Walleye management strategy for Little Bay de Noc, Lake Michigan

Michigan DNR Fisheries Division
Marquette Fisheries Research Station and Northern Lake Michigan Management Unit

July 2012

Summary

The purpose of this document it to provide a brief overview of: 1) the historical background of walleye stocks and fisheries in the Michigan waters of Green Bay; 2) recent changes in habitat conditions pertinent to walleye management; and 3) the Michigan Department of Natural Resources' (DNR) current understanding of reproduction of Green Bay walleye stocks. This information provides the basis for the walleye management objectives for northern Green Bay and Little Bay de Noc (LBDN), and development of decision criteria specific to walleye management in LBDN. This approach can provide a template for walleye management decision-making in other areas of northern Green Bay, such as Big Bay de Noc (BBDN).

Background on walleye stocks in the Michigan waters of Green Bay

Walleye have provided commercial and sport fisheries in the Michigan waters of Green Bay for many years. Historical commercial harvest of walleyes for Lake Michigan came almost exclusively from northern Green Bay (Michigan Water Resources Commission 1963). For Michigan waters of Green Bay, walleye yields appeared to be highest in LBDN, followed by BBDN, and then the southern ports of Cedar River, Ingallston, and Menominee. The exact location of where walleyes were taken from cannot be pin-pointed from this information since commercial fishing licenses at this time stipulated that fish landed at ports could be taken from waters within 50 miles of the port. Nevertheless, available information suggests that walleye abundance was higher in LBDN than BBDN. We obtained monthly commercial catch summaries from the Michigan Historical Center's Archives of Michigan for northern Green Bay ports during 1941-1957, years when peak walleye harvests occurred (Appendix 1). Of the 6.17 million pounds of walleyes harvested during this time 53.6% came from LBDN ports, 44.1% from BBDN ports, and 2.4% from the port of Cedar River. Top ports and percentages of the total harvest from them were Escanaba (43%), Garden (20%), Gladstone (11%), Nahma (10%), and Fayette (7%). The Michigan Water Resources Commission (1963) stated that walleye production was not significant in southern ports during this time and, even in peak years, walleye landings at Menominee never exceeded 10,000 pounds. However, walleye landings at Cedar River annually exceeded 25,000 pounds during 1948-1950 (Archives of Michigan records).

Higher walleye abundance in LBDN today compared to BBDN is not that surprising when differences in habitat conditions between the two bays are considered. For example, LBDN has numerous large- to medium-sized undammed rivers with high-gradient rapids for spawning (i.e., Whitefish, Rapid, Tacoosh, Ford), excellent sheltered reef-spawning and nursery habitats for developing eggs, fry, and juvenile walleyes, and deepwater habitats adjacent to shallow flats for foraging. Big Bay de Noc, on the other hand, has more rigorous conditions for walleye reproduction, with no high-quality river-spawning habitats similar to LBDN, and shoreline spawning areas that are generally more exposed to high wave action and offer less protection for eggs and fry. Deepwater habitats, which provide the low-light conditions preferred by walleyes, are well offshore (and often less accessible to small boat anglers) in BBDN, with the exception of areas west of the Garden Peninsula. It is possible that peak walleye catches during 1941-1957 may have resulted from exceptional year classes from reef-spawning spawning stocks since exceptional landings occurred in BBDN as well as LBDN. For the southern ports (Cedar River, Ingallston, and Menominee), excessive predation by smelt, and later alewife, may have limited walleye recruitment given the following: smelt and alewife were the primary commercially harvested species during 1940-1962 (Michigan Water Resources Commission 1963); studies have documented such effects (e.g., Fielder et al. 2007; Madenjian et al. 2008); and exceptional walleye year classes in Green Bay followed a major smelt die-off in 1943 (J. Peterson, Michigan DNR Fisheries Division retired; Michigan Water Resources Commission 1963). The Menominee River is also dammed about two miles upstream of its mouth, resulting in impoundment and/or inaccessibility of the bulk of potential walleye spawning habitat.

Commercial fisheries for walleyes in much of Lake Michigan eventually collapsed in response to numerous perturbations including over-fishing, pollution, dams and barriers, loss of nursery wetland habitats, and interactions with non-native species (Kapuscinski et al. 2010). Interactions with alewife and smelt (e.g., predation on walleye fry) have been implicated as the most likely contributor to the decline of walleye populations in northern Green Bay (Schneider et al. 1991). Water quality conditions improved following passage and enforcement of the Clean Water Act, and in 1971, DNR Fisheries Division began stocking LBDN-strain walleye fingerlings back into LBDN in an effort to rebuild stocks. In the mid-1980s walleye rearing efforts were stepped up and walleye stocking was expanded to include other areas of Lake Michigan, namely BBDN, Cedar River, and Menominee. Efforts to restore natural reproduction appeared to be achieving some success, because by 1988 modest numbers of naturally-produced juvenile walleyes were collected off the mouth of the Whitefish River in LBDN (Schneider et al. 1991), and Schneeberger (2000) noted a strong 1991 year class of walleyes in LBDN. Later, age data from walleye tagging and netting surveys in LBDN indicated good representation of walleye year classes for all eight odd-numbered years when stocking did not occur (Zorn and Schneeberger 2011). Similar data from Menominee River walleyes identified the occurrence of at least eight naturally-produced year classes in the river before the DNR initiated stocking. Similar data for BBDN and Cedar River suggest walleye stocks were very low or absent prior to initial stocking efforts (Zorn and Schneeberger 2011). A 2006 survey of the Menominee River walleye spawning run showed a very large, naturally-produced 2003 year class and evidence of reproduction in several other years (T. Zorn, unpublished data). Data from a 2005 survey of the Cedar River walleye spawning run showed evidence of some natural reproduction, but not to the extent observed in the Menominee River (T. Zorn, unpublished data).

Current status of reproduction of northern Green Bay walleye stocks

An oxytetracycline (OTC) marking study was initiated in LBDN and BBDN in 2004 to obtain a better understanding of the relative contribution of hatchery-reared fish to walleye stocks in northern Green Bay. As of the end of the 2009 field season, 75% of 1,958 age-0 to age-3 walleyes examined in LBDN were of wild origin and 61% of 699 walleyes examined in BBDN were naturally-produced (Zorn 2010). Substantial natural reproduction has occurred every year in LBDN, and three naturally-produced year classes (2003, 2005, and 2007) have been larger (based on assessment catches) than any year class supplemented by stocking (Figure 1). Contributions of stocked walleyes are more evident in BBDN. While one strong non-stocked year class (2007) occurred, the likelihood of weak or failed reproduction (as seen in 2004 and 2008) was much more likely (Figure 1).

In summary, LBDN reproduction has been consistent and sport fishery harvests of walleyes for northern Green Bay in recent decades are approaching commercial landings in previous decades, though less than in early and peak years of the commercial fishery (Figure 2). Compared to LBDN, walleye reproduction in BBDN is lower and less consistent, and sport fishery harvests of walleye are lower. Less data are available for the Menominee River, but a fairly consistent fishery and evidence of natural reproduction exist for at least the last decade (Zorn and Schneeberger 2011).

Current status of the aquatic environment of the Bays de Noc (BDN)

Major changes in Lake Michigan have been accompanied by corresponding changes in the BDN. Zebra and quagga mussel invasions in the early 1990s have caused dramatic increases in water clarity, and have been associated with declines in forage fish abundance and changes in walleye use of BDN (Zorn and Schneeberger 2011; T. Zorn, unpublished data). For example, walleyes now commonly migrate out of the LBDN shortly after spawning and spend much of the growing season in Lake Michigan proper, rather than remaining in the northern portions of LBDN. In addition, August-September surface summer water temperatures have increased 4 ºF (averaging ~0.2 ºF per year) since 1988. Reduced forage fish abundance, dense goby populations, and increased abundance of smallmouth bass (a benthic predator and prized sportfish) and freshwater drum (a molluscivore) in LBDN are similar to observations in other areas of the Great Lakes where *Dreissenid* mussels and gobies have invaded (Tyson et al. 2009; D. Fielder, DNR, unpublished data). Given increased water clarity (less plankton production) and reduced forage fish populations, it is probably unrealistic to expect LBDN to support walleye population levels similar to those observed in late 1980s and early 1990s. Lake Michigan and BDN environments are expected to continue to change, and we are uncertain if or when they will achieve a long-term (stable) equilibrium, and what conditions will be if equilibrium is achieved. Management strategies must take into account the fact that the BDN environment is changing.

Northern Green and LBDN walleye management objectives

Based upon Schneider et al.’s (2007) report “Ecology, management, and status of walleye, sauger, and yellow perch in Michigan”, we propose the following general management objectives for walleye in the Michigan waters of Green Bay.

- Protect and restore essential habitats (e.g., spawning areas in rivers and reefs, important nursery habitats such as river estuaries)
- Maintain abundance of adult walleyes so optimal natural reproduction is likely assured in all self-sustaining walleye waters (e.g., LBDN, Menominee River) in all years
- Provide management recommendations and facilitate compliance with sport, subsistence, and commercial fisheries to avoid overfishing, equitably distribute angler harvest, and maximize opportunities for participation.
- Maintain walleye fishing opportunities with stocking (where feasible) by striking a balance between public demand and constraints imposed by environments, resources, and economics

Schneider et al. (2007) stated that “The greatest amount of genetic diversity within Michigan can be retained by preserving the genetic traits of individual stocks.” Furthermore, they noted that “Preserving and managing self-sustaining populations is the most economical and best way to protect the genetic diversity in fish populations.” Jennings et al. (1996) showed that river- or reef-spawning are genetically heritable traits. Strong homing tendencies of walleyes to spawning rivers in northern Green Bay (Schneeberger 2000; Zorn and Schneeberger 2011) enable natural selection to shape each population over time, so that spawning walleyes will make the best use of the spawning environment (river and estuary conditions) available to them. Given the importance of natural reproduction to the LBDN walleye population, proposed management actions should foster development of individual spawning stocks and additional natural reproduction.

Additional, more specific walleye objectives for LBDN adapted from Schneider et al. (2007) are:

- Stable population in terms of age and size distribution of adults
- Relatively stable (preferably self-sustaining) recruitment with few missing or extremely weak year classes
- Stable fishery yield
- Sustainable balance between predator and prey fishes, as evidenced by stable walleye growth and prey fish populations
- Stable natural mortality and relatively low fishing mortality to maintain quality of fishery (i.e., availability of large walleyes). Note: Annual survival of adult walleyes in LBDN is relatively stable at about 55% and angler exploitation is relatively low at about 10%, after non-reporting is factored in (Zorn and Schneeberger 2011).

Proposed criteria for stocking decisions and current status

Given these changes and the competing demands of Lake Michigan waters and many inland fisheries for walleyes, we propose using several criteria to guide stocking decisions for northern Green Bay waters managed for walleye. The criteria were initially proposed at a May 2011 meeting with BDN stakeholder groups, and fine-tuned over the course of five meetings of the group during 2011. These guidelines are adapted from decision criteria used for walleye management in Saginaw Bay (Fielder and Baker 2004). Walleye were considered "rehabilitated" in Saginaw Bay when walleye reached a density whereby they exerted pressure on the prey base such that walleye growth declined to rates closer to state averages, and where natural reproduction contributed more to walleye year classes than stocked fish. Our work also parallels the "red flags analysis" approach used to guide stocking decisions for another top predator in Lake Michigan, Chinook salmon (Claramunt et al. 2008). The red flags analysis uses a suite of biological indicators to assess the Chinook salmon health, evaluate the balance between predator and prey fishes, and guide management decisions. The red flags analysis compares the value of each indicator variable to the typical range of variation of that variable over the period of data collection (i.e., the 80th and 20th percentiles).

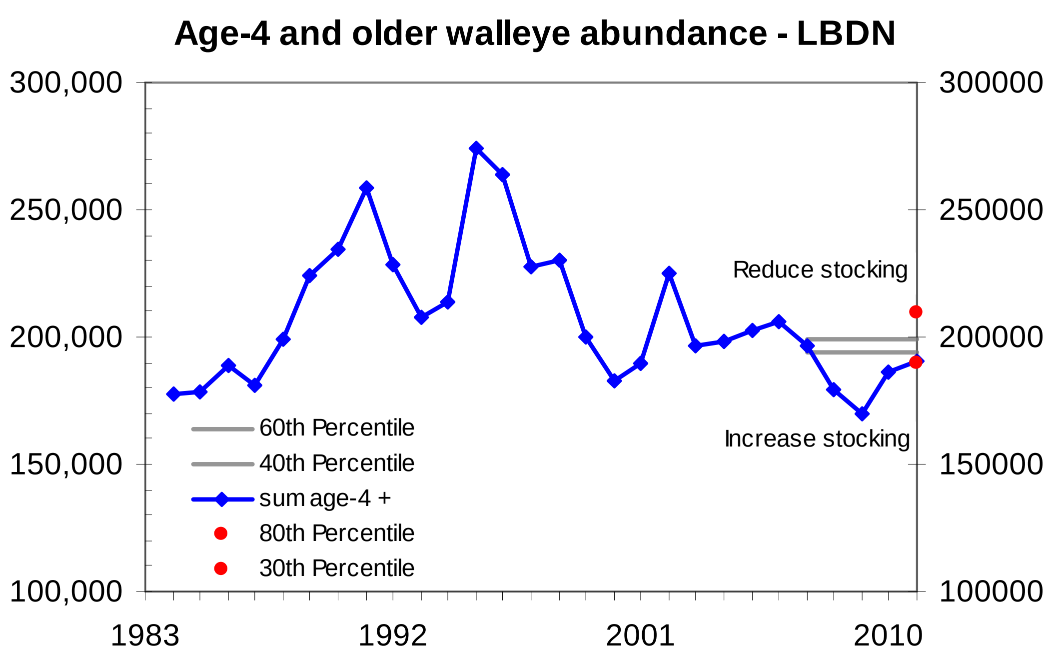
Walleye stocking decisions for LBDN should be guided by evaluation of multiple criteria documenting the status of the walleye population and its forage base. The proposed criteria describe:

- Trends in the walleye population abundance;
- The amount and sources of walleye reproduction;
- Predator-prey balance (prey fish abundance and walleye growth).

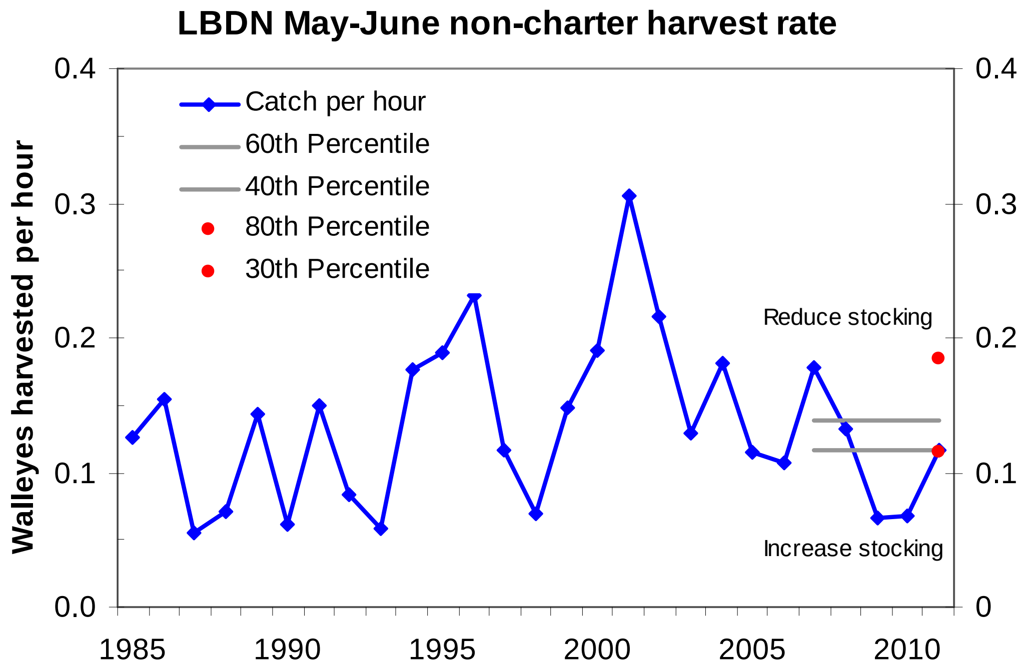
To reflect the changing nature of the BDN environment and fish community, we propose using percentiles from the previous 15 years as benchmarks for comparison with the most recent data. Thus, the benchmarks will adjust over time as the suitability of the BDN environment for walleyes and their forage changes. When fewer than 15 years of data were available, percentiles were computed from the existing data. A red flag is triggered for a variable when values for 3 of the last 5 years fall outside the 60th and 40th percentiles, and when the most recent value for a variable falls outside of the 80th and 20th percentiles. We used the 30th rather than the 20th on adult walleye abundance metrics (i.e., age-4 and older abundance, non-charter catch rate) as a proactive measure to trigger stocking sooner in the event of unexplained declines in the adult walleye population. The following discussion provides more background and a summary of the current findings for each of the proposed decision criteria.

Walleye abundance. For northern Green Bay, our long-term objective is to support a relatively stable, self-sustaining population and high-quality fishery for walleye. Fish species that live in environments where reproductive success is highly variable from year to year (e.g., walleye) are typically long-lived, lay huge numbers of small eggs, and rely on having many opportunities (years) to attempt to reproduce successfully. We acknowledge that walleye reproductive success varies considerably from year to year, but seek to manage the stock to achieve optimal levels of natural reproduction when suitable conditions occur. This should be done through measures that protect the spawning stock from overexploitation and the population's genetic integrity (e.g., regulations and stocking only when necessary). Persistent values above the upper percentiles suggest stocking reduction or cessation may be prudent, while values below the lower percentiles suggest increased stocking might be appropriate.

The primary estimate of abundance comes from the statistical catch-at-age model which incorporates DNR survey and angler creel data, tribal subsistence harvest, and documented illegal harvests during 2004-2009. The abundance of age-4 and older walleyes in 2011 was between the 80th and 30th percentiles which suggests no stocking change, and for 3 of the last 5 years walleye abundance was below the 40th percentile which supports increased stocking.



May-June non-charter angler catch rates of walleyes also provide an index of walleye abundance. The May-June non-charter catch rate was chosen because walleye are primarily targeted by anglers during these months. These indices are influenced by temporal changes in the environment of LBDN (e.g., water clarity and temperature changes over time), as well as changes in demographics, technology, and techniques of LBDN's charter and non-charter anglers. Thus, harvest rates may not always reflect true trends in abundance. The 2011 non-charter harvest rate was between the 30th and 80th percentiles suggesting no change. However, harvest rates were below the 40th percentile for 3 of the last 5 years which supports increased stocking. Charter harvest rates were not chosen for use in this analysis because they essentially represent the efforts of only two charter operators, and overall catch rates would be highly influenced by changes in their operations and additions of new charter operations.

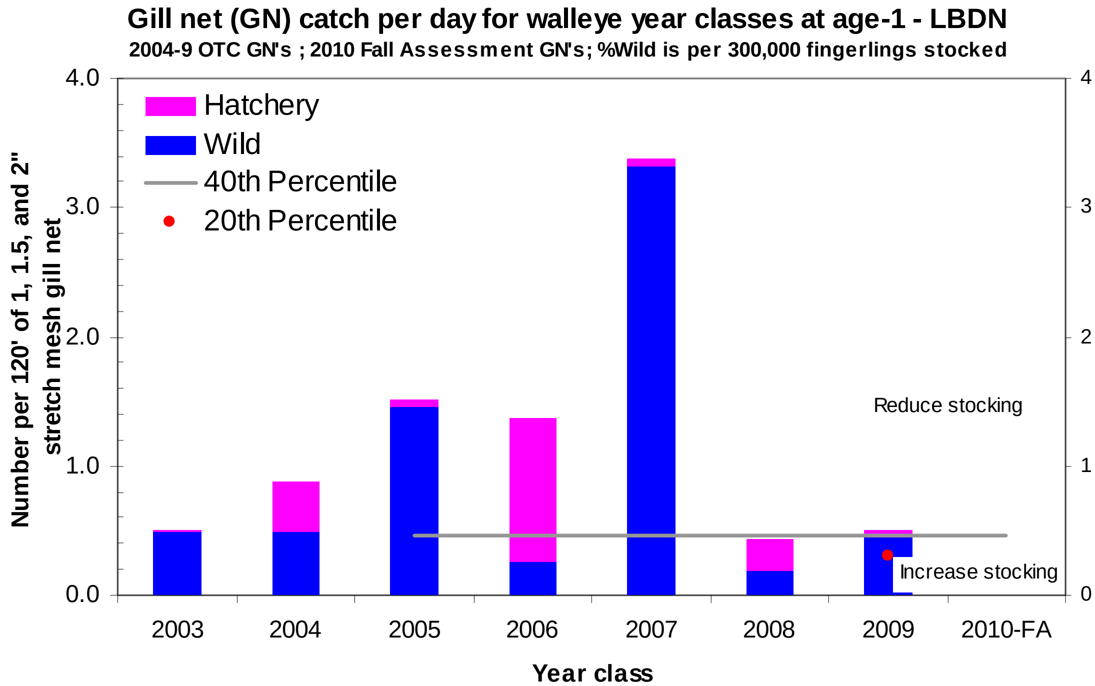


Amount and sources of walleye recruitment. Ideally, the management objectives for LBDN should be achieved without dependence on stocking. In the Saginaw Bay walleye rehabilitation strategy, walleye stocking was to decrease or cease when three of the last five year classes consisted of more naturally-reproduced than hatchery walleyes (Fielder and Baker 2004). Though the density of walleyes stocked into Saginaw Bay was 7.6 times lower than is called for in the current LBDN prescription, stocking has not occurred there since 2005 following the crash of Lake Huron's alewife population. Similarly, Wisconsin's Fox River, which drains into southern Green Bay and hosts a large walleye run, has not been stocked since 1984 (Kapuscinski et al. 2010). Sustainable fisheries in Saginaw Bay and Wisconsin's Fox River based on natural reproduction demonstrate that it is possible to achieve stable walleye populations without stocking.

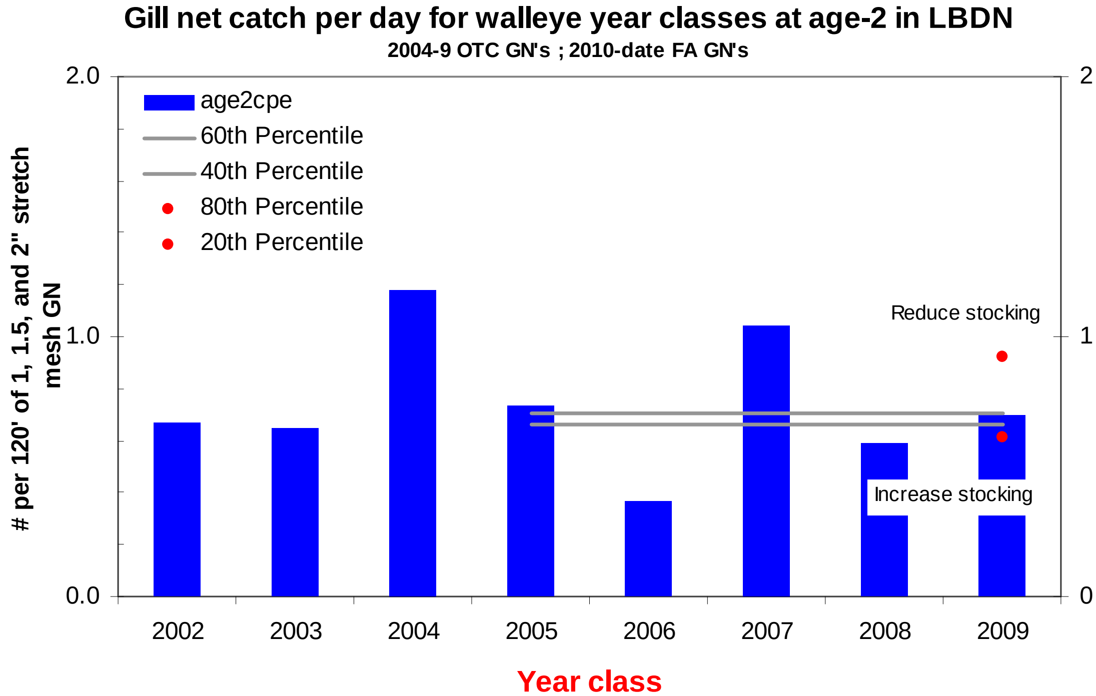
Several studies have evaluated the effectiveness of supplemental walleye stocking (i.e., stocking in waters where natural reproduction occurs) in inland lakes, but no specific guidelines exist for Great Lakes populations. Agency studies based on many lakes in Wisconsin (Kampa and Jennings 1998; Jennings 2005), Ontario (Kerr et al. 1996), and Minnesota (Li et al. 1996) showed that stocked walleyes did not contribute positively to walleye population size in waters where natural reproduction occurred, primarily due to suppression of adjacent year classes by stocked walleyes. The findings led the Wisconsin and Ontario authors to recommend against stocking walleyes in such waters. Michigan DNR's fish stocking guidelines, primarily used for inland lakes, recommend no walleye stocking for 2-3 years if measured reproductive success is "relatively good", and stocking on a 2-3 year rotation to avoid year class suppression in lakes that cannot be evaluated annually (MDNR 2004). Possibly reflecting the limited effectiveness of supplemental stocking, a more recent survey of agencies in North American states and provinces showed increased use of walleye stocking to create and maintain artificial fisheries with little expectation of natural reproduction (Kerr 2008).

Reproductive success of self-sustaining walleye populations is highly variable from year to year, with years of strong recruitment being infrequent. Given this understanding, our objective for LBDN is a walleye population that is relatively stable (preferably self-sustaining) with few missing or extremely weak year classes. Since different numbers of walleye fingerlings are stocked each year, estimates of percent wild (natural reproduction) are standardized for every 300,000 fingerlings stocked. An average of 274,526 walleye fingerlings were stocked in LBDN in alternate years of 2004, 2006, and 2008. A red flag is triggered to reduce or stop stocking when 3 of the last 5 year classes consist of more naturally-reproduced than hatchery walleyes or when the survey catch rate for naturally-reproduced walleyes is above the 40th percentile for the last 10 years (or above the 20th percentile for the most recent year) in non-stocked years. Conversely, increased stocking may be appropriate when natural reproduction contributes less than stocking in stocked years, or when reproduction is below the 40th percentile in unstocked years, for 3 of the last 5 years (20th percentile for the most recent year).

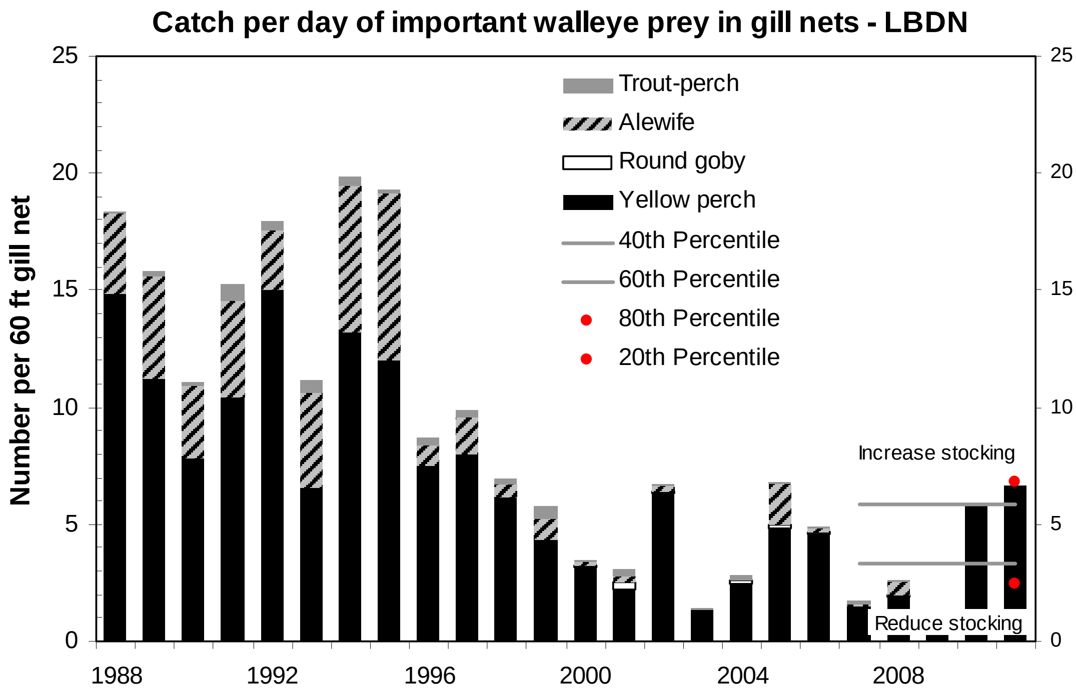
A total of 131,143 hatchery walleyes were stocked in LBDN in 2010, but they could not be distinguished from naturally-reproduced fish due to poor oxytetracycline (OTC) marks on reference fish. Since we could not assess the natural reproduction component of age-1 walleyes in 2011 (or the 2010 year class), data for the 2005-2009 year classes were used in the analysis. Age-1 hatchery fish outnumbered wild fish in two stocked years (2006 and 2008), and wild age-1 walleyes were slightly below the 40th percentile in 2009, suggesting increased stocking is warranted. Due to a poor OTC mark in 2010, neither the percent wild nor the catch rate of wild age-1 walleyes could be evaluated for 2011.



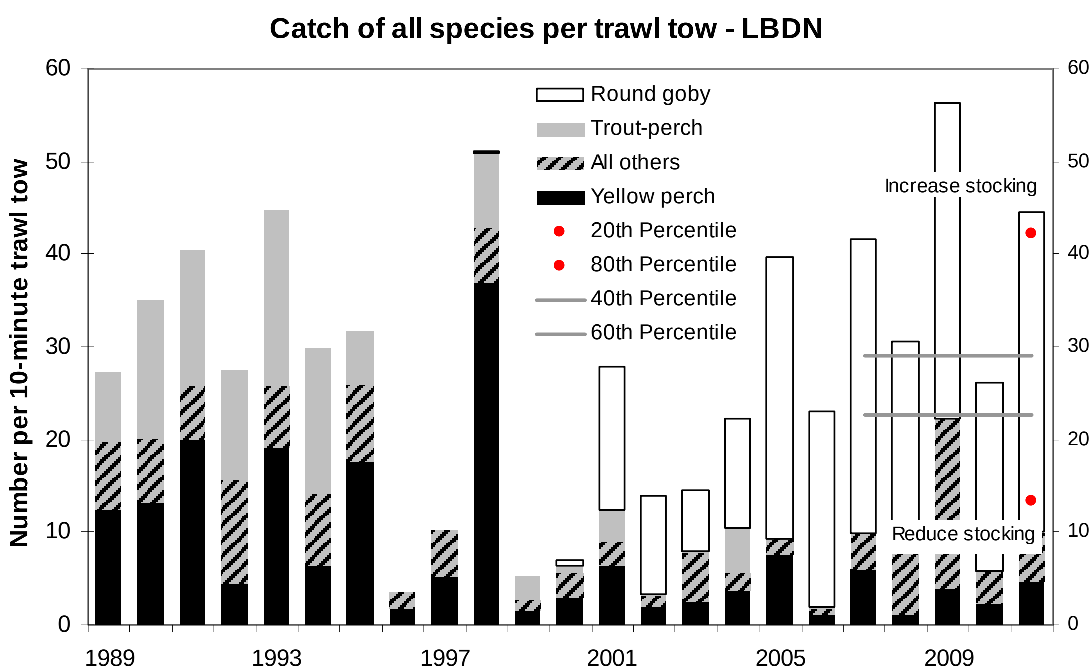
Even though natural reproduction of walleye populations is highly variable from year to year, we still desire a population that does not show long-term declining trends in year class strength. This indicator provides an additional index of reproduction (wild and hatchery combined) and overall recruitment of juvenile walleyes to the fishery. A red flag indicating stocking could begin or increase would be triggered when survey catch rates for age-2 walleyes are below the 40^{th} percentile for at least 3 of the last 5 years; decrease or cessation of stocking would be suggested when most values are above the 60^{th} percentile. Likewise, values in the most recent year that are above the 80^{th} (or below 20^{th}) percentiles would trigger stocking decreases (or increases). Results from this metric were mixed. The majority of values for the last 5 years were neither above the 60^{th} percentile nor below the 40^{th} percentile, suggesting no change in stocking rate is needed. The value for the most recent year was between the 80^{th} and 20^{th} percentiles which also indicated no need for stocking changes.



Prey fish abundance. As top-level piscivores, walleye help keep the forage base "in check", helping to prevent prey fish populations from becoming overabundant. Long-term decreased (or elevated) forage fish abundance may indicate a walleye population out of balance with the prey base, and the need for management actions to reduce (or increase) walleye population abundance. Trends in prey fish catch per effort (CPE) in DNR trawl and gill net surveys are used to track forage fish abundance. Increases (or decreases) in walleye stocking are recommended when forage fish catch rates are above the 60th (or below the 40th) percentile value in 3 of the last 5 years, or outside the 80th and 20th percentiles in the most recent year. Forage fish catch rates in gill nets were below the 40th percentile for 3 of 5 years supporting reduced stocking, but between the 80th and 20th percentiles in the most recent year indicating no need for change.



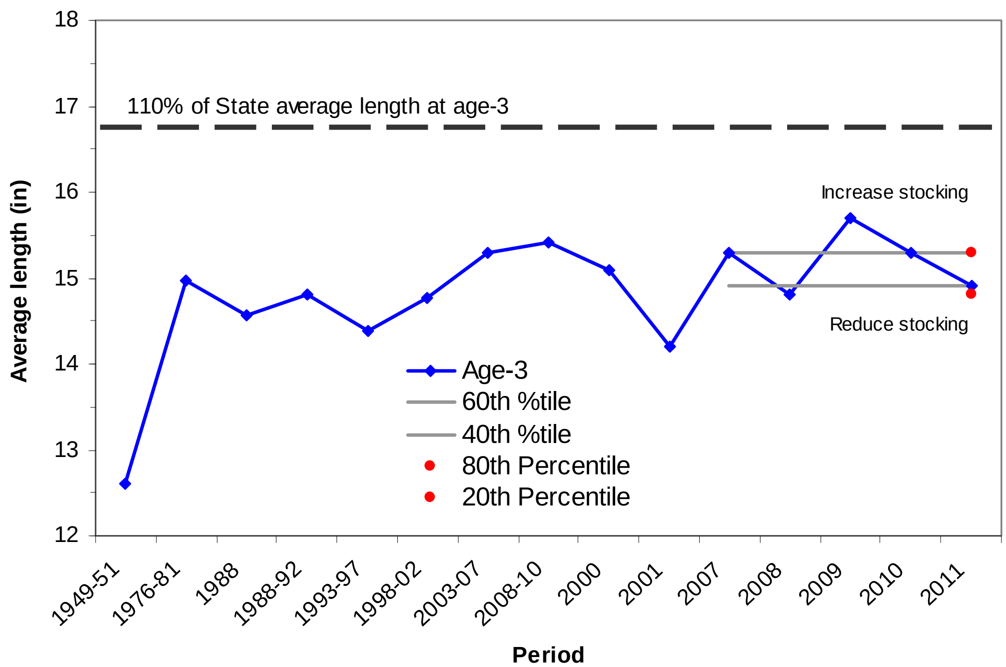
Forage fish catch rates from trawling were above the 60th percentile in 3 of 5 years (due to high abundance of round goby) suggesting increased stocking, and above the 80th percentile in 2011 which also supported stocking increases.



Walleye growth. Walleye densities should be sufficient to provide adequate predation pressure on forage fishes, especially alewife, a key competitor and likely predator on walleye fry. Conversely, walleye densities should not increase to the point that growth is stunted, as occurred in 1949-1951 (see figure below). Data from Saginaw Bay and Lake Erie walleyes showed that walleye grew fast when their abundance was low relative to that of their forage base, but declined as their abundance increased and they began to exert control on the forage base. Fielder and Baker (2004) stated a recovered population of Saginaw Bay walleyes would grow no faster than 110% of the state mean length at age-3, which equals 16.7 inches for fish caught in September (Schneider et al. 2000). Note that the State mean length at age values from Schneider et al. (2000), are based primarily on Great Lakes walleyes and are more pertinent to LBDN than mean length at age values that were recently developed using data from inland lake surveys (K. Wehrly, unpublished data).

Our recovery objective for northern Green Bay walleyes would be for growth rates that are stable and do not exceed 110% of state average. Growth data for age-3 walleyes in LBDN were grouped into the time periods to increase sample size for calculating averages (left side in figure below); averages for individual years since 2000 occur on the right half of the plot. Since only one age-3 male was observed per year in netting surveys during 2000-2008, "average" lengths for individual years during this period are suspect. The mean length of an age-3 male walleye in LBDN was 14.9 inches, well below the 110% benchmark. Yearly sample sizes for years before 2009 are probably too low for trend analysis (comparison with percentiles), but neither set of percentiles suggest a need for stocking changes. Existing data show no dramatic trend aside from increased growth rates after 1949-1951 period of exceptionally high walleye densities.

LBDN male walleye average length at age-3



Management direction

Depending upon where the data lie with respect to its percentiles, any given red flag may indicate a recovered, self-sustaining population where stocking could be reduced or stopped, or one where continued or increased stocking is appropriate. Therefore, we propose that stocking decisions are guided by collective findings (average) of the individual metrics, where stocking directions are scored as follows: Increase (+1), Reduce (-1), and No change or OK (0). The trend in the average value over time serves as a barometer to indicate whether stocking should increase or decrease from levels used during the last 15 years, and hence is referred to as the “Stocking Barometer”. A summary of all metric findings and Stocking Barometer scores for 2011 occurs in Table 1. Stocking Barometer scores are above zero suggesting that similar or increased levels of stocking (relative to those used during the last 15 years) would be appropriate at the present time.

We conducted a retrospective analysis, using data from prior years to compute Stocking Barometer scores and compared them to estimated walleye abundance levels in LBDN. This analysis proved that using the Stocking Barometer makes sense. For example, Stocking Barometer scores indicated the need for stocking reductions during the early 1990s when walleye populations were high, but elevated Stocking Barometer scores supported increased stocking during 2007-2011, when walleye abundance was relatively low (Table 2; Figure 3). These recommendations seem reasonable given changes in walleye abundance, system productivity, and harvest (legal and illegal) that have been documented during this period.

Table 1. Benchmark and most recent values for indicator variables for walleye management in LBDN. The direction of stocking change suggested by each metric and overall Barometer score (average of metric values) are shown. Benchmark values of “15-yr mean” for natural reproduction variables are based on data from 2003-2009, and growth data (except for 2010) were combined for several years to increase sample size. Values shown for “Percent unmarked or age-1 wild CPE” are age-1 gill net catch-per-effort values for naturally produced walleyes from the 2003-2009 year classes.

			3 of 5 year percentiles				Recent year's percentiles		
Variable	2011	15yr mean	60th	40th	Direction		80th	20th	Direction
Abundance* **									
Age-4+ population estimate	190,659	198,871	198,963	194,112	Increase		209,876	189,896	OK
Non-charter May-June CPH	0.12	0.14	0.14	0.12	Increase		0.18	0.12	OK
Natural reproduction									
Percent unmarked or age-1 wild CPE*	--**	0.95	0.50	0.47	Increase		1.27	0.30	
Age-2 gill net CPE	0.70	0.74	0.71	0.66	OK		0.92	0.62	OK
Prey fish abundance									
Gill net forage CPE	6.63	4.68	5.84	3.35	Reduce		6.77	2.45	OK
Trawl CPE	44.5	27.6	28.9	22.7	Increase		42.2	13.3	Increase
Walleye growth									
Mean length at age-3 in September	14.90	15.03	15.30	14.90	OK		15.30	14.80	OK
Barometer score					0.43				0.17

* Defined as >50% naturally reproduced fish per 300,000 fish stocked, or in unstocked years, age-1 CPE >20th percentile for naturally-produced fish for 2004-2009.
** Percent wild could not be evaluated in 2010 due to a poor OTC mark
*** 30th percentiles used for both abundance metrics

Table 2. A) Walleye stocking recommendations for Little Bay de Noc from indicators with 15+ years of data, using 80th and 20th percentiles (30th percentile for No. Age4+ and Angler CPH metrics), and comparisons with the most recent year. B) Walleye stocking recommendations from indicators using 60th and 40th percentiles, and the majority of findings for the previous 5 years. Percentiles were calculated each year from the 15 most recent years of data, except as indicated by asterisks. Descriptions for abbreviated headings are as follows: Age3 Growth- mean length of age-3 male walleye; No. Age4+- Estimated number of age-4 and older walleyes; Angler CPH- Angler harvest per hour of walleyes in May and June; Forage TR- number of fish caught per 10-minute trawl tow; Forage GN- catch per day from gill nets of prey fishes important in walleye diets (i.e., yellow perch, alewife, round goby, trout perch); Age2 CPE- catch per effort of age-2 walleyes in gill nets; Age1 CPE- catch per effort of age-1 walleye in gill nets and percentage hatchery contribution to year class; Barom. Score- stocking barometer score recommending stocking direction (i.e., increase (+1), reduce (-1), and no change (0)) relative to stocking levels used during the last 15 years.

A)

Year	Age3 Growth	No. Age4+	Angler CPH	Forage TR	Forage GN	Age2 CPE	Age1 CPE	# Reduce	# Increase	# Ok	Barom. Score
1998		OK						0	0	1	0.00
1999		Increase	OK					0	1	1	0.50
2000		Increase	Reduce					1	1	0	0.00
2001		Increase	Reduce					1	1	0	0.00
2002		OK	Reduce	OK	OK			1	0	3	-0.25
2003		Increase	OK	OK	Reduce			1	1	2	0.00
2004		Increase	OK	OK	Reduce	OK	Reduce	2	1	3	-0.17
2005		OK	Increase	OK	OK	OK	Reduce	1	1	4	0.00
2006		OK	Increase	OK	OK	Reduce	Reduce	2	1	3	-0.17
2007		Increase	OK	Increase	Reduce	OK	Increase	1	3	2	0.33
2008		Increase	OK	OK	Reduce	Increase	Reduce	2	2	2	0.00
2009*		Increase	Increase	Increase	Reduce	Reduce	Increase	2	4	0	0.33
2010*	OK	Increase	Increase	OK	OK	Increase	Reduce	1	3	3	0.29
2011*	OK	OK	OK	Increase	OK	OK		0	1	5	0.17

*Includes growth, age2 CPE, and age1 CPE recommendations using percentiles based on <15 years of data

B)

Year	Growth	No. Age**4+**	Angler CPH	Forage TR	Forage GN	Age2 CPE	Age1 CPE	# Reduce	# Increase	# Ok	Barom. Score
1998		Reduce						1	0	0	-1.00
1999		Reduce	Reduce					2	0	0	-1.00
2000		OK	OK					0	0	2	0.00
2001		Increase	OK					0	1	1	0.50
2002		Increase	Reduce	Reduce	Reduce			3	1	0	-0.50
2003		Increase	Reduce	Reduce	Reduce			3	1	0	-0.50
2004		Increase	Reduce	Reduce	Reduce			3	1	0	-0.50
2005		Increase	Reduce	OK	Reduce			2	1	1	-0.25
2006		Increase	OK	OK	Reduce			1	1	2	0.00
2007		Increase	Increase	OK	Reduce			1	2	1	0.25
2008		Increase	Increase	Increase	Reduce			1	3	0	0.50
2009*		Increase	Increase	Increase	Reduce			1	3	0	0.50
2010*	OK	Increase	Increase	Increase	Reduce	Reduce	Increase	2	4	1	0.29
2011*	OK	Increase	Increase	Increase	Reduce	OK	Increase	1	4	2	0.43

*Includes growth, age2 CPE, and age1 CPE recommendations using percentiles based on <15 years of data

Literature Cited

Baldwin, N. A., R. W. Saalfeld, M. R. Dochoda, H. J. Buettner, and R.L. Eshenroder. 2009. Commercial Fish Production in the Great Lakes 1867-2006 [online]. Available from http://www.glfc.org/databases/commercial/commerc.php.

Claramunt, R. M., D. F. Clapp, B. Breidert, R. F. Elliott, C. P. Madenjian, D. M. Warner, P. Peeters, S. R. Robillard, and G. Wright. 2008. Status of chinook salmon in 2005. *Edited by* D. F. Clapp and W. Horns. Great Lakes Fishery Commission Special Publication 08-02. Pages 71-80.

Fielder, D. G., and J. P. Baker. 2004. Strategy and options for completing the recovery of walleye in Saginaw Bay, Lake Huron. Michigan Department of Natural Resources, Fisheries Division, Special Report 29. Ann Arbor.

Fielder, D. G., J. S. Schaeffer, and M. V. Thomas. 2007. Environmental and ecological conditions surrounding the production of large year classes of walleye (Sander vitreus) in Saginaw Bay, Lake Huron. Journal of Great Lakes Research (Supplement 1): 118-132.

Jennings, M. J., J. M. Kampa, G. R. Hatzenbeler, and E. E. Emmons. 2005. Evaluation of supplemental walleye stocking in northern Wisconsin lakes. North American Journal of Fisheries Management 25:1171-1178.

Jennings, M. J., J. E. Claussen, and D. P. Philipp. 1996. Evidence for heritable preferences for spawning habitat between two walleye populations. Transactions of the American Fisheries Society 125:978-982.

Kampa, J. M. and M. J. Jennings. 1998. A review of walleye stocking evaluations and factors influencing stocking success. Research Report 178. Wisconsin Department of Natural Resources. Spooner, Wisconsin.

Kapuscinski, K. L., T. G. Zorn, P. J. schneeberger, R. P. O'Neal, and B. T. Eggold. 2010. The status of Lake Michigan walleye stocks. Pages 15-70 *in* Status of walleye in the Great Lakes: proceedings of the 2006 Symposium. Great Lakes Fishery Commission Technical Report 69.

Kerr, S. J. 2008. A survey of walleye stocking activities in North America. Fish and Wildlife Branch. Ontario Ministry of Natural Resources. Peterborough, Ontario.

Kerr, S. J., B. W. Corbett, D. D. Flowers, D. Fluri, P. E. Ihssen, B. A. Potter, and D. E. Seip. 1996. Walleye stocking as a management tool. Percid Community Synthesis, Walleye Stocking Working Group, Ontario Ministry of Natural Resources, January 1996.

Li, J., Y. Cohen, D. H. Schupp, and I. R. Adelman. 1996. Effects of walleye stocking on year-class strength. North American Journal of Fisheries Management 16:840–850.

Madenjian, C. P., R. O'Gorman, D. B. Bunnell, R. L. Argyle, E. F. Roseman, D. M. Warner, J. D. Stockwell, and M. A. Stapanian. 2008. Adverse effects of alewives on Laurentian Great Lakes fish communities. Transactions of the American Fisheries Society 28:263-282.

MDNR (Michigan Department of Natural Resources). 2004. Stocking guidelines for various species of fish. Chapter 5 *in* Dexter, J. L., Jr., and R. P. O'Neal, editors. Michigan fish stocking guidelines II: with periodic updates. Michigan Department of Natural Resources, Fisheries Special Report 32, Ann Arbor.

Michigan Water Resources Commission. 1963. Commercial fishing in the Michigan waters of Green Bay. October 30, 1963 staff report.

Schneeberger, P. J. 2000. Population dynamics of contemporary yellow perch and walleye stocks in Michigan waters of Green Bay, Lake Michigan, 1988-96. Michigan Department of Natural Resources, Fisheries Research Report 2055, Ann Arbor.

Schneider, J. C., T. J. Lychwick, E. J. Trimberger, J. H. Peterson, R. O'Neal, and P. J. Schneeberger. 1991. Wallleye rehabilitation in Lake Michigan, 1969-1989. Pages 23-62 *in* P. J. Colby, C. A. Lewis, and R. L. Eshenroder, editors. Status of walleye in the Great Lakes: case studies prepared for the 1989 workshop. Great Lakes Fishery Commission, Special Publication 91-1, Ann Arbor.

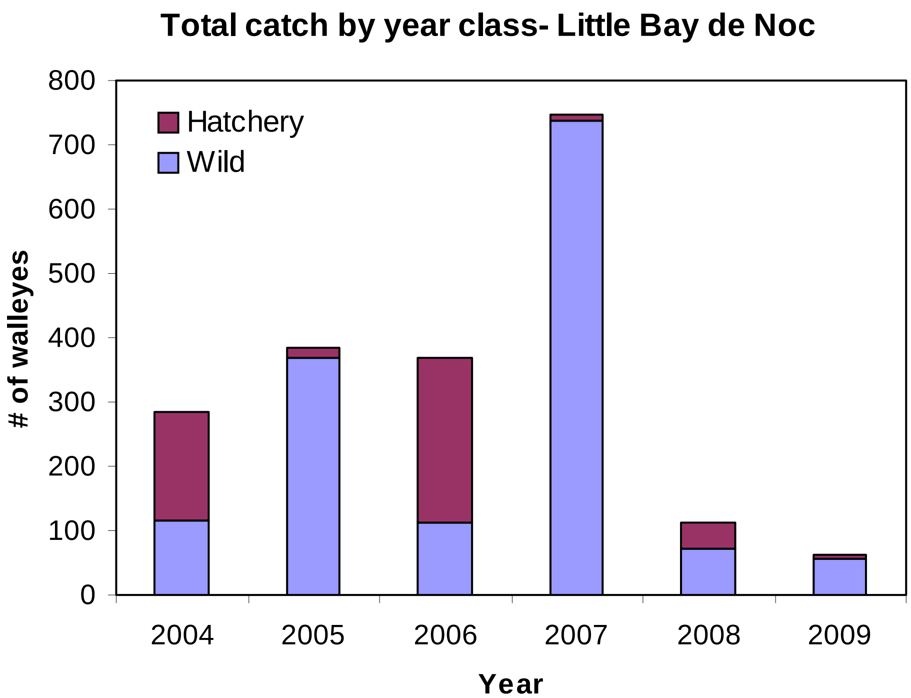
Schneider, J.C., P.W. Laarman, and H. Gowing. 2000. Age and growth methods and state averages. Chapter 9 *in* Schneider, James C. (ed.) 2000. Manual of fisheries survey methods II: with periodic updates. Michigan Department of Natural Resources, Fisheries Special Report 25, Ann Arbor.

Schneider, J. C., R. P. O'Neal, and R. D. Clark, Jr. 2007. Ecology, management, and status of walleye, sauger, and yellow perch in Michigan. Michigan Department of Natural Resources, Fisheries Division, Special Report 41. Ann Arbor.

Tyson, J.T., R.A. Stein, and J.M. Dettmers [EDS.]. 2009. The state of Lake Erie in 2004. Great Lakes Fishery Commission Special Publication 09-02.

Zorn, T. G. 2010. Influence of lotic and nearshore habitats on fish populations in Great Lakes and inland lake ecosystems, with emphasis on walleye. Annual progress report for study 521, Project F-80-R-11, October 1, 2009 to September 30, 2010, Sport Fish Restoration Program. Michigan Department of Natural Resources, Fisheries Division, Lansing.

Zorn, T.G., and P.J. Schneeberger. 2011. Changes in habitat and fish community in the Michigan waters of Green Bay 1988-2005. Michigan Department of Natural Resources, Fisheries Research Report 2096, Ann Arbor.



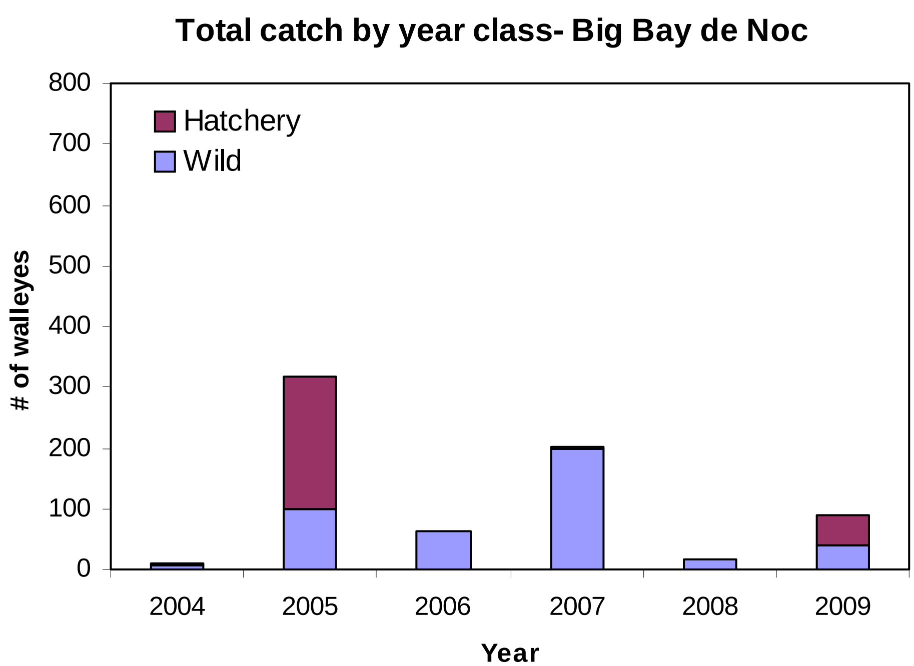


Figure 1. Total numbers of age-0 to age-3 walleyes examined by year class and reproductive origin.

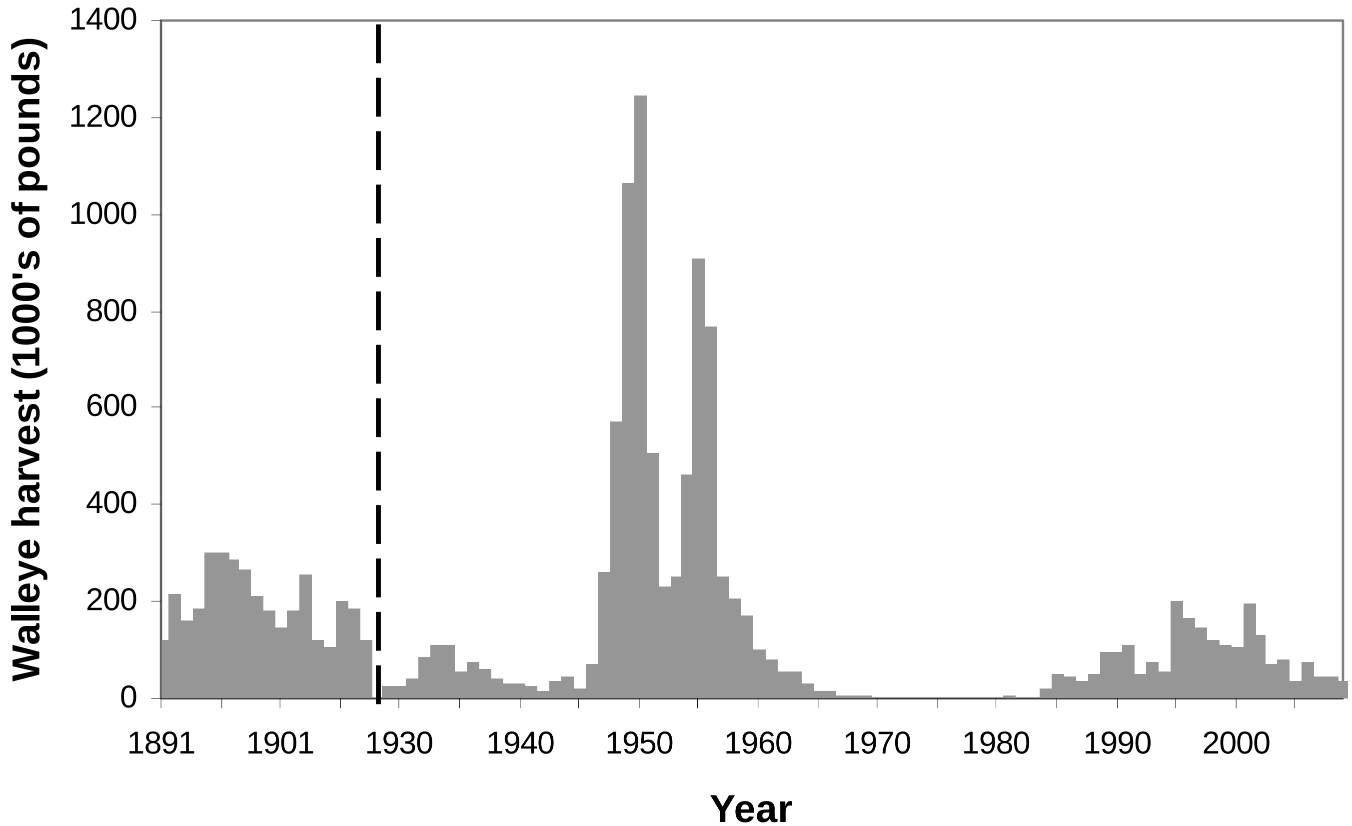


Figure 2. Historic harvest of walleyes in northern Green Bay. Catches after 1985 are entirely from the sport fishery, and the roughly 72,000 pounds of walleyes illegally harvested from Little Bay de Noc from 2004-2009 are not included. Vertical dash indicates a break in the time series for 1909-1928 where data were unavailable. High yields in the late 1940s and early 1950s represent the combination of exceptionally strong year class(es) and use of larger trap nets which were more effective on walleye. Data obtained from Baldwin et al. (2009) and DNR Fisheries Division (unpublished data).

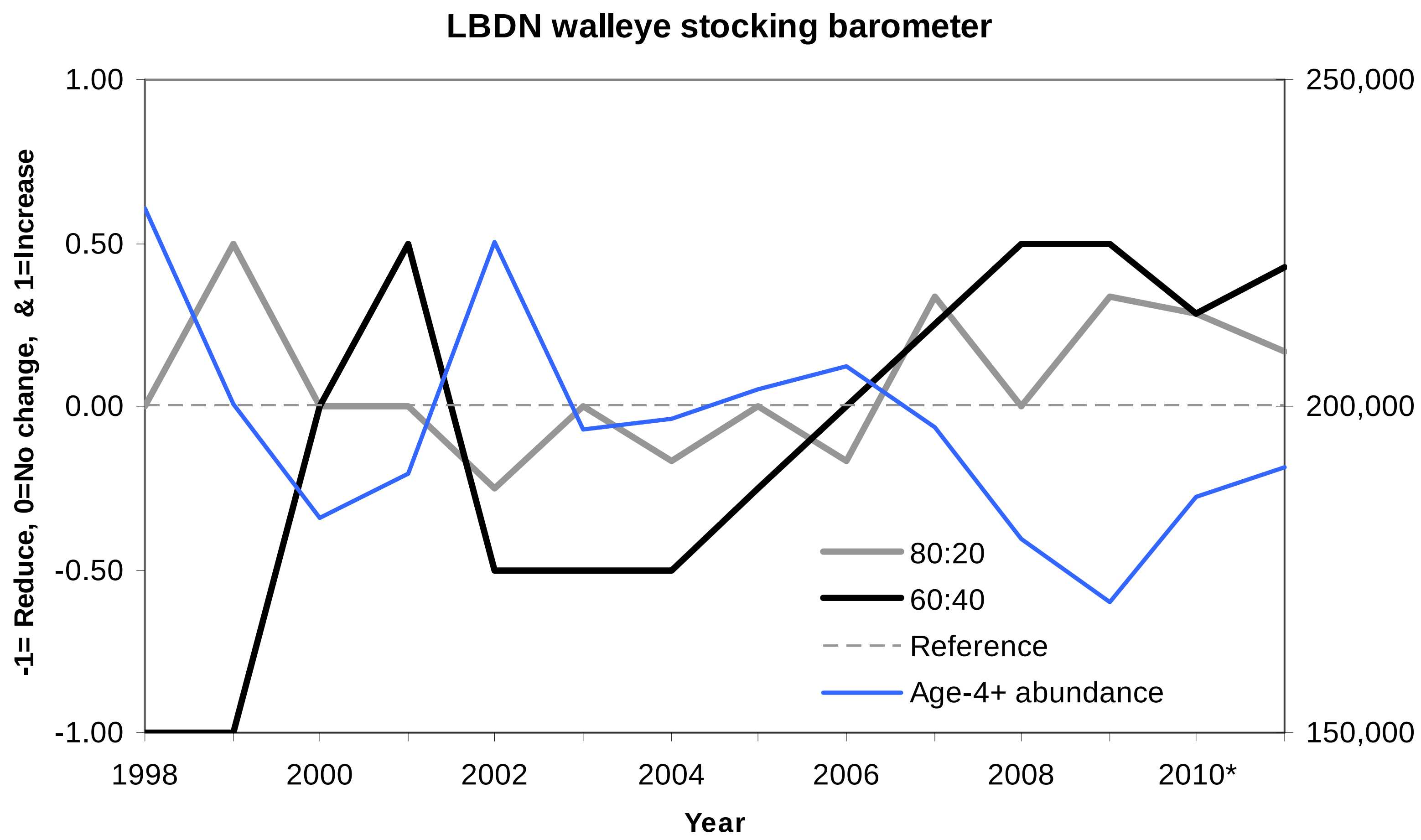


Figure 3. Walleye stocking barometer values for Little Bay de Noc from retrospective analysis. Values represent analyses based on 5-year (60:40) and 1-year (80:20) periods. A value of 1 indicates that all metrics pointed towards increased stocking, while a value of -1 indicates that all metrics pointed towards stocking reductions (the Reference line indicates no change from status quo is recommended). The estimated abundance of age-4 and older walleyes is shown for comparison.

Appendix 1. Commercial landings of walleyes at northern Lake Michigan ports from 1941 to 1957. Data from State of Michigan Archives in Lansing. Notes: The landing for Fayette in 1956 was missing, and therefore estimated using the overall ratio of Fayette to Garden landings (i.e., Garden landings averaged 2.91 times higher than Fayette landings). In almost every year, the commercial fishery at Rapid River did not report landings from May through November, and appeared to target suckers and carp from December through April.

														Harvest per acre	
Year	**Garden**	**Stonington**	**Fayette**	**Nahma**	**Ensign (Ogoı**	**Gladstone**	**Escanaba**	**Rapid R**	**Cedar R**	**Total**	**LB total**	**BB total**	**%of BDNasLB**	**LB**	**BB**
1941	302	0	53		624		3,066		59	4,104	3,066	979	75.8%	0.077	0.010
1942	423	0	68	251	858	10,789	2,625		38	15,052	13,414	1,600	89.3%	0.337	0.017
1943	166	0	1,005	456	1,308	0	3,895		8	6,838	3,895	2,935	57.0%	0.098	0.031
1944	832	72	729	978	1,413	31,425	5,846	0	38	41,333	37,271	4,024		0.937	0.043
1945	790	0	1,215	892	718	12,505	2,500	0	540	19,160	15,005	3,615	80.6%	0.377	0.039
1946	6,461	7	1,830	2,705	10,126	29,177	10,526	201	2,203	63,236	39,904	21,129	65.4%	1.003	0.226
1947	29,514	435	8,444	31,069	42,239	46,747	70,798	0	2,878	232,124	117,545	111,701	51.3%	2.956	1.197
1948	98,231	242	18,311	76,995	47,177	66,850	141,135	0	26,092	475,033	207,985	240,956	46.3%	5.230	2.583
1949	186,673	4,444	62,372	124,035	57,037	100,838	306,068	0	29,674	871,141	406,906	434,561	48.4%	10.232	4.658
1950	176,332	11,911	71,763	80,129	82,073	86,576	701,507	98	34,728	1,245,117	788,181	422,208	65.1%	19.820	4.526
1951	92,303	13,888	31,417	46,579	47,661	28,514	231,644	0	13,672	505,678	260,158	231,848	52.9%	6.542	2.485
1952	53,923	59	17,857	18,613	8,305	18,411	107,883	0	7,576	232,627	126,294	98,757	56.1%	3.176	1.059
1953	40,115	5,045	8,253	16,996	19,998	25,106	109,635	0	4,487	229,635	134,741	90,407	59.8%	3.388	0.969
1954	91,492	2,099	27,488	33,207	28,160	29,592	251,278	0	4,171	467,487	280,870	182,446	60.6%	7.063	1.956
1955	235,129	3,085	86,081	89,226	34,439	56,578	318,552	1,036	10,853	834,979	376,166	447,960	45.6%	9.459	4.802
1956	191,858	9,394	65,931	37,981	28,213	64,891	298,214	0	8,708	705,190	363,105	333,377	52.1%	9.131	3.573
1957	39,370	1,422	24,730	12,346	14,665	35,423	95,927	0	632	224,515	131,350	92,533	58.7%	3.303	0.992
Averages:	73,171	3,065	25,150	35,779	25,001	40,214	156,535	95	8,609	363,132	194,462	160,061	60.3%	4.890	1.716
% of total:	20%	1%	7%	10%	7%	11%	43%	0%	2%						