Length-weight relationships of the Emerald Shiner (*Notropis atherinoides* - Rafinesque, 1818) in the Western Basin of Lake Erie

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ABSTRACT. Total length and standard length (mm) were compared to weight (mg) in the Emerald Shiner (*Notropis atherinoides* - Rafinesque, 1818) in the western basin of Lake Erie. Length and weight relationship (n = 400), length-frequency distribution, and sex ratios were evaluated for coastal and tributary habitats and compared to open water habitats. A strong positive correlation was observed between length and weight for both males and females. For males (n = 195) there was a significant positive relationship between standard length (SL) and weight (F = 935.64, d.f = 195; R^2 = 0.989) and between total length (TL) and weight (F = 918.75, d.f. = 195; R^2 = 0.991). In females (n = 205), there was also a strong positive correlation between SL and weight (F = 1108.18, d.f. = 204; R^2 = 0.976) and between TL and weight (F = 1208.86, d.f. = 204; R^2 = 0.983). This same positive relationship between SL and weight (F = 1909.58, d.f. = 399; R^2 = 0.984,) and between TL and weight (F = 1960.07, d.f. = 399; R2 = 0.988) that was found for the individual sexes was present in the combined data for the two sexes. Length-weight relationship patterns in Emerald Shiner were significantly influenced by sex (ANCOVA, F= 313.03, $p < 0.01$) and habitat (ANCOVA, F = 6.693, p = 0.013). Three separate age classes were distinguished in the data. Age 0 males ranged from 15-33 mm TL, while age 0 females ranged from 18-30 mm TL. Age I males ranged from 39-78 mm TL and Age I females ranged from 42-78 mm TL. Age II+ males ranged from 78-111 mm TL and Age II+ females ranged from 81-108 mm TL. Emerald Shiner exhibit indeterminate growth and sex influenced growth patterns based on the von Bertalanffy growth model.

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INTRODUCTION

The fish fauna of Lake Erie is comprised of an estimated 114 species (Leach and Nepszy 1976); however, little information is available on the basic life history for the majority of the non-game species (Hartman and others 1992). Cyprinidae represent 51 percent of the Lake Erie fish fauna (Hubbs and others 2004) and are an important staple of most game fish species diets (Simon 2011). Minnows are essential to energy transfer from lower to upper trophic levels by converting nutrients from zooplankton and aquatic insects to the broader food web (Hartman and others 1992). Understanding the rates of growth and relationships between weight and length are important for our knowledge of life history and population age structure. Accurately modeling aquatic ecosystem function depends on information that can be acquired through simple and cost effective techniques (Froese 2006).

The Emerald Shiner (*Notropis atherinoides* - Rafinesque, 1818) is a relatively abundant minnow native to the Great Lakes. Its range extends from Eastern Texas to Alabama and northward to the Finger Lakes of New York State and the Mackenzie River of the Northwest Territories (Campbell and MacCrimm 1970). Emerald Shiner inhabits lakes and rivers and is a popular prey item for highly sought after piscivores, such as *Sander vitreus.* A regional bait industry has developed around its use by sport fisherman (Pothoven and others 2009). Despite their extensive range and relative abundance, Emerald Shiner populations declined in the Great Lakes during the 1950s, coinciding with the introduction of the Alewife, *Alosa pseudoharengus*, which is known to compete directly for zooplankton prey items and also is known to consume Emerald Shiner eggs and larvae (Schaeffer and others 2008). Although Emerald Shiner has recovered, the condition remains unknown throughout much of its range.

This study investigated the relationship between length and weight in Emerald Shiner to understand growth patterns based on sex with respect to habitat. In addition, the sex ratio and length-frequency distribution was used to predict age structure. Both length and weight relationships are useful in comparing

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different populations and evaluating ecological patterns. Lake Erie individuals were collected from both coastal shoreline and tributary habitats in the western basin and were compared to open water populations. The purpose of this study was to determine patterns in sex growth differences, and specific correlations between two measures of length (i.e., total length [TL] and standard length [SL]) and weight based on sex. Differences in growth were assessed to find whether differences between Emerald Shiner populations in the western basin were associated with coastal (i.e., shoreline and tributary water) compared to open water habitats. Lastly, the growth range and age structure of individuals from the Bass Islands were compared to other populations in the Great Lakes region.

MATERIALS AND METHODS

Study Area

The Laurentian Great Lakes encompass one-fifth of the available freshwater in the world (Steffen and others 2014). Lake Erie is globally the 10th largest lake and stores about two percent of the total volume of all of the Great Lakes (FWPCA 1968; Munawar and others 1999). Lake Erie is the shallowest, most southern, and the most productive of the Great Lakes (Michalak and others 2013). It has three separate basins, the western, central, and eastern basins, with depth increasing in an easterly direction (FWPCA 1968). This study was conducted in the western basin near the Bass island archipelago, which is comprised of 31 islands in Ottawa County, Ohio. The study area has four major tributaries that include the Huron, Portage, Sandusky, and Vermillion rivers (Fig. 1).

Field Methods

All study data were collected in the western basin of Lake Erie between 2004 and 2014 using a variety of gears to reduce bias. Studies were collected for a variety of purposes as part of investigations of the Bass Island region. Individual Emerald Shiner were collected from coastal (including shoreline and tributary habitats) and open water habitats. Individuals used in the current study were collected during ichthyological investigations during the spawning season of 2014

FIGURE 1. Lake Erie showing the Western Basin and primary tributaries and locations sampled within the study area.

(June-July) (see Supplemental Materials: Specimens Examined Section). Length and weight relationships were based on 400 individuals from coastal and open water habitats, while length-frequency distribution and sex ratios were based on random samples of 400 individuals from dates in July. Lot collections are part of the permanent collection of the Museum of Biodiversity, F.T. Stone Laboratory, The Ohio State University and are housed at Gibraltar Island.

Laboratory Methods

Individual fish were randomly subsampled from site-specific collection lots and blotted dry to remove excess moisture prior to wet weighing using a Sartorius balance with a resolution of 1 μg (Middleton and others 2013). Due to the precision of the balance used in the analysis it was impractical to measure live individuals or to attempt to weigh fish in the field. Fish were anesthetized in MS222 and fixed in 10 percent formalin. Fish used in the laboratory analysis were soaked in water just prior to being measured. The relationship between freshly preserved individuals was tested to verify weight accuracy. Fish shrinkage was stable after seven days after which lengths and weights were measured. Shrinkage was less than five percent of the true weight of live individuals; however, it is recognized that data might not completely reflect the length-weight relationships of live individuals. All specimens had similar treatment methods, so it is assumed that there is no reason to expect that preservation bias varied by location or sex. Sex was determined using a Zeiss dissection microscope. Male gonopods were elongated, sausage-shaped, and resided within a shallow trough just posterior to the anus and anterior to the anal fin origin, while the female cloaca possessed a circular, mound of villiform tissue with a short, flattened tube for egg deposition. Length measurements included standard length (SL) and total length (TL), which was measured using digital calipers to the nearest 0.01 mm. The SL was measured from the tip of the snout, horizontally, to the posterior tip of the notochord at the hypural plate, while TL was measured from the tip of the snout, horizontally, to the tip of the depressed caudal fin (Hubbs and Lagler 2004). All measurements were based on the standard procedure described in Hubbs and Lagler (2004). Age groups of individual Emerald Shiner were determined using length-frequency distribution analysis (Nielson and Johnson 1983), where ages were decided according to elevated peaks in the distribution.

Statistics

Regression analysis was used to model weight as a function of length (i.e., SL and TL). Analysis of Covariance (ANCOVA)(STATISITICA 11.0) with length as the covariate was used to compare weight between sexes and habitats. Habitat class was assessed to determine size effect, by separating populations into coastal (tributary and shoreline) and open water groups (Sokal and Rohlf 2012). Emerald Shiner age groups were determined by sex using length-frequency distribution analysis (Nielsen and Johnson 1983). A two way Analysis of Variance (ANOVA) (Sokal and Rohlf 2011) was used to determine if there were significant differences in size distribution according to age or sex. A chi-squared test was performed to see if there was any significant difference in the sex ratio between males and females in the random subsample. Fulton's condition factors for males, females, and the general population were calculated using the relationship between weight and total length (TL) of each individual (Nielson and Johnson 1983). Weight was plotted by TL for all individuals within each subset and a trend line was applied to best fit each scatter plot graph, with the b value of each line equation representing the Fulton's condition factor. The von Bertalanffy growth model was used to determine growth rate for each sex using the formula,

$$L\ (t) = L_{\infty} * (1- \exp\ (-K* (t - t_0)))$$

where, L (t) is the length at any given age (years), K is equal to the b-value or slope of the regression plot of $-\ln\ (1 - L_{(t)} / L_{\infty})$ (von Bertalanffy 1934; Ricker 1975).

RESULTS

We examined 12,863 individuals from 19 Western basin Lake Erie sites and randomly subsampled 400 individuals based on coastal (n = 265 individuals), tributary (n = 19 individuals), and open water (n = 116 individuals). Male Emerald Shiner showed a significant positive, power function between SL and weight (R^2 = 0.989, F = 935.64, d.f. = 194, Fig. 2a) and between TL and weight (R^2 = 0.991, F = 918.75, d.f. = 194; Fig. 3a). Female Emerald Shiner had a strong positive, power function between SL and weight (R^2 = 0.976, F = 1108.18, d.f. = 204; Fig. 2b) and between TL and weight (R^2 = 0.983, F = 1208.86, d.f. = 204; Fig. 3b). The combined data for the two sexes showed a significant positive, power function between SL and weight (R^2 = 0.984, F = 1909.58, d.f. = 399; Fig. 2c) and between TL and weight (R^2 = 0.988, F = 1960.07, d.f. = 399; Fig. 3c). These regression analyses, comparing TL to weight and SL to weight, were found to have Fulton Condition Factors (*b*) of -5.379 and -4.995, both representing negative allometric growth (Fig. 4a and 4b).

Length-weight relationship patterns in Emerald Shiner were significantly influenced by sex (ANCOVA, F = 313.03, p < 0.01). There was a significant difference in length-weight relationships between coastal compared to open water habitats (ANCOVA, F = 6.693, p = 0.013).

The sex ratio from the random subsample of 400 individuals was not significantly different (Chi-squared p = 0.383). Males were slightly outnumbered by females 1:1.05. Length-frequency distribution of male (Fig. 5a) and female (Fig. 5b) individuals showed no significant size difference within age class (p > 0.05). There were no significant difference in age class size for Age 0 male and female individuals (ANOVA F = 0.506, d.f. = 25, p = 0.483); Age I (ANOVA, F = 0.567, d.f. = 317, p = 0.452); and Age II+ (ANOVA, F = 0.271, d.f. = 52, p = 0.605). Male Age 0 individuals ranged from 15-33 mm TL, while female Age 0 ranged from 18-30 mm TL. Male Age I ranged from 39-78 mm TL, while female Age I ranged from 42-78 mm TL. Male

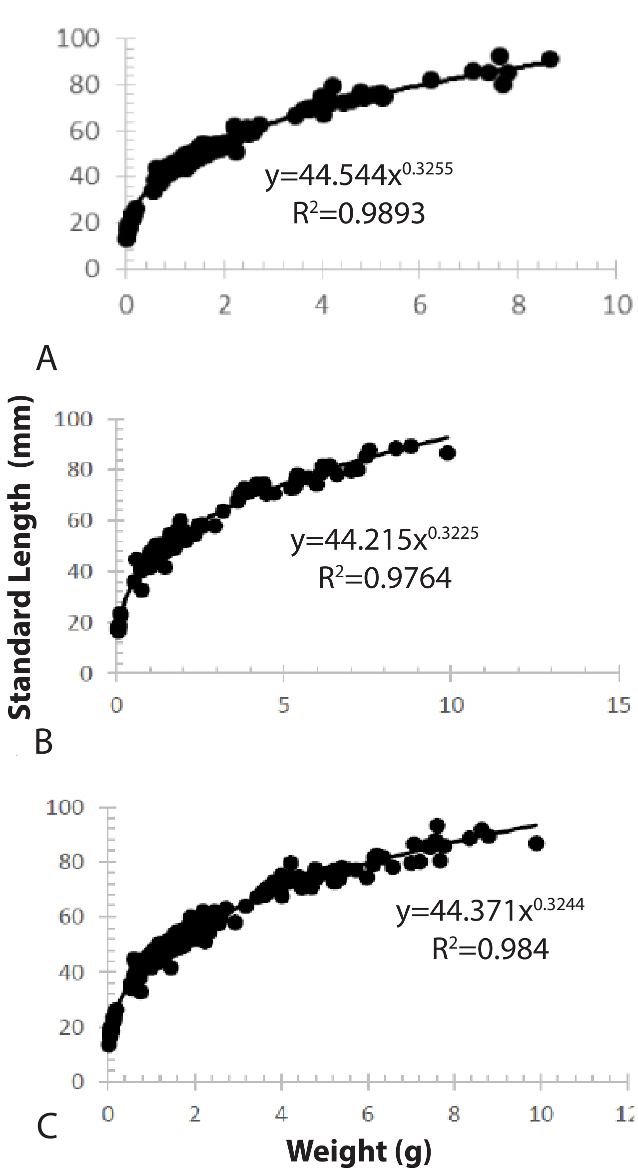

FIGURE 2. Standard length (mm SL) and weight (g) relationship for Emerald Shiner (*Notropis atherinoides*). (A) Males (B) Females and (C) both males and females in the Western Basin of Lake Erie.

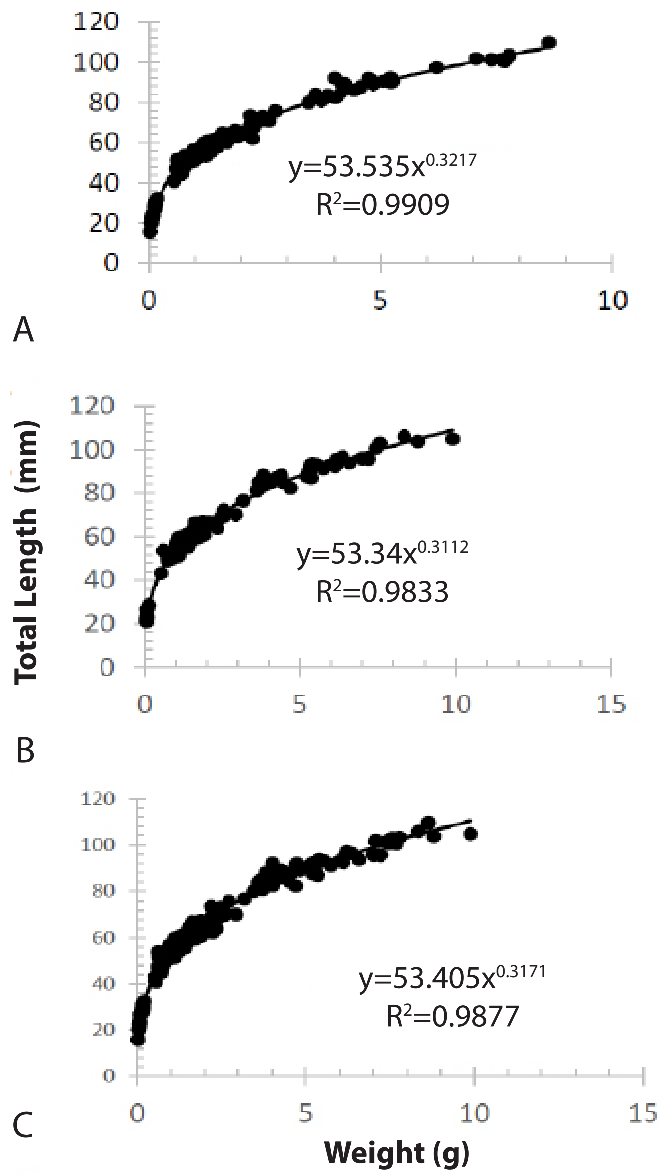

FIGURE 3. Total length (mm TL) and weight (g) relationship for Emerald Shiner *Notropis atherinoides*. (A) Males (B) Females and (C) both males and females in Western Basin of Lake Erie.

Age II+ ranged from 78-111 mm TL, and female Age II+ ranged from 81-108 mm TL (Table 1). The von Bertalanffy growth model observed that individual growth occurred at a greater rate in males than females for the Western Lake Erie population (Fig. 6).

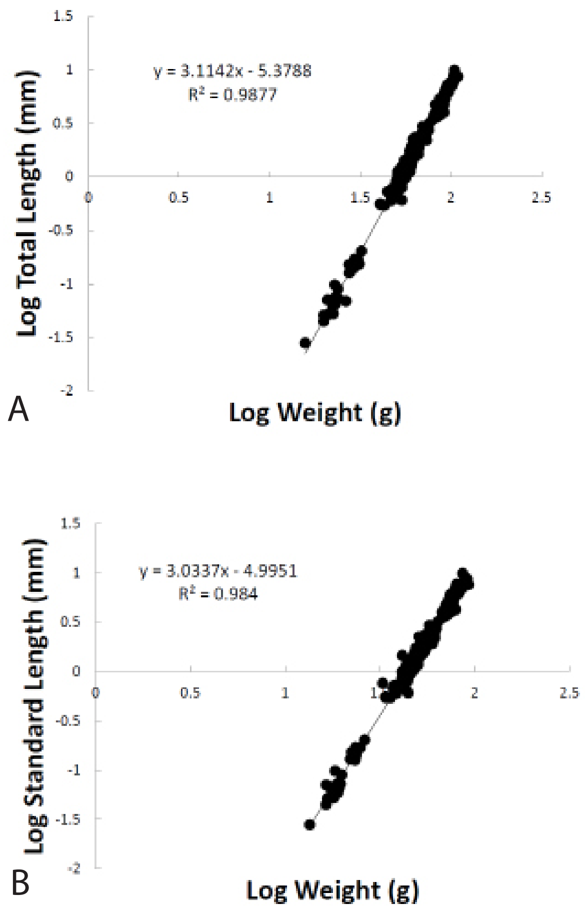

FIGURE 4. Log normalized length-weight relationship for Emerald Shiner (*Notropis atherinoides*) TL (A) and SL (B) n = 400.

DISCUSSION

Carlander's (1969) review of age and growth relationship studies found three previous studies had been published. Relationships on size and age included South Dakota (Fuchs 1967), Alabama (Swingle 1965), and Manitoba, Canada (Schaap 1989). Relationships between length and age (in years) have been studied in Illinois (Dobie and others 1948, 1956), Michigan (Hubbs 1922), Ohio (Fish 1932; Gray 1942; Trautman 1957, 1981), South Dakota (Fuchs 1967), Wisconsin (Becker 1964, 1983), and Canada (Campbell and MacCrimmon 1970) (Table 1). No latitudinal gradient was observed within the Great Lakes region, i.e., northern latitudes of Wisconsin to southern latitudes of Ohio. This study found that southern populations attained larger size at age than northern populations. In addition a positive relationship was observed between age and weight. Sex based differential growth was observed with females tending to be larger than males based on both mean TL and mean weight; however, in this study males attained larger size within age than females for every age class. The positive regression analysis relationships of Emerald Shiners show that they are indeterminate growers. Positive correlations between length and weight show that a significant, positive relationship between age and length, as well as age and weight, exists for Western basin populations. A difference in size at age between sexes was observed between males and females with mean male differences of 3-5 mm TL larger than females. The analysis of length and weight by sex were not statistically different; however, other studies found size differences between sex. These were not statistically tested, but were based on observed differences. We evaluated our results using ANOVA, ANCOVA, length-frequency, and von Bertalanffy growth models. Our results show that although males were on average larger than females at each age class that the variance associated with each sex was not statistically significant. Growth rates from the von Bertalanffy calculations showed that males grew at a faster rate than females.

Our test of habitat was simply the difference between tribuatary compared to lake coastal shoreline and island populations. Significant differences in TL and weight were not expected between sex or habitat due to lack of isolation and ability to migrate freely between habitats. ANCOVA analyses and von Bertalanffy growth models found that there was a difference in relationship between sex, while ANCOVA analyses showed that lake individuals were larger than tributary individuals based on slope differences in habitat length-weight relationships. Differences might have been attributed to females were expected to have increased weights and increased Fulton Condition factors than males due to the timing of the study. The Fulton Condition factor, which is based on the b-factor in the logarithmic relationship between length and weight, showed that Emerald Shiner exhibited negative allometric growth. This suggests that individuals were growing in length faster than they were putting on weight. Potential explanations might be that the metabolic energy needs to yolk ova in females caused a decrease in expected weight.

Gray (1942) reported on Emerald Shiner growth in the Bass Island region of Lake Erie. Our current study revealed increased growth for every age class compared to Gray's (1942) study of Emerald Shiner from the Bass Islands. Our study also found that Bass Island region individuals exhibited smaller size than statewide individuals during age 0, while better growth was seen during ages I and II+. Similar growth was observed during age II for most of the Great Lakes populations (Table 1). Length at age relationships found in this study of the Bass Island region of Lake Erie found that maximum length sizes, i.e., L_∞ values are the highest in the Great Lakes.

The importance of understanding basic length-weight, age and growth, and condition factors of members of the family Cyprinidae is critical for determining the trophic structure of a dynamic system such as Lake Erie. Although population dynamics of cyprinids have not been well studied, the high economic significance of a strong minnow foundation in the food web is critical for stability in the Western basin (Hubbs and others 2004). Emerald Shiner populations may reflect changing conditions and can serve as an early warning indicator of Lake Erie fish assemblage stability. They are extremely important commercially since they support a large bait fish industry and can serve as a dominant food source for top predator, whole body carnivores (Hubbs and others 2004).

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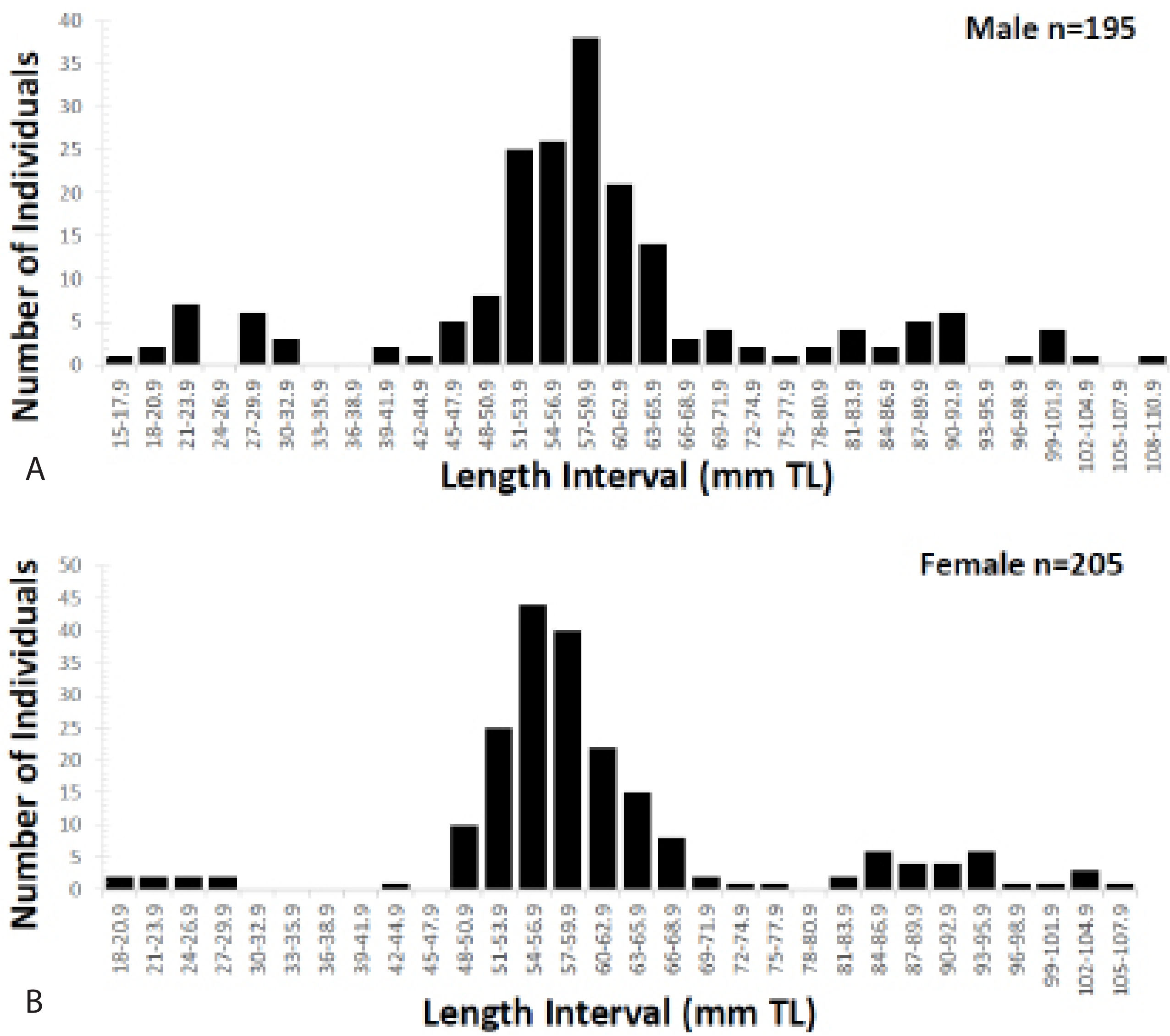

FIGURE 5. Length frequency distribution for male (A) and female (B) Emerald Shiner (*Notropis atherinoides*) in the Western Basin of Lake Erie.

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Table 1
Emerald Shiner age and growth relationships based on literature from the Great Lakes region and Midwestern United States

Location	TL Range (mm) Age 0	Age I	Age II+	Study
Canada				
Male	18-38	50-79	82-88	Campbell and MacCrimmon (1970)
Female	--	51-84	85-96	
Illinois	--	44	76	Dobie and others (1948); Dobie and others (1956)
Michigan	--	32-72	84-108	Hobbs (1922)
Ohio	35-58	33-71	64-84	Trautman (1981)
Ohio (statewide)	25-58	33-71	99	Trautman (1957)
Lake Erie, Bass Islands	10-23	30-63	55-89	Gray (1942)
Lake Erie (lakewide)	5-23	--	--	Fish (1932)
Lake Erie, Bass Islands				Current Study
Male	15-33	39-78	78-111	
Female	18-30	42-78	81-108	
South Dakota	--	45-92	75-95	Fuchs (2011)
Wisconsin	38-45	45-61	73-95	Becker (1983)
	41-53	--	--	Becker (1964)

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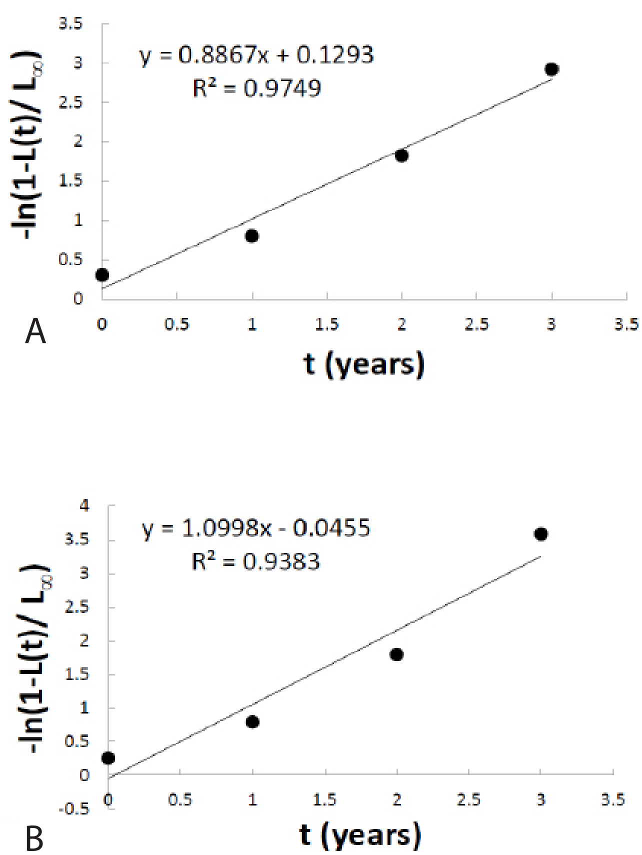

FIGURE 6. von Bertalanffy growth plot showing the slope K, t_0, and a reasonable estimate of L_∞ for Emerald Shiner (*Notropis atherinoides*). (A) Males and (B) Females in the Western Basin of Lake Erie.

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SUPPLEMENTAL MATERIALS

Specimens Examined

OHIO: Ottawa Co. Lake Erie, Alligator bar, SW Shore Gibraltar, Gibraltar Island, Put-in-Bay Twp., 41.657450N -82.822980W, VI:19:2013, EEOB 5930, (N=26 [25]); Lake Erie, Eastpointe, East North Bass Island , North Bass Island, Put-in-Bay Twp. 41.280900N -82.169910W, VIII:5:2004, N. Utrup & EEOB621 (N=15 [14]); Lake Erie, NE Island, Rattlesnake Island, Trawl 0.125 mi NE of Rattlesnake Island, Put-in-Bay Twp. , 40.965000N -82.511360W (B), 41.412990N -82.507820W (E), VI:24:2013 TP Simon & EEOB 5930 (N = 5 [5]); Lake Erie, 1.3 mi off Catawba Island, ODNR Trawl track #021, Catawba Island, Put-in-Bay Twp. 41.561683N -82.867983W (B), 41.556423N -82.867400W (E), VI:27:2011, TP Simon & EEOB 621 (N=5634 [33]); Lake Erie, off Lutz Point Trawl #2, Schoolhouse Bay, Middle Bass Island, Put-in-Bay Twp., 41.686417N -82.784533W (B), 41.685517N -82.795533W (E), VII:8:2011, TP Simon & EEOB 621 (N=3594 [30]); Lake Erie, Dock Beach, 0.5 mi N Put-in-Bay, SW Gibraltar Island, Gibraltar Island, 41.657648W - 82.820960W, VI:25:2014, TP Simon & EEOB 5930 (N=166 [46]); Lake Erie, NE Beach Access, NE Beach, 0.5 mi N Put-in-Bay, Gibraltar Island, Put-in-Bay Twp., 41.657648N -82.820960W, VI:25:2014, TP Simon & EEOB 5930, (N=166 [30]); Lake Erie, Dock Beach, SW Gibraltar Island, 0.5 mi N Put-in-Bay, Gibraltar Island, Put-in-Bay Twp., 41.657710N -82.821800W, VI:22:2012, TP Simon & EEOB 5930 (N=2365 [40]); Portage River, at Ohio State Rd 590 bridge, Elmore, Elmore Twp., 41.476660N -82.953200W, VII:9:2001, NJ Utrup

& EEOB 621, (N=2 [2]); Portage River, Ohio State Road 51 bridge, Elmore, Elmore Twp., 41.476660N -82.953200W, VII:7:2000, C.L. Smith & EEOB 621 (N=17 [17]); Lake Erie, 1.3 mi off Rattlesnake Island, Rattlesnake Island, Put-in-Bay Twp., 41.676110N -82.854500W (B), 41.668170N - 82.856900W (E), VI:23:2003, C.L. Smith & EEOB 621 (N=16 [16]); Lake Erie, Lookout beach, N side Gibraltar Island, 0.6 mi N Put-in-Bay, Put-in-Bay Twp., 41.688773N -82.820780W, VI:25:2014, TP Simon & EEOB 5930 (N=30 [30]); Lake Erie, South side End of Catawba Ave, 1.6 mi S Put-in-Bay, South Bass Island, Put-in-Bay Twp. 41.642120N -82.836490W, VI:27:2014, TP Simon & EEOB 5930, (N=23 [22]); Lake Erie, Trawled NE direction off trawl position B, Schoolhouse Bay, Middle Bass Island, Put-in-Bay Twp., 41.666928N -82.783509W (B), 41.683413N -82.783427W (E), VI:30:2014, TP Simon & EEOB 5930, (N=26 [26]); Lake Erie, Alligator Bar, SW Shore Gibraltar, 0.5 mi NW of Put-in-Bay, Gibraltar Island, Put-in-Bay Twp., 41.65745N -82.822980W, VII:6:1983, RF Jezerinac (N=356 [10]); Lake Erie, 1.3 mi off Rattlesnake Island, Rattlesnake Island-Green Island trawl track, Green Island, Putt-in-Bay Twp., 41.676110N - 82.8545W (B), 41.668170N -82.856900W, VI:27:2011, TP Simon & EEOB 621, (N=212 [6]).