Age and Growth of a Landlocked Population of Blueback Herring and Management Implications[1]

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Abstract: A landlocked population of blueback herring (*Alosa aestivalis*) was established in 1982 in Lake Theo, Texas, and persisted for 7 years. Analysis of scales provided inaccurate ages for fish older than age 1. Analysis of otoliths provided valid ages of blueback herring, but protracted formation of annuli on otoliths limited the use of otoliths for back-calculating lengths of these fish. Fish in this landlocked population attained maximum total lengths of 240 mm, lived 2 years, and spawned only once. The disappearance of blueback herring in Lake Theo was attributed to their short life cycle and production of weak year classes. Future use of blueback herring as a forage fish may require additional stocking to supplement weak or missing year classes to maintain the population.

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Blueback herring is an anadromous clupeid indigenous to the Atlantic coast of North America (Scott and Crossman 1973). Landlocked populations occur in coastal lakes and southeastern reservoirs (Bozeman and Van Den Avyle 1989). Blueback herring were experimentally stocked into Lake Theo, Texas, to be evaluated as an alternative forage fish (Guest 1990). The initial stocking of adult fish in 1982 resulted in a reproducing population that persisted until August 1988. No blueback herring were collected after that date.

The rapid growth of blueback herring to 180–220 mm total length during their first 2 years allows age estimation by length-frequency analysis. However, the

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occurrance of few fish >240 mm in Lake Theo limits the use of length-frequency analysis to the first 1 or 2 years of their life. Age determination of blueback herring is essential to evaluation of the growth rate of this potential forage fish and is needed to understand the loss of the Lake Theo population.

Marcy (1969) and Kornegay (1978), applying the criteria of Cating (1953) for aging American shad *Alosa sapidissima* with scales, aged anadromous blueback herring. Guest (1990) aged blueback herring from a landlocked population (Lake Theo, Texas) using scales; however, he interpreted scales by simultaneous consideration of sampling date, length-frequency distributions, and reproductive state. Guest found some scales had checks that were classed as false annuli and counted spawning scars (as described by Cating 1953) as annuli. Kornegay (1978) aged anadromous blueback herring with otoliths but only found 57% agreement between ages assigned from otoliths and scales.

In this paper, we compare otoliths and scales for aging a landlocked population of blueback herring and provide evidence that otoliths are a valid ageing structure. The resulting information about age and growth of blueback herring is then used to develop 2 hypotheses to explain the disappearance of this population of blueback herring.

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Methods

Adult blueback herring from the Cooper River, South Carolina, were stocked into Lake Theo (Briscoe County, Texas), a 30-ha reservoir, in March 1982 (Guest 1990). Blueback herring were sampled quarterly during December 1982 to January 1984 and monthly during March 1984 to April 1986 and May 1987 to August 1988 with experimental gillnets (19, 25, 38, and 51 mm square mesh) and electrofishing. Total lengths of all fish collected were measured to the nearest millimeter.

The growth of year classes was determined by length-frequency analyses. Mean lengths were calculated for each year class for each sample and used as observed lengths for comparisons with lengths back calculated from scales and otoliths.

Scales were obtained from fish collected during May–August 1985 and May 1987–August 1988. Scales were removed from an area directly below the dorsal fin and above the midline (Marcy 1969). Scales were pressed between 2 glass slides and viewed with a microfiche reader. Scales were aged by 2 readers independently from other data about the fish. All growth checks that appeared to be annuli or spawning scars were counted as annuli. Then, the scales were viewed simultaneously by the 2 readers, differences in interpretation resolved, and measurements of scale radius and distance to annuli (distal edge) made to the nearest millimeter along the first transverse groove on a microfiche reader screen. Scales were classified as "unreadable" if an age could not be assigned or if the 2 readers could not agree on age or location of presumed annuli.

Otoliths (sagittae) were dissected from fish collected April–August 1985 and all fish collected in 1987–1988. Whole otoliths were submerged in water in a black Syracuse dish (Schramm and Doerzbacher 1984) and viewed with a dissecting microscope. Photographs of whole otoliths were also prepared with a photographic enlarger (Doerzbacher and Schramm 1984). Transverse cross sections through the nucleus in the dorso-ventral plane were prepared similar to the method described by Hoyer et al. (1985), covered with immersion oil, and viewed with a compound microscope. Using opaque bands as presumptive annuli, ages were assigned independently of date or length data by 2 readers for all 3 viewing methods. An opaque band was considered an annulus if translucent material was visible distal to the opaque band. Then all preparations of the otoliths were viewed simultaneously by the 2 readers (both readers agreed on number and location of annuli on all otoliths) and measurements were made on the photograph to the nearest 0.025 mm with a dial micrometer. Otolith radius and distances to annuli were the maximum distances from the center of the nucleus to the edge of the otolith and the distal edge of each annulus (opaque band) measured in the posterior-dorsal field.

Estimated lengths at the time of annulus formation were back calculated from scales by intercept-corrected direct proportion (Bagenal and Tesch 1978) and from otoliths by direct proportion (Schramm et al. 1992). These back-calculated lengths were compared to observed lengths (from length-frequency analysis) during April–May (the time of annulus formation on scales, Guest 1990) for the appropriate year class and tested for significant difference by a *t*-test.

Results

Length-frequency distribution revealed no overlap in lengths of fish in successive year classes during the first 2 years of growth (Fig. 1). Young-of-the-year blueback herrings were first collected in July–December. Mean total lengths of fish in March–May were 98–170 mm for age 1 fish and 204–214 mm for age 2 fish. Lengths in January–February of age 0 fish of the 1985 and 1987 year classes were considerably smaller than those of 1982, 1983, and 1984 year classes.

Year classes were produced in 1982–1985 and in 1987, but there was no evidence for a 1986 year class (Fig. 1). Although samples were not collected from April 1986 to May 1987, collection of only 3 fish in the length range 100–170 mm (the length range of all other year classes of age 1 blueback herring during summer) during May–July 1987 indicated the 1986 year class was weak or absent. The 1987 year class was collected during July 1987 to January 1988. Although monthly sampling was continued through August 1988, only 3 blueback herring (189–199 mm long, presumed to be the 1987 year class) were collected in August 1988.

The scales of blueback herring closely matched the descriptions of Cating

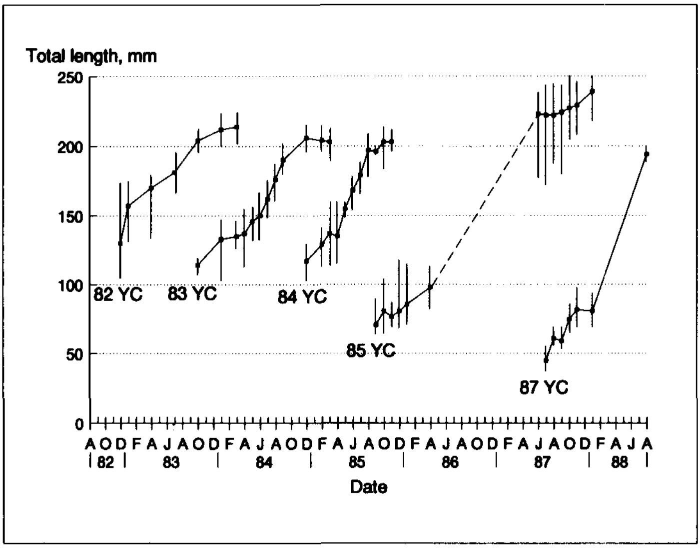

Figure 1. Mean lengths (10 mm size classes, vertical lines are ranges) of 5 year classes (YC) of blueback herring in Lake Theo, Texas, December 1982 through August 1988.

(1953) and Kornegay (1978). "Scar-like" checks considered to be spawning marks were present in the scales of 33% and 85% of 2-year-old fish collected in 1985 and 1987. These spawning marks were found in scales from fish collected in June 1985 and from fish collected during July 1987 through January 1988.

The otoliths of blueback herring were thin and relatively narrow opaque bands (annuli) separated by translucent zones of varying width were apparent in whole views and cross sections. In whole views, we found opaque bands generally were most conspicuous in the posterior-dorsal portion of the otolith. Also, newly formed opaque bands first appeared in this portion of the otolith.

Ages assigned from otolith whole views and cross sections agreed in 93% of the comparisons (Table 1). We used otolith whole views for all further analyses of otoliths. Ages assigned from scales and otoliths agreed for 66% of the comparisons.

Ages assigned from scales did not show good agreement with expected ages based on lengths (Fig. 2). In particular, a high proportion of fish >190 mm (expected to be age 2 fish) were assigned age 1 by scale analysis and, therefore, would be 1986 year class fish.

Ages assigned from otoliths also indicated a high proportion of fish >190 mm during June–August were age 1 (Fig. 3). However, unlike fish aged by scales, almost all fish expected to be age 2 had 2 annuli in the otoliths after September indicating annulus formation in otoliths was not complete until September.

We found significant ($P \leq 0.001$) relationships between scale radius (SR) and

Table 1. Comparison of ages of blueback herring assigned from analysis of scales, whole views of otoliths, and cross sections of otoliths.

Assigned age	Assigned age from otolith whole view 0	1	2
	Otolith cross sections		
0	15	0	1
1	0	15	2
2	0	0	11
	Scales		
0	24	0	1
1	5	39	23
2	1	21	55
3	0	0	12

fish total length (TL, Equation 1) and between otolith radius (OR) and fish total length (Equation 2).

$$TL = 14.803 + 1.777(SR),\ N = 200,\ R^2 = 0.93 \qquad \text{Equation 1}$$

$$TL = -25.403 + 0.315(OR),\ N = 203,\ R^2 = 0.84 \qquad \text{Equation 2}$$

No substantial improvement in fit was found for these relationships by logarithm transformation. The intercept value from Equation 1 was used to back calculate lengths of fish from scale measurements.

Lengths back calculated from otoliths were smaller than observed lengths for the 1983 year class and larger than observed lengths for the 1985 year class (Table 2). Lengths back calculated from scales from age 1 and age 2 fish differed from observed lengths for the 1983 and 1985 year classes (Table 2). Twelve fish collected in 1987 were age 3 (1984 year class) based on analysis of scales (Fig. 2). Back-calculated lengths from these age 3 fish at age 1 (mean 92.5 mm, SD = 5.7) and age 2 (mean 171.9, SD = 33.8) were significantly smaller than observed lengths of the 1984 year class in May 1985 and May 1986 (Table 2). Considering the second annulus of these 12 fish to be a false annulus, back-calculated lengths were not different from the observed lengths of the 1985 year class in May 1986 and May 1987.

Discussion

The 1982, 1983, and 1984 year classes of blueback herring in Lake Theo grew to approximately 130–150 mm in their first year. The 1985 and 1987 year classes grew more slowly. All year classes grew to 200–250 mm in their second year. The maximum length was considerably smaller than that attained by landlocked populations in South Carolina reservoirs (Prince and Barwick 1981).

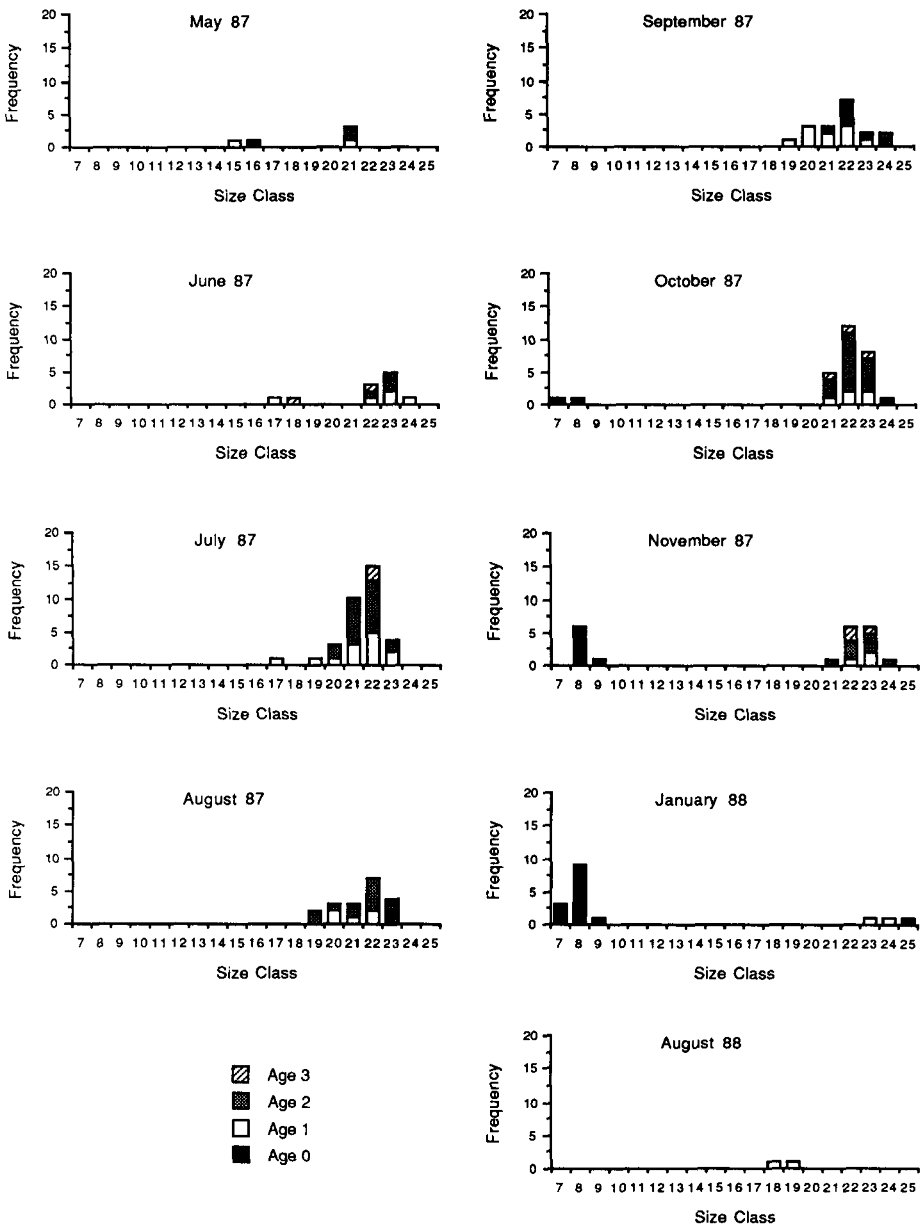

Figure 2. Age and length distribution of blueback herring collected from Lake Theo, Texas, in 1987 and aged from scales.

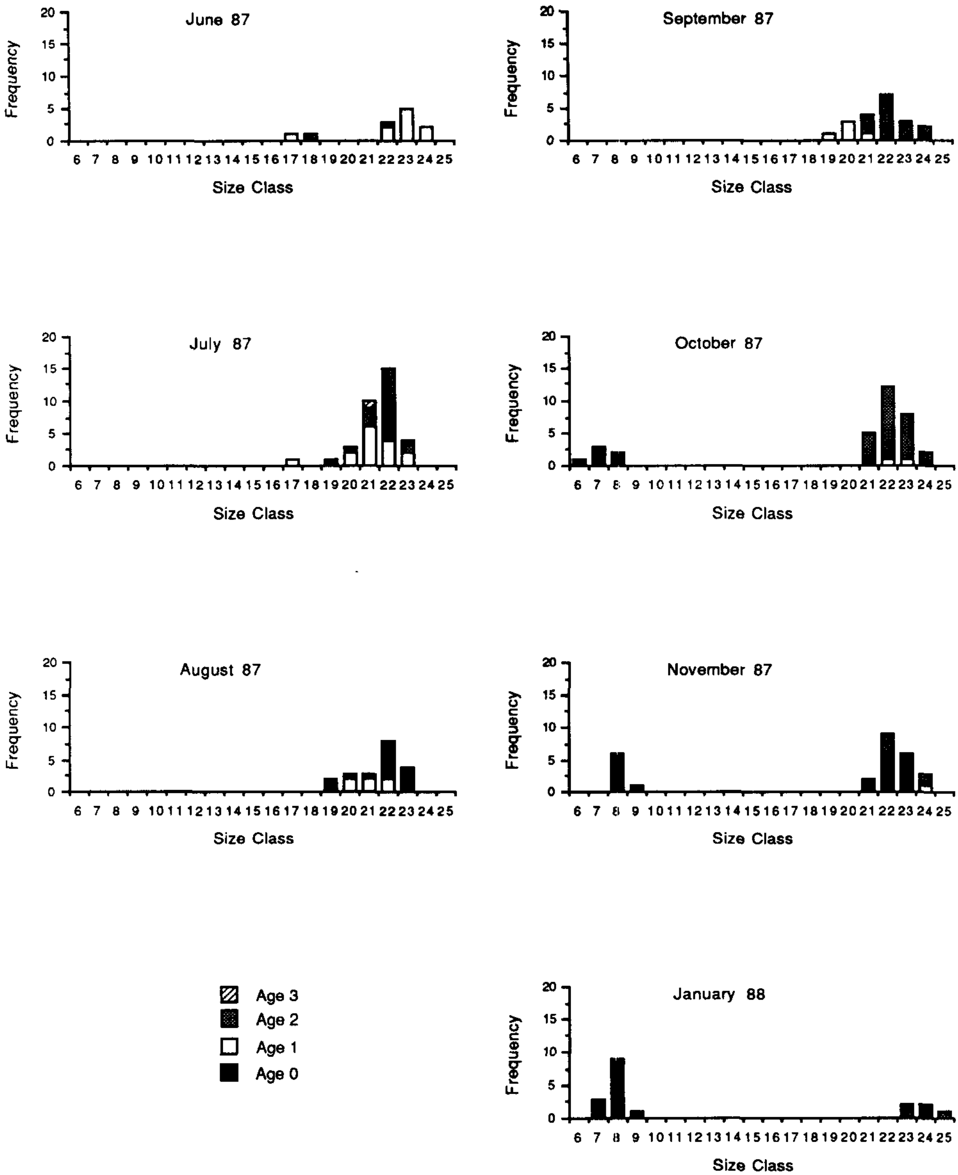

Figure 3. Age and length distributions of blueback herring collected from Lake Theo, Texas, in 1987 and aged from otoliths.

Table 2. Mean lengths (mm) of blueback herring at ages 1 and 2 estimated from scales and otoliths. Values in parentheses are sample size, standard deviation.

Year class	Observed length[a]		Scales		Otoliths	
	Age 1	Age 2	Age 1	Age 2	Age 1	Age 2
1983	165.7	206.2	133.3[b]	158.9[b]	137.2[b]	180.4[b]
	(16,48.5)	(14.81.7)	(14,15.1)	(3,37.6)	(17,7.1)	(7,22.0)
1984	134.0	204.2	133.9		140.1	
	(18,89.6)	(5,67.7)	(23,19.2)		(10,12.1)	
1985	98.4	191.4	91.6	211.3[b]	149.1[b]	204.4[b]
	(15,30.0)	(5,31.0)	(85,18.1)	(73,19.8)	(131,13.4)	(99,12.2)

[a]From length-frequency analysis, see Figure 1.
[b]Significantly different ($P < 0.05$) from observed length in April–May.

Scales of blueback herring in this landlocked population were difficult to interpret. Reasonable ages can be assigned to blueback herring scales when they are interpreted in conjunction with length and spawning data from frequently collected samples; however, assignment of reasonable ages requires interpreting spawning scars as annuli and some growth checks as false annuli (Guest 1990). Inaccurate ages were assigned when scales were aged independently from length-frequency data. The assignment of a large proportion of fish >190 mm (sizes typical of 2-year-old fish) collected in 1987 to the weak 1986 year class indicates recognizable annuli may not form on scales. The discrepancies between back-calculated lengths of age 3 fish with the observed lengths of the 1984 year class at ages 1 and 2 indicates false annuli that can not be distinguished from true annuli can be formed on scales. False annuli in blueback herring scales have been reported (Kornegay 1978).

The relative scarcity of fish collected during August 1987 through January 1988 that were age 1 from analysis of otoliths (1986 year class) agrees with evidence for a weak 1986 year class from length-frequency analysis. The occurrence, with 1 exception, of no fish aged older than age 2 by analysis of otoliths also agrees with growth curves determined by length-frequency analysis. We conclude that otoliths provided accurate ages of this population of blueback herring.

The annuli in otolith whole views were generally distinct and ages were easily assigned to whole otoliths viewed with a microscope or in enlarger-produced photographs. With few exceptions, ages assigned to cross sections of otoliths agreed with ages assigned to otolith whole views. It is not necessary, at least for 1- and 2-year-old fish, to analyze otolith cross sections to age blueback herring. Although otoliths provided accurate ages for this blueback herring population, caution is recommended in the use of otoliths. Because annulus formation may not be complete until after August, fish for aging should be collected in late fall through spring. The protracted formation of annuli in otoliths also presents problems for back-calculation of length. The greater back-calculated lengths than the observed lengths of the 1984 and 1985 year classes are likely related to the protracted annulus formation.

An important attribute of a desirable forage fish is stable abundance (Ney 1981).

Loss of a population is an extreme case of unstable abundance. The loss of the blueback herring population in Lake Theo can be related to its short life span. Blueback herring in their native marine habitat live 7–10 years (Marcy 1969, Kornegay 1978), attain sexual maturity at ages 3 or 4 (Loesch and Lund 1977) and total lengths of 240–280 mm (Marcy 1969), and spawn several times during their life. Blueback herring in Lake Theo reached sexual maturity at age 2 and total lengths of 200 mm. Length-frequency analysis of monthly samples and analysis of otoliths indicated few fish in Lake Theo lived beyond age 2. Therefore, each year class spawned only once and the production of a year class was dependent on reproduction by the year class produced 2 years earlier.

There were no obvious environmental factors associated with the production of a weak 1986 year class and the loss of the 1987 year class. The 1986 year class would have been spawned by the 1984 year class. Abundance of age 2, 1984 year class fish, was relatively low. Apparently, few fish of the 1984 year class lived long enough to spawn in 1986 and a weak 1986 year class was produced. The 1987 year class was produced by the strong 1985 year class, but the 1987 year class essentially disappeared after January 1988. Considering the relatively slow growth rate of the 1987 year class and the scarcity (or absence) of blueback herring produced in 1986, it is possible that predation focused on a single year class could have caused high mortality of the 1987 year class and subsequent loss of the population. Alternatively, the population dynamics may be related to nutrition. Guest (1986) noted a drastic decline in zooplankton density in 1985; the 1985 year class grew slowly. Crustacean zooplankton density was lower in the summer 1987 than in 1986 (Conley, unpubl. data). Given the continued presence of the 1985 year class through the summer and fall of 1987, high predation on the low density of zooplankton could have resulted in insufficient food to sustain the 1987 year class.

The loss of this population, introduced to provide a forage fish for largemouth bass, and the short life span indicates landlocked blueback herring may not reliably provide a stable population of forage fish. Managers should be aware that use of blueback herring as a forage fish in landlocked waters may require maintenance stocking following production of a weak or missing year class.

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