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DIRECT AND INDIRECT EFFECTS
OF RECENT GIZZARD SHAD INTRODUCTIONS IN
FOUR SOUTH DAKOTA SMALL IMPOUNDMENTS

BY
BRANDON VANDERBUSH

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Wildlife and Fisheries Sciences

Specialization in Fisheries Science

South Dakota State University

2019

THESIS ACCEPTANCE PAGE

Brandon Vanderbush

This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree.

Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Mike Brown

Advisor

Date

Michele R. Dudash

Department Head

Date

Dean, Graduate School

Date

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ABSTRACT

DIRECT AND INDIRECT EFFECTS OF RECENT GIZZARD SHAD
INTRODUCTIONS IN FOUR SOUTH DAKOTA SMALL IMPOUNDMENTS

BRANDON VANDERBUSH

2019

Managing fisheries requires balancing predators and prey. Prey stockings are often used when food sources may be limiting to support fish communities with multiple predators. Stocking of prey often results in increased predator size and could potentially lead to the consumption of nuisance species such as Black Bullheads *Ameiurus melas*. Gizzard Shad *Dorosoma cepedianum* are an often-stocked prey species and have been recently stocked into several small impoundments across South Dakota. One of the focuses of this study was to document the contribution of age-0 Gizzard Shad to predator fish food habits and growth. Gizzard Shad consumption varied between impoundments and predators, with shad primarily being consumed in western impoundments. Gizzard Shad made up to 50% of Black Crappie *Pomoxis nigromaculatus*, Largemouth Bass *Micropterus salmoides* and Walleye *Sander vitreus*. The absence of Gizzard Shad from several predator food habits resulted in either a reduced growth or little to no effect during bioenergetic simulations. Though Gizzard Shad were important to several predator food habits, the presence or absence does not seem to impact the growth of predators. Even with little impact on predator growth Black Bullheads were vulnerable to predation by these predators. However, relatively few bullheads were consumed by predators. The introduction of Gizzard Shad into impoundments seems to have limited impacts on both predator species and in turn no effect on the biological control of Black Bullheads. There is potential that future introductions will have similar results and that

predator fish may not be enhanced and that there will be no biological control of Black Bullheads. There is still unknown information about the effects of Gizzard Shad introductions within these small impoundments and future research should focus on how other species are impacted. Additionally, future research should examine under what conditions Black Bullheads are selected for as prey.

CHAPTER 1: INTRODUCTION

Management of recreational fisheries frequently involves maintaining a balance between predators and prey (Swingle 1950; Flickinger et al. 1999). Reservoir fisheries may be “out of balance” (e.g., too few prey, too many predators or “undesirable” species, size structure mismatches between prey and predators) due to their artificial nature and frequently-introduced fish assemblages that are combinations of native riverine and lacustrine fishes, and introduced fishes (Hayes et al. 1999). The creation and maintenance of reservoir fisheries are often achieved through stocking both predators and prey species (Miranda and Bettoli 2010; Moffit et al. 2010). Prey stocking has been shown to improve survival, growth and size structure of predators in some cases (Noble 1981; Wydoski and Bennet 1981; Wright and Kraft 2012).

Various species and families of prey have been done with the objective to benefitting many predators, depending predator prey preferences and what prey species may be supported in that environment. When selecting a prey species to stock, several factors should be considered (Ney 1981). First, prey should be abundant to support a number of predators; such examples may include species such as Bluegill *Lepomis macrochirus* (Noble 1981; Wright and Kraft 2012), Golden Shiners *Notemigonus crysoleucas* (Noble 1981; Wright and Kraft 2012), and silversides *Menidia spp.* (Mense 1967; Hubbs and Dean 1979; Noble 1981). Second, recruitment of prey populations should, ideally, be stable (Murdoch 1969; Ney 1981); “boom-and-bust cycles” may lead to competition with other species when prey are highly abundant or lead to decreased predator growth and survival when prey year classes are weak or absent (Stevens 1979). Third prey should preferably be primary consumers to allow for a quick efficient energy

transfer to higher trophic levels (Ney 1981). Fourth, prey should not exhibit anti-predator behaviors or have defensive structures (i.e., hard parts) that may deter predation (Carver et al. 1978; Holm et al. 2009; Fine et al. 2011; Wright and Kraft 2012). Fifth prey species should be non-emigrating due to concerns with potential negative influences on other connected waterbodies (Ney 1981). Finally prey species should be innocuous to other trophic levels within a waterbody and not negatively impact other levels (Ney 1981). These characteristics can be used to determine the suitability of a stocked prey species to meet management goals of a fish community.

A prey species that has been widely stocked into reservoirs in the United States is Gizzard Shad *Dorosoma cepedianum* (Heidinger 1983; Dettmers and Stein 1992; Dettmers and Stein 1996; Moyle and Cech 2003). Several studies have documented the importance of Gizzard Shad to predator food habits including, but not limited to: Walleye *Sander vitreus* (Stroud 1949; Jester and Jensen 1972, Quist et al. 2004, Ward et al. 2007; Wuellner et al. 2010); Black and White Crappies *Pomoxis nigromaculatus* and *P. annularis* (Michaletz 1997); Largemouth Bass *Micropterus salmoides* (Lewis et al. 1974; Pasch 1974; Storck 1986); Smallmouth Bass *M. dolomieu* (Wuellner et al. 2010); and White Bass *Morone chrysops* (Aggus 1973; Storck 1986; Michaletz 1993; Ahrens et al. 2010). High consumption of Gizzard Shad by predators has been linked to higher abundance, faster growth, and improved body condition (e.g., Hartman and Margraf 1992; Michaletz 1997; Garvey and Stein 1998; Ward et al. 2007; Wuellner et al. 2010). Hartman and Margraf (1992) found a positive relationship between consumption of Gizzard Shad and age-1 Walleye growth. Michaletz (1997) found that Walleye growth was higher (17 mm) for at least one year when age-0 Gizzard Shad were abundant

compared to one year when shad abundance was relatively low. Several Largemouth Bass populations in Ohio reservoirs had higher growth rates (0.06 – 0.12 g/d) when Gizzard Shad were present compared to a reservoir with only Bluegill (0.04 g/d; Garvey and Stein 1998). Most Gizzard Shad reach sexual maturity by age-II and a single female shad can produce over 2 hundred thousand eggs (Bodola 1955). Because of a high fecundity, along with high caloric densities and soft bodies predator fish often select for Gizzard Shad over other prey items (Eggleton and Schramm 2002). According to Ney's (1981) defined characteristics, Gizzard Shad would be considered suitable prey and is obvious why they are often stocked as a prey species.

Gizzard Shad are native to the Missouri River basin in South Dakota (Heidinger 1983) but have been introduced into several reservoirs and small lakes across the state (Ward 2007; Wuellner et al. 2008; VanDeHey 2013). Both native and introduced Gizzard Shad populations in South Dakota have been linked to positive effects on predators. In Angostura Reservoir in western South Dakota, Ward et al. (2007) found increased growth and abundance of Walleye over several years following the introduction of Gizzard Shad. Wuellner et al. (2010) found that if native Gizzard Shad were absent in Lake Sharpe, growth of Walleye and Smallmouth Bass *Micropterus dolomieu* would be reduced substantially. VanDeHey et al. (2013) showed that stocking Gizzard Shad to supplement the existing prey base increased body condition and growth rates for Walleye in several northeastern South Dakota natural lakes. Because of these positive effects, Gizzard Shad stocking has continued in many reservoirs and has recently expanded to other waterbodies within the state (Gene Galinat and Dave Lucchesi, South Dakota Department of Game, Fish and Parks, *personal communication*).

To date, no research has been done to assess the effects of Gizzard Shad introductions in small reservoir (< 200 ha) fish communities in South Dakota. These waters are recreationally important across the state and can each generate >\$35,000 in revenues annually, on average (Sundmark and Gigliotti, *in press*). Adult Gizzard Shad are captured in the spring from other self-sustaining populations and introduced prior to spawning so that the young-of-the-year shad will provide a prey resource (Wuellner et al. 2008; VanDeHey et al. 2010; Fincel et al. 2017). Year-to-year stocking schedules vary by waterbody. If a sufficient number of adults survive the winter to reproduce the following spring, then stocking additional pre-spawn adults may not be necessary due to the high reproductive capacity of Gizzard Shad (Noble 1981). However, stocking may be needed annually when adult survival is low or nonexistent (Gene Galinat and Dave Lucchesi, South Dakota Department of Game, Fish and Parks, *personal communication*).

While the stocking of Gizzard Shad may provide some positive direct benefits to recreational fisheries, shad introductions may also negatively affect fish communities through direct and indirect pathways. Previous research has found that negative impacts of Gizzard Shad may occur due to “middle-out” processes (DeVries and Stein 1992), impacting both lower and higher trophic levels; such impacts may differ depending on the life stage of the shad (e.g., juvenile v. adult; Stein et al. 1995; Aday et al. 2003). Adult Gizzard Shad can alter nutrient cycling and increase internal nutrient loading by feeding on detritus and excreting wastes; both processes may release sequestered nitrogen and phosphorous from lake and reservoir sediments (Mundahl 1991; Schaus et al. 2002). Increases in nitrogen and phosphorous can then increase phytoplankton and zooplankton density (Stein et al. 1995). Additionally, adult and juvenile Gizzard Shad may alter

zooplankton abundances, diversity, and size structure within a waterbody as a result of consumption (Drenner et al. 1984; Threlkeld and Drenner 1987; Lazzaro et al. 1992; Stein et al. 1995). Changes in the zooplankton community increase densities of phytoplankton as there are smaller and fewer zooplankton to consume phytoplankton (Brooks and Dodson 1965; Lazzaro 1987; Stein et al. 1995).

The various impacts Gizzard Shad have on phytoplankton and zooplankton may affect other trophic levels within a fish community and alter the balance within a reservoir (Drenner et al. 1984; Threlkeld and Drenner 1987; DeVries and Stein 1992; Lazzaro et al. 1992; Stein et al. 1995). For example, altered zooplankton size structure resulting from Gizzard Shad consumption can negatively affect larval Bluegill *Lepomis macrochirus* survival as both fishes rely on this food source (Stein et al. 1995; Bremigan and Stein 1997). Additionally, abundance, growth rates, and maximum sizes of older Bluegills may be reduced in the presence of juvenile Gizzard Shad due to competition for food resources (DeVries et al. 1991; DeVries and Stein 1992; Stein et al. 1995; Aday et al. 2003). More complex relationships exist between Gizzard Shad and Largemouth Bass. Young-of-year Gizzard Shad may quickly outgrow the gape-limitations of juvenile Largemouth Bass (Noble 1981; Stork 1986; Hambright et al. 1991), forcing bass to switch to less energetically favorable prey, which may lead to reductions of bass body size and increase the risk of overwinter mortality (Stein et al. 1995). Further, competition between Gizzard Shad and Bluegill may have consequences for Largemouth Bass populations as reductions in the abundance of Bluegill may further reduce available food for bass (Stein et al. 1995; Bremigan and Stein 1997). Thus, the various effects Gizzard

Shad may have on a fish community can alter or destabilize trophic structure within a reservoir (DeVries and Stein 1992).

High abundances of other fishes in small impoundments may further alter physical habitat, water quality, and fish communities. Many species, both non-native and native, have some potential of becoming overabundant under certain conditions, and the impacts they have on their respective communities may differ. For example, Common Carp *Cyprinus carpio* are commonly known to increase turbidity and increase internal nutrient loading in many waters where they are not native (Crivelli 1983; Meijer et al. 1990; Roberts et al. 1995; Drenner et al. 1997). Drenner et al. (1997) found that ponds with Common Carp had higher turbidity levels [12 – 15 nephelometric turbidity units (NTU) higher] than ponds without carp. Common Carp have also been associated with reductions of aquatic vegetation due to their feeding habits (Bajer et al. 2009). An overabundance of Bluegills *Lepomis macrochirus* in small waterbodies can negatively impact Largemouth Bass populations through competition, reduced recruitment (Smith 1976; Wright and Kraft 2012) and growth of Largemouth Bass (Smith 1976). Overabundant species may lead to further imbalances within aquatic ecosystems, but various management options may help to mitigate these impacts (Wydoski and Wiley 1999).

Nuisance fish are often controlled with various chemical, mechanical, and biological methods (Wydoski and Wiley 1999); each control method may produce various rates of success and has its own set of distinct advantages and disadvantages. Chemical control methods are often preferred because costs are generally low, planning and application are relatively easy, and effects are relatively long lasting (Lennon et al. 1970; Eschmeyer 1975; Bandow 1989). Chemical treatments may include rotenone,

antimycin, copper sulfate, squoxin, and toxaphene, to name a few (Meronek et al. 1996). Several drawbacks to these kinds of treatments exist. First, treatments can indiscriminately kill desirable fishes or those of conservation importance (Bettoli and Maceina 1996). Second, the success rate of chemical treatments is highly variable as the effectiveness of treatments may be related to water body size, depth, and temperature and species' chemical resistance (Parker 1970; Marking and Bills 1976; Bradbury 1986). Finally, opposition due to concerns over water odors and flavor following the execution of a chemical treatment (Cohen et al. 1960, 1961) may limit public support for this management option (Wydoski and Wiley 1999).

Mechanical removal (e.g., barriers, commercial fishing, water-level manipulation, or netting with seines or passive fishing gears to selectively harvest undesirable fish) is another commonly used option for controlling nuisance species (Wydoski and Wiley 1999). Mechanical control methods often require substantial labor and time to remove the appropriate number of individuals from the population of interest (Wydoski and Wiley 1999), but efficiency may be improved by combining chemical and mechanical treatments that may stimulate fish movement to the removal gear of choice (Brown 1964). Success rates of mechanical removals vary widely (average ~43%; Meronek et al. 1996) and may depend on the gear of choice. For example, Kulp and Moore (2000) found that the removal of invasive Rainbow Trout *Oncorhynchus mykiss* via electrofishing allowed for successful reproduction of native Brook Trout *Salvelinus fontinalis* while not impacting native Blacknose Dace *Rhycolis atratulu* in an Appalachian stream. In contrast, there was no improvement of the Rainbow Trout fishery in Pyramid Lake, Alberta, when Longnose Suckers *Catostomus catostomus* were

removed through a combination of gill and fyke netting and seining (Rawson and Elsey 1950). One potential negative consequence of mechanical removal is the increased growth and fecundity of the undesirable fish population as fecundity and survival may respond in a compensatory manner as relative abundance decreases (Wydoski and Wiley 1999). In fact, previous research has shown that undesirable fish populations can reach abundances similar to pre-treatment levels within 1 – 5 years after a mechanical removal effort (Wydoski and Wiley 1999).

The final control method often used is biological which is rooted in ecological theory and involves manipulation of food web dynamics via increased predation pressure or reductions of prey species via increased predation through stocking (Schuyttema 1977; Reynolds 1994; Wydoski and Wiley 1999). The introduction of predator fish can provide a relatively low cost tool for controlling small-bodied nuisance fish (e.g., young-of-the-year or species whose maximum size is relatively small) when the abundance and size of predators are appropriately matched to smaller bodied nuisance fish (Miller et al. 1989; Reynolds 1994; Wydoski and Wiley 1999). Predator introductions are often used to control various species within impoundments (Steward et al. 1981; Hartman and Margraf 1993; Anderson and Neumann 1996). Success rates of predator introductions are relatively lower (~24% success rate) when compared to either mechanical or chemical controls (Meronek et al. 1996).

One species that is commonly found in reservoirs and small lakes and often considered an undesirable species is Black Bullhead *Ameiurus melas* (Carlander and Moorman 1956; Jenkins 1958; Brown et al. 1999). Black Bullheads can reach nuisance abundances in both their native (Carlander and Moorman 1956; Jenkins 1958; Brown et

al. 1999) and introduced habitats (Wheeler 1978; Boet 2001; Copp et al. 2005). High biomasses of Black Bullheads can lead to short- and long-term physical and chemical changes within aquatic ecosystems (Carlander 1955; Carlander and Moorman 1956; Jenkins 1958; Brown et al. 1999). For example, nesting activities exhibited by Black Bullheads may have short-term effects (e.g. 1 – 2 months) on aquatic food webs due to the displacement of aquatic vegetation (Kahl 1991; Braig and Johnson 2003), mixing of sediments, and reduction in photic zone (Kahl 1991). Increases in both surface and bottom turbidity have been observed in response to increases in Black Bullhead biomass in controlled settings (Braig and Johnson 2003). In European waterbodies, Leunda et al. (2008) found that introduced Black Bullheads affected native fishes directly and indirectly either through consumption of those fish or through reduction of prey (i.e., invertebrates) and destruction of nursery habitat. Documentation of the impacts of overabundant Black Bullheads around the world has prompted interest in the development effective control methods (Cucherousset et al. 2006; Leunda et al. 2008; Ribeiro et al. 2008; Novomeska et al. 2013).

Various methods have been tried to control Black Bullheads abundances, including chemical (Clemens and Martin 1953; Bandow 1989; Bettoli and Maceina 1996; Ward et al. 2013) and mechanical removal (Hanson et al. 1983; Cucherousset et al. 2011) and the introduction of predator fishes (Blankman 2004). Short- or long-term success rates of all three methods vary widely (Meronek et al. 1996). For example, Bandow (1989) used winter rotenone treatments to successfully reduce Black Bullhead populations in some small Minnesota waterbodies, but bullhead abundance was only reduced for a year or two. Mechanical removal of Black Bullheads with fyke-nets

reduced the standing population of bullheads >76 mm (total length) and increased the size structure of the remaining population for at least five years (Hanson et al. 1983). The introduction of Flathead Catfish *Pylodictis olivaris* reduced Black Bullhead populations within several small farm ponds to undetectable levels, but Flathead Catfish were not recovered after initial introduction (Blankman 2004). To date, limited information exists on the ability of other predators to control Black Bullhead populations, especially in larger bodies of water (e.g., lakes and impoundments).

Many efforts to use biological controls for overabundant species involve introducing new members into a community (Steward et al. 1981; Hartman and Margraf 1993; Anderson and Neumann 1996). However, introductions of new piscivores may involve some unintended risks to other members of aquatic communities (Simberloff and Stiling 1996; USACE 2012). Using existing members of the community as a means for biological control may reduce these risks. In addition, the use of existing predators in a community to control Black Bullhead may be advantageous as costs could be relatively low (Meronek et al. 1996). To date, no research has examined control of Black Bullheads by existing predator communities. However, several lines of research support the possibility. Liao et al. (2002) found that Largemouth Bass consumed Black Bullheads throughout the growing season (i.e., May – October); in fact, bullheads occurred in ~50% of all bass stomachs sampled. Northern Pike *Esox lucius* have been found to consume some Black Bullheads in a shallow bog lake, but bullheads only constituted a small proportion of food items (2%; Pierce et al. 2003). Though several predators have been found to consume Black Bullheads, control may not be feasible if bullhead size exceeds predator gape limitations. Blankman (2004) found that Black

Bullheads were only consumed by Flathead Catfish greater than 1.4 kg (Blankman 2004). Only Walleyes that had reached at least 380 mm TL were able to consume Black Bullheads in Lake Thompson, South Dakota (Isaak et al 1993). Further research is needed in order to learn which predators and size of predators may be able to control Black Bullhead through consumption.

Because small impoundments provide recreational benefits, research is needed to understand the dynamics of predators and prey in these systems in order to keep fish communities in balance and sustain recreational fisheries. Introductions of Gizzard Shad into these waters may increase predator growth rates and abundance so that biological control of nuisance species such as Black Bullhead may be possible. To date, no study has addressed these particular relationships in small impoundments. Thus, I completed a field study to address the following objectives:

1. Document the relative contribution of age-0 Gizzard Shad to the food habits and growth of several fish predators within four small South Dakota reservoirs.
2. Determine whether existing predators are consuming and potentially acting as a biological control of Black Bullheads following the introduction of Gizzard Shad.

Information gleaned from this study can be used to make decisions on when and where to stock Gizzard Shad and to determine under what conditions biological controls of Black Bullheads may be possible.

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CHAPTER 2. INFLUENCE OF AGE-0 GIZZARD SHAD CONSUMPTION ON PREDATOR FOOD HABITS AND GROWTH RATES WITHIN FOUR SMALL SOUTH DAKOTA RESERVOIRS

INTRODUCTION

Managing fisheries involves maintaining a balance between predators and prey assemblages (Swingle 1950; Flickinger et al. 1999). Reservoir fisheries may be out of balance (e.g., too few prey, too many predators or undesirable species) due to their artificial nature and altered fish assemblages (Hayes et al. 1999). The creation and maintenance of reservoir fisheries are often achieved through stocking both predators and prey species (Miranda and Bettoli 2010). Prey stocking is sometimes needed when a complex piscivore community is not supported by the existing prey assemblage and density (Ney and Orth 1986; Wright and Kraft 2012). Prey abundance and size structure must be adequate to support predator survival, growth, and reproduction in order to support a quality angling experience (Ney and Orth 1986).

A common prey species that has been widely stocked across reservoirs in the United States is Gizzard Shad *Dorosoma cepedianum* (Heidinger 1983; Dettmers and Stein 1992; Dettmers and Stein 1996; Moyle and Cech 2003). Several studies have documented the importance of Gizzard Shad to many predators, including but not limited to: Walleye *Sander vitreus* (Stroud 1949; Jester and Jensen 1972, Quist et al. 2004, Ward et al. 2007; Wuellner et al. 2010), Black and White Crappies *Pomoxis nigromaculatus* and *P. annularis* (Michaletz 1997), Largemouth Bass *Micropterus salmoides* (Lewis et al. 1974; Pasch 1975; Storck 1986), Smallmouth Bass *M. dolomieu* (Wuellner et al. 2010), and White Bass *Morone chrysops* (Aggus 1973; Storck 1986; Michaletz 1993; Ahrens et al. 2010). High consumption of Gizzard Shad by predators has been linked to

higher abundance, faster growth, and improved body condition (e.g., Hartman and Margraf 1992; Michaletz 1997; Gravey and Stein 1998; Ward et al. 2007; Wuellner et al. 2010). Gizzard Shad can increase abundance of predator fish by improving condition and survival (Stein et al. 1995; Ward et al. 2007). For example, Stein et al. (1995) indicated that Gizzard Shad increased condition of Largemouth Bass improved their overwinter survival. Hartman and Margraf (1992) found a positive relationship between consumption of Gizzard Shad and age-1 Walleye growth. Michaletz (1997) found that when age-0 Gizzard Shad were abundant, Walleye and White Crappie growth rates were faster when Gizzard Shad were abundant. In Ohio reservoirs with Gizzard Shad as the prey base, Largemouth Bass had higher growth rates (0.06 – 0.12 g/d) compared to those with Bluegill *Lepomis macrochirus* prey bases (0.04 g/d; Garvey and Stein 1998). Gizzard Shad are often selected by predators over other prey items due to their high abundance, high caloric densities, and soft bodies (Eggleton and Schramm 2002) and their ability to thrive in reservoirs (*see* Stein et al. 1995 for review). Thus, Gizzard Shad are often a popular choice for prey stockings (Heidinger 1983; Dettmers and Stein 1992; Dettmers and Stein 1996; Moyle and Cech 2003).

Gizzard shad are native to South Dakota within the Missouri River basin but have been stocked in several water bodies within the state outside of their native range (Wuellner et al. 2008; VanDeHey et al. 2013). Studies of predator food habits in one Missouri River reservoir (native), one large impoundment (introduced), and two natural lakes (both introduced) have found that Gizzard Shad may positively impact predator growth and condition, at least during certain times of the year (Ward 2007; Wuellner et al. 2010; VanDeHey et al. 2013). Typically, age-0 Gizzard Shad become available to

predation in South Dakota mid-July and are vulnerable until at least September (Ward et al. 2007; Wuellner et al. 2008). Wuellner et al. (2010) found that after native Gizzard Shad were available for predator consumption in Lake Sharpe (e.g., July – October), growth increased for both Walleye and Smallmouth Bass compared to prior months. Further, if Gizzard Shad were not available during the growing season, growth of both predators would be reduced based on bioenergetic simulations (Wuellner et al. 2010). In Angostura Reservoir, Walleye mean lengths at age increased by at least 100 mm and relative abundance increased nearly 140% after the introduction of Gizzard Shad (Ward et al. 2007). VanDeHey et al. (2013) found that Walleye body condition and growth rates increased slightly following Gizzard Shad stocking in two natural lakes in eastern South Dakota. However, Gizzard Shad, both native and introduced, in South Dakota experience winterkill events (Porath 2006; Wuellner et al. 2008). This generally occurs when temperatures reach lethal limits for Gizzard Shad around 4°C (Fetzer et al. 2011). The reduction and limitation of Gizzard Shad populations within the South Dakota (Wuellner et al. 2008), can reduce or prevent any negative impacts often associated with shad (Drenner et al. 1984; Threlkeld and Drenner 1987; DeVries and Stein 1992; Lazzaro et al. 1992; Stein et al. 1995). By understanding the impacts and population dynamics of Gizzard Shad, it can improve the management of predator species (Ward et al. 2007). Because of the positive impacts Gizzard Shad and the winterkill events that limit any negative impacts, shad have become a viable management tool with South Dakota to manage predator fish (Gene Galinat and Dave Lucchesi, South Dakota Department of Game, Fish and Parks, *personal communication*).

To date, no research has been done to assess the effects of Gizzard Shad introductions in small reservoir (< 200 ha) fish communities in South Dakota. These waters are recreationally important across the state and can generate, on average, >\$35,000 in revenues annually (Sundmark and Gigliotti 2019). Since 2012, 11 different small impoundments have been stocked with Gizzard Shad across the state (Gene Galinat and Dave Lucchesi, South Dakota Department of Game, Fish and Parks, *personal communication*). Adult Gizzard Shad are captured from other water bodies and introduced prior to their spawning period so that the young-of-the-year shad will provide a prey resource (Wuellner et al. 2008; VanDeHey et al. 2010; Fincel et al. 2017). Year-to-year stocking schedules vary by waterbody. If at least some adults survive the winter to reproduce the following spring, stocking additional pre-spawn adults may not be necessary due to the prolific reproductive capacity of Gizzard Shad (Noble 1981). However, stocking may be needed annually when adult survival is low or nonexistent (Gene Galinat and Dave Lucchesi, South Dakota Department of Game, Fish and Parks, *personal communication*). Recent introductions of Gizzard Shad into these impoundments provide an opportunity to assess the investigate potential effects of shad on predators in small impoundments. The objectives of this study are to document the consumption of Gizzard Shad by several predators in four small impoundments across South Dakota and assess the impact of that consumption on predator growth using bioenergetics models to simulate growth in the absence of Gizzard Shad.

METHODS

This study included four small impoundments (< 200 ha; Pope et al. 2009) across South Dakota (Figure 2-1). The largest of the four impoundments is Bear Butte Lake

(surface area = 74 ha) located west of Bear Butte State Park. Mean and maximum depth of this reservoir were 2 and 4 m, respectively. Lake Curlew (surface area = 53 ha) is located 24 km north of New Underwood and has a mean depth of 3 m and maximum depth of 7 m. Marindahl Lake (surface area = 56 ha) is located 27 km northeast of Yankton and is the deepest of the four impoundments (mean depth = 4 m; maximum depth = 9 m). Lake Alvin is the smallest impoundment (surface area = 42 ha) and is located 21 km southeast of Sioux Falls; mean and maximum depths are 3 and 8 m, respectively. A minimum of two suspended temperature loggers (HOBO® pendant data logger) were randomly placed in each impoundment at a depth of 1 m from the surface. At locations where depth ≥ 5 m, a second logger was placed at a depth of 1 m from the bottom. Temperatures were recorded and collected each month, and daily averages were calculated from hourly temperatures.

Fish predators were sampled in Bear Butte Lake and Lake Curlew in 2017 and in Lakes Alvin and Marindahl in 2018. Predator fishes including Black Bullhead *Ameiurus melas*, Black Crappie, Channel Catfish *Ictalurus punctatus*, Largemouth Bass, Northern Pike *Esox lucius*, Smallmouth Bass, Walleye and White Crappie were collected from each impoundment when present from May through September in both years (Table 2-1). These months were considered the “growing season” for predators and encompass months prior to Gizzard Shad availability (May and June; hereafter, referred to as “pre-availability”) and a period of shad availability (July – September; hereafter, referred to as “post-availability”) within South Dakota (Ward et al. 2007; Wuellner et al. 2010). The shad available period is when age-0 Gizzard Shad are large enough to be selected by predator fish as viable prey; generally occurring mid-July in South Dakota (Ward et al.

2007; Wuellner et al. 2008; Wuellner et al. 2010). Fish were collected during the last two weeks of each month primarily using daytime and nighttime direct current (12 – 16 A; 170 V), high-pulse frequency (120 pulses * s⁻¹) electrofishing. Electrofishing was supplemented with short-term (10 – 120 min) gill net sets [using either a single bar mesh net (45.7 x 1.8 m; bar mesh = 76.2 mm) or an experimental net (45.7 x 1.8 m; 6,7.6-m panels; bar mesh = 12.7, 19.1, 25.4, 31.8, 38.1, and 50.8 mm)]. Additionally, short-term (60 – 120 min) and overnight sets of modified-fyke net sets (frame = 0.9 x 1.5 m; bar mesh = 19 mm) were used to capture remaining numbers of predators as needed. All collected fish were measured for total length (TL; mm) and gape width (mm) and weighed to the nearest 1 g.

Stomach contents of predators were collected using gastric lavage if fish were collected alive or stomach excision if mortality occurred during sampling. Each individual predator's stomach contents were preserved in an 80% ethanol solution for later identification and enumeration. The goal of this study was to obtain a minimum of 20 fish with food in their stomachs for two age categories (juvenile and adult; Table 2-2) of each predator species for each impoundment and month. The number of empty stomachs encountered was tallied for each predator by month and age category. Preserved stomach contents were later identified to order for invertebrates and to species for identifiable fish prey when possible; each identified prey item was wet weighed (0.001 g). Food habits were summarized for each predator within each impoundment by month by calculating a mean percent composition by wet weight and a frequency of occurrence (O_i ; Bowen 1996) of prey items among all predator food habits of that size

class (Bowen 1996). Both food habit metrics were visually compared between the pre- and post-availability periods within each reservoir.

Fish Bioenergetics 4.0 (Deslauriers et al. 2017) was used to model the relative impact of Gizzard Shad on growth in terms of weight (g) of Black Crappie, Largemouth Bass, and Walleye from Bear Butte and Curlew Lakes. Lakes Alvin and Marindahl were not included in bioenergetics modeling due to the lack of predator fish consuming Gizzard Shad and the inconsistency in predator collections from month to month (see Results). Bioenergetics modeling only focused on these three predators due to consistency in collections from month to month. Information required for the models included food habits data, caloric values of prey items, water temperature, and initial (May) and final (September) predator weights within each age category. Models were run from the first to the last day of sampling in each impoundment (i.e., 127 days total). Caloric values of prey species were estimated using published literature (Table 2-3). The proportions of maximum consumption (p) obtained from observed predator growth was recorded for the observed food habits.

Because there have been no previous food habits studies in these reservoirs prior to the introduction of Gizzard Shad, we used bioenergetic simulations to predict what predator growth may have been if shad were not present within each impoundment. Percent composition by weight for each remaining prey item observed in predator food habits was calculated without the presence of Gizzard Shad. The p-values of maximum consumption from observed predator food habits and growth were held constant in simulations. Specific growth rates were visually compared between both conditions (i.e., with and without Gizzard Shad in predator food habits).

RESULTS

Food Habits

Black Bullhead – No juvenile Black Bullheads were collected in any impoundment, but adults were collected in all four impoundments in nearly all months (Table 2-4; Figure 2-2). The percentage of empty stomachs among adult Black Bullhead decreased between the pre- and post-available periods in Bear Butte Lake and Lake Alvin but increased between the pre- and post-available periods in Curlew and Marindahl lakes (Table 2-4). Food habits of adult Black Bullheads differed between all four impoundments (Figure 2-2). Among identifiable prey items, aquatic vegetation composed a substantial proportion of adult Black Bullhead food habits in lakes Alvin and Marindahl during most months (Figure 2-2). Invertebrates and fish composed a relatively higher proportion of food habits in lakes Curlew and Bear Butte respectively, in most months (Figure 2-2). No Gizzard Shad were consumed in any month in any of the impoundments (Table 2-5).

Black Crappie – Juvenile and Adult Black Crappie were captured from all four impoundments (Table 2-4). The percentage of empty stomachs decreased between the pre- and post-available period for juvenile Black Crappie in Curlew and Marindahl lakes but increased in Bear Butte Lake and Lake Alvin between the same two periods (Table 2-4). The percentage of empty stomachs for adult Black Crappie increased between the pre- and post-available period in Curlew and Marindahl lakes but decreased in Bear Butte Lake and Lake Alvin (Table 2-4).

Food habits of juvenile and adult Black Crappie differed between age groups (Figure 2-3). Invertebrates were a substantial proportion of the food habits of both age groups across all months of the growing season in all four impoundments, but the

consumption of fish was higher for adult Black Crappie compared to juveniles in most impoundments and months (Figure 2-3). No Gizzard Shad were consumed by Black Crappie of any age in the two eastern impoundments, but shad were often the only food item consumed by individual adult Black Crappie in the two western impoundments between July and September (Figure 2-3). In Bear Butte Lake, at least 53% (± 6) of all adult Black Crappie consumed at least one Gizzard Shad during the post-available period (Table 2-5). Approximately 12% (± 5) of juvenile Black Bullhead in Curlew Lake consumed Gizzard Shad between June and July; 48% (± 6) of adult crappie consumed Gizzard Shad in this reservoir between July and September (Table 2-5).

Channel Catfish – Adult Channel Catfish were only sampled in sufficient numbers in Bear Butte and Marindahl lakes; juveniles were excluded due to a low number of individuals sampled (Table 2-4). The percentage of empty stomachs increased between the pre- and post-available periods in Bear Butte Lake but decreased in Lake Marindahl (Table 2-4). Food habits of adult Channel Catfish in differed between both pre- and post-available period in both reservoirs (Figure 2-5). Consumption of aquatic vegetation appeared to be generally higher in the pre- versus post-available period in both reservoirs, and fish consumption was generally higher in the late post-available period (e.g., September; Figure 2-4). Consumption of Gizzard Shad by adult Channel Catfish was only noted in Bear Butte Lake and over one month (August; Figure 2-4). During that month, 25% of all adult Channel Catfish collected consumed at least one Gizzard Shad (Table 2-5). No Gizzard Shad were consumed by adult Channel Catfish in Marindahl Lake during any month (Table 2-5; Figure 2-4).

Largemouth Bass – Adult and juvenile Largemouth Bass were captured in all four impoundments, but juvenile bass were not captured during the pre-available period in Bear Butte Lake and the post-available period in Lake Alvin and Marindahl Lake (Table 2-4). The percentage of empty stomachs among juvenile Largemouth Bass increased from the pre- and post-available period in Curlew Lake (Table 2-4). The percentage of empty stomachs among adult Largemouth Bass decreased between the pre- and post-available periods in Lake Marindahl but increased in the other three impoundments (Table 2-4).

Food habits of juvenile and adult Largemouth Bass were relatively similar within impoundments and between the pre- and post-available period when both ages were collected (Figure 2-5). Invertebrates and fish composed a substantial portion of food habits for both age groups in all four impoundments (Figure 2-5). Gizzard Shad consumption occurred most frequently among Largemouth Bass in Curlew Lake (Figure 2-5); adult bass consumed shad every month between July and September and juvenile bass consumed shad only in August (Table 2-5; Figure 2-5). Gizzard Shad were only consumed by adult Largemouth Bass in Lake Alvin in August (Table 2-5; Figure 2-5). No Gizzard Shad were consumed by juvenile or adult Largemouth Bass in either Bear Butte Lake or Lake Marindahl in any month (Table 2-5; Figure 2-5).

Northern Pike – No juvenile Northern Pike were collected in any impoundment and adults were only collected in sufficient numbers in Bear Butte Lake (Table 2-4). The percentage of empty stomachs decreased between the pre- and post-available periods in this impoundment (Table 2-4). Fish composed the highest proportion of adult Northern Pike food habits in all months, and Gizzard Shad composed the highest proportion of

pike food habits in the latter two months post-available period (i.e., August and September; Figure 2-6). At least 74% (± 10) of adult Northern Pike collected between these two months consumed at least one Gizzard Shad (Table 2-5).

Walleye – Juvenile Walleye were captured in all four impoundments, and adult Walleye were captured in all impoundments except Marindahl Lake (Table 2-4). The percentage of empty stomachs decreased between the pre- and post-available periods for juvenile Walleye in all the impoundments except Marindahl Lake (Table 2-4). The percentage of empty stomachs for adult Walleye decreased between the pre- and post-available periods in Bear Butte Lake but increased between those same time periods in Lake Curlew (Table 2-4). No empty stomachs were observed among the four adult Walleye collected in either time period, in Lake Alvin (Table 2-4).

Food habits of juvenile and adult Walleye were similar among all four impoundments and between the two age groups in impoundments where both were collected (Figure 2-7). Both juveniles and adults primarily consumed fish across all months in all impoundments (Figure 2-7). Consumption of Gizzard Shad differed by age group and impoundment but were often the only food item consumed by individual juvenile and adult Walleye (Figure 2-7). In Bear Butte Lake, Gizzard Shad consumption began in July for both juvenile and adult Walleye, with at least 40% (± 10) of all juvenile Walleye and 49% (± 6) of adult Walleye consumed at least one Gizzard Shad during the post-available period (Table 2-5). Consumption of Gizzard Shad by Walleye began earlier in Curlew Lake compared to Bear Butte Lake (Figure 2-7), with at least 35% of all juvenile Walleye and 32% (± 5) of all adult Walleye consumed in Curlew Lake. At least one Gizzard Shad was consumed during the months that followed the initiation of shad

consumption (Table 2-5). The only case of Gizzard Shad consumption in eastern impoundments occurred in Lake Alvin during July. The only juvenile Walleye collected consumed a single Gizzard Shad (Table 2-4; Figure 2-7). The remaining of juvenile and all adult Walleye in Lake Alvin consumed various fish species throughout the pre- and post-available periods (Figure 2-7). Juvenile Walleye mainly consumed *Lepomis* spp., Largemouth Bass, and smaller Walleye, while adult Walleye consumed fish (Figure 2-7). In Marindahl Lake, juvenile Walleye did not consume any Gizzard Shad in either period (Table 2-4); instead, they mainly consumed various fish species consisting of Black Crappie, Largemouth Bass, and White Sucker during the pre- and post- available period (Figure 2-7). The only juvenile Walleye sampled in August consumed a single Largemouth Bass (Figure 2-7).

Bioenergetics Simulations of Predator Fish Growth

Bioenergetic modeling indicated that the presence or absence of Gizzard Shad in predator food habits influenced growth differently depending on the predator species, age group, or impoundment. Simulations showed two distinct trends among simulated predator growth due to the absence of Gizzard Shad in food habits. One of the two trends observed was the negligible difference in growth due to the presence or absence of Gizzard Shad in predator food habits. Predator simulations that exhibited this trend were juvenile and adult, Black Crappie and Largemouth Bass in Curlew Lake (Figure 2-9 and 2-10) and juvenile Walleye in Bear Butte Lake (Figures 2-9, 2-10 and 2-12). The other predators examined experienced a reduction in growth due to the absence of Gizzard Shad in food habits, though growth was only slightly reduced. These predators were

adult Walleye in Bear Butte Lake (Figure 2-11), adult Black Crappie and, both juvenile and adult Walleye in Curlew lake (Figures 2-8 and 2-12).

DISCUSSION

Prey stocking is often used to improve recruitment, abundance, and growth of predator fishes (Wright and Kraft 2012) but deciding which prey fish to stock can be difficult as managers try to maximize the benefits but minimize the potential impacts an introduced species may have in the community (Kircheis and Stanley 1981; Ney 1981; Noble 1981; Wydoski and Benner 1981; Wright and Kraft 2012). Ney (1981) outlined several characteristics that identify which prey species may provide the most benefit, including high fecundity, trophic efficiency (i.e., relatively easy capture and high caloric density), and relatively high vulnerability to predation. Gizzard Shad meet these criteria, and, thus, have been stocked widely throughout the United States (Swingle 1950; Noble 1981; Garvey and Stein 1998; Kim and DeVries 2001; Quist 2004). However, stocking prey with these characteristics may not translate into realized benefits, and results may differ by waterbody and predator characteristics. Thus, introductions of Gizzard Shad should be monitored over time to determine whether other members of the fish community are impacted either positively or negatively (Swingle 1949; Noble 1981; Stork 1986; Garvey and Stein 1998; Hambright et al. 1991; Wright and Kraft 2012). This study provides some information on the effects of Gizzard Shad introductions to many predators in small impoundments in the norther temperate region.

The contribution of Gizzard Shad to predator food habits differed by species and region (west versus east). Across all four reservoirs, Black Crappie, Largemouth Bass,

Northern Pike and Walleye appear to consume Gizzard Shad more frequently than Black Bullhead and Channel Catfish. Similar results have been found in other reservoirs in the region. For example, several researchers have found that Walleye readily consume Gizzard Shad in many reservoirs across the United States (e.g., Stroud 1949; Johnson et al. 1988; Quist et al. 2002; Olson et al. 2007; Raborn et al. 2007). Within South Dakota, Ward et al. (2007) found that Walleye consumed Gizzard Shad from mid-July to September in Angostura Reservoir, located within the western part of the state. Similarly, other research has shown that Black Crappie, Largemouth Bass, and Northern Pike consume Gizzard Shad in other waters like Pomme de Terre and Stockton lakes, Missouri (i.e., Black Crappie; Michaletz 1997), Walker County Lake in Alabama (i.e., Largemouth Bass; Irwin et al. 2003), and Lakes Logan and Rupert and several central and northern Ohio reservoirs (i.e., Northern Pike; Haedrick 1985; Wahl and Stein 1993). Other studies have documented some consumption of Gizzard Shad by Black Bullheads (Kutkuhn 1958; Snow et al. 2017) and Channel Catfish (Jearld and Brown 1971; Dagel et al. 2010) but to a much lesser degree. In South Dakota, no prior studies have documented the food habits of Black Crappie, Largemouth Bass, Northern Pike, Black Bullheads, or Channel Catfish within smaller impoundments where Gizzard Shad have been stocked. This study allowed for comparisons of predator food habits and the importance of Gizzard Shad to predator growth as a result of that consumption across a wide geographic range.

The relative consumption of Gizzard Shad differed between predators collected in western and eastern impoundments; higher rates of consumption were noted in western impoundments consistently among predators. Various factors acting in concert may

explain why Gizzard Shad were not consumed to a greater extent in eastern impoundments. First, high winter mortalities of Gizzard Shad in eastern impoundments may have limited the availability of the next year class of shad in the following growing season. Winter temperatures tend to be lower in eastern compared to western South Dakota (NOAA 2019). Winterkill is a common occurrence among Gizzard Shad populations in northern latitudes and can lead to reduced recruitment and population bottlenecks (Walburg 1964; Porath 2006; Wuellner et al. 2008). During spring 2018, local biologists stocked around 80 pre-spawn adult Gizzard Shad into each eastern impoundment, due to potential winterkill that occurred in the season prior (Dave Lucchesi, South Dakota Department of Game, Fish and Parks, *personal communication*). Consequently, stress caused by stocking may have reduced the condition of adult Gizzard Shad (Francis-Floyd 2002; Barton and Iwama 2003; Harmon 2009), leading to potential reductions in fecundity and survival of progeny (Willis 1987; Miranda and Muncy 1988). Thus, availability of juvenile Gizzard Shad for predator consumption may have been diminished in eastern compared to western impoundments.

Additionally, several flooding events occurred in spring 2018 that increased flow, turbidity, and habitat availability along the shoreline (*personal observation*). Flooding may have led to entrainment of larval and juvenile over each impoundment's spillway (Dave Lucchesi, South Dakota Department of Game, Fish and Parks, *personal communication*). Additionally, increased turbidity and creation of newly flooded terrestrial habitats resulting from flooding events may have reduced interactions between Gizzard Shad and their potential predators (Schramm and Zale 1985; Gregory and Levings 1996). Predators may have then shifted their food habits to prey that were more

abundant and easier to capture (Werner and Hall 1974; Gillen et al. 1981; Ney 1981; Stephens and Krebs 1986). In this study, we did not quantify the availability of Gizzard Shad or alternative prey. Continuous monitoring of larval and juvenile Gizzard Shad abundance and that of other prey may help managers identify years when shad or alternative may be less available to predators and when stocking may be necessary to support the existing shad population.

The consumption of Gizzard Shad by some observed predators (i.e., Black Crappie, Largemouth Bass and Walleye) in western impoundments allowed for modeling to identify potential impacts of shad on predator growth rates. Overall, growth rates of predators that consumed a relatively smaller proportion of Gizzard Shad were less affected by the absence of shad than those predators who consumed a much higher proportion. However, in some cases, consumption of Gizzard Shad may not have translated to faster growth. For example, Black Crappie in Curlew Lake consumed a relatively high amount of Gizzard Shad, but simulated growth rates were similar whether shad were present in food habits or not. When Gizzard Shad are absent, it may be possible for at least some predators to switch to abundant alternative prey that may provide similar energetic benefits (Orpwood et al. 2006; Biro et al. 2007). Predators that are more opportunistic feeders may be able to make this switch more readily than more specialized predators (e.g., Walleye; Graeb et al. 2005; Galarowicz et al. 2006; Biro et al. 2007; Wuellner et al. 2010). However, the bioenergetics scenarios without the inclusion of Gizzard Shad in predator food habits may not provide the most accurate representation of predator growth patterns (Wuellner et al. 2010). This inaccuracy is due to the lack of knowledge about predator food habits prior to the introduction of Gizzard Shad into these

impoundments and knowledge about how predator food habits would shift due to the absence of shad. Predators may have started consuming alternative or additional prey to maintain body mass (Biro et al. 2007). Evaluations of the impacts of stocked Gizzard Shad on predator growth in future studies should attempt to evaluate growth rates of those predators prior to stocking to better understand differences in growth.

Overall, results from this study both support and contrast those of previous studies regarding the benefits of Gizzard Shad to reservoir fish populations both outside and within South Dakota. While Gizzard Shad do meet the criteria defined by Ney (1981) in regard to identifying prey species to stock, not all predators and waters may experience the same benefits as evidenced in this study. Further, stocking Gizzard Shad may lead to other impacts to fish communities via “middle-out” food web effects (Drenner et al. 1984; Threlkeld and Drenner 1987; Mundahl 1991; DeVries and Stein 1992; Lazzaro et al. 1992; Stein et al. 1995; Schaus et al. 2002; Aday et al. 2003). Thus, introductions of Gizzard Shad should be carefully considered prior to stocking events and continuously monitored to determine if and which predators benefit from such stockings and which, if any, predators and prey are negatively affected. Further research is needed to identify abiotic and biotic factors that influence the stocking success of Gizzard Shad and how those factors and potential impacts influence stocking decisions.

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Table 2 - 1. List of species present in each of the four reservoirs included in this study (2017 and 2018). “P” indicates the presence of predator fish and “NP” indicates the absence of predator fish. Asterisks indicate that the species was found during South Dakota Department of Game, Fish and Parks annual standard surveys or the species was caught rarely during this study.

| Species | Impoundment | | | |
|-----------------|-------------|--------|-------|-----------|
| | Bear Butte | Curlew | Alvin | Marindahl |
| Black Bullhead | P | P | P | P |
| Black Crappie | P | P | P | P |
| Channel Catfish | P | P | P | P |
| Largemouth Bass | P | P | P | P |
| Northern Pike | P | * | * | NP |
| Walleye | P | P | P | P |

Table 2 - 2. Length ranges used to classify juvenile and adult predators captured in this study. Categories are based on previous studies documenting the total lengths of predators when they reach sexual maturity.

| <u>Length Categories (mm)</u> | | | |
|-------------------------------|----------|-------|-----------------------------------|
| Species | Juvenile | Adult | Sources |
| Black Bullhead | < 140 | ≥ 140 | Carlander (1969) |
| Black Crappie | < 180 | ≥ 180 | Willis et al. (2001) |
| Channel Catfish | < 300 | ≥ 300 | Willis et al. (2001) |
| Largemouth Bass | < 200 | ≥ 200 | Holland and Petters (1992) |
| Walleye | < 380 | ≥ 380 | Kansas Fishes Committee (2014) |

Table 2 - 3. Energy densities [Joules/wet weight (g)] of prey items consumed by predators in this study. Energy densities of unknown invertebrates or fish were found by calculating the mean of energy densities of known orders or species. The energy density of unidentifiable food was calculated as the mean of all identifiable prey items across all orders and species.

| Groups | Order or Species | Energy density | Sources |
|---------------|----------------------------|----------------|----------------------------|
| Invertebrates | Amphipoda | 3394 | James et al. (2011) |
| | Annelids | 1954 | Ciancio et al. (2007) |
| | Arachnida | 3314 | Cummins (1967) |
| | Arhynchobdellida | 1243 | James et al. (2011) |
| | Cladocera | 1314 | Cummins (1967) |
| | Coleoptera | 7616 | Cummins (1967) |
| | Copepoda | 2301 | Cummins (1967) |
| | Decapoda | 2963 | Cummins (1967) |
| | Diptera | 2922 | James et al. (2011) |
| | Ephemeroptera | 3508 | James et al. (2011) |
| | Hemiptera | 6141 | James et al. (2011) |
| | Hymenoptera | 8575 | James et al. (2011) |
| | Molluska | 2008 | Cummins and Wucheck (1971) |
| | Odonata | 3300 | James et al. (2011) |
| | Oligochaeta | 2395 | James et al. (2011) |
| | Trichoptera | 1704 | James et al. (2011) |
| | Unidentified invertebrates | | 3416 |

| Groups | Order or Species | Energy density | Sources |
|-------------|---------------------|----------------|--------------------------|
| Fish | Catostomidae | 4102 | Ruetz et al. (2009) |
| | Cyprinidae | 4268 | Chipps et al. (2000) |
| | Lepomis spp. | 3807 | Liao et al. (2004) |
| | Other Percidae spp. | 5497 | Liao et al. (2004) |
| | Pomoxis spp. | 6286 | Liao et al. (2004) |
| | Black Bullhead | 3694 | Liao et al. (2004) |
| | Gizzard Shad | 5108 | Miranda and Muncy (1989) |
| | Largemouth Bass | 5291 | Liao et al. (2004) |
| | Walleye | 5349 | Liao et al. (2004) |
| | Unidentified fish | 4842 | |
| Other Items | Aquatic Vegetation | 2703 | Cummins (1967) |
| | Peromyscus | 1853 | Cummins (1967) |
| | Anseriformes | 1853 | Cummins (1967) |
| | Unidentified prey | 4112 | |

Table 2 - 4. Percent empty stomachs of juvenile and adult predator fish observed with empty stomachs in two western (Bear Butte Lake and Curlew Lake) and two eastern (Lake Alvin and Marindahl Lake) South Dakota impoundments sampled in 2017 and 2018. Categories for periods indicate months when Gizzard Shad *Dorosoma cepedianum* were not available for consumption by predators (“Pre”; May and June) and those months in which shad were available for consumption (“Post”; July – August). Blanks indicate that no predators of that species and age category were collected from that lake in that period. Number of fish sampled in parenthesis.

| Predator | Period | Age Category | Impoundment | | | |
|-----------------|--------|--------------|-------------|----------|---------|-----------|
| | | | Bear Butte | Curlew | Alvin | Marindahl |
| Black Bullhead | Pre | Juvenile | | | | |
| | Post | | | | | |
| | Pre | Adult | 53 (92) | 14 (21) | 53 (89) | 39 (57) |
| | Post | | 38(170) | 52 (23) | 32 (84) | 46 (46) |
| Black Crappie | Pre | Juvenile | 25 (8) | 18 (33) | 4 (27) | 67 (6) |
| | Post | | 38 (16) | 15 (39) | 6 (34) | 0 (47) |
| | Pre | Adult | 6 (65) | 9 (58) | 5 (42) | 5 (41) |
| | Post | | 5 (61) | 13 (71) | 0 (40) | 44 (9) |
| Channel Catfish | Pre | Juvenile | | | | |
| | Post | | | | | |
| | Pre | Adult | 19 (27) | | | 60 (10) |
| | Post | | 24 (37) | | | 23 (30) |
| Largemouth Bass | Pre | Juvenile | 50 (2) | 20 (5) | | |
| | Post | | | 22 (9) | 25 (36) | 10 (50) |
| | Pre | Adult | 33 (12) | 33 (91) | 33 (51) | 55 (27) |
| | Post | | 37 (30) | 42 (143) | 39 (61) | 48 (62) |
| Northern Pike | Pre | Juvenile | | | | |
| | Post | | | | | |
| | Pre | Adult | 57 (42) | | | |
| | Post | | 49 (103) | | | |
| Walleye | Pre | Juvenile | 51 (24) | 46 (37) | 50 (12) | 23 (30) |
| | Post | | 24 (33) | 31 (85) | 9 (11) | 55 (17) |
| | Pre | Adult | 56 (32) | 49 (53) | 0 (2) | |
| | Post | | 30 (96) | 65 (198) | 0 (2) | |

Table 2 - 5. Frequency of Occurrence (O_i) of Gizzard Shad in both juvenile and adult predator fish by month in two western (Bear Butte and Curlew Lakes) and two eastern (Lake Alvin and Marindahl Lake) South Dakota impoundments sampled in 2017 and 2018, respectively. Zeros indicate that predators were collected during that month but that none of them consumed any Gizzard Shad. Number of fish sampled for stomach samples in parenthesis.

| Predator | Month | Age category | O_i | | | |
|-----------------|-----------|--------------|------------|---------|--------|-----------|
| | | | Bear Butte | Curlew | Alvin | Marindahl |
| Black Bullhead | May | Juvenile | | | | |
| | June | | | | | |
| | July | | | | | |
| | August | | | | | |
| | September | | | | | |
| | May | Adult | 0 (20) | 0 (14) | 0 (23) | 0 (14) |
| | June | | 0 (23) | 0 (4) | 0 (19) | 0 (21) |
| | July | | 0 (34) | 0 (4) | 0 (19) | 0 (15) |
| | August | | 0 (37) | 0 (7) | 0 (19) | 0 (4) |
| | September | | 0 (35) | | 0 (19) | 0 (9) |
| Black Crappie | May | Juvenile | 0 (1) | 0 (6) | | |
| | June | | 0 (7) | 5 (21) | 0 (26) | 0 (2) |
| | July | | 0 (2) | 17 (29) | 0 (17) | 0 (18) |
| | August | | 0 (8) | 0 (3) | 0 (13) | 0 (21) |
| | September | | 0 (6) | 0 (1) | 0 (2) | 0 (8) |
| | May | Adult | 0 (34) | 0 (35) | 0 (20) | 0 (20) |
| | June | | 0 (27) | 0 (18) | 0 (20) | 0 (19) |
| | July | | 53 (19) | 43 (28) | 0 (20) | 0 (3) |
| | August | | 55 (20) | 58 (24) | 0 (15) | 0 (1) |
| | September | | 53 (19) | 40 (10) | 0 (15) | 0 (1) |
| Channel Catfish | May | Juvenile | | | | |
| | June | | | | | |
| | July | | | | | |
| | August | | | | | |
| | September | | | | | |
| | May | Adult | 0 (8) | | | 0 (2) |
| | June | | 0 (14) | | | 0 (2) |
| | July | | 0 (23) | | | |
| | August | | 25 (4) | | | 0 (17) |
| | September | | 0 (3) | | | 0 (6) |

| Predator | Month | Age category | O_i | | | |
|-----------------|-----------|--------------|------------|---------|---------|-----------|
| | | | Bear Butte | Curlew | Alvin | Marindahl |
| Largemouth Bass | May | Juvenile | 0 (2) | 0 (3) | | |
| | June | | | 0 (1) | | |
| | July | | | | | 0 (13) |
| | August | | | 20 (5) | 0 (19) | 0 (20) |
| | September | | | 0 (2) | 0 (8) | 0 (12) |
| | May | Adult | 0 (4) | 0 (24) | 0 (14) | 0 (2) |
| | June | | 0 (4) | 0 (37) | 0 (20) | 0 (10) |
| | July | | 0 (2) | 24 (29) | 0 (14) | 0 (23) |
| | August | | 0 (3) | 24 (25) | 9 (11) | 0 (5) |
| | September | | 0 (14) | 24 (29) | 0 (12) | 0 (5) |
| Northern Pike | May | Juvenile | | | | |
| | June | | | | | |
| | July | | | | | |
| | August | | | | | |
| | September | | | | | |
| | May | Adult | 0 (14) | | | |
| | June | | 0 (4) | | | |
| | July | | 0 (5) | | | |
| | August | | 83 (23) | | | |
| | September | | 64 (24) | | | |
| Walleye | May | Juvenile | 0 (11) | 0 (4) | | 0 (4) |
| | June | | 0 (1) | 6 (16) | 0 (6) | 0 (19) |
| | July | | 33 (3) | 80 (5) | 100 (1) | 0 (6) |
| | August | | 50 (8) | 41 (29) | 0 (4) | |
| | September | | 36 (14) | 36 (25) | 0 (5) | 0 (1) |
| | May | Adult | 0 (8) | 40 (10) | 0 (1) | |
| | June | | 0 (6) | 18 (17) | 0 (1) | |
| | July | | 20 (5) | 32 (19) | | |
| | August | | 53 (36) | 28 (18) | 0 (1) | |
| | September | | 50 (26) | 42 (33) | 0 (1) | |

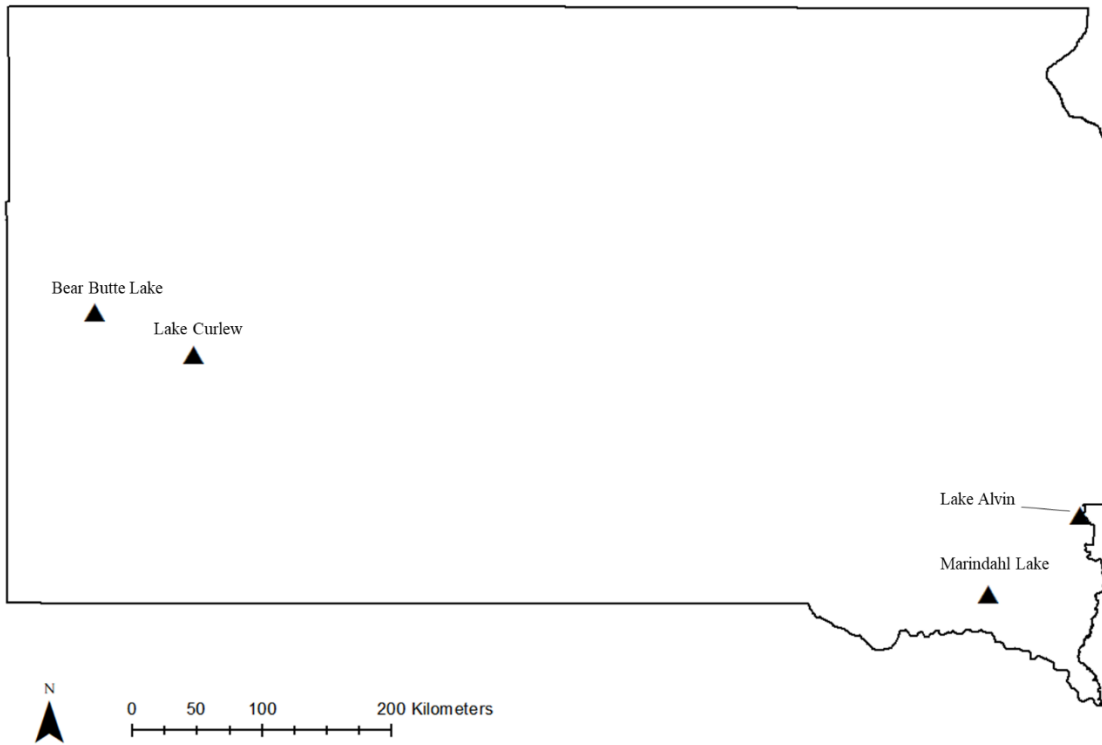


Figure 2 - 1. Locations of the four small reservoirs in South Dakota used in this study. Bear Butte and Curlew Lakes are the most western impoundments and were sampled in 2017. Lakes Alvin and Marindahl are the two most eastern impoundments and were sampled in 2018.

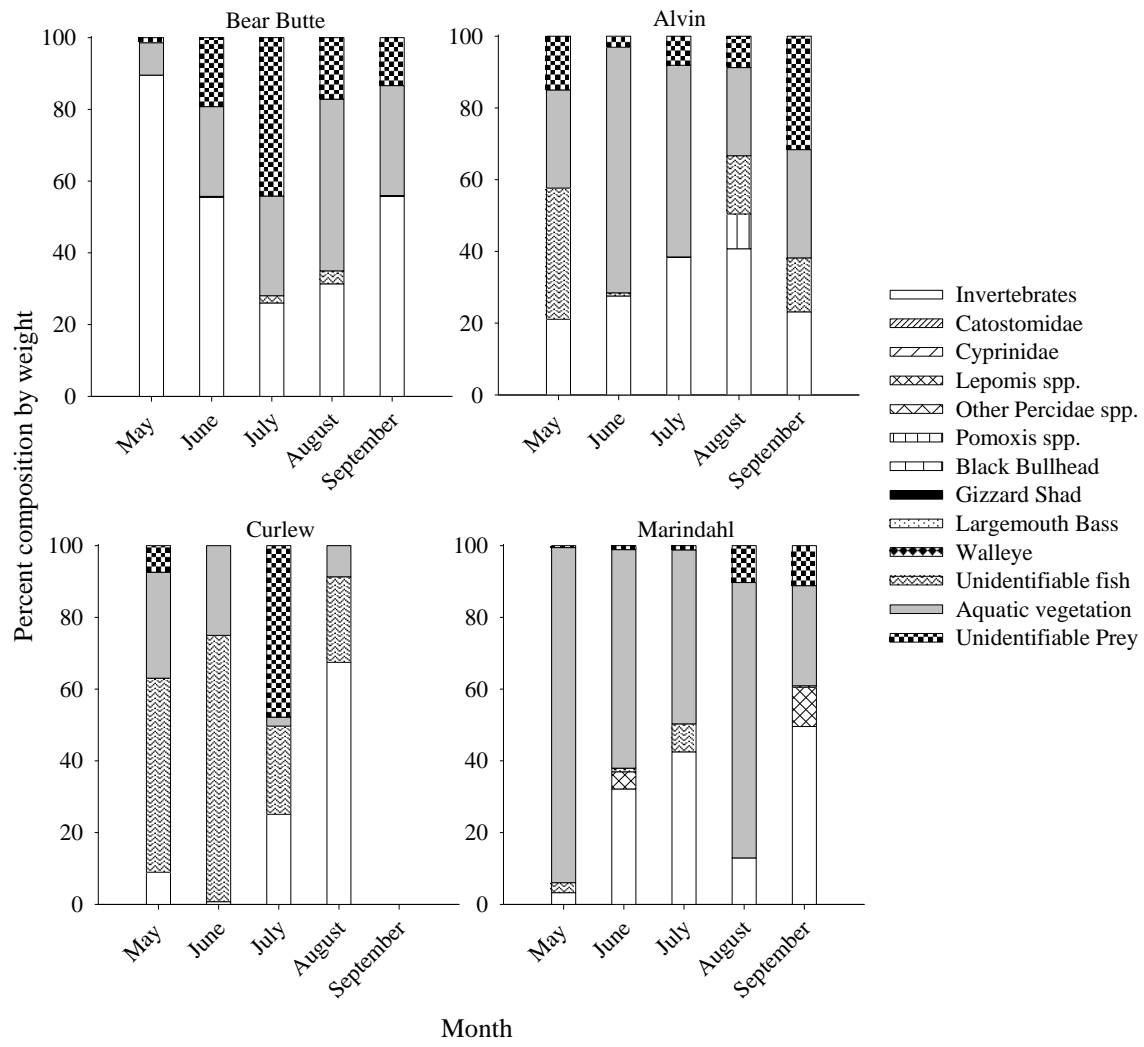


Figure 2 - 2. Food habits of adult Black Bullhead collected in two western (Bear Butte and Curlew lakes) and two eastern (Lakes Alvin and Marindahl) South Dakota impoundments sampled in 2017 and 2018, respectively.

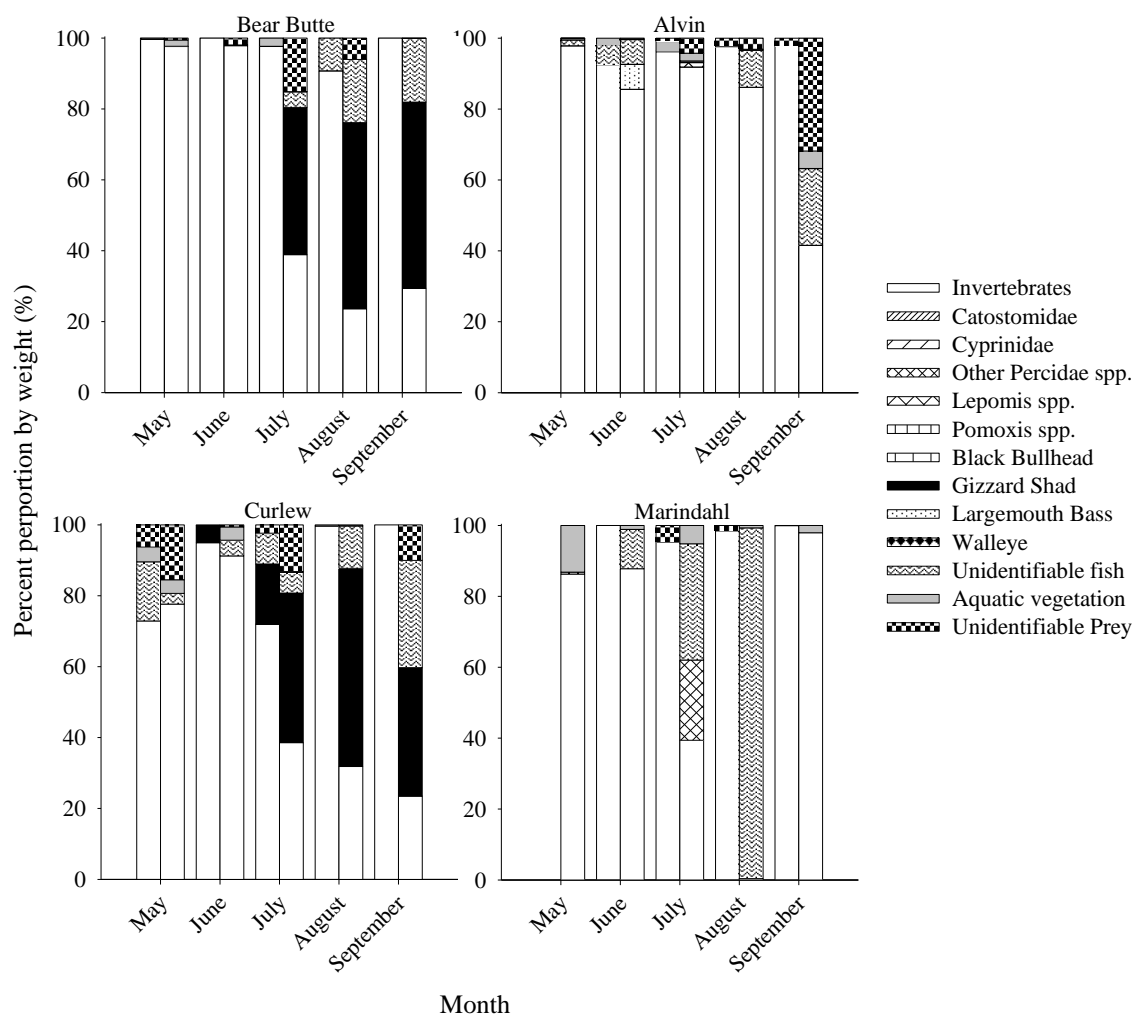


Figure 2 - 3. Food habits of juvenile (left bar at each month) and adult (right bar at each month) Black Crappie collected in two western (Bear Butte and Curlew lakes) and two eastern (Lakes Alvin and Marindahl) South Dakota impoundments sampled in 2017 and 2018, respectively.

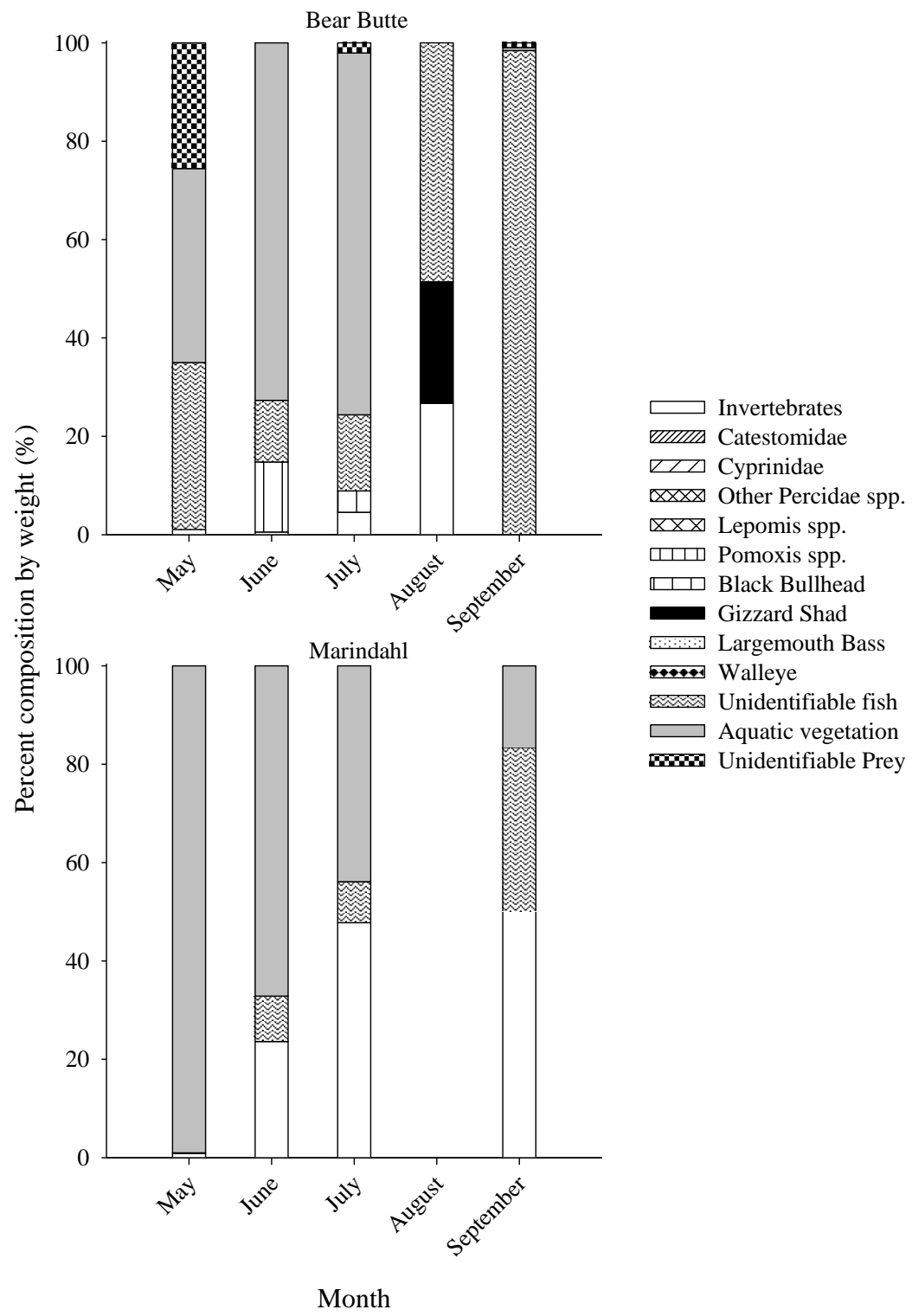


Figure 2 - 4. Food habits adult Channel Catfish collected in one western (Bear Butte Lake) and one eastern (Marindahl Lake) South Dakota impoundments sampled in 2017 and 2018, respectively.

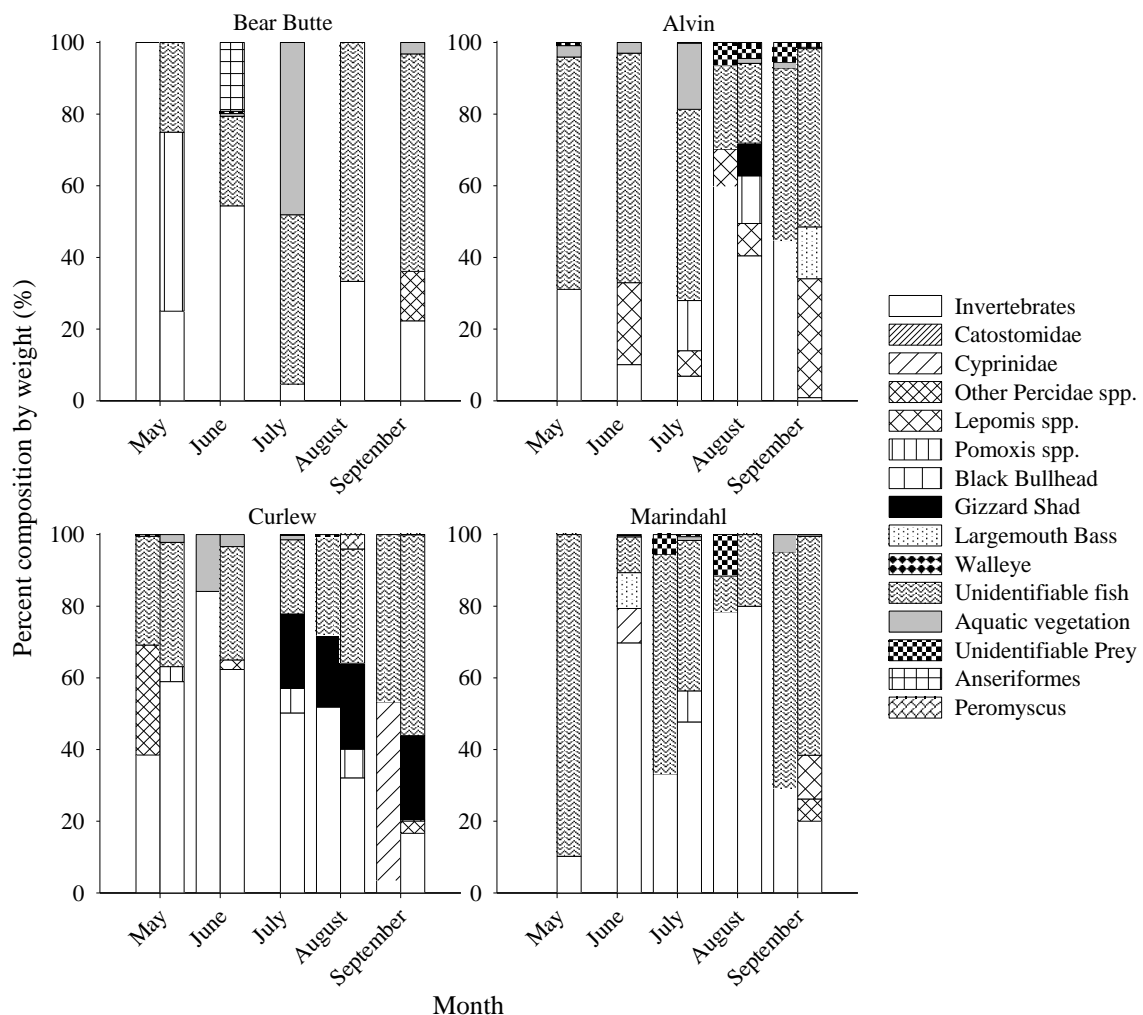


Figure 2 - 5. Food habits of juvenile (left bar at each month) and adult (right bar at each month) Largemouth Bass collected in two western (Bear Butte and Curlew lakes) and two eastern (Lakes Alvin and Marindahl) South Dakota impoundments sampled in 2017 and 2018, respectively. A breakdown of invertebrates and fish orders and families, respectively, can be found in Table 2-3.

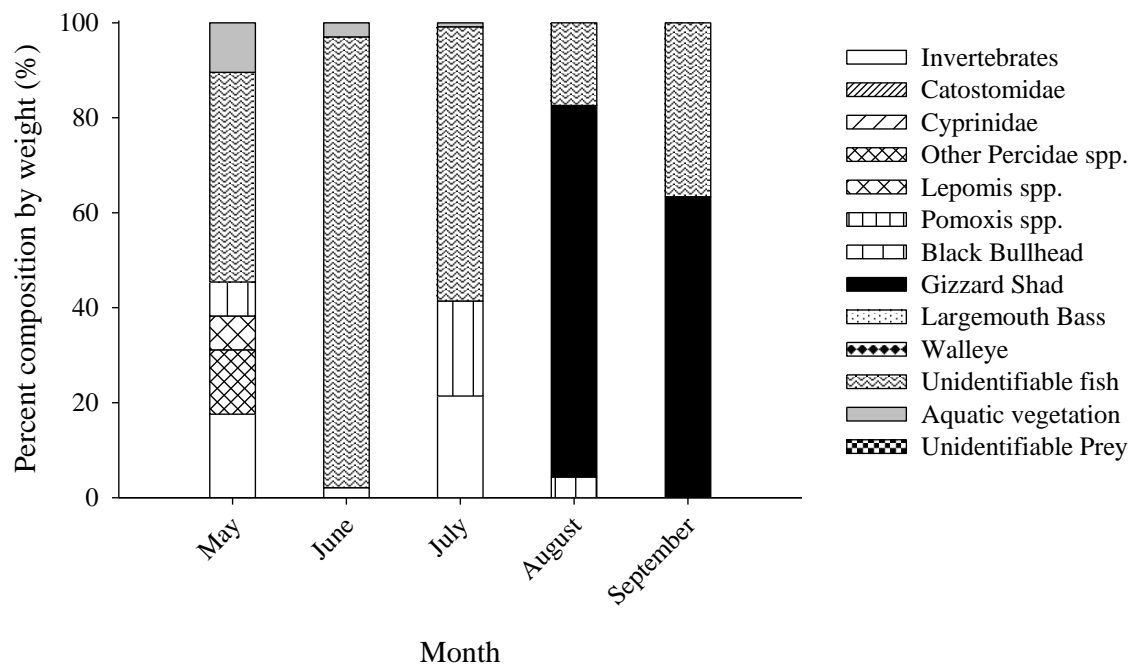


Figure 2 - 6. Food habits of adult Northern Pike collected in Bear Butte Lake in 2017.

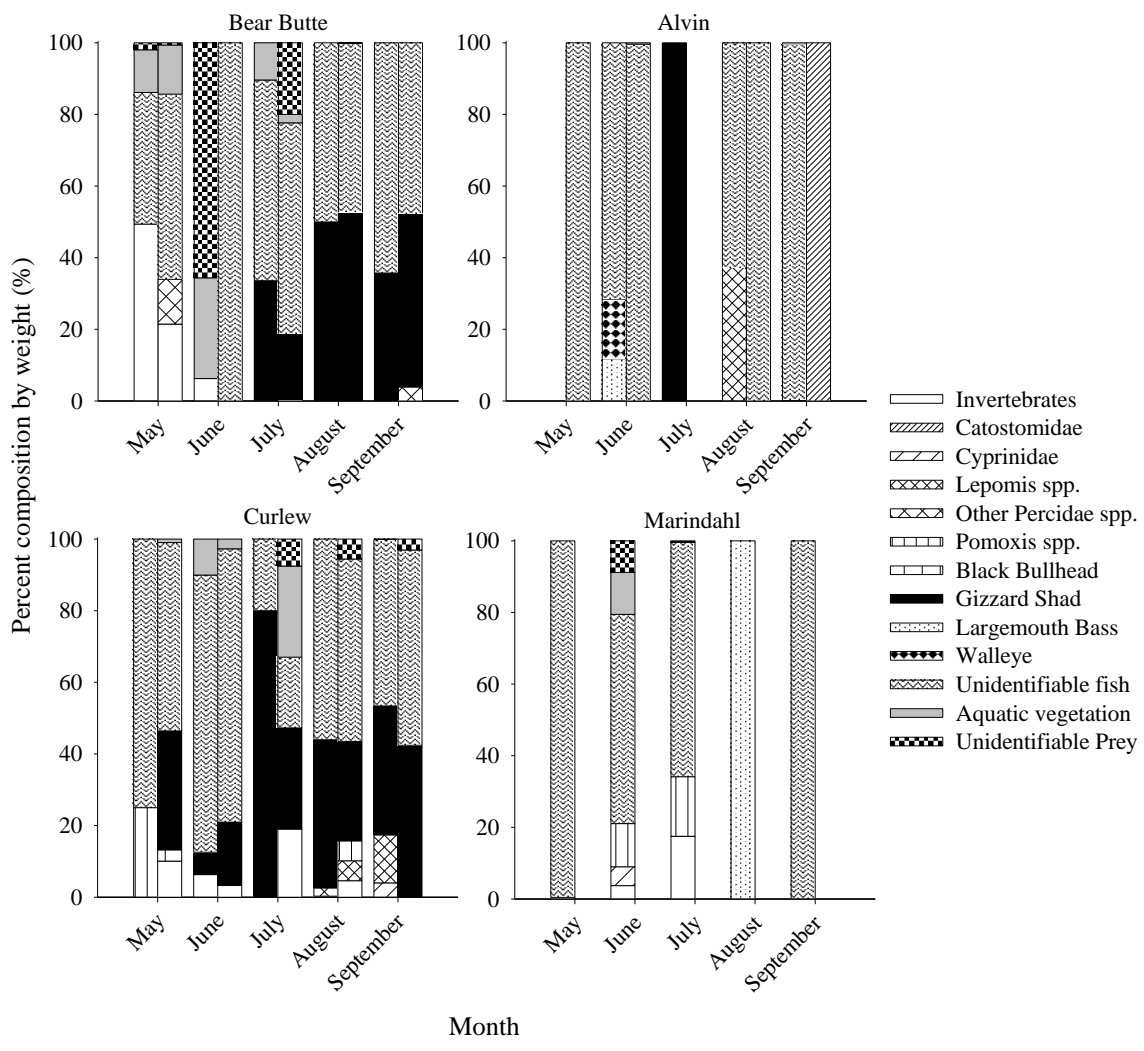


Figure 2 - 7. Food habits of juvenile (left bar at each month) and adult (right bar at each month) Walleye collected in two western (Bear Butte and Curlew lakes) and two eastern (Lakes Alvin and Marindahl) South Dakota impoundments sampled in 2017 and 2018, respectively.

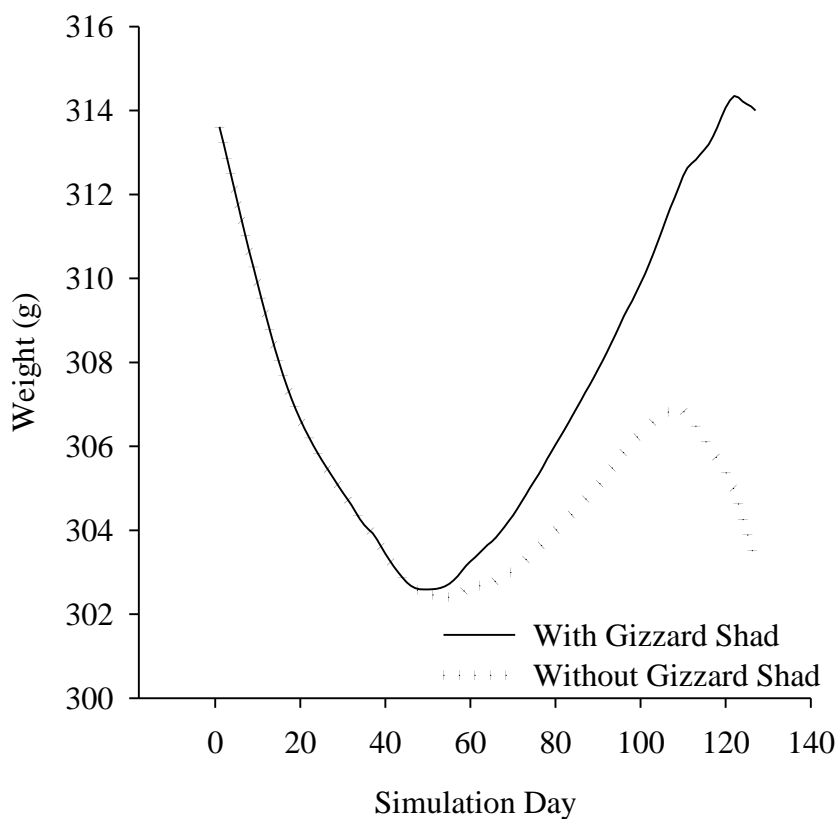


Figure 2 - 8. Growth simulations of adult Black Crappie in Bear Butte Lake with and without Gizzard Shad as part of crappie food habits. “With Gizzard Shad” represents growth simulations under observed food habits data. “Without Gizzard Shad” represents how Black Crappie growth may respond if Gizzard Shad were not present in the food habits. Both simulations assume the same maximum consumption rate.

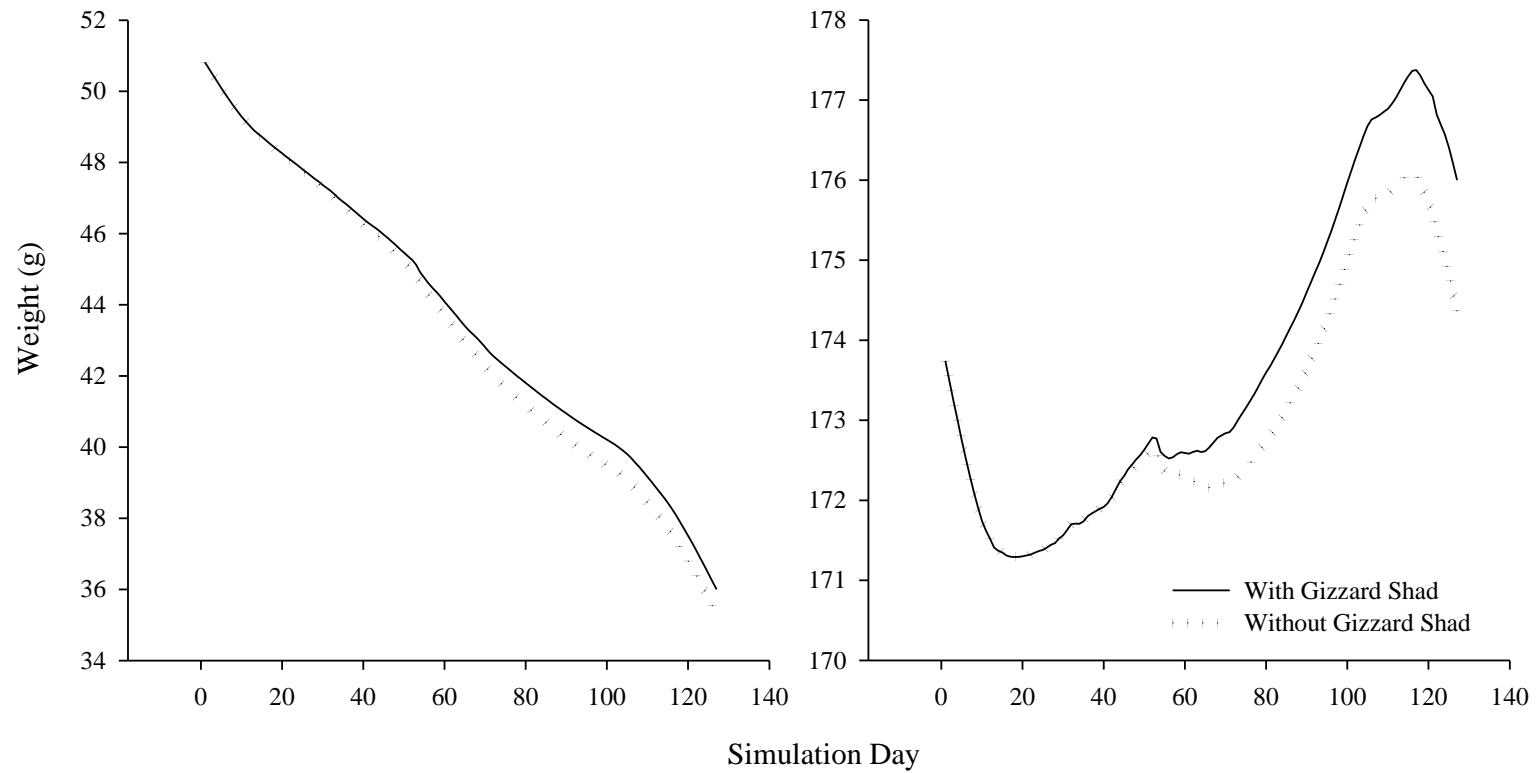


Figure 2 - 9. Growth simulations of juvenile (Left) and adult (Right) Black Crappie in Curlew Lake with and without Gizzard Shad as part of crappie food habits. “With Gizzard Shad” represents growth simulations under observed food habits data. “Without Gizzard Shad” represents how Black Crappie growth may respond if Gizzard Shad were not present in the food habits. Both simulations assume the same maximum consumption rate.

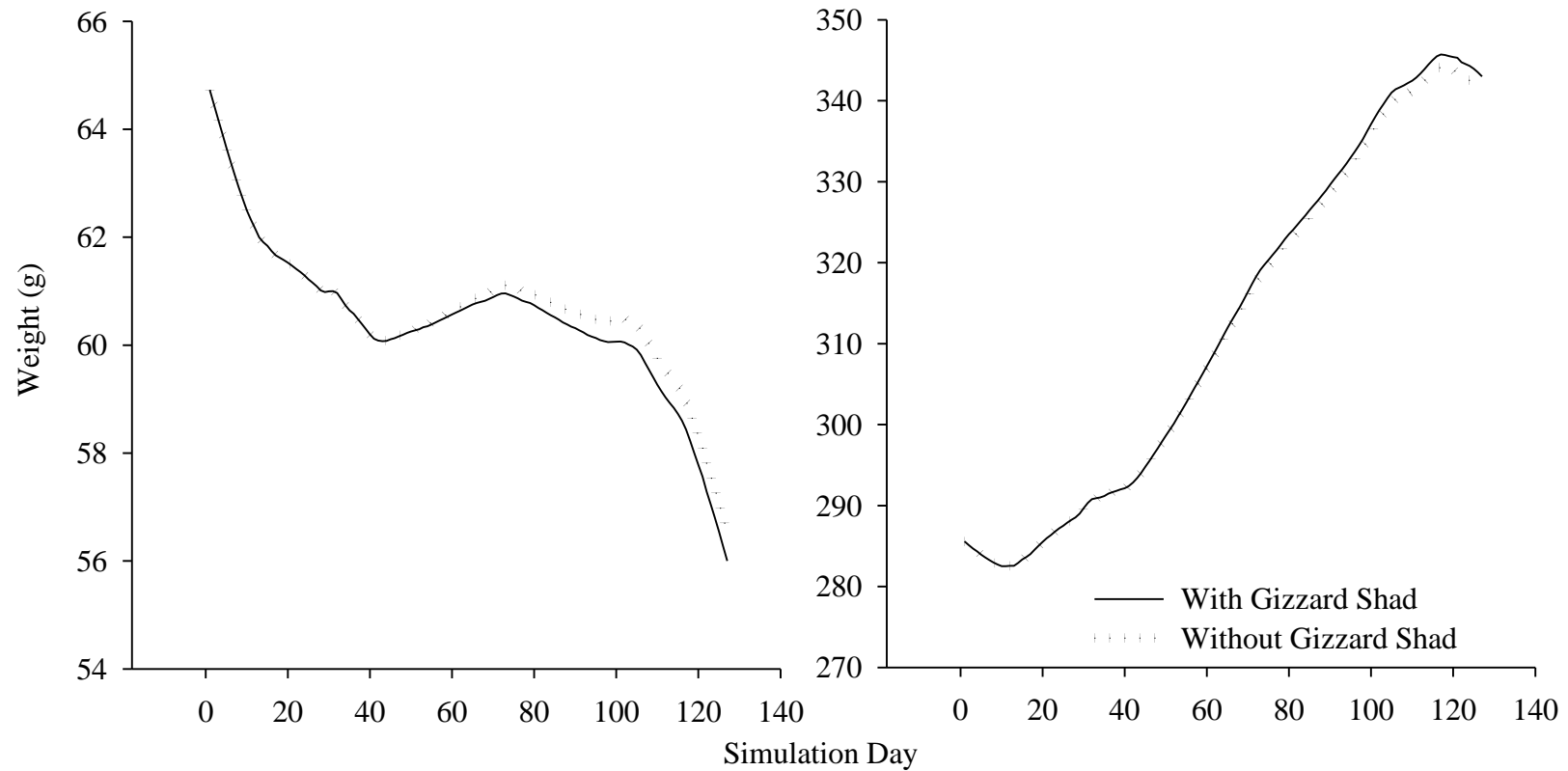


Figure 2 - 10. Growth simulations of juvenile (Left) and adult (Right) Largemouth Bass in Curlew Lake with and without Gizzard Shad as part of crappie food habits. “With Gizzard Shad” represents growth simulations under observed food habits data. “Without Gizzard Shad” represents how Black Crappie growth may respond if Gizzard Shad were not present in the food habits. Both simulations assume the same maximum consumption rate.

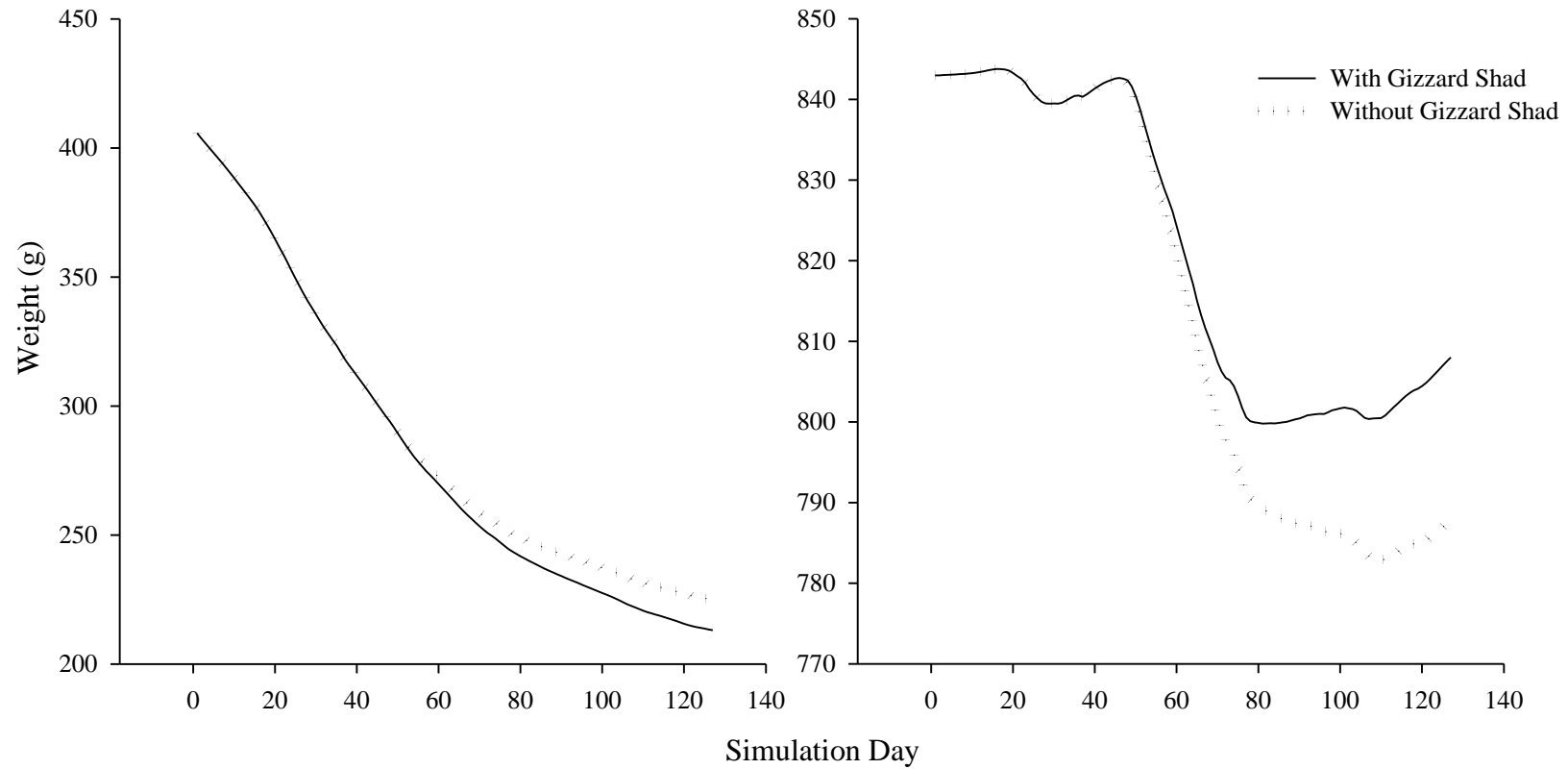


Figure 2 - 11. Growth simulations of juvenile (Left) and adult (Right) Walleye in Bear Butte Lake with and without Gizzard Shad as part of crappie food habits. “With Gizzard Shad” represents growth simulations under observed food habits data. “Without Gizzard Shad” represents how Black Crappie growth may respond if Gizzard Shad were not present in the food habits. Both simulations assume the same maximum consumption rate.

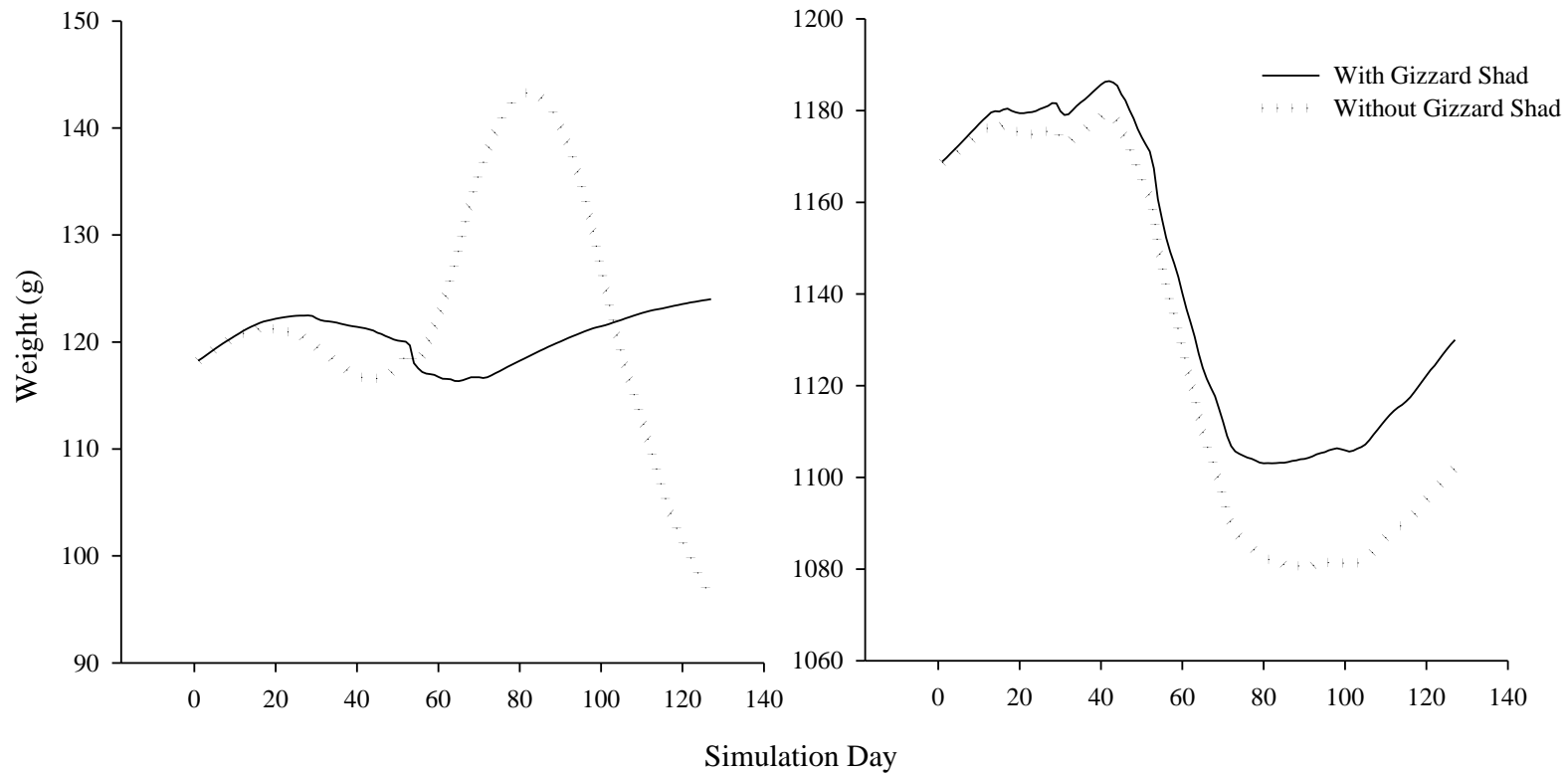


Figure 2 - 12. Growth simulations of juvenile (Left) and adult (Right) Walleye in Curlew Lake with and without Gizzard Shad as part of crappie food habits. “With Gizzard Shad” represents growth simulations under observed food habits data. “Without Gizzard Shad” represents how Black Crappie growth may respond if Gizzard Shad were not present in the food habits. Both simulations assume the same maximum consumption rate.

CHAPTER 3. EXTANT PREDATORS AS A BIOLOGICAL CONTROL FOR BLACK BULLHEADS IN SMALL IMPOUNDMENTS

INTRODUCTION

While some variation in fish populations is expected, a “balanced” community may be possible when energy and biomass inputs are similar to the outputs (Swingle 1950; Flickinger et al. 1999; Wydoski and Wiley 1999; Kroger and Tucker 2012). This “balance” can change due to external and internal nutrient loading, variations in fish species composition and abundance, water-level fluctuations, or a number of other factors (Scheffer et al. 1993; Scheffer et al. 2001). Nutrient loading can shift a waterbody from an oligotrophic state to a more eutrophic state, causing a shift in the fish community from more sensitive species such as salmonids and percids to more tolerant species such as cyprinids and ictalurids (Jeppesen et al. 2000; Jeppesen et al. 2005). An increase in abundance of some species may also induce or exacerbate internal nutrient loading that may further tip the balance of the fish community toward more tolerant species (Jenkins 1957; Wydoski and Wiley 1999; Braig and Johnson 2003). For example, Common Carp *Cyprinus carpio* have been shown to suspend nutrients and reduce water quality through feeding behaviors and excretion (Breukelaar et al. 1994; Miller and Crowl 2006; Groffman et al. 2006; Jackson et al. 2010), which may lead to a reduction of other species such as Bluegill *Lepomis macrochirus*, Black Crappie *Pomoxis nigromaculatus* and Largemouth Bass *Micropterus salmoides* over time as carp populations increase in abundance (Jackson et al. 2010).

Achieving balance in artificial ecosystems such as impounded rivers and streams may be even more challenging as ongoing changes (e.g., water-level fluctuations, various quantities and quality of water inputs, and rapid aging processes of reservoirs) alter energy and nutrient flows through these systems (Bennet 1971; Kimmel and Groeger 1986; Summerfelt 1999). Overabundant and undesirable fish species may affect nutrient distribution and energy cycling within a reservoir and may directly or indirectly affect other fish species within the community (Wydoski and Wiley 1999). Some fishes common to impoundments such as Black Bullhead (Carlander and Moorman 1956; Jenkins 1958; Brown et al. 1999), Common Carp (Breukelaar et al. 1994; Miller and Crowl 2006; Groffman et al. 2006; Jackson et al. 2010), and Gizzard Shad (Mundahl 1991; DeVries and Stein 1992; Schaus et al. 2002) have the potential to influence nutrient cycling within an impoundment due to various behaviors (Kahl 1991; Mundahl 1991; Breukelaar et al. 1994; Schaus et al. 2002; Braig and Johnson 2003; Miller and Crowl 2006; Jackson et al. 2010). The additional impacts that overabundant species may have on the nutrient loading in a system may lead to further imbalance (Jenkins 1957; Wydoski and Wiley 1999; Braig and Johnson 2003), but management options may help to mitigate these impacts (Wydoski and Wiley 1999).

One such option may involve removing undesirable, overabundant fishes through chemical, mechanical, or biological means (Wydoski and Wiley 1999). Each of these methods has unique advantages or disadvantages. For example, remediation with chemicals containing rotenone, antimycin, copper sulfate, squoxin, and toxaphene (Meronek et al. 1996) are often preferred over other methods for controlling undesirable fish as costs are relatively low, planning and execution is relatively easy, and effects are

relatively long lasting (Lennon et al. 1970; Eschmeyer 1975; Bandow 1989). However, treatments of entire waterbodies may kill desirable fish indiscriminately (Bettoli and Maceina 1996). Further, the success of partial treatments is highly variable due to water body size, depth, and temperature and species' chemical resistance (Parker 1970; Marking and Bills 1976; Bradbury 1986). Chemical control can also lead to undesirable water quality changes resulting from deteriorating fish which may produce odors and affect taste of municipal waters (Cohen et al. 1960 and 1961). These issues may lead to potential public opposition that may prevent the use of this control method (Wydoski and Wiley 1999).

Mechanical controls include the use of barriers, commercial fishing, water-level manipulation, or netting with active or passive fishing gears to selectively harvest undesirable fish (Wydoski and Wiley 1999). Often, mechanical removal requires substantial labor and time investments (Wydoski and Wiley 1999). However, mechanical methods may be combined with chemicals to improve capture by stimulating fish movement (Brown 1964). Success rates of mechanical removals are mixed. For example, Kulp and Moore (2000) found that removal of nonnative Rainbow Trout *Oncorhynchus mykiss* using electrofishing allowed for the successful reproduction of native Brook Trout *Salvelinus fontinalis* and did not negatively affect native Blacknose Dace *Rhynchthys atratulus* in an Appalachian stream. In contrast, the removal of Longnose Suckers *Catostomus catostomus* via gill and fyke netting and seining did not result in the improvement of the Rainbow Trout fishery in Pyramid Lake, Alberta (Rawson and Elsey 1950). Meronek et al. (1996) estimated that only ~43% of all mechanical control projects are successful. Relatively low success rates may be due to

the fact that growth and fecundity of fishes often increase as their relative abundance decreases (Wydoski and Wiley 1999). In short, undesirable fish populations may reach abundances similar to pre-treatment levels within 1 – 5 years after mechanical removal efforts (Wydoski and Wiley 1999).

A third option for controlling undesirable fishes includes biological control (i.e., biomanipulation) by increasing predation to reduce prey species or decreasing prey availability to control predators (Schuytema 1977). The premise of biomanipulation is rooted in ecological theory and involves alterations of food web structure and dynamics (Reynolds 1994). Predator fish introductions may provide an effective tool for controlling smaller-bodied fishes (e.g., young-of-the year or species whose maximum size is relatively small) when stocking rates and sizes of predators are appropriate (Miller et al. 1989; Reynolds 1994; Wydoski and Wiley 1999). This method of control has been used within impoundments to control nuisance species (Steward et al. 1981; Hartman and Margraf 1993; Anderson and Neumann 1996). However, predator stockings to control undesirable species may be less successful (~24% success rate) than mechanical or chemical removal methods (Meronek et al. 1996). Additionally, there is a risk of introducing a new predators species into a fish community and that risk is they may not target desired species and lead to competition with other species within the water body (Meronek et al. 1996; USACE 2014). Due to various complex interactions within a water body (Meronek et al. 1996), it is difficult to know under what conditions result in a successful biomanipulation and control of overabundant, nuisance species.

One common undesirable species in the United States and in some parts of Europe is the Black Bullhead *Ameiurus melas*; in fact, nearly 22% of undesirable fish

control projects reviewed by Wydoski and Wiley (1999) involved either Black Bullheads or other *Ameiurus* and *Catostomidae* species. Black Bullheads are native to most waters where they reach nuisance abundances (Carlander and Moorman 1956; Jenkins 1958; Brown et al. 1999) but have been introduced into many waters worldwide (Wheeler 1978; Boet 2001; Copp et al. 2005). Biomasses of Black Bullheads are frequently much higher than other fishes in the same community (Carlander 1955; Carlander and Moorman 1956), and high abundances of this species may be related to other negative consequences. For example, an increase of juvenile and adult Black Bullhead were positively related to increases in turbidity from about 10 - 12 Nephelometric turbidity units (NTUs) in the control unit (no Black Bullheads) to about 19 – 23 NTUs in experimental units (Braig and Johnson 2003). Nesting activities exhibited by Black Bullheads have been postulated to have short-term effects (e.g. 1 - 2 months) on aquatic food webs due to disruption of aquatic vegetation (Kahl 1991; Braig and Johnson 2003), sediment mixing, and photic zone reduction (Kahl 1991). Outside of their native range, Leunda et al. (2008) found that introduced Black Bullhead in the Iberian Peninsula negatively affected native fish populations directly through consumption or indirectly through consumption of plant material that provided feeding and nursery habitats and invertebrates that were commonly consumed by those fishes. Concerns with overabundance of Black Bullheads in both their native and introduced ranges has prompted interest in identifying effective means of control (Bandow 1989; Wydoski and Wiley 1999; Hanchin et al. 2002; Cucherousset et al. 2006).

Chemical treatments (Clemens and Martin 1953; Bandow 1953; Bettoli and Maceina 1996; Ward et al. 2013), mechanical removal (Hanson et al. 1983; Cucherousset

et al. 2011), and the introduction of predator fishes (Blankman 2004) have been used previously in attempts to reduce abundances of Black Bullheads in many waters, and the relative success of achieving short- or long-term control bullheads has varied among studies (Meronek et al. 1996). Bandow (1989) successfully reduced Black Bullhead populations with the use of winter rotenone treatments in some small Minnesota water bodies, but abundances of bullheads were only reduced for a year or two. Hanson et al. (1983) found that the mechanical removal of Black Bullheads with fyke-nets reduced the standing population of fish >76 mm total length (TL) and increased size structure of bullheads for at least five years. Blankman (2004) found that introduced Flathead Catfish *Pylodictis olivaris* were able to consume and reduce Black Bullheads to undetectable levels within 14 months after initial introduction, in several small farm ponds,. Though no Flathead Catfish were recovered after initial introduction, Blankman (2004) believed that if these catfish persist, they could potentially continuously control and due to their piscivorous nature (Slaughter and Jacobson 2008). To my knowledge, no information exists on the ability of other predators to control Black Bullhead populations, especially in larger bodies of water (e.g., lakes and impoundments).

Previous studies of Black Bullhead consumption by native predators provide at least some evidence to support the potential use of this approach. Liao et al. (2002) found that Largemouth Bass consumed Black Bullheads throughout the growing season (i.e., May – October) in Spirit Lake, Iowa; in fact, bullheads occurred in ~ 50% of all bass stomachs sampled. Northern Pike *Esox lucius* have been found to consume some Black Bullheads in a shallow bog lake, but bullheads only constituted a small proportion of food items (2%; Pierce et al. 2003). The use of existing predators in a community to

control Black Bullhead may be advantageous as costs could be relatively low and concerns of introducing new species into a community are avoided (Meronek et al. 1996; USACE 2014).

Biological control of Black Bullheads by any predator may not be feasible when bullhead body size exceeds predator mouth gape. Blankman (2004) found that Black Bullheads were only consumed by Flathead Catfish greater than 1.4 kg (Blankman 2004). Only Walleyes that had reached at least 380 mm TL were able to consume Black Bullheads in Lake Thompson, South Dakota (Isaak et al 1993). Black Bullheads may have the ability to make themselves larger to avoid predation (Forbes 1989; Fine et al. 2011; Sismour et al. 2013). Ictalurids in general will often flare their serrated dorsal and pectoral spines when threats are perceived (Holm et al. 2009; Fine et al. 2011). This behavior by Black Bullheads may lead to potential injury or death of predators during ingestion (Scott and Crossman 1973; Bell-Cross 1974; Forbes 1989). To determine whether biological control of Black Bullheads is possible within small impoundments by various predator species, information is needed on piscivore consumption of bullheads as well as bullhead body dimensions and predator gape widths. The objectives of this study were to: 1) document consumption of Black Bullheads by various extant predators common to four small South Dakota impoundments; and 2) determine the relative vulnerability and potential ingestion of Black Bullheads by these predators.

METHODS

Black Bullheads and their potential predators were sampled from four small impoundments (<200 ha, as defined by Pope et al. 2009) across South Dakota. Four impoundments were selected to encompass physical geographic variability within the

state. South Dakota is bisected longitudinally by the Missouri River, separating the state essentially in half. Western South Dakota is predominantly composed Mesozoic clay, sandstone, and shale (SDDENR 2015) and receives around 30 – 40 cm of precipitation annually (Hubbell et al. 1987; Pieper 2005). Manmade impoundments are the most common waterbody type within western South Dakota (SDGFP 2014). Eastern South Dakota is composed mostly of Pleistocene sediments from glacial deposits (SDDENR 2015) and receives ~ 20 cm more annual precipitation compared to the western region (Hubbell et al. 1987). Natural lakes compose the majority of waterbody types within eastern South Dakota, but impoundments of rivers are also common (Lucchesi et al. 2014). Around 70% of annual precipitations occurs during the growing season (May through October) in both regions (Hubbell et al. 1987). Historically, grasslands were prevalent across the state but rates of conversion to row crop agriculture have increased in the past decade, predominately in eastern South Dakota (Wright and Wimberly 2012; Johnson 2013 and 2014).

Bear Butte and Curlew Lakes represented western impoundments and Lake Alvin and Marindahl Lake represented eastern impoundments (Figure 3-1). Bear Butte Lake is located west of Bear Butte State Park and is the largest of the impoundments (surface area = 74 ha); mean and maximum depths are 2 and 4 m, respectively. Curlew Lake (surface area = 53 ha) has a mean and maximum depth of 3 and 7 m, respectively, and is located 24 km north of New Underwood. Marindahl Lake (surface area = 56 ha), is the deepest impoundment, with a mean and maximum depth of 4 and 9 m, respectively, and is located northeast of Yankton. Lake Alvin (surface area = 42 ha) is located 21 km southeast of Sioux Falls and has a mean and maximum depth of 3 and 8 m, respectively.

Western impoundments were sampled in 2017, and eastern impoundments were sampled in 2018.

Three predators commonly collected across all four impoundments included Channel Catfish, Largemouth Bass, and Walleye (Table 3-2). Two age groups of predators (i.e., juveniles and adults) were sampled in order to account for any potential ontogenetic shifts in food habits (Table 3-2). Predators were collected during the last two weeks of each month from May through September primarily using daytime and nighttime direct current (12 – 16 A; 170 V), high-pulse frequency (120 pulses * s⁻¹) electrofishing. Supplemental sampling was completed with short-term (10 – 120 min) gill-net sets with either a large-mesh net (45.7 x 1.8 m; bar mesh = 76.2 mm) to capture larger predators or an experimental net (45.7 x 1.8 m; 7.6-m panels; bar mesh = 12.7, 19.1, 25.4, 31.8, 38.1, and 50.8 mm) to capture predators of various sizes. Short-term (60 – 120 min) and overnight sets of modified-fyke nets (frame = 0.9 x 1.5 m; bar mesh = 19 mm) were also used as needed. All predators were measured for total length (TL; mm), gape width (mm), and weighed to the nearest 1 g. Gapes were measured by a single measurer, using a caliper to measure the width of a predator fish's gape without expanding the flesh. This was done to prevent any measurer bias and overestimating the gape of a predator fish. Kolmogorov-Smirnov tests were used compare the gape distributions between each predator species and a Bonferroni correction was used ($\alpha = 0.017$).

Stomach contents of predators were collected using gastric lavage if fish were collected alive or stomach excision if mortality occurred during sampling. Each individual predator's stomach contents were preserved in an 75% ethanol solution for

later identification and enumeration in the laboratory. We attempted to collect 20 predators by age category with food in their stomachs for each impoundment and month. Stomach contents were identified to species for fish and order for invertebrates when possible. Frequency of occurrence (O_i ; Bowen 1996) of Black Bullheads was calculated by each month and predator based on the number of stomachs that contained at least one bullhead across all examined stomachs of predators of each respective species and age group.

Black Bullheads of various sizes were sampled across all four reservoirs between May and September during the same time periods as the predators. Five, 100-m transects were randomly selected around each reservoir, and fish were collected using a beach seine (mesh = 6 mm; length = 15 m). All Black Bullheads were counted, weighed (g), and measured for total length (TL; mm) and body depth and width (mm). Body width and depth measurements were taken with the pectoral and dorsal spines extended and retracted to account for the protective mechanisms that Black Bullheads may use to avoid predation (Scott and Crossman 1973; Bell-Cross 1974; Forbes 1989). Differences between the body depth and width of Black Bullheads with and without the spines extended were compared using a paired-t test ($\alpha= 0.05$).

The potential vulnerability of Black Bullheads to predation was assessed using relative vulnerability curves and probabilities of ingestion (Hambright et al. 1991). Relative vulnerability (V) was calculated using data from all four reservoirs combined as:

$$V_d = 1 - \sum_{w=0}^d W$$

where d is the body depth or width of the Black Bullheads and W is the frequency of the gape widths of the predator under consideration. Separate vulnerability curves were calculated based on Black Bullhead body depth and width measured with and without dorsal and pectoral spines extended, respectively. Relative vulnerability values range from 0 (i.e., no Black Bullhead were vulnerable to predation by predators with a given gape width) to 1 (i.e., all Black Bullhead were vulnerable to predation by predators with a given gape width). Vulnerability curves were compared between predators visually.

Separate probability of ingestion [P(I)] were developed for each predator species using predator data combined from all impoundments. Probabilities of ingestion were calculated using the following equation (Hambricht et al. 1991):

$$P(I)_d = V_d^r * D$$

where d is the body depth or width of Black Bullheads [with either the spine(s) extended or retracted], V_d is relative vulnerability (as calculated above), r is a proportional constant to account for increased potential consumption with increasing piscivore body mass, and D is the frequency of body depths or widths of Black Bullheads. Similar to relative vulnerability, probability of ingestion ranges from 0 (i.e., no probability of ingestion of Black Bullheads) to 1 (i.e., highest probability of ingestion of Black Bullheads). Probability of ingestion was compared visually between predators and for each morphometric measurement of Black Bullheads.

RESULTS

Body Morphometrics

A total of 1,412 predators were measured for gape widths (Figure 3-2). Channel Catfish had the widest range and the overall largest gape of all three predators ($n = 170$; range = 12 – 160 mm; mean \pm standard error = 49 ± 2.2 mm). Largemouth Bass gapes were the smallest on average ($n = 590$; mean = 45 ± 0.8 mm) and varied between 4 and 93 mm. Walleye gapes were intermediate in size compared to the other two predators ($n = 652$; range = 10 – 105 mm; mean = 46 ± 0.6 mm). Channel Catfish and Largemouth Bass were the only predators that had similar gape distributions ($D = 12$; $P = 0.05$), all other predator gape distributions were significantly different (Channel Catfish v. Walleye, $D = 0.15$; $P = 0.01$; Largemouth Bass v. Walleye, $D = 0.11$; $P < 0.01$).

A total of 497 Black Bullheads were sampled among the four impoundments. Average body depth without the dorsal spine extended was 37 mm (± 0.2) and ranged from 8 – 55 mm (Figure 3-3). Body depths were significantly larger ($t = -85.0$; $P \leq 0.001$) when the dorsal spine was extended (range = 15 – 81 mm; mean = 52 ± 0.3 mm) compared to depths measured without spine extension (range = 8 – 55 mm; mean 37 ± 0.2 mm; Figure 3-3). Body width was significantly larger ($t = -124.5$; $P \leq 0.001$) when pectoral spines were extended (range = 18 – 90 mm; mean = 69 ± 0.4 mm) compared to when pectoral spines were retracted (range = 9 – 57; mean = 38 ± 0.2 ; Figure 3-4).

Frequency of Occurrence of Black Bullhead Consumption

Black Bullheads were rarely consumed by the three predators, and stomach contents generally contained a single Black Bullhead when consumption did occur (Table 3-2). Black Bullheads were only consumed by adult Channel Catfish in Bear Butte Lake in June and July (Table 3-2) and occurred in $3.5 \pm 2.7\%$ (Table 3-2) of all stomach samples collected across all months in this lake. No adult Channel Catfish consumed any

Black Bullheads in any month in the other three lakes, and no juvenile Channel Catfish consumed bullheads in any of the four lakes at any time in this study. Adult Largemouth Bass consumed Black Bullheads in all impoundments sampled but patterns of consumption differed across each lake (Table 3-2). In Bear Butte Lake, Largemouth Bass only consumed Black Bullheads in May, and bullheads occurred in $8.0 \pm 8.0\%$ of all stomach samples collected across all months (Table 3-2). In the other three lakes, Black Bullheads were consumed later in the summer (July and August) by Largemouth Bass. However, frequency of occurrence of Black Bullheads in Largemouth Bass food habits differed between the lakes (Table 3-2). Occurrence was highest for Largemouth Bass among the three lakes in Lake Alvin ($4.2 \pm 2.8\%$), and lowest in Marindahl Lake ($1.2 \pm 1.2\%$; Table 3-2). No juvenile Largemouth Bass consumed any Black Bullhead in any impoundment during the sampling periods. Adult Walleye only consumed Black Bullhead in Lake Curlew; consumption was only documented in May and occurred 4.5% (± 4.5) of stomach samples. No juvenile Walleye consumed any Black Bullhead in any impoundment during any month (Table 3-2).

Relative Vulnerability and Potential Ingestion

Black Bullhead relative vulnerability based on bullhead body depth was similar for all three predators, regardless of whether bullhead depths were measured with the dorsal spine extended or not (Figure 3-3). The smallest Black Bullheads (body depths = 5 – 12 mm) were highly vulnerable ($V_d = 0.8 - 1.0$), and the largest bullheads (body depths = 66 – 81 mm) collected were low to moderately vulnerable ($V_d = 0.01 - 0.40$). Black Bullheads were vulnerable to Channel Catfish at larger sizes compared to Largemouth Bass and Walleye (Figure 3-3). However, potential ingestion was relatively

low for all three predators regardless of whether body depths were measured without dorsal spines extended [$P(I) = 0.00 - 0.12$] or with extension [$P(I) = 0.00 - 0.09$; Figure 3-3]. Potential ingestion was similar among all three predators based on Black Bullhead body depths measured without dorsal spine extension but higher for Channel Catfish compared to the other two predators when bullhead depths were measured with the dorsal spines extended (Figure 3-3).

Black Bullhead relative vulnerability based on body width was also similar among the three predators, regardless of whether bullheads widths were measured with pectoral spines extended or not (Figure 3-3). Patterns of vulnerability were similar among all three predators; the smallest Black Bullheads (body widths = 6 – 23 mm) were highly vulnerable ($V_d = 0.8 - 1.0$) and the largest bullheads collected (body widths = 62 – 83 mm) were minimally vulnerable to predation ($V_d = 0.01 - 0.40$). All sizes of Black Bullheads, especially larger bullheads, were more vulnerable to predation by Channel Catfish than Largemouth Bass and Walleye (Figure 3-4). Potential ingestion was similar among predators [$P(I) = 0.00 - 0.11$] when pectoral spines were not extended and when pectoral spines were extended [$P(I) = 0.00 - 0.02$; Figure 3-4].

DISCUSSION

This study provides new information about the potential for biological control of Black Bullheads by an existing predator community; further, my research involved larger waterbodies (i.e., small impoundments) than previously examined (i.e., smaller ponds). Overall, most of the Black Bullheads I collected were vulnerable to a degree to all three predators common to each of the four impoundments. However, the occurrence of Black Bullheads in juvenile and adult predator stomachs was low to negligible and may reflect

the low potential ingestion values I calculated based on predator gape widths and various measures of bullhead body widths and depths.

Varied rates of consumption of Black Bullheads by the same predators and age classes I collected have been found in other studies. A few studies have examined Largemouth Bass consumption of Black Bullheads at various ages both in the wild and captivity. Pelham et al. (2001) found that juvenile Largemouth Bass did not consume any Black Bullheads in Spirit Lake, Iowa, but Liao et al. (2002) found that half of adult bass that were sampled in the same lake consumed bullheads. Lewis et al. (1961) found that captive adult Largemouth Bass consumed few Black Bullheads relative to other prey items and most bullheads were consumed by the largest bass.

Similar to Largemouth Bass, consumption of Black Bullheads by Walleye may be variable across waters and limited to just the largest individuals. Walter (2000) found that Black Bullhead were a small portion of the food habits (~4% by weight) of quality-length Walleye (≥ 381 mm TL) in Byre Lake, South Dakota, during the spring. However, Black Bullhead were not consumed at all by Walleye of any size in several other waters in the same state (Walter 2000). Liao et al. (2002) found that Black Bullheads occurred in <6% of adult Walleye (≥ 305 mm TL) in Spirit Lake, Iowa, but no juvenile Walleye consumed any bullhead in that lake (Pelham et al. 2001). To date, no study to my knowledge has documented consumption of Black Bullheads by Channel Catfish.

Two reasons may explain why variable consumption rates of Black Bullheads have been observed among different predators. First, Black Bullheads have an ability to defend themselves unlike other prey (e.g., invertebrates, small-bodied cyprinids). Black

Bullheads, like other members of the family Ictaluridae, have the ability to mechanically lock their spines (Alexander 1965) to appear bigger or damage or kill predators during ingestion (Scott and Crossman 1973; Bell-Cross 1974; Forbes 1989). Second, handling and digestion times of Black Bullheads may be longer for predators relative to other prey items (Hoogland et al. 1956; Gillen et al. 1981). Wahl and Stein (1988) found handling times by three *Esox* species significantly increased when prey had spines versus spineless prey. Several studies have documented that Walleye appear to select soft-rayed over spiny-rayed prey species (Parson 1971; Knight et al. 1984; Einfalt and Wahl 1997). Increased handling and digestion times may negate at least some of the energetic benefits that Black Bullheads may provide to predators (Werner and Hall 1974; Gillen et al. 1981; Stephens and Krebs 1986). Thus, if alternative prey items are available, predators may select alternative energy sources rather than incur injury or lose energy to consume Black Bullheads.

Results from this study provide new information on biological control of overabundant Black Bullheads. However, some limitations in this study exist. One such limitation is that I did not evaluate alternative prey sources in these reservoirs. Such information could have been used to calculate selectivity of various prey items, including Black Bullheads, by predators to further explain under what conditions predators may consume bullheads. A second limitation was that sampled Black Bullheads were all similar size, thus, smaller or larger bullheads were not sampled. This information could have helped assess the vulnerability of smaller Black Bullheads to predators as well as allow for a better understanding of bullhead population dynamics in each impoundment to determine if they are over abundant. Future research should focus on the selection of

various sizes of Black Bullhead as prey by various predators under different prey availabilities. Collectively, this information coupled with my results can provide information on the possible use of biological control of Black Bullhead by predator fish and under what conditions predators consume bullheads.

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Table 3 - 1. Total body lengths that defined juvenile and adult predators captured in this study. Age categories are based on previous studies documenting the total lengths of predators when they reach sexual maturity.

| Species | Total length (mm) | | Source |
|-----------------|-------------------|-------|-----------------------------------|
| | Juvenile | Adult | |
| Channel Catfish | < 300 | ≥ 300 | Willis et al. (2001) |
| Largemouth Bass | < 200 | ≥ 200 | Holland and Petters (1992) |
| Walleye | < 380 | ≥ 380 | Kansas Fishes Committee (2014) |

Table 3 - 2. Frequency of occurrence (O_i; %) of Black Bullhead prey items in both adult and juvenile predators across four South Dakota impoundments by month. Blanks indicate that no predators of that species and age category were collected from that lake in that month. Zeros indicate that predators were collected during that month but that none of them consumed any Black Bullhead.

| Predator | Month | Age category | Impoundments | | | |
|----------|-----------|--------------|--------------|--------|-------|-----------|
| | | | Bear Butte | Curlew | Alvin | Marindahl |
| Channel | May | | | 0 | | |
| | June | | | | 0 | |
| | July | Juvenile | | 0 | | |
| | August | | | 0 | | |
| | September | | | | | 0 |
| Catfish | May | | 0 | 0 | 0 | 0 |
| | June | | 14 | | 0 | 0 |
| | July | Adult | 4 | | 0 | 0 |
| | August | | 0 | 0 | | 0 |
| | September | | 0 | | | 0 |

| | | | Impoundments | | | |
|------------|-----------|--------------|--------------|--------|-------|-----------|
| Predator | Month | Age category | Bear Butte | Curlew | Alvin | Marindahl |
| | May | | 0 | 0 | | |
| | June | | | 0 | | |
| | July | Juvenile | | | | 0 |
| | August | | | 0 | 0 | 0 |
| | September | | | 0 | 0 | 0 |
| Largemouth | September | | | 0 | 0 | 0 |
| Bass | May | | 50 | 0 | 0 | 0 |
| | June | | 0 | 0 | 0 | 0 |
| | July | Adult | 0 | 7 | 14 | 9 |
| | August | | 0 | 8 | 18 | 0 |
| | September | | 0 | 0 | 0 | 0 |
| Walleye | May | | 0 | 0 | 0 | 0 |
| | June | | 0 | 0 | 0 | 0 |
| | July | Juvenile | 0 | 0 | 0 | 0 |
| | August | | 0 | 0 | 0 | 0 |
| | September | | 0 | 0 | 0 | 0 |
| | May | | 0 | 10 | 0 | |
| | June | | 0 | 0 | 0 | |
| | July | Adult | 0 | 0 | | |
| | August | | 0 | 0 | 0 | |
| September | | 0 | 0 | 0 | | |

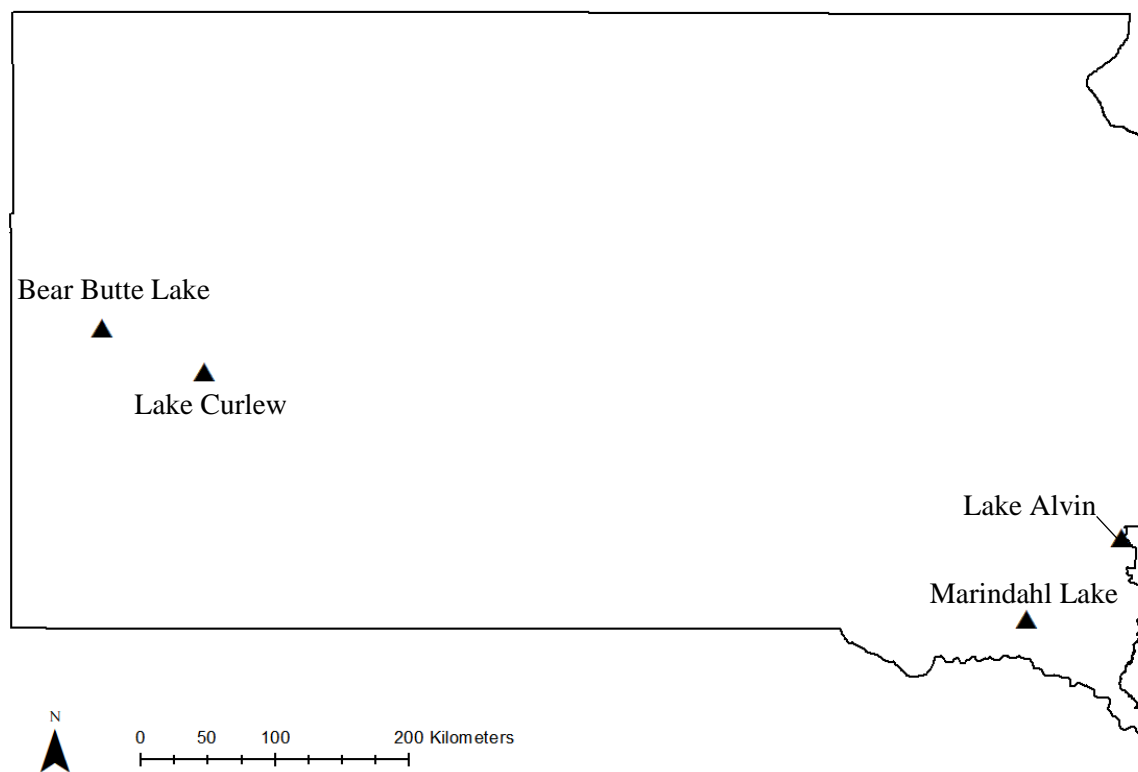


Figure 3 - 1. Locations of the four small reservoirs in South Dakota used in this study. Bear Butte and Curlew Lakes are the most western impoundments and were sampled in 2017. Lake Alvin and Marindahl Lake are the two most eastern impoundments and were sampled in 2018.

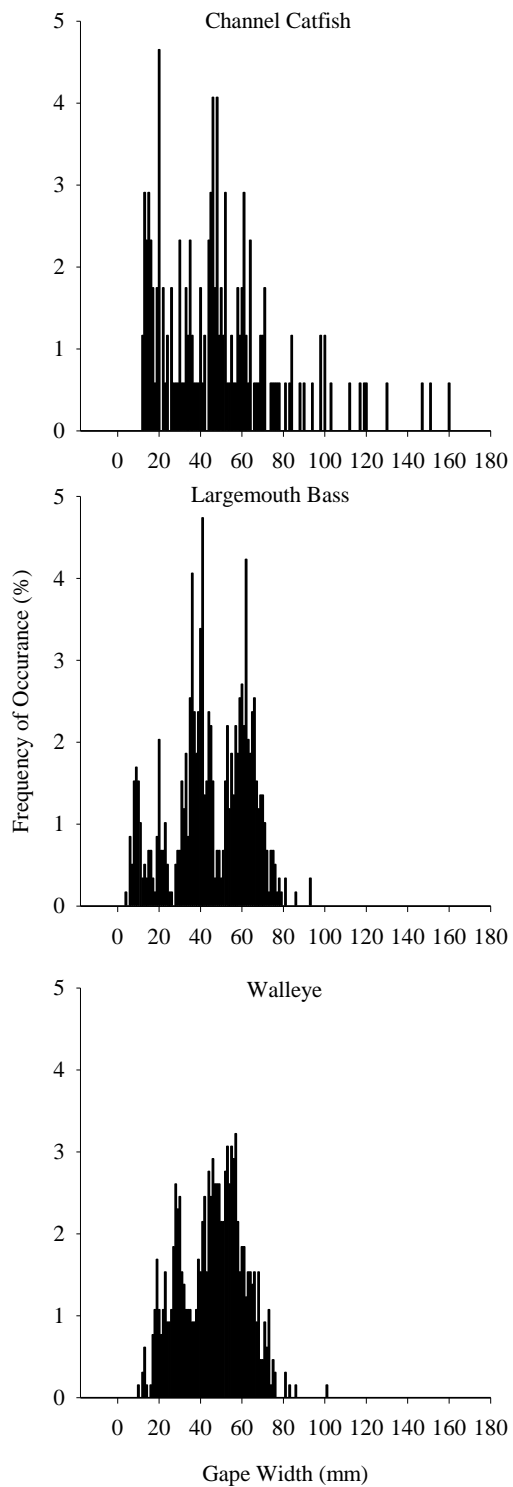


Figure 3 - 2. Frequency of occurrences of gape widths for three different predators collected from four South Dakota small impoundments. Predator species included Channel Catfish (top panel), Largemouth Bass (middle panel) and Walleye (bottom panel).

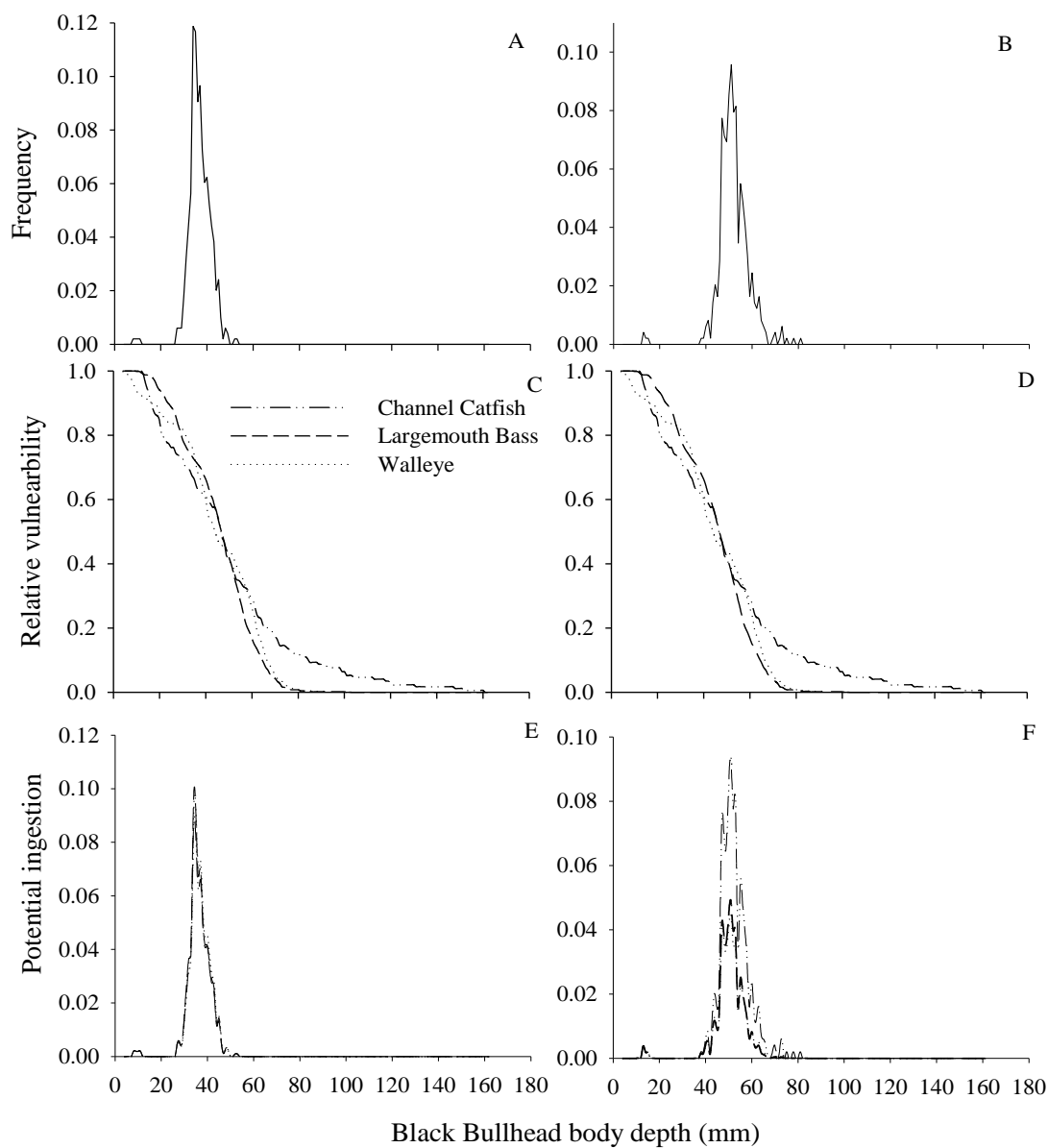


Figure 3 - 3. Comparison of body depths of Black Bullheads without (A) and with dorsal spine extended (B) and the relative vulnerability to (C and D) and potential ingestion by three predators common to four South Dakota small impoundments sampled in this study. Measurements of Black Bullhead depths and predator gape widths were based on fish collected across all four reservoirs combined.

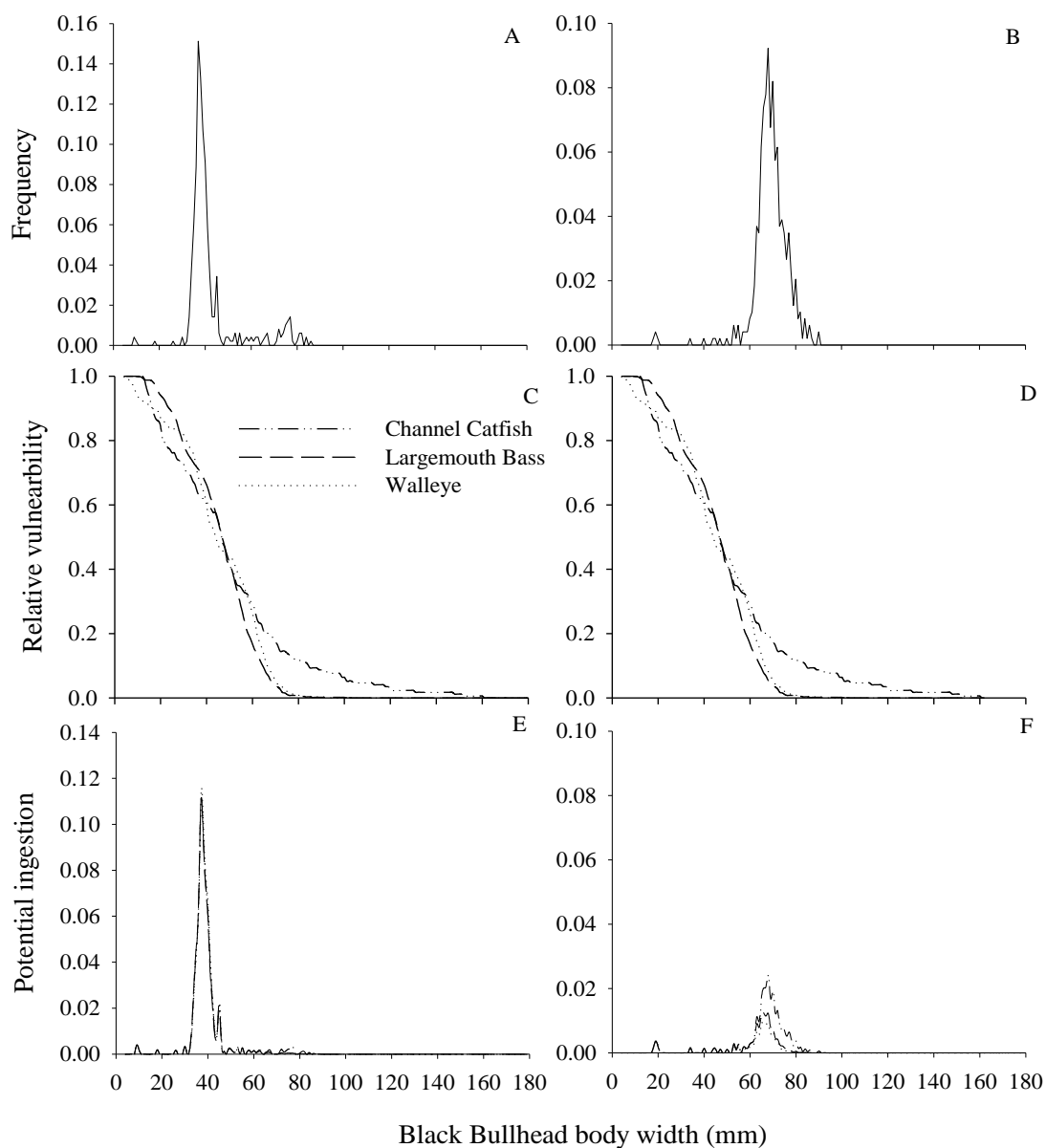


Figure 3 - 4. Comparison of body widths of Black Bullheads without (A) and with pectoral spines extended (B) and the relative vulnerability to (C and D) and potential ingestion by three predators common to four South Dakota small impoundments sampled in this study. Measurements of Black Bullhead depths and predator gape widths were based on fish collected across all four reservoirs combined.

CHAPTER 4: SUMMARY AND MANAGEMENT IMPLICATIONS

The collective results from my research provides information on the potential direct and indirect benefits of Gizzard Shad *Dorosoma cepedianum* introductions in small impoundments across South Dakota. Recent introductions of Gizzard Shad across four reservoirs allowed me to document the consumption of shad across multiple predators and to evaluate whether this consumption influenced predator growth rates. Further, my research examined the possibilities for biological control of Black Bullheads by these same predators, assuming that larger predators (resulting from faster growth rates as a result of Gizzard Shad stocking) would be more likely to consume bullheads. Collectively, my results provide managers insights on the use of Gizzard Shad stockings and biomanipulation of Black Bullheads via the existing predator community and highlight what additional research is needed in order to improve decision making for small impoundment management.

Consumption patterns of Gizzard Shad by and general food habits of predators differed across locations, species, and ages. Some interesting patterns were noted between western and eastern South Dakota reservoirs. Predators in western reservoirs appeared to consume more Gizzard Shad in general compared to the same predators in eastern reservoirs. Low consumption of Gizzard Shad in eastern reservoirs may have been due to a number of weather issues in the months prior to and during my study. First, a winterkill event potentially reduced the abundance of or extirpated adult Gizzard Shad several months prior to my field collections in eastern reservoirs. Additional pre-spawn adult Gizzard Shad were introduced in the spring following this winterkill event. However, stress from stocking could have reduced the condition of the adults, which may

have led to reductions in spawning success and survival of progeny (Willis 1987; Miranda and Muncy 1988). Additionally, there were several flooding events during the months of field collection that could have reduced the number of juvenile Gizzard Shad available for consumption. The flooding events may have increased complex habitat by flooding the shoreline and increased the turbidity within the impoundments, thus providing cover from predators. Schramm and Zale (1985) and Gregory and Levings (1996) found that an increase in either turbidity or complex habitat from flooding can reduce predator and prey interactions and can cause a shift in prey selection due to reduced water clarity and the increased habitat availability. Further, some juvenile Gizzard Shad may have been entrained through or escaped over the top of the dams of these reservoirs (Dave Lucchesi, South Dakota Department of Game, Fish and Parks, *personal communication*). Another possible explanation for the lack of consumption of Gizzard Shad observed in eastern reservoirs is that not enough pre-spawn adults were stocked in order to produce a strong year class of larvae and juveniles. To date, no research has identified the appropriate stocking densities of pre-spawn adult Gizzard Shad in northern latitudes and how various environmental conditions may affect those stocking densities.

While there is evidence from my study and others (e.g., Ward et al. 2007; Wuellner et al. 2010; VanDeHey et al. 2013) that indicate that Gizzard Shad may be important prey items to some predators and age groups, my results indicate that shad may not have a substantial impact on some juvenile and adult predator growth, at least in terms of weight. Bioenergetics models indicated that growth of most predators in most lakes was only slightly different when Gizzard Shad were eliminated from predator food

habits as compared to the growth rates I observed in my study. Similar results were found by VanDeHey et al. (2013). Where the growth of Walleye in several small waterbodies were only slightly affected by the introduction of Gizzard Shad. However, some exceptions were noted (i.e., adult Black Crappie and Walleye in Bear Butte Lake and Walleye in Curlew Lake) and that the absence of Gizzard Shad may result in reduced growth of some predators. The reduced growth modeled for several predators under the absence of Gizzard Shad was similar to what Wuellner et al. (2010) found in Walleye and Smallmouth Bass in Lake Sharpe, South Dakota. Though results from my study were similar to other studies within South Dakota, the full extent of the impact Gizzard Shad are having in these small impoundments is not known. There were several limitations of this study that could have helped assess the impacts of Gizzard Shad introductions. One limitation was the lack of predator food habit information prior to introductions. This information could help assess the impacts Gizzard Shad introductions are having on food habits and growth. Another limitation is the lack of knowledge on how Gizzard Shad introductions are affecting other species within these impoundments. Though this study did not observe any negative impacts on observed species, other species not examined may be affected by Gizzard Shad introductions. Future research should examine predator food habits and growth prior to Gizzard Shad introductions and how these introductions impact other species.

While Gizzard Shad may provide benefits to some predators in smaller impoundments in certain cases, Black Bullheads are commonly noted as being overabundant and a nuisance in many communities across their range (Carlander and Moorman 1956; Jenkins 1958; Brown et al. 1999). Methods for controlling Black

Bullheads using various techniques have been studied, though the use of predators as a control has been studied to a lesser extent (Blankman 2004). My research documented not only the occurrence of Black Bullheads in food habits of several predators in four impoundments but also modeled the potential for bullhead consumption based on four different measures of body size. To my knowledge, my study was the first to examine vulnerability of Black Bullhead to predation based on bullhead width and depth, both measured with and without pectoral or dorsal fins extended, respectively. My results indicated that vulnerability of Black Bullheads to predation in these four impoundments was relatively high, regardless of body depth or height or whether spines were extended or not. However, actual consumption of Black Bullheads by predators was relatively low for all three predators. Other studies have shown that consumption of Black Bullheads by these predators is limited in general and may only be possible by the largest individuals (Walter 2000; Pelham et al. 2001; Liao et al. 2002). One possible explanation for low consumption rates of Black Bullheads may be related to the danger (Scott and Crossman 1973; Bell-Cross 1974; Forbes 1989) and increased handling times associated with fish with hard spines (Hoogland et al. 1956; Gillen et al. 1981). Forbes (1989) hypothesized that Black Bullheads may not be “profitable” to predators in terms of energy gained from consumption due to potential damage and risk of mortality from spine-related injuries (Scott and Crossman 1973; Bell-Cross 1974; Forbes 1989). Research in the laboratory and field may be needed to further understand under what conditions consumption of Black Bullheads differ (e.g., availability of other “soft body” prey items; degree spatial overlap between bullheads and predators; size selection of bullheads by predators) in order to determine whether biological control of bullheads via

predation may be possible in my study lakes as well as in other systems across their range.

Overall, the information gained from my research on the impacts of Gizzard Shad introductions and the potential for biological control of Black Bullheads by predators in small impoundments can be used to inform management decisions that may bring predators and prey in balance in dynamic systems such as small impoundments. However, additional research is needed to understand the dynamics of predators and prey in these systems. More specific information is needed regarding the interactions of Gizzard Shad and Black Bullheads with other members of their communities. Such questions may include:

1. What stocking levels for small waterbodies are needed to maintain Gizzard Shad populations in northern latitudes?
2. How do existing prey populations change after the introduction of Gizzard Shad into a waterbody, and are there any effects on other trophic levels?
3. What biotic and abiotic conditions affect predator selection for or against Black Bullhead prey?
4. How does biological control of Black Bullheads via predation compare to other methods of control (e.g., chemical, mechanical) in terms of ecological impacts, duration of results, and costs?

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