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Growth and Condition of Largemouth Bass (*Micropterus nigricans*) and Bluegill (*Lepomis macrochirus*) in a Minnesota, USA, Lake with Separate Dredged and Non-Dredged Basins

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Abstract: The objective of this study was to assess the growth rates and general body condition of two common game fishes (largemouth bass *Micropterus nigricans* and bluegill *Lepomis macrochirus*) in a productive midwestern USA lake, Lake Winona, 20+ years after one of its two separate basins was partially dredged. We also used historical lake survey data spanning 19 years before and 15 years after dredging to assess the pre- and post-dredging growth of these species. Dredging was expected to improve the growth rates and conditions (relative weights) of both species due to post-dredging changes to lake habitats (more open water and reduced macrophyte beds) and the fish community structure in the dredged basin. Both species displayed significantly faster growth in the dredged basin, with the bluegill by age 3 and the bass by age 6. The mean relative weights of both species were significantly higher in the non-dredged basin (bass were in good condition: 106% versus 100%; bluegill were in fair condition: 84% versus 80%), although both bluegill and largemouth bass exhibited significant declines in relative weight with increasing lengths in the non-dredged basin. The growth rates for largemouth bass have declined from historical levels, especially in the non-dredged basin, whereas bluegill growth rates have remained stable or improved, especially in the dredged basin. Overall, largemouth bass and bluegill growth rates and relative weights are responding to differences in habitat and fish communities between dredged and non-dredged basins, indicating that the two lake basins are isolated enough from one another to allow for separate biological responses to occur in each.

Keywords: growth rates; dredging; relative weight; bluegill; largemouth bass

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1. Introduction

Dredging to remove accumulated sediments is a common rehabilitation technique for freshwater lakes, reservoirs, rivers, and estuaries [1–6]. Although expensive, dredging often is undertaken when multiple benefits (e.g., improving navigation, increasing water storage, reducing internal nutrient cycling, removing toxicants or nuisance aquatic plants, producing fill materials for development, and improving fisheries) can be achieved simultaneously, making the expenditure of funds more cost-effective [2,7–9]. The effectiveness lifespan of a dredging project is highly variable (e.g., months to 50+ years), and is largely dependent on the volume of the materials removed and the localized sedimentation rates [2].

Some dredging projects have been undertaken, in part, with the goals of improving system fisheries in various ways. These projects have attempted to enhance fish production via increased lake volume [3], improve fish abundance through expanded habitat diversity [10], and reduce overabundant and stunted fishes by eliminating protective shallow habitats [9]. Unfortunately, post-dredging monitoring to assess whether fishery goals were met is rarely conducted, with project success usually determined by some other factor(s) such as the volume of materials removed, proportion of habitats improved, or some other non-biological benchmark [9]. The true impacts of dredging on fish and fisheries typically have been studied only on very short-term time scales during and immediately following active dredging, such as fish stress or spawning/developmental problems caused by exposure to suspended sediments, displacement due to noise and other disturbances, or entrainment by the dredge itself [4,10–12]. The longer-term effects of dredging on fish communities or fish growth rates have been examined less often [5,9], but some game fish species may respond favorably to dredging and produce higher catch rates in combination with an increased angling effort [3,9,13–15].

Freshwater fishes display a variety of movement patterns within lakes, reservoirs, and river systems [16–25]. Regular, predictable movements can occur diurnally, seasonally, annually, or over longer time periods for a variety of reasons, including feeding, spawning, predator avoidance, and others [19,21–23,25], whereas some individuals may remain within a relatively small home range (<1 hectare) for years at a time, others may display rapid movements over short time periods (e.g., 1 km/h) [16,21]. Similarly, some fish living in open systems may never move from their home bay or cove [20,22], whereas others can move through entire chains of interconnected lakes, navigating through a series of restrictive culverts and shallows along the way [21].

The objective of our study was to examine present-day growth rates and conditions of two common (and the most sought after by anglers) game fishes (largemouth bass *Micropterus nigricans* and bluegill *Lepomis macrochirus*) in a productive midwestern USA lake comprised of two separate basins: one basin partially dredged 20+ years ago and the other not dredged. We examined fish growth rates and conditions in each basin separately, hypothesizing that improved game fish communities in the dredged basin (based on significant abundance changes and balanced size structures; bluegill and black crappie [*Pomoxis nigromaculatus*] abundances were reduced, bass abundance was increased, and black crappie size structures were improved) [9] also would lead to better growth rates and conditions in fish in the dredged basin relative to the non-dredged basin. We used this information to create von Bertalanffy growth models [26] for each species in each basin, allowing us to estimate the rates of change in length (K) and maximum achievable lengths (L_∞) for both species in each system, as well as to estimate how many years were required for the fish in each basin to achieve specific lengths. We also used fish growth data, collected in the 19 years before and 15 years after dredging by the Minnesota Department of Natural Resources (DNR), to develop pre- and post-dredging growth models for comparison to our current, basin-specific models.

2. Study Area

Lake Winona (44°02′19.54″ N, 91°38′37.24″ W; 197 m above sea level) is a 129-hectare floodplain lake, situated within a cut-off side channel of the Mississippi River in southeastern Minnesota, USA. It is categorized as a Minnesota lake class 38 system: shallow, alkaline, highly eutrophic, with a warmwater fish community dominated by bluegill and largemouth bass [27]. It existed as a single basin (3.2 km long × 0.5 km wide) until the lake was first dredged in 1913, when the construction of the Huff Street dike and causeway split the lake in two (Figure 1), creating a 36-hectare western basin and a 93-hectare eastern basin [28]. The basins are connected only by a single concrete culvert (~3 m in diameter) that allows for limited inter-basin movements of water (mostly on windy days) and fish.

The entire lake is on the state list of impaired waters due to excess phosphorus [29], with nutrient sources differing slightly between basins. Both basins receive stormwater runoff from city streets, parking lots, and a highway via numerous storm sewer outlets located around the lake perimeter. The western end of the western basin also receives inflows from a rerouted and channelized Gilmore Creek (designated as County Ditch #2; 3.9 km in length), and outflows exit the eastern end of the eastern basin, flowing through County Ditch #3 for 3.5 km to the Mississippi River. A flood control pumping station within the outflow ditch blocks fish movement between the lake and the river.

Angling is common in both basins during both the open-water season and during the winter through the ice. Anglers have shoreline access along the entire lake perimeter, as well as from one fishing pier in the western basin and three piers in the eastern basin. There are two boat launch ramps in the eastern basin and a single launch ramp in the western basin. There have been no studies of angling pressure conducted on Lake Winona.

Figure 1. Aerial view of Lake Winona, Minnesota, USA, showing the dredged eastern basin (**right**) and the non-dredged western basin (**left**) separated by the Huff Street dike and causeway. The lake is bordered to the north by city parks and residential areas, and to the south by a highway and forested blufflands.

In addition to the initial dredging in 1913, the lake has been dredged four other times: in the 1930s, 1950–1953, 1957–1958, and 1999–2001. Together, these projects deepened the lake by removing soils that had eroded from the watershed and washed into the lake due to rerouting of a local stream [28]. Dredged materials were used to fill nearby wetlands and other low-lying areas to create parklands, athletics fields, and lands for hospital, school, and commercial construction projects.

The most recent dredging of Lake Winona in 1999–2001 was restricted to the eastern basin only. That dredging project increased the basin's mean depth by >60% (from 2.6 m to 4.2 m) while increasing basin volume by 28% and reducing the littoral zone area (lake area < 3 m deep) by >30% [30]. Littoral zone reduction and the subsequent elimination of submersed macrophyte beds was estimated to impact the cover for up to 500,000 fish, proposed to force overabundant and stunted prey fishes into open water, where they would be more vulnerable to capture by larger predatory species [9,28].

3. Methods

3.1. Field Work

Collections of largemouth bass and bluegill were made on five dates between 29 September and 6 November 2023 (at or near the end of the 2023 growing season) from the eastern and western basins of Lake Winona. Basins were usually sampled on separate days. The entire shorelines of the lake basins were electrofished with a boat-mounted electrofisher (Smith-Root VVP-15B) to sample each species. In total, 70 largemouth bass and 70 bluegill were collected from the two basins. Each fish was weighed on a top-loading portable balance (wet mass, nearest g) and measured on a bump board (total length, TL, nearest mm). To interpret fish age and growth rates, multiple scales were collected from the left side of each fish, posterior to the pectoral fin and below the lateral line, using a small knife. Scales were placed in paper envelopes labeled with the fish's wet mass and total length, and allowed to dry flat in the envelopes until examination in the lab. Scales were used for age and growth interpretation rather than the preferred otoliths (due to easier interpretation of annuli) [31] to eliminate the need to sacrifice fish (thereby keeping them alive and available to the angling public) and to keep the methodology consistent with past procedures used by the Minnesota DNR for historical analyses for these species (i.e., scales used for aging and growth). We acknowledge that the use of scales for aging bluegill and largemouth bass may result in underestimating the ages of older fish [31].

3.2. Lab Work

Multiple scales from each fish were mounted between two glass microscope slides and examined under 40× magnification and low light on a compound microscope. Only scales that displayed no signs of regeneration were used. Multiple scales from each fish were examined until a fish age was determined by agreement between two examiners. Then, a single representative scale was selected for measurements. That scale was measured from the focus to each annulus along a straight line out to the anterior scale edge using an ocular micrometer [32]. Scale measurements were recorded on data sheets and used to back-calculate lengths at each annulus.

3.3. Data Analyses

Largemouth bass and bluegill length and wet mass data were used to make several comparisons between lake basins. Within each species, we pooled data for both male and female fish, assuming no sex-specific variation in growth. Although multiple studies have reported differences in growth rates between the sexes for both species [33–37], we combined male and female data to be comparable to past studies of these species in Lake Winona. We acknowledge that pooling unknown ratios of males and females may introduce some bias if growth rates differed between the sexes. For each species, non-parametric Mann–Whitney tests were used to determine whether the lengths or masses of fish used in this study varied between the dredged eastern basin and the non-dredged western basin. Analysis of covariance (ANCOVA) comparisons of the TL–mass relationships of $\log_{10}$-transformed (to meet normality assumptions) TLs and masses were made to determine if each species exhibited similar patterns between basins [38]. Statistical tests were performed using a combination of Microsoft Excel and a statistical computation website (www.vassarstats.net; accessed on 27 June 2024).

Fish length and wet mass data also were used to calculate the relative weights (as a measure of general body condition) of all individuals of both species collected in the eastern and western basins. The relative weight (W_r) formula used was $W_r = 100 \times (W/W_s)$, where W was the wet mass of the fish in g and W_s was the standard wet mass for a fish of the same TL (in mm) [38,39]. To determine the W_s for each fish, separate standard length–wet mass equations were used for each species [38,39]. These equations were as follows:

For bluegill: $\log_{10}W_s = 3.316 \times \log_{10}TL - 5.374$;

For largemouth bass: $\log_{10}W_s = 3.273 \times \log_{10}TL - 5.528$.

Relative weights for both species were compared between the eastern and western basins using Mann–Whitney tests [38]. In addition, simple linear regression analyses were used to compare the relative weights and TLs of each species within each basin to determine if relative weights changed as the TL increased.

Fish total lengths at all annuli were determined by back-calculating the length at each annulus using the following formula: fish TL at annulus = [(distance from scale focus to annulus/distance from scale focus to scale edge) × fish TL at capture)], where TL is in mm [32]. These data were used to compare the length-at-annulus values for each species between the eastern and western basins through a series of Mann–Whitney tests for each annulus with sufficient sample sizes in both basins.

Ford–Walford plots were produced using back-calculated mean sizes, graphing the TL at age t + 1 (on the Y axis) versus the TL at age t (X axis), where t = fish age in years [26,31]. These plots were used to create von Bertalanffy growth models for each species in each basin. This was performed using the Ford–Walford plot slope and Y-intercept to calculate two von Bertalanffy growth model parameters: $K = -\ln$ slope and L_∞ = intercept/(1 − slope) [26,31]. These values, L_∞ and K, were used to produce the von Bertalanffy growth model, $l_t = L_\infty \times (1 - e^{-K(t-t_0)})$, which was used to estimate the length of each fish at each year [26,31,32]. These results of length-at-age calculations were graphed to create the final von Bertalanffy growth models. Final growth models for each lake basin were used to estimate the ages (t) required for bluegill to reach 100 mm and 150 mm TL, and for largemouth bass to reach 200 mm and 300 mm TL, in each of the basins.

Historical lake survey data for Lake Winona were used to compare the pre-dredging and post-dredging growth rates for each species (Table 1). These data were obtained from Dan Spence, MN DNR-Fisheries, Lake City, MN, USA. Back-calculated growth data for each species were compared for surveys before (pre-1999) versus after (post-2001) dredging. Unfortunately, historical data collected from both basins were combined by the DNR to create a single lake-wide assessment of growth, so separate basin comparisons were not possible. Ford–Walford plots were produced using back-calculated mean sizes, and then used to create von Bertalanffy growth models for each species for the combined basins both before and after dredging in the same manner as described above. These lake-wide historical growth models were then compared to the current, basin-specific growth models, as well as current, lake-wide growth models created by combining data from both basins. We also compared Lake Winona growth models to growth models created using statewide median length-at-age data for bluegill (specifically from Minnesota lake class 38 lakes) [40] and mean growth data for largemouth bass obtained from a select, productive subset of Minnesota's 24 sentinel lakes [41].

Table 1. Years and numbers of Minnesota Department of Natural Resources surveys of Lake Winona that included back-calculated growth estimates for bluegill and largemouth bass pre- and post-dredging of the eastern basin.

Species/Period	Years	Number
Bluegill		
Pre-dredging	1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1991, 1993, 1997, 1999	12
Post-dredging	2003, 2006, 2009, 2012, 2014	5
Largemouth bass		
Pre-dredging	1983, 1984, 1985, 1986, 1987, 1988, 1989, 1991, 1993, 1997	10
Post-dredging	2003, 2006, 2009, 2014	4

4. Results

4.1. Fish Size and Age

The sizes of the two species of fish collected for this study generally were similar between the two basins (Table 2). Bluegill exhibited similar lengths and masses (both medians and ranges) in both basins, with neither lengths nor masses differing significantly between basins. Although largemouth bass appeared to be slightly larger in the western basin, neither lengths nor masses differed significantly between basins. Despite this lack of difference, ANCOVA analyses detected significant differences between basins in the TL–mass relationships for both bluegill (Y intercepts: $F_{1,68} = 3.5$, $p = 0.066$; slopes: $F_{1,67} = 6.08$, $p = 0.016$) and largemouth bass (Y intercepts: $F_{1,68} = 19.24$, $p < 0.0001$; slopes: $F_{1,67} = 8.79$, $p = 0.0042$).

Table 2. Median total lengths (mm) and wet masses (g) of bluegill and largemouth bass from eastern and western basins of Lake Winona, September–November 2023, that were used in growth analyses. N = sample size. Results of Mann–Whitney tests between basins are included.

Species/Basin	N	Total Length (Range)	Wet Mass (Range)
Bluegill			
Eastern	23	133 (111–183)	37 (22–109)
Western	47	140 (79–183)	45 (8–105)
Mann–Whitney test results		U = 572, p = 0.810	U = 544, p = 0.920
Largemouth bass			
Eastern	37	193 (63–355)	86 (3–667)
Western	33	194 (67–420)	91 (3–928)
Mann–Whitney test results		U = 625, p = 0.960	U = 646, p = 0.849

Estimated ages of the individual bluegill and largemouth bass examined differed between species and between lake basins (Table 3). Bluegill ranged in age from 2 to 6 years in both basins, whereas bass ranged from age 1 to age 11. Age distributions did not differ between basins for bluegill (contingency table X^2 = 7.37, df = 4, p = 0.118), but largemouth bass were skewed significantly older in the western basin (mean age = 3.90 years) than in the eastern basin (mean age = 3.35 years; contingency table X^2 = 15.50, df = 7, p = 0.030).

Table 3. Numbers and ages (years) of bluegill and largemouth bass from eastern and western basins of Lake Winona, September–November 2023, that were used in growth analyses.

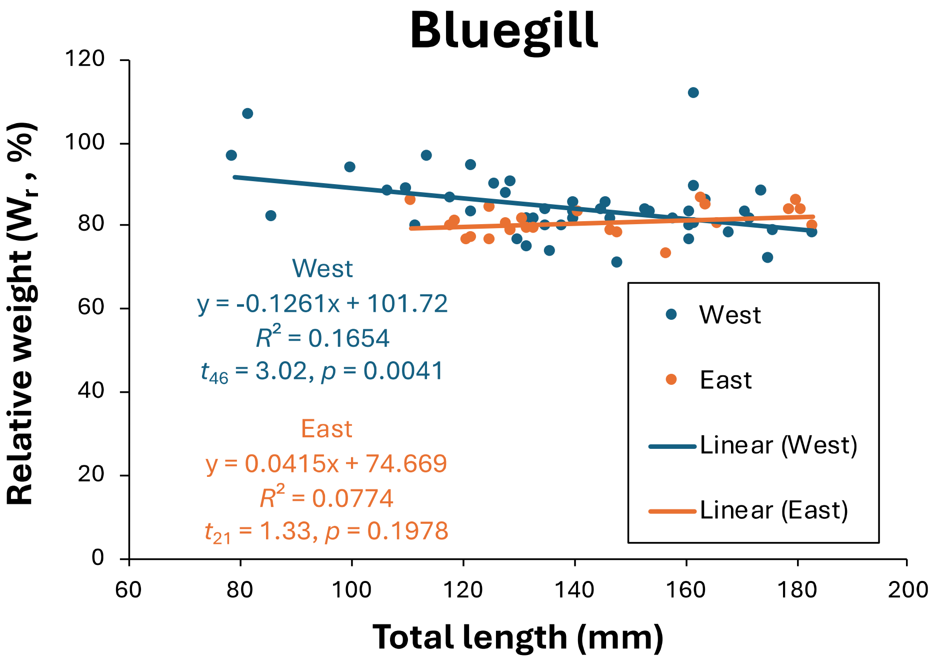
	Age										
Species/Basin	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Bluegill											
Eastern	0	3	8	4	4	4					
Western	0	4	6	7	21	9					
Largemouth bass											
Eastern	6	14	4	1	3	4	5				
Western	9	8	1	4	1	3	1	2	2	1	1

4.2. Relative Weights

On average, both species of fish had significantly higher relative weights in the western basin than in the eastern basin (Table 4). Most largemouth bass displayed good body condition in both basins, with W_r values $\geq$ 100, whereas most bluegill in both basins displayed poorer W_r values < 85. For both species in the eastern basin, the relative weights did not change significantly as the fish increased in length (Figure 2). However, the relative weights of both species in the western basin declined significantly as the fish increased in length (Figure 2). For both species, it appeared that it was mostly the smaller fish that had higher relative weights in the western basin than in the eastern basin, as the relative weights were similar in both basins for bluegill > 150 mm TL and for bass > 300 mm TL (Figure 2).

Table 4. Mean (±SD) relative weights of bluegill and largemouth bass from eastern and western basins of Lake Winona, September–November 2023. Results of Mann–Whitney tests comparing relative weights between basins are included.

Species	Eastern	Western	U	p
Bluegill	80.6 (3.5)	84.0 (7.8)	387	0.0281
Largemouth bass	100.0 (11.4)	106.0 (11.6)	501	0.0293



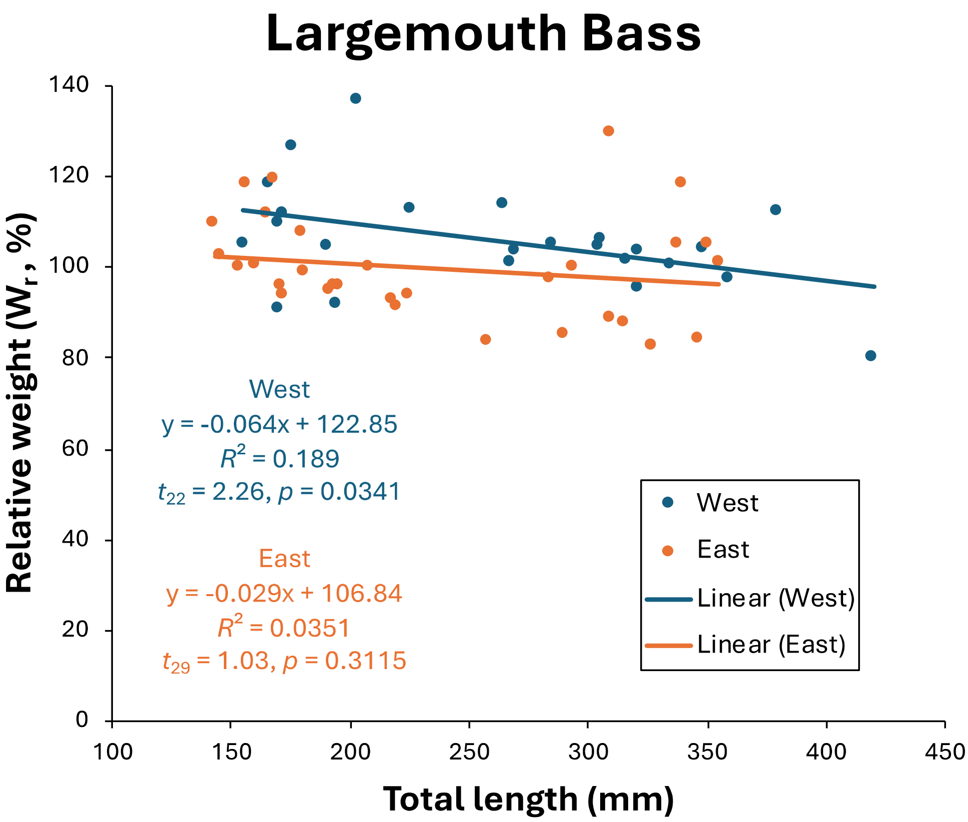


Figure 2. Relative weights (W_r) versus total lengths of bluegill and largemouth bass from eastern and western basins of Lake Winona, September–November 2023. Results of least squares regression analysis for each basin are included.

4.3. Back-Calculated Lengths

Fish total length back-calculations at each scale annulus produced the growth patterns expected, with slowly decelerating growth with increasing age for both species in both basins (Figure 3). Bluegill in the eastern basin exhibited greater TLs than fish in the western basin at every age interval, whereas largemouth bass TLs appeared similar in both basins until age 5 and after, when eastern basin fish displayed greater TLs (Figure 3).

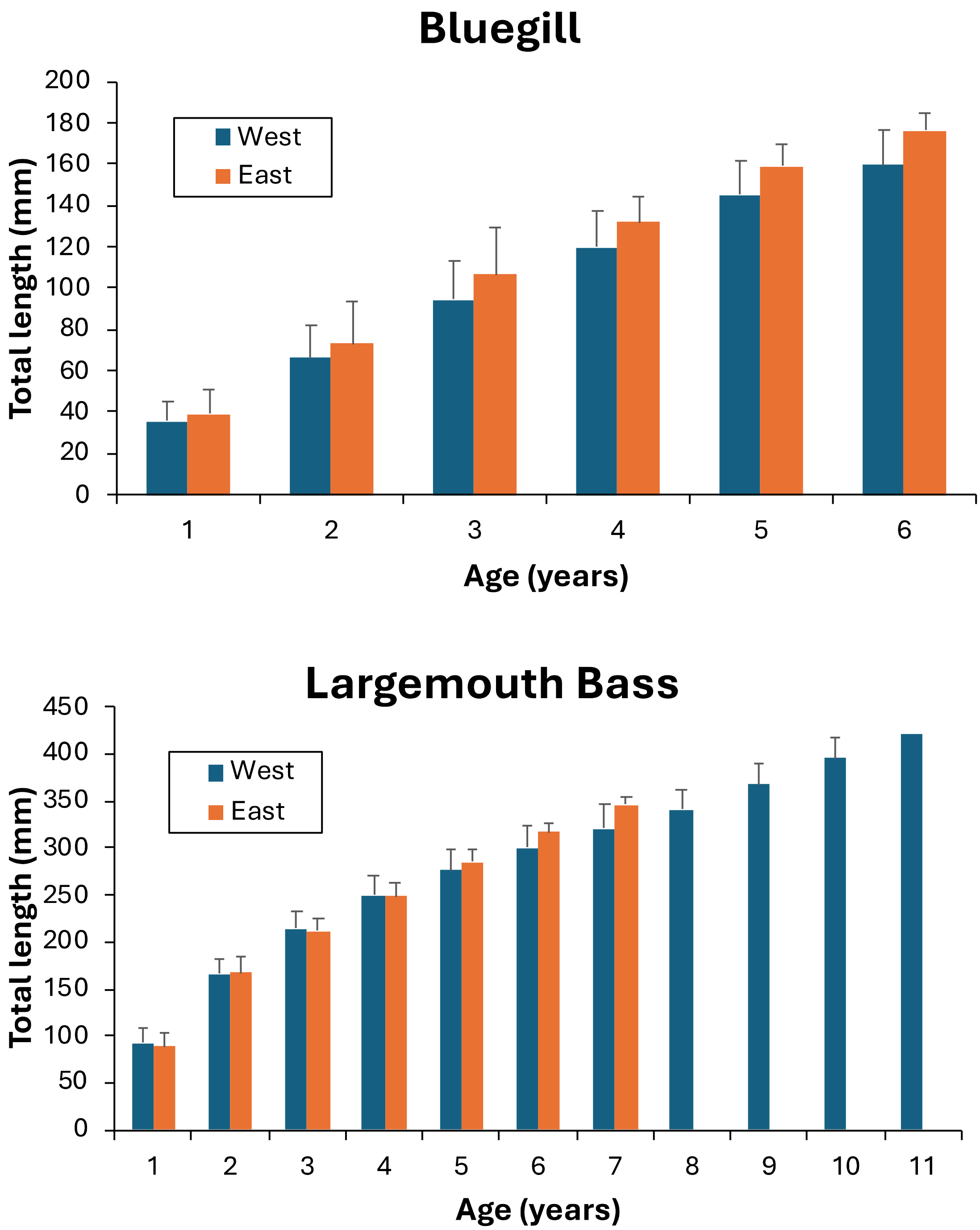


Figure 3. Length-at-age data for bluegill and largemouth bass from eastern and western basins of Lake Winona, September–November 2023. Values are means (+SD) based on growth rate back-calculation from scales.

When back-calculated lengths were compared statistically between basins at each annulus, generally similar patterns emerged for both species (Table 5). Bluegill TLs were significantly different between basins by age 3 and later, being larger in the eastern basin (Table 5). For largemouth bass, significant size differences between basins were not evident until age 6, with eastern basin fish being larger (Table 5).

Table 5. Mean (±SD) total length (mm) at annulus of bluegill and largemouth bass from eastern and western basins of Lake Winona, September–November 2023. Results of Mann–Whitney tests comparing lengths at annulus between basins are included.

Species/Annulus	Eastern	Western	*U*	*p*
Bluegill				
1	39 (12)	35 (9)	625	0.1492
2	73 (21)	66 (16)	617	0.1711
3	107 (22)	95 (19)	557	0.0307
4	132 (12)	120 (18)	319	0.0125
5	159 (11)	145 (17)	179	0.0188
6	177 (9)	159 (17)	30	0.0457
Largemouth bass				
1	88 (17)	93 (16)	691	0.1736
2	167 (17)	166 (15)	357	0.4013
3	211 (14)	214 (17)	138	0.3409
4	248 (15)	250 (20)	103	0.4168
5	285 (13)	276 (22)	40	0.0548
6	317 (9)	300 (24)	74	0.0110
7	346 (7)	320 (26)	30	0.0256

4.4. Growth Models–Von Bertalanffy

When back-calculated length data were used to create von Bertalanffy growth models for bluegill and largemouth bass in Lake Winona, both species displayed faster growth rates in the eastern basin than the western basin (Table 6). Based on the basin-specific growth models, bluegill in the eastern basin reached 100 mm and 150 mm TL 0.33 and 0.75 years earlier, respectively, than bluegill in the western basin (Table 6). Similarly, largemouth bass in the eastern basin reached 200 mm and 300 mm TL 0.48 and 0.59 years earlier, respectively, than bass in the western basin (Table 6).

Table 6. Various von Bertalanffy growth model statistics for bluegill and largemouth bass from Lake Winona. Current models (present study) for eastern and western basins separately and combined are shown along with models for pre- (1982–1999) and post-dredging (2003–2014) time periods (both basins analyzed together, data collected by Minnesota Department of Natural Resources). Minnesota state median growth rates also are included. The t_{100}, t_{150}, t_{200}, and t_{300} values represent the ages (in years) required to reach 100 mm and 150 mm TL for bluegill and 200 mm and 300 mm TL for largemouth bass, based on the specific growth models.

Species/Basin/Period	*K*	L_∞ (mm)	t_{100} (Years)	t_{150} (Years)
Bluegill				
Eastern basin	0.14099	311	2.75	4.67
Western basin	0.14087	281	3.12	5.42
Combined basins	0.13513	298	3.03	5.18
Pre-dredging	0.22427	219	2.72	5.45
Post-dredging	0.18200	233	3.08	5.67
MN lake class 38 median	0.20875	211	3.08	5.94
Largemouth bass			**t_{200} (years)**	**t_{300} (years)**
Eastern basin	0.22227	435	2.77	5.26
Western basin	0.16029	493	3.25	5.85
Combined basins	0.17364	481	3.10	5.63
Pre-dredging	0.22180	494	2.34	4.21
Post-dredging	0.15782	562	2.79	4.84
MN state median	0.27233	502	1.87	3.34

Whole-lake growth models developed using Minnesota DNR pre- and post-dredging data indicated that both bluegill and bass grew more slowly post-dredging than they did prior to dredging, requiring 0.3 to 0.6 years longer to achieve specific TL benchmarks (Table 6). Current, combined-basin growth models indicated that bluegill in Lake Winona were growing at or slightly faster than both the Minnesota DNR post-dredging rates and the median growth rates for bluegill in Minnesota class 38 lakes (time to reach 100 mm and 150 mm TL; Table 6). In contrast, largemouth bass in Lake Winona (combined basins) currently were growing more slowly than both the Minnesota DNR post-dredging rates and the state median rates, especially based on the time needed to reach 300 mm TL (Table 6).

5. Discussion

The present study revealed several patterns related to the growth and condition of bluegill and largemouth bass in Lake Winona. First, older age groups of both species displayed significantly faster growth rates in the eastern basin of Lake Winona relative to the western basin. Second, both species exhibited significantly higher relative weights (i.e., better condition) in the western basin, with bass in both basins having good relative weights, whereas bluegill in both basins had poorer relative weights. Finally, the current growth rates of largemouth bass are slower than either historical pre- or post-dredging rates, especially in the western basin, whereas current bluegill growth rates are similar to, or slightly faster than, historical rates, especially in the eastern basin.

The dredging of the eastern basin of Lake Winona during 1999–2001 improved the game fish communities in that basin relative to the pre-dredged condition [9], so it was suspected that at least some of those game fishes also would exhibit better growth rates in the dredged basin relative to the non-dredged basin. Game fish catch rates, size distributions, and mean weights were found to improve after lake dredging, but only black crappie previously were reported to grow faster after lake dredging [9]. The dredging of Lake Winona led to significant reductions in bluegill densities [9] in a system where they previously had been overabundant and stunted [28]. Reduced bluegill abundance should lead to reduced competition for food, allowing for improved growth rates [42]. Recent (October 2023) electrofishing surveys (N. Mundahl, unpublished data) in both the eastern and western basins of Lake Winona indicate that bluegill catch rates in the dredged eastern basin are less than one-third that of the non-dredged western basin (eastern: 5.9 bluegill/minute; western: 18.6 bluegill/minute), suggesting reduced competition among bluegill in the eastern basin likely was related to the differences in bluegill growth rates observed between the two basins. In addition, since bluegill feed primarily on zooplankton in open water [42], the lower abundance of bluegill combined with the proportionally greater volume of open water in the eastern basin after dredging would indicate a situation that would lead to better growth rates for bluegill in that basin as opposed to the western basin.

Largemouth bass growth rates in the dredged eastern basin of Lake Winona also were higher than in the non-dredged western basin. As with bluegill, the relative abundance of bass in the dredged eastern basin was much lower (by 61%) than in the western basin based on fall electrofishing data (N. Mundahl, unpublished data), suggestive of possible reduced competition among bass for prey items. Largemouth bass in Lake Winona previously have displayed higher mean mass at lower relative abundances [9]. Reduced competition among bass could extend from the earliest life stages, when bass are competing with bluegill for invertebrate prey, up through the stage or size when bass become entirely piscivorous [42]. However, similar growth rates of bass in both basins up through age 5 suggest that possible density-related effects on growth rates are delayed. Even though bluegill abundance was lower in the eastern basin, the abundances of other potential bass prey fishes (e.g., gizzard shad *Dorosoma cepedianum*, brook silverside *Labidesthes sicculus*, golden shiner *Notemigonus crysoleucas*, and yellow perch *Perca flavescens*) were higher in the eastern basin (N. Mundahl, unpublished data), providing bass with greater numbers of more prey types than were available in the non-dredged basin. This potentially better foraging environment for bass in the eastern basin certainly could have resulted in the improved growth rates observed for older bass in this dredged basin.

One potential limitation of the largemouth bass growth model we determined for the eastern basin was the lack of fish older than age 7 for use in model development. This lack of old, slower-growing bass (which may have been influenced somewhat by our use of scales rather than otoliths to age bass) may have caused our model to inadequately characterize the asymptotic growth of a classic von Bertalanffy growth curve [26]. Many midwestern USA lakes have largemouth bass populations that exhibit little change in growth rate through their first six years of life [43]. We collected no bass older than age 7 years from the eastern basin, even though we captured several older bass (up through age 11) in the western basin. Past data from the Minnesota DNR have included back-calculated lengths for fish up to age 10 years from Lake Winona. Other lakes in southern Minnesota have reported bass with maximum ages of 11 to 19 years (T. Stevens, Minnesota Department of Natural Resources–Fisheries, personal communication; 28 June 2024). Such growth data from old bass were needed to produce a better growth model that displayed decelerating growth among the oldest age classes (e.g., ages 8 and beyond) [26]. However, the lack of these older fish in our current study did not impact our ability to detect significant size differences in ages 6 and 7 bass between the two basins.

Contrary to expectations, both bluegill and largemouth bass in the non-dredged western basin had significantly higher relative weights than did their conspecifics in the dredged eastern basin. Populations of many species of fish that exhibit rapid growth rates often are in better condition (i.e., greater mass at a given length) than slower-growing populations of the same species [44–47]. In fact, relative weights have been used to predict annual growth rates in largemouth bass in midwestern USA ponds [48]. However, several studies have failed to observe significant relationships between growth rates and W_t [40,49–51], including for largemouth bass [49]. Lake Winona data on bluegill and largemouth bass apparently provide two more examples of fish populations that do not demonstrate positive relationships between growth rate and relative weights.

Differences in largemouth bass relative weights between basins probably are not biologically meaningful, as relative weights in the range of 95 to 105% are considered healthy [38,39,47]. Bass relative weights were similar to values reported from collections made Lake Winona in 2014 [9]. However, significant declines in relative weight with increasing bass length in the western basin (but not in the eastern basin) may indicate that food resources (i.e., forage fish) for those larger, older fish may not be as available or abundant as they are in the eastern basin. Decreasing relative weights with increasing lengths have been reported previously when largemouth bass are in crowded situations [47]. The non-dredged western basin also had a lower diversity and abundance of forage fishes (except for bluegill) compared to the eastern basin (see above), plus that basin had much more extensive macrophyte beds where largemouth bass are less effective in capturing prey fishes [52–54].

In contrast, bluegill relative weights averaged <85% in both basins, levels that often indicate stressful conditions [38,39], implying that bluegill in both basins of Lake Winona may be experiencing food shortages, intense predation, or other related stresses. Like largemouth bass, bluegill in the western basin (but not the eastern basin) exhibited significant declines in relative weights with increasing fish length. While smaller bluegill (<125 mm TL) may have been able to find sufficient zooplankton in the limited open waters of the western basin to maintain relative weights of 90% or higher, larger bluegill with greater metabolic (and hence forage) demands [42] may have been more severely impacted and consequently often had relative weights < 80%. Bluegill relative weights in both basins are much lower than they were in 2014 (mean W_r = 101%) [9], suggesting worsening, more stressful conditions for bluegill in both basins during the past decade.

When current Lake Winona growth models for bluegill and largemouth bass were compared to historical, whole-lake models (both pre-and post-dredging), bluegill appeared to be growing at rates similar to or slightly faster than past years, especially in the eastern basin. In contrast, largemouth bass have continued the trend of ever-slower growth rates, becoming slower from the pre-dredging years through the post-dredging years to the present time, and most dramatically so in the non-dredged western basin. Both trends could be the result of density-dependent growth, which is common in systems where competition for food or space resources is high [42,55]. Decreased bluegill abundance and increased bass numbers post-dredging [9] may produce the shifts in growth rates observed in these species among the time periods examined. However, neither bass nor bluegill have previously demonstrated density-dependent growth in Lake Winona [9], and bass electrofishing catch rates in the lake have decreased post-dredging by >60% from 2006 to 2022 (N. Mundahl, unpublished data), which should lead to faster rather than the slower growth observed. Consequently, the changes observed in bluegill and largemouth bass growth models for Lake Winona may not have resulted from only simple changes in physical habitat and species abundances. Instead, we cannot rule out the possibility that several additional factors, such as changes in the stocking of other species such as walleye (*Sander vitreus*) or increased angler efforts and harvest may have affected the lake environment enough to alter the growth rates of bluegill and largemouth bass. Continuing assessments will be needed to better understand the changing fish community dynamics within the post-dredging Lake Winona.

The most recent dredging of Lake Winona in 1999–2001 produced significantly different environments in the dredged eastern basin relative to the non-dredged western basin. Dredging has significantly altered several game fish populations [9], leading to inter-basin differences in abundances and growth rates of largemouth bass and bluegill, beginning shortly after dredging [9] and continuing now for over two decades after dredging ended. These longer-term, positive effects of dredging on fish communities [3,9,13–15] contrast with the short-term, negative effects on fish often associated with the dredging process itself [4,10–12]. Additional studies, including both pre- and post-dredging monitoring of fish communities, are needed to adequately understand the effects of dredging on fish, especially if the dredging is intended, in whole or in part, to improve the fishery.

We have no information on possible movements of bass or bluegill between the western and eastern basins. The differences in growth rates and relative weights that we observed between basins are suggestive that inter-basin movements are relatively limited. However, both bass and bluegill are capable of making extensive movements [20,21,24], even passing through restrictive culverts similar to those separating the two basins of Lake Winona [21]. A movement study of bass and bluegill in Lake Winona could address whether there is sufficient mixing of bass and bluegill between the two basins for them to function as single, lake-wide populations, or whether the two basins represent isolated sub-populations. We suspect that fish movements through the single, small culvert are limited, keeping fish populations in the two basins relatively isolated from one another and allowing for the differences in growth rates and relative weights observed.

Although the Minnesota DNR continues to monitor and manage Lake Winona as a singular system, our results indicate that such an approach may not provide a truly accurate picture of the actual community dynamics within either basin. Despite having a culvert connecting the two basins, the basins behave differently physically (e.g., differing ice-on and ice-off dates and thermal stratification profiles) (N. Mundahl, unpublished data) and chemically (e.g., differing nutrient loadings and sources) [29], so biological differences between basins should not be surprising. If possible, we suggest that future efforts could be made to monitor the fish communities in the two basins separately to better document the differing nature of the two systems.

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