CHARACTERISTICS OF TWO SELF-SUSTAINING POPULATIONS OF PADDLEFISH IN NORTHEAST OKLAHOMA

By

ASHLEY NEALIS

Bachelor Science in Wildlife and Fisheries Ecology

Oklahoma State University

Stillwater, Oklahoma

2006

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 2013

CHARACTERISTICS OF TWO SELF-SUSTAINING

POPULATIONS OF PADDLEFISH IN

NORTHEAST OKLAHOMA

Thesis Approved:

Dr. Jim Long

Thesis Adviser

Dr. Daniel Shoup

Dr. Andy Dzialowski

ACKNOWLEDGEMENTS

I would first like to thank my major advisor, Dr. Jim Long for his patience and guidance over the last three years. This process, and his role in it, has been invaluable to me. Also, I thank my committee members Dr. Daniel Shoup and Dr. Andy Dzialowski for their insight and advice. The Oklahoma Department of Wildlife Conservation provided all funding and equipment for this study, and allowed me the time to further my education.

Brad Johnston and Eric Brennan deserve a medal for their tireless field work in both freezing and sweltering conditions, and for spending countless hours in a small room aging jaws with an irritable pregnant lady. They make work fun and I appreciate them for that. Brent Gordon and Jeff Boxrucker opened doors for me professionally. They encouraged me to pursue my graduate degree and without their support, and willingness to take a chance on me, I would not be where I am today. I would like to thank Jason Schooley, Chris Whisenhunt and Nate Copeland for their help, in the field, and out, Kurt Kuklinski for his help with statistical analysis, Andrea Crews for the use of her survey data, and Dennis Scarnecchia for providing me with prepared jaw sections.

I am thankful for the support of my family. My mother has always truly believed that I could do anything and has encouraged me in whatever I chose. Most of all, I would like to thank my husband, Justin and my baby girl, Alby Mae. Their love has kept me going, and I have pushed to complete this endeavor so I can give more of myself to them.

Name: ASHLEY NEALIS

Date of Degree: DECEMBER, 2013

Title of Study: CHARACTERISTICS OF TWO SELF-SUSTAINING POPULATIONS OF PADDLEFISH IN NORTHEAST OKLAHOMA

Major Field: NATURAL RESOURCE ECOLOGY AND MANAGEMENT

Abstract: Oklahoma has several self-sustaining populations of paddlefish (*Polyodon spathula*) that support sport fisheries, including Grand Lake O' The Cherokees (Grand Lake) and Keystone Lake. The Oklahoma Department of Wildlife Conservation (ODWC) has operated a Paddlefish Research Center (PRC) on Grand Lake since 2008, which has increased communication with paddlefish anglers and provided information about fishery-dependent population trends, suggesting declines in overall fish size. Whether these declines were unique to Grand Lake or indicative of a broader pattern were unknown. Comparing angler harvest and paddlefish population characteristics between these two self-sustaining populations would aid managers in conserving this species in Oklahoma. Thus, I sought to: 1) determine differences in fishing pressure between reservoirs and, 2) estimate and compare characteristics of these two paddlefish populations. Post-season paddlefish angler surveys indicated no significant difference in per-angler effort (days fishing per angler) between the two reservoirs in both 2010 and 2011. However, Grand Lake had significantly higher per-angler harvest. Paddlefish gillnetting data from winter 2010 and 2011 showed no significant difference in relative abundance between the populations although, differences in length frequencies, relative weights, growth and reproductive condition were documented. Mean lengths, relative weights and gonadal fat indices for both male and female paddlefish from Keystone Lake were significantly greater than those from Grand Lake, while gonadosomatic index values were significantly greater for females from Grand Lake.

TABLE OF CONTENTS

Chapter Page

I. ANGLER USE OF TWO RESERVOIR POPULATIONS OF PADDLEFISH IN NORTHEAST OKLAHOMA 1

Introduction..1
Study Area 3
Methods...4
Results...5
Discussion 6
References..10
Tables...13
Figures..15
Appendices..17

II. CHARACTERISTICS OF TWO SELF-SUSTAINING POPULATIONS OF PADDLEFISH IN NORTHEAST OKLAHOMA..19

Introduction..19
Study Area 21
Methods...22
Results...25
Discussion 26
References..31
Tables...37
Figures..39

LIST OF TABLES

Table Page

CHAPTER I

1 Mean per angler: effort, harvest, catch, harvest per unit effort and catch per unit effort from 2010 and 2011 post-season paddlefish survey data for Grand and Keystone reservoirs. Superscripts denote significant differences between lakes within years based on a t-test and $P < 0.05$..13

2 Percentage of respondents who fished given areas (separate questions, multiple responses allowed) and mean fish kept per person for Grand and Keystone Lakes, by residency, in 2010 and 2011. Superscripts denote significant differences between residency within years based on a chi-squared test and $P < 0.05$......14

CHAPTER II

1 Number of sample sites, number of fish caught, and CPUE (mean and standard deviation) for winter paddlefish gill netting on Grand and Keystone reservoirs, Oklahoma from 2010 and 2011. 37

2 Mean relative weights (Wr) of male and female paddlefish from Grand and Keystone reservoirs, Oklahoma, from 2010 and 2011 38

LIST OF FIGURES

Figure Page

CHAPTER I

1 Locations of Grand Lake ‘O the Cherokees and Keystone Lake in northeast Oklahoma where differences in paddlefish populations were assessed in 2010 and 2011…..15

2 Distribution of 2010 and 2011 paddlefish permit holders by zip code of residence in the continental United States (Crews, Oklahoma Department of Wildlife Conservation, unpublished data)…..16

CHAPTER II

1 Locations of Grand Lake ‘O the Cherokees and Keystone Lake in northeast Oklahoma where differences in paddlefish populations were assessed in 2010 and 2011…..39

2 Length frequencies for female paddlefish from Grand and Keystone reservoirs obtained during 2010 and 2011 winter gill netting. Length frequencies were compared using a Kolmogorov-Smirnov test.. 40

3 Length frequencies for male paddlefish from Grand and Keystone reservoirs obtained during 2010 and 2011 winter gill netting. Length frequencies were compared using a Kolmogorov-Smirnov test. 41

4 Mean length-at-age for female paddlefish from Grand and Keystone Reservoirs, Oklahoma from 2011. Error bars are 1 SD around the mean and numbers above error bars denote number of fish assigned that age...42

5 Mean length-at-age for male paddlefish from Grand and Keystone Reservoirs, Oklahoma from 2011. Error bars are 1 SD around the mean and numbers above error bars denote number of fish assigned that age...43

Figure Page

6 Age bias graphs for paddlefish age estimates from Keystone Reservoir (2011) between all possible pairs of comparisons among three readers. Solid line indicates 1:1 agreement in age estimates between the two readers (*X* axis and *Y* axis) being compared. Error bars are 1 SD around the mean age assigned by reader *Y* for every fish assigned an age by reader *X*.. 44

7 Age bias graphs for paddlefish age estimates from Grand Lake (2011) between all possible pairs of comparisons among three readers. Solid line indicates 1:1 agreement in age estimates between the two readers (*X* axis and *Y* axis) being compared. Error bars are 1 SD around the mean age assigned by reader *Y* for every fish assigned an age by reader *X*.. 45

8 Age bias graphs for paddlefish age estimates from Grand Lake (2011) between A. Nealis and the University of Idaho. Solid line indicates 1:1 agreement in age estimates between the two labs (*X* axis and *Y* axis) being compared. Error bars are 1 SD around the mean age assigned by lab *Y* for every fish assigned an age by lab *X*.. 46

9 Gonadosomatic index (mean and standard error range) versus age (n $\geq$ 4) for female paddlefish 2011 in Grand and Keystone reservoirs... 47

10 Ratio of gonadal fat body (GFB) weight to total fish weight (mean and standard error range) versus age (n $\geq$ 4) for female paddlefish 2011 in Grand and Keystone reservoirs... 48

11 Gonadosomatic index (mean and standard error range) versus age (7-13 only) for male paddlefish 2011 in Grand and Keystone reservoirs..........................49

12 Ratio of gonadal fat body (GFB) weight to total fish weight (mean and standard error range) versus age (7-13 only) for male paddlefish 2011 in Grand and Keystone reservoirs... 50

CHAPTER I

ANGLER USE OF TWO RESERVOIR POPULATIONS OF PADDLEFISH IN NORTHEAST OKLAHOMA

Introduction

Major recreational fisheries for paddlefish (*Polyodon spathula*) tend to exist where paddlefish make spawning runs, especially in tailwaters below dams, and snagging is the primary method of capture (Quinn 2009). Declines in paddlefish populations have been linked to overharvest, particularly by commercial anglers (Pasch and Alexander 1986, Quinn 2009). However, concern over sport fishing has also resulted in regulation changes to protect these fisheries (Carlson and Bonislawsky 1981, Mestl and Sorensen 2009). The number of states allowing sport harvest of paddlefish dropped from 17 to 14 since 1983, and recreational paddlefish fisheries vary in their scale of harvest and intensity of management (Bettoli et al. 2009). Common methods of management include seasons, creel limits, length limits and quota systems (Hansen and Paukert 2009).

In Oklahoma, robust self-sustaining paddlefish populations support sport fisheries in several localities, the most important being Grand Lake (Combs 1982, Ambler 1994) where creel limits are the primary method of harvest management (Gordon 2009). To provide further information on paddlefish sport harvest, the Oklahoma Department of Wildlife Conservation (ODWC) established the Paddlefish Research Center (PRC) in 2008. This center takes data from angler-harvested fish (length, weight, sex, age) and sells the processed caviar to enhance funding for management of paddlefish in the state, but managers have voiced concerns about whether this center encourages excessive harvest. Only one other such center operates in the United States, at Glendive, Montana. However, the idea of a free fish-cleaning service inflating harvest has not been a problem there because Montana manages the harvest of paddlefish with a quota system. To manage harvest in Oklahoma, the ODWC has implemented a mandatory, yet free, permit system.

The installation of the PRC on Grand Lake has not only allowed for increased paddlefish management, it has increased communication with paddlefish anglers. An annual post-season survey of paddlefish permit holders provided an opportunity to compare the angler use of the Grand Lake resource with another paddlefish sport fishery in the region. Keystone Reservoir also has a self-sustaining paddlefish population that supports a sport fishery and produced a new Oklahoma state record paddlefish in 2011. However, Keystone lacks the popularity and angling access of the Grand Lake area. With a concurrent examination of paddlefish angler use at these two reservoirs, I hope to 1) estimate and compare per-angler use (effort, catch and harvest) of paddlefish in

Keystone Reservoir and Grand Lake and 2) seek to explain differences and discuss their implications.

Study Area

Keystone Reservoir

Keystone Reservoir is a 9,073-hectare impoundment of the Arkansas River located in north-central Oklahoma in the cross-timbers ecoregion (Woods et al. 2005) (Figure 1). The dam was completed in 1964 and is operated by the U.S. Army Corps of Engineers for flood control, water supply, hydroelectric power, navigation, and fish and wildlife. The Cimarron River is a highly mineralized tributary with salinity ranging from 0.54 to 3.85 ppt, while the Arkansas River arm ranges from 0.29 to 0.76 ppt (Oklahoma Water Resources Board 2010). The Arkansas River arm is categorized as hypereutrophic, while the rest of the reservoir is eutrophic (Oklahoma Water Resources Board 2010). Bank access for paddlefish angling is sparse in the Keystone Reservoir area. Anglers can snag from the bank below Kaw Dam, approximately 175 km upstream from Keystone, but only when fish migrate this far up the Arkansas River. Other bank angling access on the Arkansas and Cimarron Rivers typically consists of unimproved locations at some bridge crossings and wildlife management areas.

Grand Lake O' The Cherokees (Grand Lake)

Grand Lake is an 18,817-hectare impoundment of the Grand River located in northeast Oklahoma in the Ozark Highlands ecoregion (Woods et al. 2005). The lake was completed in 1940 and is operated by the Grand River Dam Authority for flood control and hydroelectric power. Grand Lake is categorized as eutrophic and salinity ranges from 0.10 to 0.25 ppt (Oklahoma Water Resources Board 2010). The Grand Lake area possesses ample paddlefish bank angling opportunities. Popular improved locations can be found at the Riverview City Park in Miami, OK and at the Connors Bridge crossing on the Neosho River.

Methods

I used a modification of the annual post-season survey of paddlefish permit holders, administered by the ODWC since the opening of the PRC in 2008, to assess differences in fisheries between reservoirs in 2010 and 2011. The main modification was the language used to locate the source of paddlefish angling to ensure comparability between my two target reservoirs (Appendix A). Free permits, available through license vendors, are required of all paddlefish anglers, and this database provided the sampling frame for the survey. A pre-survey postcard notifying recipients of the upcoming survey was sent to 12,000 randomly-selected permit holders, followed by a survey and cover letter with a postage-paid reply envelope. A second mailing was sent to non-respondents 3-4 weeks later.

For the 2010 and 2011 post-season surveys, the following questions were included to estimate relative differences in effort and harvest of paddlefish between Keystone and Grand: 1) Did you fish for paddlefish around Grand Lake? and 2) Did you fish for paddlefish around Keystone Lake? For survey participants that answered "Yes" to either of these questions, they were asked: 1) number of days fished, 2) number of fish kept and 3) number of fish released. For each respondent and reservoir, effort (number of days), harvest (number of fish kept), catch (number of fish caught [released + harvested]), mean harvest rate (number harvested/effort; HPUE), and mean catch rate (number caught/effort; CPUE) were calculated on a per-angler basis. Differences in effort, mean harvest, mean catch, mean HPUE, and mean CPUE between reservoirs were assessed with t-tests and adjusted for experiment-wise error rate with a Bonferroni correction ($P \leq \alpha/n$; where n = 2, the number of year-based tests), resulting in a significance level of $P < 0.025$. Other variables examined for differences included residency of respondents (Oklahoma resident or non-resident) and mean number of fish kept. When separated according to state-residency status, I used chi-square to compare the proportion of each who fished each lake and a t-test to compare mean number of fish harvested at the $P < 0.05$ significance level.

Results

Unique, useable surveys were received from 4,512 anglers from a sampling frame of 38,944 permits in 2010 and 3,142 anglers out of 45,807 permits in 2011 (A. Crews, Oklahoma Department of Wildlife Conservation, unpublished data). Of active paddlefish anglers (anglers who answered “yes” to fishing for paddlefish in the given year) throughout Oklahoma, 58% in 2010 and 61% in 2011 fished for paddlefish in the Grand Lake area. Conversely, only 9% (2010) to 7% (2011) fished for paddlefish in the Keystone Lake area. The remainder of active paddlefish anglers fished at other areas.

Mean harvest per angler and mean HPUE per angler were greater at Grand Lake than at Keystone Lake, despite similar mean effort per angler between areas, for both 2010 and 2011 (Table 1). Measures of catch, however, were not consistent. In 2010, no significant difference was found in mean CPUE, but mean catch was higher at Grand, while in 2011, there was no difference in mean catch, but mean CPUE was higher at Keystone.

Differences in the residency of anglers, and the harvest behavior of those anglers were apparent (Table 2). In both 2010 and 2011, a higher percentage of non-resident respondents fished the Grand Lake area than resident respondents and the non-residents kept more fish per person than residents. In contrast, a higher percentage of resident respondents fished the Keystone Lake area than non-resident respondents, and there was no significant difference in fish kept per angler between residency status for either year (Table 2).

Discussion

Regardless of catch or effort, more fish were harvested per angler at Grand Lake than at Keystone Lake. One factor possibly contributing to the greater harvest per angler in the Grand Lake area is the ease of harvest by bank anglers. The Grand Lake area has two popular bank angling areas: Miami City Park and Conner's Bridge. Both of these areas allow anglers to park their vehicles within a few meters to their angling location, allowing for ease of transportation of a harvested fish to their vehicle. There are no such bank angling locations at the Keystone Lake area. Snagging locations at Keystone Lake are remote and not easily accessed by vehicle, making anglers hike at least 250 m through wooded areas to reach them. As paddlefish can be quite heavy (often in excess of 20 kg, and sometimes growing to over 45 kg), the proximity to transportation could influence the decision to harvest a fish and would help explain a higher harvest rate per angler in the Grand Lake area. Studies evaluating the relationship between access and pressure have found pressure highest on lakes with good road access (Gunn and Sein 2000, Kaufman et al. 2009), thus increasing overall harvest. However, the paddlefish presents a unique situation where access could directly affect per-angler harvest if the weight of the fish influences the decision to harvest.

It appears that differences in the residency status of people utilizing the resource may also play a role in the higher per-angler harvest at Grand Lake. The close proximity of Grand Lake to neighboring states, paired with the national popularity of the fishery, draws anglers from all over the country (Figure 2). A higher percentage of non-residents fish the Grand Lake area than resident anglers; and the non-residents that fish the Grand Lake area keep more fish than the residents who fish the area. This is not the case in the Keystone Lake area where there is greater utilization by residents than non-residents. It is understandable that non-residents keep more fish, as they are not afforded as many fishing opportunities for paddlefish as resident anglers. However, other surveys of paddlefish anglers have not found the same relationship. Scarnecchia et al. (1996) found actual harvest expectations were higher for residents than non-residents on the Lower Yellowstone River in Montana and Hayden (2009) suggested that snaggers utilizing Lake of the Ozarks in Missouri were homogenous in their consumptive attitudes, regardless of distance traveled.

Another difference between Grand Lake and Keystone Reservoir that may contribute to harvest in the Grand Lake area is the presence of the Paddlefish Research Center. Anglers who used the PRC in 2010 and 2011 were asked of the hypothetical disposition of the paddlefish they had processed at the PRC, had the service not been available. Most anglers (78% in 2010 and 76% in 2011) indicated they would have processed the paddlefish themselves (Crews, Oklahoma Department of Wildlife Conservation, unpublished data). In 2011 anglers were asked additional questions to determine the possible impact of the PRC on harvest. Nearly one in five anglers strongly agreed with the statement "I plan my paddlefishing trips based on when the Center is open". The majority of anglers strongly disagreed with the statements "I only keep paddlefish when I know the Center is open" and "If I had to clean my own paddlefish, I probably wouldn't keep any". However, for both of these latter statements, residents were significantly more likely than non-residents to agree (Crews, Oklahoma Department of Wildlife Conservation, unpublished data). Although most anglers indicate that the PRC does not influence their decision to harvest a fish, this could be affected by respondent error in the form of prestige bias, especially by resident anglers. Prestige bias is the tendency for respondents to answer in a way that makes them feel or look better (National Research Council 2006). While anglers would like to think they would have cleaned a fish in the absence of the free service, they may not have when actually faced with the task. While not specifically tested, the difference in harvest rate between Grand, where free cleaning services exist, and Keystone provide a proxy and show a 2-3 increase in harvest at Grand (Table 2). This comparison is also confounded by differences in bank angling access. Possible respondent bias, and the planning of trips around the free cleaning service suggest the presence of the PRC as a contributing factor to the higher harvest rate per angler in the Grand Lake area.

The location and popularity of the Grand Lake paddlefish sport fishery, along with the availability of a free fish cleaning service in the area, make it the primary target of paddlefish angling in Oklahoma. It is concerning that, regardless of catch and effort, per-angler harvest at Grand Lake is greater than in the Keystone Lake area. With over-exploitation contributing to declines in paddlefish populations nation-wide, managers should take great care to monitor harvest and continue to investigate angler behavior and motivations for harvest in the Grand Lake fishery. Fishing access developments at other reservoirs in the region that support paddlefish sport fisheries could create bank angling opportunities elsewhere, thus transferring paddlefish harvest pressure away from the Grand Lake area. Comparison of the per-angler harvest at Grand Lake to lakes in the region with more comparable bank angling access, like at Ft. Gibson, could shed more light on the effect of the free fish-cleaning service.

References

Ambler, M.E. 1994. Paddlefish investigations: fish research surveys in Oklahoma lakes and reservoirs. Oklahoma Department of Wildlife Conservation, Federal Aid in Sport Fish Restoration Project F-37-R, Final Report, Oklahoma City.

Bettoli, P.W., J.A. Kerns, and G.D. Scholten 2009. Status of paddlefish in the United States. Pages 23-38 *in* C.P. Paukert and G.D. Scholten, editors. Paddlefish management, propagation, and conservation in the 21st century: building from 20 years of research and management. American Fisheries Society, Symposium 66, Bethesda, Maryland.

Carlson, D.M., and P.S. Bonislawsky. 1981. The paddlefish (*Polyodon spathula*) fisheries of the Midwestern United States. Fisheries 6: 17-27.

Combs, D.L. 1982. Angler exploitation of paddlefish in the Neosho River, Oklahoma. North American Journal of Fisheries Management 4: 334-342.

Gordon, B. 2009. Paddlefish harvest in Oklahoma. Pages 223-234 *in* C.P. Paukert and G.D. Scholten, editors. Paddlefish management, propagation, and conservation in the 21st century: building from 20 years of research and management. American Fisheries Society, Symposium 66, Bethesda, Maryland.

Gunn, J.M., and R. Sein 2000. Effects of forestry roads on reproductive habitat and exploitation of lake trout (*Salvelinus namaycush*) in three experimental lakes. Canadian Journal of Fisheries and Aquatic Sciences 57: 97-104.

Hansen, K.A. and C.P. Paukert 2009. Current management of paddlefish sport fisheries. Pages 277-290 *in* C.P. Paukert and G.D. Scholten, editors. Paddlefish management, propagation, and conservation in the 21st century: building from 20 years of research and management. American Fisheries Society, Symposium 66, Bethesda, Maryland.

Hayden, S.C. 2009. The social and cultural aspects of paddlefish snaggers at the Lake of the Ozarks. Doctoral dissertation, University of Missouri-Columbia.

Kaufman, S.D., E. Snucins, J.M. Gunn and W. Selinger 2009. Impacts of road access on lake trout (*Salvelinus namaycush*) populations: regional scale effects of overexploitation and the introduction of smallmouth bass (*Micropterus dolomieu*). Canadian Journal of Fisheries and Aquatic Sciences 66: 212-223.

Mestl, G. and J. Sorensen 2009. Joint management of an interjurisdictional paddlefish snag fishery in the Missouri River below Gavins Point Dam, South Dakota and Nebraska. Pages 235-260 *in* C.P. Paukert and G.D. Scholten, editors. Paddlefish management, propagation, and conservation in the 21st century: building from 20 years of research and management. American Fisheries Society, Symposium 66, Bethesda, Maryland.

National Research Council. 2006. Review of Recreational Fisheries Survey Methods. Washington, DC: The National Academies Press.

Oklahoma Water Resources Board. 2010. 2008-2009 Oklahoma Lakes Report – Beneficial Use Monitoring Program. 182pp.

Pasch, R.W. and C.M. Alesander. 1986. The effects of commercial fishing on paddlefish populations. Pages 46-53 *in* J.G. Dillard, L.K. Graham, and T.R. Russell, editors. Paddlefish status, management, and propagation. American Fisheries Society, North Central Division, Special Publication 7, Bethesda, Maryland.

Quinn, J.W. 2009. Harvest of Paddlefish in North America. Pages 223-234 *in* C.P. Paukert and G.D. Scholten, editors. Paddlefish management, propagation, and conservation in the 21^{st} century: building from 20 years of research and management. American Fisheries Society, Symposium 66, Bethesda, Maryland.

Scarnecchia, D.L., P.A. Stewart and Y. Lim 1996. Profile of recreational paddlefish snaggers on the lower Yellowstone River, Montana. North American Journal of Fisheries Management 16: 872-879.

Woods, A.J., J.M. Omernik, D.R. Butler, J.G. Ford, J.E. Henley, B.W. Hoagland, D.S. Arndt, and B.C. Moran 2005. Ecoregions of Oklahoma (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,250,000).

Table 1. Mean per-angler: effort, harvest, catch, harvest per unit effort and catch per unit effort from 2010 and 2011 post-season paddlefish survey for Grand and Keystone reservoirs. Superscripts denote significant differences between lakes within years based on a t-test and $P < 0.05$.

Variable	2010		2011	
	Grand	Keystone	Grand	Keystone
N (anglers)	967	155	640	75
Mean effort (days/angler)	4.79^{a}	4.23^{a}	3.94^{a}	5.14^{a}
Mean harvest (# kept/angler)	1.49^{a}	0.59^{b}	1.46^{a}	0.76^{b}
Mean catch (# caught/angler)	8.09^{a}	5.38^{b}	4.91^{a}	6.30^{a}
Mean HPUE (# kept/days/angler)	0.36^{a}	0.16^{b}	0.44^{a}	0.21^{b}
Mean CPUE (# caught/days/angler)	1.63^{a}	1.53^{a}	1.39^{a}	2.72^{b}

Table 2. Percentage of Oklahoma paddlefish survey respondents who fished given areas (separate questions, multiple responses allowed) and mean fish kept per person for Grand and Keystone Lakes, by residency, in 2010 and 2011. Superscripts denote significant differences between residency within years based on a chi-squared test and $P < 0.05$.

Variable	2010		2011	
	Resident	Non-resident	Resident	Non-resident
Respondents who fished area				
Grand	43%[a]	89%[b]	38%[a]	93%[b]
Keystone	14%[a]	4%[b]	12%[a]	2%[b]
Mean fish kept per person				
Grand	1.1[a]	1.8[b]	1.1[a]	1.7[b]
Keystone	0.6[a]	0.5[a]	0.8[a]	0.4[a]

Figure 1. Locations of Grand Lake ‘O the Cherokees and Keystone Lake in northeast Oklahoma where differences in paddlefish populations were assessed in 2010 and 2011.

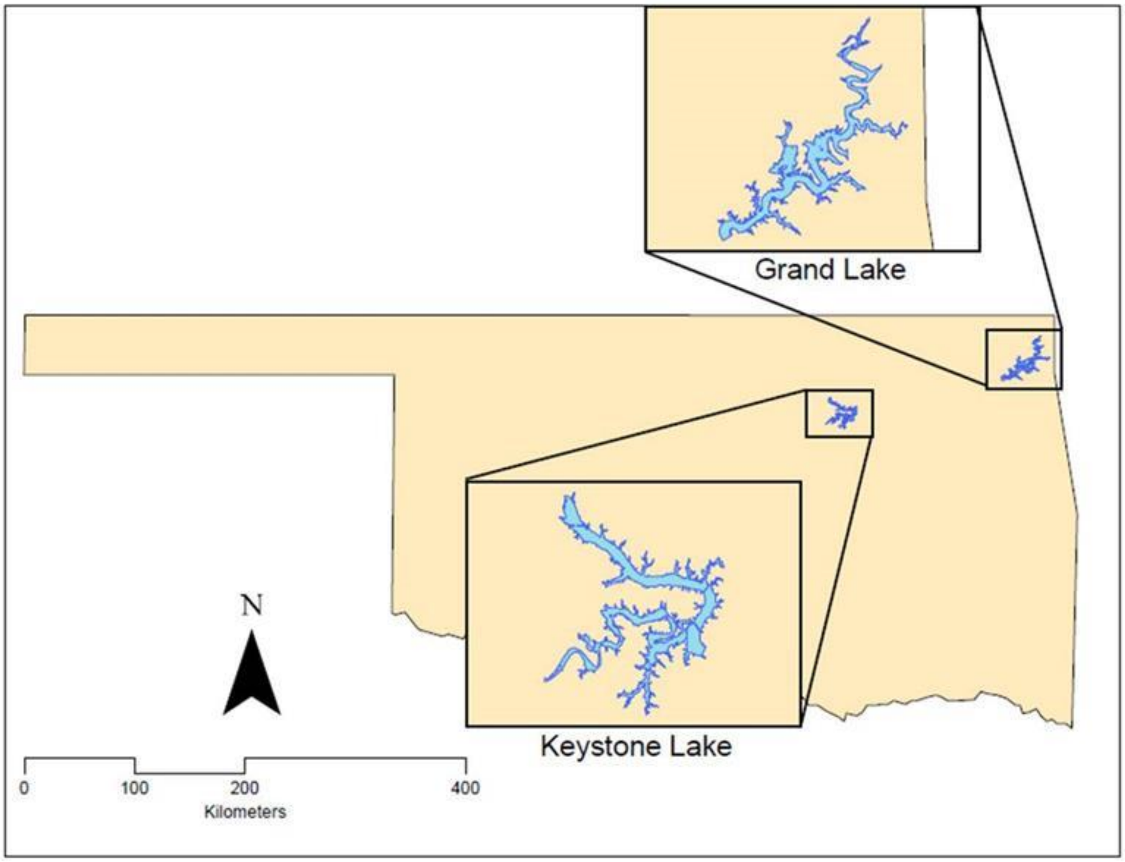
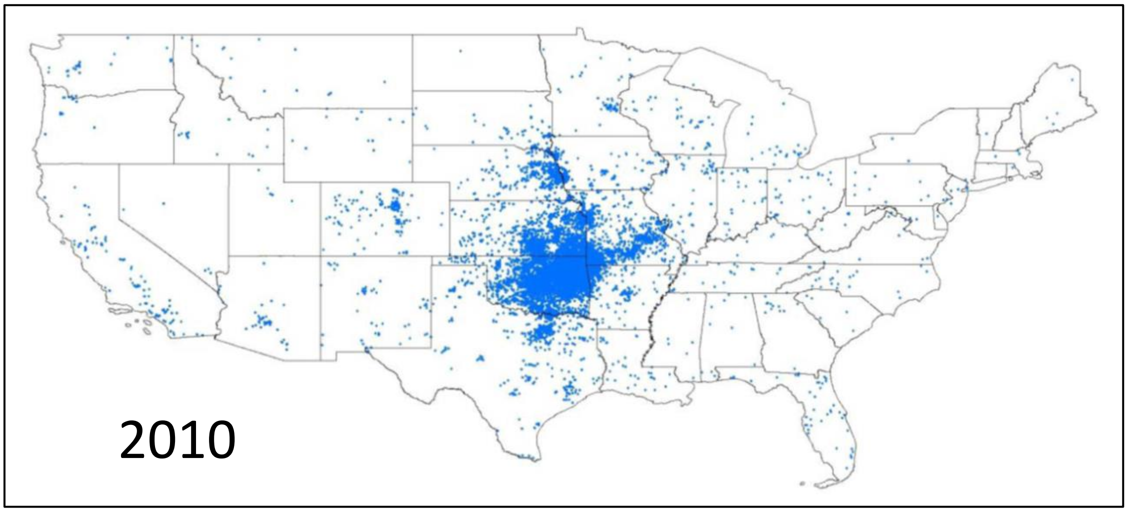
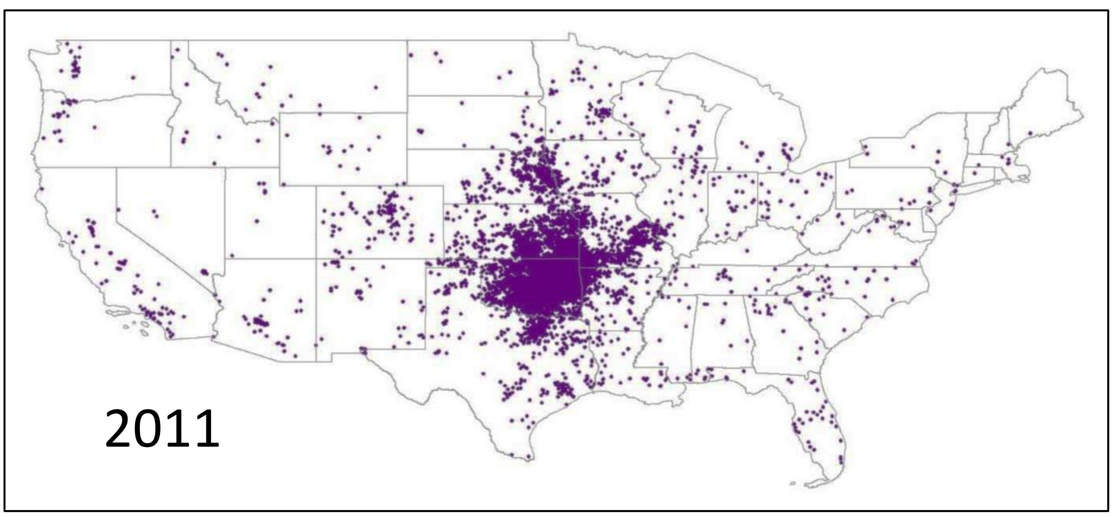


Figure 2. Distribution of 2010 and 2011 paddlefish permit holders by zip code of residence in the continental United States (Crews, Oklahoma Department of Wildlife Conservation, unpublished data).





Appendix A

2011 Paddlefish Angler Survey

1. Did you fish for paddlefish in Oklahoma during 2011?

   ☐ Yes
   ☐ No → 1a. If no: Our records show that you have a free paddlefish permit. Did you intend to get the free paddlefish permit?

   ☐ Yes
   ☐ No

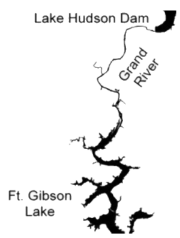
   If you did not fish for paddlefish in Oklahoma during 2011, your survey is now complete. Please mail it today. Thank you!

2. Did you fish for paddlefish **around Grand Lake?** (For example: Miami Park, Conner's Bridge, Twin Bridges, Gray's Ranch, Neosho River, Grand Lake, etc.)

☐ Yes →
☐ No

Total for all your paddlefishing in the **Grand Lake area:**	
Number of days fished:	_____ days
Number of fish kept:	_____ fish kept
Number of fish released:	_____ fish released

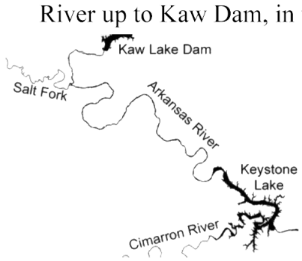
3. Did you fish for paddlefish **around Fort Gibson?** (For example: below Hudson dam, the low water dam north of 412, in the river south of 412, Ft. Gibson Lake, etc.)



☐ Yes →
☐ No

Total for all your paddlefishing **north of Ft. Gibson:**	
Number of days fished:	_____ days
Number of fish kept:	_____ fish kept
Number of fish released:	_____ fish released

4. Did you fish for paddlefish **around Keystone Lake?** (For example: in Keystone, in the Arkansas River up to Kaw Dam, in the Salt Fork, in the Cimarron River, etc.)



☐ Yes →
☐ No

Total for all your paddlefishing in the **Keystone area:**	
Number of days fished:	_____ days
Number of fish kept:	_____ fish kept
Number of fish released:	_____ fish released

5. Did you fish for paddlefish **anywhere else in Oklahoma**? (For example: Pensacola tailwaters, Hudson Lake, Ft. Gibson tailwaters, Arkansas River from Keystone to the Arkansas state line, Verdigris River to Oologah dam, Texoma tailwaters, Eufaula tailwaters, etc.)

   ☐ Yes
   ☐ No

6. Did you fish for paddlefish in 2011 during the catch-and-release days (Monday and Friday)?

☐ Yes
☐ No

7. During 2011, did you have any paddlefish processed at the Paddlefish Research and Processing Center, at Twin Bridges State Park?

☐ Yes → 7a. How many? _________
☐ No

8. Do you think another Paddlefish Research and Processing Center should be opened in Oklahoma, closer to Fort Gibson?

☐ Yes
☐ No

If you did not use the Center at Twin Bridges, your survey is now complete.

9. If the Paddlefish Research and Processing Center had not been available this year, what would you have done with the paddlefish you took to the Center?

☐ Processed the paddlefish myself
☐ Released the paddlefish
☐ Processed some paddlefish and released some
☐ Don't know/not sure

10. Please indicate your agreement with the following statements:

	Strongly Disagree 1	2	3	4	**Strongly Agree** 5
I was satisfied with my experience using the Center in 2011	1	2	3	4	5
If I had to clean my own paddlefish, I probably wouldn't keep any	1	2	3	4	5
I am concerned too many paddlefish are harvested in Oklahoma	1	2	3	4	5
The workers at the Center were friendly and professional	1	2	3	4	5
People keep more paddlefish now than before the Center opened	1	2	3	4	5
The paddlefish Center is a good idea	1	2	3	4	5
I only keep paddlefish when I know the Center is open	1	2	3	4	5
I will probably use the Center again next time	1	2	3	4	5
The Center encourages people to keep fish they would otherwise release	1	2	3	4	5
The regulations should be changed to reduce paddlefish harvest	1	2	3	4	5
I plan my paddlefishing trips based on when the Center is open	1	2	3	4	5

11. Did you fish for paddlefish in Oklahoma before 2008 when the Center was first opened?

☐ Yes
☐ No 11a. What year did you start paddlefishing in Oklahoma? __________

Use this space for comments or feedback about Oklahoma's paddlefish program. If you would like a response, please provide your contact information. ____

____

____

Thank you! Please mail your completed survey today!

CHAPTER II

CHARACTERISTICS OF TWO SELF-SUSTAINING POPULATIONS OF PADDLEFISH IN NORTHEAST OKLAHOMA

Introduction

Population characteristics of paddlefish (*Polyodon spathula*) have been documented in rivers and reservoirs, mostly in the southeastern United States (Pasch et al. 1980, Hageman et al. 1988, Hoffnagle and Timmons 1989, Reed et al. 1992, Hoxmeier and DeVries 1997, Lein and Devries 1998, Scholten and Bettoli 2005, O'Keefe and Jackson 2009), but rarely have direct comparisons between populations with concurrent sampling been conducted that would help biologists better understand how site-specific environmental factors affect these populations. In the Alabama River drainage, for example, Lein and DeVries (1998) conducted concurrent sampling and found variation in paddlefish movement and CPUE were related to differences in the hydrologic and thermal regimes of the two study rivers. Although growth rates did not differ between rivers, there were differences in age distributions and mean fish length and weight, which may have been attributed to differences in historical exploitation of these populations (Lein and DeVries 1998).

In Oklahoma, paddlefish are highly valued and robust populations support fisheries in several localities. The most important of these fisheries is at Grand Lake (Combs 1982, Ambler 1994), which is the only one in the state that has been investigated on a regular basis. However, even this thriving fishery has seen recent declines. Results of research conducted between 1978 and 1994 (Ambler 1981, Combs 1981, Combs 1982, Ambler 1987, Ambler 1994) prompted the Oklahoma Department of Wildlife Conservation (ODWC) to close the fishery to commercial harvest and reduce recreational creel limits (Gordon 2009). To provide further information on the paddlefish population and harvest, the ODWC established the Paddlefish Research Center (PRC) in 2008, which takes data from angler-harvested fish (length, weight, sex, age) and sells the processed caviar to enhance funding for management of paddlefish in the state.

The operation of the PRC on Grand Lake has not only increased data for paddlefish management, but also direct communication with paddlefish anglers. In recent years, paddlefish anglers have complained of a decrease in fish size on Grand Lake, which mirrored results obtained by the ODWC using PRC harvest data (J. Schooley, ODWC, unpublished data). In contrast, fisheries biologists have noticed that paddlefish in Keystone Reservoir tend to be larger than paddlefish in Grand Lake (K. Moore, Oklahoma Department of Wildlife Conservation, personal communication). Apart from anecdotal reports, nothing was known about the paddlefish population in Keystone Reservoir until 1996 (Paukert, 1998), which has also not been investigated since, hindering any direct comparisons between the two reservoir systems.

Understanding the paddlefish population in Keystone Reservoir in concert with studying the population at Grand Lake may provide valuable insight into the reported declines in paddlefish at Grand Lake. Thus, the objectives for this study were to 1) estimate and compare population characteristics (size, age, growth, mortality, relative abundance) of paddlefish in Keystone Reservoir and Grand Lake and 2) seek to attribute differences to any site-specific environmental factor.

Study Area

Keystone Reservoir

Keystone Reservoir is a 9,073-hectare impoundment of the Arkansas River located in north-central Oklahoma in the cross-timbers ecoregion (Woods et al. 2005) (Figure 1). The dam was completed in 1964 and is operated by the U.S. Army Corps of Engineers for flood control, water supply, hydroelectric power, navigation, and fish and wildlife. The Cimarron River is a highly mineralized tributary with salinity ranging from 0.54 to 3.85 ppt, while the Arkansas River arm ranges from 0.29 to 0.76 ppt (Oklahoma Water Resources Board 2010). The Arkansas River arm is categorized as hypereutrophic, while the rest of the reservoir is eutrophic (Oklahoma Water Resources Board 2010).

Grand Lake O' The Cherokees (Grand Lake)

Grand Lake is an 18,817-hectare impoundment of the Grand River located in northeast Oklahoma in the Ozark Highlands ecoregion (Woods et al. 2005). The lake was completed in 1940 and is operated by the Grand River Dam Authority for flood control and hydroelectric power. Grand Lake is categorized as eutrophic and salinity ranges from 0.10 to 0.25 ppt (Oklahoma Water Resources Board 2010).

Methods

Relative Abundance

At both lakes, I established potential sampling sites every 0.8 km along the main channel starting at the dam and along major tributary channels starting at their confluence with the main channel. I then randomly selected 24 of these sites for sampling by gill nets (monofilament, 182-m long, 7.3-m deep, 152-mm bar mesh) during December of 2010 and 2011 when water temperatures were below 10°C to minimize mortality (Paukert 1998). Nets were set perpendicular to the main river channel for approximately 8 hours during the day and then retrieved. Paddlefish that were caught were measured, (mm eye-fork length, EFL, Ruelle and Hudson 1977), weighed (nearest 0.05 kg), and released. I calculated catch-per-unit-effort (CPUE) as the number of fish collected per 1328.6 m^2 of gill net per 24 hours (Paukert and Fisher 1999), which was compared between reservoirs with a t-test each year.

Age Structure

Fish Collection

Keystone - Following the gill netting to estimate relative abundance in 2010, I then collected paddlefish for age estimation by setting gill nets overnight from January through March 2011. I measured EFL and weight (0.05 kg) of each fish collected, and removed their jaw bones for age estimation. Gonads were also removed to determine sex (male, female, juvenile), gonad weight and gonadal fat weight.

Grand - During the months of March and April 2011, paddlefish were processed by the Oklahoma Department of Wildlife Conservation's Paddlefish Research Center (PRC) on Grand Lake. A random sample of 300 fish were measured (mm, EFL), weighed (0.05 kg), had their jaw bones removed for age estimation, and had their gonads removed to determine sex (male, female, juvenile), gonad weight and gonadal fat weight.

Age Estimation, Growth and Mortality

I cleaned jaw bones from the paddlefish and sectioned them posterior to the point of greatest curvature to 0.635-mm thick with a low-speed, diamond-edged saw (Scarnecchia et al. 1996). Three readers of similar experience level independently estimated age of each fish, without knowledge of fish size or sex, by counting annuli along the mesial arm (Adams 1942) under magnification. If there was agreement among all readers, or agreement between two readers plus or minus 1 year from the third reader, I assigned the modal age. If an age was not assigned with this protocol, an age from the three readers in consultation was assigned. If a fish could not be assigned an age after consultation, it was eliminated from the dataset for all age-related calculations.

I constructed age-bias plots to graphically assess reader bias using the methods of Campana et al. (1995). These graphs plot the average ages estimated by one reader for all fish against the age determined by a second reader. Bias was visually determined in relation to a 1:1 line of agreement for all possible pairs of readers (Campana et. al 1995). Furthermore, paddlefish dentary sections obtained by the Oklahoma Department of Wildlife Conservation at the Paddlefish Research Center are routinely sent to the University of Idaho for age interpretation by D. Scarnecchia and I created an age bias plot of my age estimates and those of the Scarnecchia laboratory as an additional assessment of bias.

I assigned ages to unaged fish with a length-age key and estimated total annual mortality with a catch curve (Van Den Avyle and Hayward 1999). I determined mean length-at-age for males and females separately and calculated growth with Walford plots and von Bertalanffy growth functions (Van Den Avyle and Hayward 1999). Where sample size prevented the use of von Bertalanffy growth functions, I assessed differences in mean length at age for those ages where sample sizes were sufficient ($n \geq 4$) between reservoirs with analysis of covariance (ANCOVA) with age as the covariate.

Size Structure and Condition

After developing length-frequency histograms, I compared distributions between reservoirs for each sex separately using two-sample Kolmogorov-Smirnov (K-S) tests (Bell et al. 1985). Using their respective standard weight equations (Brown and Murphy 1993), I calculated relative weights (Wr) for males and females, and compared Wr between reservoirs for each sex with a t-test. I separated gonads from the associated gonadal fat bodies (GFB), which are discrete clumps of fatty tissue attached to the gonads (Scarnecchia et al. 2007), weighed them (0.01 kg), and calculated the gonadosomatic index (GSI; [(gonad weight – GFB weight) / total fish weight] x 100) (DeVlaming et al. 1982). I also expressed GFB as a percentage of total fish weight (Scarnecchia et al. 2007), and tested for differences between reservoirs with analysis of covariance (ANCOVA) with age as the covariate. To meet the assumptions of normality, GFB data for male paddlefish were transformed using an arcsine square root transformation, and female GFB data were transformed using a $\log_{10}$ transformation.

Results

Relative abundance was similar between Grand Lake and Keystone Reservoir in both sampling years (t-test, $P > 0.1$ both years), with total catches ranging from 193 to 299 fish with 24-net nights per reservoir per year (Table 1). Other population characteristics usually differed between reservoirs. For example, relative weights (Wr) were significantly greater in Keystone Lake for males and females in 2010 and 2011 (Table 2) and paddlefish in Keystone tended to consist of larger individuals than those in Grand Lake regardless of sex (Figure 2 -5). Lengths of paddlefish in Keystone were skewed to the right with the highest frequency of fish around 1150 mm EFL for females (Figure 2) and 1100 mm EFL for males (Figure 3). In contrast, the peak frequency of paddlefish in Grand Lake occurred near 1050 mm EFL for females (figure 2) and 950 mm EFL for males (Figure 3).

I could not use von Bertalanffy growth functions to describe growth because fish from Grand Lake were too skewed toward older age classes and Walford plots for the fish from Keystone had negative slopes. At Grand Lake adequate numbers of fish ($n \geq 4$) for comparing mean length at age were only available for females aged 9-13 and males 7-13. However, for those age groups with sufficient numbers, paddlefish at Keystone had a greater mean length at age for females ($P = 0.01$) and males ($P = 0.03$) than at Grand, but the two populations grew at similar rates from ages 9 - 13 (Figures 4 and 5). For the fully recruited paddlefish population at Keystone (ages 8-16) I estimated the annual mortality rate at 34.8%. I could not calculate annual mortality for paddlefish at Grand Lake because I could not create a proper length-age key since most of the population were part of just a few older age classes.

Visual inspection of the age bias plots revealed greater bias between readers for dentary sections from Keystone paddlefish than those from Grand (Figures 6 and 7). More bias existed among readers for fish aged 5-9 than for other ages from Keystone (Figure 6). For both Keystone and Grand, all comparisons of readers fell within one standard deviation of the agreement line, except age 14 between readers 1 and 2 for Grand (Figures 6 and 7). When comparing ages between my estimates and those from the University of Idaho, a consistent bias for ages 13 and older was evident (Figure 8).

Fish at Keystone converted relatively more energy into fat while fish at Grand tended to convert more energy into gonads. We collected gonads from 84 females at Keystone, 33 of which were not gravid. Of the 33 non-gravid, 13 were of the age of sexual maturity, but possessed no mature eggs. For gravid female fish, GSI was greater at Grand than at Keystone ($P < 0.01$) (Figure 9), while GFB was greater at Keystone ($P < 0.01$), but decreasing at a greater rate (Figure 10). While no differences in GSI were found between the two reservoirs for male paddlefish (Figure 11), GFB was also greater at Keystone than at Grand ($P = 0.01$) (Figure 12).

Discussion

Paddlefish in Keystone Reservoir exhibited greater body size, body condition and growth rates than fish in Grand Lake despite similar relative abundance. As in other populations, such as the Yellowstone-Sakakawea stock (Scarnecchia et al. 2007), an inverse relationship between GSI and GFB was observed, although paddlefish from Keystone Reservoir had higher GFB values, and female paddlefish from Grand Lake had higher GSI values.

From previous experience sampling these two reservoirs, I hypothesized Grand Lake would have significantly higher relative abundance than Keystone Reservoir. At Grand Lake, past sampling efforts involved fixed sites, whereas I used random sites for inter-lake comparisons. Large numbers of paddlefish could reliably be caught at certain sites at Grand Lake, while Keystone Reservoir was not as predictable. It is possible that fish at Grand Lake utilize certain areas more heavily, whereas fish at Keystone are more randomly distributed, although the reason why is unknown. Preliminary results from telemetry work being conducted on paddlefish in Grand Lake indicated that one site in the upper reservoir was utilized at a higher frequency than other areas in 2011and 2012 (48% and 44% of total detections, respectively; Johnston and Schooley 2012). At Keystone, in comparison, paddlefish avoided the Cimarron River arm in the summer (Paukert 1998, Paukert & Fisher 2000), and moved in response to high flows in the spring (Paukert & Fisher 2001a), but did not otherwise utilize any one area of the reservoir more than others. These data, thus, could be used to develop robust sampling designs to best monitor these two disparate populations.

The annual mortality rate at Keystone was similar to estimates made previously (26.6% to 33.9%; Paukert 1998) and to other southern paddlefish stocks with only recreational fishing (26-48%, Reed et al. 1992; 34-36%, Hoxmeier & DeVries 1997). Though I couldn’t calculate an annual mortality rate for the fully recruited paddlefish population at Grand Lake, age data compiled from the PRC for fish aged 12 and older yielded an annual morality rate of 48% (J. Schooley, ODWC, unpublished data). Truncating my catch curve for Keystone Reservoir to age 12 would result in an annual mortality rate of 43%, similar to the population at Grand Lake.

I was able to assess the precision of our age estimates among readers, but had no way to determine accuracy. Bias among readers for Oklahoma paddlefish existed, but appeared minimal in most cases. However, more bias was evident when comparing age estimates with those from D. Scarnecchia at the University of Idaho. Scarnecchia et al. (2006) validated ages in the Yellowstone-Sakakawea paddlefish stock in Montana and North Dakota up to age 10 with 83% accuracy using a two-reader double-blind protocol with a tolerance for minor disagreement (±1 year for fish < age 20). Using the same methodology, Pierce et al. (2011) accurately estimated the age 8.6% of fish from Lake Francis Case and aged 50% of dentaries within one year. Representative reference photographic plates of dentary sections from fish of a range of ages have been prepared, which could aid of validation of ages for the Grand Lake stock (Scarnecchia et al. 2011), but because the ease of interpreting dentaries varies with locality (Scarnecchia et al. 2006), validation of paddlefish age from all the Oklahoma stock should also be pursued.

The differences I found in GFB and GSI between Grand and Keystone seem best interpreted as differences in reproductive periodicity. Gonadal fat reserves are depleted with successive spawns and unspawned females tend to reabsorb their eggs (Scarnecchia et al. 2007). With longer periods between spawns, GFB reserves will deplete at a slower rate, allowing energy to be allocated for somatic growth, as is the case when female paddlefish prepare to spawn, but instead reabsorb eggs when unable to complete that activity. Anecdotally, I observed that approximately twenty percent of mature Keystone females possessed eggs at some intermediate stage of development other than mature. In contrast, nearly all female paddlefish brought to the PRC were sexually mature (personal observations) possessing mature eggs. These differences appear to be fixed between reservoirs. For example, Paukert and Fisher (2001b) noted inconsistent spawning migrations of paddlefish at Keystone Reservoir, suggesting these fish do not spawn every year. Alternatively, paddlefish at Grand Lake are brought to the PRC at various times in the spring when paddlefish spawn and rarely do female paddlefish possess eggs in something less than a mature state. Because the PRC receives revenue from caviar sales, which require mature ova, anecdotal observations of maturity status is likely to be accurate. Data from a long-term tagging program at both reservoirs would be useful to test this hypothesis.

An understanding of the *in-situ* river ecology and hydrology may also help explain apparent differences in spawning periodicity between Grand and Keystone Reservoirs. Paukert and Fisher (2001b) found that paddlefish in Keystone did not migrate up the rivers every year to spawn, requiring sustained periods of high water and cool water temperatures that only occur periodically in this system. At Keystone Reservoir, where the main tributaries are typical prairie systems, extreme low flows impede the movement of paddlefish upriver. Whereas at Grand Lake, tributaries are deeper and more channelized with few natural obstacles to paddlefish migration. Additionally, upstream impoundments are more prevalent at the Keystone system compared to the Grand Lake system. Approximately 175 km above Keystone Reservoir, the Arkansas River is impounded, whereas Grand Lake does not have an impoundment until approximately 338 km upstream.

Further explaining differences in paddlefish growth and condition between the two reservoirs is the presence of bighead carp (*Hypophthalmichthys nobilis*) in Grand Lake, which was first found in 1992 (Pigg et al. 1993). Prior to this discovery, paddlefish reached 1000 mm average length by age 9 (Combs 1981), whereas this average size was not reached until age 12 in 2011. Reproduction of bighead carp has not been documented, but specimens are annually caught by anglers in the Neosho River. A bighead carp snagged in the Neosho River in April 2011, determined to be 9 years old, could not have come from the 1988 introduction and indicates additional, unknown introductions or undocumented reproduction (Long and Nealis 2011). Bighead carp can alter the structure of zooplankton communities (Cooke et al. 2009), reducing the overall size of zooplankton available (Radke and Kahl 2002; Kim et al. 2003). Paddlefish generally consume larger-size zooplankton (Kolar et al. 2005) and zooplankton community dominated by smaller individuals could negatively affect paddlefish. Schrank et al. (2003) confirmed that paddlefish relative growth can be negatively affected by interspecific competition with bighead carp. Additional information on the bighead carp population is needed to help test this interspecific competition hypothesis, which seems likely given this species has not been found at Keystone Reservoir where paddlefish individuals are more robust.

References

Adams, L.A., 1942. Age determination and rate of growth in *Polyodon spathula*, by means of growth rings of the otoliths and dentary bone. American Midlands Naturalist 28: 617-630.

Ambler, M.E. 1981. Paddlefish investigations: fish research surveys in Oklahoma lakes and reservoirs. Oklahoma Department of Wildlife Conservation, Federal Aid in Sport Fish Restoration Project F-37-R, Final Report, Oklahoma City.

Ambler, M.E. 1987. Paddlefish investigations: fish research surveys in Oklahoma lakes and reservoirs. Oklahoma Department of Wildlife Conservation, Federal Aid in Sport Fish Restoration Project F-37-R, Final Report, Oklahoma City.

Ambler, M.E. 1994. Paddlefish investigations: fish research surveys in Oklahoma lakes and reservoirs. Oklahoma Department of Wildlife Conservation, Federal Aid in Sport Fish Restoration Project F-37-R, Final Report, Oklahoma City.

Bell, J.D., G.J.S. Craik, D.A. Pollard, and B.C. Russell. 1985. Estimating length frequency distributions of large reef fish underwater. Coral Reefs 4:41-44.

Brown, M.L., and B.R. Murphy. 1993. Management evaluation of body condition and population size structure for paddlefish: a unique case. Prairie Naturalist 25:93-108.

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Transactions of the American Fisheries Society 124:131-138.

Carlson, D.M., and P.S. Bonislawsky. 1981. The paddlefish (*Polyodon spathula*) fisheries of the Midwestern United States. Fisheries 6:17-27.

Combs, D.L. 1981. Paddlefish investigations: fish research surveys in Oklahoma lakes and reservoirs. Oklahoma Department of Wildlife Conservation, Federal Aid in Sport Fish Restoration Project F-37-R, Final Report, Oklahoma City.

Combs, D.L. 1982. Angler exploitation of paddlefish in the Neosho River, Oklahoma. North American Journal of Fisheries Management 4: 334-342.

Cooke, S.L., W.R. Hill and K.P. Meyer. 2009. Feeding at different plankton densities alters invasive bighead carp (*Hypopthalmichys nobilis*) growth and zooplankton species composition. Hydrobiologia 625: 185-193.

DeVlaming, V., G. Grossman, and F. Chapman. 1982. On the use of the gonadosomatic index. Comparative Biochemistry and Physics 73:31-39.

Gordon, B. 2009. Paddlefish harvest in Oklahoma. Pages 223-233 *in* C.P. Paukert and G.D. Scholten, editors. Paddlefish management, propagation, and conservation in the 21st century: building from 20 years of research and management. American Fisheries Society, Symposium 66, Bethesda, Maryland.

Hageman, J.R., D.C. Timpe, and R.D. Hoyt. 1988. The biology of paddlefish in Lake Cumberland, Kentucky. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 40(1986):237-248.

Hoffnagle, T.L., and T.J. Timmons. 1989. Age, growth, and catch analysis of the commercially exploited paddlefish population in Kentucky Lake, Kentucky-Tennessee. North American Journal of Fisheries Management 9:316-326.

Hoxmeier, R.J.H., and D.R. DeVries. 1997. Habitat use, diet, and population structure of adult and juvenile paddlefish in the lower Alabama River. Transactions of the American Fisheries Society 126: 288-301.

Johnston, B.R. and J.D. Schooley. 2012. Grand Reservoir paddlefish telemetry and spawning frequency: fish research and surveys for Oklahoma lakes and reservoirs. Oklahoma Department of Wildlife Conservation, Federal Aid in Sport Fish Restoration Project F11AF00318-34, Interim Performance Report, Oklahoma City.

Kim, B.H., M.S. Han, and N. Takamura. 2003. Effects of fish introduction on the length of the tail of cryptomonads in mesocosms experiments. Oecologia 136:73-79.

Kolar, C. S., D.C. Chapman, W.R. Courtenay Jr., C.M. Housel, J.D. Williams, and D.P. Jennings. 2005. Asian Carps of the Genus *Hypophthalmichthys* (Pisces, Cyprinidae)—A Biological Synopsis and Environmental Risk Assessment. U.S. Fish and Wildlife Service 183 pp.

Lein, G.M., and D.R. DeVries. 1998. Paddlefish in the Alabama River drainage: Population characteristics and the adult spawning migration. Transactions of the American Fisheries Society 127:441-454.

Long, J.M. and A. Nealis. 2011. Age estimation of a large bighead carp from Grand Lake, Oklahoma. Proceedings of the Oklahoma Academy of Science 91:15-18.

O'Keefe D.M., and D.C. Jackson 2009. Population characteristics of paddlefish in two Tennessee-Tombigbee waterway habitats. Pages 83-102 *in* C.P. Paukert and G.D. Scholten, editors. Paddlefish management, propagation, and conservation in the 21st century: building from 20 years of research and management. American Fisheries Society, Symposium 66, Bethesda, Maryland.

Oklahoma Water Resources Board. 2010. 2008-2009 Oklahoma Lakes Report – Beneficial Use Monitoring Program. 182pp.

Pasch, R.W., P.A. Hackney, and J.A. Holbrook II. 1980. Ecology of paddlefish in Old Hickory Reservoir, Tennessee, with an emphasis on first year life history. Transactions of the American Fisheries Society 109:157-167.

Paukert, C.P. 1998. Population ecology of paddlefish in the Keystone Reservoir System, Oklahoma. Master's thesis. Oklahoma State University, Stillwater.

Paukert, C.P., and W.L. Fisher. 1999. Evaluation of paddlefish length distributions and catch rates in three mesh sizes of gill nets. North American Journal of Fisheries Management 19: 599-603.

Paukert, C.P. and W.L. Fisher. 2000. Abiotic factors affecting summer distribution and movement of male paddlefish, *Polyodon spathula*, in a prairie reservoir. The Southwestern Naturalist 45:133-140.

Paukert, C.P. and W.L. Fisher. 2001a. Characteristics of paddlefish in a southwestern U.S. reservoir, with comparisons of lentic and lotic populations. Transactions of the American Fisheries Society 130: 634-643.

Paukert, C.P. and W.L. Fisher. 2001b. Spring movements of paddlefish in a prairie reservoir System. Journal of Freshwater Ecology 16(1): 113-124.

Pierce, L.L., B.D.S. Graeb, D.W. Willis, J.S. Sorensen and M.A. Pegg. 2011. Stocking Success of Paddlefish in Lake Francis Case, South Dakota: Population Characteristics and Sport Fishery Potential. Transactions of the American Fisheries Society 140: 1359-1369

Pigg, J., J. Stahl, M. Ambler, and J. Smith. 1993. Two potential sources of exotic fish in Oklahoma. Proceedings of the Oklahoma Academy of Science 73:67.

Radke, R.J., and U. Kahl. 2002. Effects of a filter-feeding fish [silver carp, *Hypophthalmichthys molitrix (Val.)*] on phyto- and zooplankton in a mesotrophic reservoir: results from an enclosure experiment. Freshwater Biology 47:2337-2344.

Reed, B.C., W.E. Kelso, and D.A. Rutherford. 1992. Growth, fecundity, and mortality of paddlefish in Louisiana. Transactions of the American Fisheries Society 12:378-384.

Rosen, R.A., D.G. Hales, and D.G. Unkenholz. 1982. Biology and exploitation of paddlefish in the Missouri River below Gavins Point Dam. Transactions of the American Fisheries Society 111:216-222.

Ruelle, R., and P.L. Hudson. 1977. Paddlefish (*Polyodon spathula*): growth and food of young of the year and a suggested method for measuring length. Transactions of the American Fisheries Society 106: 609-613.

Runstrom, A.L., Vondracek, B., and C.A. Jennings. 2001. Population statistics for paddlefish in the Wisconsin River. Transaction of the American Fisheries Society 130:546-556.

Scarnecchia, D.L., P.A. Stewart, and G.J. Power. 1996. Age structure of the Yellowstone-Sakakawea paddlefish stock, 1963-1993, in relation to reservoir history. Transactions of the American Fisheries Society 125: 291-299.

Scarnecchia, D.L., L.F. Ryckman, Y. Lim, G.J. Power, B.J. Schmitz and J.A. Firehammer. 2007. Life history and the costs of reproduction in Northern Great Plains paddlefish (*Polyodon spathula*) as a potential framework for other Acipenseriform fishes. Reviews in Fisheries Science 15: 211-263.

Scarnecchia, D.L., B.D. Gordon, J.D. Schooley, L.F. Ryckman, B.J. Schmitz, S.E. Miller, and Y. Lim. 2011. Southerna and northern great plains (United States) paddlefish stocks within frameworks of Acipenseriform life history and the metabolic theory of ecology. Reviews in Fisheries Science 19:278-298.

Scholten G.D., and P.W. Bettoli. 2005. Population characteristics and assessment of overfishing for an exploited paddlefish population in the lower Tennessee River. Transactions of the American Fisheries Society 134:1285-1298.

Schooley, J.D., D.L. Scarnecchia, and A. Crews. *In press*. Population Trends and Regulatory Options for Oklahoma's Grand Lake Stock of Paddlefish *Polyodon spathula*. Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies.

Schrank, S., C. Guy, and J. Fairchild. 2003. Competitive interactions between age-0 bighead carp and paddlefish. Transactions of the American Fisheries Society 132:1222-1228.

Van Den Avyle, M.J and R.S. Hayward. 1999. Dynamics of exploited fish populations. Pages 127-163 *in* C.C. Kohler and W.A. Hubert, editors. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.

Woods, A.J., J.M. Omernik, D.R. Butler, J.G. Ford, J.E. Henley, B.W. Hoagland, D.S. Arndt, and B.C. Moran 2005. Ecoregions of Oklahoma (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,250,000).

Table 1. Number of sample sites, number of fish caught, and CPUE (mean and standard deviation) for winter paddlefish gill netting on Grand and Keystone reservoirs, Oklahoma from 2010 and 2011.

Variable	2010		2011	
	Grand	Keystone	Grand	Keystone
Sample sites	24	24	24	24
Fish caught	220	224	193	299
CPUE (Mean)	30.23	28.52	26.00	37.63
CPUE (SD)	52.42	22.84	35.75	20.63

Table 2. Mean relative weights (Wr) of male and female paddlefish from Grand and Keystone reservoirs, Oklahoma, from 2010 and 2011.

Reservoir	2010		2011	
	Male	Female	Male	Female
Grand	91.58*	92.40*	92.33*	90.50*
Keystone	103.10*	102.90*	106.20*	101.70*

*$P < 0.01$ (t-test between reservoirs for each year and sex separately)

Figure 1. Locations of Grand Lake 'O the Cherokees and Keystone Lake in northeast Oklahoma where differences in paddlefish populations were assessed in 2010 and 2011.

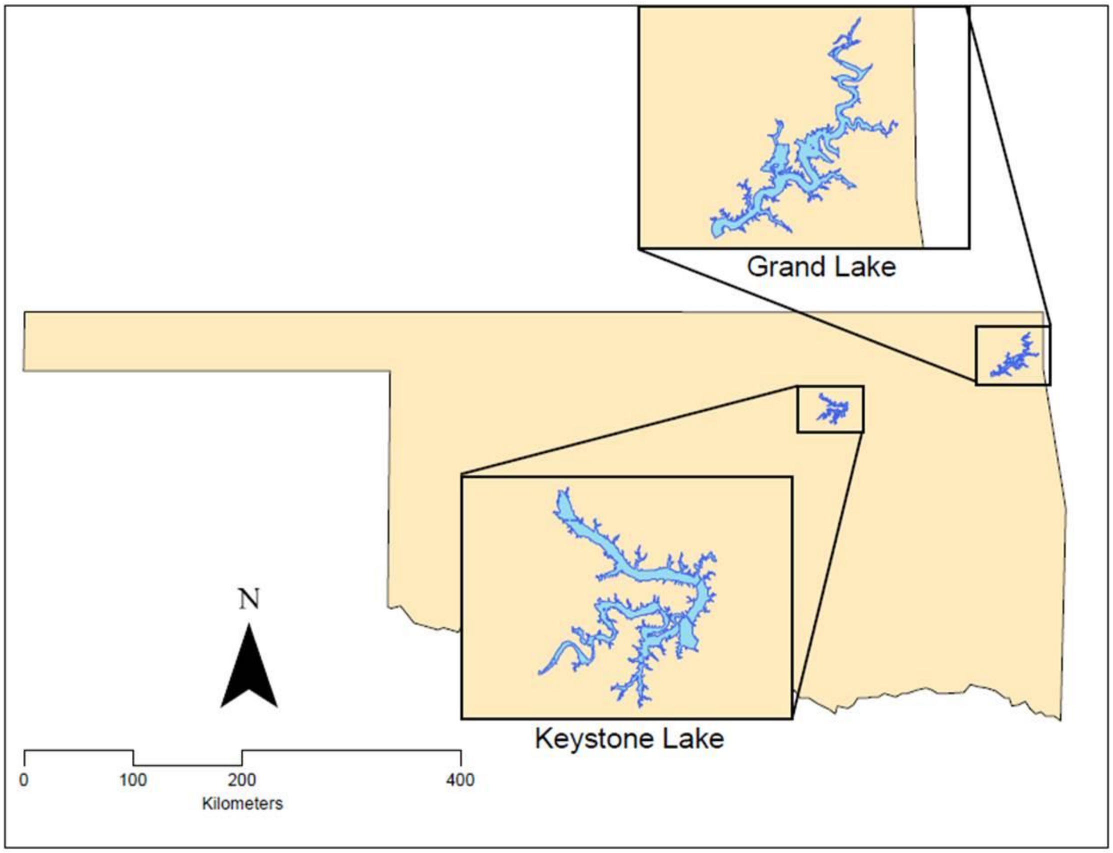
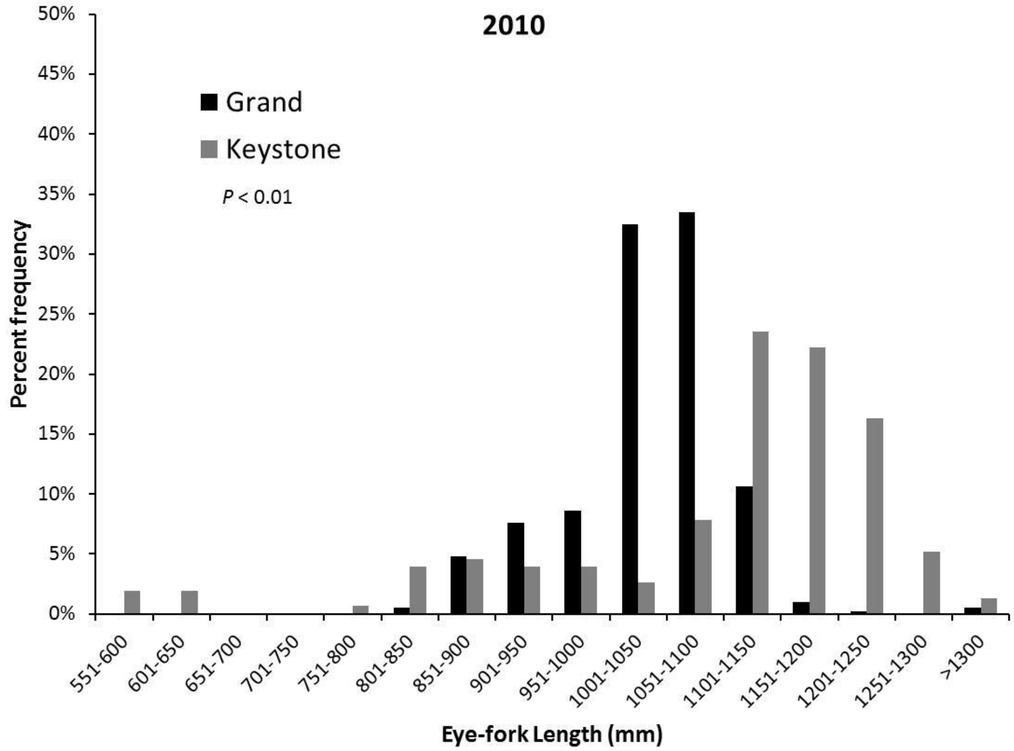


Figure 2. Length frequencies for female paddlefish from Grand and Keystone reservoirs obtained during 2010 and 2011 winter gill netting. Length frequencies were compared using a Kolmogorov-Smirnov test.



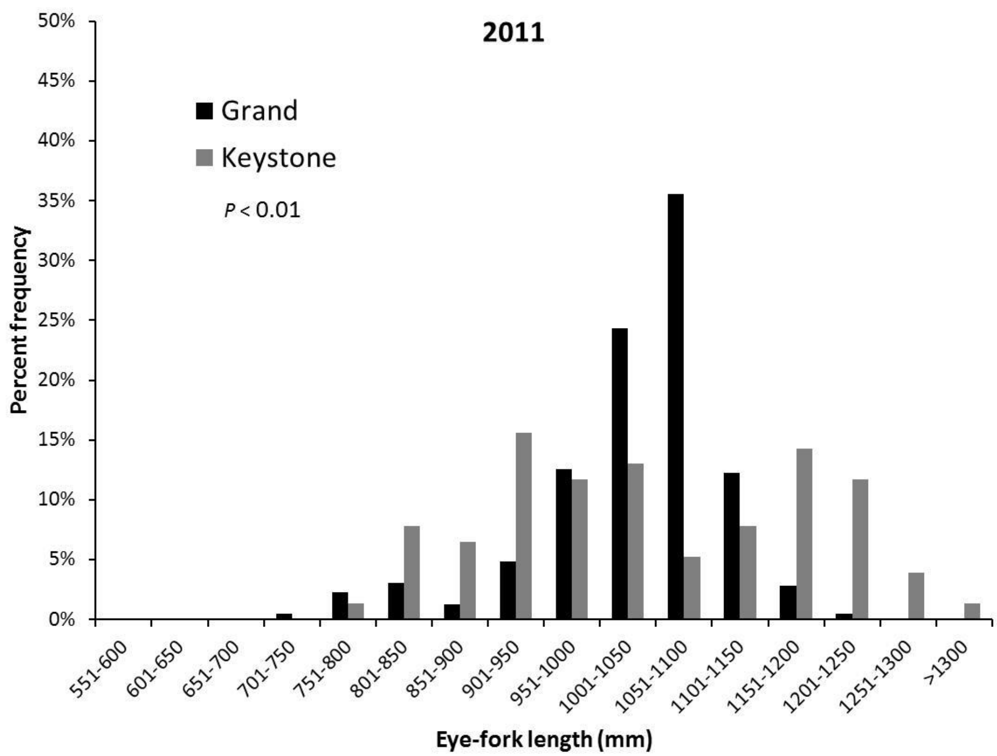
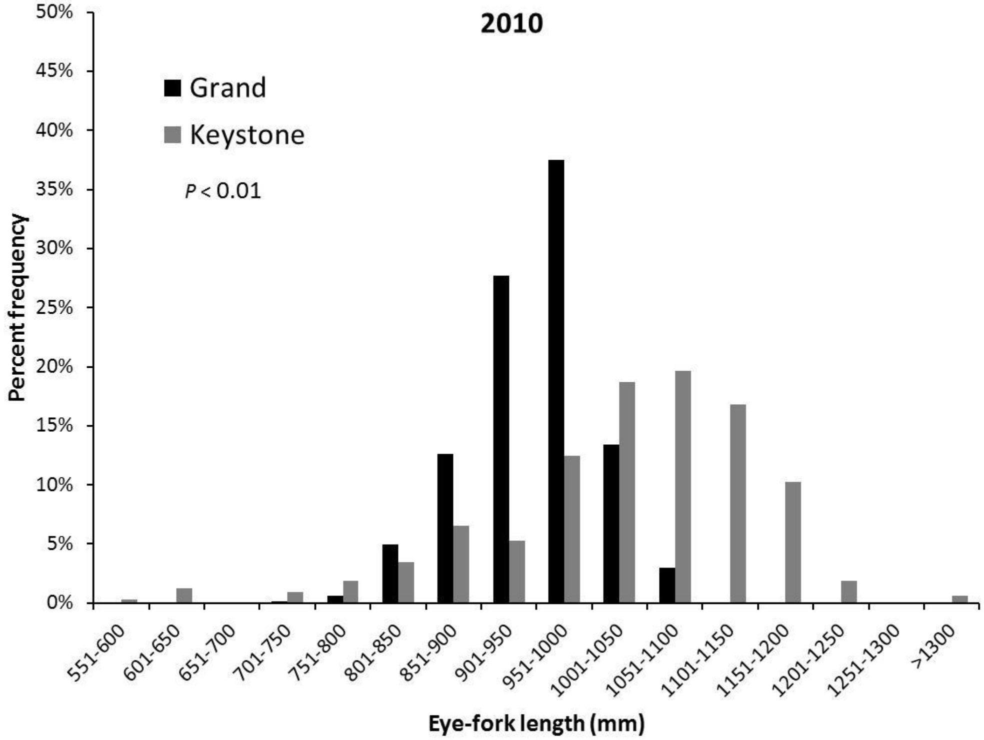


Figure 3. Length frequencies for male paddlefish from Grand and Keystone reservoirs obtained during 2010 and 2011 winter gill netting. Length frequencies were compared using a Kolmogorov-Smirnov test.



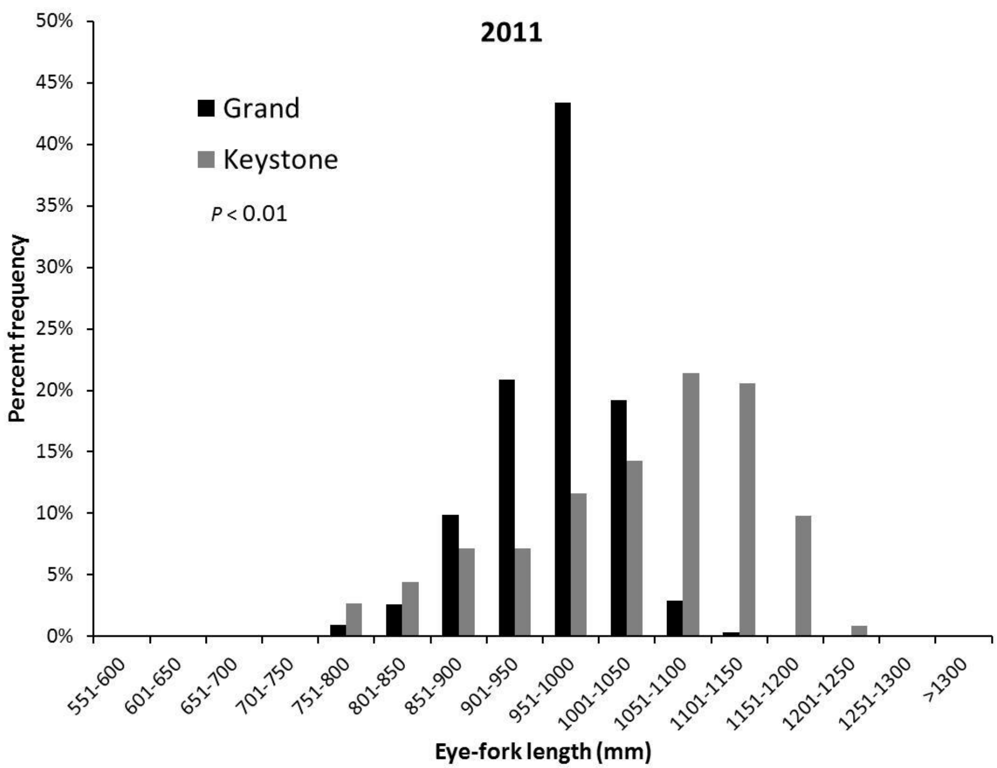


Figure 4. Mean length-at-age for female paddlefish from Grand and Keystone Reservoirs, Oklahoma from 2011. Error bars are 1 SD around the mean and numbers above error bars denote number of fish assigned that age.

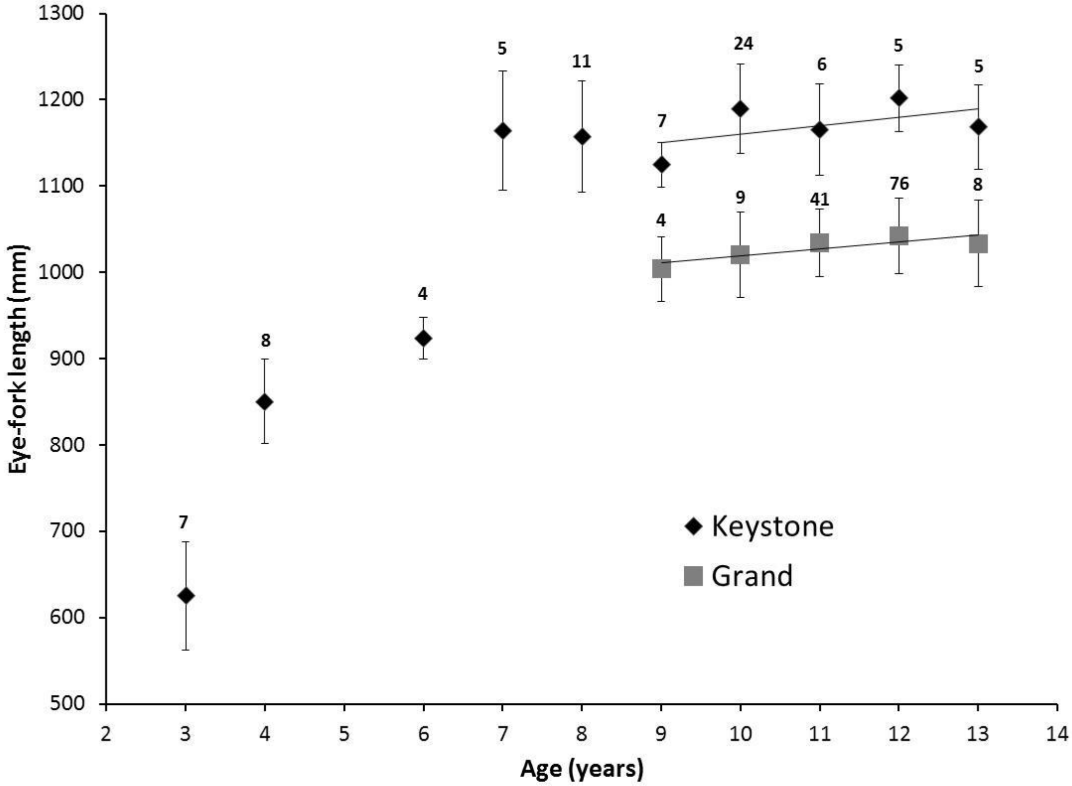


Figure 5. Mean length-at-age for male paddlefish from Grand and Keystone Reservoirs, Oklahoma from 2011. Error bars are 1 SD around the mean and numbers above error bars denote number of fish assigned that age.

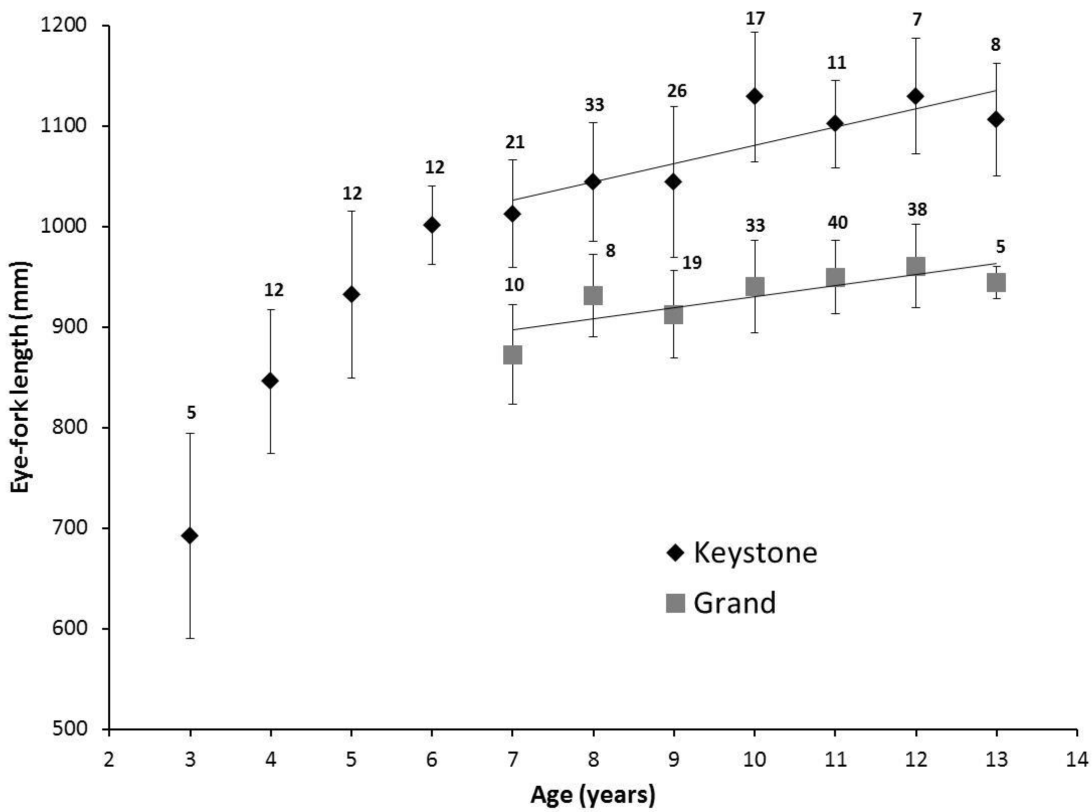


Figure 6. Age bias graphs for paddlefish age estimates from Keystone Reservoir (2011) between all pair-wise combinations of three readers. Solid line indicates 1:1 agreement in age estimates between the two readers (*X* axis and *Y* axis) being compared. Error bars are 1 SD around the mean age assigned by reader *Y* for every fish assigned an age by reader *X*.

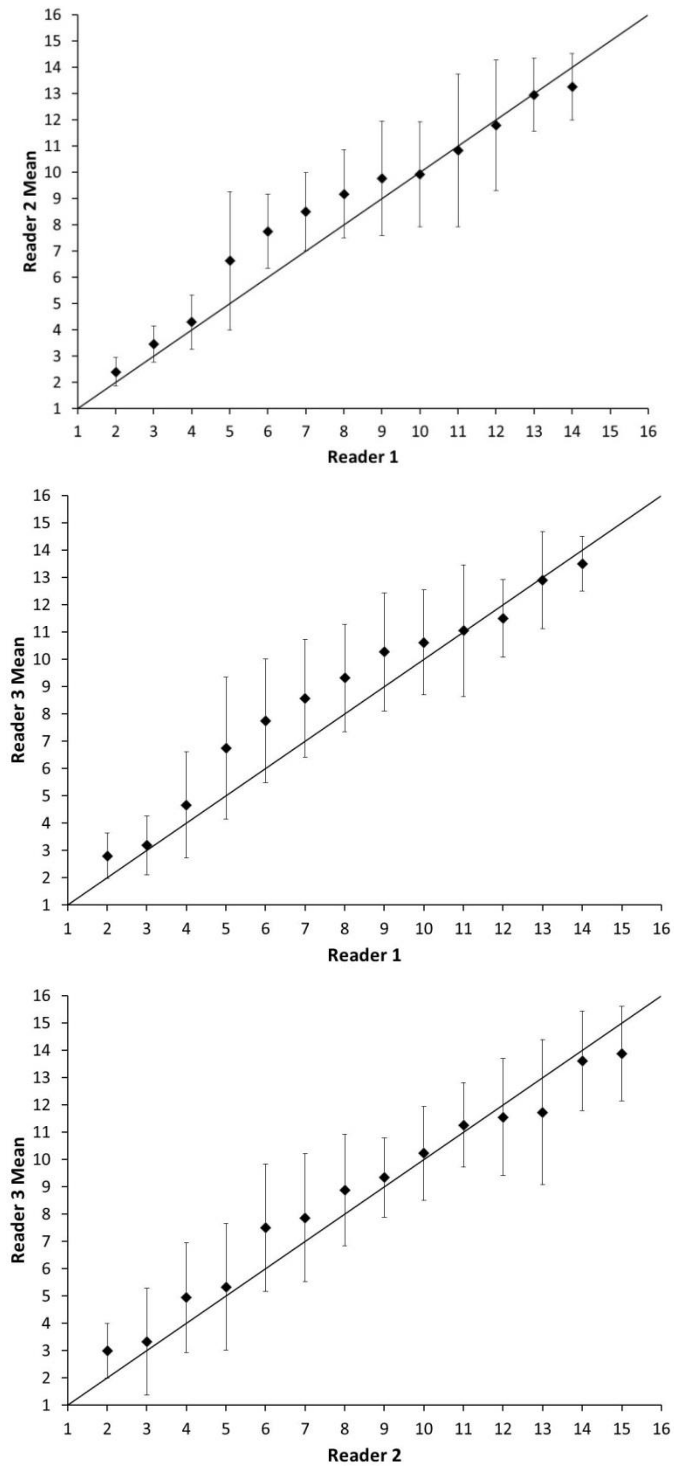


Figure 7. Age bias graphs for paddlefish age estimates from Grand Lake (2011) between all pair-wise combinations of three readers. Solid line indicates 1:1 agreement in age estimates between the two readers (*X* axis and *Y* axis) being compared. Error bars are 1 SD around the mean age assigned by reader *Y* for every fish assigned an age by reader *X*.

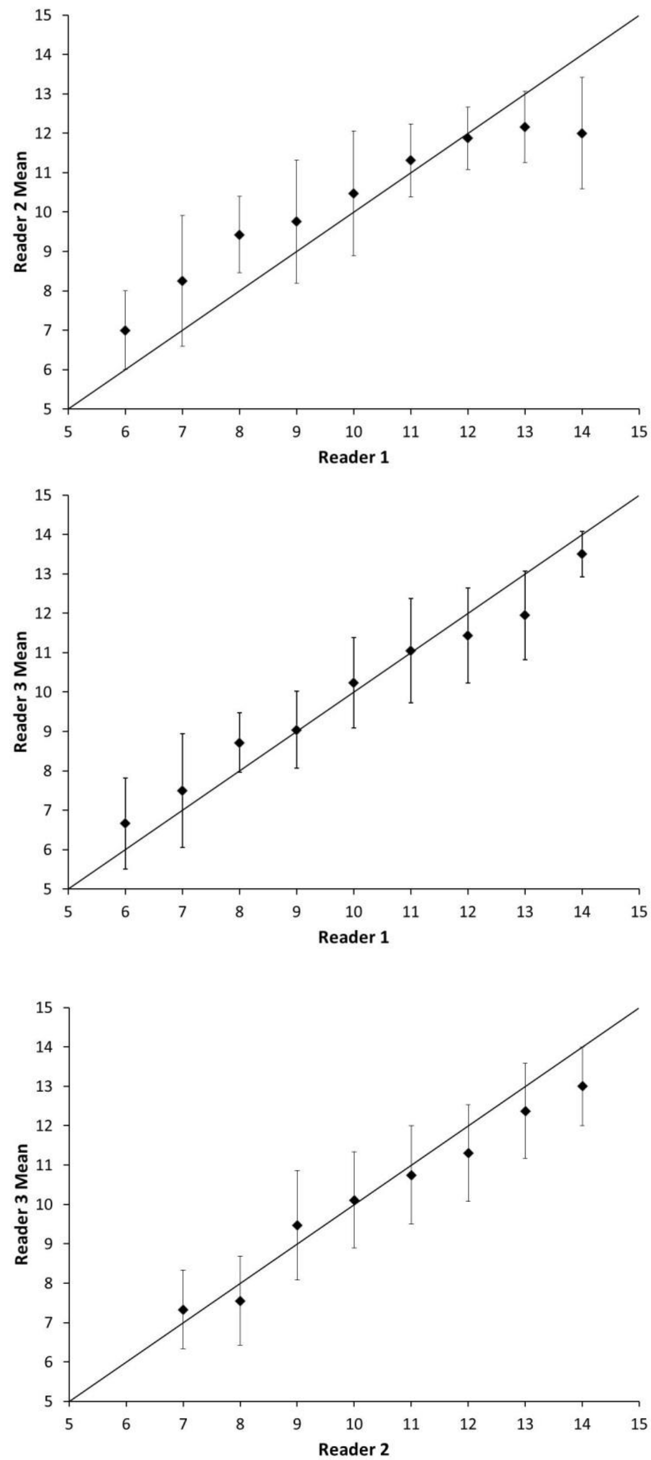


Figure 8. Age bias graphs for paddlefish age estimates from Grand Lake (2011) between A. Nealis and the University of Idaho. Solid line indicates 1:1 agreement in age estimates between the two labs (*X* axis and *Y* axis) being compared. Error bars are 1 SD around the mean age assigned by lab *Y* for every fish assigned an age by lab *X*.

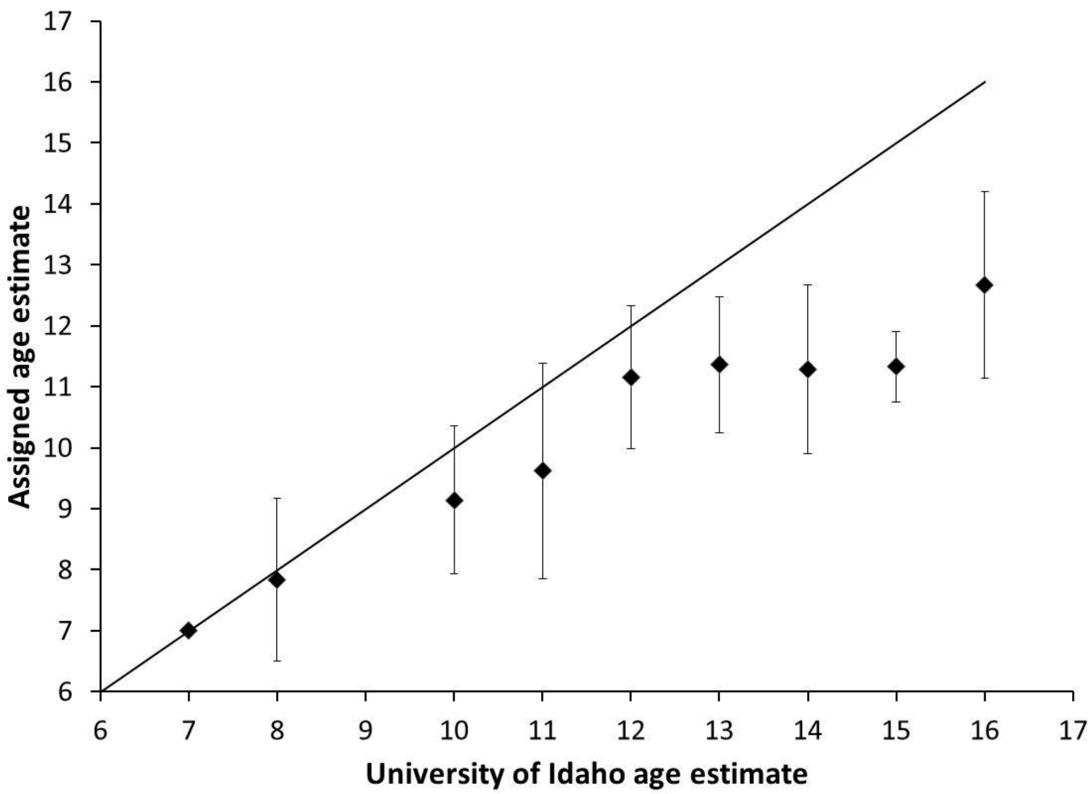


Figure 9. Gonadosomatic index (mean and standard error range) versus age ($n \geq 4$) for female paddlefish 2011 in Grand and Keystone reservoirs.

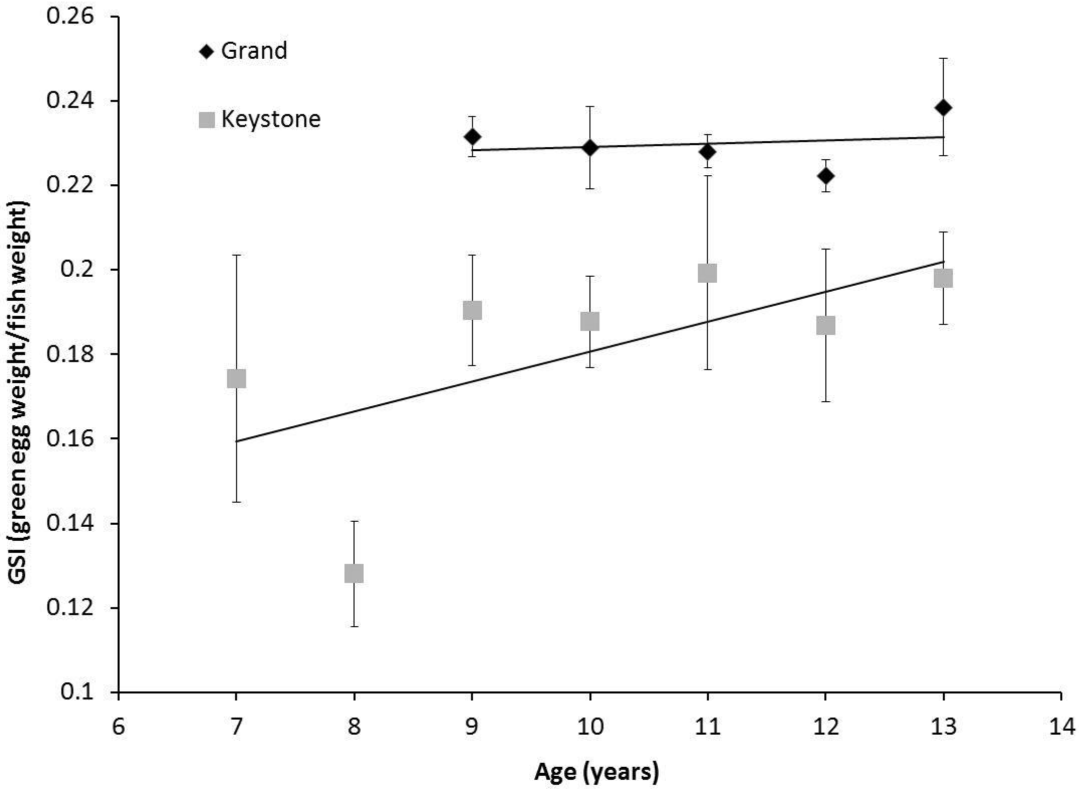


Figure 10. Ratio of gonadal fat body (GFB) weight to total fish weight (mean and standard error range) versus age ($n \geq 4$) for female paddlefish 2011 in Grand and Keystone reservoirs.

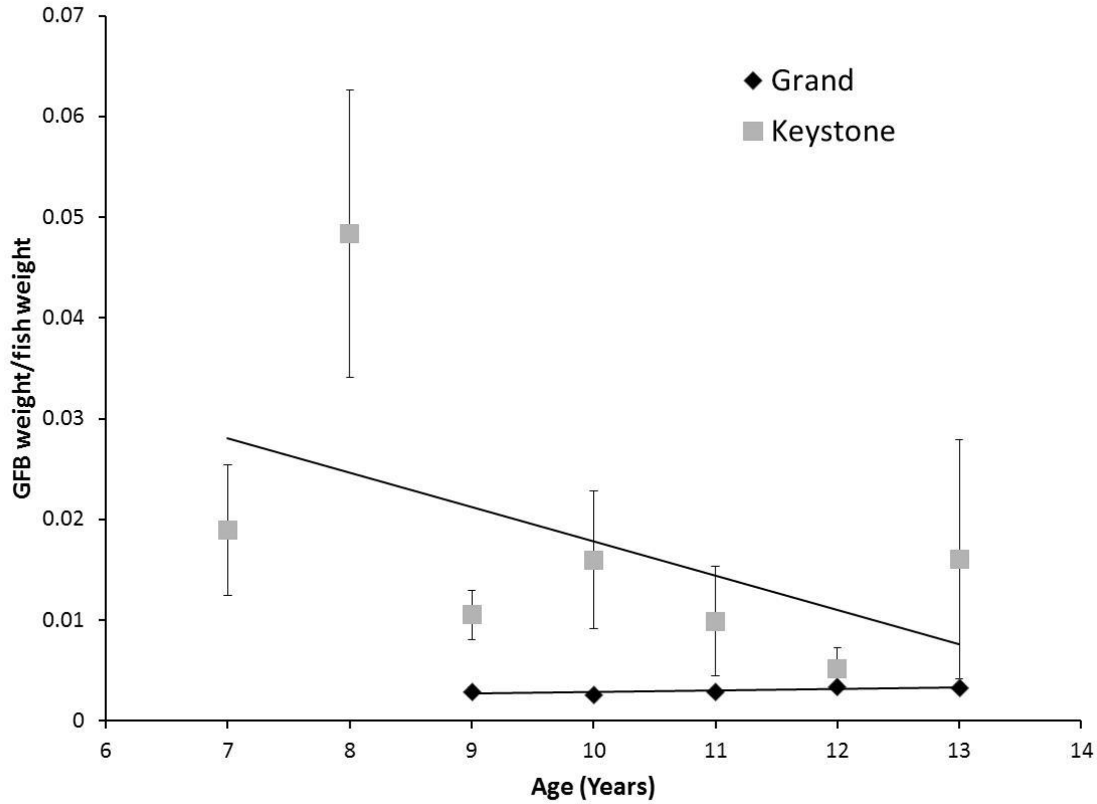


Figure 11. Gonadosomatic index (mean and standard error range) versus age (7-13 only) for male paddlefish 2011 in Grand and Keystone reservoirs.

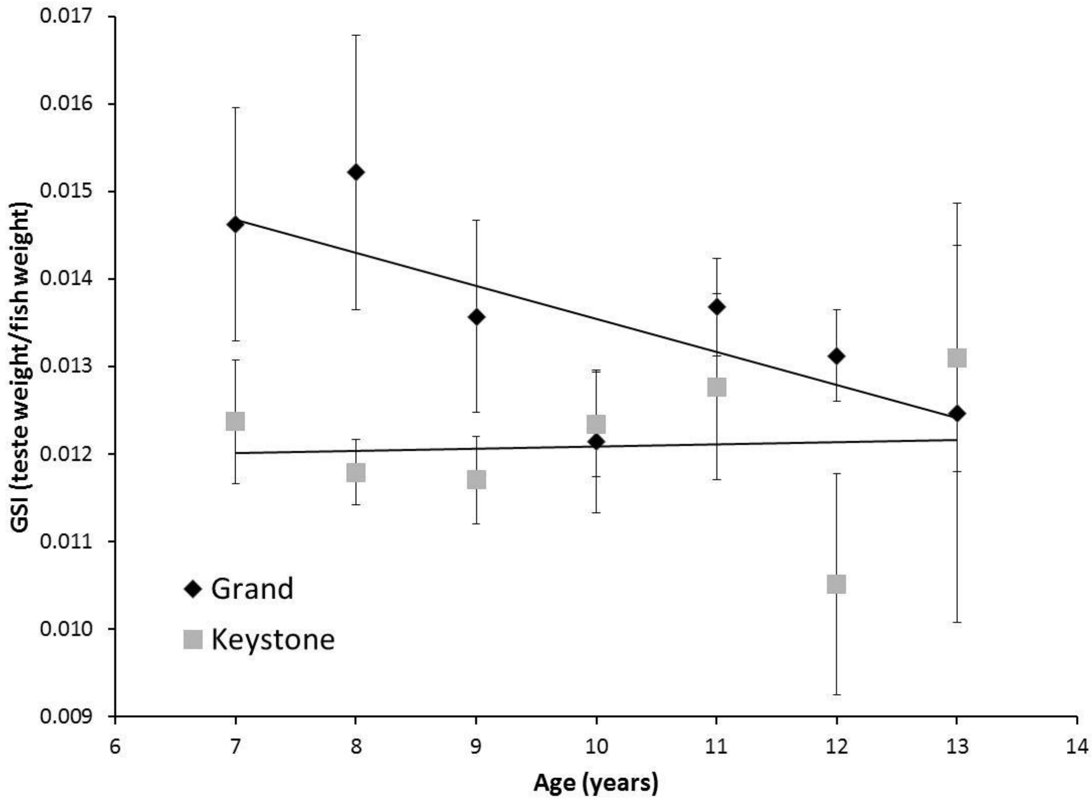
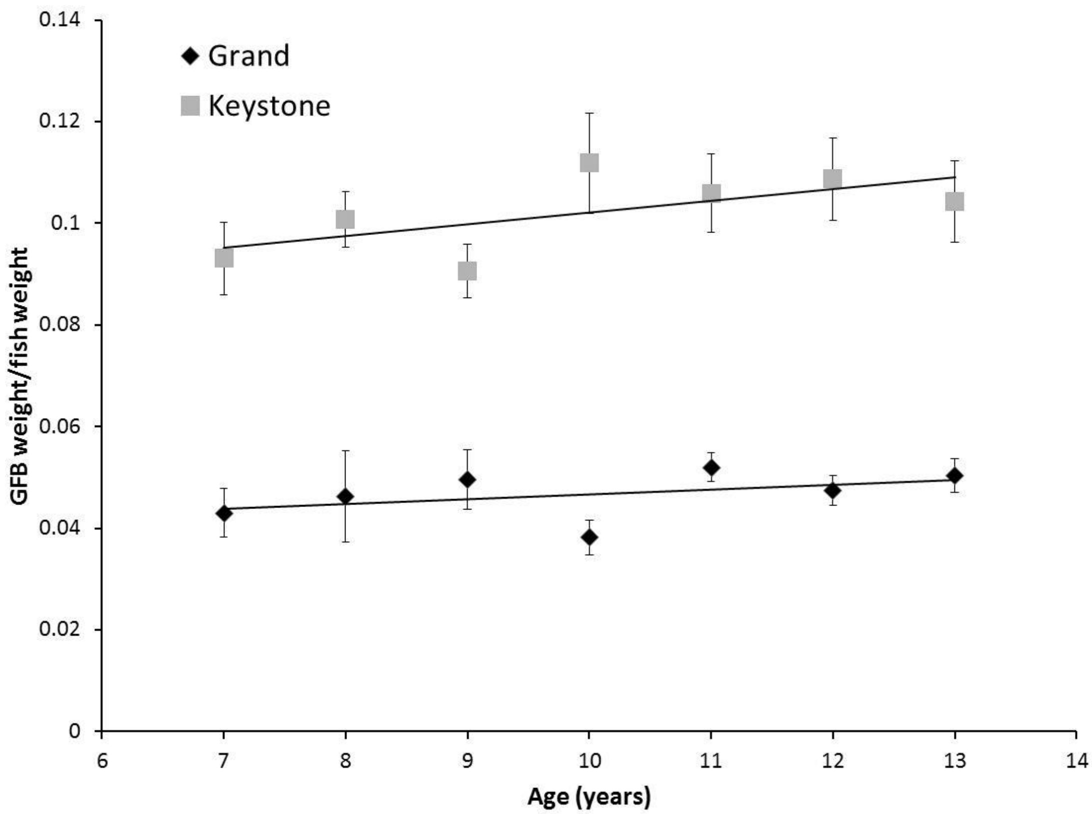


Figure 12. Ratio of gonadal fat body (GFB) weight to total fish weight (mean and standard error range) versus age (7-13 only) for male paddlefish 2011 in Grand and Keystone reservoirs.



VITA

Ashley Ann Nealis

Candidate for the Degree of

Master of Science

Thesis: CHARACTERISTICS OF TWO SELF-SUSTAINING POPULATIONS OF PADDLEFISH IN NORTHEAST OKLAHOMA

Major Field: Natural Resource Ecology and Management

Biographical:

Education:

Completed the requirements for the Master of Science in Natural Resource Ecology and Management at Oklahoma State University, Stillwater, Oklahoma in December, 2013.

Completed the requirements for the Bachelor of Science in Wildlife and Fisheries Ecology at Oklahoma State University, Stillwater, Oklahoma in 2006.

Experience:

Fisheries Biologist, Northeast Region, Oklahoma Department of Wildlife Conservation, October 2008 – Present

Program Coordinator, Aquatic Nuisance Species, Oklahoma Department of Wildlife Conservation, January 2008 – October 2008

Research Technician, Oklahoma Cooperative Fish and Wildlife Research Unit January 2006 – October 2007

Fisheries Intern, Streams Division, Oklahoma Department of Wildlife Conservation, May 2006 - August 2006

Professional Memberships:

American Fisheries Society

Oklahoma Chapter of the American Fisheries Society