2015

Evaluation of Age, Growth and Diet of Channel Catfish (Ictalurus punctatus) in Cheat Lake, West Virginia

Corbin D. Hilling

Evaluation of Age, Growth and Diet of Channel Catfish (*Ictalurus punctatus*) in Cheat Lake, West Virginia

Corbin D. Hilling

A thesis submitted to the
Davis College of Agriculture, Natural Resources, and Design
at West Virginia University

in partial fulfillment of the requirements for the degree of

Master of Science
in
Wildlife and Fisheries Resources

Stuart A. Welsh, Ph.D., Chair
George T. Merovich Jr., Ph.D.
David I. Wellman, M.S.

School of Natural Resources

Morgantown, WV

2015

Keywords: *Ictalurus punctatus*, age, growth, diet, Cheat Lake, West Virginia, hydropower reservoir

ABSTRACT

Evaluation of Age, Growth and Diet of Channel Catfish (*Ictalurus punctatus*) in Cheat Lake, West Virginia

Corbin D. Hilling

This thesis describes population characteristics of Channel Catfish (*Ictalurus punctatus*) in Cheat Lake, West Virginia in two chapters. The first chapter is comprised of a literature review on the ecology, diet and growth of Channel Catfish, as well as the influence of water level fluctuations on biota. The second chapter examines the age, growth and fall diet of Channel Catfish in Cheat Lake, West Virginia. Acidification has historically impaired Cheat Lake's fish community, but recent mitigation efforts within the Cheat River watershed have improved water quality and species richness. Presently, Channel Catfish are abundant and attain desirable sizes for anglers. I evaluated the age, growth and fall diet of the population. A sample of 155 Channel Catfish was collected from Cheat Lake from 5 August to 4 December 2014, a subsample of which was aged (n = 148) using lapillus otoliths. Four growth models (von Bertalanffy, logistic, Gompertz and power) were fit to length at age data and compared using an information theoretic approach. Fall diets were collected from 55 fish sampled from 13 October to 4 December 2014. Total lengths of individuals in the sample ranged from 154–721 mm and ages ranged from 2–19 years. The von Bertalanffy growth model was AIC_c -selected as the best approximating model, and the power and Gompertz models also had considerable support. Diets were numerically dominated by Diptera larvae, specifically Chironomidae and Chaoboridae, while 39% of stomachs contained terrestrial prey items. This study provides baseline data for management of Cheat Lake's Channel Catfish population. Further, this study fills a knowledge gap in the scientific literature on Channel Catfish, as few studies have examined the population ecology of Channel Catfish in the Central Appalachian region.

Acknowledgments

I would like to thank my graduate advisor Dr. Stuart Welsh for introducing me to fisheries science as an undergraduate and allowing me to pursue a master's degree at West Virginia University. I would also like to thank my graduate research committee members Dr. George Merovich and Dave Wellman for their contributions to this project and all the guidance they have provided. I am extremely gracious for the contributions of Dustin Smith to this project. He spent countless hours assisting with field and lab work and was a tremendous asset in completion of my project. My gratitude goes to Dr. Patricia Mazik and Becky Nestor for their administrative support. I would like to thank Joni Aldinger, Eric Miller, Austin Rizzo and Patricia Thompson for assistance with various aspects of my research. I would also like to thank all our technicians whom provided assistance in fish collections. A special thank you goes out to Nate Taylor and Brandon Keplinger for providing invaluable advice and guidance.

I would especially like thank my family for their unending support. I would like to thank my parents David and Sadie Hilling for their support and encouragement. To my wife, Lindsey, thank you for all your support and patience during the continuation of my education.

I would like the thank West Virginia University Division of Forestry and Natural Resources and USGS Cooperative Fish and Wildlife Research Unit for allowing me to use their laboratory and equipment to complete my objectives. I would also like to thank West Virginia Division of Natural Resources and LS Power Development, LLC, for providing financial support. This study was conducted under the auspices of WVU-ACUC protocol #10-040

Table of Contents

Acknowledgements……………………………………………………………………..…….iii

Table of Contents……………………………………………………………………..…...iv

List of Tables……………………………………………………………………………...v

List of Figures……………………………………………………………………………vi

Chapter 1: Literature Review…………………………………………………………...1

Ictalurus punctatus…………………………………………………………………...1

Channel Catfish Diet…………………………………………………………………4

Growth…………………………………………………………………………………6

Study Area……………………………………………………………………………..8

Hydropower Restrictions……………………………………………………………9

Water Level Fluctuations…………………………………………………………...10

Summary……………………………………………………………………………12

Literature Cited……………………………………………………………………..13

Chapter 2: Evaluation of Age, Growth and Fall Diets of Channel Catfish in Cheat Lake, West Virginia……………………………………………………………………………...…25

Abstract……………………………………………………………………………..25

Introduction…………………………………………………………………………26

Study Area…………………………………………………………………………….26

Methods……………………………………………………………………………….27

Fish Collection……………………………………………………………..27

Specimen Processing……………………………………………………….29

Analyses…………………………………………………………………….30

Results………………………………………………………………………………35

Discussion…………………………………………………………………………..39

Management Implications…………………………………………………………..43

Literature Cited……………………………………………………………………..45

List of Tables

Table 1. Mean relative weights (W_r) of Cheat Lake Channel Catfish (n = 155). W_r is summarized by Gabelhouse (1984) length categories, where length was measured as total length (TL) in millimeters. Percentile values were determined from Brown et al. (1995) using distributions of W_r by length category. NA indicates an insufficient sample size for calculation……………….54

Table 2. Results of model selection for four candidate growth models for 148 Channel Catfish from Cheat Lake, West Virginia………………………………………………………………...55

Table 3. Parameter estimates from fitting of four candidate models to length at age data from 148 Channel Catfish from Cheat Lake, West Virginia………………………………………..55

Table 4. Results of model selection for four candidate growth models for 86 female Channel Catfish from Cheat Lake, West Virginia……………………………………………………..…..56

Table 5. Parameter estimates from fitting of four candidate models to length at age data from 86 female Channel Catfish from Cheat Lake, West Virginia……………………………………….56

Table 6. Results of model selection for four candidate growth models for 60 male Channel Catfish from Cheat Lake, West Virginia……………………………………………………...57

Table 7. Parameter estimates from fitting of four candidate models to length at age data from 60 male Channel Catfish from Cheat Lake, West Virginia…………………………………………57

Table 8. Description of Channel Catfish growth from Cheat Lake, West Virginia (n = 148). Mean RGI values and Hubert (1999) percentiles are provided to compare Cheat Lake Channel Catfish growth to populations throughout the species range. …………………………………...58

Table 9. Diet contents of 41 Channel Catfish from Cheat Lake, West Virginia collected from 13 October to 4 December 2014. Food items were quantified by percent frequency of occurrence (O_i), mean percent frequency by number (MN_i) and prey-specific abundance (P_i)...…………....59

List of Figures

Figure 1: Cheat Lake, West Virginia with general sampling locations noted…………………….60

Figure 2. Length frequency distribution of Cheat Lake, West Virginia Channel Catfish (n = 155) using 25 mm bins………………………………………………………………………………...61

Figure 3. Relationship between total length and weight of Channel Catfish from Cheat Lake, West Virginia (n = 155). A power curve was fit to the data……………………………………..62

Figure 4. Age structure of Channel Catfish (n = 148) from Cheat Lake, West Virginia………..63

Figure 5. Catch curve regression used for estimation of instantaneous mortality. Number of fish collected in each age group (Catch) was natural logarithm-transformed to linearize catch data. Line was fit to ages 3–19...64

Figure 6. Plot of residuals from catch-curve regression in Figure 5. Regression line was fit to natural logarithm-transformed catch data and natural logarithm-residuals are presented……….65

Figure 7. Four candidate growth models fit to length at age data of 148 Channel Catfish (ages 2–19) from Cheat Lake, West Virginia……………………….……………………………………66

Chapter 1: Literature Review

Ictalurus punctatus

Channel Catfish (*Ictalurus punctatus*) is an economically important species in North America due to its popularity among recreational and commercial fishermen, as well as aquaculturists. Channel Catfish was described in 1818 by Samuel Rafinesque and is a member of the family of North American catfishes, Ictaluridae. Fishes within the family Ictaluridae are characterized by the presence of an adipose fin, four pairs of barbels, dorsal and pectoral spines, abdominal pelvic fins and an absence of scales (Etnier and Starnes 1993, Page and Burr 2011). In addition to these characters, Channel Catfish specifically have a deeply forked caudal fin with 15–18 rays, a rounded anal fin with 24–32 rays (generally 24–27) and often spotted sides (Etnier and Starnes 1993, Page and Burr 2011). The rounded anal fin can be used to distinguish Channel Catfish from Blue Catfish (*Ictalurus furcatus*) whose anal fin has a straight edge (Etnier and Starnes 1993, Page and Burr 2011). The dorsum and sides of Channel Catfish are blue, gray or olive in color, while the ventral surface of the fish is white to yellow. Median fins of small individuals often have a dark border (Page and Burr 2011).

Channel Catfish is a warm water species native to the central drainages of North America from the Saskatchewan River and Great Lakes to the Gulf of Mexico (Etnier and Starnes 1993, Wolters and Avery 2011). Due to its extreme popularity as both sport and table fare, the Channel Catfish has been widely introduced and can be found across North America (Etnier and Starnes 1993). The Channel Catfish typically inhabits medium to large rivers, but also occurs in small streams, natural lakes, reservoirs and farm ponds (Etnier and Starnes 1993).

Channel catfish spawning generally occurs once annually during late spring and early summer, when water temperatures reach the range of 21 to 29°C, with about 26°C being optimal

(Clemens and Sneed 1957, Busch 1985, Etnier and Starnes 1993, Hubert 1999). Temperatures exceeding 29°C result in adverse effects on egg development and reduced fry survival (Busch 1985). Spawning sites feature the cover of ledges, woody debris, man-made structures such as barrels or tires and cavities in the bank (Busch 1985, Etnier and Starnes 1993). Males clear mud and debris from the spawning site and defend the resulting nest from other males (Busch 1985, Hubert 1999). Clemens and Sneed (1957) noted largest Channel Catfish spawned first, while smaller individuals spawned later in the spawning season. After spawning, the male chases the female from the nest, guards it and cares for the young (Busch 1985, Etnier and Starnes 1993, Hubert 1999).

Habitat use of post-larval Channel Catfish is not well understood (Hubert 1999). Holland (1986) noted that Channel Catfish are speleophils and are rarely collected at early life stages, likely due to seclusion of spawning sites. Post-larval Channel Catfish have been found drifting with currents, primarily at night (Armstrong and Brown 1983, Floyd et al. 1984, Muth and Schlumbach 1984, Holland-Bartels and Duval 1988, Brewer and Rabeni 2003). Armstrong and Brown (1983) suggested post-larval drift to be related to feeding patterns, not selection of habitat (Hubert 1999).

In Channel Catfish, habitat use in the juvenile stage is better understood than the post-larval stage. In a fifth order prairie stream, juvenile Channel Catfish were most densely distributed in riffles and woody habitats (Braaten and Berry 1997). In larger rivers, juvenile Channel Catfish were found to be common in main channels and main channel borders in the lower half of the water column of the Upper Mississippi River (Helms 1975, Holland-Bartels and Duval 1988). However, Phelps et al. (2011) found main channel habitat use to be infrequent, but use of channel borders, islands and artificial structures was common. Phelps et al. (2011) also noted congregations in shallow areas with sandy substrate and low velocities. Irwin et al. (1999) found diel habitat shifts in age-0 Channel Catfish where fish occupied main channel habitats during the day and shallow, slow habitats at night. Seasonal changes in habitat use have also been noted. Brewer and Rabeni (2008) found that juveniles selected low velocities in summer and switched to deep water, fine substrate habitat in autumn. Irwin et al. (1999) also found evidence of ontogenetic habitat shifts during the first year of life, but this could be related to seasonal habitat changes (Brewer and Rabeni 2008).

Adult Channel Catfish appear to be generalists with respect to habitat. Driscoll et al. (1999) found no preference for habitat or channel type in the Lower Mississippi River. However, high abundances in main channel habitats have been observed (Gido and Propst 1999, Jackson and Jackson 1999). Use of shallow habitats has also been documented (Fischer et al. 1999, Butler and Wahl 2011), as well as selection of low velocity waters (Kelsch and Wendel 2003, Butler and Wahl 2011). Jolley and Irwin (2011) found no differences in habitat use of reservoirs and tailwaters of the Coosa River, Alabama. A study on habitat alteration in the Kansas River found no differences in catch rates as a result of sand dredging (Fischer et al. 2012). Substrata of intermediate particle size (2–255 mm) were selected for in the Fox River, however, fine substrates were used most frequently, but not in excess of their availability (Butler and Wahl 2011). Butler and Wahl (2011) noted radio-tagged fish were infrequently near cover; but preferred woody cover to boulders when used. In contrast, other studies provided evidence of extensive use of cover (Fischer et al. 1999, Kelsch and Wendel 2003). McMahon and Terrell (1982) suggested both riverine and lacustrine habitats with abundant cover would be most suitable for Channel Catfish.

Seasonal changes in habitat use of adult Channel Catfish have been noted in the literature. Seasonal movement events from flowing areas in the fall to impounded, lentic overwintering areas have been observed (Butler and Wahl 2011). Other studies documented upstream movements during spring or summer and downstream fall movements to deeper overwintering areas or to larger rivers (Dames et al. 1989, Pellett et al. 1998, Fago 1999). A telemetry study in a Missouri small impoundment also found seasonal differences in distribution (Fischer et al. 1999). Fischer et al. (1999) found Channel Catfish occupied a large range during spring, were confined to the shallower areas of the impoundment in the summer and used a restricted range during the winter.

Channel Catfish Diet

Channel Catfish have been characterized in the literature as omnivores, consuming a wide variety of prey items, including vegetative, animal and detrital materials (Bailey and Harrison 1948, Perry 1969, Marsh 1981, Edds et al. 2002, Dagel et al. 2010). Filamentous algae has been observed in Channel Catfish diets in multiple populations (Perry 1969, Griswold and Tubb 1977, Marsh 1981, Michaletz 2006). In addition to algae, several studies found use of various plant materials, such as aquatic vegetation, seeds, seed pods and acorns (Bailey and Harrison 1948, Perry 1969, Crumpton 1999, Edds et al. 2002, Dagel et al. 2010). Channel Catfish have also been observed to consume large numbers of invertebrates, including both aquatic and terrestrial insects, crustaceans and mollusks (Bailey and Harrison 1948, Perry 1969, Jearld and Brown 1971, Lewis 1976, Griswold and Tubb 1977, Weisberg and Janicki 1990, Crumpton 1999, Edds et al. 2002, Michaletz 2006, Dagel et al. 2010). Vertebrates are also common diet items. Fishes are the most common vertebrate in diet studies, but amphibians, reptiles, birds and mammals have also been represented in Channel Catfish diets (Bailey and

Harrison 1948, Perry 1969, Jearld and Brown 1971, Griswold and Tubb 1977, Hill et al. 1995, Edds et al. 2002, Dagel et al. 2010). Also, detritus and sediment are frequently observed in Channel Catfish stomach contents (Perry 1969, Lewis 1976, Crumpton 1999, Dagel et al. 2010). Crumpton (1999) found 64% of the diet by weight was detritus in individuals from the Clermont Chain of Lakes, Florida.

Channel Catfish exhibit an ontogenetic diet shift. Walburg (1975) reported post-larvae (15–20 mm) mainly consumed zooplankton (*Daphnia* and *Diaptomus*) and small aquatic insects in a Missouri River reservoir. A study in a lotic system found small Chironomidae larvae and pupae comprised the majority of the diet of Channel Catfish alevins (standard length = 14–16 mm) (Armstrong and Brown 1983). As Channel Catfish grow, they continue to rely heavily on aquatic insects until they reach approximately 300 mm, when fish and other prey items are incorporated more heavily into the diet (Bailey and Harrison 1948, Jearld and Brown 1971, Edds et al. 2002). The size at which diets diversify has varied in other food habit studies from 376–400 mm (Perry 1969, Michaletz 2006). Ontogenetic diet shift may result from changes in gape limitation as mouth size increases with somatic growth (Easton and Orth 1992, Tabor et al. 2007, Duffy et al. 2010). The magnitude of the ontogenetic shift may be related to a large change in stomach capacity as Channel Catfish grow (Gosch et al. 2009).

Channel catfish are dietary generalists, consuming food items in proportion to their availability (Hubert 1999). As generalists, Channel Catfish feed opportunistically on seasonally or locally available food items. Bailey and Harrison (1948) reported that use of food items of terrestrial origin varied seasonally as they were available, including wild grapes, American elm seeds and flying insects. Channel catfish also consume food items that rapidly become available due to environmental changes. Lewis (1976) suggested large numbers of insects in Channel

Catfish diets were related to displacement by a 12.5 m rise in lake elevation in Bluestone Lake, West Virginia.

Channel Catfish feeding occurs primarily between dusk and dawn (Armstrong and Brown 1983, Weisberg and Janicki 1990). Weisberg and Janicki (1990) found Channel Catfish stomachs contained significantly more food items at night than during the day. In addition to diel patterns in feeding, foraging rates vary with temperature. Bailey and Harrison (1948) reported Channel Catfish feed consistently from 10-35°C. However, feeding may slow precipitously below 10°C (Hubert 1999). Clady (1981) noted Channel Catfish feeding was reduced between 11–21°C in aquaculture pens. Channel Catfish are believed to feed primarily on benthos as prey items were correlated with benthic communities as opposed to drift (Weisberg and Janicki 1990). Bailey and Harrison (1948) suggested that feeding likely subsides temporarily during spawning.

Growth

Somatic growth (growth hereafter) is an important aspect of fish ecology as survivorship and fitness can vary with body size. As fish grow, their susceptibility to predation is reduced as they reach a size refuge, becoming unavailable to certain predators (Perrson et al. 1996). Reduced gape limitation as a fish grows larger allows for inclusion of larger prey items in diets (Mittlebach and Perrson 1988 , Easton and Orth 1992, Tabor et al. 2007).

Overwinter mortality has also been found to be size dependent (Post et al. 1998, Hurst and Conover 1998, Schultz et al. 1998, Garvey et al. 2004). Fast growth can improve lifetime reproductive success, as large fish often have greater fecundity than small fish (Nitschke et al. 2001). Larger fish may also have advantages in obtaining mating opportunities in some taxa (Nelson 1995).

Numerous studies have looked at factors that influence Channel Catfish growth. Andrews and Stickney (1972) found temperature influenced growth, as growth of fingerlings was greatest at 30°C. Starostka and Nelson (1974) observed cessation of Channel Catfish growth when temperatures declined below 18°C. Bonar et al. (1997) noted lower growth rates of Channel Catfish in Washington lakes where *Lepomis spp.* and Yellow Perch (*Perca flavescens*) may compete with young Channel Catfish. Further, Bonar et al. (1997) suggested that differences in Channel Catfish growth between lakes were related to forage as individuals in lakes with crayfish and sculpins (Cottidae) exhibited greatest growth. Shoup et al. (2007) found that forage fish and icthyoplankton abundance were associated with growth, while growth was negatively associated with benthic macroinvertebrate abundance. Shoup et al. (2007) suggested benthic macroinvertebrate abundance could be negatively related to Channel Catfish growth due to their lower quality as a food source than fish.

Channel Catfish growth has been studied in much of the species' natural and introduced range and considerable variation exists in growth rates between populations (Hubert 1999). In a review of Channel Catfish growth data, Hubert (1999) noted minimum and maximum mean lengths at age 3 to be 157 mm and 429 mm, respectively. Geographic differences in growth were not evident (Hubert 1999). Bonar et al. (1997) found that growth of Channel Catfish in stocked Washington lakes was similar to growth reported in the southern and eastern United States. Rypel (2011) noted Channel Catfish growth did not correlate with climatic variables, but found a latitudinal countergradient when normalizing for mean annual temperature. In a study of 144 Texas reservoirs, Durham et al. (2005) found Channel Catfish growth was linked to growing season length, with greatest growth at intermediate lengths (~270 d). Tyus and Nikirk (1990) suggested slow growth in the Green and Yampa Rivers was related to high summer flows, suboptimal temperatures and short growing seasons. Meta-analysis of growth data from both lentic and lotic systems found growth positively correlated with lentic habitats (Rypel 2011). Shoup et al. (2007) found a positive correlation with Channel Catfish growth and littoral area in 11 Illinois reservoirs.

There have been conflicting results in the study of growth differences between sexes of Channel Catfish. Some studies have observed faster growth in males than females (Beaver et al. 1966, Simco et al. 1989). Simco et al. (1989) noted males grew 10% longer than females by 26 months of age. De Roth (1965) also saw faster growth in males once sexual maturity was reached, but noted similar growth prior to maturation. Starostka and Nelson (1974) found males grew faster for the first 6 years of life, but female lengths were greater in fish older than age 7. Other studies have found no differences in growth related to sex (Haxton and Punt 2004, Marshall et al. 2009).

Study Area: Cheat Lake, West Virginia

Cheat Lake was created in 1926 upon the completion of the Lake Lynn Hydropower Dam on the Cheat River. The Lake Lynn Dam was built approximately 30 m south of the Mason-Dixon Line, 5.6 km from the confluence of the Cheat and Monongahela Rivers in Point Marion, Pennsylvania. The lake was originally named Lake Lynn by the West Penn Power Company, but has commonly been referred to as Cheat Lake. Cheat Lake covers an area of 700.4 ha, flowing 20.9 km with a width ranging from 0.8–1.2 km (Schwartz 1991).

The Cheat River watershed has a long history of pollution, primarily due to acid mine drainage (AMD) and acid precipitation. In 1995, American Rivers ranked Cheat River as the 8th most endangered river in North America due to AMD in the lower section of the river (Williams et al. 1999). In 1998, 45 streams were on the 303(d) list from the final 60 km of the Cheat River main stem (WVDEP 1996). Welsh and Perry (1997) found fish distributions were altered by acidification in the upper portions of the Cheat River Watershed. As expected, Cheat Lake's water quality and fish assemblage reflected acidification influences. Only 14 fish species were collected in 1955, most of which were from the families Ictaluridae or Catastomidae (Core et al. 1959). Clovis (1971) found pH to be between 4.0 and 5.5 in 17 sites sampled for pH in an aquatic plant survey within Cheat Lake. Corbett (1977) found that direct tributaries to the lake carried acidic waters of pH < 3.0. Due to mitigation efforts throughout the watershed, water quality of Cheat Lake has improved. Water quality data have been collected since 2004 where Cheat River enters Cheat Lake and pH has generally remained above 6.0 (Jernejcic and Wellman 2011). Fisheries surveys from 1997 to 2009 yielded 46 different species (Jernejcic and Wellman 2011), a large improvement from the 1955 surveys that collected only 14 species (Core et al. 1959). While conditions have vastly improved, pH in the Cheat River dropped below 6.0 for nearly the entire month of May 2009 (Jernejcic and Wellman 2011), suggesting a need for continued monitoring and mitigation efforts.

Hydropower Restrictions

In 1994, the Lake Lynn Hydropower Station was due for license renewal. The Federal Energy Regulatory Commission requires that hydropower projects support fish populations. As a result, the new license required biomonitoring of the aquatic resources of Cheat Lake (Jernejcic and Wellman 2011). The Federal Energy Regulatory Commission also mandated changes to dam operation. The facility must maintain a minimum discharge of 6 m^3s^{-1} to alleviate effects of acidic tributaries downstream of the dam (Jernejcic and Wellman 2011). This minimum discharge requirement also allowed for the establishment of a tailwater fishery. The Federal Energy Regulatory Commission also imposed lake elevation regulations to promote recreation and increase fish recruitment. Lake elevation must be maintained between 264.6 and 265.2 m (above sea level) from May through October for summer recreation and to support fish spawning efforts. To allow maximum power production, the lake can fluctuate between 261.2 and 265.2 m from November through March. During April, the lake elevation fluctuates between 263.0 and 265.2 m, which may benefit Walleye (*Sander vitreus*) and Yellow Perch recruitment (Jernejcic and Wellman 2011).

Water Level Fluctuations

Aquatic organisms within reservoirs are influenced by water level fluctuations. Frequently, water management plans are in place to promote as stable of an environment as possible and can be manipulated seasonally to promote fisheries (Beam 1983, Miranda et al. 1984, Beck and Willis 1997, Maceina and Stimpert 1998, Maceina 2003). Despite regulation of water level fluctuations, biota can be impacted due to changes in habitat availability, behavior, population dynamics and aquatic communities.

Water level fluctuations have been documented to influence habitat availability for aquatic life. Gaeta et al. (2014) found lake level reductions (>1.1 m) resulted in exposure of 76% of formerly submerged course woody debris, which was subsequently unavailable to fish. Zohary and Ostrovsky (2011) also suggested excessive water level fluctuations reduce habitat complexity, reflected in changes in littoral substrate and macrophyte availability. Wilcox and Meeker (1992) observed reductions in water level reduced nursery and foraging habitat, as well as availability of macrophytes used as spawning substrate. Low water during re-vegetation season followed by high water in the nursery season seemed to promote habitat production in an Oklahoma reservoir (Fisher and Zale 1991).

Behavioral changes related to water level fluctuations have also been noted in the literature. In a lab study, Floodmark et al. (2004) found juvenile brown trout *Salmo trutta* exhibited lower consumption rates in fluctuating water levels compared to stable high water levels. Jones and Rogers (1998) noted Palmetto Bass (male White Bass *Morone chrysops* x female Striped Bass *Morone saxatilis*) used deeper areas during drawdown of a Colorado irrigation reservoir. Rogers and Bergersen (1995) found Largemouth Bass *Micropterus salmoides* movement differed in periods of drawdown and full pool in Colorado lakes. Largemouth bass used larger areas during drawdown than full pool periods (Rogers and Bergersen 1995).

Water level fluctuations could also impact population dynamics of fishes though inhibition of spawning and reduced survival of larvae and juvenile fishes. Clark et al. (2008) found water level fluctuations were correlated with nest abandonment by Smallmouth Bass *Micropterus dolomieu* and predicted decreases in egg to dispersal survival with increasing fluctuation amplitude. In Normandy Reservoir (Tennessee), Sammons et al. (1999) found survival of young of the year Largemouth Bass was negatively related to reduced water levels. Yamamoto et al. (2006) collected fewer eggs of cyprinid fishes in reed zones during low water level in a flood control lake. Gaeta et al. (2014) noted Yellow Perch numbers declined below detection and Largemouth Bass growth rates declined due to habitat losses associated with water level fluctuations.

Water level fluctuations have also been documented to impact aquatic systems at the community level. Furey et al. (2006) noted drawdown regimes resulted in differences in benthic macroinvertebrate communities. White et al. (2011) noted benthic macroinvertebrate communities were influenced by water level fluctuation amplitudes. Benthic macroinvertebrate communities between natural lakes and reservoirs were similar until amplitudes exceeded 1.5 m, while species richness declined as amplitude exceeded 2.0 m (White et al. 2011).

Summary

Most aspects of the life history of Channel Catfish have been well studied, but considerable variation exists throughout the range of the species. This literature review chapter includes information on Channel Catfish ecology, the study area for my thesis research, and water level fluctuation in hydropower reservoirs and its influence on biota. The literature review chapter is provided in support of my thesis research on population characteristics and fall diet habits of Channel Catfish in Cheat Lake, a hydropower reservoir in northern West Virginia.

Literature Cited

Andrews, J. W. and R. R. Stickney. 1972. Interactions of feeding rates and environmental temperature on growth, food conversion, and body composition of channel catfish. Transactions of the American Fisheries Society 101:94–99.

Armstrong, M. L. and A. V. Brown. 1983. Diel drift and feeding of channel catfish alevins in the Illinios River, Arkansas. Transactions of the American Fisheries Society 112:302–307.

Bailey, R. M. and H. M. Harrison, Jr. 1948. Food habits of the southern channel catfish (*Ictalurus lacustrus punctatus*) in the Des Moines River, Iowa. Transactions of the American Fisheries Society 75:110–138.

Beam, J. H. 1983. The effect of annual water level management on population trends of white crappie in Elk City Reservoir, Kansas. North American Journal of Fisheries Management 3:34–40.

Beaver, J. A., K. E. Sneed, and H. K. Dupree. 1966. The difference in growth of male and female channel catfish in hatchery ponds. The Progressive Fish–Culturist 28:47–50.

Beck, H. D. and D.W. Willis. 1997. Relations between environmental variables and age–0 white bass abundance in four Missouri River reservoirs. Journal of Freshwater Ecology 12:567–575.

Bonar, S. A., J. Pahutski, B. D. Bolding, D. Fletcher, and M. Divens. 1997. Survival and growth of channel catfish stocked in Washington lakes. North American Journal of Fisheries Management 17:773–778.

Braaten, P. J. and C. R. Berry, Jr. 1997. Fish associations with four habitat types in a South Dakota prairie stream. Journal of Freshwater Ecology 12:477–489.

Brewer, S. K. and C. F. Rabeni. 2008. Seasonal and diel habitat shifts by juvenile ictalurids in a flow-regulated prairie river. American Midland Naturalist 159:42–54.

Busch, R. L. 1985. Channel catfish culture in ponds. Pages 13–84 *in* C.S. Tucker, editor. Developments in aquaculture and fisheries science, vol. 15: Channel catfish culture. Elsevier Science Publishers, Amsterdam, Netherlands.

Butler, S. E. and D. H. Wahl. 2011. Distribution, movements and habitat use of channel catfish in a river with multiple low-head dams. River Research and Applications 27:1182–1191.

Clady, M. D. 1981. Cool–weather growth of channel catfish held in pens alone and with other species of fish. Progressive Fish-Culturist 43:92–95.

Clark, M. E., K. A. Rose, J. A. Chandler, T. J. Richter, D. J. Orth, and W. Van Winkle. 2008. Water-level fluctuation effects on centrarchid reproductive success in reservoirs: a modeling analysis. North American Journal of Fisheries Management 28:1138–1156.

Clemens, H. P. and K. E. Sneed. 1957. The spawning of the channel catfish *Ictalurus punctatus*. U.S. Fish and Wildlife Special Science Report–Fish 219:1–11.

Clovis, J. F. 1971. Aquatic vascular plant distribution in Cheat Lake (Lake Lynn), West Virginia. Castanea 36:153–163.

Corbett, R. G.. 1977. Effects of coal mining on ground and surface water quality, Monongalia County, West Virginia. The Science of the Total Environment 8:21–38.

Core, E. L., et al. 1959. Biological investigations of Cheat Lake: Summary. West Virginia University, Morgantown, West Virginia.

Crumpton, J. E. 1999. Relative abundance, age, growth and food habits of channel and white catfish from the Clermont Chain of Lakes, Florida. Pages 115–119 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Dagel, J. D., M. R. Wuellner, and D. W. Willis. 2010. Channel catfish diets include substantial vegetation in a Missouri River reservoir. The Prairie Naturalist 42:1–7.

Dames, H. R., T. G. Coon, and J. W. Robinson. 1989. Movements of channel and flathead catfish between the Missouri River and a tributary, Perche Creek. Transactions of the American Fisheries Society 118:670–679.

De Roth, G. C. 1965. Age and growth studies of channel catfish in Western Lake Erie. The Journal of Wildlife Management 29:280–286.

Driscoll, M. T., H. L. Schramm, Jr., and W. R. Davis. 1999. Relative abundances of catfishes in main channel and secondary channel habitats in the lower Mississippi River. Pages 231–237 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Duffy, E. J., D. A. Beauchamp, R. M. Sweeting, R. J. Beamish, and J. S. Brennan. 2010. Ontogenetic diet shifts of juvenile chinook salmon in nearshore and offshore habitats of Puget Sound. Transactions of the American Fisheries Society 139:803–823.

Durham, B. W., K. L. Pope, and G. R. Wilde. 2005. Factors affecting regional variation in growth of channel catfish. North American Journal of Fisheries Management 25:93–97.

Easton, R. S. and D. J. Orth. 1992. Ontogenetic diet shifts of age-0 smallmouth bass (*Micropterus dolomieu* Lacepède) in the New River, West Virginia, USA. Ecology of Freshwater Fish 1:86–98.

Edds, D. R., W. J. Matthews, and F.P. Gelwick. 2002. Resource use by large catfishes in a reservoir: is there evidence for interactive segregation and innate differences? Journal of Fish Biology 60:739–750.

Etnier, D. A. and W. C. Starnes. 1993. Fishes of Tennessee. University of Tennessee Press, Knoxville, Tennessee.

Fago, D. 1999. Movement of channel catfish in the Lower Wisconsin River and Pools Numbers 10 and 11 of the Mississippi River using radiotelemetry. Pages 177–185 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Fischer, J., C. Paukert, and M. Daniels. 2012. Fish community response to habitat alteration: Impacts of sand dredging in the Kansas River. Transactions of the American Fisheries Society 141:1532–1544.

Fischer, S. A., S. Eder, and E.D. Aragon. 1999. Movements and habitat use of Channel Catfish and Blue Catfish in a small impoundment in Missouri. Pages 239–255 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Fisher, W. L. and A.V. Zale. 1991. Effect of water level fluctuations on abundance of young-of-year largemouth bass in a hydropower reservoir. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 45:422–431.

Floodmark, L. E. W., L. A. Vollestad, and T. Forseth. 2004. Performance of juvenile brown trout exposed to fluctuating water level and temperature. Journal of Fish Biology 65:460–470.

Floyd, K. B., R. D. Hoyt, and S. Timbrook. 1984. Chronology of appearance and habitat partitioning by stream larval fishes. Transactions of the American Fisheries Society 113:217–223.

Furey, P. C., R. N. Nordin, and A. Mazumder. 2006. Littoral benthic macroinvertebrates under contrasting drawdown in a reservoir and a natural lake. Journal of the North American Benthological Society 25:19–31.

Gaeta, J. W., G. G. Sass, and S. R. Carpenter. 2014. Drought-driven lake level decline: effects on coarse woody habitat and fishes. Canadian Journal of Fisheries and Aquatic Sciences 71:315–325.

Garvey, J. E., K. G. Ostrand, and D. H. Wahl. 2004. Energetics, predation, and ration affect size-dependent growth and mortality of fish during winter. Ecology 85:2860–2871.

Gido, K. B. and D. L. Propst. 1999. Habitat use and association of native and nonnative fishes in the San Juan River, New Mexico and Utah. Copeia 1999:321–332.

Griswold, B. L. and R. A. Tubb. 1977. Food of yellow perch, white bass, freshwater drum, and channel catfish in Sandusky Bay, Lake Erie. The Ohio Journal of Science 77:43–47.

Gosch, N. J. C., K. L. Pope, and P. H. Michaletz. 2009. Stomach capacities of six freshwater fishes. Journal of Freshwater Ecology 24:645–649.

Haxton, T. and K. Punt. 2004. Abundance and demography of Channel Catfish in a large northern river. North American Journal of Fisheries Management 24:1440–1446.

Helms, D. R. 1975. Variations in the abundance of channel catfish year classes in the upper Mississippi River and causative factors. Iowa Department of Conservation Technical Series 75–1, Des Moines.

Hill, T. D., W. G. Duffy, and M. R. Thompson. 1995. Food habits of channel catfish in Lake Oahe, South Dakota. Journal of Freshwater Ecology 10:319–323.

Holland, L. E. 1986. Distribution of early life history stages of fishes in selected pools of the Upper Mississippi River. Hydrobiologia 136:121–130.

Holland-Bartels, L. E. and M. C. Duval. 1988. Variations in abundance of young-of-the-year channel catfish in a navigation pool of the upper Mississippi River. Transactions of the American Fisheries Society 117:202-208.

Hubert, W. A. 1999. Biology and management of Channel Catfish. Pages 3–22 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Hurst, T. P. and D. O. Conover. 1998. Winter mortality of young-of-the-year Hudson River striped bass (*Morone saxatilis*): size-dependent patterns and effects on recruitment. Canadian Journal of Fisheries and Aquatic Sciences 55:1122–1130.

Irwin, E. R., M. C. Freeman, and K. M. Costley. 1999. Habitat use by juvenile channel catfish and Flathead Catfish in lotic systems in Alabama. Pages 223–230 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Jackson, J. R. and D. C. Jackson. 1999. Macrohabitat use by catfishes in a southeasten United States floodplain-river ecosystem. Pages 215–222 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Jearld, Jr., A. and B .E. Brown. 1971. Food of the channel catfish (*Ictalurus punctatus*) in a southern Great Plains reservoir. American Midland Naturalist 86:110–115.

Jernejcic, F. and D. Wellman. 2011. The recovery of Cheat Lake: A success story. West Virginia Wildlife. Spring: 2–6.

Jolley, J. C. and E. R. Irwin. 2011. Catfish population characteristics in tailwater and reservoir habitats of the Coosa River, Alabama. Pages 155–166 *in* P.H. Michaletz and V.H. Travinichek, editors. Conservation, ecology and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Jones, M. S. and K. B. Rogers. 1998. Palmetto bass movements and habitat use in a fluctuating Colorado irrigation reservoir. North American Journal of Fisheries Management 18:640–648.

Kelsch, S. W. and J. L. Wendel. 2003. Lotic habitat availability and use by channel catfish in the Red River of the North. Journal of Freshwater Ecology 19:473–484.

Lewis, G. E. 1976. Summer food of channel catfish in a West Virginia flood control reservoir. The Progressive Fish Culturist 38:177–178.

Maceina, M. J. and M. R. Stimpert. 1998. Relations between reservoir hydrology and crappie recruitment in Alabama. North American Journal of Fisheries Management 18:104–113.

Maceina, M. J. 2003. Verification of the influence of hydrologic factors on crappie recruitment in Alabama reservoirs. North American Journal of Fisheries Management 23:470–480.

Marsh, P. C. 1981. Food of channel catfish in the Coachella Canal, California. Journal of the Arizona-Nevada Academy of Science 16:91–95.

Marshall, M. D., M. J. Maceina, and M. P. Holley. 2009. Age and growth variability between sexes of three catfish species in Lake Wilson, Alabama. North American Journal of Fisheries Management 29:1283–1286.

McMahon, T. E. and J. W. Terrell. 1982. Habitat suitability models: channel catfish. United States Department of the Interior Fish and Wildlife Service. FWS/OBS-82/10.2. 29 pages.

Michaletz, P. H. 2006. Prey resource by bluegill and channel catfish in small impoundments. Fisheries Management and Ecology 13:347–354.

Mittlebach, G. G. and L. Perrson. 1998. The ontogeny of piscivory and its ecological consequences. Canadian Journal of Fisheries and Aquatic Sciences 55:1454–1465.

Miranda, L. E., Shelton, W. L., and T. D. Bryce. 1984. Effects of water level manipulation on abundance, mortality, and growth of young-of-the-year largemouth bass in West Point Reservoir, Alabama–Georgia. North American Journal of Fisheries Management 4:314–320.

Muth, R. T. and J. C. Schmulbach. 1984. Downstream transport of fish larvae in a shallow prairie river. Transactions of the American Fisheries Society 113:224–230.

Nelson, C. M. 1995. Male size, spawning pit size and female mate choice in a lekking cichlid fish. Animal Behavior 50:1587–1599.

Nitschke, P., M. Mather, and F. Juanes. 2001. A comparison of length-, weight-, and age-specific fecundity relationships for cunner in Cape Cod Bay. North American Journal of Fisheries Management 21:86–95.

Page, L. M. and B. M. Burr. 2011. Peterson field guide to freshwater fishes of North America north of Mexico. Houghton Mifflin Harcourt Publishing, Boston, Massachusetts.

Pellett, T. D., G. J. Van Dyck, and J.V. Adams. Seasonal migration and homing of channel catfsh in the Lower Wisconsin River, Wisconsin. North American Journal of Fisheries Management 18:85–95.

Perrson, L., J. Andersson, E. Wahlstrom, and P. Eklov. 1996. Size-specific interactions in lake systems: predator gape limitation and prey growth rate and mortality. Ecology 77:900–911.

Perry, Jr., W. G. 1969. Food habits of blue and channel catfish collected from a brackish-water habitat. The Progressive Fish-Culturist 31:47–50.

Phelps, Q. E., S. J. Tripp, J. E. Garvey, D. P. Herzog, R. A. Hrabik, D. E. Ostendorf, J. W. Ridings, and J. W. Crites. 2011. Juvenile channel catfish habitat use in the Middle Mississippi River. Pages 535–543 *in* P.H. Michaletz and V.H. Travinichek, editors. Conservation, ecology and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Post, D. M., J. F. Kitchell, and J. R. Hodgson. 1998. Interactions among adult demography, spawning date, growth rate, predation, overwinter mortality, and the recruitment of largemouth bass in a northern lake. Canadian Journal of Fisheries and Aquatic Sciences 55:2588–2600.

Rogers, K. B. and E. P. Bergersen. 1995. Effects of fall drawdown on movement of adult Northern Pike and Largemouth Bass. North American Journal of Fisheries Management 15:596–600.

Rypel, A. L. 2011. Meta-analysis of growth for five North American catfishes: effects of climate, hydrologic habitat, and latitudinal countergradients. Pages 661–677 *in* P.H. Michaletz and V.H. Travinichek, editors. Conservation, ecology and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Sammons, S. M., L. G. Dorsey, P. W. Bettoli, and F. C. Fiss. 1999. Effects of reservoir hydrology on reproduction by largemouth bass and spotted bass in Normandy Reservoir, Tennessee. North American Journal of Fisheries Management 19:78–88.

Schultz, E. T., D. O. Conover, and A. Ehtisham. 1998. The dead of winter: size-dependent variation and genetic differences in seasonal mortality among Atlantic silversides (Atherinidae: *Menidia menidia*) from different latitudes. Canadian Journal of Fisheries and Aquatic Science 55:1149–1157.

Schwartz, F. J. 1991. Depth and storage capacity changes in Cheat Lake, West Virginia, during the 64–year period 1926–1990. The Journal of the Elisha Mitchell Scientific Society 107:115–122.

Shoup, D. E., S. P. Callahan. D. H. Wahl, and C. L. Pierce. 2007. Size-specific growth of bluegill, largemouth bass and channel catfish in relation to prey availability and limnological variables. Journal of Fish Biology 70:21–34.

Simco, B. A., C. A. Goudie, G. T. Klar, N. C. Parker, and K. B. Davis. 1989. Influence of sex on growth of channel catfish. Transactions of the American Fisheries Society 118:427–434.

Starostka, V. J. and W. E. Nelson. 1974. Age, growth, sexual maturity, and food of channel catfish in central Lake Oahe, 1968–69. U.S. Fish and Wildlife Service Technical Papers 81, Washington, D.C.

Tabor, R. A., E. J. Warner, K. L. Fresh, B. A. Footen, and J.R. Chan. 2007. Ontogenetic diet shifts of prickly sculpin in the Lake Washington Basin, Washington. Transactions of the American Fisheries Society 136:1801–1813.

Tyus, H. M. and N. J. Nikirk. 1990. Abundance, growth, and diet of channel catfish, *Ictalurus punctatus*, in the Green and Yampa Rivers, Colorado and Utah. The Southwestern Naturalist 35:188–198.

Walburg, C. H. 1975. Food of young-of-year channel catfish in Lewis and Clark Lake, a Missouri River reservoir. American Midland Naturist 93:218–221.

Weisberg, S. B. and A. J. Janicki. 1990. Summer feeding patterns of white perch, channel catfish, and yellow perch in the Susquehanna River, Maryland. Journal of Freshwater Ecology 5:391–405.

Welsh, S. A. and S. A. Perry. 1997. Acidification and fish occurrence in the upper Cheat River Drainage, West Virginia. Journal of the American Water Resources Association 33:423–429.

West Virginia Division of Environmental Protection (WVDEP). 1996. An ecological assessment of the Cheat River Watershed. Office of Water Resources. Charleston, West Virginia. Report number: 0502004–1996.

White, M. S., M. A. Xenopoulos, R. A. Metcalfe, and K. M. Somers. 2011. Water level thresholds of benthic macroinvertebrate richness, structure, and function of boreal lake stony littoral habitats. Canadian Journal of Fisheries and Aquatic Science 68:1695–1704.

Wilcox, D. A. and J. E. Meeker. 1992. Implications for faunal habitat related to altered macrophyte structure in regulated lakes in northern Minnesota. Wetlands 12:192–203.

Williams, D. R., M. E. Clark, and J.B. Brown. 1999. Stream water quality in coal mined areas of the lower Cheat River Basin, West Virginia and Pennsylvania, during low-flow conditions, July 1997. U.S. Geological Survey. Water-Resources Investigations Report 98–4258.

Wolters, W. R. and J. Avery. 2011. Channel catfish. Pages 196–199 *in* Encyclopedia of animal science, 2nd edition. Taylor and Francis, New York, New York.

Yamamoto, T., Y. Kohmatsu, and M. Yuma. 2006. Effects of summer drawdown on cyprinid fish larvae in Lake Biwa, Japan. Limnology 7:75–82.

Zohary, T. and I. Ostovsky. 2011. Ecological impacts of excessive water level fluctuations in stratified freshwater lakes. Inland Waters 2011:47–59.

Chapter 2. Evaluation of Age, Growth and Fall Diet of Channel Catfish in Cheat Lake, West Virginia

Abstract

Evaluation of Age, Growth and Fall Diet of Channel Catfish in Cheat Lake, West Virginia

Corbin D. Hilling

Acidification has historically impaired Cheat Lake's fish community, but recent mitigation efforts within the Cheat River watershed have improved water quality and species richness. Presently, Channel Catfish are abundant and attain desirable sizes for anglers. I evaluated the age, growth and fall diet of the population. A sample of 155 Channel Catfish was collected from Cheat Lake from 5 August to 4 December 2014, a subsample of which was aged (n = 148) using lapillus otoliths. Four growth models (von Bertalanffy, logistic, Gompertz and power) were fit to length at age data and compared using an information theoretic approach. Fall diets were collected from 55 fish sampled from 13 October to 4 December 2014. Total lengths of individuals in the sample ranged from 154–721 mm and ages ranged from 2–19 years. The von Bertalanffy growth model was AIC_c-selected as the best approximating model, and the power and Gompertz models also had considerable support. Diets were numerically dominated by Diptera larvae, specifically Chironomidae and Chaoboridae, while 39% of stomachs contained terrestrial prey items. This study provides baseline data for management of Cheat Lake's Channel Catfish population. Further, this study fills a knowledge gap in the scientific literature on Channel Catfish, as few studies have examined the population ecology of Channel Catfish in the Central Appalachian region.

Introduction

Channel Catfish (*Ictalurus punctatus*) is an economically important species in North America due to its popularity among recreational and commercial fishermen, as well as aquaculturalists. Channel Catfish are native to the central drainages of North America (Etnier and Starnes 1993), and have been extensively introduced elsewhere to enhance sport fisheries (Marsh 1981, Tyus and Nikirk 1990, Bonar et al. 1997). Presently, the range of Channel Catfish extends throughout much of the United States (Hubert 1999a). Due to its importance to humans and extensive range, Channel Catfish have been studied extensively. However, few published studies examine Channel Catfish populations in the Central Appalachians presenting a gap in the knowledge base on the species. Given the extensive variability between populations, filling in gaps may help elucidate factors influencing Channel Catfish population dynamics.

Cheat Lake has one of the more prolific Channel Catfish populations of West Virginia's reservoirs. Currently, no management practices are in place to maximize Channel Catfish production in Cheat Lake and limited data exist on the population. This study focuses on estimation of population characteristics of Cheat Lake Channel Catfish and evaluation of fall diets. My objectives were to estimate size structure, age structure, mortality, condition, growth and fall diets for Cheat Lake's Channel Catfish population, thus providing a baseline for future management decisions and filling a regional knowledge gap in the population ecology of Channel Catfish.

Study Area: Cheat Lake, West Virginia

Cheat Lake (also referred to as Lake Lynn) is a 700.4 ha hydropower reservoir on the Cheat River near Morgantown, West Virginia (Figure 1). The reservoir flows 20.9 km from the head of the lake to the Lake Lynn Hydropower Dam (Figure 1). Cheat Lake features a riverine section that flows into a shallow transitional area, followed by a deep lacustrine section. Acid precipitation (Welsh and Perry 1997) and acid mine drainage (Freund and Petty 2007, Merovich and Petty 2007, Merovich et al. 2007) within the Cheat River Watershed have impacted downstream sections of the Cheat River, including Cheat Lake. Fish survey reports from Cheat Lake during the 1950s documented a total of 14 species, predominately from the families Catostomidae and Ictaluridae (Core et al. 1959). However, mitigation efforts throughout the watershed have led to improved water quality within Cheat Lake and a resurgence of fish species richness. Since 1997, nearly 50 fish species have been collected from Cheat Lake (D.M. Smith, West Virginia University School of Natural Resources, personal communication). As a hydropower reservoir, the Federal Energy Regulatory Commission requires monitoring of fish populations to minimize impacts of hydropower operations. Consequently, water level fluctuations in Cheat Lake are regulated seasonally to sustain fisheries.

Methods

Fish Collection

Channel Catfish were collected from Cheat Lake from 5 August 2014 to 4 December 2014 using gill nets, boat electrofishing and baited hoop nets. Sampling sites were strategically selected in areas with historic success in Channel Catfish collection or favorable habitat. Areas with submerged woody debris were avoided in gill net and hoop net sampling to minimize the likelihood of net entanglement. Mean catch per unit effort was calculated for all sampling gears.

Gill nets were the primary gear used due to prior success in Cheat Lake biomonitoring surveys. Two different types of nets were fished, including nets of dimensions 38.1 m x 1.8 m (comprised of five 7.6 m panels of bar mesh sizes 1.9-, 2.5-, 3.8-, 5.1- and 6.4-cm) and 45.7 m x 1.8 m (comprised of six 7.6 m panels of bar mesh sizes 3.8-, 4.4-, 5.1-, 3.8-, 4.4- and 5.1-cm).

The shorter 38 m experimental gill nets were used initially to avoid exclusion of smaller Channel Catfish, but their use was discontinued when few small individuals were collected. The 46 m gill nets were subsequently used in an effort to maximize catch rates. Gill nets were tied to woody debris on shore and set perpendicular to the shoreline. Nets were anchored to the lake bottom using cinder blocks adjoined to the sinking line of the gill net. Nets were fished over-night and pulled in the order they were set.

High frequency boat electrofishing was conducted using a Smith-Root boat-mounted electrofisher with a typical output of 4–6 amps. Sampling took place from dusk to 2400 hours in shallow areas (<2.5 m) with suitable water clarity. On some occasions, bait was used to lure Channel Catfish into shallow areas to improve their susceptibility to electrofishing. Cheese trimmings (Memphis Net & Twine) or Charlie Blood B Dough Bait (Memphis Net & Twine) contained in mesh bags were attached to a carabineer. The carabineer was clipped to a rope connecting an anchor to a buoy. Buoys were used to mark the exact site of bait deployment. Electrofishing in areas adjacent to buoys took place approximately 30–60 minutes after deployment. Electrofishing was used to target small individuals not recruited to other gears.

Several studies have suggested baited tandem hoop nets as the most effective gear for sampling Channel Catfish in lentic systems (Sullivan and Gale 1999, Michaletz and Sullivan 2002, Flammang and Schultz 2007, Richters and Pope 2011). Suitable sites for tandem hoop nets in Cheat Lake were limited due to steep banks and submerged woody debris. As a result, single hoop nets were set in coves and mouths of tributaries where depths were shallow (<3 m) and bathymetry was relatively flat. Hoop nets were composed of seven 1.2 m fiberglass hoops with 3.8 cm mesh with restrictive throats on the second and fourth hoops. Cheese trimmings or Blood Dough Bait contained in mesh bags were placed in the cod end of the hoop-net. Regularly collected limnological profiles were used to ensure hoop nets were set above the thermocline. Neely and Dumont (2011) suggested baited, tandem hoop net sets are most effective if set for 2–3 days. In Cheat Lake, intense recreational boating prevented long term sets and hoop nets were set over-night. After low success rates during pilot sampling, hoop nets were used sparingly.

Specimen Processing

Collected Channel Catfish were immediately placed on ice to preserve specimen integrity and slow digestion of stomach contents. Collection site was indicated with the use of color-coded rubber bands placed around the caudal peduncle of the fish. Channel Catfish were measured total length (TL) to the nearest mm and weighed to the nearest g using a battery operated digital scale (Ohaus® Valor 2000 Series- Model V21PW6).

Sex of Channel Catfish was determined with three different methods. First, I used a non-invasive technique based on observation of the urogenital area (Grizzle and Rogers 1976). The efficacy of this visual method of determining sex can vary seasonally and with developmental status of the individual fish. Second, sex determination was aided by use of a technique described by Norton et al. (1976), in which probes are used to distinguish numbers of openings in the urogenital papillae. Using the probing method, sex determination is possible regardless of season or development status (Norton et al. 1976). The third method was direct observation of gonads during dissection. Released Channel Catfish were sexed using the Grizzle & Rogers (1976) method and the adipose fin was excised. Most fish were definitively sexed using direct observation of gonads, while it was helpful to use the Norton et al. (1976) method for smaller fish.

Lapillus otoliths (lapilli, hereafter) were extracted from Channel Catfish for age analysis. Lapilli were cleaned of all soft tissue and allowed to dry in coin envelopes. Annulus interpretation on whole Channel Catfish lapilli is difficult due to opaqueness. To gain a view of the transverse plane, I used the protocol described by Buckmeier et al. (2002). In accordance with this technique, lapilli were burnt on a Carolina™ Hot Plate/Stirrer to produce a dark amber color. Burnt lapilli were mounted to a glass microscope slide using Crystalbond™ 509 (Electron Microscopy Sciences). Lapilli were sanded using 400 or 600 grit wet/dry sandpaper to remove the top third of the otolith. The transverse plane was polished using 1200 and 2500 grit automotive grade sandpaper to improve clarity of annuli. Mounted lapilli were immersed in water to reduce glare and viewed under a dissecting microscope (2–4x magnification). Two independent readers counted annuli and discrepancies were resolved by mutual examination.

Fish collected from 13 October 2014 to 4 December 2014 were included in diet analysis. Gill nets were used exclusively to sample fish for diet analyses. A sample of 55 stomachs was excised and preserved in a 95% ethanol solution (Dagel et al. 2010). Stomach contents were removed in the laboratory and identified to family or the lowest practical taxonomic level. Prey items were counted with the exception of detritus, which was noted as present or absent due to difficulty in counting detrital matter. Counted prey items were labeled as either aquatic or terrestrial in origin. Empty stomachs were noted as such and excluded from further analysis.

Analyses

In order to estimate the size structure of the Cheat Lake Channel Catfish population, a length frequency histogram was constructed and proportional size distributions were calculated. The length frequency histogram was constructed using length-group interval guidelines presented in Neumann et al. (2012). Proportional size distributions (PSDs) were calculated (Gabelhouse 1984, Neumann et al. 2012), and associated confidence intervals (95%) were calculated using the equation presented by Gustafson (1988). PSDs were calculated using the following length categories; stock (280–409 mm), quality (410–609 mm), preferred (610–709 mm), memorable (710–909 mm) and trophy (≥910 mm) (Gabelhouse 1984). The length-weight relationship was evaluated using curve-fitting in the nls (Non-linear Least Squares) package using a Gauss-Newton algorithm in R (Version 3.1.2, The R Foundation for Statistical Computing). A power model $W = aL^b$ was fit to length and weight data, where W is weight (g), L is TL (mm) and a and b are estimated parameters (Neumann et al. 2012).

Age class data and catch curve linear regression in R were used to estimate an instantaneous mortality rate (Z) of Channel Catfish. Weighted linear regression was used to lessen the influence of older, less common age classes (Maceina 1997). The annual mortality (A) rate was subsequently calculated as $A = 1 - e^{-Z}$ (Miranda and Bettoli 2007). Hubert (1999b) stated in a meta-analysis of 102 Channel Catfish age studies that most studies had few fish less than three years old, indicating Channel Catfish may not fully recruit to sampling gears until age 3. As a result, fish younger than age 3 were excluded from catch-curve analysis. Catch-curve analysis assumes no age estimation error, as well as constant recruitment, mortality and catchability over all age classes considered (Miranda and Bettoli 2007, Smith et al. 2012).

The relative weight index was used to estimate condition of Cheat Lake's Channel Catfish population. Relative weight (W_r) is calculated as $W_r = (W/ W_s) \times 100$, where W is the weight of an individual fish in g and W_s is the standard weight (Wege and Anderson 1978). Standard weight of Channel Catfish is calculated as $\log_{10}(W_s) = -5.800 + 3.294 \log_{10}(L)$, where L is the TL of an individual fish in mm (Brown et al. 1995). The relative weight index is applicable for estimation of condition of Channel Catfish ≥70 mm TL (Brown et al. 1995). Relative weights were summarized using the five-category system presented by Gabelhouse (1984) with the addition of a sixth category (sub-stock) to encompass small fish not represented in the other categories (Shuman et al. 2011). Relative weights within length categories were compared using analysis of variance (ANOVA) at significance level $\alpha = 0.05$. Blackwell et al. (2000) suggested that calculation of a population mean W_r is inappropriate without determining if there are significant differences between length groups. Memorable and trophy size classes were omitted from ANOVA due to inadequate sample sizes. Power analysis was performed to determine the probability of making a type II error (Peterman 1990, Blackwell et al. 2000). W_r values were reported as whole numbers (Blackwell et al. 2000).

Length at age data were used to compare Cheat Lake Channel Catfish growth to standards presented by Hubert (1999b) and Jackson et al. (2008). Hubert (1999b) provides growth standards for Channel Catfish from age 3–10 allowing assignment of percentiles to mean length at age data. Cheat Lake Channel Catfish growth was compared using the relative growth index (RGI) to the standard length (L_s) equation presented by Jackson et al. (2008), where $L_s = 843.6[1 – e^{-0.096(age+0.669)}]$. RGI values were calculated as RGI = (L_t /L_s) x 100 (Quist et al. 2003). RGI values were calculated for all aged fish and RGI values were averaged by age class. Mean RGI values were compared to an average value of 100, where RGI values greater than 100 indicate fast growth, while RGI values less than 100 indicate slow growth (Quist et al. 2003). Mean RGI values were presented from ages 3–10 as Hubert (1999b) indicated most studies lack adequate sample sizes outside this range.

Channel Catfish length at age data were used to fit four growth models using a Gauss-Newton algorithm in the nls package of R. The four candidate models were the von Bertalanffy (VBGM), logistic, Gompertz and power models.

$$\text{VBGM: } L(t) = L_\infty[1 – exp(–k(t–t_0))]$$

$$\text{Gompertz: } L(t) = L_\infty\, exp[– (exp(–G(t–t_0)))]$$

$$\text{Logistic: } L(t) = L_\infty[1 + exp(-G(t-t_0))]^{-1}$$

$$\text{Power: } L(t) = b_0 + b_1\, t^{\,B2}$$

All candidate models, except the power model, include a maximum length term (L_∞), indicative of asymptotic growth. However, the power model assumes indeterminate growth. The VBGM assumes the growth rate decreases linearly with size (Katsanevakis 2006, Katsanevakis and Maravelias 2008). In the VBGM, k describes how quickly L_∞ is reached and t_0 is the theoretical age when length equals zero (Quist et al. 2012). The Gompertz and logistic models are sigmoidal curves. The Gompertz model assumes an exponential decrease in growth rate with age (Katsanevakis 2006), while the logistic model is symmetrical about an inflection point (Quist et al. 2012). In the Gompertz model, t_0 is the inflection point of the curve and G is the instantaneous growth rate at age t_0 (Quist et al. 2012). The parameters G and t_0 in the logistic model are the instantaneous growth rate at the origin of the curve and the theoretical age when length is zero, respectively (Quist et al. 2012).

The four candidate growth models were compared for goodness of fit using an information theoretic approach. Akaike's Information Criterion with a small sample bias correction (AIC_c) was used to rank models in order of decreasing fit (Burnham and Anderson 2002, Anderson 2008, Katsanevakis and Maravelias 2008, Burnham et al. 2011). The AIC_c was calculated as below, where RSS is the residual sum of squares calculated for a model of interest, n is the number of observations in the sample and k is the number of parameters estimated by the model (Katsanevakis and Maravelias 2008). The model with the lowest AIC_c value was considered the "best" approximating model (Burnham et al. 2011). The AIC_c values were used to calculate Δ values, and AIC_c weights (w_i) were calculated for each model and used as relative measures of evidence for each model (Akaike 1983, Burnham and Anderson 2002). All AIC_c calculations were completed in R using the AICcmodavg package.

$$AIC = n\left(\log\left(2\pi\frac{RSS}{n}\right)+1\right)+2k$$

$$AICc = AIC + \frac{2k(k+1)}{n-k-1}$$

$$\Delta_i = AICc_i - AICc_{min}$$

$$w_i = \frac{exp(-0.5\Delta_i)}{\sum_{i=1}^{4} exp(-0.5\Delta_k)}$$

Multimodel inference was used to reduce uncertainty associated with using a single model (Buckland et al. 1997, Burnham et al. 2011). Estimates of L_∞ from the VBGM, Gompertz and logistic models were used to find the model average asymptotic length ($\overline{L_\infty}$ or Mean L_∞) (Katsanevakis and Maravelias 2008). The parameter $\overline{L_\infty}$ was estimated using a weighted average. Akaike weights from AIC_c were rescaled to exclude the weight of the power model using the equation below, where w_i^* was the rescaled weight of model *i*, w_i is the weight of model *i* calculated in AIC_c , and $w_{1\text{-}3}$ are the weights of the three asymptotic models calculated in AIC_c (Katsanevakis and Maravelias 2008, Yin and Tzeng 2009) . The parameter $\overline{L_\infty}$ was calculated by finding the summation of the products of each models L_∞ and w_i^*. Standard errors on $\overline{L_\infty}$ estimates were calculated using an equation presented by Katsanevakis (2006).

$$w_i^* = w_i\,(w_1 + w_2 + w_3)^{-1}$$

$$Mean\ L_\infty = \sum_{i=1}^{3}\left(w_i^* \hat{L}_{\infty i}\right)$$

$$SE(\overline{L_\infty}) = \Sigma_{i=1}^{3} w_i^*[var(\hat{L}_{\infty,i} \mid g_i) + (\hat{L}_{\infty,i} - \overline{L_\infty})^2]^{1/2}$$

Diets were summarized using percent frequency of occurrence (O_i), mean percent frequency by number (MN_i) and prey-specific abundance (P_i). Frequency of occurrence was calculated as $O_i = J_i P^{-1}$ x 100, where J_i was the number of stomachs containing a particular food item and P was the total number of stomachs containing food (Chipps and Garvey 2007). Mean percent composition by number was calculated as below, where P was the total number of stomachs containing food, Q is the number of prey item categories and $N = N_{ij}$, the number of food category i in fish j (Chipps and Garvey 2007).

$$MN_i = \frac{1}{P}\sum_{j=1}^{P}\left(\frac{N}{\sum_{i=1}^{Q} N}\right) \text{ x } 100$$

Prey-specific abundance (P_i) was calculated for each food item i as $P_i = (\Sigma S_i / \Sigma S_t)$, where ΣS_i was the total number of food item i observed and ΣS_t was the total number of prey items in stomachs with food item i in them (Amundsen et al. 1996).

Results

A total of 155 Channel Catfish were collected during the sampling period, most of which were collected using gill nets (n = 136). A smaller proportion of fish were collected using boat electrofishing (n = 17) and baited hoop nets (n = 2). Sampling efforts of gill nets, boat electrofishing and hoop nets were 85 net-nights, 3.9 h and 4 net-nights, respectively. Mean CPUE estimates of gill nets, boat electrofishing and baited hoop nets were calculated as 1.6 fish net-night^{-1}, 4.4 fish h^{-1} and 0.5 fish net-night^{-1}, respectively. The sample of Channel Catfish featured more females (n = 88) than males (n = 65). Sex of two fish was not determined due to small size. Females ranged in TL from 203–703 mm (mean = 458.0, SD = 116.5), males from 254–721 mm (mean = 486.9, SD = 106.1) and unsexed fish were 154 and 172 mm. Sex identification using gonad observation and the Grizzle and Rogers (1976) method was consistent over 99% of the time. A single fish was incorrectly sexed using the Grizzle and Rogers (1976) method. The length frequency distribution (Figure 2) shows a majority of fish collected were in excess of 400 mm.

Length data were summarized using the Gabelhouse (1984) five category system. The number of individuals in the Gabelhouse (1984) categories of stock (S), quality (Q), preferred (P), memorable (M) and trophy (T) were 34, 94, 16, 1 and 0, respectively. A total of 10 fish were shorter than the minimum stock length (280 mm). Proportional size distributions with 95% confidence intervals were estimated as follows; PSD = 77 ± 8, PSD-P = 12 ± 6, PSD-M = 1 ± 2 and PSD-T = 0. Incremental PSDs with 95% confidence intervals were estimated as follows; PSD S-Q = 23 ± 8, PSD Q-P = 65 ± 9, PSD P-M = 11 ± 6 and PSD M-T = 1 ± 2.

Curve-fitting was used to fit a power model ($W = aL^b$) to explain the relationship between length and weight (Figure 3). Parameter estimates for a and b were 4.086×10^{-7} (SE = 2.026×10^{-7}) and 3.499 (SE = 0.07759), respectively. Allometric growth was supported over isometric growth as b was not equal to 3.0. The parameter estimate of $b = 3.499$ indicates Cheat Lake Channel Catfish body shape becomes more rotund with growth in length.

Relative weight (W_r) was calculated for all Channel Catfish collected (n = 155) (Table 1). Mean W_r of the sub-stock, stock, quality and preferred categories were 98, 93, 93 and 91, respectively. ANOVA indicated there was no significant difference between W_r of different length groups (F = 0.703648, df = 3, 150, p = 0.551268). Power analysis determined power to be 0.14, indicating calculation of a grand total mean W_r could be biased , as probability of a type II error in the ANOVA was high ($\beta = 0.86$).

Age was estimated for 148 Channel Catfish using lapilli. Initial agreement between independent readers was 87% and agreement within 1 year was 96%. An age was agreed upon for all individuals after mutual examination. Estimated ages ranged from age 2 (n = 5) to age 19 (n = 1). Age-0 (young-of-the-year) and age-1 fish were absent from the sample. The age frequency plot (Figure 4) showed the largest age classes in the sample were age-3,4 and 7 fish, while ages 5 and 6 were less frequent.

A total of 143 fish from age 3 to age 19 were included in catch-curve analysis. Instantaneous mortality (Z = - 0.163 ± .079 (95% CI)) was estimated using weighted linear regression (Figure 5). Annual total mortality (A = 17.8% ± 9.4 (95% CI)) was calculated from instantaneous mortality. Based on the residual plot of the regression line (Figure 6), the inequality of residuals indicates likely violation of one or more of the assumptions of catch-curve analysis.

Four candidate growth models were fit to length-at-age data from 148 Channel Catfish (ages 2–19, length 154–721 mm) (Figure 7). The VBGM was selected by AIC_c as the best approximating model of Cheat Lake Channel Catfish growth (w_i = 0.39), while the power (w_i = 0.38, Δ = 0.02) and Gompertz (w_i = 0.17, Δ = 1.65) models were also supported (Table 2). The logistic model was the least supported model (w_i = 0.06, Δ = 3.74). Using model averaging of the parameter estimates from the three asymptotic models (Table 3), $\overline{L_\infty}$ was estimated as 589.767 mm (SE = 16.77147).

The candidate models were also fit to length at age data from both female and male Channel Catfish from Cheat Lake, separately. Candidate models were fit to length at age data for 86 female Channel Catfish. The power model was selected as the best approximating growth model (w_i = 0.71). The three asymptotic models had considerably less support (Table 4). Using model averaging of the parameter estimates of the three asymptotic models (Table 5), female $\overline{L_\infty}$ was estimated as 614.8235 mm (SE = 30.48035). The four models were also fit to length at age data for 60 male Channel Catfish. The logistic model was selected as the best approximating model (w_i = 0.38), while the Gompertz (w_i = 0.34, Δ = 0.22) and VBGM (w_i = 0.24, Δ = 0.96) had considerable support (Table 6). The power model had little support (w_i = 0.04, Δ = 4.40). Using model averaging of the parameter estimates of the three asymptotic models (Table 7), male $\overline{L_\infty}$ was estimated as 603.6369 mm (SE = 27.84863).

Cheat Lake Channel Catfish growth was compared to growth standards produced from populations throughout the species range (Table 8). Using the Hubert (1999b) growth standards, Cheat Lake Channel Catfish mean lengths at age were at the 75th percentile or above for ages 3–8. Age-9 fish were between the 50th and 75th percentile, while age-10 fish were between the 25th and 50th percentile. Similar results were found using the Relative Growth Index. Fish of ages 3–9 exhibited a mean RGI value greater than 100, while the mean RGI value of age-10 fish was 94.85 (SD = 18.17).

Stomach contents were quantified for 55 Channel Catfish TL ranging from 274–606 mm (mean = 458.2, SD = 73.0). Channel Catfish stomachs contained food items 74.5% of the time. Of the stomachs containing food items, 31.7% contained detritus and 2.4% contained detritus only. Fall diets were numerically dominated by aquatic invertebrates (Table 9). Chironomidae and Choaboridae larvae were the most common prey items, while Ephemeroptera and Sialidae larvae were also frequently present (Table 9). Piscivory was observed as fish remains were present in 9.8% of stomachs with food items.

Terrestrial food items were present in 39% of stomachs. A wide diversity of terrestrial invertebrate taxa were consumed, with Lepidoptera being the most common (Table 9). Flying insects were commonly identified in stomach contents. Mammalian remains were also present in Channel Catfish diets, as Rodentia were found in 4.9% of stomachs and were the only prey items present in those stomachs. Channel Catfish stomachs also contained seasonally available fruits and acorns 14.6 % of the time. Acorns (*Quercus spp.*), grapes (*Vitis spp.*) and paw-paw (*Asimina triloba*) seeds were identified in stomach contents.

Discussion

Given the lack of regional published data on Channel Catfish growth, the robust population of Channel Catfish in Cheat Lake provided an opportunity to gather data on age, growth, and diet within a West Virginia hydropower reservoir. Channel Catfish in Cheat Lake exhibited faster than average growth, based on published growth standards. Low exploitation may contribute to Cheat Lake Channel Catfish reaching relatively old ages compared to other populations. Fall diet of catfish was also comparable to other studies. However, the high incidence of terrestrial items possibly suggests increased availability related to constant small water level fluctuations in Cheat Lake. The data gathered provide valuable information for potential future management of the population and for comparison to other populations in the region.

Cheat Lake's Channel Catfish population includes an abundance of quality sized fish. However, size structure estimated above could be biased due to selectivity of sampling gears (Colombo et al. 2008). Colombo et al. (2008) found Channel Catfish PSD in the Wabash River, Indiana differed by more than 40 when comparing samples collected with hoop nets and AC electrofishing. In a Missouri impoundment, Sullivan and Gale (1999) found similar PSDs from hoop net and gill net samples. Using multiple gears in this study could have reduced biases associated with a single sampling gear, but a vast majority of fish were collected using gill nets due to low catch rates using other gears. Use of gill nets as the primary sampling gear, likely excluded small Channel Catfish.

Baited electrofishing did not appear to increase catch in numbers, but may have increased CPUE by increasing catch rate. Catch numbers appeared to be similar to non-baited electrofishing, but required less time investment (~120 sec per site). The method appeared to concentrate local fish around the bait, but did not appear to draw additional fish from other areas. Presence of cheese trimmings in the stomachs of collected fish was noted during dissection. This method may be more effective in lotic systems where flows carry scent of baits downstream or smaller impoundments. Further study is required to determine if using bait during electrofishing can actually increase catch rates.

Cheat Lake Channel Catfish W_r was above 90 for all length categories. Cheat Lake Channel Catfish W_r appears to be similar to estimates from six Missouri River Reservoirs where estimates ranged from 89 to 93 with a single reservoir estimated as 81(Bouska et al. 2011). Barada and Pegg (2011) found Channel Catfish condition declined below average as fish grew longer, attributing this trend to differences in food availability for length categories. However, Cheat Lake has a large forage base, dominated by Gizzard Shad (*Dorosoma cepedianum*), Emerald Shiner (*Notropis atherinoides*) and three *Lepomis* species (D.M. Smith, unpublished data). Cheat Lake Channel Catfish W_r may decline below average due to intraspecific competition, resulting from large numbers of quality length fish. Another possible explanation may be due to seasonal differences in W_r (Blackwell et al. 2000). Fish in this study were collected in late summer and fall after spawning had taken place.

Cheat Lake Channel Catfish annual total mortality was estimated as A = 17.8% using catch-curve analysis. Hubert (1999a) found annual mortalities ranging from 13 to 88% from over 50 Channel Catfish populations. The annual mortality estimate presented above is relatively low compared to the range of estimates in other populations. Low mortality rates could be related to low exploitation of Channel Catfish in Cheat Lake. Haxton and Punt (2004) estimated annual mortality as 15.7% in the Ottawa River, while claiming there is little fishing pressure for the species. Low mortality rates may allow Cheat Lake Channel Catfish to reach relatively old ages. A maximum observed age in Cheat Lake of 19 years, is relatively old compared to most populations. Bouska et al. (2011) also noted low mortality rates (12–25%) and long-lived fish with maximum ages ranging from 14–28 years, suggesting 28 years was the oldest wild Channel Catfish on record. Hubert (1999a) observed a most frequent maximum age of 8 years and noted few bodies of water produce fish in excess of 15 years.

Cheat Lake Channel Catfish experience rapid growth based on the standards presented by Hubert (1999) and Jackson et al. (2008). Growth studies on Yellow Perch (*Perca flavescens*) and Walleye (*Sander vitreus*) in Cheat Lake have also observed fast growth (Taylor 2013; D.M. Smith, unpublished data). Channel Catfish growth has been correlated with a number of factors, including forage abundance, latitude and limnological variables (Shoup et al. 2007, Rypel 2011) Abundant Gizzard Shad, Emerald Shiners and *Lepomis spp.* in Cheat Lake may provide a forage base conducive to fast Channel Catfish growth. Rypel et al. (2011) described a latitudinal countergradient when normalizing for mean annual temperature. Cheat Lake is located just south of the Mason-Dixon Line and may experience fast growth rates due to moderate latitudinal and thermal influences Meta-analysis of growth data from both lentic and lotic systems found growth positively correlated with lentic habitats (Rypel 2011). The shallow transitional section, coves and upper riverine section of Cheat Lake may promote fast growth rates. Shoup et al. (2007) found a positive correlation with Channel Catfish growth and littoral area in 11 Illinois reservoirs.

Frequently in fisheries science, somatic growth is described using a single model selected *a priori* (generally the VBGM) (Katsanevakis 2006, Katsanevakis and Maravelias 2008). Katsanevakis and Maravelias (2008) noted the VBGM often had the highest L_∞ estimate. This trend was also noted in the present study. Selecting the VBGM *a priori* could lead to over estimates of L_∞. Future growth modeling efforts should use an information theoretic approach comparing multiple models to minimize biases associated with use of a single model. Using multimodel inference, females were estimated to reach total lengths 11 mm greater than male Channel Catfish. A few studies have refuted sex related differences in growth (Haxton and Punt 2004, Marshall et al. 2009), while others have supported faster growth by males (Beaver et al. 1966, De Roth, Starostka and Nelson 1974, Simco et al. 1989).

Diets of Cheat Lake Channel Catfish are consistent with results of other diet studies. Numerous studies observed extensive use of macroinvertebrates and a large presence of dipterans in Channel Catfish diets (Bailey and Harrison 1948, Jearld and Brown 1971, Griswold and Tubb 1977, Weisberg and Janicki 1990, Crumpton 1999, Michaletz 2006). Piscivory in Cheat Lake Channel Catfish appeared to be infrequent, as was seen by Crumpton (1999). Infrequent encounters of fish in Channel Catfish stomachs could be the result of selection of prey items requiring less energy expenditure or handling time. Also, fish could have been lost in diets by regurgitation due to sampling stress. Sutton et al. (2004) found large piscivorous fish have higher regurgitation rates than small nonpiscivorous fish. Stomach content retention by gill net collected Channel Catfish may be high, as they are primarily caught by entanglement of spines, not wedging (Sutton et al. 2004).

Cheat Lake Channel Catfish were found to use terrestrial food items between 13 October and 4 December 2014. Use of terrestrial food items has been documented in other systems

(Bailey & Harrison 1948, Lewis 1976, Hill et al 1995, Crumpton 1999, Edds et al. 2002). Inclusion of terrestrial food items in fall diets may supplement growth or may simply be the result of opportunistic foraging. Sweka and Hartman (2008) used bioenergetics modeling to determine that inclusion of terrestrial invertebrates in diets improved Brook Trout (*Salvalinus fontinalis*) growth in two West Virginia streams. While trophic dynamics in small streams and reservoirs are quite different, consumption of vulnerable terrestrial organisms could provide calories with small energetic investment. Channel Catfish have been described as opportunistic foragers (Bailey and Harrison 1948, Lewis 1976). Use of terrestrial prey items may be due to increased availability of terrestrial insects and tree fruits. Water level fluctuations could have led to displacement of terrestrial food items through inundation of previously exposed substrate.

Management Implications

Data presented in this study provide a baseline for future management decisions. Information on Cheat Lake, as well as other Central Appalachian Channel Catfish populations, are limited and this study will fill an information gap in the scientific literature. Based on the fast growth and abundance of quality length Channel Catfish in Cheat Lake, further management may not be needed at this time. Addition of access points within the riverine section of Cheat Lake may provide shoreline anglers more opportunities for Channel Catfish during spring and summer, when Channel Catfish are concentrated there. Conducting an angler survey would allow fisheries managers to quantify angling effort for Channel Catfish on Cheat Lake and also determine angler attitudes on size structure and abundance. Diet information presented above is limited by a fairly small sample size and collection during a short temporal period. Collection and comparison of diets among seasons could determine how prey item use varies throughout the year. Comparing Channel Catfish diets to diets of other game fishes in Cheat Lake could provide information on competitive interactions. Due to small sample sizes and temporal complexities associated with gill net sampling, no conclusions could be made on the influence of water level fluctuations on Channel Catfish feeding. Further research is required to better understand how water level fluctuations affect feeding behavior of Channel Catfish.

Literature Cited

Akaike, H. 1983. Information measures and model selection. International Statistical Institute 44:277–291.

Amundsen, P. A., H. M. Gabler, and F. J. Staldvik. 1996. A new approach to graphical analysis of feeding strategy from stomach contents data – modification of the Costello (1990) method. Journal of Fish Biology 48:607–614.

Anderson, D. R.. 2008. Model based inference in the life sciences: a primer on evidence. Springer, New York, New York.

Bailey, R. M. and H. M. Harrison, Jr. 1948. Food habits of the southern channel catfish (*Ictalurus lacustrus punctatus*) in the Des Moines River, Iowa. Transactions of the American Fisheries Society 75:110–138.

Barada, T. J. and M. A. Pegg. 2011. Population characteristics of channel catfish in the Platte River, Nebraska. Pages 81–94 *in* P.H. Michaletz and V.H. Travinichek, editors. Conservation, ecology and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Beaver, J. A., K. E. Sneed, and H. K. Dupree. 1966. The difference in growth of male and female channel catfish in hatchery ponds. The Progressive Fish–Culturist 28:47–50.

Blackwell, B. G., M. L. Brown, and D. W. Willis. 2000. Relative weight (W_r) status and current use in fisheries assessment and management. Reviews in Fisheries Science 8:1-44.

Bonar, S. A., J. Pahutski, B. D. Bolding, D. Fletcher, and M. Divens. 1997. Survival and growth of channel catfish stocked in Washington lakes. North American Journal of Fisheries Management 17:773–778.

Bouska, W. W., C. Longhenry, P. Bailey, D. Fryda, and H. Headley. 2011. Channel catfish populations, management, and angler use in the Main–Stem Missouri River Reservoirs. Pages 167–176 *in* P.H. Michaletz and V.H. Travinichek, editors. Conservation, ecology and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Brown, M. L., F. Jaramillo, Jr., D. M. Gatlin III, and B. R. Murphy. 1995. A revised standard weight (Ws) equation for channel catfish. Journal of Freshwater Ecology 10:295–302.

Buckland, S. T., K. P. Burnham, and N. H. Augustin. 1997. Model selection: an integral part of inference. Biometrics 53:603–618.

Buckmeier, D. L., E. R. Irwin, R. K. Betsill, and J. A. Prentice. 2002. Validity of otolith and pectoral spines for estimating ages of channel catfish. North American Journal of Fisheries Management 22:934–943.

Burnham, K. P. and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach 2nd edition. Springer, New York, New York.

Burnham, K. P., D. R. Anderson, and K. P. Huyvaert. 2011. AIC model selection and multimodel inference in behavioral ecology: some background, observation, and comparisons. Behavioral Ecology and Sociobiology 65:23–35.

Chipps, S. R. and J. E. Garvey. 2007. Assessment of diets and feeding patterns. Pages 473–514 *in* C.S. Guy & M.L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland, USA.

Colombo, R. E., Q. E. Phelps, J. E. Garvey, R. C. Heidinger, and T. Stefanavage. 2008. Gear-specific population demographics of channel catfish in large midwestern river. North American Journal of Fisheries Management 28:241–246.

Core, E. L., et al. 1959. Biological investigations of Cheat Lake: Summary. West Virginia University, Morgantown, West Virginia.

Crumpton, J. E. 1999. Relative abundance, age, growth and food habits of channel and white catfish from the Clermont Chain of Lakes, Florida. Pages 115–119 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Dagel, J. D., M. R. Wuellner, and D. W. Willis. 2010. Channel catfish diets include substantial vegetation in a Missouri River reservoir. The Prairie Naturalist 42:1–7.

De Roth, G. C. 1965. Age and growth studies of channel catfish in western Lake Erie. The Journal of Wildlife Management 29:280–286.

Edds, D. R., W. J. Matthews, and F. P. Gelwick. 2002. Resource use by large catfishes in a reservoir: is there evidence for interactive segregation and innate differences? Journal of Fish Biology 60:739–750.

Etnier, D. A. and W. C. Starnes. 1993. Fishes of Tennessee. University of Tennessee Press, Knoxville, Tennessee.

Flammang, M. K. and R. D. Schultz. 2007. Evaluation of hoop-net size and bait selection for sampling channel catfish in Iowa impoundments. North American Journal of Fisheries Management 27:512–518.

Freund, J. G. and J. T. Petty. 2007. Response of fish and macroinvertebrate bioassessment indices of water quality in a mined Appalachian watershed. Environmental Management 39:707–720.

Gabelhouse, Jr., D.W. 1984. A length-categorization system to assess fish stocks. North American Journal of Fisheries Management 4:273-285.

Griswold, B. L. and R. A. Tubb. 1977. Food of yellow perch, white bass, freshwater drum, and channel catfish in Sandusky Bay, Lake Erie. The Ohio Journal of Science 77:43–47.

Grizzle, J. M. and W. A. Rogers. 1976. Anatomy & Histology of the Channel Catfish. Auburn University Agricultural Experiment Station, Auburn Alabama.

Gustafson, K. A. 1988. Management briefs: Approximating confidence intervals for indices of fish population size structure. North American Journal of Fisheries Management 8:139–141.

Haxton, T. and K. Punt. 2004. Abundance and demography of channel catfish in a large northern river. North American Journal of Fisheries Management 24:1440–1446.

Hill, T. D., W. G. Duffy, and M.R. Thompson. 1995. Food habits of channel catfish in Lake Oahe, South Dakota. Journal of Freshwater Ecology 10:319–323.

Hubert, W. A. 1999a. Biology and management of channel catfish. Pages 3–22 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Hubert, W. A. 1999b. Standards for assessment of age and growth data for channel catfish. Journal of Freshwater Ecology 14:313–326.

Jackson, Z. J., M. C. Quist, and J. G. Larscheid. 2008. Growth standards for nine North American fish. Fisheries Management and Ecology 15:107–118.

Jearld, Jr., A. and B. E. Brown. 1971. Food of the channel catfish (*Ictalurus punctatus*) in a southern Great Plains reservoir. American Midland Naturalist 86:110–115.

Katsanevakis, S. 2006. Modelling fish growth: model selection, multi-model inference and model selection uncertainty. Fisheries Research 81:229–235.

Katsanevakis, S. and C. D. Maravelias. 2008. Modelling fish growth: multi-model inference as a better alternative to *a priori* using von Bertalanffy equation. Fish and Fisheries 9:178–187.

Lewis, G. E. 1976. Summer food of channel catfish in a West Virginia flood control reservoir. The Progressive Fish Culturist 38:177–178.

Maceina, M. J. 1997. Simple application of using residuals from catch-curve regressions to assess year-class strength in fish. Fisheries Research 32:115–121.

Marsh, P. C. 1981. Food of channel catfish in the Coachella Canal, California. Journal of the Arizona-Nevada Academy of Science 16:91–95.

Marshall, M. D., M. J. Maceina, and M. P. Holley. 2009. Age and growth variability between sexes of three catfish species in Lake Wilson, Alabama. North American Journal of Fisheries Management 29:1283–1286.

Merovich, Jr., G. T. and J. T. Petty. 2007. Interactive effects of multiple stressors and restoration priorities in a mined Appalachian watershed. Hydrobiologia 575:13–31.

Merovich, Jr., G. T., J. M. Stiles, J. T. Petty, P. F. Ziemkiewicz, and J. B. Fulton. 2007. Water chemistry-based classification of streams and implications for restoring mined Appalachian watersheds. Environmental Toxicology and Chemistry 26:1361–1369.

Michaletz, P. H. and K. P. Sullivan. 2002. Sampling channel catfish with tandem hoop nets in small impoundments. North American Journal of Fisheries Management. 22:870–878.

Michaletz, P. H. 2006. Prey resource by bluegill and channel catfish in small impoundments. Fisheries Management and Ecology 13:347–354.

Miranda, L. E. and P. W. Bettoli. 2007. Mortality. Pages 229–277 *in* C.S. Guy & M.L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland, USA.

Neely, B. C. and S. C. Dumont. 2011. Effect of soak duration on precision on channel catfish catch with boated, tandem hoop nets. Pages 557–561 *in* P.H. Michaletz and V.H. Travinichek, editors. Conservation, ecology and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Norton, V. M., K. B. Davis, and H. Nishimura. 1976. A technique for sexing channel catfish. Transactions of the American Fisheries Society 105:460–462.

Neumann, R. M., C. S. Guy, and D. W. Willis. 2012. Length, weight, and associated indices. Pages 637–676 *in* A.V. Zale, D.L. Parrish, and T.M. Sutton, editors. Fisheries Techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Peterman, R. M. 1990. Statistical power analysis can improve fisheries research and management. Canadian Journal of Fisheries and Aquatic Science 47:2–15.

Quist, M. C., C. S. Guy, R. D. Schultz, and J. L. Stephen. 2003. Latitudinal comparisons of walleye growth in North America and factors influencing growth of walleyes in Kansas reservoirs. North American Journal of Fisheries Management 23:677–692.

Quist, M.C., M.A. Pegg, and D.R. DeVries. 2012. Age and growth. Pages 677–731 *in* A.V. Zale, D.L. Parrish, and T.M. Sutton, editors. Fisheries Techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Richters, L. K. and K. L. Pope. 2011. Catch of channel catfish with tandem-set hoop nets and gill nets in lentic systems of Nebraska. Pages 573–580 *in* P.H. Michaletz and V.H.

Travinichek, editors. Conservation, ecology and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Rypel, A. L. 2011. Meta-analysis of growth for five North American catfishes: effects of climate, hydrologic habitat, and latitudinal countergradients. Pages 661–677 *in* P.H. Michaletz and V.H. Travinichek, editors. Conservation, ecology and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Shoup, D. E., S. P. Callahan, D. H. Wahl, and C. L. Pierce. 2007. Size-specific growth of bluegill, largemouth bass and channel catfish in relation to prey availability and limnological variables. Journal of Fish Biology 70:21–34.

Shuman,D.A., et al. 2011. Pallid Sturgeon size structure, condition, and growth in the Missouri River Basin. Journal of Applied Ichthyology 27:269–281.

Simco, B. A., C. A. Goudie, G. T. Klar, N. C. Parker, and K. B. Davis. 1989. Influence of sex on growth of channel catfish. Transactions of the American Fisheries Society 118:427–434.

Smith, M. W., A. Y. Then, C. Wor, G. Ralph, K. H. Pollock, and J. M. Hoenig. 2012. Recommendations for catch-curve analysis. North American Journal of Fisheries Management 32:956–967.

Starostka, V. J. and W. E. Nelson. 1974. Age, growth, sexual maturity, and food of channel catfish in central Lake Oahe, 1968-69. U.S. Fish and Wildlife Service Technical Papers 81, Washington, D.C..

Sullivan, K. P. and C. M. Gale. 1999. A comparison of channel catfish catch rates, size distributions, and mortalities using three different gears in a Missouri impoundment.

Pages 293–300 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Sutton, T. M., M. J. Cyterski, J. J. Ney & M. C. Duval. 2004. Determination of factors influencing stomach content retention by striped bass captured using gillnets. Journal of Fish Biology 64:903–910.

Sweka, J. A. and K. J. Hartman. 2008. Contribution of terrestrial invertebrates to yearly brook trout prey consumption and growth. Transactions of the American Fisheries Society 137:224–235.

Taylor, N. D. 2013. Assessment of age, diet and growth of Yellow Perch (*Perca flavescens*) in Cheat Lake, West Virginia. Master's Thesis, West Virginia University, Morgantown, West Virginia.

Tyus, H. M. and N. J. Nikirk. 1990. Abundance, growth, and diet of channel catfish, *Ictalurus punctatus*, in the Green and Yampa Rivers, Colorado and Utah. The Southwestern Naturalist 35:188–198.

Vokoun, J. C. and C. F. Rabeni. 1999. Catfish sampling in rivers and streams: a review of strategies, gears and methods. Pages 271–286 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Wege, G. J. and R. O. Anderson. 1978. Relative weight (Wr): a new index of condition for largemouth bass. Pages 79–91 *in* G.D. Novinger and J.G. Dillard, editors. New approaches to the management of small impoundments. American Fisheries Society, North Central Division, Special Publication 5, Bethesda, Maryland.

Weisberg, S. B. and A. J. Janicki. 1990. Summer feeding patterns of white perch, channel catfish, and yellow perch in the Susquehanna River, Maryland. Journal of Freshwater Ecology 5:391–405.

Welsh, S. A. and S. A. Perry. 1997. Acidification and fish occurrence in the upper Cheat River Drainage, West Virginia. Journal of the American Water Resources Association 33:423–429.

Yin, Y. J. and W. N. Tzeng, 2009. Modelling growth of Japanese eel *Anguilla japonica* in the lower reach of the Kao-Ping River, southern Taiwan: an information theory approach. Journal of Fish Biology 75:100–112.

Table 1: Mean relative weights (W_r) of Cheat Lake Channel Catfish (n=155). W_r is summarized by Gabelhouse (1984) length categories, where length was measured as total length (TL) in millimeters. Percentile values were determined from Brown et al. (1995) using distributions of W_r by length category. NA indicates an insufficient sample size for calculation.

Length Category	TL	n	Mean W_r	95% CI	Percentile
Sub-stock	<280	10	98	(88, 108)	50 – 75th
Stock	280-409	34	93	(90, 96)	50 – 75th
Quality	410-609	94	93	(91, 95)	50th
Preferred	610-709	16	91	(84, 97)	10 – 25th
Memorable	710-909	1	115	NA	75 – 90th
Trophy	≥ 910	0	NA	NA	NA

Table 2: Results of model selection for four candidate growth models for 148 Channel Catfish from Cheat Lake, West Virginia.

Model	K	AIC_c	ΔAIC_c	AIC_c Weight
VBGM	4	1655.22	0	0.39
Power	4	1655.24	0.02	0.38
Gompertz	4	1656.87	1.65	0.17
Logistic	4	1658.96	3.74	0.06

Table 3: Parameter estimates from fitting of four candidate models to length at age data from 148 Channel Catfish from Cheat Lake, West Virginia.

Model	Parameter	Estimate	SE
VBGM	L_∞	595.308	16.561
	k	0.292	0.041
	t_0	0.439	0.326
Gompertz	L_∞	585.010	14.338
	G	0.381	0.049
	t_0	1.786	0.202
Logistic	L_∞	578.825	13.148
	G	0.470	0.056
	t_0	2.664	0.178
Power	b_0	762.266	89.141
	b_1	-873.711	45.572
	B_2	-0.621	0.178

Table 4: Results of model selection for four candidate growth models for 86 female Channel Catfish from Cheat Lake, West Virginia.

Model	K	AIC_c	ΔAIC_c	AIC_c Weight
Power	4	958.69	0	0.71
VBGM	4	961.40	2.71	0.18
Gompertz	4	963.08	4.39	0.08
Logistic	4	964.79	6.10	0.03

Table 5: Parameter estimates from fitting of four candidate models to length at age data from 86 female Channel Catfish from Cheat Lake, West Virginia.

Model	Parameter	Estimate	SE
VBGM	L_∞	621.096	31.854
	k	0.192	0.045
	t_0	-0.805	0.773
Gompertz	L_∞	607.136	25.860
	G	0.251	0.050
	t_0	1.162	0.397
Logistic	L_∞	598.336	22.487
	G	0.311	0.056
	t_0	2.432	0.331
Power	b_0	1089.278	562.895
	b_1	-1036.618	480.896
	B_2	-0.274	0.243

Table 6: Results of model selection for four candidate growth models for 60 male Channel Catfish from Cheat Lake, West Virginia.

Model	K	AIC_c	ΔAIC_c	AIC_c Weight
Logistic	4	670.56	0.00	0.38
Gompertz	4	670.78	0.22	0.34
VBGM	4	671.52	0.96	0.24
Power	4	674.96	4.40	0.04

Table 7: Parameter estimates from fitting of four candidate models to length at age data from 60 male Channel Catfish from Cheat Lake, West Virginia.

Model	Parameter	Estimate	SE
VBGM	L_∞	612.377	31.482
	k	0.304	0.739
	t_0	0.593	0.535
Gompertz	L_∞	603.317	27.204
	G	0.391	0.083
	t_0	1.890	0.320
Logistic	L_∞	598.403	24.831
	G	0.474	0.092
	t_0	2.752	0.287
Power	b_0	766.316	148.615
	b_1	-940.001	96.481
	B_2	-0.689	0.336

Table 8: Description of Channel Catfish growth from Cheat Lake, West Virginia (n = 148). Mean RGI values and Hubert (1999) percentiles are provided to compare Cheat Lake Channel Catfish growth to populations throughout the species range.

Age	n	Mean TL	Mean RGI	SD	Percentile
3	22	309	123.18	19.84	75-90
4	21	394	129.10	14.34	90-95
5	6	416	117.49	23.23	75-90
6	11	505	126.61	12.25	90-95
7	39	503	114.33	14.06	75-90
8	4	549	115.15	16.78	75-90
9	7	543	106.41	15.59	50-75
10	7	533	94.85	18.17	25-50

Table 9: Diet contents of 41 Channel Catfish from Cheat Lake, West Virginia collected from 13 October to 4 December 2014. Percent frequency of occurrence (O_i), mean percent frequency by number (MN_i) and prey-specific abundance (P_i)

Food Item	O_i	MN_i	P_i
Aquatic	***82.9***	***73.5***	***95.1***
Annelida	**7.3**	**4.9**	**40.0**
Hirudinea	2.4	1.3	50.0
Oligachaeta	4.9	3.6	39.5
Bivalvia	**7.3**	**2.9**	**11.8**
Corbiculidae	2.4	0.2	8.3
Sphaeridae	7.3	2.7	10.3
Crayfishes	**9.8**	**3.8**	**20.8**
Diptera	**48.8**	**36.6**	**86.8**
Chaoboridae	31.7	9.0	29.0
Chironomidae (larvae)	44.0	26.4	60.5
Chironomidae (pupae)	4.9	0.9	1.0
Tipulidae	2.4	0.3	12.5
Ephemeroptera	**22.0**	**7.5**	**8.2**
Ephemeridae	9.8	1.5	3.6
Heptageniidae	9.8	5.1	27.6
Leptophlebiidae	2.4	0.9	33.3
Gammaridae	**7.3**	**0.9**	**7.2**
Fishes	**9.8**	**8.1**	**26.7**
Odonata	**2.4**	**0.5**	**20.0**
Anisoptera	2.4	0.3	10.0
Zygoptera	2.4	0.3	10.0
Sialidae	**22.0**	**8.2**	**14.9**
Terrestrial	***39.0***	***26.5***	***27.9***
Aranae	**4.9**	**1.3**	**22.2**
Cicadellidae	**9.8**	**0.7**	**4.2**
Coleoptera	**4.9**	**1.1**	**22.2**
Diploda	**2.4**	**0.1**	**2.8**
Diptera (Adult)	**4.9**	**1.8**	**33.3**
Formicidae	**4.9**	**0.6**	**11.6**
Fruit and Nuts	**14.6**	**6.3**	**21.7**
Acorns	2.4	0.7	25.0
Wild Grapes	9.8	3.0	20.3
Paw-Paw	2.4	2.6	100
Hemiptera	**10.0**	**2.5**	**8.7**
Lepidoptera	**14.6**	**6.5**	**22.1**
Muscidae	**2.4**	**0.1**	**2.6**
Rodentia	**4.9**	**5.3**	**100**
Vespidae	**4.9**	**0.2**	**3.6**
Detritus	**31.7**	**-**	**-**

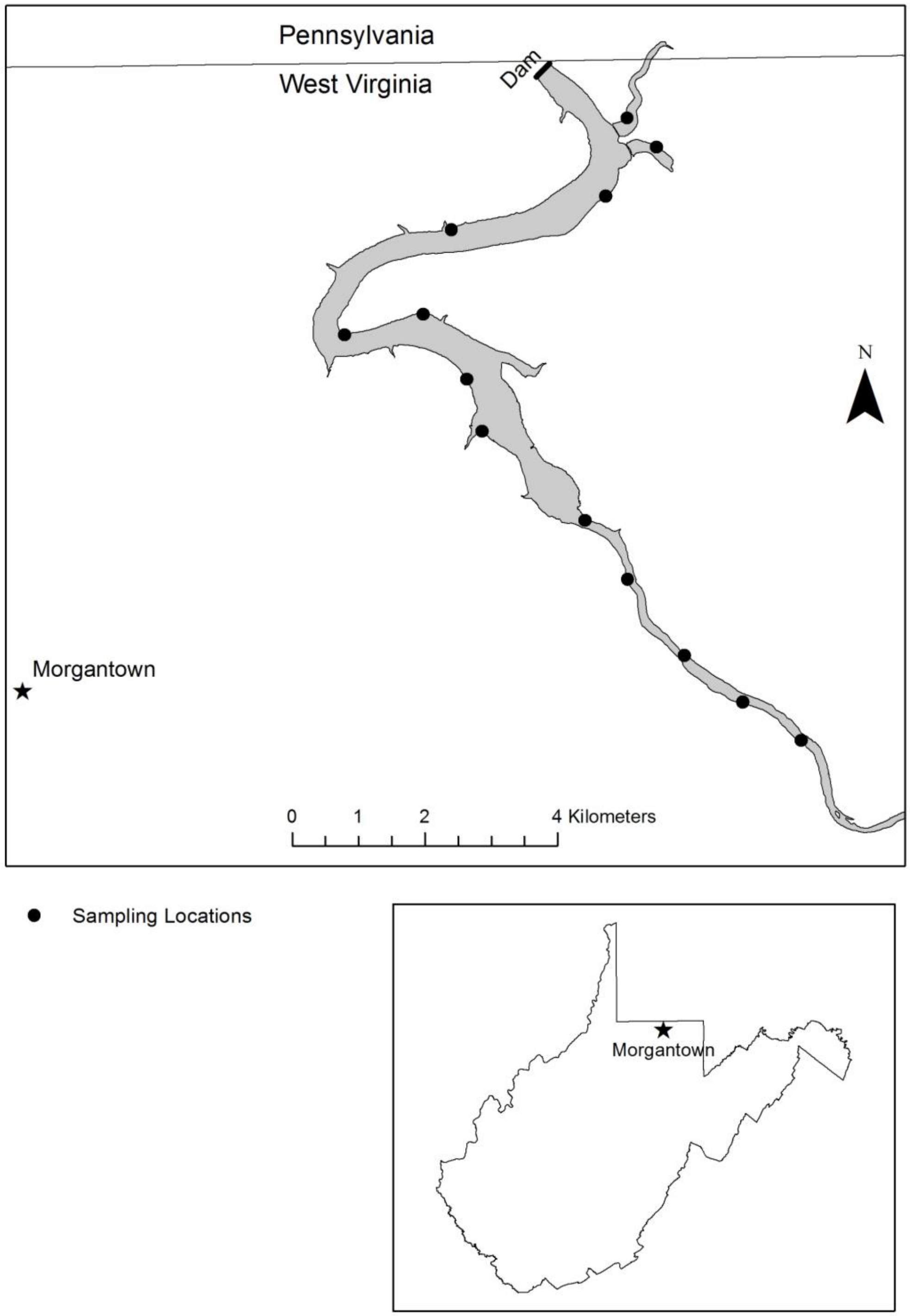

Figure 1: Cheat Lake, West Virginia with general sampling locations noted.

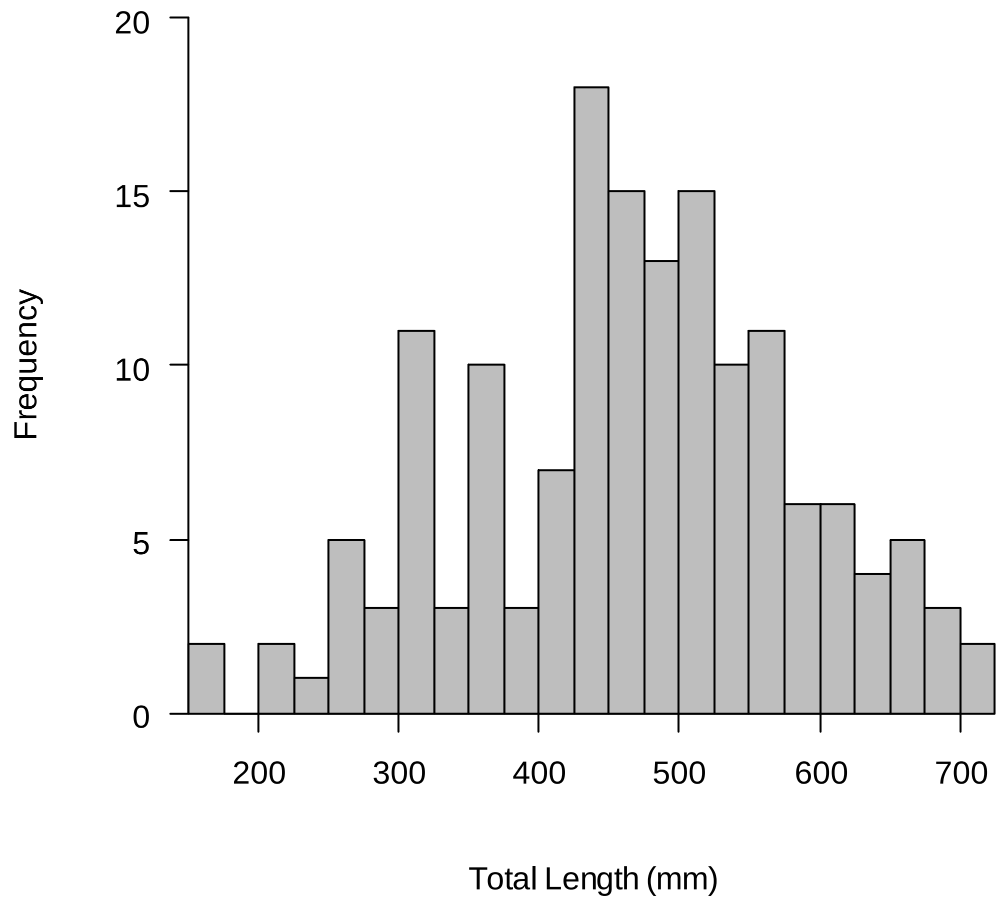

Figure 2: Length frequency distribution of Cheat Lake, West Virginia Channel Catfish (n = 155) using 25 mm bins.

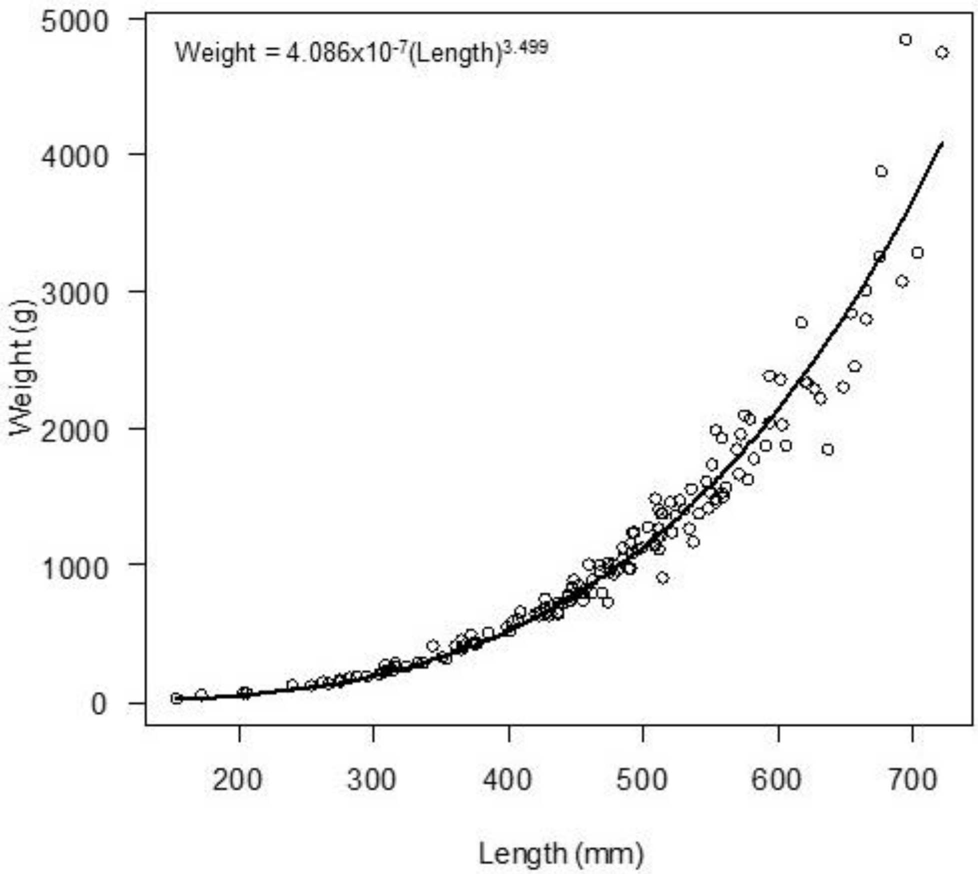

Figure 3: Relationship between total length and weight of Channel Catfish from Cheat Lake, West Virginia (n = 155). A power curve was fit to the data.

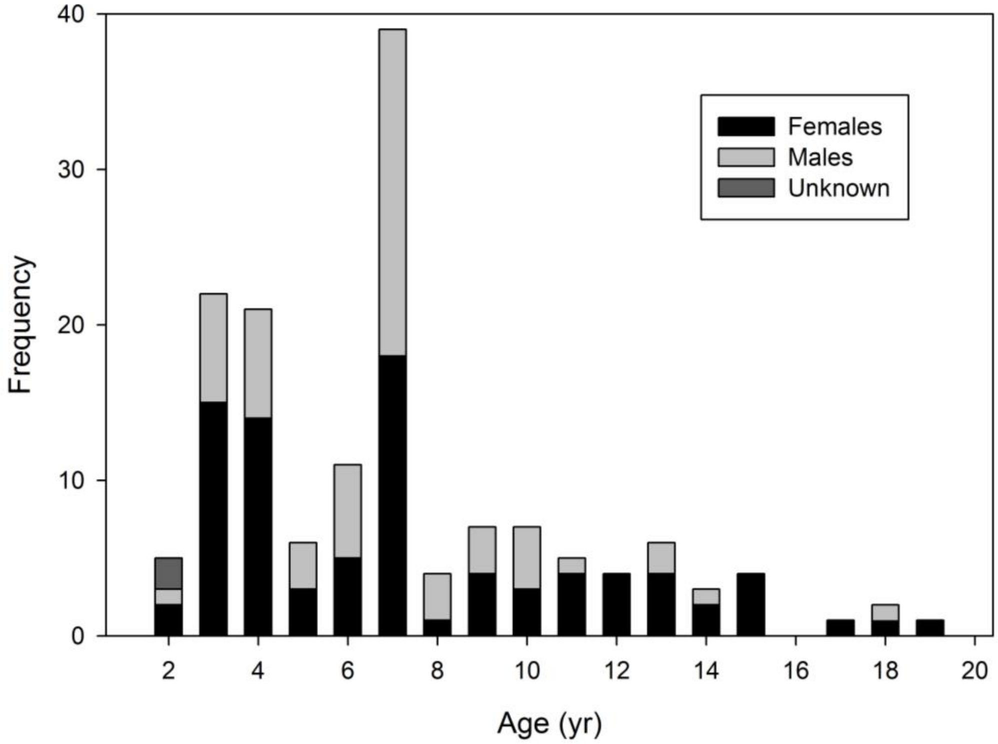

Figure 4: Age structure of Channel Catfish (n = 148) from Cheat Lake, West Virginia.

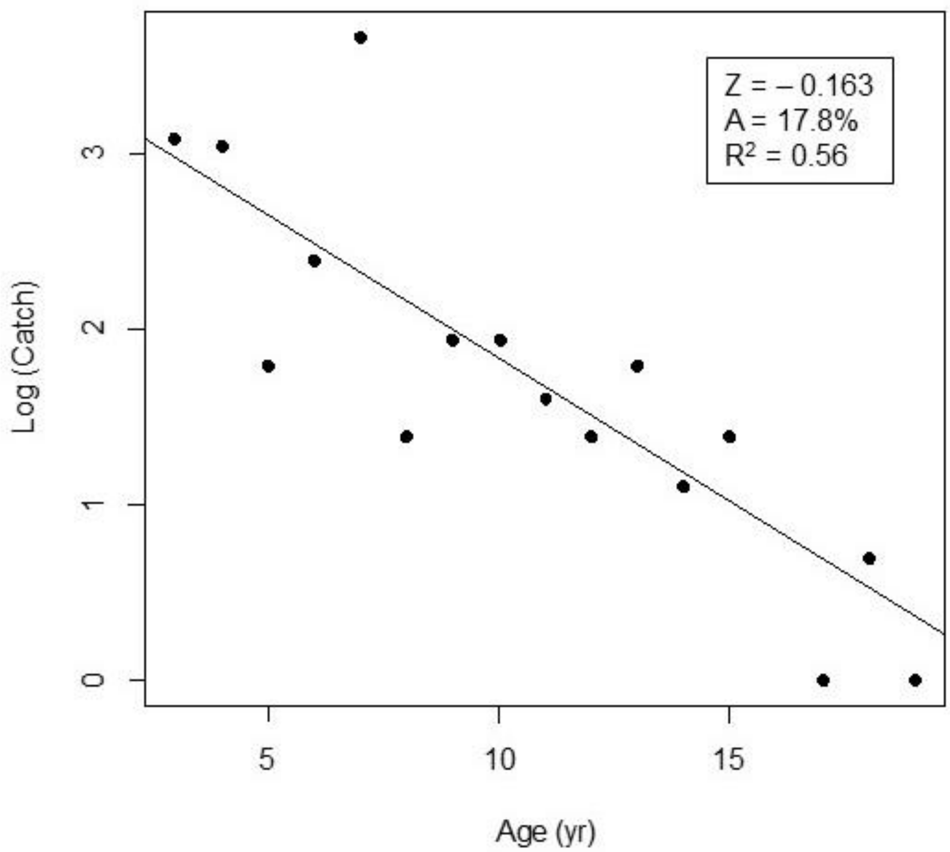

Figure 5: Catch curve regression used for estimation of instantaneous mortality. Number of fish collected in each age group (Catch) was natural logarithm-transformed to linearize catch data. Line was fit to ages 3–19.

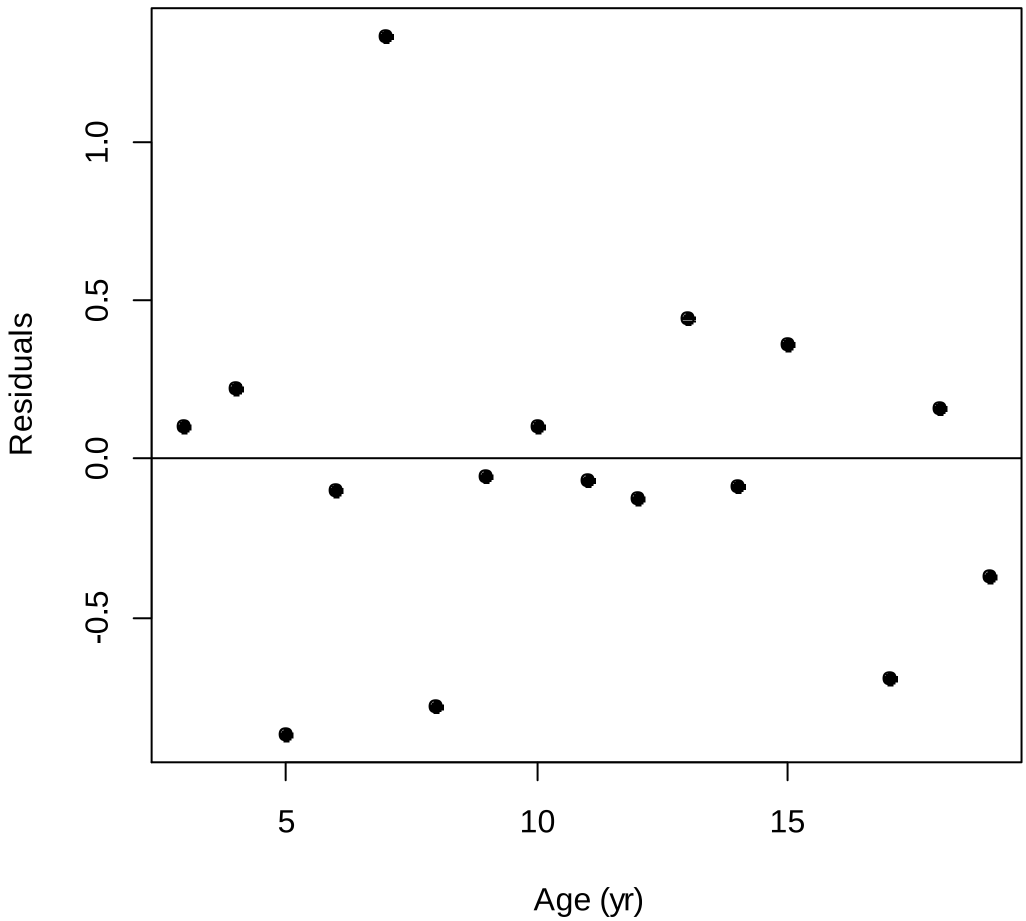

Figure 6: Plot of residuals from catch-curve regression in Figure 5. Regression line was fit to natural logarithm-transformed catch data and natural logarithm-residuals are presented.

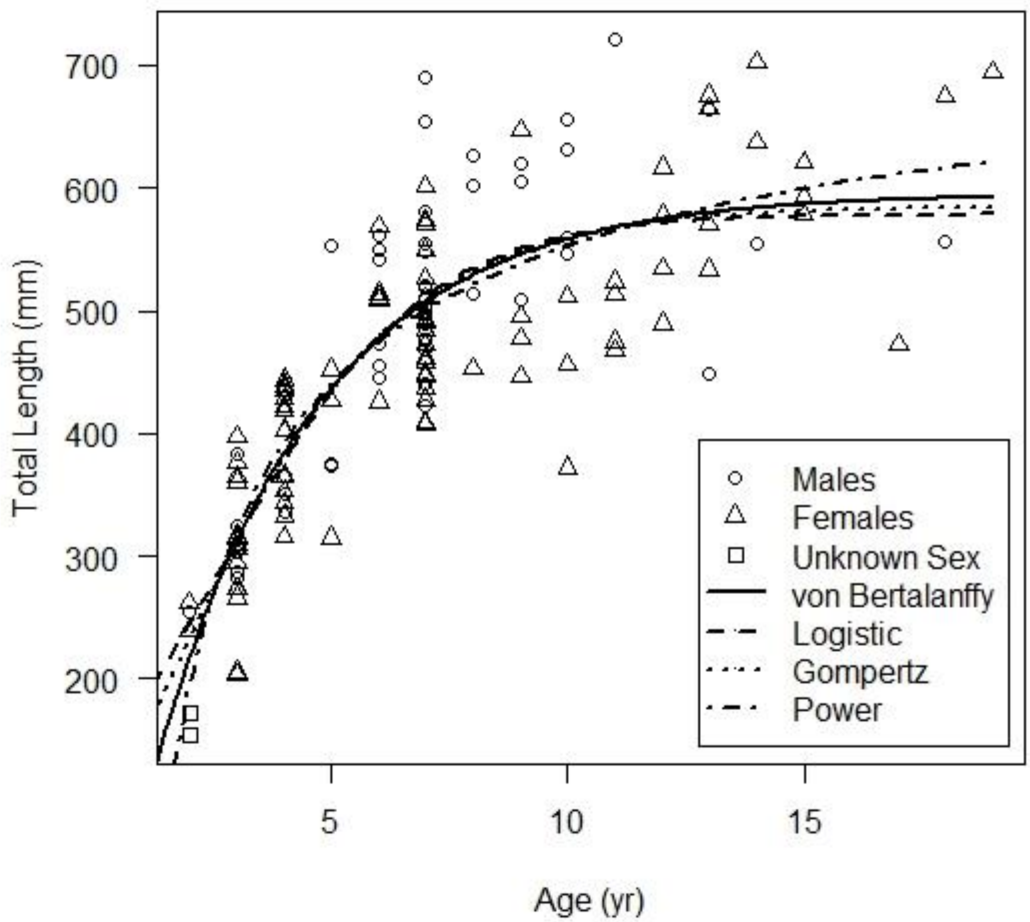

Figure 7: Four candidate growth models fit to length at age data of 148 Channel Catfish (ages 2–19) from Cheat Lake, West Virginia.