LIFE HISTORY OF JUVENILE ALLIGATOR GAR

(*ATRACTOSTEUS SPATULA*) IN OKLAHOMA

By

RICHARD SNOW

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St. Gregory's University

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Thesis Approved:

Dr. James M. Long

Thesis Adviser

Dr. Daniel E. Shoup

Dr. Anthony A. Echelle

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LIFE HISTORY OF JUVENILE ALLIGATOR GAR (ATRACTOSTEUS SPATULA) IN OKLAHOMA

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Abstract: Daily ring formation has been validated for a variety of fish species, but there is little known information or data on ageing young of year Alligator Gar *(Atractosteus spatula).* Artificially spawned Alligator Gar fry with a known spawn date, hatch date, and swim-up date were stocked into two ponds at Tishomingo National Fish Hatchery and reared from 9 to 91 days post-hatch. Up to 10 individuals were sampled each week, and age in days was estimated from counts of presumptive daily rings in the otoliths (sagittae, lapilli, and astericsi). Mean daily ring count and known age were closely related to swim-up (sagitta $r^2 = 0.98$, lapillus $r^2 = 0.99$, asteriscus $r^2 = 0.93$) indicating that daily ring deposition occurred in the otoliths of Alligator Gar 2 days after swim-up. Daily increment counts were accurate through 73 (sagitta), 86 (lapillus), however accuracy for asteriscus was very low throughout 86 days from swim-up. Age-bias plot for the lapillus visually showed no bias between readers. The resulting regression of ring counts against known age (age = -0.96 + 1.03*estimated age) was applied to wild caught Alligator Gar collected in the summer of 2013 from Lake Texoma, Oklahoma, to estimate spawn dates. Spawn dates seem to coincide with rising pool elevation of Lake Texoma and water pulses of tributaries.

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CHAPTER I

LIFE HISTORY OF JUVENILE ALLIGATOR GAR (*ATRACTOSTEUS SPATULA*) IN OKLAHOMA

This thesis consists of one manuscript written for submission to Transactions of the American Fisheries Society. Chapter I is an introduction to the thesis. The manuscripts are complete as written and do not require supporting material. Chapter II is titled ‘Documenting utility of otoliths for estimating age and spawning times of Alligator Gar.’

CHAPTER II

DOCUMENTING UTILITY OF OTOLITHS FOR ESTIMATING AGE AND SPAWNING TIMES OF ALLIGATOR GAR (*ATRACTOSTEUS SPATULA)*

Introduction

Understanding early life history ecology of fishes (e.g., spawning and rearing) is vital for effective management (Quasim and Qayyum 1961). Most fishes are highly fecund, due to high mortality throughout the egg, larval and juvenile stages (Houde 1997). Body size and water temperature are two variables that have been closely related to survival, with water temperature accounting for up to 50% of the variation in survival and growth (Chambers and Trippel 1997). For example, year-class strength of centrarchids are affected by water temperature (Pope and Willis 1998) and body size as a function of birth date and growth rate (Kohler et al. 1993; Cargnelli and Gross 1996). Understanding physical and biological factors affecting early life history will provide managers with a useful perspective on recruitment.

Estimating daily age of young-of-year has been successfully used for many species and is useful for linking recruitment success to environmental variation. In Goldeye *(Hiodon alosoides)*, strong year classes were associated with warm, calm spring seasons that supported growth and survival of eggs and larvae (Donald 1997). Lecomte-Finiger (1992) found that otolith microstructure of the European Eel (*Anguilla anguilla*) provided a reliable record of its larval life history regarding the transition from marine to freshwater environments. Daily age estimation thus allows for back calculating spawn dates that can give insight into environmental factors affecting recruitment.

Validation of daily age is therefore critical to ensure realistic estimates of age and hatch dates. Many structures have provided age information for fishes, but otoliths typically yield the most accurate daily age estimates (Pannella 1971; Campana and Neilson 1985; Jones 1986). Daily growth increments provide fisheries managers with a tool for determining a number of important early life history characteristics associated with age and growth of juvenile fishes, such as patterns of reproduction and recruitment, hatch date, and growth and mortality rates (Miller and Stork 1984; Durham and Wilde 2008). Formation of the first growth increment, which is important for estimating hatch dates, varies among species. For example, it forms at hatching in White Crappie *Pomoxis annularis* (Sweatmen and Kohler 2011), at swim-up in Spotted Bass *Micropterus punculatus* (DiCenzo and Bettoli 1995); the day after swim-up in Gizzard Shad *Dorosoma cepedianum* (Davis et al. 1985), and 2-3 days after hatching in Spotted Seatrout *Cynoscion nebulosus* (Powell et al. 2000). Thus, daily rings must be validated for each species of interest (Campana and Neilson 1985).

Many reproductive studies of Alligator Gar (*Atractosteus spatula)* have emphasized the adult life-stage, while few studies have focused on the environmental factors affecting early life history stages (Ferrara 2001). Because spawning of Alligator Gar is likely linked to seasonal flooding, successful recruitment may be sporadici (Inebnit 2009). The ability to quantify the events or factors influencing Alligator Gar spawning habits would lead to a better understanding of factors affecting abundance of local populations. In this paper, I evaluate environmental conditions associated with spawning dates back-calculated from daily growth rings.

Hatcheries have provided useful information about early life history of Alligator Gar, but work on daily age is lacking. Mendoza et al. (2002) described the nutritional stages of larval development in Alligator Gar as follows: lecithotrophic (yolk sac nutrtion only) at 1-4 days after hatching (DAH), lecithoextrophic (yolk sac and exogenous nutrition; = swim-up stage) at 5-8 DAH, and exotrophic (exogenous feeding only) at 9 DAH (Mendoza et al. 2002). This has limited utility for estimating age or timing of reproduction of wild-caught fish, especially after the exotrophic stage. Validating daily increments would make it possible to apply age estimation techniques to wild-caught fish and back-calculate date of spawn, which would lead to better understanding of factors influencing reproduction and recruitment patterns for this important species.

Few studies have investigated methods for estimating age of Alligator Gar (Buckmeier et al. 2012) and none have focused on daily growth increments. Daily ring formation has been validated for a variety of other species (e.g., African Catfish *Clarias gariepinus*, Nyamweya et al. 2010; Black Porgy *Acanthopagrus schlegeli*, Huang and Chiu 1997; European Barbel *Barbus barbus*, Vilizzi et al. 2013; Largemouth Bass *Micropterus salmoides*, Miller and Stork 1984; Spotted Seatrout, Powell et al. 2000), but not for Alligator Gar. Accurate age and growth data is essential for a complete understanding of life history, aiding management of the species. The purpose of this study is to better understand early life history ecology of Alligator Gar by, 1) validating daily age increments in otoliths of known-age juvenile Alligator Gar reared at a hatchery and 2) determine environmental factors related to Alligator Gar spawning by estimating spawning date of wild-caught fish.

Methods

Daily Age Validation

Sample collection.- Fertilized Alligator Gar eggs were obtained and hatched on May 1 and 2, 2012 at Louisiana State University Agricultural Center Extension, Baton Rouge, Louisiana. Larvae reached swim-up (lecithoextrophic stage with active feeding with some yolk-sac nutrition) four to five days after hatch. They were transported to the Tishomingo National Fish Hatchery, Tishomingo, Oklahoma, and released into two rearing ponds on May 10, 2012, eight to nine days after hatch. A weekly sample of up to10 fish was subsequently collected with seines, sacrificed and preserved in 70% ethanol until all fish had been harvested.

Otolith Preparation.- Harvested fish were labeled with date harvested, measured to the nearest mm TL, and weighed to the nearest gram prior to dissection. Mathiesen and Popper’s (1987) description of *Lepisosteus* inner ear anatomy provided reference material for determining how to extract the sagitta, asteriscus and lapillus otolith pairs. Otoliths were removed by positioning the specimen dorsal-side down under a dissection microscope (20-50X magnification) and removing the head via a transverse incision anterior to the pectoral girdle. Dissection pins secured the head to a dissection platform at the upper jaw and opercles. Using forceps, the bottom jaw and gill structures were removed and the ventral side of the braincase was exposed. The parasphenoid was then detached to expose the inner ear structures, located just under the large bulbous portion of the parasphenoid. A lateral incision with a scalpel in the rostral region slightly anterior of the parasphenoid was used to separate the parasphenoid from the braincase. After removal of the parasphenoid, the saccule and lagena were revealed, allowing the sagittae and asterisci, respectively to be removed. The lapilli were then removed after removing brain matter from around the utricles.

Otoliths were cleaned and stored dry (Butler 1992) in color coded vials to distinguish otoliths type. Before viewing, otoliths were browned at 104°C on a hot plate to increase contrast between accretion and discontinuous zones (Secor et al.1992). After browning, otoliths were placed flat in Loctite 349 embedding medium (Mauck and Boxrucker 2004) for sectioning with a low speed saw (blade = 127 mm disc, 0.4 mm thick).

Otolith Sectioning.-Sagittae were sectioned in a transverse plane near the anterior portion of the otolith according to Buckmeier et al. (2012; Figure 1), whereas asterisci were sectioned at a transverse plane (Figure 2), and lapilli in a frontal plane (Figure 3). Otolith sections were mounted on glass microscope slides (3”x1”x 1mm) with thermoplastic cement and polished wet with 600-grit sandpaper to enhance visibility of daily rings.

Age Estimation.- To estimate daily ages, otoliths were examined under immersion oil independently by two readers (Hoff et al. 1997) using a high resolution monitor connected to an optic-mount digital camera attached to an Olympus BH-2 microscope. Otoliths were selected at random with no reference to known age or fish size to reduce bias. Growth increments were counted from the outer edge to the nucleus margin at a power of 100x, 200x and 400x depending on size of otolith and ability to fit the image on the monitor. A second count from the nucleus margin to the outer edge was conducted to verify the first count. If necessary, otoliths were polished multiple times to reveal growth increments near the nucleus (Roberts et al. 2004).

Statistical analyses.- Linear regression analysis was used to determine the relationship between mean reader-assigned age and known age from swim-up for each otolith type and to the hypothesis that slope = 1(one daily ring counted per day of age) and intercept = 0 (first ring formed at swim-up). Accuracy of mean daily age estimation was measured for each age as the proportion of ages within 5% of known age. The measure of 5% was chosen to illustrate the readability among otoliths. Other studies have used less than 10% (Miller and Stork 1984) or estimates within 3 days (Sakaris and Irwin 2008) as a reliable precision level when determining age. The deviation of the mean estimated age from known age was calculated for each otolith type (Miller and Stock 1984; Sakaris and Irwin 2008). Age-bias plots, mean age estimated by Reader 2 for each age estimated by Reader 1, were constructed for each otolith type to assess reader bias and precision (Campana et al. 1995; Vilizzi and Gordon 2013).

Environmental Factors Related to Alligator Gar Spawning

Study area.-Age-0 Alligator Gar were sampled in the river-reservoir interface section of the Red River of Lake Texoma (Fig. 4). The Red River flows 860 km along Oklahoma’s border with Texas and is impounded by Denison Dam, forming Lake Texoma. The Red River is a typical prairie river with sand and silt substrate, woody debris deposited from flooding events, and occasional rock outcrops. During high-water events, the Red River reconnects to adjacent flood plain and cut-off oxbow lakes where Alligator Gar spawn.

*Samplin*g.-Mini-fyke nets (0.6 m x 6.35 m; with 3.175 mm mesh, 3.81 m lead, 0.6 m x 1.92 m rectangular cab, and 510 mm metal throat) were used to sample age-0 Alligator Gar in backwater areas and coves where woody vegetation and woody debris was abundant (Brinkman 2008). Nets were deployed using an adaptive random cluster sampling design, which has been used to effectively sample rare species such as Alligator Gar (Tompson 1990). A 100-m gridded map of all backwaters and shallow-water coves in the river-reservoir interface was used to randomly select sample sites. Mini fyke nets were deployed in the months of May through July in 2012 and 2013. Sampling effort in 2012 consisted of 36 net night and 90 net nights of effort were completed in 2013.When a juvenile Alligator Gar was collected, additional neighboring grid sites were subsequently sampled. All Alligator Gar collected were weighed to the nearest gm, measured to the nearest mm TL, and their lapilli otoliths were removed by following the otolith preparation methods mentioned previously. The lapilli were sectioned in a frontal plane and viewed by two readers independently with a high resolution monitor connected to an optic-mount digital camera attached to an Olympus BH-2 microscope. Daily ages were estimated independently, then discussed until reaching agreement on age.

Statistical analyses.-Linear regression analysis was used to determine relationships between age and total length, age and weight, and total length and weight. Length and weight were $\log_{10}$ transformed to correct for non-linearity. Spawn dates were estimated with the regression equation derived for lapilli from known-age gars as described above. Pool elevation data for Lake Texoma at Denison Dam, obtained from the U.S. Army Corps of Engineers, and river discharge for the Red River upstream of Lake Texoma from a U.S. Geological Survey gage (#07316000) were compared with spawning dates back-calculated from the analysis of daily growth rings.

Results

Daily Age Validation

I examined otoliths from 100 known-age Alligator Gar with ages ranging from 4 to 86 days since swim-up (Table 1; Fig. 5). Collecting 10 fish per week was easy until week 8 when fewer fish were present, presumably because of cannibalism. At this date, mean fish size increased greatly, which continued through the end of the study in week 12. Sagittae and lapilli were dissected from all samples, but asterisci were not present in Alligator Gar younger than 15 days.

Multiple nuclei within the nucleus margin of both sagittae and lapilli (Fig. 6) prevented counting rings until swim-up. Although asterisci were not present until 15 days after hatch, multiple nuclei did not appear problematic for counting rings. Ring formation in sagittae and lapilli was regular after swim-up, and daily rings in asterisci were observed regularly beginning 11 days after swim-up.

Lapilli provided the most accurate and precise measures of daily age (Table 1-2; Figs. 7-9). Although regression estimates of slopes between estimated age and known age for all otoliths differed significantly from 1.0 ($P < 0.01$; Table 2; Fig. 7), estimates based on lapilli were the closest (1.03). Similarly, mean deviation between estimated age and known age was consistently low for lapilli during the full 86 day study. Error for sagittae was low through the first 65 days after swim-up, but ages were underestimated for older larvae (Fig. 8). Mean age estimation errors for asterisci were the highest of the three otolith types and increased steadily through age of the fish. In general, daily age estimates based on sagittae and lapilli were often accurate within 5% of known age (Table 1). Percent accuracy from sagittae decreased with fish age whereas those based on lapilli increased. Estimates based on asterisci had low accuracy through the 86 day study. Visual inspection of the age-bias plots revealed minimal bias between readers for lapilli, with moderate and high bias for sagittae and asterisci (Fig. 9).

Environmental Factors Related to Alligator Gar Spawning

Nine age-0 Alligator Gar (102 to 176 mm TL) were collected during July 2013 and were estimated to be from 50–63 days old since swim-up. Spawn dates were estimated to have occurred from May 18 to June 1, 2013. Lake Texoma pool elevation rose steadily during the estimated time of spawning, from 187 m on May 15 to 188 m on June 10, 2013 (Figure 10). Flow data from upstream in the Red River recorded two pulse events coincident with the estimated time of spawning (Fig. 11).

Based on the slope of the regression equation relating size to age, Alligator Gar captured in summer of 2013 grew an average of 5.49 mm ($r^2 = 0.85$, $P < 0.01$; Figure 12) and 1.15g ($r^2 = 0.82$, $P < 0.01$; Figure 13) per day. The length-weight regression indicated a cubed relationship ($\log_{10}$ weight (g) = 3.50 ($\log_{10}$ TL (mm) – 6.58; $r^2 = 0.96$, $P < 0.01$; Fig. 14).

Discussion

Results from this study indicate that the lapillus is the most useful otolith for estimating daily age of Alligator Gar and that the first distinct increment of otolith growth occurred the 2 days after swim-up. The lapillus was the most accurate and precise, probably as a result of daily growth rings being deposited relatively evenly, with little need to polish near the nucleus. Although the estimated slope (1.03) of the regression between known and estimated age was statistically different from 1.0, it can be practically equivalent. For example, an Alligator Gar estimated to be 100 days old would be 103 days old based on the linear regression. Many studies have found poor accuracy estimating age past 100 days and our study validated ages only through 86 days, making for minimal correction based on our estimated slope value of 1.03 rings per day. For example, Hussy et al. (2012) found daily growth increments of Boarfish (*Capros aper*) otoliths to fade out past 104 days on average. Sakaris and Irwin (2008) reported pond-raised Channel Catfish (*Ictalurus punctatus*) to be accurately aged up to 100 days post-hatch, with decreased accuracy thereafter due to compressed rings near the edge of the otolith. DiCenzo and Bettoli (1995) found similar results with Spotted Bass (*Micropterus punctulatus*), underestimating age after 94 days due to compression of daily rings. Using lapilli, I validated daily age formation in Alligator Gar up to 86 days since swim-up; past this age, further validation would be warranted.

Many validation studies use known-age fish based on chemical (e.g., oxytetracycline, Calcein, or alizarin complexone) or physical marks. Examples include Lake Tanganyika Sardine *Limnothrissa miodon* (Meisfjord 2006); Pejerrey *Odontesthes bonariensis* (Brown and Fuentes 2005); Lost River Sucker *Deltistes luxatus* and Shortnose Sucker *Chasmistes brevirostris* (Hoff 1997). However, this fails to document when the first ring forms, which is critical to estimate spawning dates. In my study, using known-age fish from hatch, I was able to determine that the first ring in the lapillus formed 2 days after swim-up, which allows one to accurately back-calculate spawn dates. For Alligator Gar specifically, this improves estimates that have previously had to rely on estimations of growth obtained from hatchery or laboratory studies and size at hatch to calculate spawn dates (e.g., May and Echelle 1968; Echelle and Riggs 1972). Using hatchery-reared fish to estimate growth and back-calculate spawn dates introduces additional sources of error such feeding ration and temperature that influences growth. For example, in my study, Alligator Gar in the hatchery grew an average of 4 mm/day compared to 5.5 mm/day for Alligator Gar in the wild. Because the individuals in the hatchery grew slower than estimated by otoliths obtained from wild fish, spawning date estimates based on growth rates would be skewed toward earlier periods.

Many validation studies only document that rings form daily and fail to determine maximum-age utility (i.e., the maximum age for which estimates are accurate). For example, Nyamweya et al. (2010) estimated an age of 22.8 days post-hatch in African Catfish (*Clarias gariepinus*) fry known to be 23 days, but they then estimated ages of wild African Catfish (Clarias gariepinus) past 160 days old, which was well beyond their validated ages. Durham and Wilde (2008) marked juvenile cyprinid fish from the Brazos River in Texas with alizarin and validated daily ring formation for 30 days since the alizarin markngi, but their maximum-age utility was unknown. I found that daily ages estimated from lapilli for Alligator Gar were accurate through 86 days since swim-up. Whether accurate age estimates could be determined past 86 days is unknown and needs further study. While sagittae, the largest of the otoliths in non-ostariophysean fish (Secor et al. 1992; Long and Stewart 2010), are the most commonly used otoliths by fisheries managers, I found lapilli to be more useful for estimating daily age of Alligator Gar.

Sagittae appear useful for estimating age of Alligator Gar < 70 days old, but poor precision and accuracy was evident in older fish. Sagittae develop a concave cross-section as they grow, resulting in extra preparatory work to reveal growth increments near the nucleus margin, which led to loss of outer daily rings (Campana and Neilson 1985). The lapillus may take more effort to find but it provided better age estimates for a longer period.

The use of lapilli in adult Alligator Gar age estimation might therefore prove useful. Transverse sections of sagittae from adult Alligator Gar exhibit annuli, becoming more difficult to identify near the ventral edge which could lead to underestimation of age (DiBenedtto 2009; Brinkman 2008; and Buckmeier et al. 2012). Buckmeier et al. (2012) described difficulties identifying the first annulus due to the presence of checks and accessory marks and error among readers (Brinkman 2008) can range widely I also found that error increased in sagittae past 70 days. Because lapilli were more useful than sagittae for estimating daily age, similar results may be found when estimating annual age and future research is needed to determine this utility would be useful.

The back calculated dates of spawn for wild-caught Alligator Gar corresponded with an increase in pool elevation and two pulses of water from the Red River. Few observations of Alligator Gar spawning behavior and collections of age-0 fish exist, providing limited insight into reproduction of this species (May and Echelle 1968; Echelle and Riggs 1972; Brinkman 2008; Inebnit 2009). It is generally accepted that inundated vegetation is essential for reproduction and survival of larval Alligator Gar. In particular, Alligator Gar eggs are deposited on vegetation, where they adhere. Moreover, the snout tip of larval gar is modified as an adhesive, papillose disk that allows larva to remain attached to vegetation until swim-up (Aguilera et al. 2002; Balfour and Parker 1882) and this likely affects not only egg-laying, but juvenile recruitment. For example, Inebnit (2009) found poor survival of larval Alligator Gar in the Fourche La Fave River, Arkansas after water levels receded, stranding developing fish attached to previously flooded vegetation. Persistent drought since 2011 kept water levels low in Lake Texoma until early 2013, which allowed herbaceous vegetation to establish and grow in the draw-down zone on shore lines and disconnected back water areas. Subsequent inundation of these areas created attachment substrate for Alligator Gar eggs and larvae. The cycle of drying, encroachment of terrestrial vegetation, and subsequent flooding should be examined in future research related to spawning and recruitment of Alligator Gar in reservoirs.

Understanding that Alligator Gar spawning behavior coincides with rises in reservoir pool elevation and pulses of water from inflowing rivers can be used for management purposes. Since spawning of Alligator Gar is linked to seasonal flooding, successful recruitment may be infrequent. Alligator Gar have the potential to overcome year-class failures because of late maturity, highly fecundity, and high adult survival (Ferrara 2001; Buckmeier 2008; Inebnit 2009). Reservoir water levels could, in theory, be manipulated to allow re-vegetation of backwaters. Subsequent flooding during the Alligator Gar spawning season might enhance recruitment.. Water levels would need to be maintained for at least 8 days after spawning to allow Alligator Gar to reach the lecithoextrophic stage (i.e., swim-up) when larvae are no longer attached to vegetation (Inebnit 2009).

In conclusion, the analysis of daily growth rings in lapilli can provide fisheries managers with previously unavailable early life history perspectives on Alligator Gar. The methods provided in this study should assist future research on survival of age-0 individuals, recruitment of young fish, and interannual variability in recruitment of Alligator Gar.

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TABLE 1.Accuracy of daily age estimates among otoliths for age-0 Alligator Gar, defined as the percentage of estimates within ± 5% of known age since swim-up.

			Percent within 5% of known age		
Known Age (days)	N	Mean TL (mm)	Sagitta	Lapillus	Asteriscus
Week 1 (4)	10	19	50	0	Not present
Week 2 (11)	10	34	60	50	0
Week 3 (18)	10	71	75	80	0
Week 4 (25)	10	99	55	55	15
Week 5 (32)	10	121	50	60	15
Week 6 (39)	10	159	55	95	15
Week 7 (46)	10	206	80	100	0
Week 8 (52)	9	257	94	94	11
Week 9 (61)	8	276	75	100	0
Week 10 (73)	4	321	88	100	25
Week 11 (79)	3	393	33	83	0
Week 12 (86)	6	332	42	83	17

TABLE 2. Linear regression results among otoliths for estimated ring counts from known age of Alligator Gar.

	Y-intercept				Slope			
Otolith	Estimate	95 % Lower CI	95 % Upper CI	*P*□	Estimate	95 % Lower CI	95 % Upper CI	*P*□
Sagitta	1.46	0.62	2.29	<0.01	0.94	0.92	0.96	<0.01
Lapillus	-0.96	-1.48	-0.45	<0.01	1.03	1.02	1.04	<0.01
Asteriscus	-5.46	-7.13	-3.79	<0.01	0.9	0.86	0.93	<0.01

□null hypothesis that estimate = 0

□null hypothesis that estimate = 1

FIGURE 1. Photograph of the whole sagitta otolith (left) and sectioned otolith (right) from a 186 mm Alligator Gar noting orientation (P = posterior, A = anterior, V = ventral, D = dorsal). The sectioned otolith is viewed at a transverse plane. The location of the nucleus (N) is near the dorsal anterior tip.

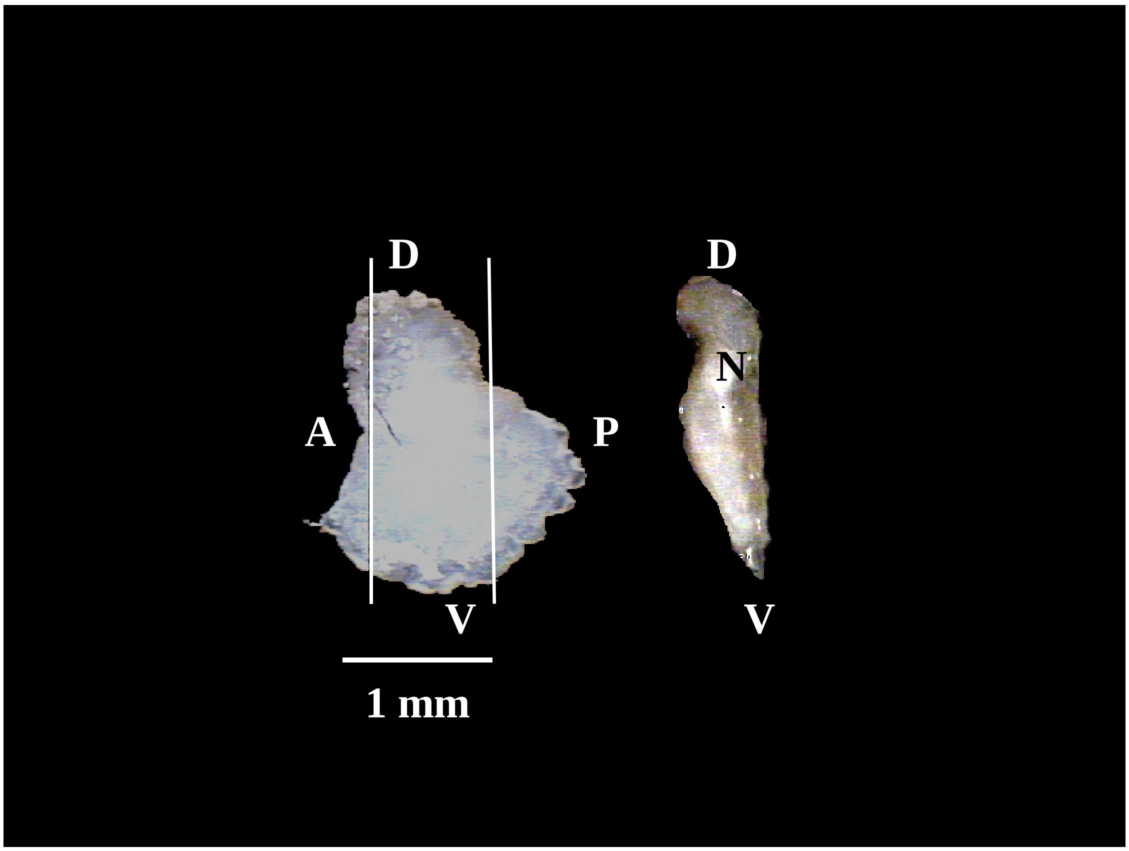


FIGURE 2.Photograph of the whole asteriscus (left) and sectioned otolith (right) from a 186 mm Alligator Gar noting orientation (P = posterior, A = anterior, V = ventral, D = dorsal). The sectioned otolith is viewed at a transverse plane. The location of the nucleus (N) is centralized when sectioned.

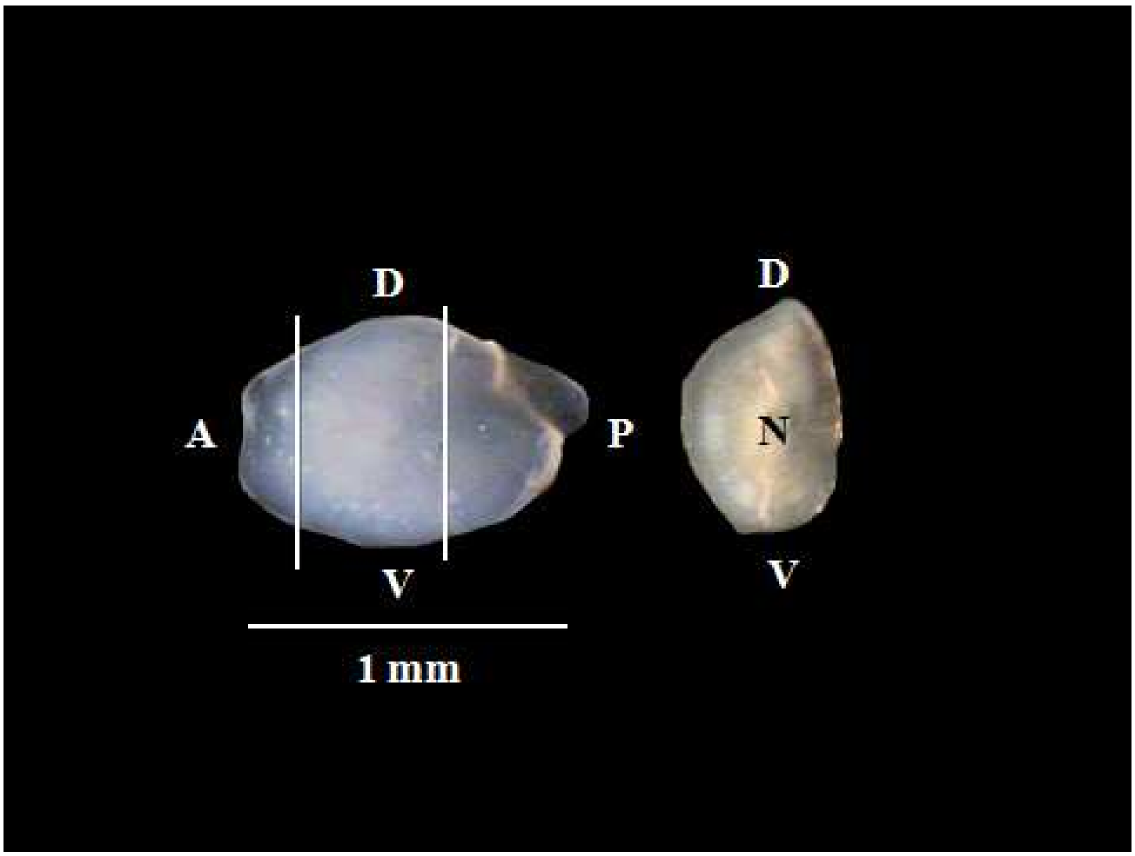


FIGURE 3. Photograph of the whole lapillus otolith (left) and sectioned otolith (right) from a 186 mm Alligator Gar noting orientation (P = posterior, A = anterior, V = ventral, D = dorsal). The sectioned otolith is viewed at a frontal plane. The location of the nucleus (N) is centralized when sectioned.

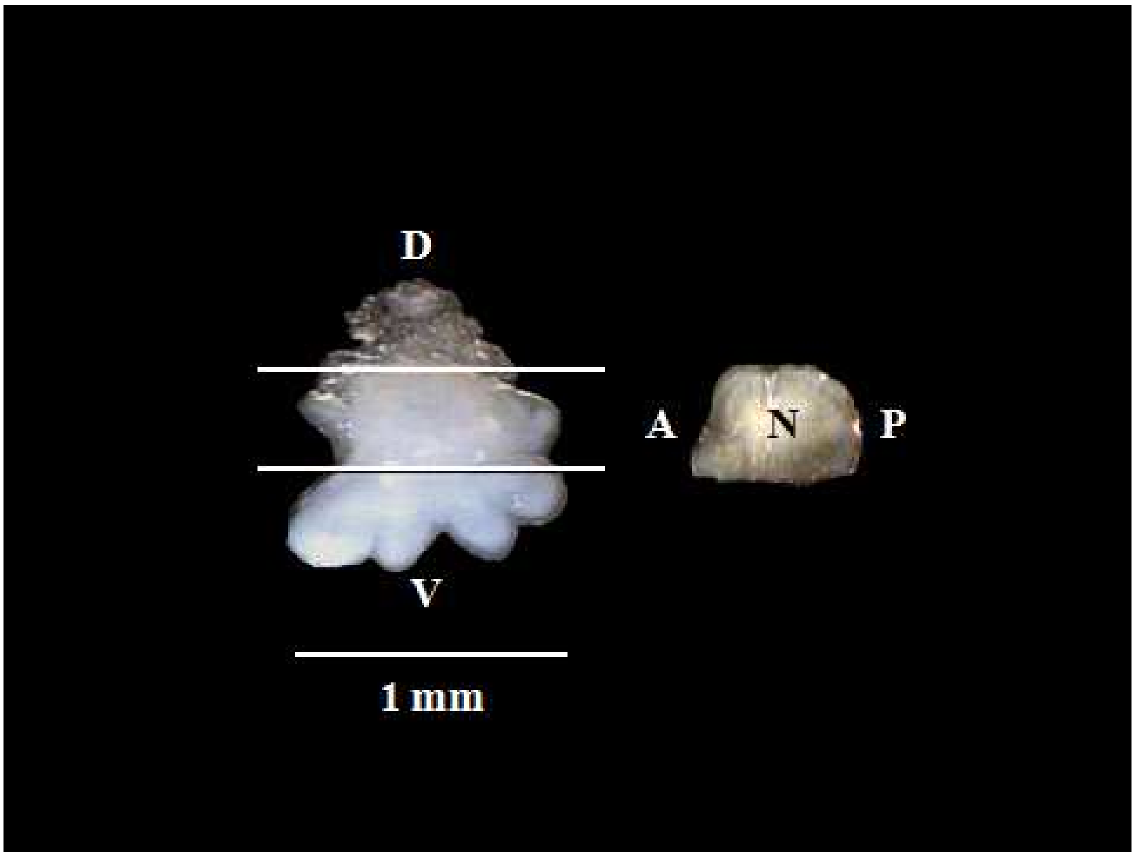


FIGURE 4.Location of Lake Texoma in south central Oklahoma where age-0 Alligator Gar were sampled in 2012 and 2013.

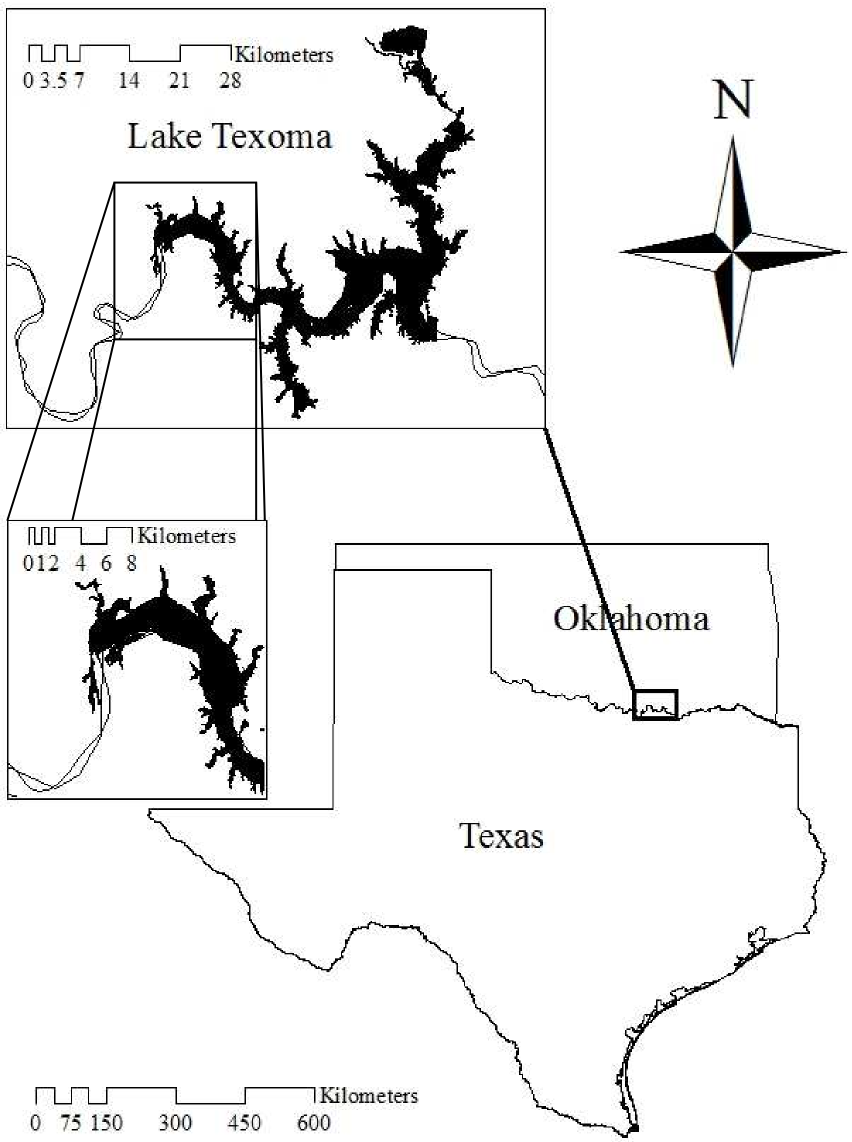


FIGURE 5. Mean length-at-age (± 1 SD) for known-age Alligator Gar sampled from a hatchery rearing pond at Tishomingo National Fish Hatchery, Oklahoma. The solid line represents a best-fit line of exponential growth.

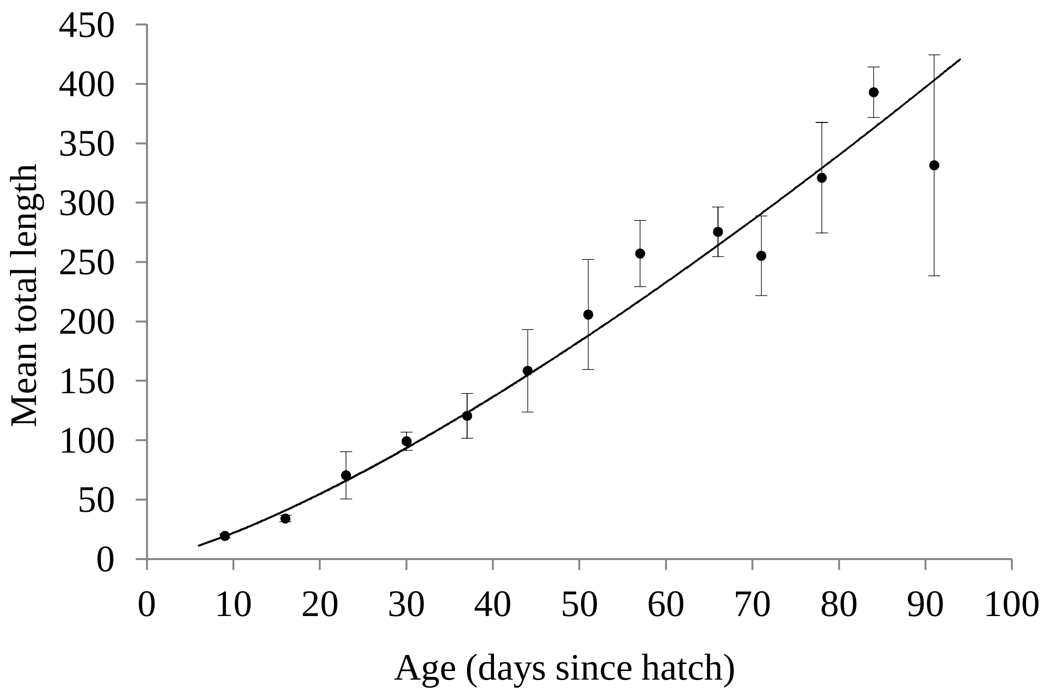


FIGURE 6. Multiple nuclei within the nucleus margin of a sagitta(A) and lapillus (B) otolith of age-0 Alligator Gar. Multiple nuclei within the asteriscus (C) were not apparent.

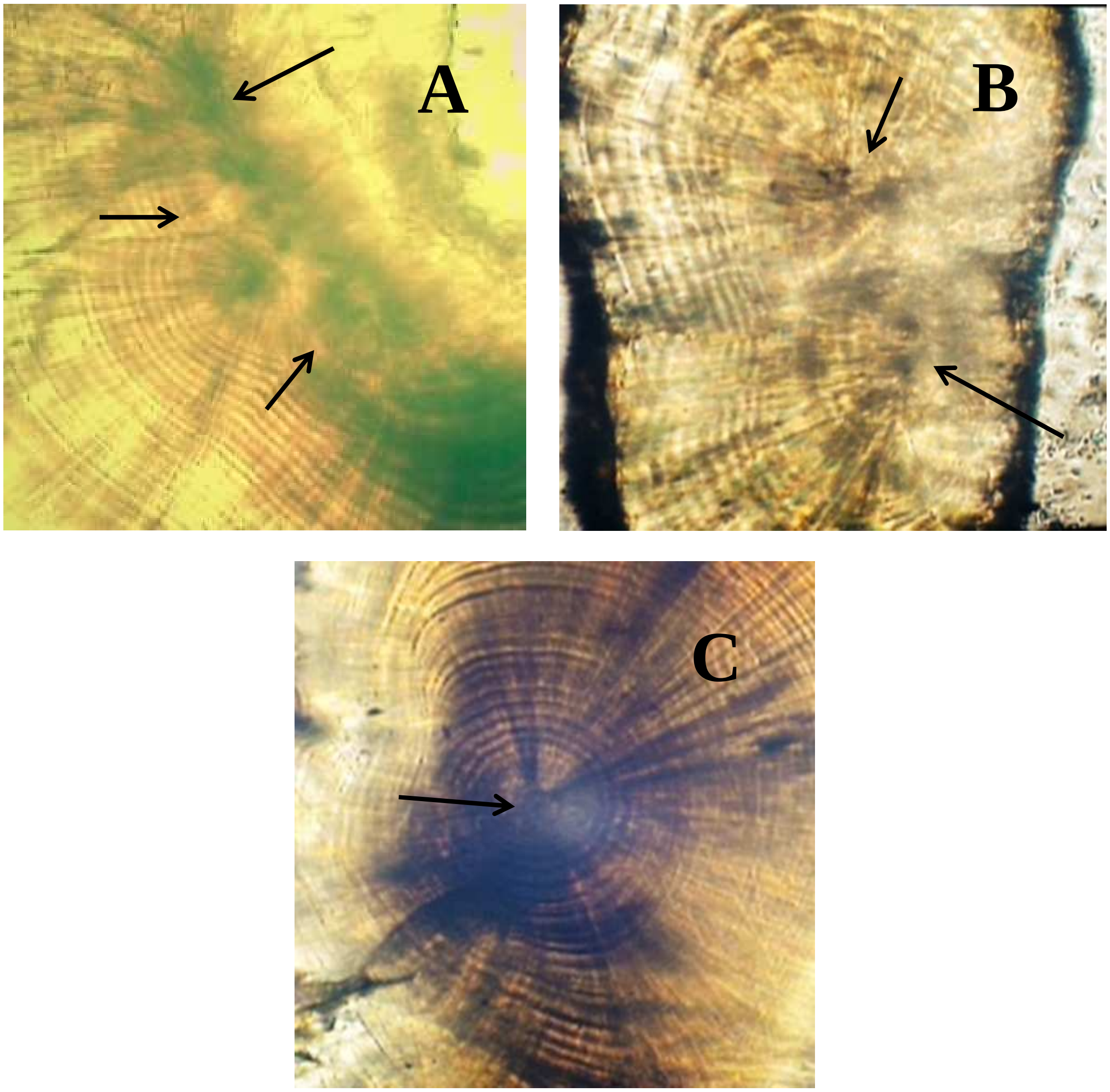


FIGURE 7. Regression between mean ring counts among otoliths of known age Alligator Gar from swim-up. The solid line represents the regression line and the dash line represents a 1:1 relationship between estimated age and known age.

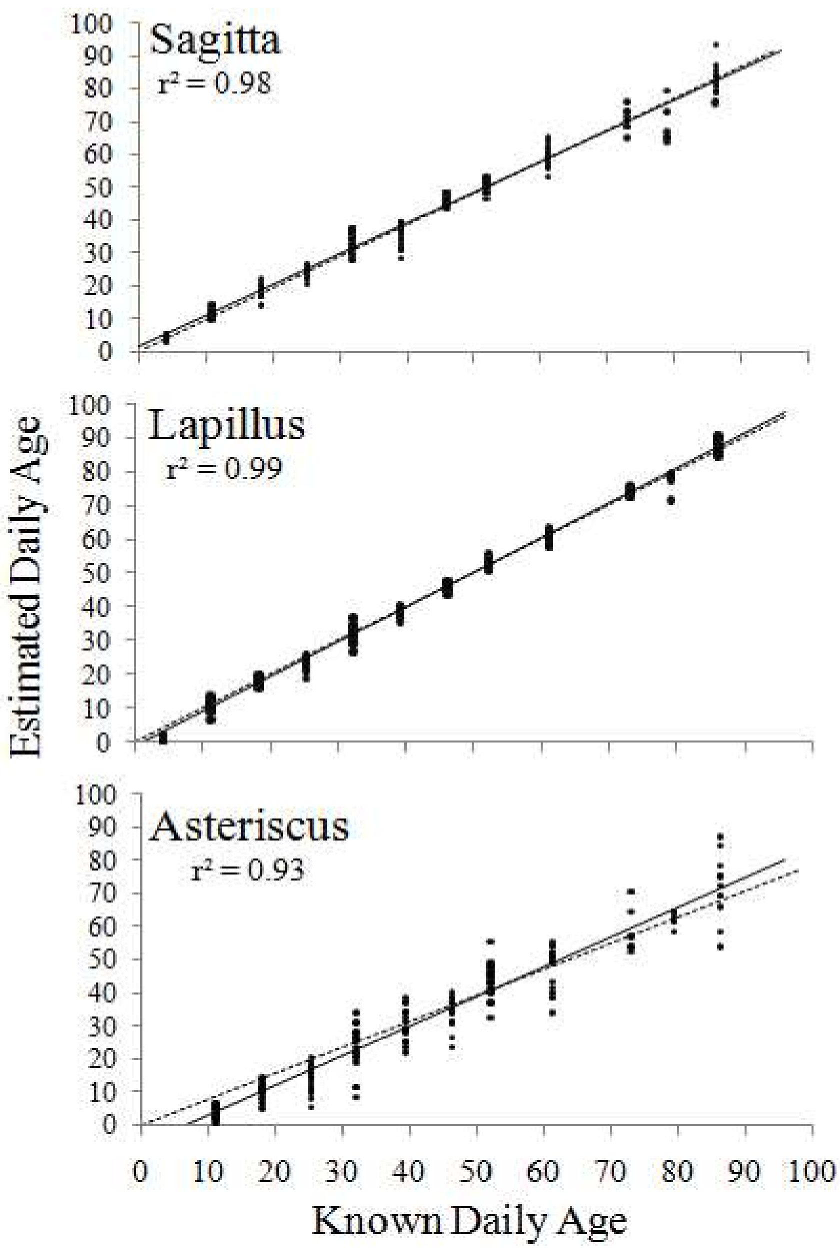


FIGURE 8.Mean difference (±1 SE) between estimated age and known-age for three otolith types of Alligator Gar.

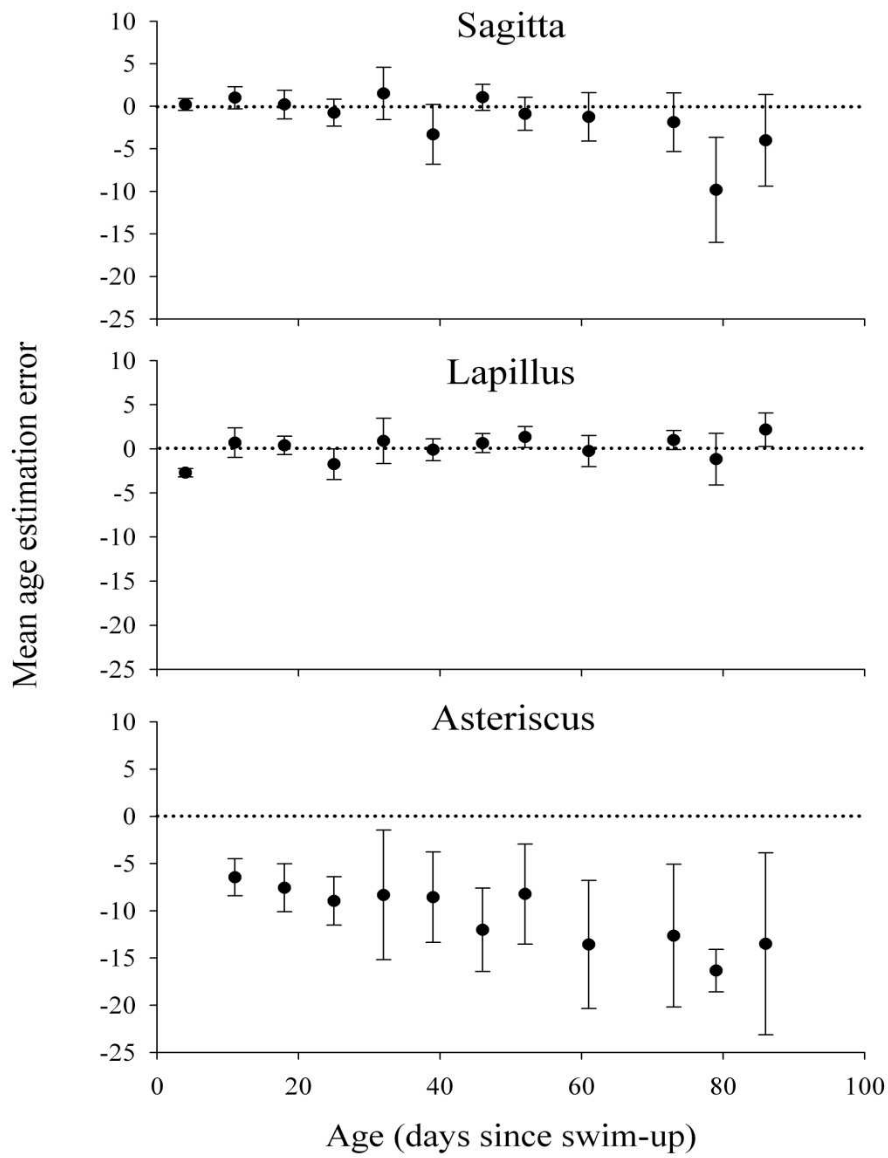


FIGURE 9.Age-bias plots between mean age (±1 SD) estimated by reader 2 and ages estimated by reader 1 among otolith types. The solid line represents a 1:1 relationship between reader 1 and reader 2.

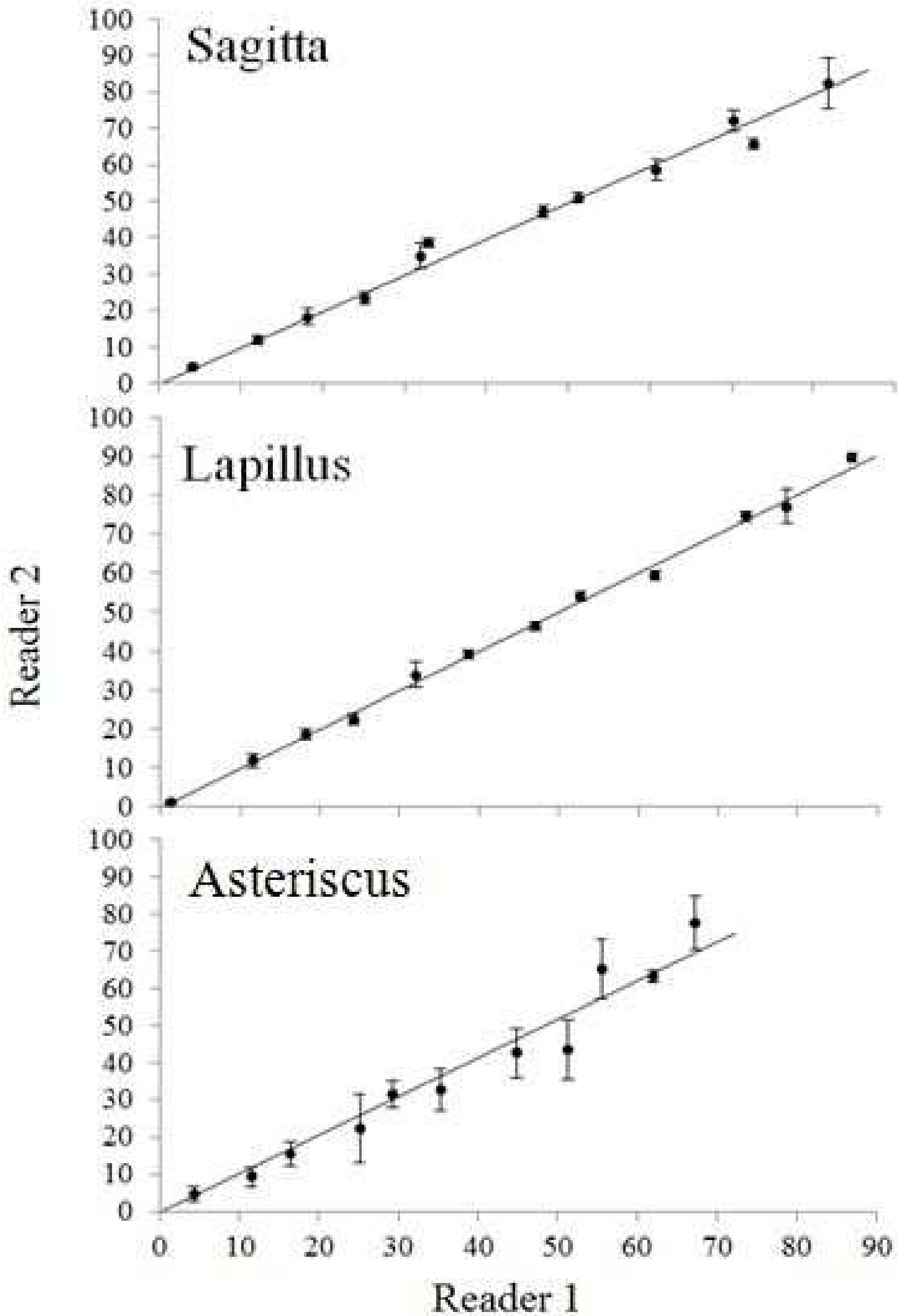


FIGURE 10.Frequency of back-calculated spawn dates in 2013 estimated from daily rings in lapilli otoliths of Alligator Gar in relation to pool elevation of Lake Texoma at Denison Dam, Oklahoma.

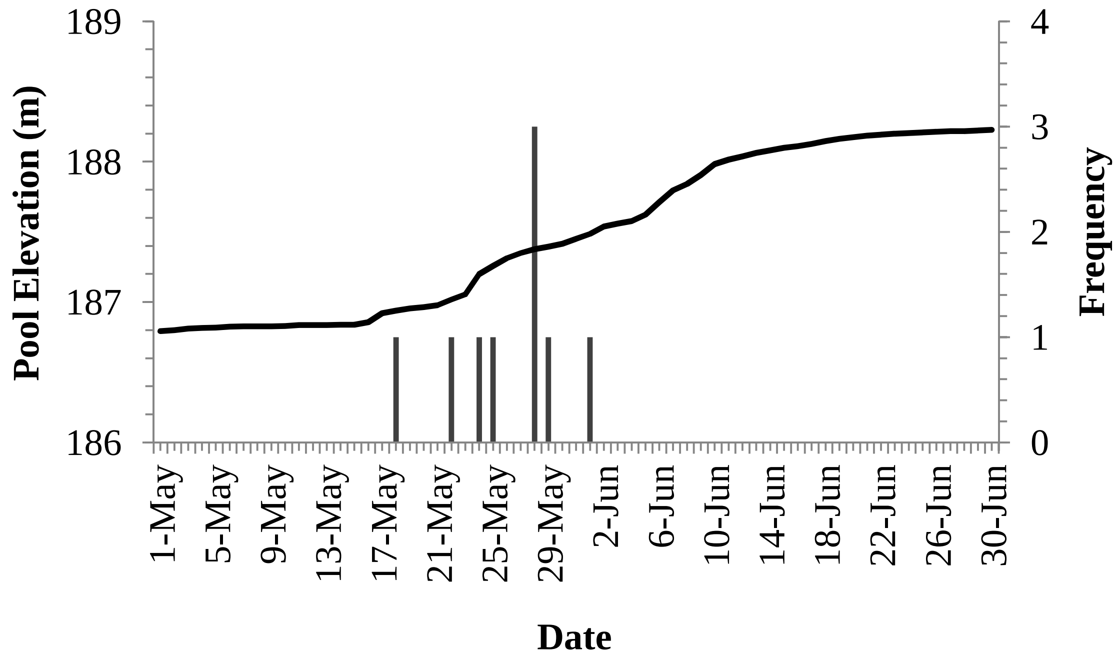


FIGURE 11.Frequency of back-calculated spawn dates in 2013, estimated from daily rings in lapilli otoliths of Alligator Gar in relation to discharge (USGS gage 07316000) of the Red River into Lake Texoma, Oklahoma.

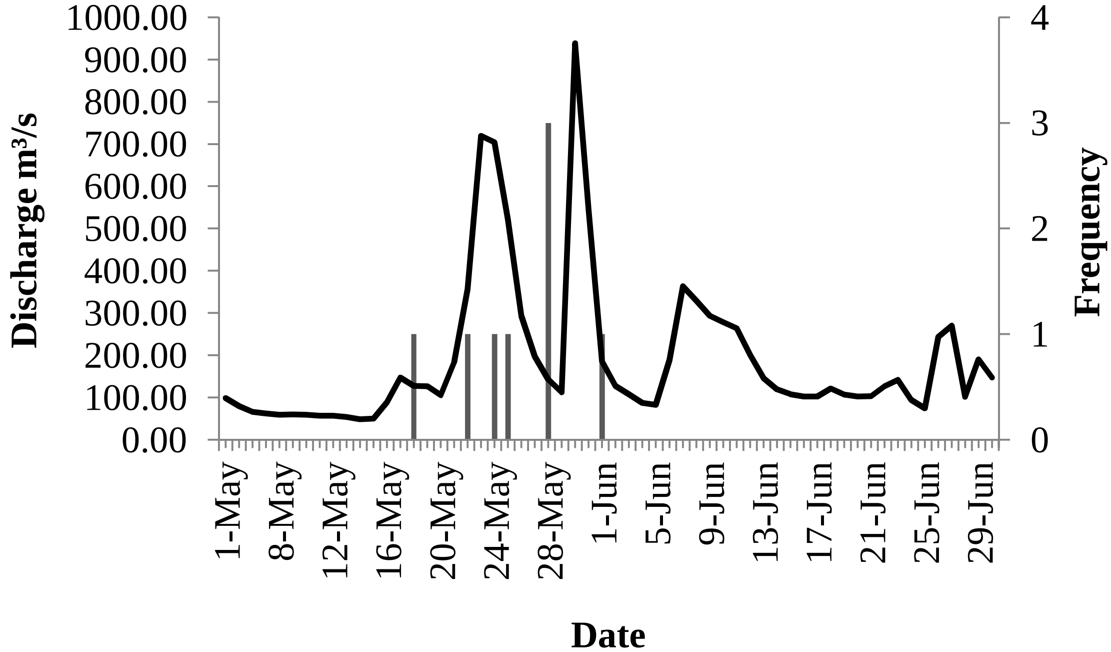


FIGURE 12.Relationship between total length and age of age-0 Alligator Gar captured from Lake Texoma, Oklahoma in July, 2013.Age was estimated using lapilli sectioned in a frontal plane. Solid line is fit from linear regression.

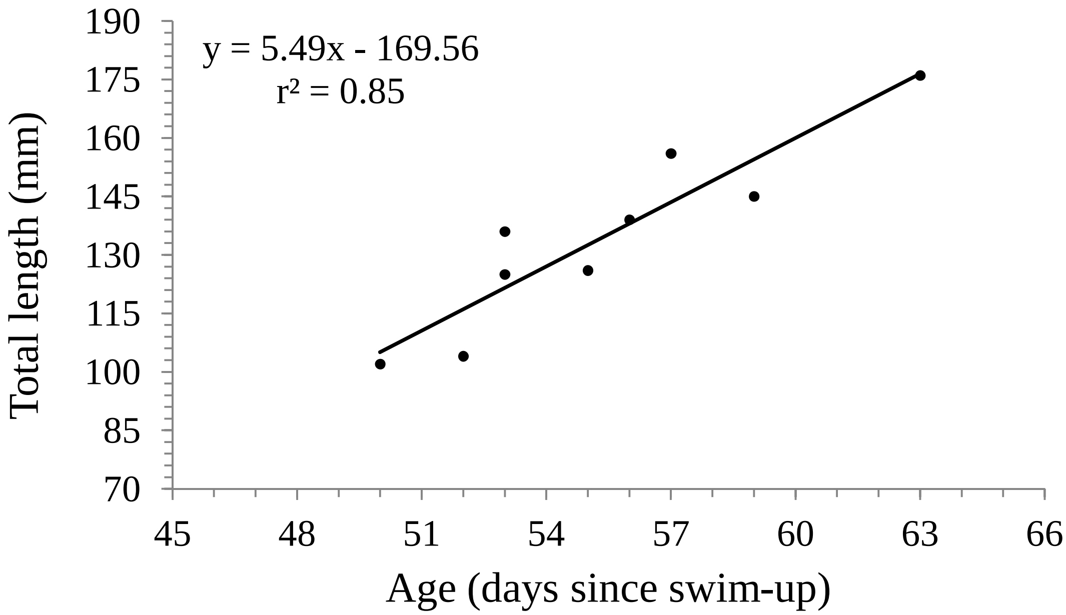


FIGURE 13.Relationship between age and weight of age-0 Alligator Gar captured from Lake Texoma, Oklahoma in July, 2013. Age was estimated using lapilli sectioned in a frontal plane. Solid line is fit from linear regression.

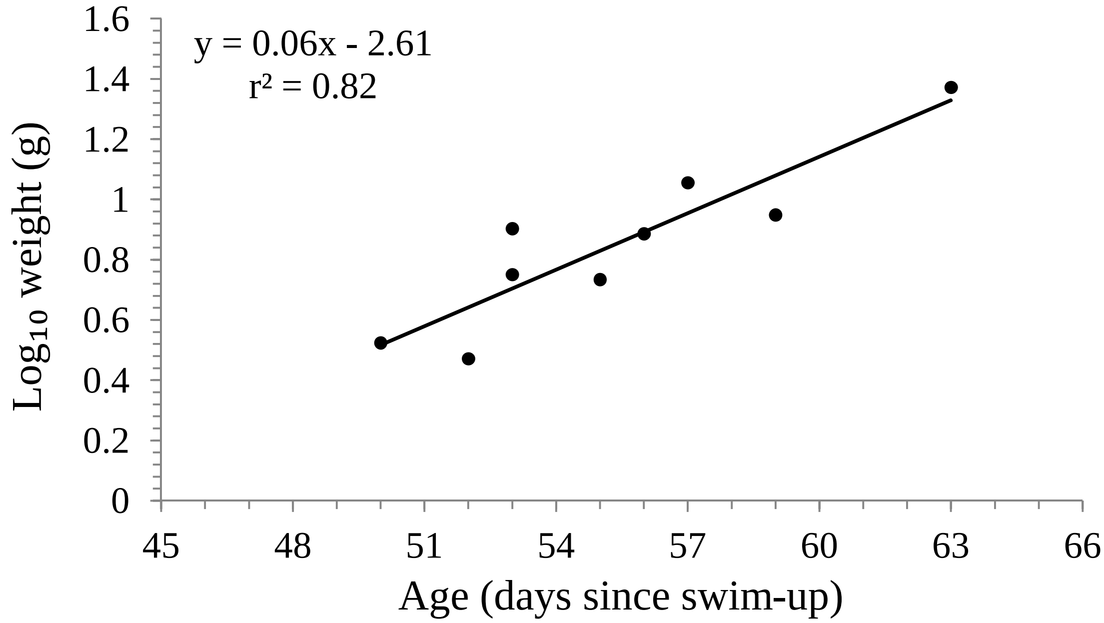
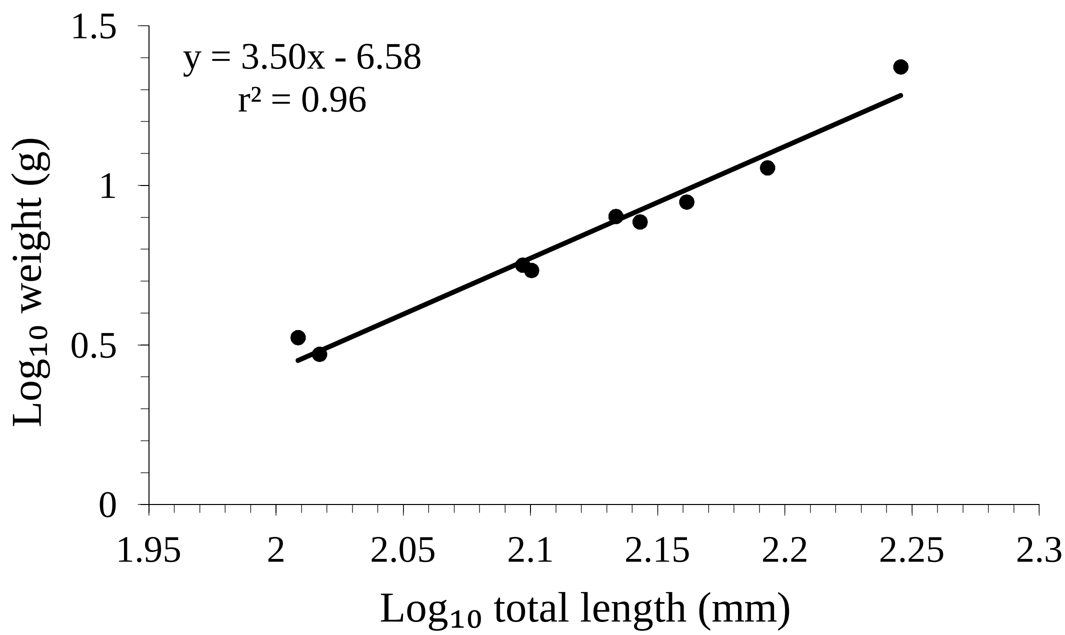


FIGURE 14. Relationship between $\log_{10}$ weight and $\log_{10}$ length for age-0 Alligator Gar captured from Lake Texoma, Oklahoma in Date, 2012. Solid line is fit from linear regression.



VITA

Richard Snow

Candidate for the Degree of

Master of Science/Arts

Thesis: TYPE FULL TITLE HERE IN ALL CAPS

Major Field: Natural Resource Ecology and Management

Biographical:

Education:

Completed the requirements for the Master of Science in Natural Resource Ecology and Management Oklahoma State University, Stillwater, Oklahoma in May, 2014.

Completed the requirements for the Bachelor of Sciences in Conservation Biology at St. Gregory's University, Shawnee, Oklahoma in May of 2007.

Experience:

Fisheries Technician for Oklahoma Department of wildlife Conservation at the Oklahoma Fisheries Research Laboratory in Norman, Oklahoma from Feb. 2008 – present.

Professional Memberships:

American Fisheries Society
Oklahoma Chapter of the American Fisheries Society