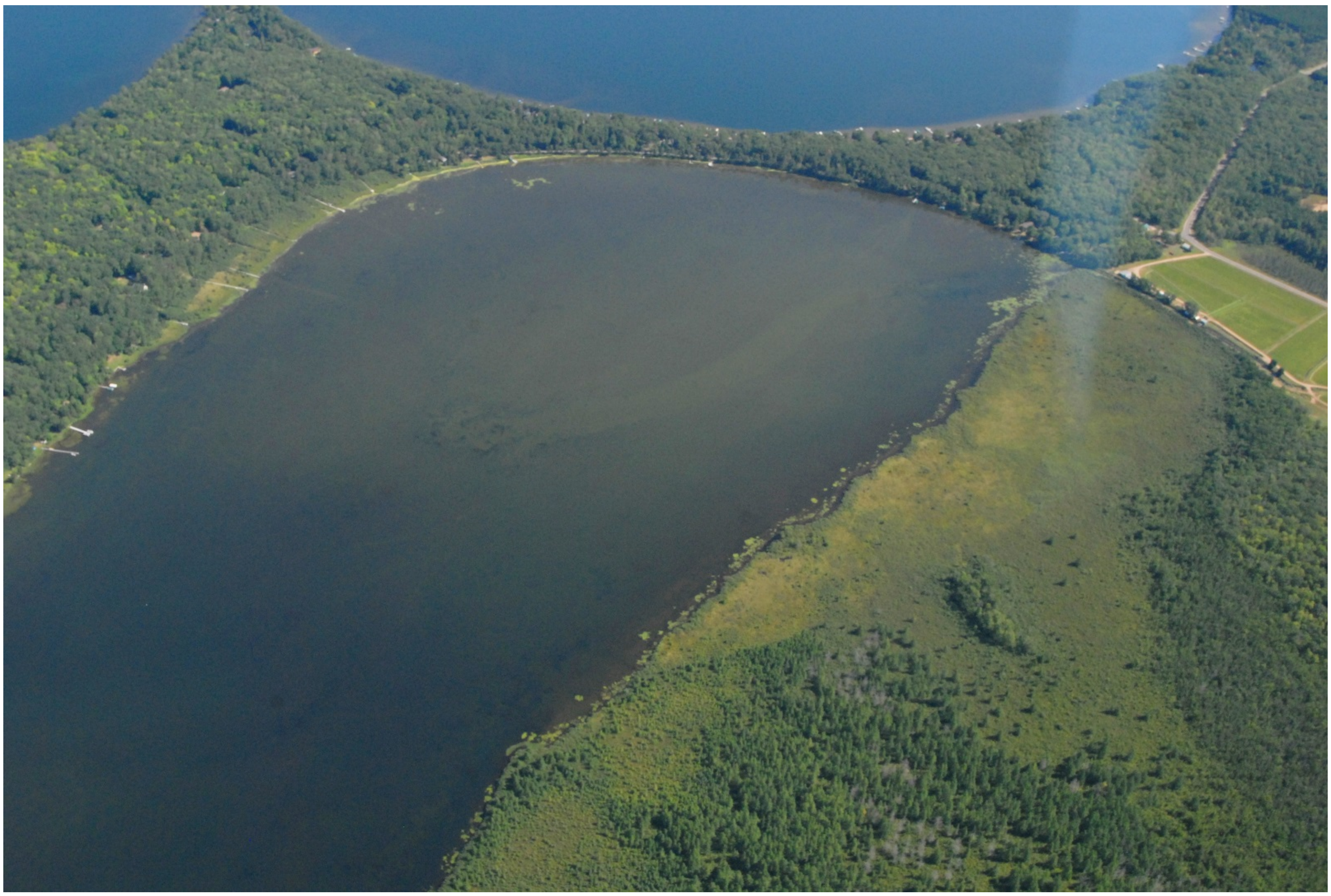
Loss of Beneficial Uses

Musky Bay, Lac Courte Oreilles

May 2013

By Frank Pratt, Fisheries Biologist



View of Lac Courte Oreille's Musky Bay with Central Bay in Upper Top.
Photo Credit: Steve Umland

Acknowledgments
Many thanks to all of my colleagues at Wisconsin DNR. Also special thanks to Gary Pulford, Bruce Wilson, and Dan Tyrolt for editing assistance.

Table of Contents

Figures

Tables

Executive Summary

This report summarizes stressors relating to the loss of fishable and recreational beneficial uses in Musky Bay based on examination of: (1) observed and estimated dissolved oxygen depletion rates ; (2) winterkill incidence ; (3) loss of key muskellunge spawning habitat; and (4) extensive aquatic plant growth, especially the exotic, curly leaf pondweed - all leading to seasonal loss of research and recreational navigation, fishing, and swimming.

Introduction

The term "impairment" describes the loss of swimmable and fishable beneficial uses caused by a variety of physical, chemical and habitat degradations affecting the biology and ecosystem function. At present Wisconsin DNR recognizes Musky Bay as impaired based on total phosphorus, professional judgment pertaining to community structure (atypical macrophytes) and the "overwhelming" number of public comments describing degradation (Johnson, 2012; WDNR, 2013). This report includes additional causal analyses of impairments found in Musky Bay of Lac Courte Oreilles that should be considered in future 303(d) listing processes.

Information Sources

Information assembled in this document was obtained from Wisconsin Department of Natural Resources (WDNR) Hayward Fishery Files (HFFs) and Lac Courte Oreilles Conservation Department (LCOCD) records. The LCOCD has maintained a long-term LCO monitoring program including temperature and oxygen profiles spanning the period 1996 through 2012. Quality assured data from the LCOCD monitoring program has been used to define Musky Bay thermal mixing patterns and dissolved oxygen depletion rates. Published oxygen requirements for sports fisheries survival and propagation have been used to evaluate Musky Bay conditions. Musky Bay fish-kills, tabulated by the WDNR are summarized and compared to Sawyer County lake winter fish-kills patterns. Fishery research notes on survey navigation during routine fall electro-fishing surveys , were also evaluated. These records may not have been fully assessed in previous WNDR WisCALM evaluations.

Background

Lac Courte Oreilles (LCO) is classed as a "two story" fishery, supporting both cold and warm water fish species). This lake draws thousands of visitors from Wisconsin, Minnesota, Illinois and states as far away as Hawaii (Wilson, 2010). LCO provides around 20,000 fishing trips per year, with a minimum value of at least $700,000 per annum. Musky Bay accounts for about 12% of the total annual fishing effort – 2400 trips and $75,000 per year (Pratt and Neuswanger, 2006). Historically, Musky Bay has been an important muskellunge spawning area for Lac Courte Oreilles (Johnson, 1986). The lake had long been considered as a world-class muskellunge fishery. (Pratt and Neuswanger, 2006).

Prior to 2008, Musky Bay's fisheries were monitored ~ annually using standard WDNR Fisheries electro-shock surveying methods. The Governor Thompson Hatchery relied upon collection of walleye, northern pike, and up until very recently, muskellunge from Musky Bay, for regional fisheries propagation. However, no successful muskellunge spawning in Musky Bay has been documented since the early 1970s (Johnson, 1986).

The Fish Management Plan (FMP) for Lac Courte Oreilles (Pratt and Neuswanger, 2006), recognizes Musky Bay as fishery-impaired due to very poor muskellunge reproduction and recommends consideration of dredging to restore spawning habitat.

Northern pike have long been suspected as an additional limiting factor to sustainable muskellunge reproduction (Caplan, 1982, Johnson, 1986; Inskip, 1986). In the 2006 litigation, State of Wisconsin, et al vs. Zawistowski (as cited in Andersen, 2006) WDNR Fisheries staff testified that Musky Bay was impaired for muskellunge reproduction. At that time, it was difficult to distinguish the relative effects of competition/predation by northern pike from habitat degradation. Recent DNA studies (Sloss, 2006; Sloss et. al., 2008), coupled with population manipulation now offer additional inter-species insights.

In 2007, in a cooperative venture by WDNR and the LCO Band of Ojibwe, about 1700 spawning northern pike were removed from Musky Bay. (Only six mature muskellunge were captured, and released). At that time, removal and control of northern pike was viewed as a pilot control effort to enable muskellunge recruitment. However, despite removal of 60% of northern pike from Musky Bay, successful muskellunge reproduction was not observed there (Pratt, 2007).

Musky Bay Morphometric Characteristics

Musky Bay covers about 271 acres (about 5.4% of the lake) and is one of eight embayments subject to bay-to-bay mixing within the 5,030 acre Lac Courte Oreilles basin. As can be seen in Table1, Musky Bay is shallow with maximum and mean depths of 18 feet and 5.5 feet, respectively. Estimated water residence time for Musky Bay was relatively long (> 3 years). As such, it has less volume to dilute pollutant inflows and can be expected to be sensitive to external and internally generated pollutant loads. Musky Bay is a polymictic basin (Wilson, 2010) and subject to temporary thermal stratifications disrupted by storm-induced mixing events with LCO's West Bay. Periodic withdrawal and discharge from cranberry bogs, located along it southern shore, can amount to substantial portions of the Bay's total water volume (e.g. 89 acres of bogs times 10 bog flooding's per year times one foot average depth per bog).

Table 1: Select Morphometric Characteristics

Characteristic	Musky Bay (% lake total surface)	Main Lac Courte Oreilles
Surface area (acres)	271 (5.4%)	5039
Max depth (ft.)	18	90
Mean depth (ft.)	5.5 (Volume 1488 acre-feet)	32
Trophic state	Eutrophic	Oligotrophic/ Mesotrophic

Musky Bay Sediment Characteristics

Sediment characteristics are a critically important habitat component for fisheries such as muskellunge and have been the subject of considerable research (Barr (1991); Fitzpatrick et al. (2003), Garrison and Fitzgerald (2003), Zorn et. al. (1998), and James (2012). These studies have documented relatively recent (e.g. over the past 30-40 years) degradations of Musky Bay including highly reduced, nutrient rich, oxygen poor substrates. They also have documented a recent increase in diatoms indicative of algal mats (Garrison and Fitzgerald, 2003).

Critical dissolved oxygen concentration ranges are summarized in Table 2 according to fish species, life stage, habitat, and season based on information from Cristel (2009); Davis (1976); Dombeck (1986); WDNR Fisheries Handbook (2013); and Zorn et. al. (1998)). Fish stress has been noted at ambient oxygen concentrations less than 3.0 ppm that may trigger fish migration and stress to fisheries. At 2.0 ppm dissolved oxygen levels, the fish community is at moderate to severe risk, depending on the species. Oxygen less than 2.0 ppm at the top of the sediment, may make it unsuitable for survival and incubation of muskellunge eggs. At 1.0 ppm, all fish are severely stressed and some species will die. At 0.5 ppm, fish mortality is likely. Winterkills occur under ice conditions as the water layer has less than 1.0 ppm dissolved oxygen resulting in substantial mortality to resident fish populations. In Musky Bay this occurs about 20% of the winters which is a very high occurrence for this region.

Table 2: Critical Fisheries Dissolved Oxygen Concentrations

Oxygen (ppm)	Habitat	Season	Species	Life Stage	Effect	Frequency
3.0	Bottom waters	Summer	All	All	Stress/movement	100%
	Water Column	Winter	Mu,WE,LMB	All	Incipient stress/movement	100%
2.0	Sediment	Spring	Mu	Eggs	Poor incubation/Mortality	100%
	Water Column	Winter	Mu,WE, LMB	All	Stress/Movement	100%
1.0	Water Column	Winter	Mu, WE,BC	All	Severe Stress/Movement/Mortality	30%
			NP,BC,BG		Stress/Movement	
0.5	Water Column	Winter	All	All	Mortality	20%

Species key: NP = northern pike; Mu = muskellunge; WE = walleye; BC = black crappie; LMB = largemouth bass. The frequency is an annual frequency of occurrence. For example winterkill at < 1.0 ppm likely to occur twice in a ten year period = 20%.

The WDNR Fisheries Management Handbook (2013) recognizes minimum oxygen levels as a critical long-term limiting factor to fisheries. Failure to meet management criteria indicates a sub-optimal at-risk fishery and stocking would not be considered cost-effective to maintain a long-term fishery. The Fisheries Management Handbook has established restrictions to fish stocking based on winterkill incidence including:

- Winterkill frequency of less than 20% of winters for bass and northern pike; and
- Winterkill frequency of less than 10% of winters for muskellunge and walleye.

Muskellunge Spawning Habitat Oxygen Requirements

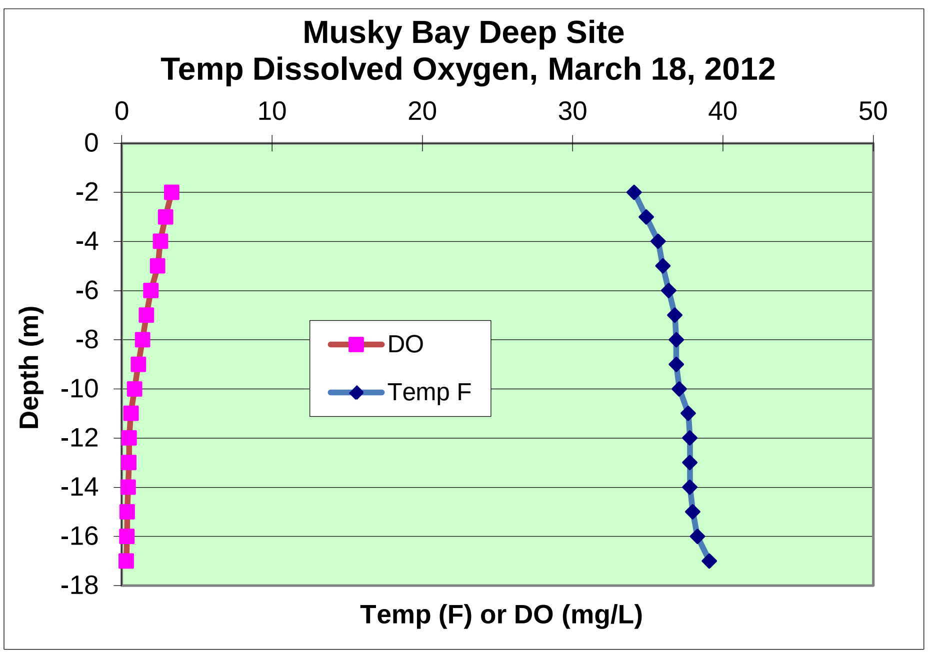
As cited by Pratt and Neuswanger (2006), the LCO genetic strain of muskellunge deposit their eggs on the lake bottom, where survival depends upon available oxygen along the sediment-water interface. Eutrophic conditions can severely limit oxygen availability at this critical life cycle stage as nutrient-enriched sediments cause increased oxygen depletion from the decay of organic matter. Poorly oxygenated sediments degrade spawning habitat as muskellunge eggs require more than 2 ppm oxygen concentrations for survival to fingerling stage. Nutrient-enriched sediments can also serve as a reservoir of phosphorus for pelagic and profundal plant growth that, in a positive feedback loop, generate increased production with resulting decomposition and greater oxygen depletion. Lastly, enriched sediments may serve as a fertile substrate for invasive species such as curly leaf pondweed which, through excessive growth generate further sediment-water interface oxygen oscillations.

Prior to 1970, Musky Bay was acknowledged as the major muskellunge spawning site for LCO (Johnson, 1986; Pratt and Neuswanger, 2006). Since that time, there has been no evidence of successful natural reproduction in Musky Bay. Muskellunge eggs are deposited on lake bottom surfaces while, northern pike eggs, by contrast, have an adhesive egg allowing them to cling to vegetation, well up in the oxygenated water column. In an in vivo experiment, Zorn et. al. (1998) found no muskellunge egg survival at oxygen levels at less than 2 ppm. (Table 2). Low sediment oxygen levels have been demonstrated by other investigations as a critical cause of muskellunge egg mortality (Dombeck et. al, 1984; Zorn et. al., 1998; Pratt and Neuswanger, 2006; Andersen, 2006).

Musky Bay's Oxygen Depletion Rates

Monitoring conducted by the LCOCD in 2012 defined very low winter oxygen concentrations at the Musky Bay deep site. By March 18, 2012, a peak oxygen value peak value of 3.2 mg/l was noted just below the ice with progressively lower concentrations at depth to a value of 0.3 mg/l above the bottom (Figure 1). The corresponding estimated oxygen depletion rate was quite high with an estimated value of 420 mg/day.

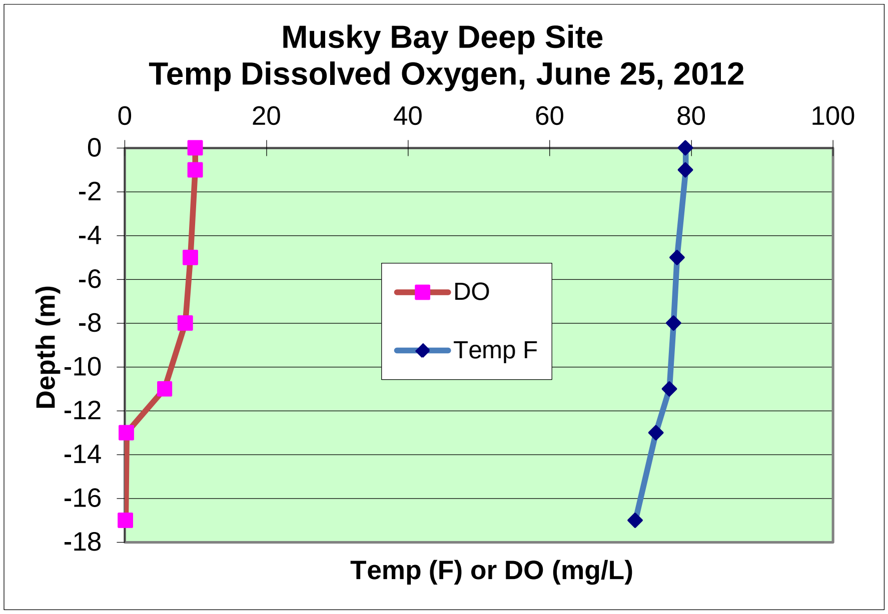
Figure 1: Winter Musky Bay Temperature and Dissolved Oxygen Concentration Profile for March 18, 2012.



With the seasonal progression, 2012 thermal stratification in Musky Bay had begun by June 15th. By June 25th, pronounced anoxia was observed as values ranged from 5.8 mg/l at the surface to 0.46 mg/l at the 17 foot depth level. This drop in oxygen concentration indicates a very high volumetric oxygen depletion rate in excess of 600 mg/m3/day.

Reviewing historical data, Musky Bay thermally stratifies about 2-4 times over the non-ice period, with a temporal thermal stratification coverage extending over about 60% of the summer. When summer stratification lasts more than 2 weeks, oxygen concentrations can be quickly depleted in bottom waters. In general terms, volumetric oxygen depletion rates of 500 mg/m3/day are extremely high values and have been noted for shallow productive reservoir systems (Walker, 1996) and not in oligotrophic-mesotrophic systems.

Figure 2: Summer Musky Bay Temperature and Dissolved Oxygen Concentration Profile for June 15, 2012.



Peak oxygen depletion rates were calculated from winter and summer oxygen profile data obtained by the LCOCD during 2003 – 2012 monitoring seasons at the Musky Bay deep site and summarized in Table 3. The relative magnitude of impacts to water column oxygen concentrations was more widespread during the ice covered months affecting most or all of the water column under ice.

Table 3: Oxygen Depletion History in Musky Bay, 2003-2013, by Season and Depth Strata.

Season	Depth	Depletion rate (mg/d)	D.O.	Frequency	Biological Impairment	Type Years	Percent of Musky Bay Volume**
Summer	10-18’	600	<2.0	All years, 1-4 times/summer over 1-4 weeks duration	Fish migrate, eggs suffocate, P recycled from sediments	2012 Fig. 1	3%
Winter	6-18’	420	<2.0	All years, most of winter	Fish migrate, eggs suffocate, P recycled from sediments	2012 Fig.2	50%
Winter	0-18’	340	<1.0	20% years, 4-8 weeks duration	Fish mortality or migration , eggs suffocate, P recycled from sediments	2003, 2009	100%

This summary from Heiskary and Wilson (2005), summarizes the relationship between oxygen depletion rates and lake phosphorus concentrations. [Note for comparison purposes, Musky Bay average concentrations have been in excess of 40 ug P/l.]

> “Areal and volumetric measures of hypolimnetic oxygen depletion vary directly with total phosphorus concentrations as modified by lake morphometry (Walker 1979 & 1985b). For typical lakes, total phosphorus concentrations above 10-15 µg/l will usually result in the depletion of hypolimnetic oxygen concentrations. Our analysis of 74 minimally impacted Minnesota lakes tends to confirm this observation (Heiskary and Wilson, 1990). Nordin (1986) examined hypolimnetic oxygen depletion and phosphorus relationships from lakes in British Columbia. In this analysis, a range of total phosphorus concentrations between 5-15 µg/l was proposed for the protection of salmonid (coldwater) fisheries. It was noted that oxygen depletions generally began to occur when TP concentrations exceeded 10 µg/l, which is often used as an upper boundary for oligotrophic (Nurnberg, 1996). Expressed in other terms, an average summer chlorophyll-a of 2 µg/l and a corresponding summer-mean Secchi depth of 4.5 m and a AHOD of 0.25 g/m2/day also generally describe the transition from oligotrophy to mesotrophy (Rast and Lee, 1983).”

Winter-kill Incidence

Oxygen can be rapidly depleted under ice cover when photosynthetic oxygen production cannot keep up with aquatic respiration and decay of dead organic material in the sediment and the water column. The thickness and clarity of the ice, and the amount of snow cover, and the duration of ice cover are critically important. When there is insufficient light penetration for photosynthesis, oxygen concentrations may quickly decline. A further result of elevated dissolved oxygen depletion is the incidence of winter-kills.

Musky Bay is compared to other winter-kill lakes in Sawyer County, 1960 to 2013, based on documentation from the WDNR's HFF's. For comparison, winter kill data from Spring Lake is used to typify winterkill-prone productive lakes of the NW Wisconsin region. It is comparable to Musky Bay in size and drainage area, but with slightly higher average total phosphorus concentration (mean TP ~ 45).

In 2009, a winterkill occurred in Musky Bay about five (5) weeks into the ice cover period with a corresponding estimated mean daily oxygen depletion rate of 340 mg/day, which is typical of highly eutrophic, winterkill prone lakes (Charlton (1990), Mathias and Barcia (1979), Babin and Prepas (1984), Charlton (1990), Welch et. al.(1976), Moss and Scott(1961). Over the entire dissolved oxygen depletion rate averaged 190 mg/day and ranged from 40 to 690 mg/day. At a sustained depletion rate of 690 mg ppm/day, a fishery could become endangered (less than 2.0 mg/L) within about two weeks.

Table 4: Musky Bay calculated oxygen depletion rates (2003-2012) based on oxygen profile data and estimated days for depletion from 9.0 mg/L to 2.0 and 1.0 mg/L.

Mean Dissolved Oxygen Depletion Rate mg/day	Range (lowest to highest in mg/day)	Days to Endangerment (2.0 mg/L)	Days to Imperilment (1.0 mg/L or acute)
190	40 - 690	37 (10-175 days)	42 (12-200 days)

Historically, there has been a sharp decline in Sawyer County winter fish-kills from a peak of 35 incidences in the 1960-1979 time period to 3 noted from 2000-2012. Over the most recent years, Musky Bay has the greatest number of documented fish-kills, as tabulated by the WDNR's Hayward Fisheries Office, and accounts for about 2/3's of winterkills in Sawyer County tabulated since 1996. The increased incidence of fish-kills in Musky Bay is counter to the overall reduction in fish-kills tabulated from other Sawyer County lakes. It should be noted that Spring Lake was the only other winter-kill lake tabulated in 2012 in Sawyer County.

Table 5: Sawyer County Winter-kill Tabulation 1960-2013 from WDNR Hayward Fishery Files.

Lakes	Period	Winterkills	Winterkills/year	Trend
All County	1960-1979	35	1.75	
	1980-2002	17	0.77	56% Decrease
	2003-2013	3	0.30	58% Decrease
Spring	1960-1979	9	0.45	
	1980-2002	6	0.27	40% Decrease
	2003-2013	1	0.10	63% Decrease
Musky Bay	1960-1979	0	0	
	1980-2002	0	0	
	2003-2013	2	0.20	Large Increase

Northern Pike Removal to Improve Muskellunge Spawning

This examination is based on muskellunge research, with particular attention to the work of Zorn et. al. (1998) which specifically examined Musky Bay. Zorn attributed the loss of spawning muskellunge populations in Musky Bay to (1) increasing competition from northern pike and/or (2) habitat degradation. Northern pike may have competitive advantages over muskellunge due to (1) its gelatinous egg structure adhering to aquatic plants in the more oxygenated zones and (2) better low oxygen avoidance/survival. Adult northern pike are less likely to succumb to winterkill as they are more prone to low DO migration/avoidance than muskellunge (Davis , 1976; Table 2). Hence, removal of northern pike should improve the odds for muskellunge survival during the spawning period. This hypothesis was tested by the Wisconsin DNR Hayward office as they mechanically removed northern pike in April 2007 coupled with an examination of LCO muskellunge DNA genotypes by Sloss et al. (2006). If removal of northern pike aids muskellunge reproduction, then a strong species interaction is expected. If the genotype is stable over time then natural reproduction is occurring somewhere in LCO outside of Musky Bay (AFS, 2003)

The removal of 60% of the northern pike spawning population from Musky Bay in 2007 resulted in no discernible effect to either species, indicating, at best, a weak inter-species interaction. In this regard, the DNA study of Sloss (2006) and Sloss et. al. (2008) shows remarkable long-term genetic stability in the entire Lac Courte Oreilles, just not in Musky Bay. This indicates continued and successful natural reproduction, elsewhere in LCO (AFS, 2003). Northern pike are present throughout the lake, and therefore, their presence cannot be the dominant factor in the decline of Musky Bay's muskellunge population. Based on this cumulative weight of evidence, impaired muskellunge recruitment may be due to degraded habitat. At present, Wisconsin DNR stocks about 1250 large fingerling muskellunge per year, at a cost of around $13,000.

WDNR Hayward Fisheries Survey Navigation Impairment

Annual fall WNDR along with Great Lakes Indian Fish and Wildlife Commission (GLIFWC) surveys of Musky Bay have been an important assessment tool for tracking fisheries populations. Fishery survey field notes were used to gauge the relative ability to navigate within Musky Bay in performance of the surveys. A boom-shocker boat needs to operate close to shore, continuously, at 1-2 mph, at a speed comparable to a trolling fishing boat. Excess macrophyte growth can impede the survey. Survey notes were obtained from paper file survey notes from 1990 to 2010, to provide a measure of navigation impairment (Table 5). The WDNR Fisheries survey assessments may serve as a surrogate measure for typical fishing. recreational boating, and swimming accessibility based on interference from excess aquatic plants

Two levels of impairment are defined in Table 6: (1)survey made harder and less effective, but still completed; or (2) surveys cancelled, or not completed. The survey navigation data under-estimates the effects nuisance level aquatic plant growth has on the typical lake-user's navigation during the height of the growing season for curly leaf pondweed or *Cladophora* filamentous mats. By September, aquatic plant growth is usually on the decline. Hence, fall survey navigation impairments are an underestimate of summer peak growth conditions.

During the 1990s, 40% of the surveys were impeded to some extent by nuisance level aquatic plant growth, and 10% were cancelled. By 2000, cancellations had increased to 50%. After2008, the Musky Bay sampling site was eliminated, totally , due to excessive aquatic plant growth. It is now likely that peak summer conditions are more restrictive, to general recreation (especially with peak curly leaf pondweed) Hence, Musky Bay is now severely impaired for typical fishing, recreational boating, and swimming during most of the summer.

Table 6: Tabulation of WDNR and GLIFWC fall electrofishing survey navigation impairment notations.

Survey Date	Agency	Investigator	Comments	Outcome
10-27-92	GLIFWC	White	"Dense vegetation"	Completed with some difficulty
09-05-96	GLIFWC	Quagon	"Heavy vegetation"	Completed with some difficulty
10-22-97	GLIFWC	Taylor	"A lot of ...vegetation. ...few fish"	Completed with some difficulty
09-02-98	GLIFWC	Taylor	"Heavy weeds"	Could not survey station
09-11-03	WDNR	Pratt/Warwick	"Not navigable"	Skipped station
09-18-08	WDNR	Pratt/Warwick	"Motor fouling"	Could not complete survey station
2009-2012	WDNR	Pratt/Wolter/Warwick	No longer feasible	Station permanently discontinued

Curly Leaf Pondweed (CLP), an Aquatic Invasive Species

The effect of CLP and its treatment regime on native plants in Musky Bay was documented by Stantec (2012) and summarized in Table 6 . From 2007 to 2011, macrophyte species diversity, richness and density decreased at all Musky Bay sites. During this time, Stantec found that 48% of the native species declined, 14% disappeared, and 65% remained stable, and only 7% increased. Jones (2010), and Heiskary and Valley (2010) found that CLP have similar negative impact on native species in Minnesota lakes.

Table 7: Musky Bay aquatic plant survey summary following invasive introduction Curly Leaf Pondweed in 2005 and first treated in 2007. From Aquatic Plant Management Report (Stantec, 2011).

Index	2007 Transects	2011 Transects	Indication
Community FQ1	35.0	30.9	Moderate loss
Simpson Diversity Index	0.84	0.75	Moderate loss
Native spp. /site	3.5	2.1	Significant loss
Species Richness	29	25	Significant loss
Species increased	NA	2	Moderate loss
Species decreased	NA	14	Moderate loss
Species stable	NA	19	Moderate loss
Species lost	NA	4	Significant loss

WisCALM (2012) does not recognize Aquatic Invasive Species (AIS), including curly leaf pondweed, as a biological impairment although its presence may profoundly affect native aquatic communities. As a result, curly leaf pondweed is typically treated to reduce its dominance by recurrent and long-term chemical measures. Literature citations have indicated that CLP can play as substantial role in increasing sediment oxygen depletion and also may affect internal loading of phosphorus. (Roesler, 2011; James, 2013; Heisarky and Valley, 2010; Waisel et. al., 1990, UW Extension 2013).

As stated by the UW Extension (2013): *"Curly leaf pondweed was the most severe nuisance aquatic plant in the Midwest until Eurasiian Water Milfoil appeared. It forms dense surface mats that interfere with aquatic recreation.....tolerance for low light and low water temperature allow it to get a head start and out-compete native plants in the spring. In mid-summer when most aquatic plants are growing, curly leaf die offs may result in critically low oxygen. Furthermore, decaying plants can increase nutrients, which contribute to algae blooms, as well as create unpleasant, stinking messes."*

Lastly, the WDNR and the Courte Lakes Association have expended considerable funds for the control of CLP to facilitate lake user navigation estimated to be about $40,000 per year. The Wisconsin AIS program directly accounts for 6 million dollars of the entire 9 million dollar Lake Grants budget. That degree of funding priority and institutional will seems to imply that AIS, in general, comprise a universally identified biological impairment.

Summary

This report summarizes biological impairments and associated loss of beneficial uses in Musky Bay and potential stressors based on examination of data collected from Lac Courte Oreilles and from the scientific literature.

1. Oxygen depletion has made Musky Bay the most winterkill prone water in Sawyer County in recent years, counter to county-wide patterns.
2. Elevated oxygen depletion rates do not provide suitable habitat conditions needed for successful muskellunge spawning in Musky Bay
3. Excess macrophyte growth impedes research, navigation, fishing, and swimming in Musky Bay.
4. CLP plays a key role in oxygen depletion, nutrient recycling, competition with native plants, and degraded research and recreation. It should be re-considered as a biological impairment in Musky Bay and elsewhere. It is recommended that AIS be considered a statewide biological impairment.
5. Degradation trends should play a more prominent role in ORW lake management such that early detection can aid in early rehabilitative actions.
6. The impairment history for Musky Bay strongly illustrates the need for early detection of degradation patterns coupled with rapid interventions by corrective actions by regulatory agencies as a part of antidegradation efforts. Otherwise, the viable alternative is passive observation of massive degradation as seen in Musky Bay followed by lengthy and expensive Total Maximum Daily Load studies.

References

American Fisheries Society, 2003. Population Genetics: Principles and Applications in Fisheries. Eric Hallerum-Editor. AFS, Bethesda, Md.; 471 pages.

Anderson J.P., Circuit Court Judge. 2006. Findings of Fact and Law: State of Wi., et. Al. vs. William Zawistowski Jr.. Case 04CV75; 37 pages.

Barr Engineering. 1998. Lac Courte Oreilles Management Plan. Phase 1-Water Quality Study of Lac Courte Oreilles; Phase 2- Hydrologic and Phosphorous Budgets. Prepared for LCO Conservation Dept., COLA, and Wi. DNR.

Brewer, W.S., A.R. Abernathy, and M.J.B. Paynter. 1977. Oxygen consumption by freshwater sediments. Water Res., 11:471-73.

Caplan, D.L. 1982. An experimental study of interactions between young of the year pike (Esox Lucius) and muskellunge (Esox masquinony). M.S. Thesis. U WI, Madison, WI.

Charlton, M.N. 1990. Hypolimnion oxygen consumption in lakes: discussion of productivity and morphometery effects. Can. J. Fish. and Aquatic Sci., 37: 1531-1539.

Cristel, Paul. 2009. Report on winterkill in Musky Bay. LCO Conservation Dept. memo; 4 pages

Davis, J.C. 1976. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: A review. JFRBC, 33 : 2295-2315.

Dombeck, M.P., B. W. Menzel, and P. Hinz. 1984. Muskellunge Spawning Habitat and Reproductive Success. TAFS 113: 205-216.

Dombeck, M. P., B. W. Menzel, and P.N. Hinz, 1986. Natural muskellunge reproduction in Midwestern lakes. In a Treatise on the biology and propagation of muskellunge in North America; 122-134. American Fisheries Society Special Publication 15; G.E. hall, editor; 372 pages.

Fitzpatrick F., P.J. Garrison, S.A. Fitzgerald, and J.F. Elder. 2003. Nutrient, trace element, and ecological history of Musky Bay, Lac Courte Oreilles, Wisconsin, as inferred from sediment cores. USGS Water Resources Investigations Report 02-4225; 141 pp.

Garrison, P.J., and S.A. Fitzgerald. 2005. The role of shore land development and commercial cranberry farming in a lake in Wisconsin,

Heisarky, S. and R.D. Valley. 2010. Curly-leaf pondweed trends and interrelationships with water quality. MN. DNR Invest. Report 558; 37 pages.

Inskip, P.D. 1986. Negative associations between abundances of muskellunge and northern pike: Evidence and possible explanations. In Managing Muskies (G. Hall, Ed.); AFS Spec. Pub. 15: 135-150.

James, W.F., A. DeChamps, N. Turyk, and P. McGinley. 2007. Importance of *Potamogeton crispus* decay to phosphorus budget of McGinnis Lake, Wisconsin. APCRP Technical Notes Collection. ERDC/TN APCRP-EA-15. Vicksburg, MS: US Army Corps Engineers Research and Development Center.

James, W.F. 2012. Sediment characteristics and diffusive phosphorus fluxes in Lac Courte Oreilles, Wisconsin. U.W.-Stout, Sustainability Sci. Inst.; 42 pages DRAFT

Johnson, L. 1986. Population dynamics of stocked adult muskellunge (*Esox masqinony*) in Lac Courte Oreilles, Wisconsin, 1961-77. Wi. DNR, Tech Bulletin No. 160; 12 pages.

Jones, A.J. 2010. Effects of repeated early season herbicide treatment of curly leaf pondweed on native macrophyte assemblages in Minnesota lakes. U. MN. Digital Conservancy.

Kamke, K.K. 1989. Lake survey of Lac Courte Oreilles, 1988-89. WDNR internal report, Treaty Assessment Unit.

Moss, D.D. and D.C. Scott. 1961. Dissolved oxygen requirements of three species of fish. TAFS 90(4): 377-393.

Pratt, F. B. and D. Neuswanger. 2006. Lac Courte Oreilles Fishery Plan. Wi. DNR.; 18 pages.

Pratt, F. B. 1976. Comprehensive survey, Lac Courte Oreilles. Wi. DNR, Hayward Fishery Files. Internal report; 9 pages of text with attachments.

Pratt, F. B. 2003. Field survey notes- fall electrofishing, LCO monitoring stations. Wi. DNR. Hayward Fishery Files.

Pratt, F.B. 2008. Field survey notes-fall electrofishing, LCO monitoring stations. Wi. DNR. Hayward Fishery Files.

Pratt, F.B. 2007. Summary of northern pike removal from Musky Bay, April 2007. Hayward Fishery Files. Hand-written; 1 page.

Quagon, Sam. 1997. Field survey notes-GLIFWC fall survey of Lac Courte Oreilles. Hayward Fishery Files.

Stantec. 2012. 2012 Aquatic plant management report for Lac Courte Oreilles. Cottage Grove, Wi. Dec. 18, 2012 Report to COLA; 44 pages.

Sloss, B.L. 2006. Genetic analysis of Butternut Lake and Lac Courte Oreilles muskellunge populations. U.W. Stevens Point Coop. Fishery Res. Unit/ Molecular Conservation Genetics Lab, Oct. 2006 Update on Muskellunge Research in Wisconsin, 3 pages.

Sloss, B.L., R.P. Franckowiak, and E.L. Murphy. 2008. Development of new micro-satellite loci and multiplex reactions for muskellunge (*Esox masiquony*). Molecular Ecology Resources, 8: 811-13.

Taylor, Don. 1996. Field notes- GLIFWC fall survey of Lac Courte Oreilles. Hayward Fishery Files.

University of Wisconsin Extension. 2013. Aquatic invasive species education handbook. PDF file in www.uwex.edu. Chapter 7-Species Information.

Waisel, Y., J.J. Oerteli, and A. Stahel. 1990. The role of macrophytes in phosphorous turn-over: sources and sinks. Proceedings of 8th Symposium on Aquatic Weeds. EWRS: 234-248.

Same as US Dept. Interior et. al. HAS to be included later in whole lake discussions.

Welch, T.L. , E,P. Dillon, and A. Sreedharan. 1976. Factors affecting winter respiration in Ontario lakes. JFRBC, 33: 1809-1815.

White, Melvin. 1992. Field survey notes- GLIFWC fall electrofishing, Lac Courte Oreilles. Hayward Fishery Files.

Wilson, C. B. 2010. Lac Courte Oreilles Lake Management Plan. Prepared for the Lac Courte Oreilles (COLA). 52 pp.

Wisconsin DNR. 2012a. WisCALM. Latest update, currently subject to comment and revision.

Wisconsin DNR. 2013. Fisheries Management Handbook. Fish stocking guidelines. See above, Hunting Regs.

Zorn, S.A., T. L. Margenau, J. S. Diana, and C. J. Edwards 1998. The Influence of Spawning Habitat on Natural Reproduction of Muskellunge in Wisconsin. TAFS, 127: 995