# SIZE OF AGE-0 *SANDER VITREUS* PRE AND POST *DREISSENA POLYMORPHA* INFESTATION ON BRAINERD AND BEMIDJI AREA LAKES

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***Abstract*—Walleye *Sander vitreus* is the Minnesota state fish and a vital predator fish in lake ecology. Zebra mussels, *Dreissena polymorpha* were first found in Minnesota inland lakes in the 1980's. These mussels have had huge impacts on water clarity as well as phytoplankton and zooplankton population levels which affect how age-0 fish feed, especially a low light feeding predator fish like walleye. A study took place on age-0 walleye size and it supported the conclusion that age-0 walleye were negatively impacted by zebra mussels in Minnesota's large lakes. The goals of this study were to determine how the size of age-0 walleye are impacted by changing water clarity in two Minnesota lake regions (northwest and central). Fall electrofishing data was collected on age-0 walleye, zebra mussel invasion dates and water clarity measurements were collected by the Minnesota Department of Natural Resources and Minnesota Pollution Control Agency. The factors of lake (*P* = 0.00008), year (*P* = 0.00273), and zebra mussel status (*P* = 0.00069) all had statistically significant relationships with age-0 walleye size. The effect of average June Secchi (*P* = 0.13310) did not have a statistically significant difference on age-0 size. Age-0 walleye size increased post-invasion (11 mm) as well as water clarity depths (1.16 m). Water clarity measurements varied from lake to lake, but all lakes consistently increased in the first five years post invasion.**

## I. INTRODUCTION

The zebra mussel, *Dreissena polymorpha* have been a highly debated and researched invertebrate since their introduction into Minnesota's inland waters. These small inhabitants can alter ecosystems dramatically as has been seen in many lakes as a result of their invasion in the mid 1980s (Depew 2021). Zebra mussels are very efficient aquatic invaders in freshwater lakes and are highly specialized to filter feed on pelagic food, then returning their feces to the benthic zone. Through secreting this food out of the pelagic zone it increases the water clarity in lakes, increasing the depth surface light can reach into the water column. For example, in Oneida lake in New York, the average depth receiving 1% surface light was increased from 6.7 m pre zebra mussel invasion to 7.8 m after the invasion of zebra mussels. This represented a 23% aerial expansion (Zhu et al. 2006). The water clarity change not only affects phytoplankton abundance, but it also affects zooplankton abundance in the initial years following invasion of an ecosystem (Pace 2010). This is not only impactful on micro and macroinvertebrates, but it also will affect the whole lake ecology. Meaning it affects how age-0 fish feed and what they can feed on.

The state fish of Minnesota is the walleye *Sander vitreus.* This one species of fish plays a vital role in most of Minnesota's lakes ecology and has a significant role in Minnesota's economy. The Minnesota Department of Natural Resources (MN DNR) invests a lot of money, time, and effort into stocking, surveying, and researching walleye. It is logical to put in effort to gain understanding of how effective the stocking and management plans are working. One prime example was Mille Lacs Lake in central Minnesota, which was infested with zebra mussels in 2006. The Mille Lacs walleye population, which was more stable than any other walleye population in the larger lakes in Minnesota, dropped to historically low levels in the five-year timespan from 2007-2012 (Kumar 2015). This lake has been highly altered by the zebra mussel colonization and the walleye population has been in fluctuation throughout the past decade.

A previous study conducted in the year 2020 hoped to find the effects of zebra mussels on age-0 walleye. Data from nine lakes, including a majority of Minnesota's large lakes, was used. This data included near shore seins collected in years ranging from 1983-2018 from mid-July to mid-August each year (Hansen et al. 2020). This study found age-0 walleye were 9.2% smaller in zebra mussel invaded systems than uninvaded systems (Hansen et al. 2020). The 2020 study differs from this study in lakes, data collection, and classification of invaded versus uninvaded.

Through the analysis of age-0 walleye electrofishing data of five central Minnesota lakes and six northern Minnesota lakes, this study looks to find how zebra mussel invasion has affected age-0 walleye size and growth. Water clarity measurements are used as evidence of zebra mussel invasion on all analyzed lakes. Monitoring of age-0 walleye occurs on many Minnesota lakes through fall electrofishing to see how well recruitment was for the age-0 and age-1 year classes. Year class physical size and mortality is heavily affected by abiotic conditions in the spring of the year as well as the previous winter's environmental effects. Fall electrofishing is meant to measure the age-0 and age-1 cohorts in order to adjust possible management plans or stocking rates. This study uses all fish caught and measured electrofishing to analyze the size of fish in a certain timeframe.

## II. Methods

Using Secchi disk measurements as evidence of zebra mussel infestation, this study looked at the total lengths of age-0 walleye pre and post zebra mussel invasion to see what effects zebra mussels and water clarity have had on the fish. Five of the eleven lakes used in this study are located in central Minnesota, near the Brainerd lakes area. The lakes are as follows: Gull Lake, Pelican Lake, Thunder Lake, Edward Lake, and Washburn Lake. Washburn Lake has yet to be labeled infested with zebra mussels. The other six lakes in this study were from the Bemidji area and are: Bemidji, Big, Blackduck, Plantagenet, Julia, and Itasca. Julia, Itasca, and Blackduck are lakes not yet infested with zebra mussels. Bemidji, Big, and Plantagenet are lakes that contain zebra mussels. The lakes not infested with zebra mussels were used as comparative lakes to see if other abiotic factors like weather could have played a role in age-0 walleye size in a specific year.

June Secchi data was collected from the Minnesota PCA data set (MN PCA 2025). This data was collected in the field from a variety of agencies or lake monitoring groups. The month of June was chosen due to inconsistent data collection in the month of May over time. Later in the summer such as July-September warmer water temperatures support spontaneous algal blooms creating irregular data. Algal concentration in a lake is a dynamic variable that often changes drastically within a short period of time (Kislik 2018). Most years there were two to four Secchi depths taken in the month of June. To better asses the Secchi depth of that month, each Secchi measurement was then averaged.

All the lakes in this study were smaller than Minnesota's designated large lakes. The lakes in this study ranged in size from 1 to 13 $km^2$, while many of the large lakes are over 40 $km^2$. Data for the year that each lake was labeled infested with zebra mussels was collected from the Minnesota Department of Natural Resources infested waters list (MN DNR 2024).

For many Minnesota lakes routine fall electrofishing occurs within the months of August, September, and October. The data collected by these electrofishing surveys was the data used in this study. Total lengths were recorded during the surveys and some specimens were kept and aged to ensure where the size break was between age-0 and age-1 fish. In this study all the fish lengths were then averaged per year to get the mean age-0 size per year. The average fish size per year was then plotted according to lake. Lakes are monitored for zebra mussels through water surveys, survey plates, and most commonly, equipment inspection during end of year removal. The Minnesota DNR keeps a record of what year lakes have been infested. This study analyzed data from 2000-2024. This timeframe includes years pre and post zebra mussel infestation of the lakes.

To test if there was a significant difference between the continuous variable of June Secchi depth and age-0 size, a regression test was used. To test if there was a significant relationship between the categorical factor of lake and age-0 size, an ANOVA test was used. To find if there was a significant relationship between the categorical factor of year and age-0 size, an ANOVA test was used. To analyze if there was a significant relationship between the categorical fact of zebra mussel status, an ANOVA test was used. Program R was used to run these analyses. Through this testing, the main goal was to isolate the age-0 walleye size variable as much as possible to get the most accurate measurement of the effect that zebra mussels and water clarity have had on the fish.

## III. Results

The average size of age-0 walleye varied significantly among the lakes analyzed ($P < 0.001$; Figure 1). Both Blackduck Lake ($\mu$ = 170 mm, $\sigma$ = 13.3) and Edward Lake ($\mu$ = 170 mm, $\sigma$ = 20.2) had the largest average age-0 size, while Big Lake had the smallest age-0 size ($\mu$ = 147 mm, $\sigma$ = 18.0) including two years of 0 fish electro-fished over the 24 year timespan. Washburn lake had the most consistent walleye size ($\sigma$ = 9.68), while Plantagenet had the most inconsistent walleye size ($\sigma$ = 26.0) over the timespan analyzed.

Most all lakes included in this survey had an average Secchi of around two to six meters in depth. Including all years of data in the 24 year timespan, whether or not zebra mussels were present or absent, the lake with the deepest Secchi measurements was Pelican Lake ($\mu$ = 6.14 m, $\sigma$ = 1.41 m). The lake with the shallowest Secchi measurements was Blackduck Lake ($\mu$ = 3.51 m, $\sigma$ = 0.85 m). Including data from all lakes within the study's timeframe the average Secchi depth increased post invasion (1.16 m).

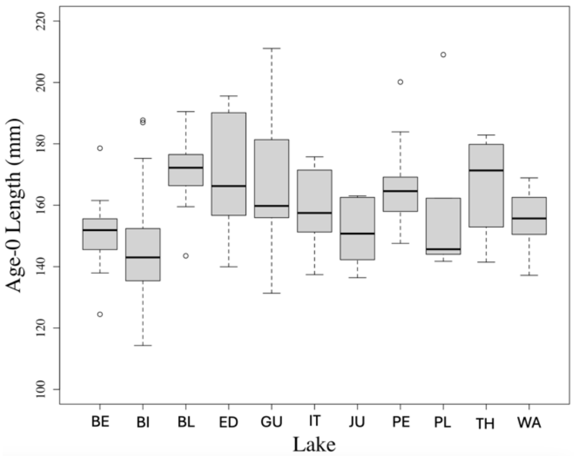


Figure 1. Age-0 walleye lengths on Bemidji and Brainerd Minnesota area lakes (P = 0.00008). All data was from the year 2000 to 2024. BE is Bemidji, BI is Big, BL is Blackduck, ED is Edward, GU is Gull, IT is Itasca JU is Julia, PE is Pelican, PL is Plantagenet, TH is Thunder, and WA is Washburn.

Average June Secchi depths in the years pre-zebra mussel infestation were relatively consistent within a meter or two of their ten-year average (Figure 2). Once infested with zebra mussels, the lakes water clarity increased drastically within the first five years of infestation. Through producing graphs of Secchi depth measurements over the last twenty-four years of data, visual confirmation supports the conclusion that water clarity increases in the years following a lakes zebra mussel status change.

Water clarity and age-0 size data appears more clustered with lakes grouping together instead of a negative correlation (Figure 3). This supports the insignificance that water clarity has on the age-0 size. Using Secchi depth measurements pre and post zebra mussel invasion a regression test was done. The water clarity variable affecting age-0 size was not statistically significant ($P$ = 0.13310). Water clarity has many factors such as chlorophyll, turbidity, sediment levels, and nutrient levels. These factors can vary dramatically year to year, sometimes even day to day on certain water bodies. Age-0 size according to lake tended to group together in this graph as well suggesting the statical significance of the lake-to-lake variability.

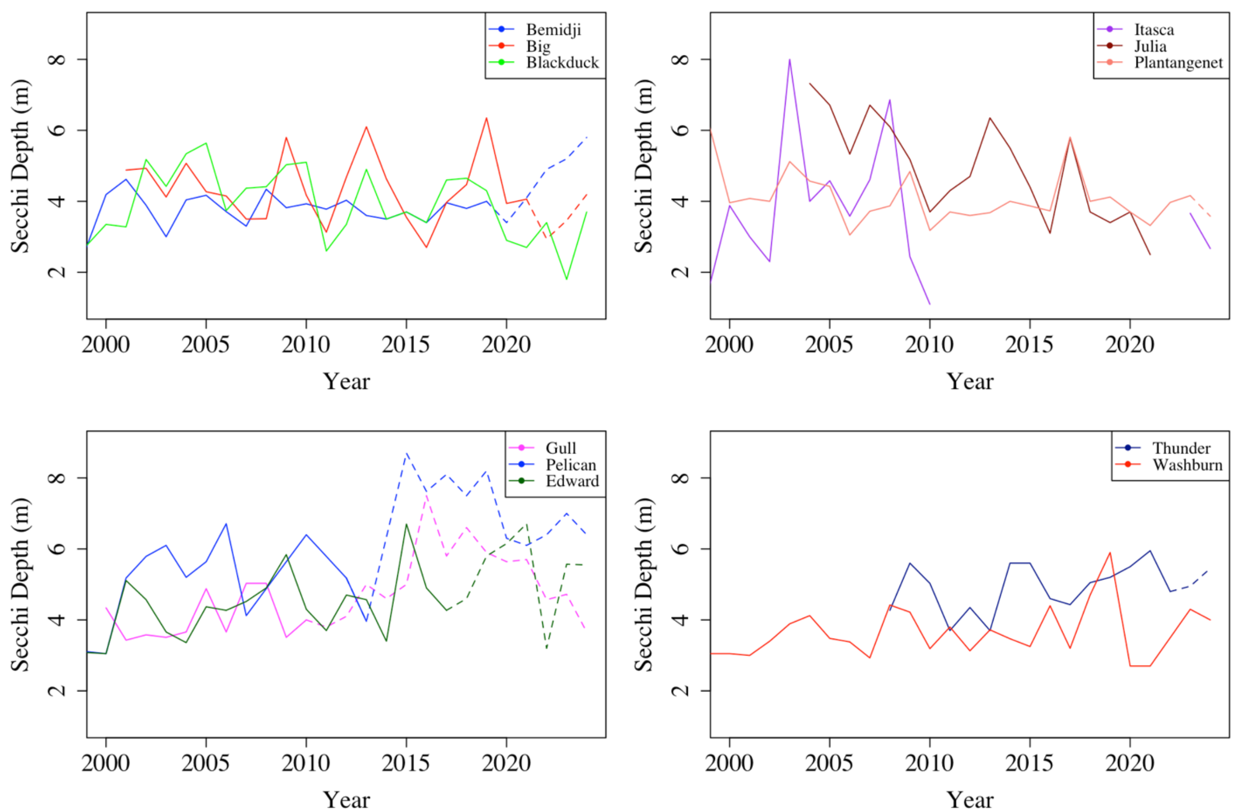


Fig. 2. Average June Secchi depths on all eleven lakes analyzed in both the Bemidji and Brainerd, Minnesota areas. Lakes are labeled by color, and the lake name appears in the legend of each graph. The dotted part of lines is data from years' post-zebra mussel invasion.

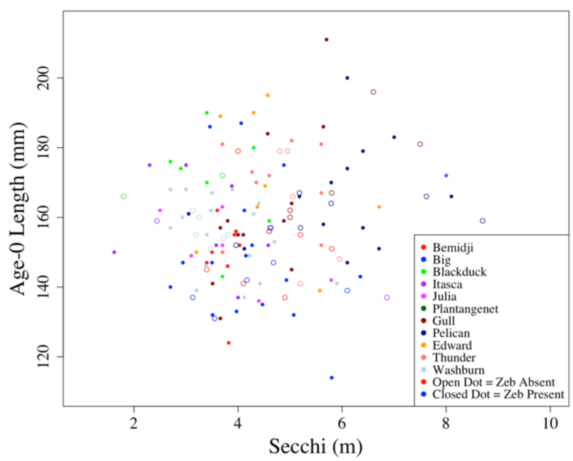


Fig. 3. Mean age-0 walleye length (y-axis) compared to average June Secchi measurements (x-axis; P = 0.13310). Each dot represents the average age-0 size each year. Open dots are years zebra mussels are absent in the lake, while closed dots are years when zebra mussels are present.

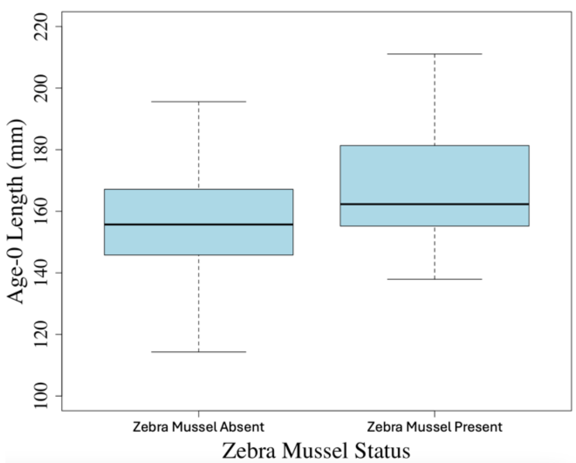


Fig. 4. Average age-0 walleye size for all lakes in this study. Each year pre and post zebra mussel infestation was analyzed in this graph. Average pre infestation age-0 size was 156 mm and average post infestation size was 167 mm (P = 0.00069).

Including every lake in this study and all age-0 size measurements pre and post zebra mussel invasion, it was found that age-0 walleye size pre and post zebra mussel invasion had a statistically significant relationship ($P = 0.00069$). On average, age-0 walleye size was shown to increase (11 mm) in the years post zebra mussel invasion (Figure 4). Age-0 size was also significantly different among years ($P = 0.0273$).

## IV. Discussion

The primary finding of this study was that age-0 walleye size was positively affected by zebra mussel presence on a low level (11 mm). This finding was similar to a Lake Erie study in 1999, where Trometer and Busch (1999) found no significant differences in age-0 growth for yellow perch *Perca flavescens* and walleye *Sander vitreous* pre and post zebra mussel invasion. These findings, however, are in contrast to another study of similar foundation. Hansen et al. (2020) found that walleye were smaller at mid-summer and grew more slowly throughout the growing season, resulting in mid-August lengths that were 15 and 18 mm (12 and 14%) smaller in lakes containing *Bythotrephes* and zebra mussels, respectively, compared to uninvaded systems. A major factor that differs from this study is lake size. Each of the large lakes that was analyzed have varying stocking rates, which could possibly vary size of individual age-0 fish throughout the year by increasing CPUE. As found across the Great Lakes region, study to study differences suggest differing results in the impact of zebra mussel on age-0 fish size. To verify the increase in size through this study, more lakes of similar size would need to be analyzed as well as possibly expanding the research region to Minnesota's southern regions. Abiotic conditions such as global warming or other unnatural occurrences such as decreased average wind over a time period could cause a shift of age-0 size on a lake.

Another large factor that was not analyzed in this study was CPUE pre and post zebra mussel invasion. This study's aim was to determine if water clarity increase, due to zebra mussel presence, has affected age-0 size. Adding analysis of a factor such as CPUE would have exceeded this studies time frame. In Oneida Lake in New York for both yellow perch and walleye, trawl CPUE was lower during the post zebra mussel period; however, recent catches often were not below projected catches (Rudstam et al. 2016). Analysis of electrofishing CPUE would need to be conducted to analyze Minnesota's age-0 catch rate. Through analysis, some of the lakes in this study have seen a decrease in number of fish caught while fall electrofishing, more specifically in lakes that have had a longer period of time post invasion. These lakes are located on the southern end of this studies range around Brainerd, Minnesota. There are also many factors that play a role in CPUE analysis. Some of the critical factors that can have a lot of variability could be the amount of time spent electrofishing as well as abiotic weather conditions experienced on the night that electrofishing occurred.

Through this study, another finding was that lake to lake variability between age-0 walleye size was significant. In a previous study, it found that inability to account for variability in Walleye abundance among lakes of the same size can lead to a mismanaged fishery (Hansen et al. 2015). This supports how crucial it is to recognize that there can be significant differences in quantity of walleyes in lakes with similar size and even within the same region. Another potential underlying difference between lakes (including the presence of other invasive species) could be driving variation in growth rates among walleye populations (Nienhuis et al. 2014). Most lakes in this study are only infested with zebra mussels. However, other non-bivalve species like starry stonewort *Nitellopsis obtusa* is found in Lake Bemidji, Thunder Lake, and Blackduck Lake. An aquatic invasive plant, Eurasion watermilfoil *Myriophyllum spicatum,* is found in Washburn Lake. Blackduck Lake has also acquired the faucet snail *Bithynia tentaculata* recently. Other aquatic invasive species, such as an aquatic plant or the faucet snail, would have to be studied further to see if it is suspect that they could affect fish growth. Growing degree days, stream or ground flow levels varying among lakes, or even base phytoplankton and zooplankton forage levels without zebra mussel effects are major factors in lake to lake variability. Some lakes are naturally more apt to growing age-0 fish more efficiently than others.

The factor of year was analyzed to be statistically significant through this study. Year factor has a lot of variables that would need to be included in its analysis. The main variable being growing degree days which can be influenced by abiotic factors such as wind, water levels, and water temperature of a specific year. Another variable that can play into year factor is interaction among other populations of fish through interspecific competition and even predation (Deangelis et al. 1993). These biotic factors can change yearly, which makes this near impossible to track or predict without further research on the specific ecosystem in question. Since many variables must be considered when comparing multi-year data sets for lake ecosystems, it is hard to analyze what the exact cause of age-0 size difference is on a year-to-year basis.

Another major finding through data analysis was the noticeable increase in water clarity in the first five years following the year of zebra mussel invasion. Around year five post invasion the clarity seemed to stable off, then in some cases even begins to decrease in years to follow. On Lake Erie's western and central basins, in the two earliest post-invasion years for which there is data (1989, 1991) did not appear to differ from pre-invasion years, but by 1996 chlorophyll a had decreased substantially (Barbiero et al. 2004). On Lake Ontario Secchi depths increased from an average of 3.9 to 6.5 m between the periods 1985-1991 and 1996- 2004, respectively (Barbiero et al. 2009). Both examples support a similar lag in peak clarity increase or turbidity decrease after the year of invasion (1989). Lake Erie and Lake Ontario are drastically different aquatic systems than the lakes in this study, with lake fetch alone being substantially different. However, possibly through more analysis of inland lakes and areas around the great lakes this pattern may be something to note.

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