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Bluegill Lengths at Capture at Age in Eastern South Dakota

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Abstract – Information concerning *Lepomis macrochirus* Rafinesque (Bluegill) growth is fundamental to their population management. Traditionally, scales were the most common structure used for estimating Bluegill ages. Back-calculated lengths to previous ages derived from annuli measurements on scales have commonly been used to assess growth. More recently, because of increased precision and accuracy, otoliths have become the most used structure. With the use of otoliths, back-calculations are rarely completed, and mean lengths at capture at age values are now reported. Because fish do not grow at the same rate throughout the growing season, it is difficult to compare lengths at age across waters when sampling is not completed at the same time of year. To enable Bluegill growth assessments, we calculated population mean lengths at age, unweighted monthly (May, June, and July) means, percentile distributions of population mean lengths at age, and von Bertalanffy models for Bluegill age data collected in eastern South Dakota using ages estimated with otoliths (16 populations) and scales (five populations). We provide monthly Bluegill unweighted mean lengths at capture by age, percentile length values by age, and von Bertalanffy models to assess Bluegill growth (ages 2–6) in eastern South Dakota and regional populations. Monthly von Bertalanffy growth models can be used to calculate age-specific standard lengths for calculating a regional relative growth index (RGI). The information provided may serve as baseline Bluegill length information for evaluating the potential impact of *Dreissena polymorpha* Pellas (Zebra Mussel) introductions in South Dakota.

Introduction

Information concerning fish growth is important in the management of fish populations. Fish growth estimates can be useful when evaluating management actions or as a surrogate measure of environmental conditions (Isley and Grabowski 2007, Quist et al. 2003). A slowing of growth may indicate stockpiling of fish below a minimum length limit (Isermann 2007, Serns 1978). When environmental conditions are favorable (e.g., high prey availability, good habitat conditions), above-average growth likely occurs, but under poor environmental conditions (e.g., limited prey availability, degraded habitat), growth may slow (Matthias et al. 2018). Additionally, the growth rate of sportfish provides information as to when fish recruit to the angler creel (Allen and Hightower 2010, Shoup and Michaletz 2017). *Lepomis macrochirus* Rafinesque (Bluegill) growth summaries (i.e., mean back-calculated lengths at age) for South Dakota waters were previously published by Willis et al. (1992 and 2001). These summaries provide biologists with growth information for comparison when analyzing regional Bluegill growth data. Scales have traditionally been the most used hard part for estimating fish ages, especially in northern latitudes (Devries and Frie 1996, Maceina et al. 2007, Jearld 1985). The use of scales for estimating fish ages has been popular because they are easy to collect and process, and fish do not need to be sacrificed (McInerny 2017). However, research has shown that scales tend to underestimate fish ages at older life stages (Edwards et al. 2005, Perrion et al. 2024, Tyszko and Pritt 2017). In two South Dakota wa-

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ters, scales were found to underestimate the ages of Bluegills age 5 and older, compared to otoliths (Edwards et al. 2005). In some cases, the age estimates from scales were up to 5 years lower than estimates from otoliths. Similarly, scales underestimated the ages of Bluegill age 6 and older compared to otoliths in Nebraska reservoirs (Perrion et al. 2024). Hoxmeier et al. (2001) compared Bluegill scale and otolith age estimates for Illinois reservoirs and indicated that ages could be estimated from scales through age 3. Scales are considered a viable option for age estimation of young (ages 0–5) centrarchids (Phelps et al. 2017).

Back-calculated lengths at age have commonly been calculated from measured annuli distances to the scale nucleus (Devries and Frie 1996). Since it is logistically unlikely for all fish sampling to occur at the same time, back-calculated lengths have primarily been used for growth comparisons (Jackson et al. 2008) by providing lengths prior to the start of the growing season. Growth standards based on back-calculated lengths provide a means to directly assess growth (e.g., 25th, 50th, and 75th percentiles) and have been proposed for many species (Jackson and Hurley 2005, Jackson et al. 2008, Quist et al. 2003, Starks and Rodger 2020). Additionally, age-specific standard lengths estimated with a von Bertalanffy model can be used to calculate the relative growth index (RGI; Casselman and Crossman 1986, Quist et al. 2003). The RGI is calculated as RGI = (L_t/L_s) x 100, where L_t is the observed length at age (t), and L_s is the age-specific standard length; an RGI >100 indicates above-average growth, and <100 represents below-average growth (Jackson et al. 2008, Quist et al. 2003, Shoup and Michaletz 2017).

Otoliths generally provide more precise and accurate age estimates versus scales and other structures (Maceina et al. 2007). An important component of otoliths is that they continue to grow and form annuli throughout a fish's life and are not resorbed during slow growth periods (Campana 1983). Sagittal otoliths (herein otoliths) have been validated for Bluegill age estimation (Hales and Belk 1992, Schramm 1989), and Phelps et al. (2017) suggested that otoliths provide the most precise and accurate age estimates for centrarchids. In many agencies, otoliths have replaced scales as the preferred structure for estimating fish ages. In South Dakota, fisheries personnel primarily use otoliths for age estimation, except in a few regional areas. The change to otoliths from scales has made comparing growth across populations more difficult because length at capture at age is reported and not a back-calculated length when estimating ages with otoliths. The lack of back-calculating previous lengths from otoliths is due to the additional time and resources necessary to prepare (e.g., sectioning and mounting) otoliths to measure annuli compared to only estimating ages.

When fish sampling occurs at the same time of year, comparisons of lengths at age can be made across waters. For example, Perrion et al. (2024) evaluated Bluegill growth across new, established, and renovated reservoirs in Nebraska by comparing lengths at age (estimated with otoliths) of fish collected in the spring. Because of seasonal length changes, comparing growth during different times within a growing season is not valid. Marginal increments beyond the last annuli on Bluegill otoliths were found to form at 22 ºC or higher water temperatures (Schramm 1989). The findings of Schramm (1989) indicate substantial Bluegill growth does not occur until water temperatures of 22 ºC, which in most years would occur in mid- to late-June in eastern South Dakota waters. Jackson et al. (2008) indicated that to develop a mean length at age North American growth standard, would require that fish sampling occurs at the same time of year across North America. Because sampling across waters does not occur at the same time, the objectives of this project were 1) Determine Bluegill population mean lengths at age by month (i.e., May, June, July), 2) Calculate unweighted mean lengths at capture across populations by month, 3) Establish percentile distributions of population mean lengths at age by month, and 4) Estimate monthly von

Bertalanffy models (which can be used to determine standard lengths at age) for Bluegill populations in eastern South Dakota. Specifically, monthly (i.e., May, June, and July) unweighted mean lengths at age; mean length percentile distributions; and von Bertalanffy models from which standard lengths can be calculated are provided for comparing Bluegill lengths at age for South Dakota and regional Bluegill populations.

Dreissena polymorpha Pellas (Zebra Mussel) have been found in numerous waters in South Dakota since 2020 (14 eastern South Dakota waters were known to have Zebra Mussels in 2024), and it is anticipated additional infestations will occur. The presence of Zebra Mussels has the potential to impact Bluegill populations, including their growth. Thus, the lengths at age information we present has the potential to serve as baseline information for monitoring changes in Bluegill growth.

Methods

Bluegills were collected with modified-fyke nets (two 0.9 m x 1.5 m frames, three 0.9 m diameter hoops, a single throat, a 0.9 m x 15.2 m lead, and 19 mm bar knotted mesh) in eastern South Dakota lakes during 2019–2023. These collections occurred during fish community surveys completed by the South Dakota Department of Game, Fish and Parks. Some waters were only sampled once during the 5 years, while others were sampled multiple years. Waters included in the analysis ranged from 4 to 885 hectares (Table 1). When more than 100 Bluegill were collected in a survey, the first 100 were measured for total length (TL, mm) and weighed (g), and then only counts of Bluegills collected by each net were made. The counted Bluegills were binned into 10 mm length classes based on the relative frequencies of the 100 measured fish. An age estimation structure (i.e., scale or otolith) was removed from at least five fish per cm-length group when available. Scales were removed from the area near the tip of the pectoral fin and below the lateral line. Since Bluegill sex is not always apparent from external characteristics, it is not recorded as part of standardized sampling in South Dakota. Thus, sex-specific growth analysis was not possible.

Scales were pressed onto acetate slides, and the impressions were viewed with a microfiche reader to identify annuli for age estimation. Otoliths were stored in plastic vials and allowed to dry for a minimum of 2 weeks before age estimation. A stereo microscope with reflected light and (or) a fiber-optic filament was used to view otoliths for age estimation. Otoliths were either viewed whole while submersed in water over a black background, or they were cracked in half at the nucleus, lightly toasted with an open flame, a thin coat of glycerin applied, and placed on end in clay for viewing. Koch et al. (2019) found no bias in estimated ages between Bluegill whole otoliths and sectioned otoliths. Age estimates were completed by an experienced reader at each of the four offices responsible for Bluegill sampling in eastern South Dakota. The scale or otolith edge was counted as an annulus when no marginal increment was apparent, or the increment was nearly equal to the distance between the previous annuli (Blackwell and Kaufman 2012). An age-length key was used to assign ages to all of the fish within a population sample for which no aging structure was collected (Isermann and Knight 2005). Sample data were grouped by the month (i.e., May, June, July) in which Bluegill collection occurred. Some waters were annually sampled during 2019–2023, and others only once. If sampling occurred in multiple years, we included the year with the highest Bluegill number. We only included samples having ≥30 fish and truncated the ages at 2–6 years because few fish <2 years and >6 years were in the samples.

Table 1. Mean total length at capture at ages 2–6 for Bluegill collected from eastern South Dakota waters by year and month. Structure used to estimate ages and n is the expanded age number following use of an age-length key. Unweighted mean lengths at age are provided for each month with the standard error provided in parentheses.

								Mean total length (mm) at age at capture				
Lake	County	Size (ha)	Year	Month	Date	Structure	n	2	3	4	5	6
Alvin	Lincoln	42	2023	May	05/22/2023	Otolith	69	120	158	170	193	
Henry	Bon Homme	42	2022	May	05/16/2022	Otolith	153	100	135	166		
Menno	Hutchinson	16	2022	May	05/17/2022	Otolith	65	98	147	183	208	220
					May unweighted mean of means			106 (7.02)	147 (6.64)	173 (5.13)	201 (7.50)	220
Clear	Marshall	493	2023	June	06/20/2023	Otolith	1052	102	130	164	173	180
Cochrane	Deuel	148	2022	June	06/28/2022	Otolith	596	100	143			
Cottonwood	Marshall	141	2021	June	06/02/2021	Otolith	54	122		197	224	215
Enemy Swim	Day	885	2023	June	06/14/2023	Otolith	2343	83	105	132	165	194
Hurley	Potter	39	2020	June	06/03/2020	Scale	79	133	148	168	179	
Leola	McPherson	7	2019	June	06/25/2019	Scale	75	122	134	143	157	
Mitchell	Davison	279	2021	June	06/02/2021	Otolith	236	124	178	191	196	220
North Buffalo	Marshall	168	2022	June	06/14/2022	Otolith	690	92	114	157	175	190
Pickerel	Day	400	2020	June	06/24/2020	Otolith	365	120	173	210	231	
Potts	Potter	21	2023	June	06/05/2023	Scale	37	155				
Richmond	Brown	300	2022	June	06/08/2022	Otolith	66	145		202	213	222
South Buffalo	Marshall	855	2021	June	06/16/2021	Otolith	1003	96	165	167	190	191
Wagner	Charles Mix	4	2023	June	06/20/2023	Scale	33	126	136			
					June unweighted mean of means			117 (5.89)	143 (7.16)	173 (8.23)	190 (7.99)	202 (6.37)
Clear	Marshall	493	2019	July	07/15/2019	Otolith	1,635	93	119	151	181	204
Enemy Swim	Day	885	2021	July	07/13/2021	Otolith	1,291		99	146	176	199
Mina	Edmunds	300	2019	July	07/30/2019	Otolith	137	173	198	215		
Roy	Marshall	855	2021	July	07/08/2021	Otolith	257	110	165	184	198	194
Wagner	Charles Mix	4	2020	July	07/06/2020	Scale	133	132	148	164		
					July unweighted mean of means			127 (17.29)	146 (17.33)	172 (12.60)	185 (6.66)	199 (2.89)

Mean lengths at capture by age were determined for each included sample. Population mean lengths at age were compared across months with ANOVA using SYSTAT13 (SYSTAT, 2009), and an $\alpha \leq 0.05$ was used to indicate statistical significance. An unweighted mean of population means at each age was calculated for May, June, and July. The use of an unweighted mean provides each population equal representation in the final mean (Willis et al. 2001). We also determined the monthly 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles for the population mean total lengths at each age for comparisons (Hubert 1999, Jackson et al. 2008, Quist et al. 2003).

The unweighted means of the population mean lengths at each age were used to estimate a von Bertalanffy growth model for each month. The von Bertalanffy model is $L_t = L_\infty[1 - e^{-k(t-t_0)}]$, where L_t is the length at time t, L_∞ is the asymptote length, k is a growth coefficient, and t_0 is when the fish would theoretically have a length of 0. Fisheries Analysis and Modeling Simulator (FAMS, Slipke and Maceina 2014) software was used to fit the von Bertalanffy growth models. The resulting von Bertalanffy models allow for the calculation of age-specific standard lengths for each month, which can be used in calculating RGI.

Results

Bluegill ages were estimated with scales for five samples, and otoliths were used to estimate ages for 16 samples (Table 1). No fish were estimated to be older than age 5 in the samples where ages were estimated with scales. June was the most represented month with 13 samples, five samples were included in July, and only three samples were from May. Samples for lakes Clear, Enemy Swim, and Wagner during 2019-2023 were not always completed in the same month; thus, we were able to include samples collected in June and July for these waters.

Mean lengths at age were variable across lakes for each month (Table 1). Mean lengths at capture for each age were not significantly different across the 3 months (age 2: $F = 0.696$, $df = 2, 17$, $p = 0.512$; age 3: $F = 0.037$, $df = 2, 15$, $p = 0.964$; age 4: $F = 0.003$, $df = 2, 15$, $p = 0.997$; age 5: $F = 0.285$, $df = 2, 12$, $p = 0.757$; and age 6: $F = 0.791$, $df = 2, 8$, $p = 0.486$). The monthly unweighted mean lengths at age (Table 1) and percentile lengths at age (Table 2) are provided for comparison purposes.

The correlation coefficients (r^2) for the monthly von Bertalanffy growth models ranged from 0.994 to 0.998, and the estimated asymptotic lengths were 301.174 (May), 252.155 (June), and 273.441 (July). The growth coefficients for May, June, and July were 0.218, 0.256 and 0.172, and the estimated theoretical times when bluegill length is 0 were -0.002, -0.399, and -1.584. The von Bertalanffy growth model curves show similar lengths for June and July, and May exhibited smaller lengths at ages 2–3 and larger lengths at older ages (Fig. 1).

Discussion

As expected, there was a considerable variation in population mean lengths at capture in the eastern South Dakota Bluegill populations. We did not test for differences among populations within each month because we were interested in developing regional descriptors of Bluegill lengths at age and not showing where differences in growth may occur. Similarly, Willis et al. (1992) noted variable growth across South Dakota Bluegill populations. Bluegill growth has also been found to be highly variable for Kansas impoundments (Neely et al. 2020). The variability in lengths at capture across populations is most likely related to the dif-

Table 2. Percentile distributions of population mean total length at age by month (May, June, July) for Bluegills in eastern South Dakota (n is the number of populations included).

			Percentile						
	Age	n	5%	10%	25%	50%	75%	90%	95%
May	2	3	98	98	99	100	110	116	116
	3	3	136	137	141	147	153	156	157
	4	3	166	167	168	170	177	180	182
	5	2	194	195	197	201	204	207	207
	6	1	220	220	220	220	220	220	220
June	2	13	88	93	100	122	126	143	149
	3	10	109	113	131	140	161	174	176
	4	10	137	142	159	168	196	203	206
	5	10	161	164	174	185	209	225	228
	6	7	183	186	191	194	218	221	221
July	2	4	96	98	106	121	142	161	167
	3	5	103	107	119	148	165	185	191
	4	5	147	148	151	164	184	203	209
	5	3	177	177	179	181	190	195	196
	6	3	195	195	197	199	202	203	204

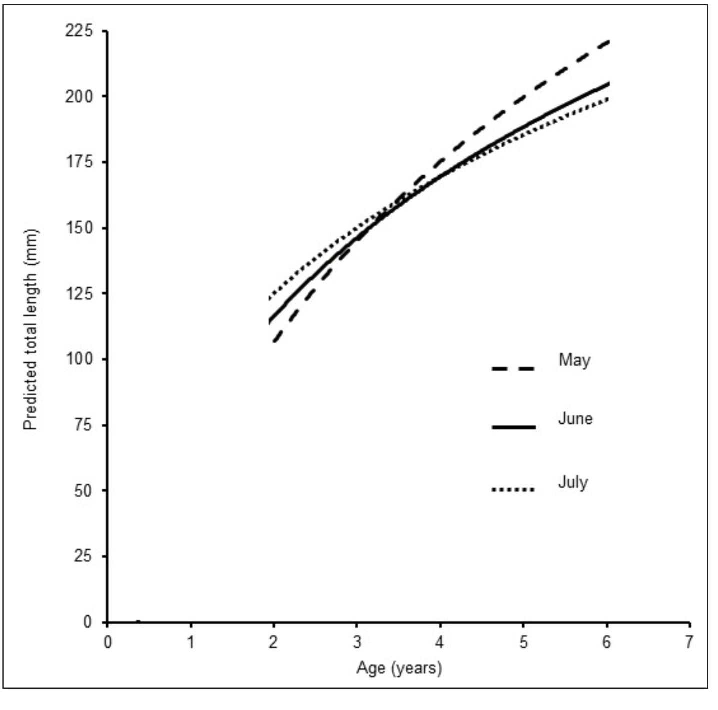

Figure 1. Monthly (May, June, July) von Bertalanffy growth (mm) curves for Bluegill across ages 2–6 in eastern South Dakota.

ferent biotic and abiotic conditions experienced by each population. Most sampling in eastern South Dakota waters containing Bluegill fisheries occurs in June. Thus, the June values we provided were developed with the most data and likely give a better representation than those for May and July, which were hampered by low numbers of included populations. Because of the limited number of populations included for May and July, we recommend caution when making inferences based on these values.

Our unweighted mean lengths and median lengths at capture at age for June were greater than the reported mean back-calculated lengths at each age but are generally similar to the next age's mean back-calculated length reported by Willis et al. (1992). For example, at age 2 our mean length (117 mm) was closer to the Willis et al. (1992) reported mean back-calculated length at age 3 (122 mm) than the reported age 2 (84 mm) back-calculated length. The back-calculated lengths at ages 2–7 provided by Willis et al. (1992) were 84, 122, 152, 166, 182, and 215 mm. In our study, mean lengths at capture at ages 2-6 in June were 117, 143, 173, 190, and 202 mm. A similar relationship was also observed between our lengths at age and the mean back-calculated lengths for lentic waters reported for the North American Great Plains (Brouder et al. 2009). The reported Bluegill back-calculated lengths at age for the Great Plains region for ages 2-6 were 100, 137, 157, 180, and 190. The fish collected in June have likely started their annual growth making their lengths closer to the next age back-calculated length. Schramm (1989) reported that marginal increments (translucent zone) began forming distal to the last annuli when water temperatures were 22 ºC, which would occur during June in South Dakota. The formation of the translucent zone is indicative of somatic growth beginning.

We did not expect the larger lengths at capture observed in May. The populations included for May are in southeastern South Dakota, which tends to have milder winters and earlier ice-outs than the rest of eastern South Dakota. The milder winters may allow for an earlier and longer growing season, which may contribute to the larger lengths observed in May. Willis et al. (2001) indicated that of the 27 populations they examined having age-5 fish, only two had mean back-calculated lengths exceeding 200 mm at age 5, and both were from southeastern South Dakota. The mean values for May should be used with caution because of the limited data availability.

Interestingly, the June and July unweighted means and resulting percentiles were similar. The similar values for June and July may result from the timing of when Bluegill growth increases in eastern South Dakota waters. Most Bluegill growth in eastern South Dakota waters likely does not occur until July or August once waters fully warm and after their spawning has occurred. Peak larval Bluegill abundances in four eastern South Dakota impoundments were found to occur in late June to early July, indicating spawning occurred in June (Edwards 2007). In eight northern Indiana lakes, Bluegill growth began in May and sharply increased from June through August before declining to a low level by September and October (Gerking 1966). South Dakota Bluegills likely follow a similar growth pattern but with a later start and increase in growth rate. The growth of other fish species in South Dakota has been found to increase during mid-summer. At Lake Goldsmith, South Dakota, monthly sampling (March–September) revealed that most of the growth in length exhibited by *Pomoxis annularis* Rafinesque (White Crappie) occurred during July and August (Guy and Willis 1995). Otoliths collected monthly from South Dakota *Perca flavescens* Mitchill (Yellow Perch) populations were found to have the lowest marginal increment measurements in July and August. The low marginal increment values suggest that Yellow Perch annual growth was beginning in July and August. Because South Dakota is farther north than Indiana, the timing of Bluegill growth is probably comparable to White Crappie and Yellow Perch in South Dakota waters.

The similarity between our mean lengths at age and the next age's back-calculated length indicates South Dakota's average Bluegill growth has changed little in nearly 4 decades. The ongoing introductions of Zebra Mussels into South Dakota waters and across the upper Midwest may change future Bluegill growth rates. These growth changes may occur because of resulting habitat changes (e.g., increased water clarity, increased submerged vegetation) and (or) shifts in Bluegill prey (e.g., zooplankton and benthic invertebrates) and feeding efficiency. Bluegill growth and associated large body size in Illinois reservoirs were linked to warm, clear lakes having abundant food resources (Hoxmeier et al. 2009). However, Mercer et al. (1999) did not observe a change in Bluegill growth in 3 years following the invasion of Zebra Mussels into a shallow, eutrophic Ontario lake.

Alternative to comparing length at age with the provided means, percentile values, or the von Bertalanffy growth models, the RGI can be calculated to summarize and interpret growth (Jackson et al. 2008, Quist et al. 2003, Shoup and Michaletz 2017). Quist et al. (2003) suggested that percentiles and RGI can be used concurrently to compare fish growth. The authors believed that percentile values are descriptive, and that RGI provides for a more refined growth comparison. The RGI typically uses standard lengths derived from von Bertalanffy model developed from many populations encompassing a large area (e.g., North America; Jackson et al. 2008). Because only values for eastern South Dakota were included in this project, our measure is a regional measure of Bluegill growth. Instead of referring to the index as RGI, it may be better to call it the South Dakota relative growth index (SDRGI). A suggested range for average growth would have SDRGI values from 90–110 based on the June 25% percentile values by age having an average SDRGI = 90 (SE = 3.30) and the 75% percentile lengths having an average SDRGI = 111 (SE = 3.04). In the future, it would be beneficial to develop monthly standard lengths for other sportfish in South Dakota waters to be able to compare lengths at capture for growth evaluations now that estimating ages with otoliths is common.

We have provided several ways for comparing Bluegill lengths at age by month when ages are estimated. Growth comparisons across waters using some standardized measure can help to guide fisheries management actions (Jackson et al. 2008). Providing the current information will allow for Bluegill growth evaluations for South Dakota and regional Bluegill populations. The information provided in this document will provide baseline information allowing for determining if Bluegill growth changes occur with an expansion of Zebra Mussel infestations. If Zebra Mussels expand to additional waters, a future update to Bluegill growth in South Dakota may be needed.

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