 2009, the water column pH averaged 7.3 ± 0.1, while conductivity averaged 103 ± 45 μ-siemens/cm^2 (Table 1).

Table 1. Estimates of water quality variables (mean ± 2 s.e.) measured in lower Green Bay and St. Marys River from January-March 2009 and February 2010. Dissolved oxygen values are reported from near bottom while other water quality variables are average values for water column. Sample sizes (n) reflect number of stations and dates sampled in Green Bay, while only one station was sampled repeatedly in St. Mary's River. Mean depth of sites sampled in Green Bay = 5.3 ± 0.4 m; mean depth of St. Marys R. site = 5.0 m. 'n.d.' indicates no data were available.

Year/Area	Temp (° C)	Spec. Cond. (μ-siem/cm)	pH	Diss. Oxyg. (mg/L)
2009 – GB n=56	0.98 (0.07)	370 (10)	7.81 (0.07)	13.85 (0.27)
2009 – SMR n=6	<0.01 (0.12)	103 (45)	7.25 (0.11)	13.79 (0.28)
2010 – GB n=79	1.89 (0.09)	354 (7)	7.98 (0.03)	14.21 (0.13)
2010 – SMR n =3	0.2 (0.06)	n.d.	n.d.	15.68 (0.19)

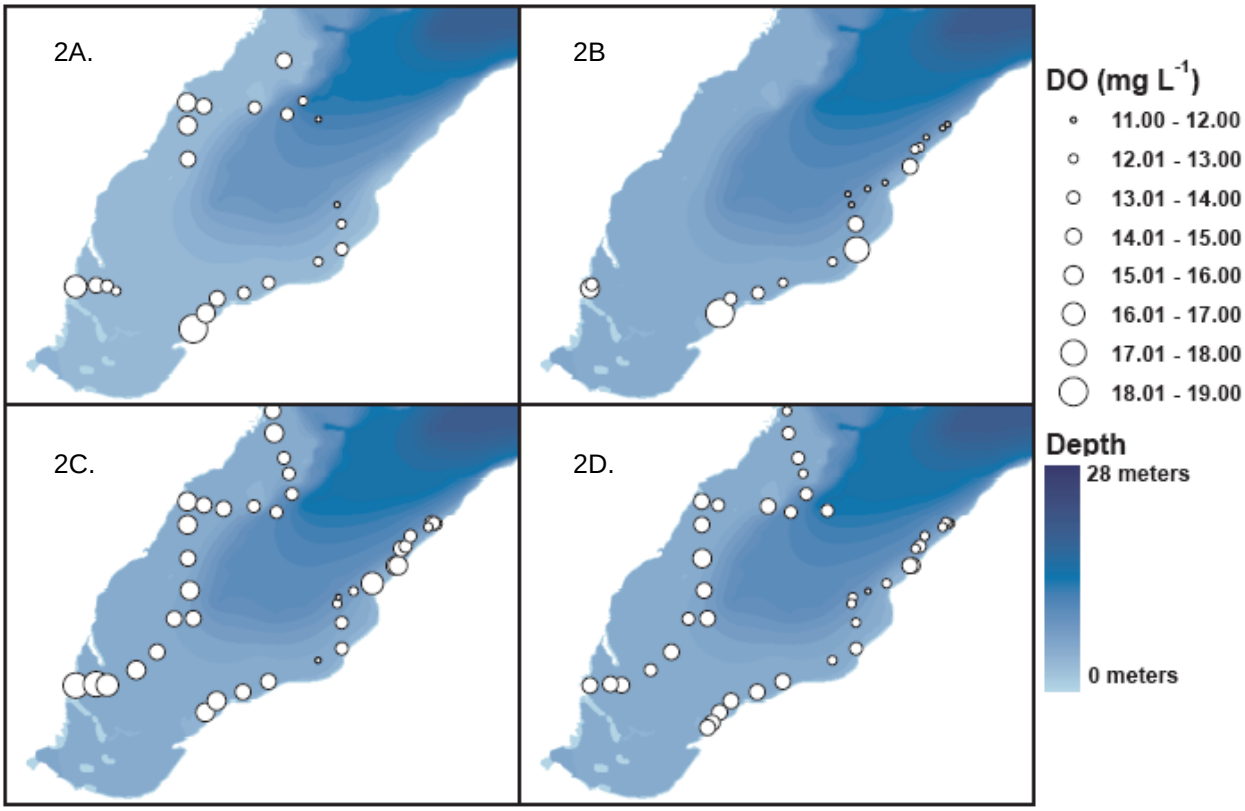

Figure 2. Dissolved oxygen concentrations (mg L^{-1}) on bottom in lower Green Bay during A. 20-21 February 2009, B. 14-15 March, 2009; C. 2 February, 2010; D. 24 February, 2010.

Task 3. Compare overwinter survival of cisco eggs in replicated chambers in lower Green Bay with those at the St. Marys River site and under controlled laboratory conditions.

In mid November 2008, cisco eggs were stripped by Michigan DNR personnel from 20 adult females in spawning condition near Sugar Island in the St. Marys River (Figure 1). After eggs were fertilized, they were brought back to the Wolf Lake State Fish Hatchery on 19 November where they incubated for several weeks in water temperatures of 3.3 °C. Fertilization success was 56%, and egg survival to the eye-up stage was approximately 76%. After the eggs eyed up around December 26th, we introduced them into our plexiglass egg incubator chambers (Manny

et al. 1989) at Wolf Lake on 15 and 21 January for placement into St. Marys River and Green Bay, respectively. We placed one fertilized cisco egg in each of 50 1-cm wells per incubator, and covered each incubator with 500-µm mesh Nitex screening to prevent egg predation. Eggs were held as control at Wolf Lake Hatchery. We transported the incubators to the study sites in coolers filled with ice water (3 °C). The eggs were held overnight at the Lake Superior State University Fish Hatchery in ambient river water (0.01 °C) before introducing them to the St. Marys River site (3 replicate incubators) on 16 January. On 21 January, we again loaded fertilized eggs into incubators at Wolf Lake State Fish Hatchery and drove them to Green Bay where we transported them to 6 sites (3 replicates/site = 18 incubators) via airboat from 22 to 23 January. At each site, we attached replicate (n=3) incubator chambers approximately 30 cm apart to a chain linked to a half-cement block. We drilled a hole in the ice, and dropped the set of incubators, half block and a marker buoy through the hole to the bottom. We marked the position of each incubator site and all water quality sites with a GPS unit. Marc Blouin and the USGS-GLSC Dive team helped us retrieve egg incubators on April 23 from the St. Marys River site and on April 28-29 from Green Bay sites. Data on egg survival were recorded the same day on the shore of St. Marys River or in at the US Fish and Wildlife Service laboratory in New Franken, WI. Egg survival was defined as the percentage of live eggs plus all fry from the total number of eggs (50) in an incubator. Egg survival also was monitored under controlled temperature (3.3 °C) and flow conditions at Wolf Lake Hatchery by MDNR personnel.

Egg survival in incubators was relatively good at all sites, and ranged from a low of 28% at Chaudoir in eastern Green Bay, to a high of 94% at Pensaukee in western Green Bay (Figure 3). Average egg survival across all sites was 65.1 ± 3.1%. Although most fry we found were dead, there were several fry still alive when the incubators were retrieved, but with yolk sacs re-absorbed, suggesting they had hatched from 1 to 3 weeks earlier. Average egg survival at the Green Bay sites was similar (average = 65.3 ± 3.7%) to egg survival at the St. Marys River site (average = 64.0 ± 3.1%). There was no significant difference in egg survival among sites (ANOVA, $F = 1.019$, d.f. = 20; $P>0.45$). Average survival at individual sites ranged from a high of 75 ± 4.4 % at Sugar Creek to a low of 56 ± 6.4 % at Chaudoir, which are both in the eastern Bay. There was no survival of eggs in one incubator chamber at Dyckesville, but this was an exception: the Nitex screen on the incubator was loose and the cells were filled with sand,

suggesting eggs may have slipped out. This incubator was treated as an outlier and excluded from statistical analysis and computation of mean survival.

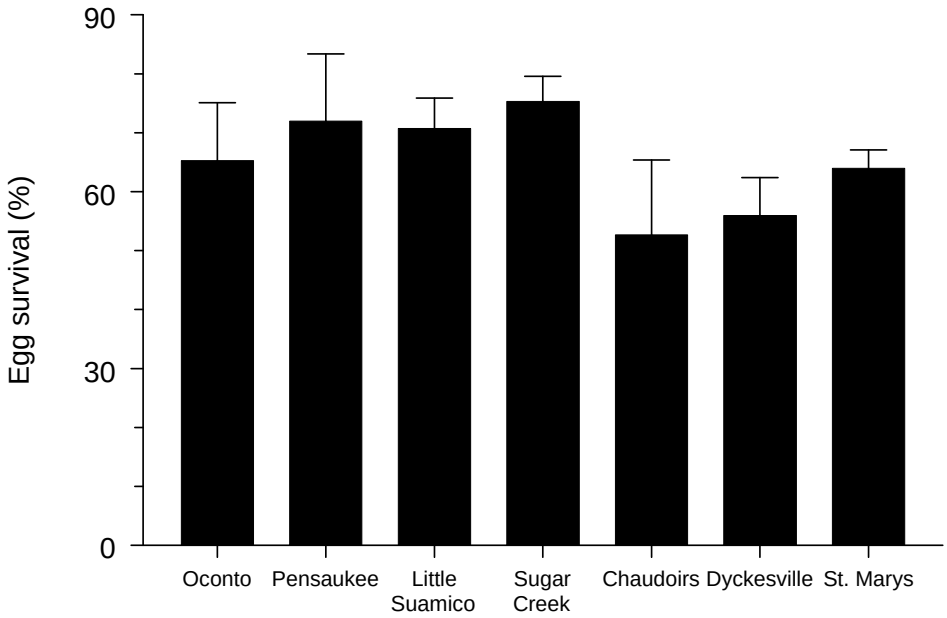

Figure 3. Mean survival (± s.e.) of lake herring eggs in incubation chambers placed on bottom at six sites in lower Green Bay and one site in St. Marys River from January to March 2009.

Results from our *in-situ* egg survival experiments were comparable to previous *in-situ* studies of cisco egg survival in St. Marys River. Savino et al. (1994) examined effects of winter shipping on cisco egg survival by placing incubators with fertilized eggs at several locations around Neebish Island, near Sugar Island in the St. Marys River. They found cisco egg survival was high, and averaged 75% compared to egg survival in our study of 64.0%. Methods were similar in both studies. Estimates of cisco egg survival at Wolf Lake Fish Hatchery were 80% from eye-up to hatch, higher than in incubators placed in the St. Marys River and Green Bay.

During winter 2010 we were unable to obtain fertilized eggs from hatchery sources for replicating the egg incubator experiments. Cisco adults spawned earlier than expected in November 2009 leaving few fertilized eggs for rearing. We contacted resource agencies in

Minnesota and Wisconsin who had eggs, but could not have the eggs tested for presence of VHS in enough time for us to conduct the survival experiments.

Otolith increments have been validated as a measure of age for cisco larvae (Oyadomari and Auer 2007). We used otoliths to determine ages of cisco larvae that had hatched in our incubator chambers left in-situ in Green Bay during winter and early spring 2009. The relationship between fish age and otolith diameter was positive and significant (R^2=0.54, P<0.05) (Fig. 4). The average age of 9 cisco larvae was 37 ± 2 days (range 32-42 days), while the average length of 29 larvae was 11.4 ± 0.7 mm TL (range 9.3-17.3 d). These results suggested that cisco larvae hatched in our incubators at least 1 month before we retrieved them during 28-29 April 2009, or approximately on 24 March 2009.

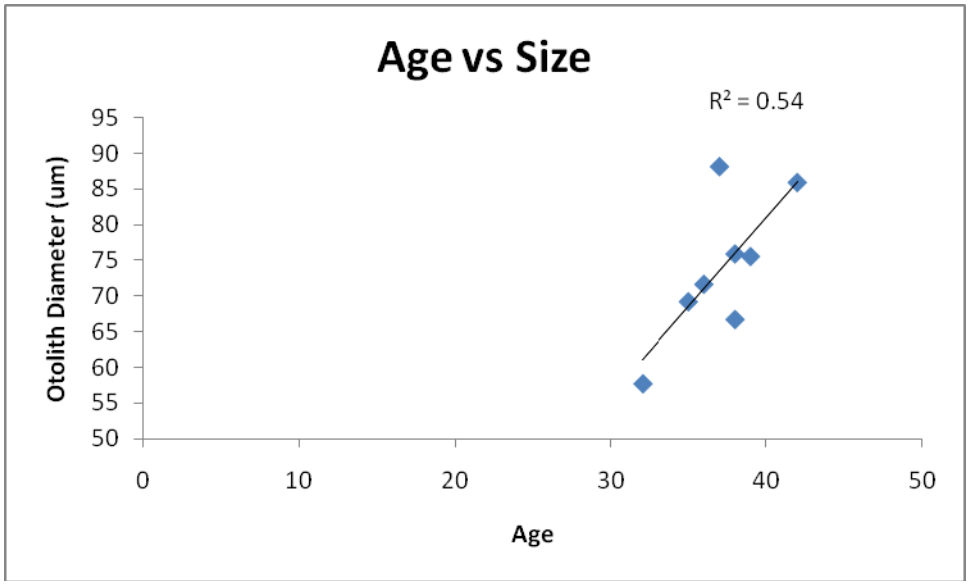

Figure 4. Age (days) vs diameter (µm) of otoliths from cisco larvae surviving in incubator chambers left in-situ in southern Green Bay during winter 2009.

Task 4: Determine whether sediment ATP concentration is an accurate predictor of winter DO conditions.

To investigate the use of ATP concentration as an accurate predictor of winter DO conditions, we met with several scientists who routinely measure dissolved oxygen content in lake or terrestrial sediments using microbial assays or use microprobes. Each person we met suggested

using either a more updated microbial assay than the ATP assay or use a dissolved oxygen microprobe (Matisoff and Neeson 2005). We decided to use the assay reported by Saiya Cork et al. (2002) for measuring extracellular enzyme activity in terrestrial soil samples. On 26 August 2010, we collected sediment samples for microbial assays at 4 sites in lower Green Bay because our examination of recent studies by scientists at Lawrence University and Univ. Wisconsin Milwaukee suggested sediments would be anoxic during this time. We collected replicate samples (n=3) of substrate in capped PVC tubes using SCUBA at each of 4 sites in lower Green Bay. We successfully obtained the sediments, but found that no site had hypoxic DO concentrations <2 mg L^{-1}. The lowest DO concentration sampled was 3.7 mg L^{-1}, and the other samples were taken at sites with DO concentrations > 4.7 mg L^{-1}. Since we were not able to obtain sediment samples from hypoxic or anoxic sediments, we decided not to try the Saiya-Cork et al. (2002) assay. In future we hope to evaluate this assay with sediments from Lake Erie's central basin which regularly experiences hypoxia and with sediments from Green Bay.

Task 5: Map water quality and suitability of historic and current cisco spawning habitats in Green Bay and at the St. Marys River site.

We reviewed and mapped several years of historic and current data on water quality in Green Bay. Overwinter bottom DO concentrations of less than 2 mg L^{-1} were frequently observed in lower Green Bay during the 1950s and 1960s (Figure 5) (Epstein *et al.*, 1974). Moreover, bottom DO concentrations of 0 mg L^{-1} were recorded at several locations in the lower bay during this time period. In contrast, the lowest bottom DO concentration observed in lower Green Bay during the winters of 2009 and 2010 was 11.2 mg L^{-1} (Figure 2). Epstein *et al.* (1974) attributed the low overwinter DO conditions on the bottom of lower Green Bay during 1938-1967 primarily to effluent from the pulp and paper industries located along the Fox River, the main tributary to Green Bay. The BOD of this effluent was unusually high (Epstein *et al.*, 1974; Harris *et al.*, 1982). During the early 1970s, new processing plants were built to treat this effluent (Harris *et al.*, 1982). Therefore, we propose that the operation of these treatment plants, beginning in the early 1970s, led to the huge improvement in overwinter water quality of lower Green Bay between 1967 and 2009.

Although low DO conditions in lower Green Bay during the winter apparently no longer

occur, low DO conditions in lower Green Bay during July and August do still occur. Bottom DO concentration less than 2 mg L^{-1} in lower Green Bay was observed on 6 August 2007 (Figure 6) (B. DeStasio, Lawrence University, Appleton, WI, U.S.A., personal communication). Similarly, low DO concentrations in lower Green Bay during summer months have been observed by researchers from two other agencies during the past five years as well (J. Kennedy, Green Bay Metropolitan Sewerage District, Green Bay, WI, U.S.A., personal communication; V. Klump, University of Wisconsin-Milwaukee, Milwaukee, WI, personal communication). Apparently, eutrophication still leads to low DO conditions in lower Green Bay during the summer, although the eutrophication problem was substantially more severe during the 1960s than it is today. Perhaps the persistence of low DO conditions during the summer months has continued to prevent the recovery of burrowing mayflies in lower Green Bay.

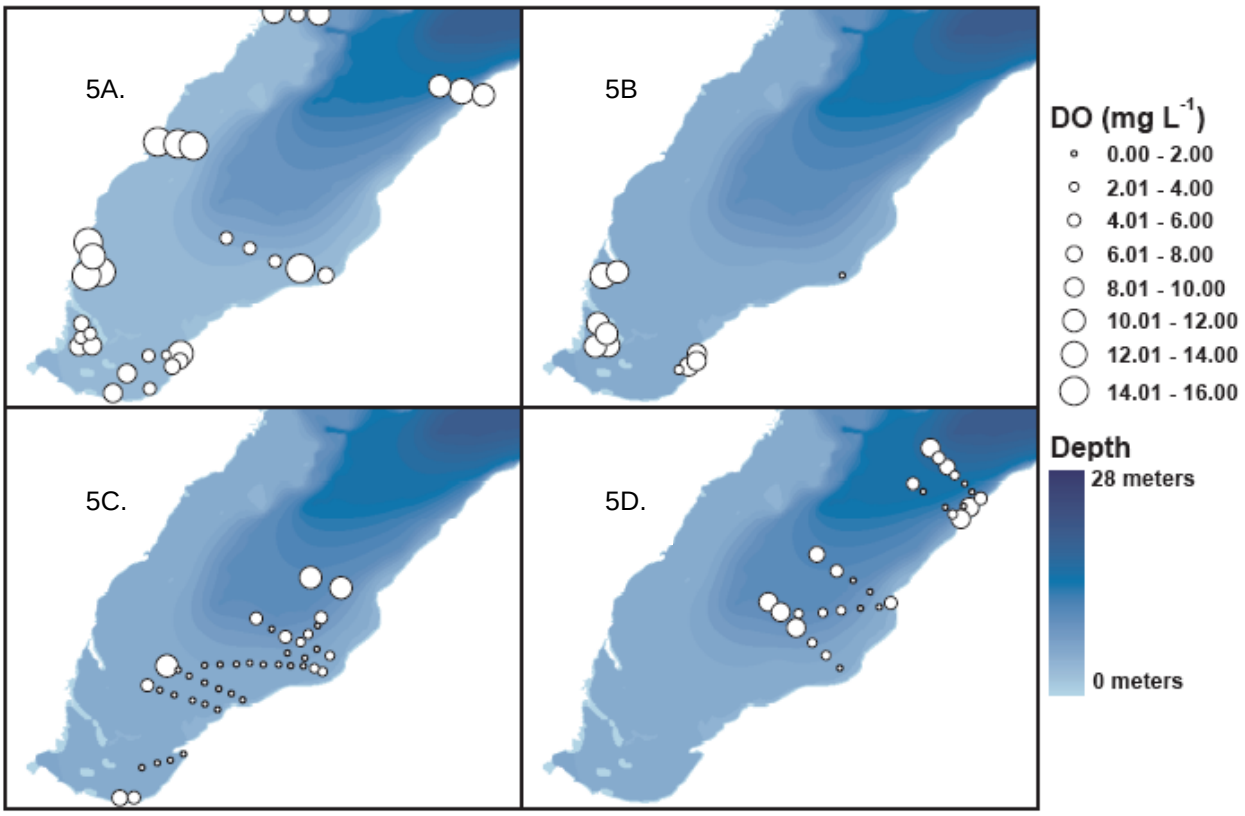

Figure 5. Dissolved oxygen concentrations (mg L^{-1}) measured on bottom in lower Green Bay during A. 9-10 February 1966; B. 10 March, 1966; C. 8-10 February 1967; and D. 9-10 March, 1967.

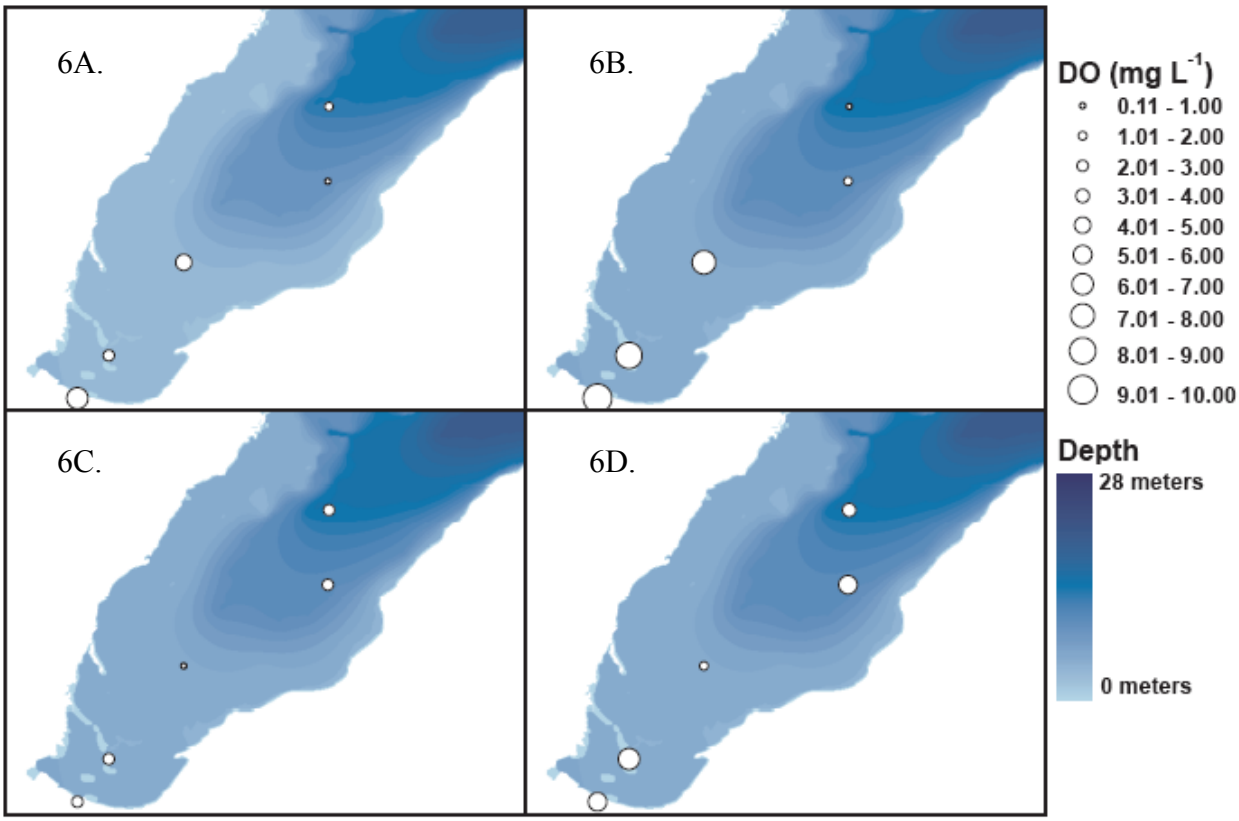

Figure 6. Dissolved oxygen concentrations (mg L^{-1}) measured on bottom in lower Green Bay during A. 1 August 2006; B. 15 August 2006; C. 6 August 2007; and D. 24 August 1967.

Management implications of your work:

The management implications of our work are that efforts to improve water quality in Green Bay through nutrient reductions have worked. Dissolved oxygen concentrations in winter would now permit good survival of young lake herring and other fishes, thus improving suitability of spawning and nursery habitats. Thus, management efforts now underway to restore lake herring would not go to waste given that environmental conditions are now suitable.

Additional restoration work needed and/or areas for future research:

1. Based upon results of our work, we recommend conducting additional measurements of water quality and habitat suitability in lake herring spawning and nursery areas during winter. These areas include Saginaw Bay Lake Huron and other areas of Lake Erie and Lake Ontario (Hamilton Harbor) where lake herring used to spawn.

2. Given the improved condition of lake herring spawning grounds in Green Bay, we suggest future restoration efforts include stocking to re-establish cisco populations in Green Bay and perhaps Saginaw Bay. Our water quality surveys indicated water quality conditions in Green Bay are sufficient to support growth and survival of cisco eggs and newly hatched fry. It would be necessary to stock sufficient numbers of juvenile lake herring over an extended period of time to re-establish a naturally reproducing spawner population. Annual recruitments in wild populations of lake herring are highly variable, thus extending the time needed to restore lake herring.

3. We also believe it would be fruitful to use nutrient loadings models to predict dissolved oxygen concentration in lake herring nursery habitats during winter in Green Bay and Saginaw Bay. The EPA report by Epstein et al. (1974) reported results from such a model, and efforts are ongoing to develop such models to predict hypoxia in Green Bay and Lake Erie. Such models would improve our ability to predict suitable habitat conditions for lake herring reproduction.

Literature Cited:

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Harris, H.J., Talheim, D.R., Magnuson, J.J., & Forbes, A.M. 1982. Green Bay in the future - a rehabilitative prospectus. Great Lakes Fishery Commission Technical Report No. 38, Ann Arbor.

Manny, B.A., Jude, D.J. & Eshenroder, R.L. 1989. Field test of a bioassay procedure for assessing habitat quality on fish spawning grounds. *Transactions of the American Fisheries Society,* **118,** 175-182.

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Savino, J.F., Blouin, M.A., Davis, B.M., Hudson, P.L., Todd, T.N. & Fleischer, G.W. 1994. Effects of pulsed turbidity and vessel traffic on Lake herring eggs and larvae. *Journal of Great Lakes Research,* **20,** 366-376.

List of presentations delivered and outreach activities:

We have made several presentations of our work. Please see below:
Presentations at Regional Meetings and Workshops:

March 2009 - Michigan Chapter of American Fisheries Society in Dundee, Michigan
January 2010 – Michigan Sea Grant Regional Fishery Workshop, Ludington, MI.

Reports at Lake Technical Committee Meetings:

- July 2009, Lake Michigan Technical Committee in Peshtigo, WI.
- January 2010, Lake Huron Technical Committee in Port Huron, MI.

***Include relevant pictures or images associated with the project:**
Several images of our field work have been submitted separately as jpg files. With this report we include others not sent before.

Geographic region project occurred in or effects:
Basically, we sampled much of lower Green Bay and one site on St. Marys River. The coordinates for specific sample sites are listed in an appendix table.

***List of reports and peer-reviewed papers completed or in-progress:** *Please attach copies of all completed reports and papers related to this work. Also, please remember to acknowledge funding support from the U.S. Fish and Wildlife Service through the Great Lakes Fish and Wildlife Restoration Act in publications, reports, presentations etc. that result from this work.*

Attached is a copy of a manuscript we will submit in 2-3 weeks for peer review in the journal Freshwater Biology which describes the work conducted on this study and its implications for lake herring restoration. In this paper, we acknowledge funding from US Fish and Wildlife Service through the Great Lakes Fish and Wildlife Restoration Act.

ACKNOWLEDGEMENTS

We greatly appreciate advice and assistance from Martha Wolgamood of MDNRE Wolf Lake State Fish Hatchery. We received able field assistance from the USGS-GLSC Dive team (Marc Blouin; from graduate students Bryan Sederberg and Michael Fainter (University of Michigan) , and from Dr. Geoffrey Steinhart and his students at Lake Superior State University who sampled water quality in St. Mary's River during late January, February and March. We received GIS assistance from Christine Joseph (University of Michigan). We appreciate storage space and logistical support from US Fish and Wildlife Service Laboratory in New Franken, Wisconsin.

Appendix Table 1A. Water quality parameters measured at surface and bottom at sites in lower Green Bay River in 22-23 January, 2009. Variables include dissolved oxygen (D.O., mg/L), pH, temperature (Temp, ° C), and specific conductivity (Sp. Cond., μ-siemens/cm^2).

Station	Depth (m)	D.O.	pH	Temp	Sp. Cond.
Oconto[1]	surface	14.03	6.70	-0.06	188
	5.5m	13.65	6.66	0.65	189
Pensaukee	Surface	14.27	7.07	0.00	362
	3.1	13.16	6.83	1.42	418
Pensaukee[1]	Surface	14.34	7.09	-0.02	289
	4.3	13.12	7.29	0.25	330
L. Suamico[1]	Surface	14.07	7.27	0.01	356
	5.0	14.23	7.21	0.32	327
L. Suamico	Surface	14.44	7.47	0.00	381
	3.7	13.37	7.47	1.50	393
Sugar Creek[1]	Surface	13.20	6.0	-0.05	299
	7.1	12.93	6.3	0.39	315
095	Surface	14.42	6.3	-0.03	244
	5.5	13.13	6.7	0.05	255
096	Surface	14.33	7.0	-0.04	216
	2.3	14.38	6.9	0.02	324
Chaudoir[1]	Surface	14.70	7.3	-0.02	305
	3.9	14.52	7.3	0.15	323
098	Surface	14.34	7.7	0.02	351
	3.2	14.84	7.3	0.17	348
Dyckesville[1]	Surface	14.39	7.7	-0.08	352
	4.4	13.90	7.6	0.94	350

[1]Incubator Sites

Appendix Table 1B. Water quality parameters measured at surface and bottom at sites in lower Green Bay River in 20-21 February, 2009. Variables include dissolved oxygen (D.O., mg/L), pH, temperature (Temp, ° C), and specific conductivity (Sp. Cond., μ-siemens/cm^2).

Station	Depth (m)	D.O.	pH	Temp	Sp. Cond.
022	Surface	15.04	6.9	-0.28	405
	5.8	14.70	7.2	0.82	507
023	Surface	15.92	7.7	0.01	419
	4.5	15.49	7.6	0.72	489
025	Surface	19.3	7.9	-0.02	493
	0.6	18.8	7.6	0.70	480
026	Surface	14.96	6.9	-0.60	480
	5.0	13.99	7.5	0.70	526
027	Surface	14.97	7.6	-0.32	273
	6.0	13.51	7.6	0.69	527
028	Surface	14.90	7.6	-0.63	327
	6..9	12.14	7.7	1.09	536
029	Surface	15.12	7.9	-0.12	234
	4.1	13.65	7.8	1.28	443
030	Surface	15.32	7.4	-0.61	280
	7.3	12.48	7.8	0.97	507
031	Surface	15.14	7.6	-0.56	310
	8.9	11.67	7.7	1.12	529
064	Surface	13.22	8.0	0.38	285
	0.6	14.27	7.9	0.55	284
066	Surface	13.54	8.0	0.27	280
	5.2	14.81	7.9	0.30	279
067	Surface	14.01	8.1	0.10	268
	13.6	12.36	7.9	0.81	274
068	Surface	14.11	8.2	0.07	267
	12.6	11.83	7.9	1.00	283
069	Surface	14.42	8.2	0.05	251
	12.9	13.16	8.0	0.95	282
070	Surface	13.94	8.1	0.14	264
	7.1	13.42	8.1	0.39	270
071	Surface	14.81	8.2	0.10	280
	3.1	14.14	8.0	1.66	337
072	Surface	15.44	8.2	0.08	267
	1.1	15.18	8.2	0.95	286
073	Surface	14.98	8.2	0.01	275
	2.3	15.26	8.2	1.34	286
074	Surface	14.69	8.2	0.07	250
	5.0	14.88	8.2	1.27	289
077	Surface	16.20	8.3	-0.09	297
	0.2	16.27	8.3	-0.04	297
078	Surface	15.97	8.2	-0.05	272

	3.5	14.96	8.2	2.0	358
080	Surface	15.05	8.3	0.03	303
	3.8	13.33	8.1	1.79	352
081	Surface	14.58	8.3	0.07	322
	4.1	12.98	8.1	1.7	351

Appendix Table 1C. Water quality parameters measured at surface and bottom at sites in lower Green Bay River in 14-15 March, 2009. Variables include dissolved oxygen (D.O., mg/L), pH, temperature (Temp, ° C), and specific conductivity (Sp. Cond., μ-siemens/cm^2).

Station	Depth (m)	D.O.	pH	Temp	Sp. Cond.
034	Surface	12.71	8.0	0.27	272
	6.8	11.97	7.8	0.68	292
035	Surface	12.87	8.0	0.41	261
	7.4	11.54	7.7	0.76	303
036	Surface	13.44	8.2	0.54	265
	8.4	11.67	7.8	0.94	318
037	Surface	13.94	8.1	0.62	231
	8.1	12.45	7.8	0.91	335
038	Surface	13.28	8.2	0.50	270
	6.6	12.41	7.9	0.79	304
039	Surface	13.98	8.3	0.71	270
	4.5	14.12	8.2	0.89	281
040	Surface	13.27	8.3	0.51	286
	6.6	11.57	8.0	1.45	336
041	Surface	13.79	8.4	0.65	268
	9.2	11.62	8.0	1.63	393
042	Surface	13.24	8.2	0.48	269
	9.5	11.18	8.0	1.57	391
043	Surface	13.85	8.4	0.10	270
	9.0	11.86	8.0	1.62	400
044	Surface	14.49	8.4	0.86	296
	7.5	11.86	8.1	1.13	408
045	Surface	14.98	8.5	1.31	289
	3.6	17.61	8.5	1.51	327
046	Surface	13.70	8.3	1.88	255
	7.0	12.12	8.0	1.48	416
047	Surface	13.79	8.4	1.31	307
	6.3	12.86	8.0	1.05	428
048	Surface	14.32	8.5	0.90	355
	5.3	13.14	8.1	1.04	429
049	Surface	15.45	8.5	0.65	405
	6.2	13.81	8.2	0.96	437
050	Surface	14.92	8.6	0.84	419

	4.9	18.46	8.6	1.17	429
054	Surface	16.72	8.8	1.14	417
	0.7	22.32	8.9	1.52	418
055	Surface	12.60	8.2	0.58	373
	1.6	13.33	8.3	1.46	384
056	Surface	13.82	8.3	0.63	402
	2.2	15.93	8.4	2.46	408

Appendix Table 1D. Water quality parameters measured at surface and bottom at sites in lower Green Bay River in 28-29 April, 2009. Variables include dissolved oxygen (D.O., mg/L), pH, temperature (Temp, ° C), and specific conductivity (Sp. Cond., μ-siemens/cm^2).

Station	Depth (m)	D.O.	pH	Temp	Sp. Cond.
Oconto[1]	Surface	11.19	8.0	6.68	294
	5.8	12.28	8.2	6.23	297
Pensaukee[1]	Surface	11.48	7.9	8.6	288
	5.8	11.96	8.3	8.1	290
L. Suamico[1]	Surface	12.79	8.3	7.9	293
	5.0	12.34	8.3	7.6	294
Sugar Creek[1]	Surface	12.46	8.4	7.68	316
	8.0	12.38	8.5	7.70	314
Chaudoir[1]	Surface	12.32	8.4	8.35	328
	4.7	12.27	8.4	8.29	327
Dyckesville[1]	Surface	11.74	8.1	8.19	321
	5.4	11.88	8.2	8.49	318

[1]Incubator Sites

Appendix Table 2. Water quality parameters measured at surface and bottom near Sugar Island, St. Mary's River from January to March 2009. Variables include dissolved oxygen (D.O., mg/L), pH, temperature (C), and specific conductivity (micro-siemens/cm2).

Date	Depth	D.O.	pH	Temperature	Sp. Cond.
16-Jan	surface	14.48	6.27	-0.04	103
	bottom	14.12	6.89	0.03	103
29-Jan	surface	13.75	7.81	-0.21	104
	bottom	13.58	7.56	-0.2	104
12-Feb	surface	13.39	7.79	-0.16	104
	bottom	14.35	7.41	-0.15	104
26-Feb	surface	13.45	7.45	-0.18	104
	bottom	13.55	6.94	-0.11	104
12-Mar	surface	13.04	8.2	-0.2	104
	bottom	12.66	7.33	-0.12	101
26-Mar	surface	14.47	7.88	0.06	103
	bottom	14.51	7.39	0.56	102

Appendix Table 3. Survival (%) of cisco eggs in incubator chambers at sites in Green Bay and St. Mary's River from mid-January to late April 2009.

Area	Site	Incubator #	Survival
Green Bay west	Oconto Shoals	4B	72
		5A	78
		3C	46
		Avg (± 1 s.e.)	65.3 ± 9.8
	Pensaukee	4D	56
		5B	94
		6B	66
		Avg (± 1 s.e.)	72.0 ± 11.4
	Little Suamico	1A	80
		1B	62
		3B	70
		Avg (± 1 s.e.)	70.7 ± 5.2
Green Bay east	Sugar Creek	2B	84
		5C	62
		6C	70
		Avg (± 1 s.e.)	75.3 ± 4.3
	Chaudoir	6A	28
		2A	60
		1C	70
		Avg (± 1 s.e.)	52.7 ± 12.7
	Dyckesville	2C	66
		3A	58
		*4A	0
		No Name	44
		Avg (± 1 s.e.)	56.0 ± 6.4
St. Mary's River	Near Sugar Island	1	62
		2	70
		3	60
		Avg (± 1 s.e.)	64.0 ± 3.1

*The mesh screen on this incubator was loose, and cells were filled with sand and gravel. Therefore it was dropped from further calculations of mean egg survival and ANOVA tests of survival among areas.

Appendix Table 4. Sample locations, dates, times (EDT), and depths (m) for water quality surveys in Green Bay and St. Mary's River, 2009. Incubators were placed in eastern Green Bay at Dyckesville, Chaudoir, Sugar Creek; and in western Green Bay at Little Suamico, Pensaukee and Oconto Shoals.

Month	Site	Date	Time	Lat. (dec. deg.)		Long. (dec. deg.)		Depth
Jan.	Dyckesville	23-Jan	11:37	44	40.239	87	45.254	5.5
	L Suamico	22-Jan	14:43	44	41.279	87	56.314	6.3
	Chaudoir	23-Jan	10:45	44	44.896	87	42.126	4.8
	Pensaukee	22-Jan	13:44	44	47.284	87	52.392	5.4
	Sugar Crk.	23-Jan	9:49	44	47.335	87	40.078	8
	Oconto	22-Jan	12:33	44	51.212	87	47.714	6.2
		22-Jan	13:20	44	48.309	87	52.988	3.6
	GB017	22-Jan	15:10	44	41.346	87	57.522	4.6
	GB095	23-Jan	10:15	44	47.256	87	39.871	6.7
	GB096	23-Jan	10:38	44	44.887	87	42.005	3.1
	GB098	23-Jan	11:30	44	40.218	87	45.147	4
Feb.	GB021	21-Feb	12:30	44	53.596	87	49.09	1.2
	GB022	20-Feb	11:28	44	37.423	87	52.238	6.3
	GB023	20-Feb	11:49	44	36.596	87	52.884	5.1
	GB025	20-Feb	12:22	44	35.716	87	53.59	0.9
	GB026	20-Feb	12:42	44	37.742	87	50.729	5.3
	GB027	20-Feb	13:03	44	38.324	87	49.319	6.8
	GB028	20-Feb	13:32	44	39.52	87	46.523	7.3
	GB029	20-Feb	14:06	44	40.225	87	45.178	4.8
	GB030	20-Feb	14:44	44	41.651	87	45.202	7.9
	GB031	20-Feb	15:08	44	42.736	87	45.452	8.4
	GB032	20-Feb	15:33	44	43.351	87	45.663	10
	GB033	20-Feb	15:52	44	43.641	87	44.561	9.7
	GB066	21-Feb	?	44	50.899	87	48.458	5.7
	GB067	21-Feb	13:18	44	48.614	87	47.381	5.3
	GB068	21-Feb	13:40	44	47.563	87	46.507	14.2
	GB069	21-Feb	14:02	44	47.864	87	48.272	14.3
	GB070	21-Feb	14:19	44	48.237	87	50.121	7.3
	GB071	21-Feb	14:40	44	48.31	87	52.993	3.7
	GB072	21-Feb	15:01	44	48.527	87	53.945	1.6
	GB073	21-Feb	15:18	44	47.227	87	53.913	2.9
	GB074	21-Feb	15:33	44	45.317	87	53.897	5.7
	GB077	21-Feb	16:30	44	38.105	88	0.249	1.1
	GB078	21-Feb	16:43	44	38.177	87	59.093	3.5
	GB080	21-Feb	16:57	44	38.127	87	58.465	4
	GB081	21-Feb	17:05	44	37.848	87	57.957	4
March	GB034	14-Mar	9:46	44	47.282	87	40.01	8.25
	GB035	14-Mar	10:08	44	47.068	87	40.283	8.25
	GB036	14-Mar	10:29	44	46.559	87	41.21	9.5
	GB037	14-Mar	10:55	44	45.985	87	41.576	9
	GB038	14-Mar	11:17	44	45.871	87	41.852	7
	GB039	14-Mar	11:44	44	44.902	87	42.132	6.75

	GB040	14-Mar	12:08	44	43.986	87	43.547	7.25
	GB041	14-Mar	13:26	44	43.627	87	44.538	9.7
	GB042	14-Mar	13:43	44	43.34	87	45.649	10.3
	GB043	14-Mar	13:56	44	42.738	87	45.444	9.6
	App. Table 4 (cont.)							
	GB044	14-Mar	14:12	44	41.649	87	45.201	8
	GB045	14-Mar	14:26	44	40.204	87	45.153	3.6
	GB046	14-Mar	14:41	44	39.518	87	46.52	7.3
	GB047	14-Mar	14:58	44	38.323	87	49.317	6.6
	GB048	14-Mar	15:11	44	37.744	87	50.732	5.5
	GB049	14-Mar	15:36	44	37.425	87	52.292	6.6
	GB050	14-Mar	15:50	44	36.594	87	52.893	5.2
	GB051	14-Mar	16:02	44	35.994	87	53.332	1
	GB055	15-Mar	9:00	44	38.227	88	0.152	1.6
	GB056	15-Mar	9:25	44	37.994	88	0.247	2.5
April	Dyckesville	28-Apr	15:42	44	40.239	87	45.254	5.5
	L Suamico	29-Apr	14:10	44	41.279	87	56.314	6.3
	Chaudoir	28-Apr	13:57	44	44.896	87	42.126	4.8
	Pensaukee	29-Apr	13:17	44	47.284	87	52.392	5.4
	Sugar Crk.	28-Apr	13:07	44	47.335	87	40.078	8
	Oconto	29-Apr	14:09	44	51.212	87	47.714	6.2