EFFECTS OF LENGTH LIMITS ON SEXUALLY SIZE DIMORPHIC FISHES


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Length limits are used by fishery managers as a method to alter size structure of fish populations. Unfortunately, biological differences between fish sexes (i.e., sexual-size dimorphism) may lead to sex-specific rates of recruitment, growth, and mortality. The addition of angler harvest to most aquatic systems likely accentuates differences in sex-specific rates by selectively harvesting the fastest-growing and largest fish from a population. The first objective of this study was to document the extent of sexual-size dimorphism for white bass and walleye at a Nebraska reservoir. Growth rates were similar between male and female white bass although male white bass were consistently shorter than their female counterparts at a given age. Male walleye grew slower and were consistently shorter than their female counterparts at a given age. The second objective was to document the size, sex, and age of white crappie, white bass and walleye harvested in two Nebraska reservoirs. Harvest was female biased for both white crappie and white bass, whereas harvest was similar for both male and female walleye. The third objective was to determine if size-, sex- or age-selective harvest was occurring for white bass and walleye at a Nebraska reservoir. Anglers harvested female white bass at a greater proportion than was sampled during NGPC annual population surveys. Anglers at Sherman Reservoir did selectively harvest walleye based on size, although in contrast to the white bass population, sex-selective harvest was not apparent for walleye. The

final objective was to provide a model that predicts possible outcomes from using different length limits for sexually size dimorphic fishes. Although there was a noticeable difference in the number of fish in a population for each length limit, the pressure applied to the population by catch-and-release mortality kept the sex ratio close to a 1:1.

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**Introduction**

Length limits are used by fishery managers as a method to alter size structure of fish populations via angler harvest.  In the 1960's and 1970's, minimum length limits gained popularity because managers believed that allowing smaller fish more time to live and grow would allow for a greater biomass of fish and thus increase harvest (Wilde 1997).  Currently, length limits are used to achieve a desired size and age structure or as a method to prevent overharvest (Noble and Jones 1999).  Additionally, they are used to manipulate predator-prey dynamics, alter sex ratios, and foster angler satisfaction (Noble and Jones 1999; Boxrucker 2002).

Fishery managers employ many types of length limits including minimum, slot, maximum, and inverse slot.  The most frequently employed is the minimum length limit, preventing anglers from harvesting fish under a prescribed length.  Minimum length limits are recommended for fish populations with poor recruitment, good growth rates, and high fishing mortality (Novinger 1984).  In theory, minimum length limits will increase abundance, improve age structure, and increase mean size of fish harvested (Colvin 1991; Munger and Kraai 1997; Hale et al. 1999; Fayram et al. 2001; Stone and Lott 2002; Isermann 2007).  Another common length limit used is the slot length limit, preventing harvest between two prescribed lengths.  Slot length limits are recommended for fish populations with good recruitment and poor growth (Anderson 1976).  In theory, slot length limits promote growth of smaller fish by reducing abundance and associated intraspecific competition of smaller fish, which ultimately increases abundance of trophy

size fish (Anderson 1976). Less common are the maximum length limit, preventing anglers from harvesting fish above a prescribed length, and the inverse slot length limit, preventing anglers from harvesting fish outside of two prescribed lengths. Maximum length limits are recommended when a population has few sexually mature adults or when large numbers of smaller fish are present and managers aim to increase growth rates (Noble and Jones 1999). Inverse slot limits (i.e., creation of a harvest slot rather than a protected slot) are recommended to protect small fish to recruitment and large fish for reproduction and attainment of trophy size (Noble and Jones 1999).

Length limits are widely used. However, success of desired outcomes varies for reasons not fully understood. Wilde (1997) believed that increasing the duration of post-treatment (i.e., after implementation of length limit) assessment would provide a more accurate assessment of fishery responses. Similarly, Allen and Pine (2000) suggested that evaluation periods of at least five years are necessary to identify a fishery response to the implemented minimum length limit. Additionally, Allen and Pine (2000) demonstrated that a minimum length limit will not achieve an increase in size structure for fish populations with great variation in recruitment.

Prior knowledge and understanding of the dynamics (i.e., recruitment, growth, and mortality) associated with a fish population are critical when managers seek to implement and achieve success from length limits. Recruitment is defined as the number of fish entering the fishery and can vary temporally and spatially. Consequently, variation in recruitment can lead to inconsistent growth by influencing ecological processes such as predator-prey interactions and intraspecific competition. Growth is defined as the rate of change in size of individuals in a population from year to year and

can vary widely due to food abundance, weather, competition, and many other factors
(Van Den Avyle and Hayward 1999). Mortality can be defined as the instantaneous
annual mortality (i.e., negative slope of catch curve) and can be split in two categories,
conditional natural mortality (i.e., death rate in the absence of fishing) and conditional
fishing mortality (i.e., exploitation rate in the absence of natural mortality) (Ricker 1975).

Although knowledge of population dynamics is important when considering
length limits, subsequent biological processes (e.g., sexual dimorphism) are also critical.
Sexual dimorphism (i.e., systematic difference in form between individuals of different
sex in the same species) is a common phenomenon found in nature and is believed to be a
result of species-specific evolutionary differences in sexual selection, parental
investment, and resource partitioning. Sexual selection occurs when competition for
mating favors larger body size; typically reflected in the male members of a species.
Alternatively, parental investment occurs when adult size is determined by constraints
imposed by parental investment in offspring (Holtby and Healey 1990). Females may
delay maturation when a relationship exists between female size and fecundity,
subsequently increasing their chances (for successful reproduction) of passing along their
genes to the next generation. Conversely, if male involvement is minor compared to
females, males may mature at a smaller size and younger age (Holtby and Healey 1990).
Resource partitioning occurs when males and females use different niches (e.g., targeted
prey for species with sex-specific size differences) and therefore compete for different
resources resulting in a fitness advantage for both sexes (Holtby and Healey 1990).

Many sportfishes exhibit sexual-size dimorphism, which may lead to sex-specific
rates of recruitment, growth, and mortality. Male bluegill *Lepomis macrochirus* must

compete with each other for the rights to spawn with a single female and later guard the nest of eggs. This competition leads to faster growth rates, and a larger maximum size for male bluegill (Ehlinger 1997). Alternatively, female walleye *Sander vitreus* (Henderson et al. 2003) and female yellow perch *Perca flavescens* (Headley and Lauer 2008) attain faster growth rates, larger maximum size, and later maturation presumably to increase fecundity and overall reproductive success. Holtby and Healey (1990) hypothesized two different population models to describe coho salmon *Oncorhynchus kisutch* sex differences. Type A populations, which consisted of adult females that were larger and rarer (male biased sex ratio) than adult males, demonstrated sex-specific differences in which females were more willing to risk predation before maturation to obtain energy necessary for faster growth, consequently causing females to have greater mortality rates than males. Conversely, Type B populations, which consisted of equal numbers and sizes of adult male and females, demonstrated no sex-specific differences in willingness to risk predation. Although sexual-size dimorphism may lead to sex-specific rates of recruitment, growth, and mortality, the addition of a human factor (i.e., angler harvest) to most aquatic systems likely amplifies sex-specific dynamics by selectively harvesting the fastest growing, largest fish of a population.

Given that rates of recruitment, growth, and mortality are likely sex specific for many sportfishes and that length limits per se are not sex specific, subtle changes in a length limit may produce drastic changes in population dynamics. Schneider (1978) suggested that increasing the minimum length limit at multiple walleye fisheries in Michigan from 330 to 381 mm would cause a 25% increase in reproductive potential, assuming a 1:1 sex ratio of each population. Many studies have evaluated the effects of

length limits; however, few have evaluated the effects on a sex basis. Therefore, my research will evaluate the effects of length limits on males and females separately for fishes that exhibit varying degrees of sexual-size dimorphism.

**Study Fishes**

Managing a fishery with a length regulation (e.g., minimum length limit) will have different effects on the population dynamics of species that exhibit sexual-size dimorphism than it will on the population dynamics of species that exhibit little to no sexual-size dimorphism. Sexual-size dimorphism, although not present in all fish species, can be viewed as a continuum for all species. On one side of the continuum are species such as bluegill, where males reach a larger maximum size than females. In the middle of the continuum are species such as white crappie *Pomoxis annularis*, where little to no size dimorphism is present. At the opposite end of the continuum are species such as walleye, where females reach a larger maximum size than males. I chose white crappie, white bass *Morone chrysops*, channel catfish *Ictalurus punctatus*, and walleye as my species of interest because they each fall into different areas of the continuum and are managed with different types of regulations. Additionally, these species constitute three of the top five most popular sportfishes in Nebraska (Hurley and Duppong 2005) and are believed to be harvested frequently enough to collect a large sample size from anglers at fish cleaning stations.

*White Crappie*

      The white crappie is a member of the Centrarchidae family and usually inhabits

lakes, ponds, and slow-flowing areas of rivers (Scott and Crossman 1973). The native

range of white crappie includes the eastern half of the USA, excluding areas along the

eastern seaboard (Baxter and Stone 1995). The present distribution of white crappie has

expanded into Texas, New Mexico, Arizona, and states along the west coast (Lee et al.

1980). In Nebraska, white crappie are found statewide with the majority inhabiting

flood-control reservoirs and small impoundments.

      The average yearly growth and age at maturity for male and female white crappie

is about the same, however late in life, females grow faster than males (Morgan 1954).

Most individuals mature at age 3 or 4, though some individuals mature at age 2 (Morgan

1954; Nelson 1974). In Clear Lake, Iowa, white crappie averaged lengths of 72, 144,

184, 208, 231, 272, and 272 mm TL at ages 1 through 7, respectively (Figure 1-1) (Neal

1961). From 1994 through 2009 white crappie in irrigation reservoirs in Nebraska

averaged lengths of 85, 168, 233, 249, 276, 294, and 294 mm TL at ages 1 through 7,

respectively (Hurley 2011).

*White Bass*

      The white bass is a member of the Moronidae family and usually inhabits lakes,

reservoirs, and rivers. The native range of this species includes much of eastern USA,

including the Great Lakes region and the Mississippi River drainage (Scott and Crossman

1973). Due to introductions, white bass currently inhabit most of the southeast and

eastern coast (Lee et al. 1980).  In Nebraska, white bass are found statewide in large streams, lakes, rerservoirs, and rivers (Scott 1967; Morris et al. 1972).

Growth and age at maturity are slightly different for males and females.  Most individuals mature at age 3, though some males mature at age 2 (Horrall 1962).  In Lake Winnebago, 8% of males were mature at age 2, and 100% were mature at age 3; 42% of females were mature at age 3, and 100% were mature at age 4 (Priegel 1971).  White bass in Lake Winnebago averaged lengths of 97, 190, 254, 274, 287, 302, 307, and 320 mm TL at ages 1 through 8, respectively (Figure 1-1) (Priegel 1971).  From 1994 through 2009 white bass in irrigation reservoirs in Nebraska averaged lengths of 139, 239, 296, 328, 345, 358, 375 and 389 mm TL at ages 1 through 8, respectively (Hurley 2011).

*Channel Catfish*

The channel catfish is a member of the Ictaluridae family and usually inhabits large rivers, but is also found in all sizes of lakes, reservoirs, and ponds (Scott and Crossman 1973; Baxter and Stone 1995).  The native range of this species includes most of the eastern two-thirds of the USA (Lee et al. 1980), but due to human introductions now are found throughout the USA (Scott and Crossman 1973).  In Nebraska, channel catfish are the third most sought after species by anglers (Hurley and Duppong 2005) and are found statewide in all types of waterbodies.

Growth and age at maturity are similar for both sexes of channel catfish.  In pool 9 of the Mississippi River, no fish was sexually mature by age 4, but by age 5 both sexes showed some degree of sexual development (17.6% were sexually mature) (Appleget and Smith 1951).  By age 9, 100% of the males and 90% of females were mature (Appleget

and Smith 1951).  Channel catfish in pool 9 of the Mississippi River averaged lengths of

75, 161, 231, 299, 361, 423, 488, 536, 610, 676, 658, and 709 mm TL at ages 1 through

12 (Figure 1-1) (Appleget and Smith 1951).  From 1994 through 2009 channel catfish in

irrigation reservoirs in Nebraska averaged lengths of 120, 203, 274, 331, 382, 427, 469,

507, 530 and 561 mm TL at ages 1 through 10, respectively (Hurley 2011).

*Walleye*

The walleye is the largest member of the Percidae family in Nebraska and usually

inhabits lakes, reservoirs, and large rivers (Scott 1967).  The native range of this species

covers most of the USA east of the Mississippi River (Scott and Crossman 1973), but the

value of walleye as a sportfish has led to the introduction of the species beyond its native

range into western USA (Scott and Crossman 1973; Colby et al. 1979).  In Nebraska,

walleye are the most sought after species by anglers (Hurley and Duppong 2005) and are

generally found in large reservoirs and rivers throughout the state (Morris et al. 1972).

Walleye express sex-specific growth rates and maturation ages.  In Lake

Winnebago, Wisconsin, male walleye mature at ages 2 through 5, and females mature at

ages 5 through 7 (Priegel 1969).  Similarly, males mature at an average age of 4.6 years,

and females at 7.8 years in the Mississippi River (Gebken and Wright 1972).  Male

walleye in Lake Winnebago averaged lengths of 142, 259, 323, 361, 384, and 396 mm

TL at ages 1 through 6, respectively, whereas female walleye averaged lengths of 152,

257, 340, 396, 439, and 472 mm TL at ages 1 through 6, respectively (Figure 1-1)

(Priegel 1969).  From 1994 through 2009 walleye in irrigation reservoirs in Nebraska

averaged lengths of 194, 323, 413, 477, 536, 586, 630, 650, 667 and 665 mm TL at ages 1 through 10, respectively (Hurley 2011).

**Study Reservoirs**

Nebraska has numerous large reservoirs where many different species of sportfish are present. White crappie, white bass, channel catfish, and walleye co-inhabit some of these reservoirs. However, only a few of these reservoirs incorporate different management strategies and special regulations.

*Calamus Reservoir*

Calamus Reservoir is a 2,104-ha irrigation reservoir located in Garfield and Loup counties within the North Loup River drainage in north-central Nebraska. Black crappie *P. nigromaculatus*, channel catfish, common carp *Cyprinus carpio*, muskellunge *Esox masquinongy*, northern pike *E. lucius*, walleye, white bass, wiper *Morone saxatilis x chrysops*, and yellow perch are present in Calamus Reservoir (NGPC 2009). Channel catfish and white bass are managed with no length limit and a daily bag limit of 10 and 15 fish, respectively (NGPC 2009). Current management of walleye in Calamus Reservoir includes a daily bag limit of four walleye with one from 381- to 457-mm TL and three or four over 457-mm TL, but no more than one walleye over 559-mm TL. Prior to 2009, there was a 457-mm TL minimum length limit with only one fish allowed over 559-mm TL, and a daily bag limit of four walleye.

The Nebraska Game and Parks Commission (NGPC) completed an annual population survey on Calamus Reservoir during 2008. Fall gillnet catch per unit effort

(CPUE) for channel catfish was greater than the previous three years; approximately 25% of the fish sampled were larger than 610-mm TL. Catch per unit effort for white bass was the greatest in 10 years with a large portion of the fish sampled between 152- to 229-mm TL (Bauer 2008). By spring 2009, these white bass likely will be big enough to be harvested by anglers; therefore, the potential exists for more white bass to be harvested than an average year. The fall gillnet CPUE for walleye was the least in the last 10 years with a catch of less than 10 fish per net night (Schuckman and Chvala 2009). The majority of the fish sampled were greater than 381-mm TL suggesting the potential for a large harvest. During 2007, the average length at age for walleye and white bass was less than the 2008 average for most ages (Figure 1-2) (Schuckman and Chvala 2009).

*Sherman Reservoir*

Sherman Reservoir is a 1,151-ha irrigation reservoir located in Sherman County within the Middle Loup River drainage in central Nebraska. Black and white crappie, channel catfish, flathead catfish *Pylodictis olivaris*, northern pike, walleye, and white bass are present in Sherman Reservoir (NGPC 2009). Channel catfish and white bass are managed with no length limit and crappie (both species) are managed with a 254-mm TL minimum length limit. The bag limit for channel catfish, white bass, and crappie is 10, 15, and 30 fish, respectively (NGPC 2009). Sherman Reservoir is one of a few reservoirs where walleye are used as broodstock for Nebraska's fish hatcheries. Current management of walleye in Sherman Reservoir includes a daily bag of two walleye greater than 381-mm TL but less than 508-mm TL, and one walleye greater than 711-mm TL. There is a slot length limit protecting walleye between 508- and 711-mm TL. Prior to

2009, there was a 457-mm TL minimum length limit with only one fish allowed over 559-mm TL, and a daily bag limit of four walleye. This regulation had been in effect since the mid-1990's.

The Nebraska Game and Parks Commission completed an annual population survey on Sherman Reservoir during 2008. The channel catfish CPUE in 2008 was less than 2007, but greater than the 10 year average. Over 50% of the channel catfish sampled were between 279- and 406-mm TL. The 2008 CPUE for crappie was the lowest in 10 years. Catch per unit effort during 2008 for white bass was less than 2007, but the size structure remained good with a large majority of fish sampled over 305-mm TL (Bauer 2008). The fall gillnet CPUE had the fewest number of walleye per net night in the last 10 years at Sherman Reservoir (Newcomb and Eifert 2009). Fall gillnet catch of walleye larger than 457-mm TL has also declined since 1999. Although only two age-groups were captured during 2007 for white crappie, the average length at age was less than the 2008 averages (Figure 1-3). During 2007, average length at age for white bass was similar to 2008 averages (Figure 1-3). During 2007, average length at age for walleye was greater than the 2008 average for most ages (Figure 1-3) (Newcomb and Eifert 2009).

The Nebraska Game and Parks Commission completed a creel (angler) survey at Sherman Reservoir during 2007. Approximately 2,500 walleye, 8,500 white bass, 14,300 crappie, and 5,500 channel catfish were estimated to be harvested by recreational anglers during April through September, 2007. The walleye harvest was the largest recorded in the Sherman Reservoir angler survey history. Numbers of crappie and channel catfish harvested have been consistent at the reservoir for the past 10 years (Eifert 2007).

**Goals**

My research has two main goals:  1) understand the extent to which sexual-size dimorphism occurs for walleye, channel catfish, white bass, and white crappie in two Nebraska reservoirs and 2) understand the effects that different length limits have on the population dynamics of fishes that exhibit sexual-size dimorphism.

**Objectives**

1)  Document the extent of sexual-size dimorphism for walleye, channel catfish, white bass, and white crappie in two Nebraska reservoirs.

2)  Document the size, sex, and age of walleye, channel catfish, white bass, and white crappie harvested in two Nebraska reservoirs.

3)  Evaluate the possible influence that different length limits may have on each species' population dynamics.

4)  Develop a model that predicts possible outcomes from using different length limits for sexually size dimorphic fishes.

**Data Sets and Thesis Order**

The following chapters have been written as stand-alone chapters.  The goal of this section is to give readers an understanding of why some data were used in one chapter but not another.  Some data were not collected, thus eliminating some comparisons.

I had planned on collecting data from four species of fish, white crappie, white bass, channel catfish and walleye.  During field collections, anglers brought a limited

number of channel catfish to the fish cleaning stations at both reservoirs. Therefore, channel catfish were eliminated from any data analysis throughout the thesis.

Information was collected from angler-harvested white crappie, white bass and walleye via fish cleaning stations at Calamus and Sherman Reservoirs during the months of April through July. The April through July timeframe was expected to be the period of greatest fishing pressure and harvest at both reservoirs. Samples were collected during two subsequent years, 2009 and 2010. Information was also collected from white crappie, white bass and walleye from Nebraska Game and Parks Commission (NGPC) annual standardized population surveys during the months of September and October. Samples were also collected during two subsequent years, 2009 and 2010.

In the second chapter, I compared males vs. females of the same species using data collected from NGPC annual standardized surveys because I believed data from the standardized surveys would potentially have the least amount of bias. The standardized surveys were unable to effectively sample white bass and walleye at Calamus Reservoir and white crappie at Sherman Reservoir. Thus, only white bass and walleye from Sherman Reservoir were used for comparisons.

In the third chapter, I wanted to give a descriptive overview of what information was collected using the method of collecting information from angler-harvested fish. In the third chapter information is presented for white bass and walleye at Calamus Reservoir. Information is also presented for white crappie, white bass and walleye at Sherman Reservoir.

In the fourth chapter, my goal was to compare data from angler-harvest collections to data from NGPC standardized surveys. As previously stated, information

from standardized surveys for white bass and walleye at Calamus Reservoir and white crappie at Sherman Reservoir was lacking.  Therefore, my comparisons were only completed for white bass and walleye at Sherman Reservoir.

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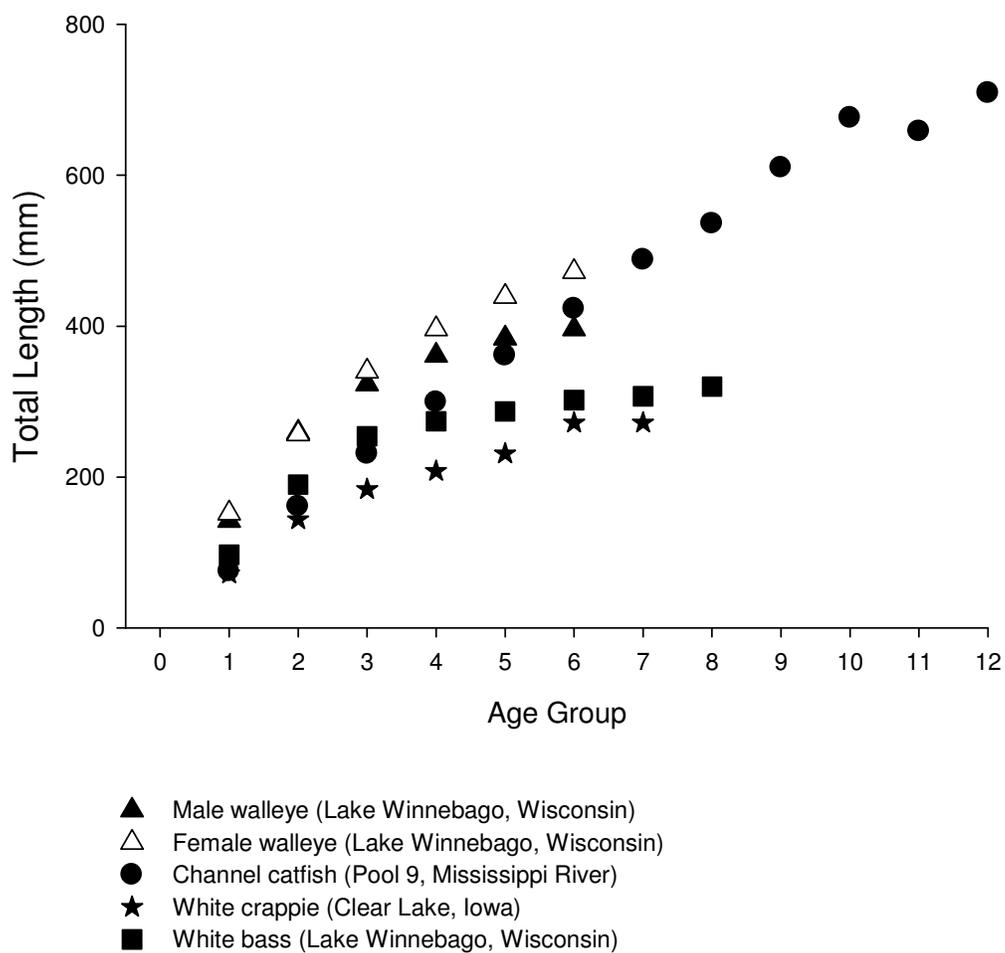
Figure 1-1. Average length at age for walleye (Priegel 1969), white bass (Priegel 1971) (Lake Winnebago, Wisconsin), channel catfish (Appleget and Smith 1951) (Pool 9, Mississippi River), and white crappie (Neal 1961) (Clear Lake, Iowa).
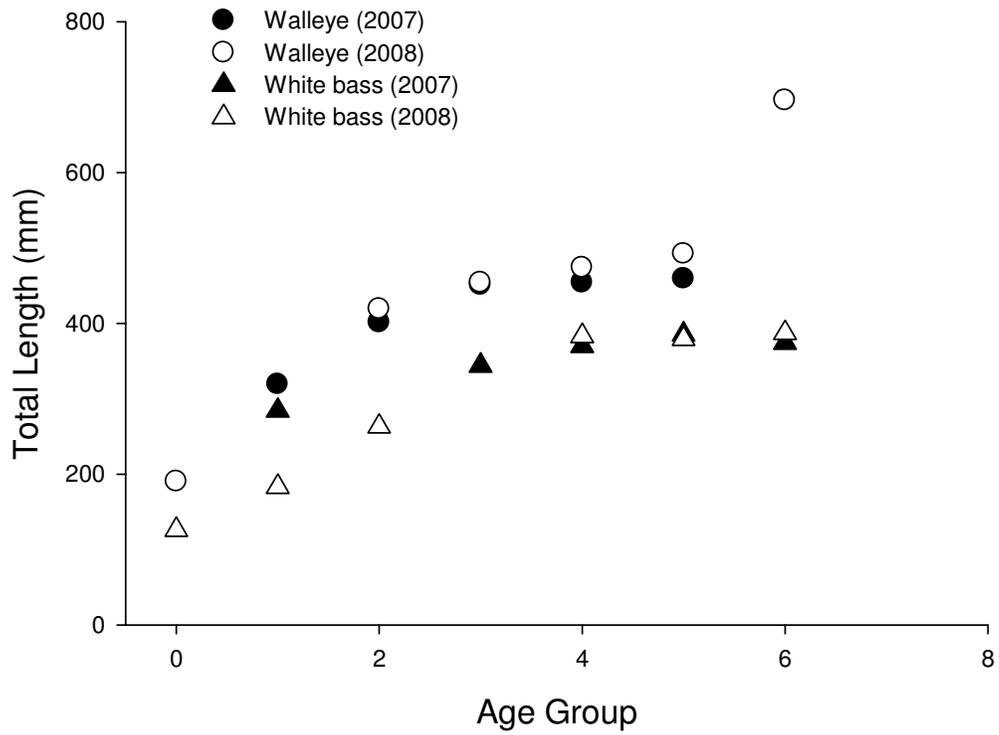
Figure 1-2.  Average length at age during 2007 and 2008 for walleye and white bass at Calamus Reservoir, Nebraska (Schuckman and Chvala 2009).
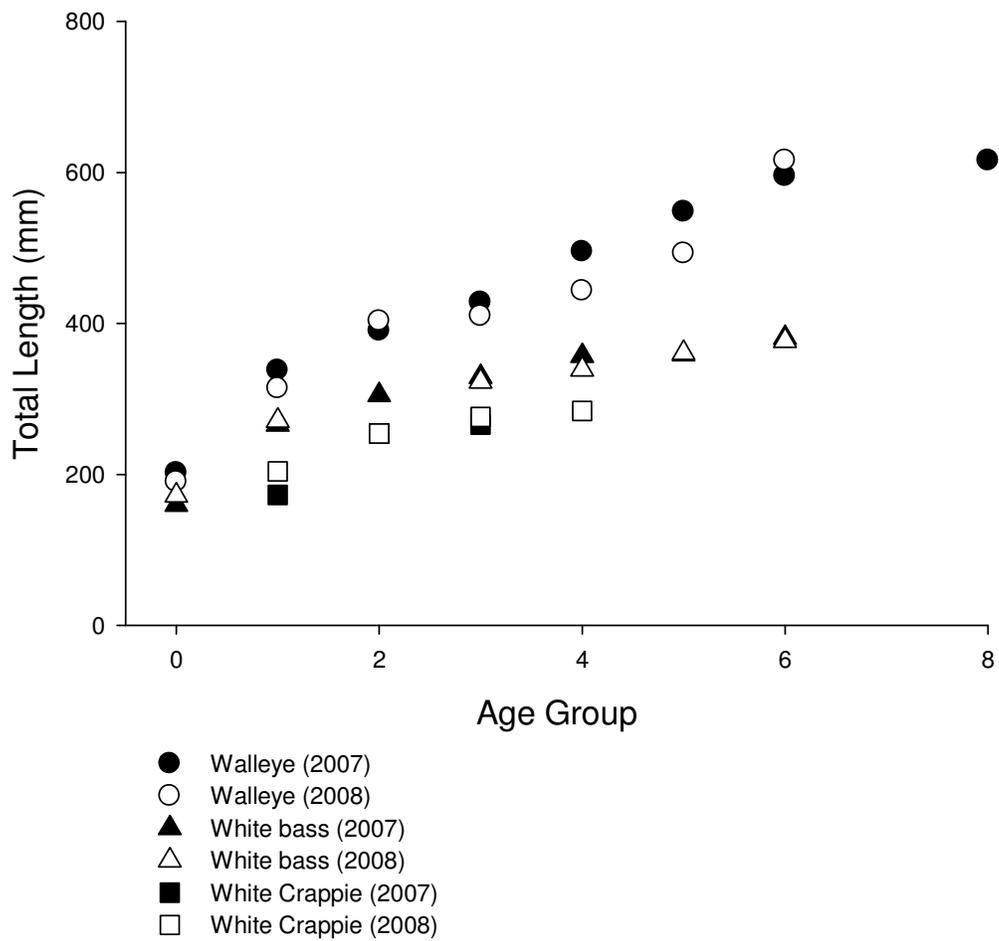
Figure 1-3. Average length at age during 2007 and 2008 for walleye, white bass, and white crappie at Sherman Reservoir, Nebraska (Newcomb and Eifert 2009).

**Chapter 2.  Sexual-size dimorphism of white bass and walleye**

**Introduction**

Sexual dimorphism is the systematic difference in form between males and females of the same species and examples include differences in growth, condition and longevity.   Differences that exist between male and female fish can lead to one sex possessing traits that cause anglers to prefer it to the other sex.  For example, Scarnecchia et al. (1989) determined that male paddlefish *Polyodon spathula*, which were smaller than their female counterparts, were being harvested at a lesser rate than female paddlefish.  Similarly, male Dungeness crabs *Cancer magister* were being harvested at a greater rate than female crabs because they attain a larger maximum size (Smith and Jamieson 1991).  Therefore, it is important to understand what differences exist between sexes of a species because species that exhibit sexual dimorphism are susceptible to different harvest rates between males and females.  In addition, differences that exist between males and females must be taken into account when setting harvest regulations and defining management goals.

White bass *Morone chrysops* and walleye *Sander vitreus* are two popular, harvest-oriented sportfish that exhibit a varying degree of sexual dimorphism.  For example, there is little difference between growth of male and female white bass, however, male walleye do not grow as fast nor attain as large of sizes as their female counterparts (Priegel 1969; Priegel 1971).  Little information is known about differences between males and females in condition, size structure and age structure for white bass and walleye populations that are recreationally harvested.  Thus, our objective was to determine what differences in

growth, condition, size structure and age structure exist between male and female white bass and walleye.

**Methods**

Information was collected from white bass and walleye that were captured by Nebraska Game and Parks Commission (NGPC) biologists as part of their standardized annual population survey at Sherman Reservoir during autumn 2009 and 2010. Fish were captured using experimental gill nets that were set in open water, allowed to fish overnight and retrieved the following day. The gill nets were 45.7-m long by 1.8-m deep, and consisted of six 7.6-m panels with bar-mesh sizes of 19, 25, 38, 51, 64 and 76 mm. All fish were measured for total length (TL; mm) and weight (g). Sagittal otoliths were removed from fish, stored in plastic vials with an identification tag, and transported to the laboratory for further processing. Sex of fish was determined by visual inspection of gonads. The liver of each fish was excised and weighed (0.1 g).

*Laboratory Analysis of Otoliths*

Sagittal otoliths were processed using the "crack and burn" method described by Lucchesi and Johnson (2006). Otoliths were sectioned through the nucleus by hand. Otoliths were then polished using 400- and 600-grit sandpaper. The polished side of the otolith was burned over an open flame for approximately three seconds. Otoliths were then placed into putty and cleaned using mineral oil. Otoliths were viewed through a dissecting microscope and annuli, which appeared as dark marks, were counted. Otoliths

were viewed by two independent readers.  Disagreement in an age estimate resulted in both readers viewing the otolith together.

*Data Analyses*

Growth

Length-at-age data for white bass and walleye were pooled across years to increase sample sizes.  Growth was described separately for male and female white bass and also for male and female walleye using the von Bertalanffy (1957) growth function, $L_t = L_\infty [1 - e^{-k(t - t_o)}]$, where $L_t$ is fish TL at time $t$, $L_\infty$ is the theoretical maximum length, $k$ is the growth coefficient, $t$ is time in years, and $t_o$ is the time at which length is theoretically $= 0$.  Von Bertalanffy growth functions were calculated using Fishery Analysis and Simulation Tools (FAST) (Slipke and Maceina 2001).  We calculated the von Bertalanffy growth functions holding $L_\infty$ constant rather than determining $L_\infty$ through an iterative process because sample sizes of large fish were lacking for some of the populations we sampled.  We used the largest fish captured for each sex and species as the corresponding $L_\infty$.  Length-at-age estimates between male and female fish of each species were compared using an Analysis of Covariance (ANCOVA), in which fish age was the covariate, total length was the dependent variable, and sex was the independent variable (Isely and Grabowski 2007).  Length-at-age comparisons were completed using PROC GLM in SAS (2002).  Statistical significance was set at $\alpha = 0.05$ for all comparisons.

Size structure

Length data for white bass and walleye were pooled across years to increase sample sizes. Fish were grouped into 25-mm length groups. Size structure was compared between male and female white bass and also between male and female walleye using a Kolmogorov-Smirnov two-sample test ($KS_\alpha$ = asymptotic test statistic) (Neumann and Allen 2007). Size structure comparisons were completed using PROC NPAR1WAY in SAS (2002). Statistical significance was set at $\alpha = 0.05$ for all comparisons.

Age structure

Age data were pooled by year. A chi-square test of homogeneity was used to determine if differences existed between age distributions of male and female white bass and also between age distributions of male and female walleye (Isely and Grabowski 2007). Statistical significance was set at $\alpha = 0.05$ for all comparisons. Mean age ± standard error (SE) was calculated for male and female white bass and also for male and female walleye for each year sampled

Condition

Weight-length relationships ($\log_{10}$ transformed) were compared between male and female fish with ANCOVA (Pope and Kruse 2007). $\log_{10}TL$ was the covariate, $\log_{10}$ total weight (Wt) was the dependent variable, and sex was the independent variable. Comparisons of weight-length relationships were completed using PROC GLM in SAS

(2002). Relative weight ($W_r$; Wege and Anderson 1978) and hepatosomatic index (HSI; Chellappa et al. 1995) are reported for descriptive purposes.

## Results

*White bass*

Slopes of length as a function of age were not different ($F = 0.11$; df = 5, 58; $P = 0.99$) between male and female white bass at Sherman Reservoir, although intercepts were different ($F = 17.99$; df = 1, 63; $P < 0.01$). Male white bass were consistently shorter than their female counterparts at a given age (Figure 2-1). Length distributions were not different ($KS_a = 1.08$, $P = 0.19$) between male and female white bass at Sherman Reservoir (Figure 2-2). During 2009, age distributions were not different ($\chi^2 = 5.76$; df = 7; $P = 0.57$) between male and female white bass at Sherman Reservoir (Table 2-1). Similarly, during 2010, age distributions were not different ($\chi^2 = 3.73$; df = 4; $P = 0.44$) between male and female white bass (Table 2-1). During 2009, the average age of male white bass was $4.15 \pm 0.42$ and the average age of female white bass was $3.45 \pm 0.50$. During 2010, the average age of male white bass was $3.30 \pm 0.50$ and the average age of female white bass was $3.71 \pm 0.71$.

Slopes of the regressions of $\log_{10}(Wt)$-$\log_{10}(TL)$ were not different ($F = 0.02$; df = 1, 68; $P = 0.88$) between male and female white bass at Sherman Reservoir (Figure 2-3). Additionally, intercepts of the regressions of $\log_{10}(Wt)$-$\log_{10}(TL)$ were not different ($F = 0.49$; df = 1, 69; $P = 0.49$) (Figure 2-3). Predicted weight at 250-mm was 191 g for male white bass and 197 g for female white bass. Predicted weight at 300-mm TL was 335 g for male white bass and 341 g for female white bass.

*Walleye*

Slopes of length as a function of age were different ($F = 12.79$; df = 5, 93; $P < 0.01$) between male and female walleye at Sherman Reservoir. Male walleye grew slower and were consistently shorter than their female counterparts at a given age (Figure 2-4). Length distributions were not different ($KS_a = 0.65$, $P = 0.79$) between male and female walleye at Sherman Reservoir (Figure 2-5). During 2009, age distributions were not different ($\chi^2 = 6.30$; df = 5; $P = 0.28$) between male and female walleye at Sherman Reservoir (Table 2-1). Similarly, during 2010, age distributions were not different ($\chi^2 = 7.41$; df = 4; $P = 0.12$) between male and female walleye (Table 2-1). During 2009, the average age of male walleye was $3.64 \pm 0.40$ and the average age of female walleye was $2.93 \pm 0.36$. During 2010, the average age of male walleye was $3.83 \pm 0.36$ and the average age of female walleye was $2.73 \pm 0.17$.

Slopes of the regressions of $\log_{10}(Wt)$-$\log_{10}(TL)$ were not different ($F = 1.58$; df = 1, 104; $P = 0.21$) between male and female walleye at Sherman Reservoir (Figure 2-6). Additionally, intercepts of the regressions of $\log_{10}(Wt)$-$\log_{10}(TL)$ were not different ($F = 1.47$; df = 1, 105; $P = 0.23$) (Figure 2-6). Predicted weight at 400-mm was 561 g for male walleye and 543 g for female walleye. Predicted weight at 500-mm TL was 1,102 g for male walleye and 1,113 g for female walleye.

**Discussion**

Differences in total length between male and female fish of a population likely influences which sex is harvested by anglers because anglers tend to selectively harvest larger individuals of a population. Carlander (1997) observed that male white bass were

shorter at a given age than females. Likewise, in three separate assessments (Colvin 2002; Guy et al. 2002; and Lovell and Maceina 2002), biologists observed similar growth between male and female white bass, but male white bass were shorter than their female counterparts. Male and female white bass from Sherman Reservoir had a similar rate of change of growth (i.e., slopes of length as function of age), but male white bass were shorter at a given age, although, difference in length was small (< 25-mm). Consequently, under the current management strategy (no size limit), neither male nor female white bass in Sherman Reservoir are likely to be selectively harvested based on length differences. Isermann et al. (2010) suggested growth advantages (i.e., differences in average length at age between male and female black crappie) of more than 10-mm may lead to sex-selective harvest in some cases, such as a fishery regulated by a minimum length limit, which forces anglers to measure individual fish. Likewise, the difference in growth between male and female white bass at Sherman Reservoir might encourage sex-selective harvest if a minimum-length limit was implemented.

Differences in condition between male and female fish of a population likely influences which fish are harvested by anglers. A fish in good condition ($W_r > 100$) will appear "larger" than a fish of the same length that is in poor condition ($W_r < 70$) and thus, a fish in good condition may be more apt to be harvested than a fish in poor condition. In addition, differences in condition may influence the foraging rate or behavior of fish. For example, a fish in good condition may be foraging at a greater rate than fish in poor condition and thus have a greater susceptibility of being caught by an angler. In contrast a fish in poor condition may be more susceptible to angling because it is more willing to risk predation than a fish in good condition to feed to survive. Little information exists

on how differences in condition could influence harvest susceptibility. Nonetheless, it seems plausible that differences in condition would have an influence. Condition did not differ between male and female white bass at Sherman reservoir. Neither male nor female white bass in Sherman Reservoir are likely to be selectively harvested based on condition differences.

Carlander (1997) observed that female walleye were consistently longer at a given age than males suggesting that there is sexual-size dimorphism in walleye. Results from my study confirmed that sexual-size dimorphism was evident in walleye from Sherman Reservoir, with males growing slower and attaining shorter maximum lengths than females. Based on differences in growth between male and female walleye at Sherman Reservoir, female walleye would have a greater chance of being harvested by anglers targeting the larger fish of the population. Sex-selective harvest of female walleye by anglers is likely to occur at Sherman Reservoir. Furthermore, any harvest of walleye greater than 508 mm would be skewed almost completely towards harvest of females.

Differences in condition between male and female walleye could influence what anglers' harvest. Despite the difference in length of male and female walleye at Sherman Reservoir, condition did not differ between males and females. As a result, neither male nor female walleye in Sherman Reservoir are likely to be selectively harvested based on condition differences.

A difference in size or age structure between males and females of a fish population would likely lead to selective harvest. Size and age structure was not different between male and female white bass and walleye from Sherman Reservoir. Thus, it is

unlikely that selective harvest of male or female white bass and walleye would occur based on differences in size and age structure at Sherman Reservoir.

In conclusion, no differences in growth, condition, size structure or age structure were observed between male and female white bass from Sherman Reservoir, thus, if selective harvest of male or female white bass is occurring, it likely is the result of processes not researched for this paper. For example, behavior differences between sexes may lead to sex-selective harvest. In contrast to white bass, we observed differences in growth but not in condition, size structure or age structure between male and female walleye. This is intriguing because one might think if there is a difference in growth then a subsequent difference in size structure would be observed. This anomaly could be a result of past processes that have influenced the current walleye population in Sherman Reservoir, such as sex-selective harvest. For many years prior to 2009, the length limit for walleye at Sherman Reservoir was an 457-mm minimum length limit. The length limit might have resulted in sex-selective harvest of female walleye. Average age of male walleye in the population was approximately one year older than the average age of female walleye in both 2009 and 2010. I believe female walleye have been selectively harvested at Sherman Reservoir in previous years, which has led to the current walleye population that is lacking older, larger females.

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Table 2-1.  Number of male and female white bass and walleye collected from Sherman Reservoir, Nebraska by age group during September and October 2009 and 2010.

| Species | Sex | Year | | Age | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| White bass | Male | 2009 | | 14 | | 4 | 10 | 1 | | 1 | 2 | | 1 | |
| | Female | | | 11 | 1 | 3 | 3 | 1 | | | | | 1 | |
| | Male | 2010 | | 6 | 4 | | | 2 | 1 | | | | | |
| | Female | | | 3 | 1 | | 1 | 2 | | | | | | |
| Walleye | Male | 2009 | | 14 | 1 | 2 | 9 | | 1 | | | | 1 | |
| | Female | | | 21 | 1 | 2 | 3 | 1 | | | | | 1 | |
| | Male | 2010 | | 4 | 11 | 2 | | 3 | 3 | | | | | |
| | Female | | | 11 | 13 | 1 | | 1 | | | | | | |

Table 2-2. Mean ± SE relative weight ($W_r$) and mean ± SE hepatosomatic index (HSI), with associated sample size (N), of male and female white bass and walleye collected from Sherman Reservoir, Nebraska during September and October 2009 and 2010. Abbreviations are S = stock, Q = quality, P = preferred, M = memorable, and T = trophy.

| Species | Sex | Size | $W_r$ (N) | HSI (N) |
|---------|-----|------|-----------|---------|
| White bass | Male | Q-P | 94 ± 4 (11) | [a] |
| | | P-M | 94 ± 2 (34) | 1.10 ± 0.10 (16) |
| | Female | Q-P | [a] | [a] |
| | | P-M | 97 ± 2 (23) | 1.56 ± 0.20 (12) |
| Walleye | Male | S-Q | [a] | [a] |
| | | Q-P | 84 ± 1 (47) | 0.71 ± 0.05 (22) |
| | Female | S-Q | 77 ± 3 (10) | [a] |
| | | Q-P | 85 ± 1 (38) | 0.78 ± 0.05 (17) |
| | | P-M | [a] | [a] |

[a] Values not reported because N < 10
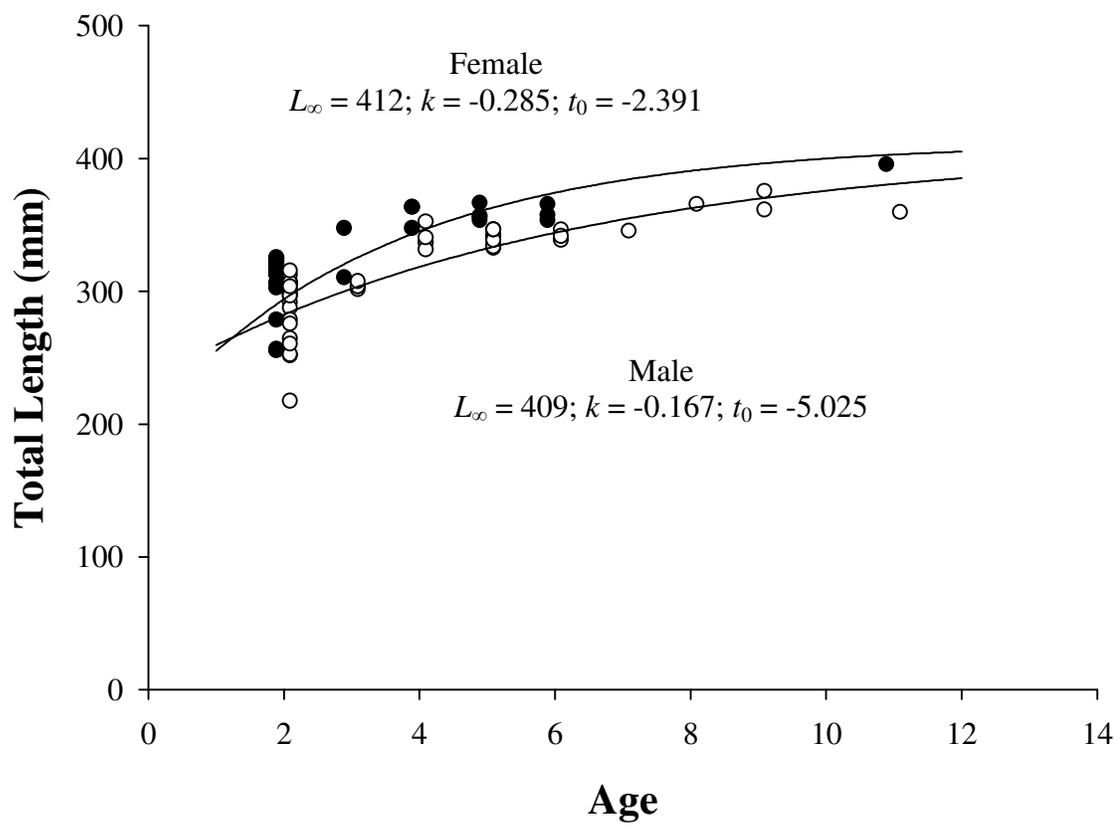
Figure 2-1. Von Bertalanffy growth curves for male (open circles) and female (closed circles) white bass collected from Sherman Reservoir during September and October 2009 and 2010.
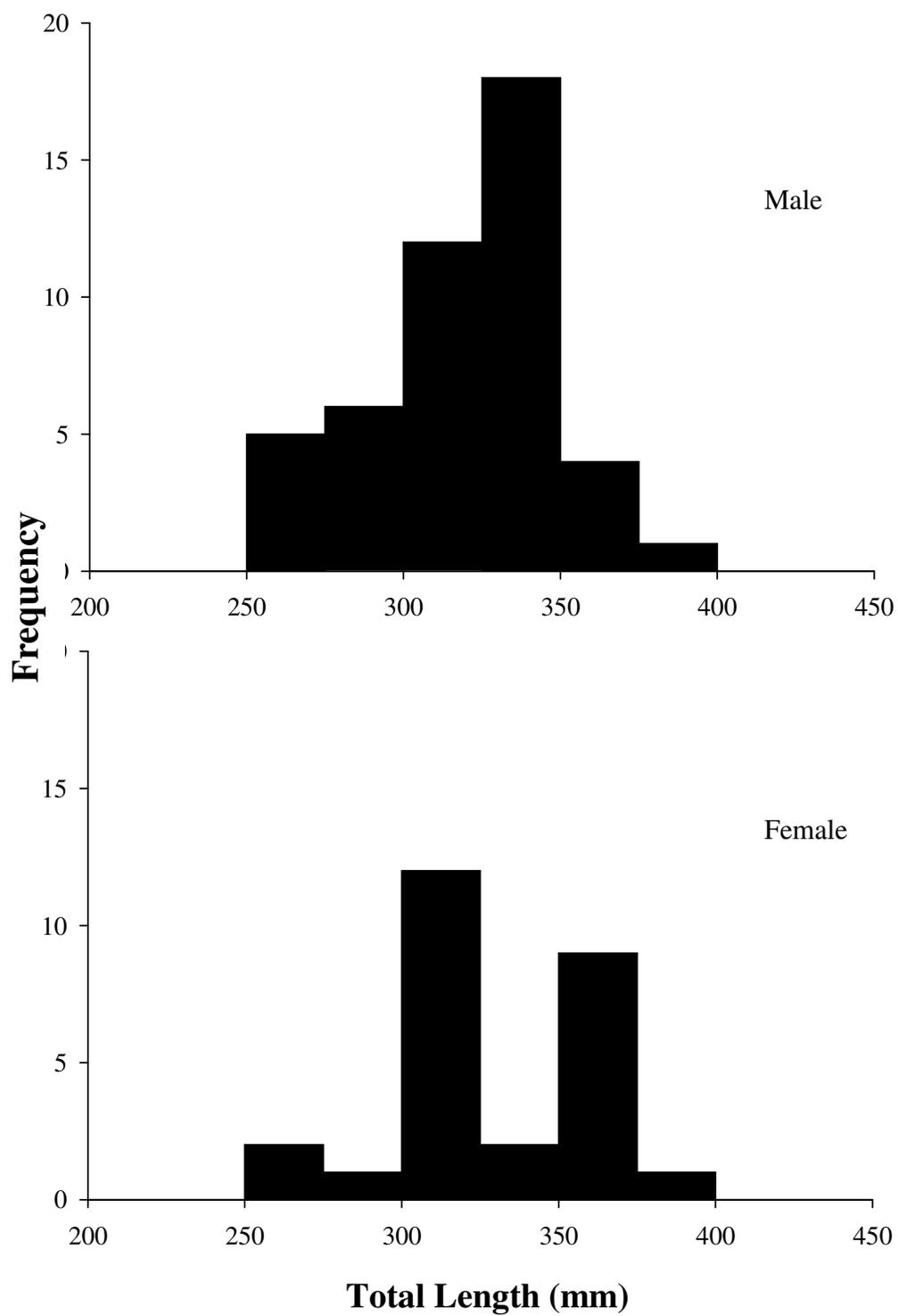
Figure 2-2. Length-frequency distributions of male (top panel) and female (bottom panel) white bass collected from Sherman Reservoir, Nebraska during September and October 2009 and 2010.
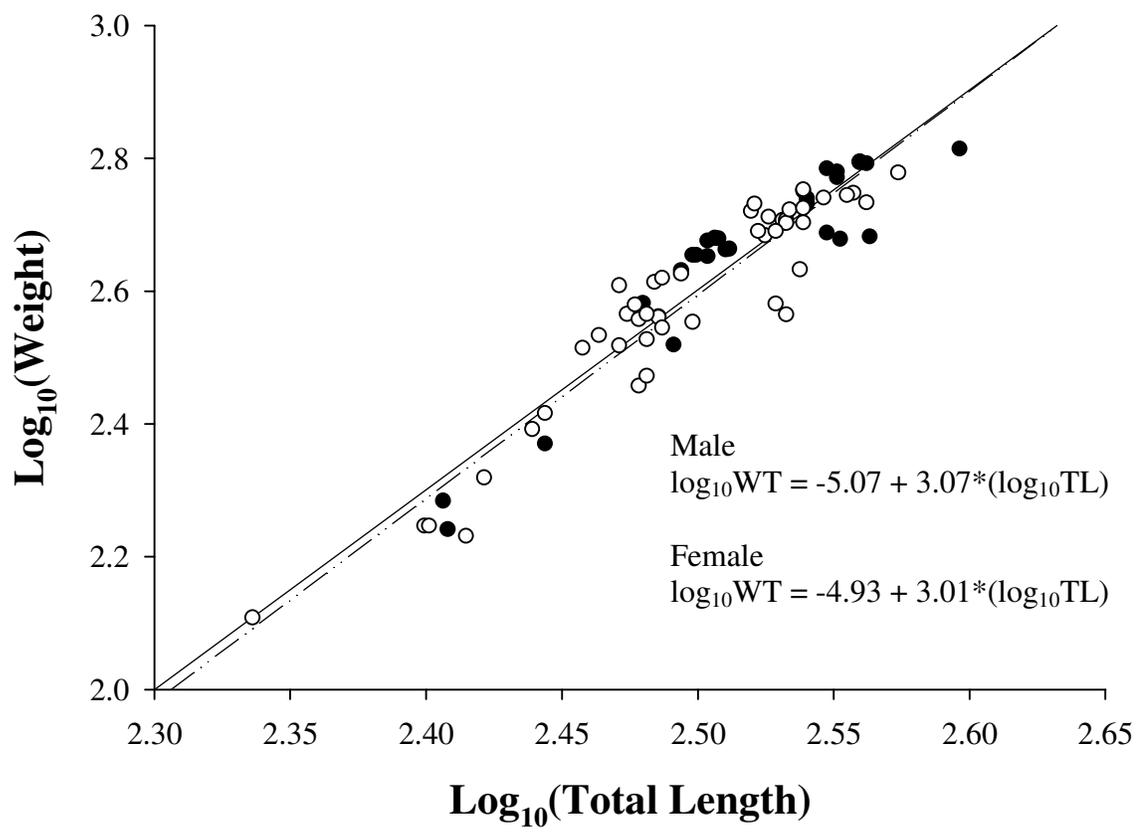
Figure 2-3. Regressions of $\log_{10}$(Total Weight [WT]) and $\log_{10}$(Total Length [TL]) for male (open circles) and female (closed circles) white bass collected from Sherman Reservoir during September and October 2009 and 2010.
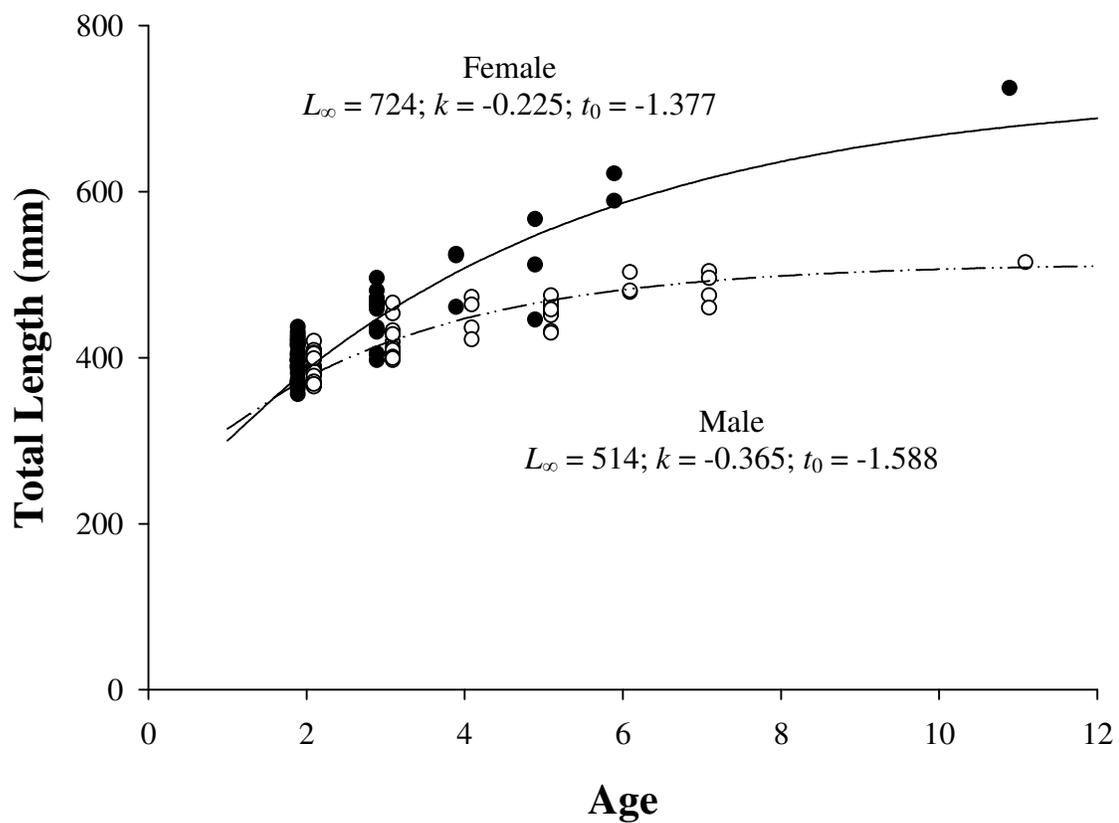
Figure 2-4. Von Bertalanffy growth curves for male (open circles) and female (closed circles) walleye collected from Sherman Reservoir during September and October 2009 and 2010.
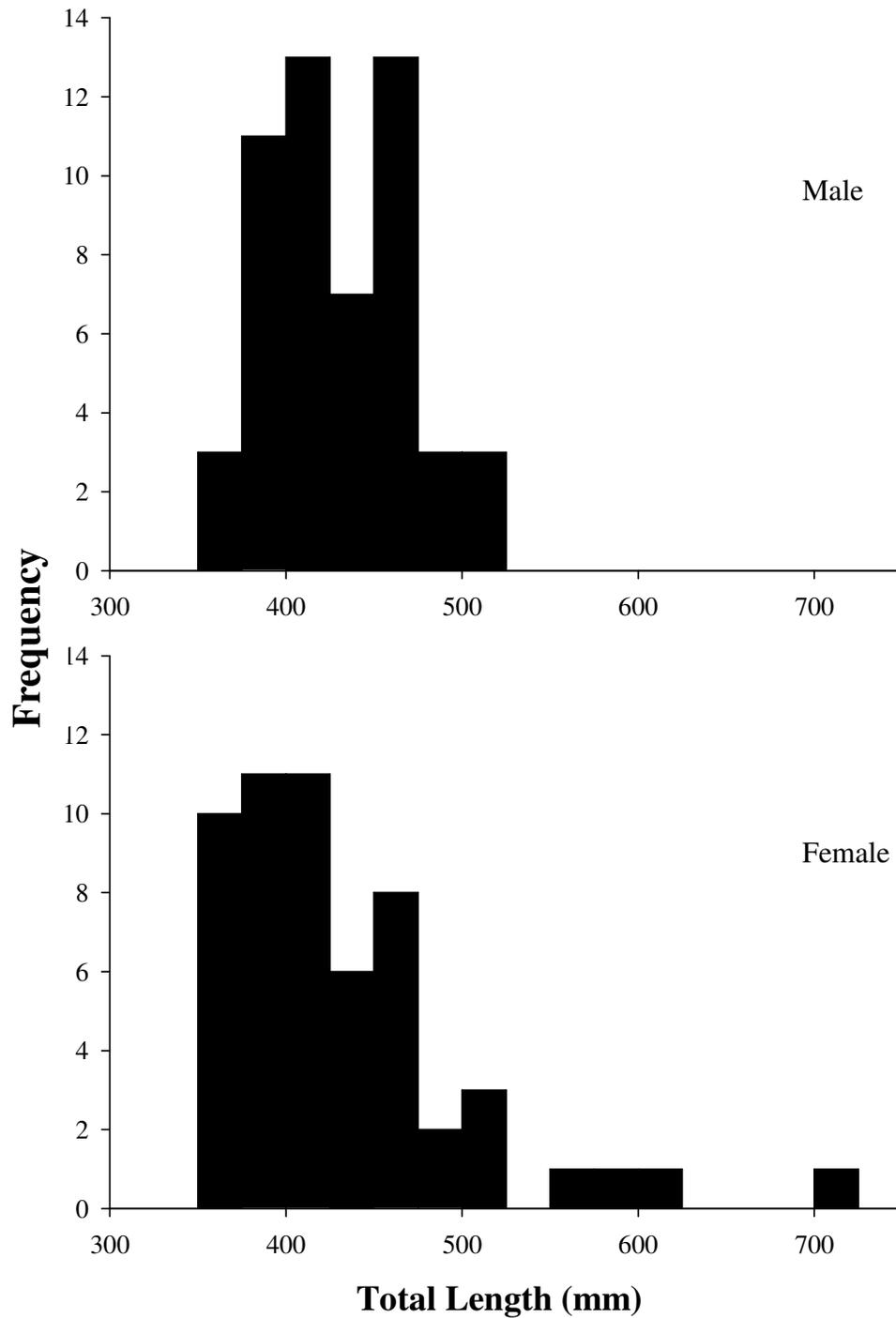
Figure 2-5. Length-frequency distributions of male (top panel) and female (bottom panel) walleye collected from Sherman Reservoir, Nebraska during September and October 2009 and 2010.
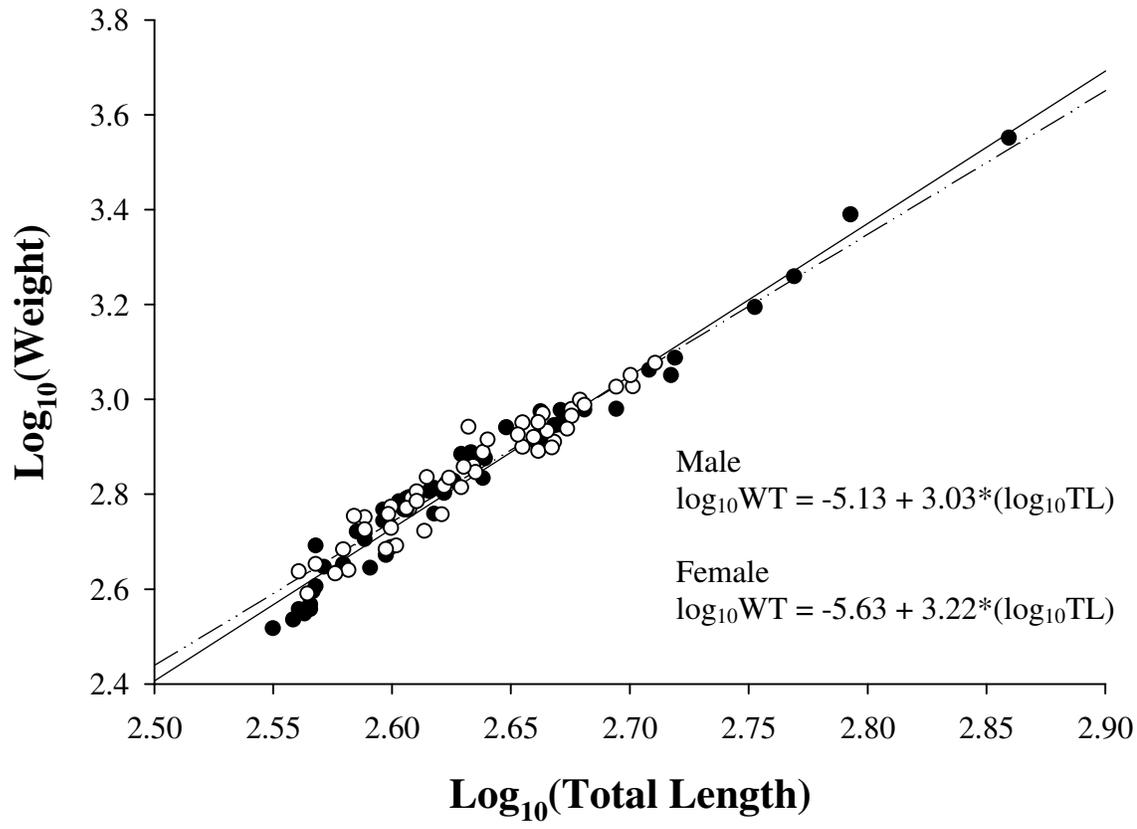
Figure 2-6. Regressions of $\log_{10}$(Total Weight) and $\log_{10}$(Total Length) for male (open circles) and female (closed circles) walleye collected from Sherman Reservoir during September and October 2009 and 2010.

## Chapter 3.  Observations from angler-harvested white crappie, white bass and walleye at two Nebraska reservoirs

**Introduction**

Angler harvest is an important component to any managed aquatic system and if large enough, can drastically affect a fish population by increasing total annual mortality. Exploitation rates have ranged from as small as 1-5% (Gerhardt and Hubert 1991; Marshall et al. 2009) to as large as 50-70% (Muoneke 1994; Michaletz et al. 2008). Creel or angler surveys are the common tool fishery managers use to evaluate angler harvest.  Further evaluations of angler harvest such as determining sex of fish being harvested are not typically recorded in a creel survey and are rarely completed.  Further evaluation can reveal useful information, which can ultimately affect management decisions.

In an effort to improve fishing, fishery managers often make modifications to harvest regulations (i.e., length and bag limits) to improve size structure, age structure, or foster angler satisfaction (Noble and Jones 1999; Boxrucker 2002).  Regulation modifications can influence both angler participation and angler harvest (Boxrucker 2002).  For example, angler effort declined dramatically although angler catch rates increased following implementation of a 254-mm minimum length limit for crappie *Pomoxis spp.* at Ft. Supply Reservoir, Oklahoma (Boxrucker 2002).  It is important for fishery managers to monitor angler harvest after regulation modification to observe trends that may influence fish populations.

Harvest is generally thought to be size selective with anglers targeting the longest and healthiest fish of a population (Goedde and Coble 1981; Miranda and Dorr 2000). Some species of fish exhibit sexual-size dimorphism, which leads to sex-specific growth (Priegel 1969; Priegel 1971), condition, or mortality. Thus, anglers may selectively harvest one sex of a species more frequently. In addition to physiological differences, behavioral differences (e.g., males guarding nests, sex segregation, etc.) between males and females of certain species might also lead to sex-specific harvest mortality (Beard et al. 1997; Ehlinger 1997). For example, at Lake Hubert, Minnesota, Isermann et al. (2010) concluded that more male black crappie *Pomoxis nigromaculatus* were harvested than female black crappie during peak nesting periods, whereas fewer male black crappie were harvested than female black crappie outside of peak nesting periods. In contrast, numbers of male and female black crappie harvested at Upper Mission Lake, Minnesota, were similar throughout the study period (Isermann et al. 2010). Sex-specific harvest mortality likely varies by species and by waterbody.

Some species of fish exhibit sex-specific natural mortality rates that could lead to one sex having greater number of harvestable size fish than the other, thus, creating a situation where sex-selective harvest is likely. Examples of fish species that exhibit sex-specific natural mortality include arrowtooth flounder *Atheresthes stomias* (Wilderbuer and Turnock 2009), starry flounder *Platichthys stellatus* (Ralston 2006) and Greenland halibut *Reinhardtius hippoglossoides* (De Cardenas 1996). For any species that has a large difference in mortality between sexes, exploitation would likely be sex-specific.

Little information exists on evaluations of angler harvest other than creel (angler) surveys. The objectives of this paper were to evaluate sex ratios of angler harvested fish

at two Nebraska reservoirs.  Additionally, this paper describes observations that came from this alternative method to evaluate angler harvest.

**Methods**

Information was collected from angler-harvested white crappie, white bass and walleye at Calamus and Sherman Reservoirs during May, June and July 2009 and 2010. Angler catch was sampled at fish-cleaning stations with an emphasis on days when angler participation was greatest (Thursday-Sunday), although other (Monday-Wednesday) days were also sampled.  Each reservoir has two fish-cleaning stations available for public use. I relied on advice from creel clerks working at the reservoirs and visual determination of angler usage to subjectively select the fish-cleaning station with greatest use on each given day.  Harvested fish from willing anglers (anglers that agreed to participate in the study) were measured for total length (TL; mm) and weighed (g).  After the angler cleaned the fish, the gonads were visually inspected to determine sex and then the gonads and liver were excised and weighed (0.1 g).  If gonads were damaged during the cleaning process, they were not weighed.  If the liver was sectioned during the cleaning process, it was weighed only if the entire liver could be retrieved.  Finally, sagittal otoliths were removed, stored in plastic vials with an identification tag, and transported to the laboratory for further processing.  If multiple angling parties arrived at the fish-cleaning station at the same time, I selected the first angler party to arrive to determine if they would allow for collection of fish information.

*Laboratory Analysis of Otoliths*

Sagittal otoliths were processed using the "crack and burn" method described by Lucchesi and Johnson (2006). Otoliths were sectioned through the nucleus by hand. Otoliths were then polished using 400- and 600-grit sandpaper. The polished side of the otolith was burned over an open flame for approximately three seconds. Otoliths were then placed into putty and cleaned using mineral oil. Otoliths were viewed through a dissecting microscope and annuli, which appeared as dark marks, were counted. Otoliths were viewed by two independent readers. Disagreement in age estimate resulted in both readers reviewing the otolith together.

*Data Analyses*

Size, age and sex structure

To determine size distribution, length data for white crappie, white bass and walleye were pooled by year and sex, and fish were grouped into 10-mm length groups. To determine age structure, age data were pooled by year and sex. To determine if one sex was being harvested more than the other, numbers of male and female fish harvested were pooled by year to determine an overall sex ratio of harvested fish for each species sampled. Chi-square tests for equal proportions ($\chi^2$; $\alpha = 0.05$) were used to determine if overall sex ratios (male to female) of harvested fish of each species significantly deviated from 1:1 ratio.

Mortality

Mortality rate was calculated for the angler-harvested fish independently for each sex. Mortality rate was calculated following the methods of Beverton and Holt (1956): $Z = K*[(L_\infty - L_{mean})/(L_{mean} - L_x)]$, where $K$ (growth coefficient) and $L_\infty$ (theoretical maximum length) are von Bertalanffy growth parameters, $L_x$ is the length above which all fish are equally vulnerable to capture, and $L_{mean}$ is the mean length of fish larger than $L_x$. The instantaneous annual mortality $Z$ was converted to total annual mortality $A$ using the equation: $A = 1 - e^{-z}$ (Miranda and Bettoli 2007).

## Results

*White Crappie in Sherman Reservoir*

During 2009, 50 harvested male white crappie and 119 harvested female white crappie were sampled at Sherman Reservoir. Ages of harvested white crappie ranged from 3 to 6 for males and 3 to 12 for females (Figure 3-1). Minimum and maximum lengths of harvested white crappie were 258 mm and 313 mm for males and 260 mm and 361 mm for females (Figure 3-2). Overall sex ratio of harvested white crappie was 1:2.4 and differed from a 1:1 ratio ($\chi^2 = 28.18$; df = 1; $P < 0.01$). Less male white crappie were harvested than female white crappie. Total annual mortality of white crappie was 0.46 for males and 0.37 for females.

During 2010, 38 harvested male white crappie and 124 harvested female white crappie were sampled at Sherman Reservoir. Ages of harvested white crappie ranged from 3 to 7 for males and 3 to 12 for females (Figure 3-1). Minimum and maximum lengths of harvested white crappie were 246 mm and 319 mm for males and 246 mm and

360 mm for females (Figure 3-2). Overall sex ratio of harvested white crappie was 1:3.3 and differed from a 1:1 ratio ($\chi^2$ = 45.66; df = 1; $P < 0.01$). Less male white crappie were harvested than female white crappie. Total annual mortality of white crappie was 0.85 for males and 0.66 for females.

*White Bass in Calamus Reservoir*

During 2009, 29 harvested male white bass and 58 harvested female white bass were sampled at Calamus Reservoir. Ages of harvested white bass ranged from 3 to 9 for males and 3 to 11 for females (Figure 3-3). Minimum and maximum lengths of harvested white bass were 271 mm and 395 mm for males and 282 mm and 416 mm for females (Figure 3-4). Overall sex ratio of harvested white bass was 1:2 and differed from a 1:1 ratio ($\chi^2$ = 9.67; df = 1; $P < 0.01$). Less male white bass were harvested than female white bass. Total annual mortality of white bass was 0.38 for males and 0.40 for females.

During 2010, 81 harvested male white bass and 63 harvested female white bass were sampled at Calamus Reservoir. Ages of harvested white bass ranged from 2 to 12 for both males and females (Figure 3-3). Minimum and maximum lengths of harvested white bass were 236 mm and 406 mm for males and 247 mm and 412 mm for females (Figure 3-4). Overall sex ratio of harvested white bass was 1:0.8 and did not significantly deviate from a 1:1 ratio ($\chi^2$ = 2.25; df = 1; $P = 0.13$). Total annual mortality of white bass was 0.58 for males and 0.52 for females.

*White Bass in Sherman Reservoir*

During 2009, 62 harvested male white bass and 98 harvested female white bass were sampled at Sherman Reservoir.  Ages of harvested white bass ranged from 2 to 11 for males and 2 to 12 for females (Figure 3-5).  Minimum and maximum lengths of harvested white bass were 259 mm and 390 mm for males and 257 mm and 410 mm for females (Figure 3-4).  Overall sex ratio of harvested white bass was 1:1.6 and differed from a 1:1 ratio ($\chi^2 = 8.10$; df = 1; $P < 0.01$).  Less male white bass were harvested than female white bass.  Total annual mortality of white bass was 0.28 for males and 0.30 for females.

During 2010, 46 harvested male white bass and 69 harvested female white bass were sampled at Sherman Reservoir.  Ages of harvested white bass ranged from 2 to 12 for both males and females (Figure 3-5).  Minimum and maximum lengths of harvested white bass were 245 mm and 375 mm for males and 236 mm and 399 mm for females (Figure 3-4).  Overall sex ratio of harvested white bass was 1:1.5 and differed from a 1:1 ratio ($\chi^2 = 4.60$; df = 1; $P = 0.03$).  Less male white bass were harvested than female white bass.  Total annual mortality of white bass was 0.36 for males and 0.40 for females.


*Walleye in Calamus Reservoir*

During 2009, 211 harvested male walleye and 176 harvested female walleye were sampled at Calamus Reservoir.  Ages of harvested walleye ranged from 3 to 8 for males and 3 to 9 for females (Figure 3-6).  Minimum and maximum lengths of harvested walleye were 384 mm and 541 mm for males and 390 mm and 645 mm for females (Figure 3-7).  Overall sex ratio of harvested walleye was 1:0.8 and did not significantly

deviate from a 1:1 ratio ($\chi^2$ = 3.17; df = 1; $P$ = 0.08).  Total annual mortality of walleye was 0.64 for males and 0.61 for females.

During 2010, 47 harvested male walleye and 48 harvested female walleye were sampled at Calamus Reservoir.  Ages of harvested walleye ranged from 3 to 8 for both males and females (Figure 3-6).  Minimum and maximum lengths of harvested walleye were 375 mm and 545 mm for males and 377 mm and 588 mm for females (Figure 3-7).  Overall sex ratio of harvested walleye was 1:1 and did not significantly deviate from a 1:1 ratio ($\chi^2$ = 0.17; df = 1; $P$ = 0.68).  Total annual mortality of walleye was 0.53 for males and 0.51 for females.

*Walleye in Sherman Reservoir*

During 2009, 92 harvested male walleye and 101 harvested female walleye were sampled at Sherman Reservoir.  Ages of harvested walleye ranged from 2 to 7 for males and 2 to 10 for females (Figure 3-8).  Minimum and maximum lengths of harvested walleye were 384 mm and 486 mm for males and 368 mm and 670 mm for females (Figure 3-7).  Overall sex ratio of harvested walleye was 1:1.1 and did not significantly deviate from a 1:1 ratio ($\chi^2$ = 0.42; df = 1; $P$ = 0.52).  Total annual mortality of walleye was 0.43 for males and 0.42 for females.

During 2010, 42 harvested male walleye and 46 harvested female walleye were sampled at Sherman Reservoir.  Ages of harvested walleye ranged from 3 to 7 for males and 3 to 6 for females (Figure 3-8).  Minimum and maximum lengths of harvested walleye were 392 mm and 504 mm for males and 383 mm and 521 mm for females (Figure 3-7).  Overall sex ratio of harvested walleye was 1:1 and did not significantly

deviate from a 1:1 ratio ($\chi^2 = 0.18$; df = 1; $P = 0.67$). Total annual mortality of walleye was 0.57 for males and 0.58 for females.

**Discussion**

*Sex Ratios of Harvested Fish*

Sex ratios of angler-harvested white crappie and white bass were female biased, whereas sex ratios of angler-harvested walleye did not deviate from a 1:1 ratio. Growth did not differ between male and female white crappie (Appendix 1); therefore, it is unlikely that the female-biased ratios were occurring because of growth differences between male and female white crappie. Maximum age for angler-harvested white crappie ranged from age-7 for male white crappie to age-12 for female white crappie. This apparent difference in longevity likely influenced the sex ratio of harvested white crappie at Sherman Reservoir. Additionally, behavioral differences between male and female white crappie may also influence the sex ratios of harvested fish. It would be possible for a single year class with a sex ratio that deviates from a 1:1 ratio to influence the overall sex ratio of what is being harvested. For white crappie, the sex ratio was consistently female biased throughout the different age-groups, increasingly becoming more female biased as age increased. This trend reflects the pattern of greater mortality for male white crappie versus female white crappie. In contrast to our findings, Isermann et al. (2010) found overall sex ratios from angler-harvested black crappie that did not deviate from a 1:1 ratio. Isermann et al. (2010) did find female biased sex ratios from test angling they completed.

The sex ratio of angler-harvested white bass at Calamus Reservoir during spring 2010 was male biased. This is in contrast to what was found at Calamus the previous year and at Sherman Reservoir both years, where the sex ratio was female biased. The spring of 2010 was one of heavy rainfall and high winds, which can severely limit boat access to Calamus Reservoir. Many of the anglers who brought fish to the cleaning station were unable to launch a boat on the reservoir; therefore, they fished from the bank. The main area of bank angling activity that I observed occurred at the Gracie Creek inflow. Male white bass will be in the spawning areas longer than females (Pflieger 1997). This aggregation of anglers near a probable aggregation of male white bass likely lead to the observed male biased sex ratios. Growth did not differ between male and female white bass at Calamus or Sherman reservoirs (chapter 2), therefore, it is unlikely that the female-biased ratios were occurring because of growth differences between male and female white bass. Similar to white crappie, the sex ratio was consistently female biased throughout the different age groups. Likely causes for the female-biased harvest include behavior differences and segregation of males and females.

Male walleye grew slower and attained a shorter maximum length than female walleye (chapter 2), thus, we hypothesized that female walleye would be selectively harvested and the concurrent sex ratio of harvested walleye would be female biased. Current length and bag limit for walleye at Calamus and Sherman Reservoirs correspond closely with asymptotic length of male walleye at each reservoir. At Sherman Reservoir, harvest of fish between 508-mm and 711-mm is not allowed, thus male walleye, whose growth slows close to 450-mm (Figure 2.2) are likely vulnerable for longer periods because of their slower growth and therefore the length limits may mask the potential for

female biased harvest by increasing opportunities for male walleye to be harvested.

Similarly, at Calamus Reservoir, harvest of fish below 457-mm and above 559-mm is

limited to one fish per angler, whereas four fish can be harvested between the two

lengths.  Further, vulnerability of walleye decreases as length increases, thus larger

females were caught proportionately less than smaller males (Serns and Kempinger

1981).  Little is known about the foraging behavior of male and female walleye, although

foraging behavior differences between males and females has been reported for some

terrestrial species (Morse 1968; Holmes 1986; Sukumar and Gadgil 1988).  The lack of

evidence about foraging behaviors of male and female walleye leaves the possibility that

a foraging behavior difference between sexes of walleye may mask the potential for

female biased harvest.


*Disparity Between Male and Female Walleye Strong Year Classes*

Recruitment success typically varies from year to year leading to populations with

both strong and weak year-classes interspersed (Maceina and Pereira 2007).

Traditionally, without collecting information on sex of fish, a year-class is assumed to

have a 1:1 male-to-female ratio.  This would be true for cases where recruitment and

mortality (natural and fishing) are equal between sexes.  Little research has been

completed about the initial sex ratio of year classes because it can be difficult and time

consuming to distinguish sex until a fish reaches sexual maturity (Olson 1968; Martin et

al. 1983).  Determination of sex in some species can be temperature dependent (Conover

and Kynard 1981).  Natural mortality can differ between sexes for a population of fish

(Ralston 2006).  Harvest of a species that displays sexual-size dimorphism is likely sex

specific with anglers selecting for the fastest growing sex.  Use of a length limit likely amplifies this trend if one sex grows to a length susceptible to angler harvest faster than the other.  Therefore, the sex ratio of year classes that have been susceptible to harvest for multiple years would likely be biased towards the slower growing sex.   During 2009 sampling at Calamus Reservoir, strong year classes were observed from 2006 (age-3), 2005 (age-4) and 2002 (age-7) for male walleye.  Only the 2006 (age-3) and 2005 (age-4) year classes appeared to be strong year classes for female walleye.  With no evidence to suggest that recruitment of males and females occurs at ratios other than a 1:1, age-7 female walleye at Calamus Reservoir likely received greater harvest mortality than the age-7 male walleye during previous years when the length limit at Calamus was an 457-mm minimum length limit, which would have led to the sex disparity in year-class strength.

*Regulation Changes*

Successful achievement of *a-priori* goals for new length limits has been mixed (Wilde 1997).  In situations where the *a-priori* goals are not achieved, it is common to modify length limits at the reservoir.  Length limits are modified to be more or less restrictive and the modification may have an immediate influence on the number of fish harvested at the reservoir.  From the mid 1990's until 2009, both Calamus and Sherman reservoirs had a 457-mm TL minimum length limit for walleye with only one fish allowed over 559-mm TL, and a daily bag limit of four.  In an effort to improve walleye size structure at both Calamus and Sherman reservoirs, NGPC modified the walleye length limits at both reservoirs on 1 January 2009.  A daily bag limit of four walleye with

no more than one walleye from 381- to 457-mm TL, two, three or four walleye from 457-mm TL to 559-mm TL, and no more than one walleye over 559-mm TL was implemented at Calamus Reservoir.  A daily bag of two walleye greater than 381-mm TL but less than 508-mm TL, and one walleye greater than 711-mm TL was implemented at Sherman Reservoir.

During 2009, immediately following regulation changes for walleye at Calamus and Sherman reservoirs, the number of walleye harvested was the largest to date (Eifert 2009; Schuckman et al. 2009).  During 2009, more walleye were sampled than either white bass or white crappie from angler-harvested fish at both Calamus and Sherman reservoirs.  Additionally, 38% of the walleye harvested at Calamus Reservoir and 52% at Sherman Reservoir were between 382-mm and 457-mm TL, a length range that was previously protected at Calamus and Sherman reservoirs.  The change in length limit, which allowed the harvest of shorter walleye at each reservoir, resulted in abnormally large numbers of walleye harvested at both reservoirs.  The large walleye harvest of 2009 was followed by a poor harvest of walleye at both Calamus and Sherman reservoirs during 2010.  During 2010, fewer walleye were sampled than either white bass or white crappie from angler-harvested fish at both Calamus and Sherman reservoirs.  No regulation changes occurred during 2009 and 2010 for white crappie and white bass.  In contrast to walleye, numbers of white crappie and white bass sampled were similar among years.

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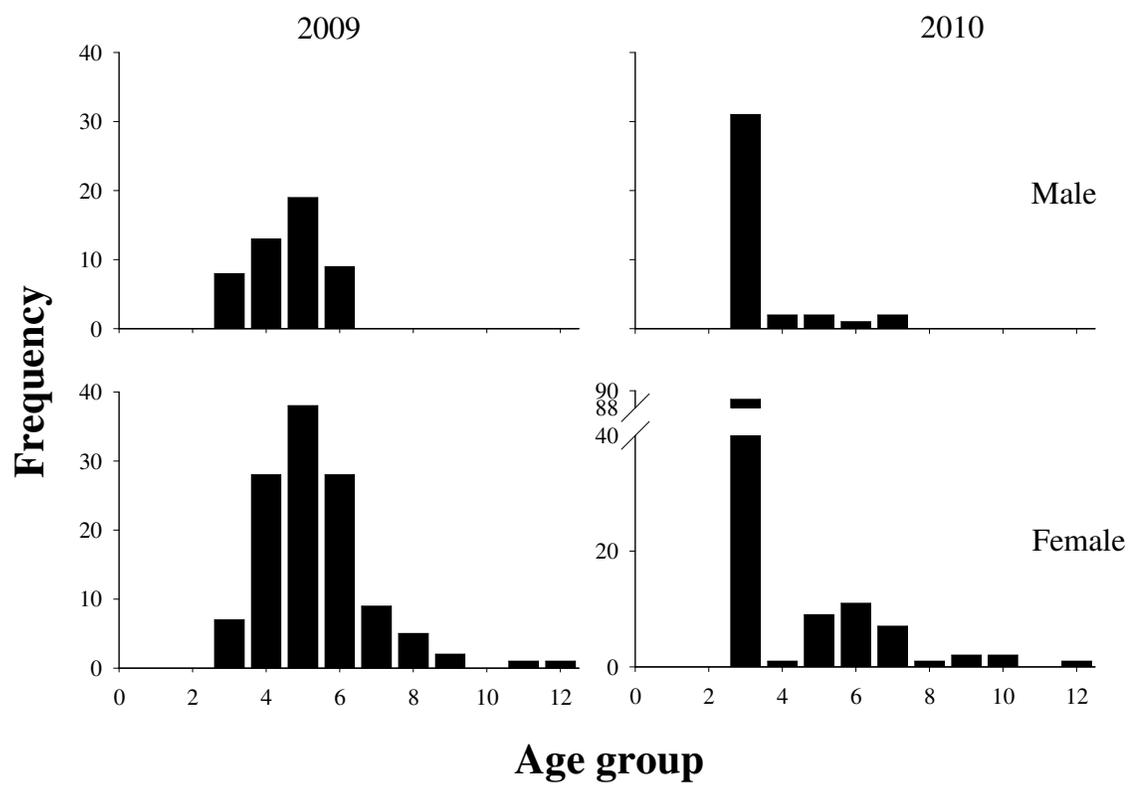
Figure 3-1. Age-frequency distributions of male (top panels) and female (bottom panels) white crappie collected from Sherman Reservoir, Nebraska during May-July 2009 (left panels) and May-July 2010 (right panels).
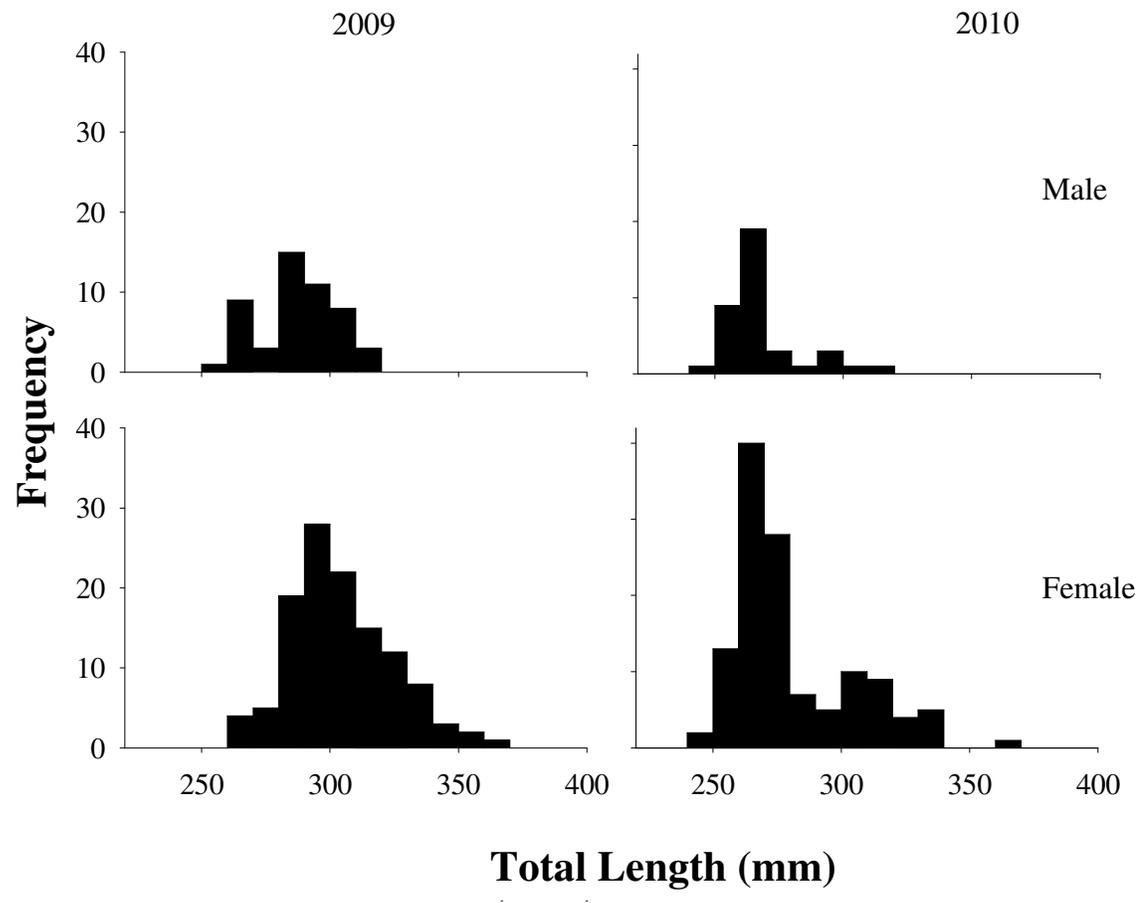
Figure 3-2.  Length-frequency distributions of male (top panels) and female (bottom panels) white crappie collected from Sherman Reservoir, Nebraska during May-July 2009 (left panels) and 2010 (right panels).
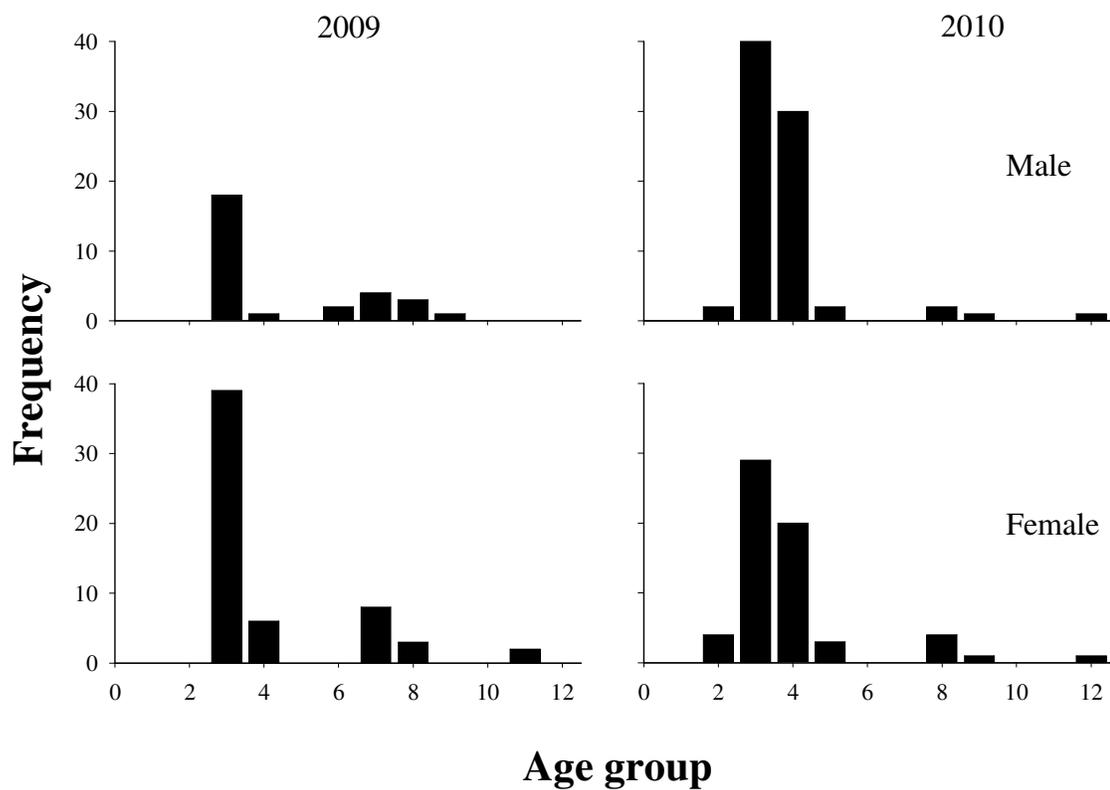
Figure 3-3.  Age-frequency distributions of male (top panels) and female (bottom panels) white bass collected from Calamus Reservoir, Nebraska during May-July 2009 (left panels) and May-July 2010 (right panels).
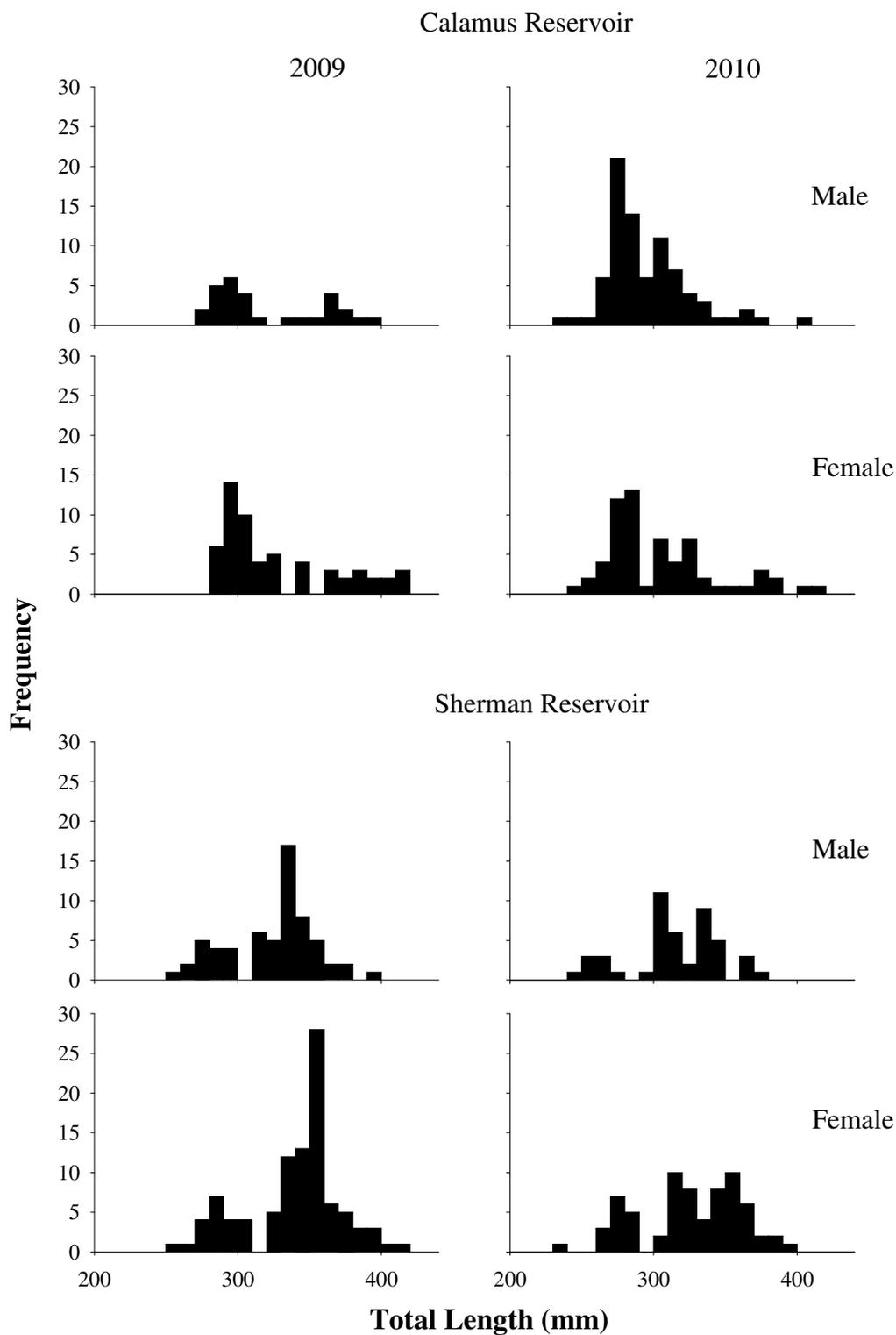
Figure 3-4. Length-frequency distributions of male (top panels of each reservoir) and female (bottom panels of each reservoir) white bass collected from Calamus (top four panels) and Sherman (bottom four panels) Reservoirs, Nebraska during May-July 2009 (left panels) and 2010 (right panels).
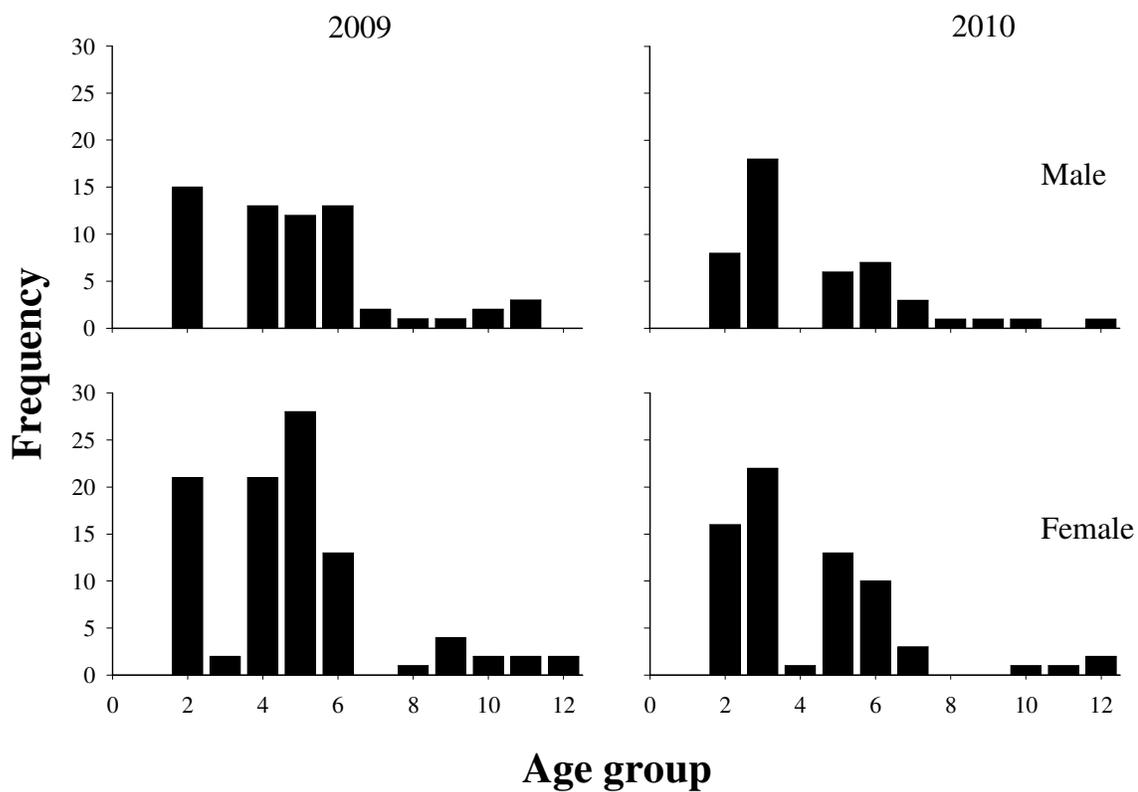
Figure 3-5.  Age-frequency distributions of male (top panels) and female (bottom panels) white bass collected from Sherman Reservoir, Nebraska during May-July 2009 (left panels) and May-July 2010 (right panels).

2009

2010

Male

Female

Frequency

0 2 4 6 8 10 12 0 2 4 6 8 10 12

**Age group**
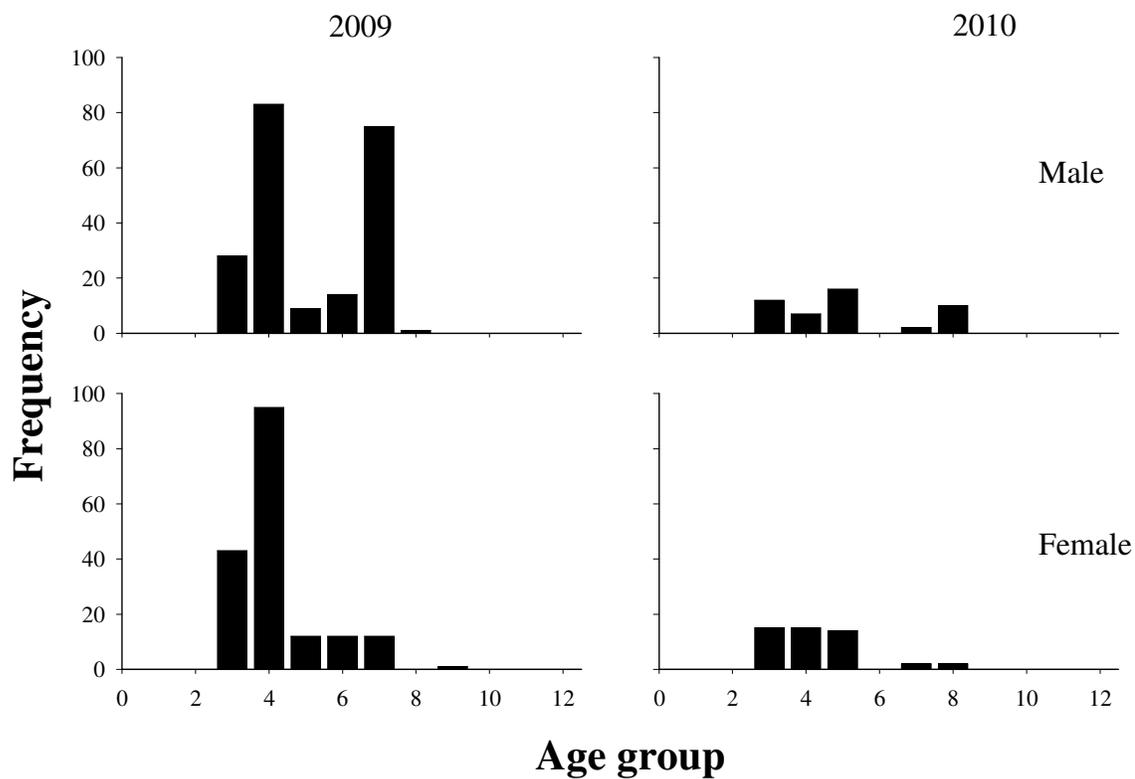
Figure 3-6. Age-frequency distributions of male (top panels) and female (bottom panels) walleye collected from Calamus Reservoir, Nebraska during May-July 2009 (left panels) and May-July 2010 (right panels).
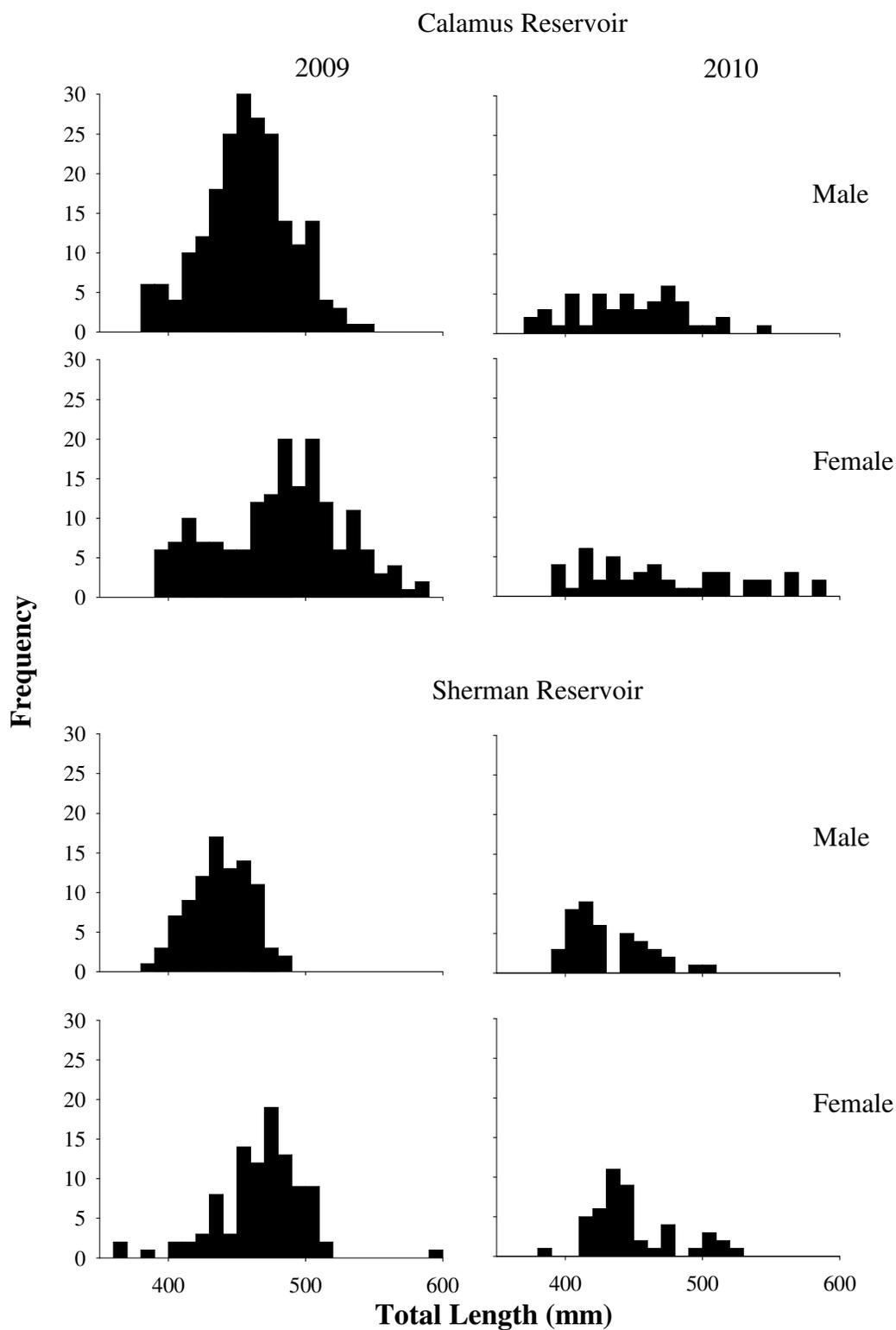
Figure 3-7. Length-frequency distributions of male (top panels of each reservoir) and female (bottom panels of each reservoir) walleye collected from Calamus (top four panels) and Sherman (bottom four panels) Reservoirs, Nebraska during May-July 2009 (left panels) and 2010 (right panels).
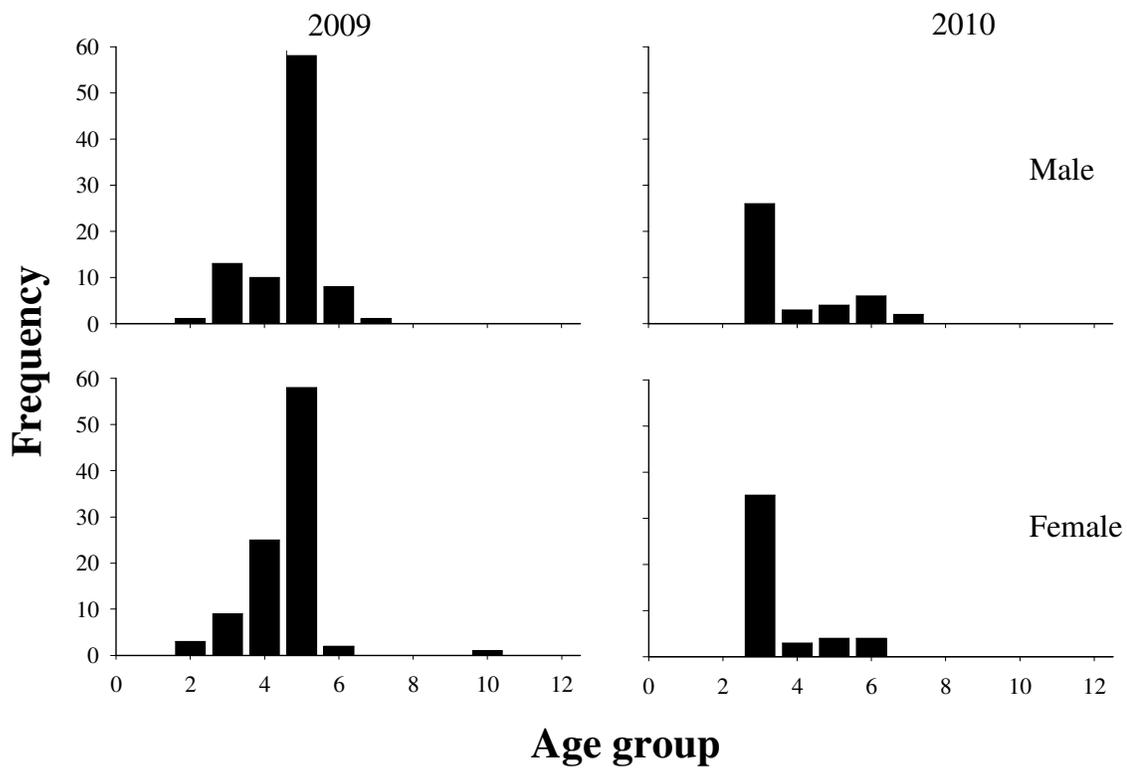
Figure 3-8. Age-frequency distributions of male (top panels) and female (bottom panels) walleye collected from Sherman Reservoir, Nebraska during May-July 2009 (left panels) and May-July 2010 (right panels).

## Chapter 4.  Selective harvest of white bass and walleye at Sherman Reservoir, Nebraska

**Introduction**

Understanding angler harvest is important to fishery management and can be thought of as two distinct theories.  First, anglers harvest individuals of a population in proportion to what is available.  Second, anglers selectively (in greater proportion to what is available) harvest individuals that possess desired traits (e.g., larger size and better condition).

Certain species of fish possess traits or exhibit behavior differences that make them more desirable to anglers.  A variety of fish species exhibit sexual-size dimorphism where one sex grows faster and attains larger size than the other.  If anglers are selectively harvesting the largest fish from these populations they would be harvesting one sex more than the other, thus, resulting in sex-selective harvest.  For example, male Dungeness crabs *Cancer magister*, which grow faster and reach larger sizes are harvested more frequently than their female counterparts (Smith and Jamieson 1991).  Yellow perch, a species that exhibits sexual-size dimorphism, have been reported to be selectively harvested based on size and age (Isermann et al. 2005).  In addition to differences resulting from sexual-size dimorphism, behavior differences between sexes can lead to one sex that is more vulnerable to anglers than another.  For example, male black crappie were harvested more frequently than females during the peak spawn (Isermann et al. 2010).  Similarly, because size is closely related to age, behavior

differences that occur between different sizes of fish likely also occur between ages of fish.

Although the effects of selective harvest are largely unknown, they could be negative. Sex-selective harvest likely leads to skewed sex ratios of the population. Skewed sex ratios have been shown to affect recruitment potential of some populations (Wilderbuer and Turnock 2009). In addition to recruitment overharvest, size-, age-, and sex-selective harvest likely would cause growth overharvest (Lauer et al. 2008). White bass and walleye are two harvest-oriented sportfish that exhibit a varying degree of sexual-size dimorphism. Male white bass have similar growth rates as female white bass whereas male walleye grow slower and attain smaller sizes than female walleye. Given this difference, I predict no size-, sex- or age-selective harvest to occur for white bass. Conversely, I predict size-, sex- and age-selective harvest to occur for female walleye. The objectives of our study were to determine if size-, sex- or age-selective harvest was occurring for male and female white bass and walleye at Sherman Reservoir, Nebraska.

**Methods**

Information was collected from angler-harvested white bass and walleye at Sherman Reservoir during May, June and July 2009 and 2010. Angler catch was sampled at fish-cleaning stations with an emphasis on days when angler participation was greatest (Thursday-Sunday), although other days (Monday-Wednesday) were also sampled. Sherman Reservoir has two fish-cleaning stations available for public use. I relied on advice from creel clerks working at the lake and visual determination of angler usage to subjectively select the fish-cleaning station with greatest use on each given day.

Harvested fish from willing anglers were measured for total length (TL; mm) and weight

(g).  After the angler cleaned the fish, the gonads were visually inspected to determine

sex.  Finally, sagittal otoliths were removed, stored in plastic vials with an identification

tag, and transported to the laboratory for further processing.  If multiple angling parties

arrived at the fish-cleaning station at the same time, I selected the first angler party to

arrive for fish information collection rather than handpicking certain fish from each party.

Information was collected for white bass and walleye that were captured by

Nebraska Game and Parks Commission (NGPC) biologists as part of their standardized

annual population survey at Sherman Reservoir during autumn 2009 and 2010.  Fish were

captured using experimental gill nets that were set in open water, allowed to fish

overnight and retrieved the following day.  The gill nets were 45.7-m long by 1.8-m deep,

and consisted of six 7.6-m panels with bar mesh sizes of 19, 25, 38, 51, 64 and 76 mm.

All fish were measured for total length and weight.  Sagittal otoliths were removed,

stored in plastic vials with an identification tag, and transported to the laboratory for

further processing.  Sex was determined by visual inspection of gonads.

*Laboratory Analysis of Otoliths*

Sagittal otoliths were processed using the "crack and burn" method described by

Lucchesi and Johnson (2006).  Otoliths were sectioned through the nucleus by hand.

Otoliths were then polished using 400- and 600-grit sandpaper.  The polished side of the

otolith was burned over an open flame for approximately three seconds.  Otoliths were

then placed into putty and cleaned using mineral oil.  Otoliths were viewed through a

dissecting microscope and annuli, which appeared as dark marks, were enumerated.

Otoliths were viewed by two independent readers.  Disagreements in age estimates resulted in both readers reviewing the otolith together.

*Data Analyses*

Length data for white bass and walleye were pooled across years to increase sample sizes and account for growth differences between years.  Fish were grouped into 25-mm length groups.  Size structure was compared between fish from NGPC standardized annual population survey and fish from angler-harvest collections using a Kolmogorov-Smirnov two-sample test ($KS_{\alpha}$ = asymptotic test statistic; SAS Institute 2002) to determine if size-selective harvest was occurring.  Comparisons were completed between males from each sampling type and then females from each sampling type to account for differences in growth between male and female fish.  Comparisons for walleye were completed for fish sampled between 375-mm TL and 525-mm TL because angler-harvested fish were limited to that size range.  Comparisons for white bass were completed for all fish sampled above 250-mm TL because angler-harvested fish were not sampled shorter than 250-mm TL.  Size structure comparisons were completed using PROC NPAR1WAY in SAS (2002).  Statistical significance was set at $\alpha$ = 0.05 for all comparisons.

Age data were pooled by year.  A chi-square test of homogeneity was used to determine if differences existed between age distributions of fish from NGPC standardized annual population survey and fish from angler-harvest collections.  Separate comparisons were completed for males and females.  Statistical significance was set at $\alpha$ = 0.05 for all comparisons.

Numbers of male and female fish harvested were pooled across months (May, June and July) to determine a sex ratio of harvested fish for each species sampled. A chi-square test of homogeneity was used to test for differences between the sex ratio of harvested fish and the sex ratio of fish sampled from NGPC population surveys to determine if sex-selective harvest was occurring. Statistical significance was set at $\alpha = 0.05$ for all comparisons.

**Results**

Length distributions did not differ between white bass harvested by anglers and white bass collected by NGPC biologists for males ($KS_a = 0.19$, $P = 1.00$; Figure 4-1) or females ($KS_a = 1.11$, $P = 0.17$; Figure 4-2). Length distributions did not differ between walleye harvested by anglers and walleye collected by NGPC biologists for males ($KS_a = 1.03$, $P = 0.23$; Figure 4-3), but did differ for females ($KS_a = 2.41$, $P < 0.01$; Figure 4-4). Female walleye harvested by anglers were longer than female walleye collected by NGPC biologists.

During 2009, age distributions did not differ between white bass harvested by anglers and white bass collected by NGPC biologists for males ($\chi^2 = 12.94$; df = 8; $P = 0.11$; Table 4-1) or females ($\chi^2 = 12.11$; df = 9; $P = 0.21$; Table 4-1). Similarly, during 2010, age distributions did not differ between white bass harvested by anglers and white bass collected by NGPC biologists for males ($\chi^2 = 6.58$; df = 8; $P = 0.58$; Table 4-1) or females ($\chi^2 = 3.30$; df = 8; $P = 0.91$; Table 4-1). During 2009, age distributions did differ between walleye harvested by anglers and walleye collected by NGPC biologists for males ($\chi^2 = 51.59$; df = 5; $P < 0.01$; Table 4-1) and females ($\chi^2 = 73.76$; df = 4; $P < 0.01$;

Table 4-1).  Male and female walleye harvested by anglers were older than male and female walleye collected by NGPC biologists.  Conversely, during 2010, age distributions did not differ between walleye harvested by anglers and walleye collected by NGPC biologists for males ($\chi^2 = 3.97$; df = 4; $P = 0.41$; Table 4-1) or females ($\chi^2 = 1.52$; df = 3; $P = 0.68$; Table 4-1).

During 2009, sex ratios differed between white bass harvested by anglers and white bass collected by NGPC biologists ($\chi^2 = 9.57$; df = 1; $P < 0.01$; Table 4-2).  The ratio of male/female white bass harvested by anglers was less than the ratio of male/female white bass collected by NGPC biologists.  During 2010, sex ratios differed between white bass harvested by anglers and white bass collected by NGPC biologists ($\chi^2 = 4.33$; df = 1; $P = 0.04$; Table 4-2).  Similarly, the ratio of male/female white bass harvested by anglers was less than the ratio of male/female white bass collected by NGPC biologists.  During 2009, sex ratios did not differ between walleye harvested by anglers and walleye collected by NGPC biologists ($\chi^2 = 0.18$; df = 1; $P = 0.67$; Table 4-2).  Similarly, during 2010, sex ratios did not differ between walleye harvested by anglers and walleye collected by NGPC biologists ($\chi^2 = 0.01$; df = 1; $P = 0.93$; Table 4-2).

**Discussion**

Anglers at Sherman Reservoir did not selectively harvest male and female white bass based on size or age, although sex-selective harvest was apparent for white bass. Anglers harvested females at a greater proportion than was sampled during NGPC annual population surveys.  This contrasts with the findings of Schultz (2004) in which he

concluded angling was selective for the largest male white bass in three Kansas reservoirs.

Anglers at Sherman Reservoir did selectively harvest female walleye based on size, although in contrast to the white bass population, sex-selective harvest was not apparent for walleye. Anglers tended to harvest the longer, presumably faster growing females of the population, but the ratio of males and females being harvested was similar to the ratio of males and females sampled during NGPC annual population surveys. During 2009, anglers selectively harvested older male and female walleye whereas during 2010 no difference was found between ages of male and female walleye harvested and male and female walleye sampled during NGPC annual population surveys. Serns and Kempinger (1981) reported no differences in exploitation rates for male and female walleye but did observe a trend of decreasing vulnerability to angling as walleye size and age increased. Mraz (1968) and Smith et al. (1952) reported exploitation rates that were greater for female walleye than male walleye. Size-, sex- and age-selective harvest has been evident in multiple populations of yellow perch *perca flavescens*, another species where females have faster growth rates than males (Isermann et al. 2005; Lauer et al. 2008; Schoenebeck and Brown 2011).

Given our *a-priori* predictions that harvest would be size-, age- and sex-selective for walleye but not for white bass, reasons beyond our initial scope (e.g., length limit, angler or fish behavior, etc.) must be influencing the harvest of white bass and walleye. Growth and condition was similar between male and female white bass (Chapter 2), thus, it is unlikely size-selectivity of one sex lead to the observed female-biased harvest. Energy demands associated with reproduction can differ between male and female fish of

a population (Henderson et al. 2003).  Additionally, segregation of males and females has been reported for other freshwater fishes (Haraldstad and Jonsson 1983).  One or both of these reasons likely influenced the female-biased harvest of white bass that was observed at Sherman Reservoir.

The length limit for walleye at Sherman Reservoir is an inverse slot length limit allowing harvest of only fish between 382- and 508-mm TL.  The length limit is designed to protect female walleye that comprise the majority of fish greater than 508-mm TL.  This targeted harvest likely increases the number of males harvested because male walleye mature at age-3 or age-4 (Priegel 1969) and subsequently growth slows.  Length of age-3 and age-4 male walleye aligns closely with the 380-mm minimum length required to be harvested, and consequently, the slower growing males are vulnerable to harvest for longer periods.  Female walleye, which mature at age-5 or age-6 (Priegel 1969), would likely grow through the length limit quicker than male walleye.  Walleye harvest at Sherman Reservoir during May-July was substantially greater during 2009 than during 2010 (Chapter 3).  During 2009, anglers likely were able to selectively harvest the larger fish available, which would lead to the observed age-selective harvest.  Conversely, with the poor fishing during spring 2010, anglers likely kept any legal-size walleye, which would explain the lack of age-selective harvest observed in 2010.

Although largely unknown, the effects of sex-selective harvest are potentially negative.  Reducing the numbers of one sex more in comparison to the other may reduce reproductive capabilities of the population.  Populations with variable recruitment may be affected more by a lack of females because capacity to produce ova is reduced (i.e.,

recruitment overfishing).  In addition to recruitment overfishing, sex-selective harvest could reduce the age at maturation (Conover and Munch 2002).

Size-selective harvest can result in genetic changes, earlier maturation of adults and reduced abundance to fish populations (Conover and Munch 2002; Jorgensen et al. 2007).  Disproportionately harvesting the larger individuals of a population selects for slower growing, earlier maturing genetics.  Additionally, studies have reported the significance of large fish to the population.  For example, survival is almost double for larvae from the largest, oldest females of a population compared to larvae from smaller, younger individuals (Berkeley et al. 2004).  These larger older females also spawn earlier which spreads out the length of the spawn and subsequently increases the odds of successful recruitment (Berkeley et al. 2004; Birkeland and Dayton 2005).  In addition to the negative consequences of size-selective harvest, positive consequences may occur. For example, reduced abundance may lead to reduced intraspecific competition, which ultimately would lead to faster growth rates, better condition, and greater fecundity.  The majority of studies investigating selective harvest have focused on marine environments. Little research has been completed on freshwater, recreational fisheries.  I believe further research is needed to investigate the consequences that selective harvest has on populations in freshwater recreational fisheries.

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Table 4-1.  Number of male (M) and female (F) white bass and walleye collected at Sherman Reservoir, Nebraska by Nebraska Game and Parks Commission (NGPC) biologists (GN, gillnet) during September and October 2009 and 2010 and from fish harvested by anglers (AH, angler harvest) during May-July 2009 and 2010.

| Species | Year | Gear | Sex | Age | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| White bass | 2009 | GN | M | 14 | | 4 | 10 | 1 | | 1 | 2 | | 1 | |
| | | AH | | 15 | | 13 | 12 | 13 | 2 | 1 | 1 | 2 | 3 | |
| | | GN | F | 11 | 1 | 3 | 3 | 1 | | | | | 1 | |
| | | AH | | 21 | 2 | 21 | 28 | 13 | | 1 | 4 | 2 | 2 | 2 |
| | 2010 | GN | M | 6 | 4 | | | 2 | 1 | | | | | |
| | | AH | | 8 | 18 | | 6 | 7 | 3 | 1 | 1 | 1 | | 1 |
| | | GN | F | 3 | 1 | | 1 | 2 | | | | | | |
| | | AH | | 16 | 22 | 1 | 13 | 10 | 3 | | | 1 | 1 | 2 |
| Walleye | 2009 | GN | M | 14 | 1 | 2 | 9 | | 1 | | | | 1 | |
| | | AH | | 1 | 13 | 10 | 59 | 8 | 1 | | | | | |
| | | GN | F | 21 | 1 | 2 | 3 | 1 | | | | | 1 | |
| | | AH | | 3 | 9 | 25 | 58 | 2 | | | | 1 | | |
| | 2010 | GN | M | 4 | 11 | 2 | | 3 | 3 | | | | | |
| | | AH | | | 26 | 3 | 4 | 6 | 2 | | | | | |
| | | GN | F | 11 | 13 | 1 | | 1 | | | | | | |
| | | AH | | | 35 | 3 | 4 | 4 | | | | | | |

Table 4-2.  Number of male (M) and female (F) white bass and walleye collected at Sherman Reservoir, Nebraska by Nebraska Game and Parks Commission (NGPC) biologists (Gillnet) during September and October 2009 and 2010 and from fish harvested (Angler harvest) by anglers during May-July 2009 and 2010.

| Species | Year | Sex | Gillnet | Angler harvest |
|---------|------|-----|---------|----------------|
| White bass | 2009 | M | 34 | 62 |
|  |  | F | 20 | 98 |
|  | 2010 | M | 13 | 46 |
|  |  | F | 7 | 69 |
| Walleye | 2009 | M | 30 | 92 |
|  |  | F | 29 | 101 |
|  | 2010 | M | 23 | 42 |
|  |  | F | 26 | 46 |

Figure 4-1. Length-frequency distribution of male white bass collected at Sherman Reservoir, Nebraska by Nebraska Game and Parks Commission (NGPC) biologists (top) during September and October 2009 and 2010 and from fish harvested by anglers (bottom) during May-July 2009 and 2010.
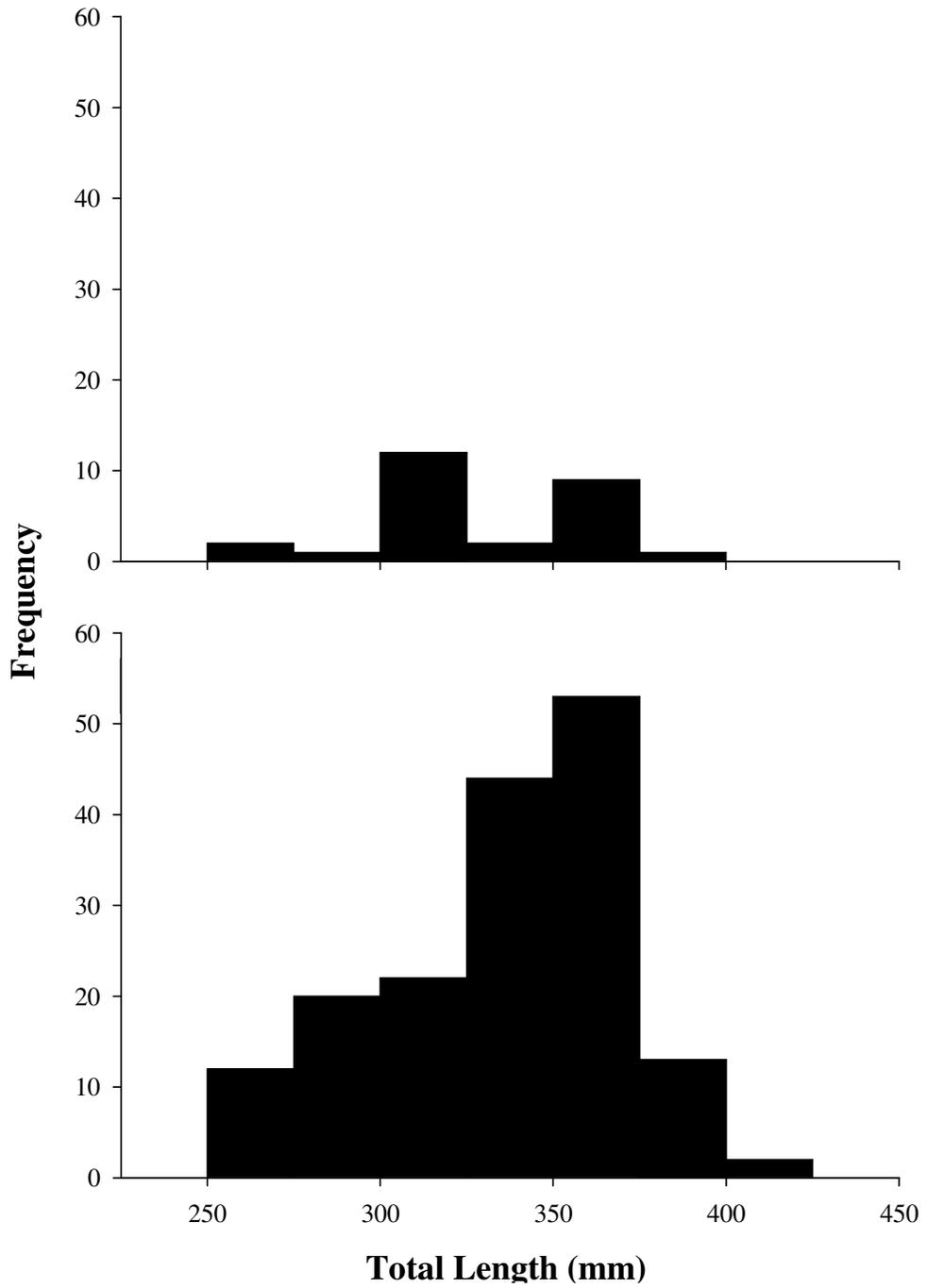
Figure 4-2.  Length-frequency distribution of female white bass collected at Sherman Reservoir, Nebraska by Nebraska Game and Parks Commission (NGPC) biologists (top) during September and October 2009 and 2010 and from fish harvested by anglers (bottom) during May-July 2009 and 2010.
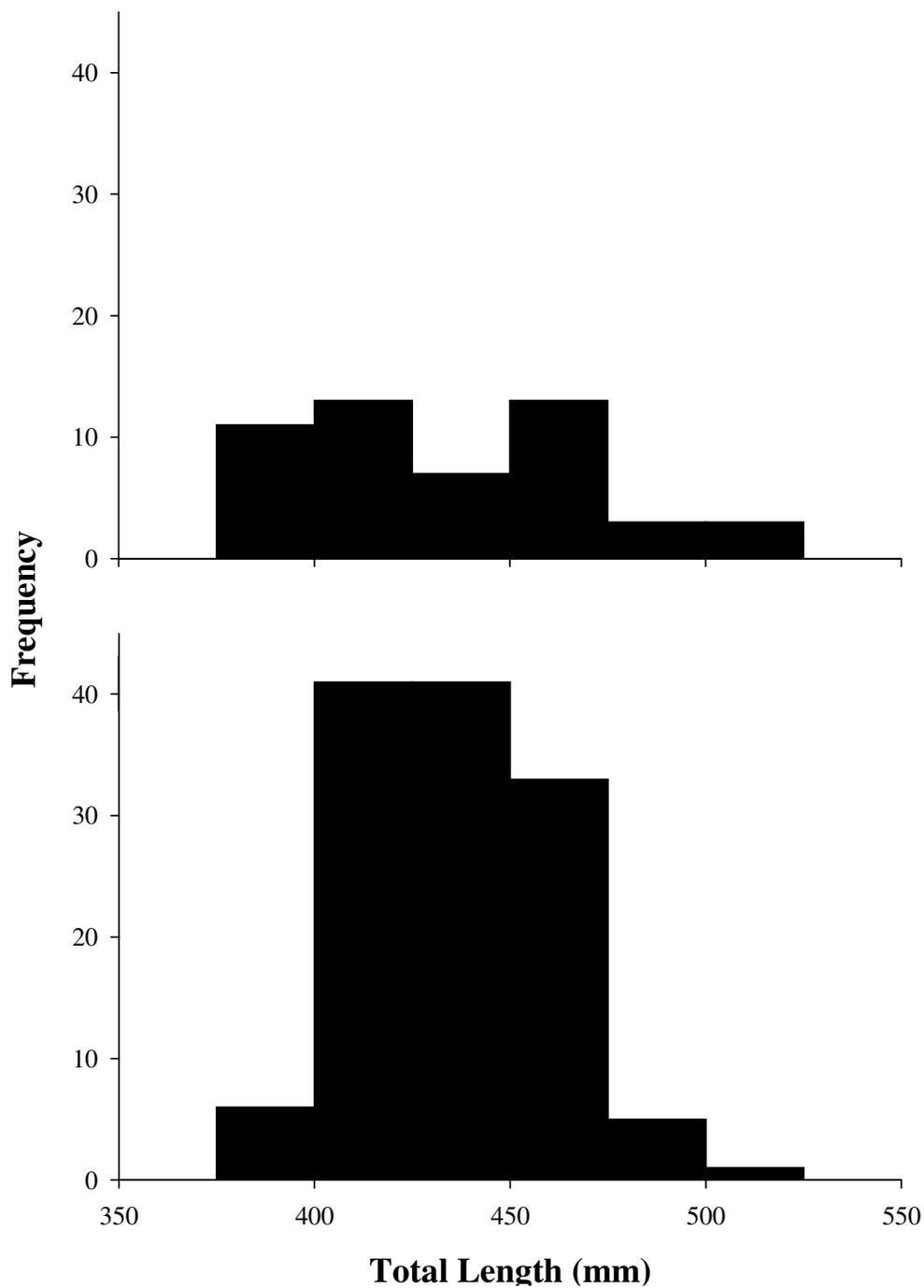
Figure 4-3. Length-frequency distribution of male walleye collected at Sherman Reservoir, Nebraska by Nebraska Game and Parks Commission (NGPC) biologists (top) during September and October 2009 and 2010 and from fish harvested by anglers (bottom) during May-July 2009 and 2010.
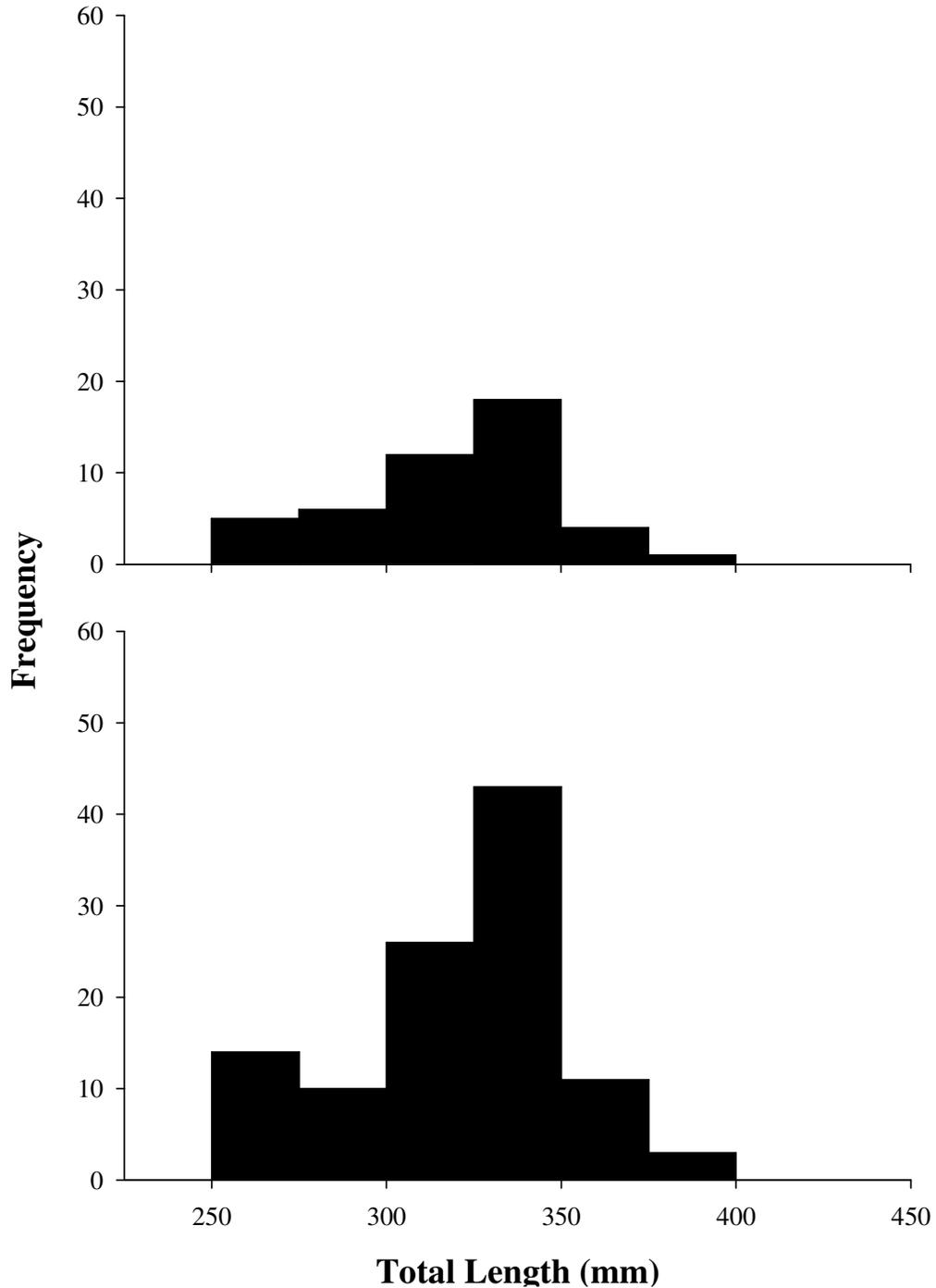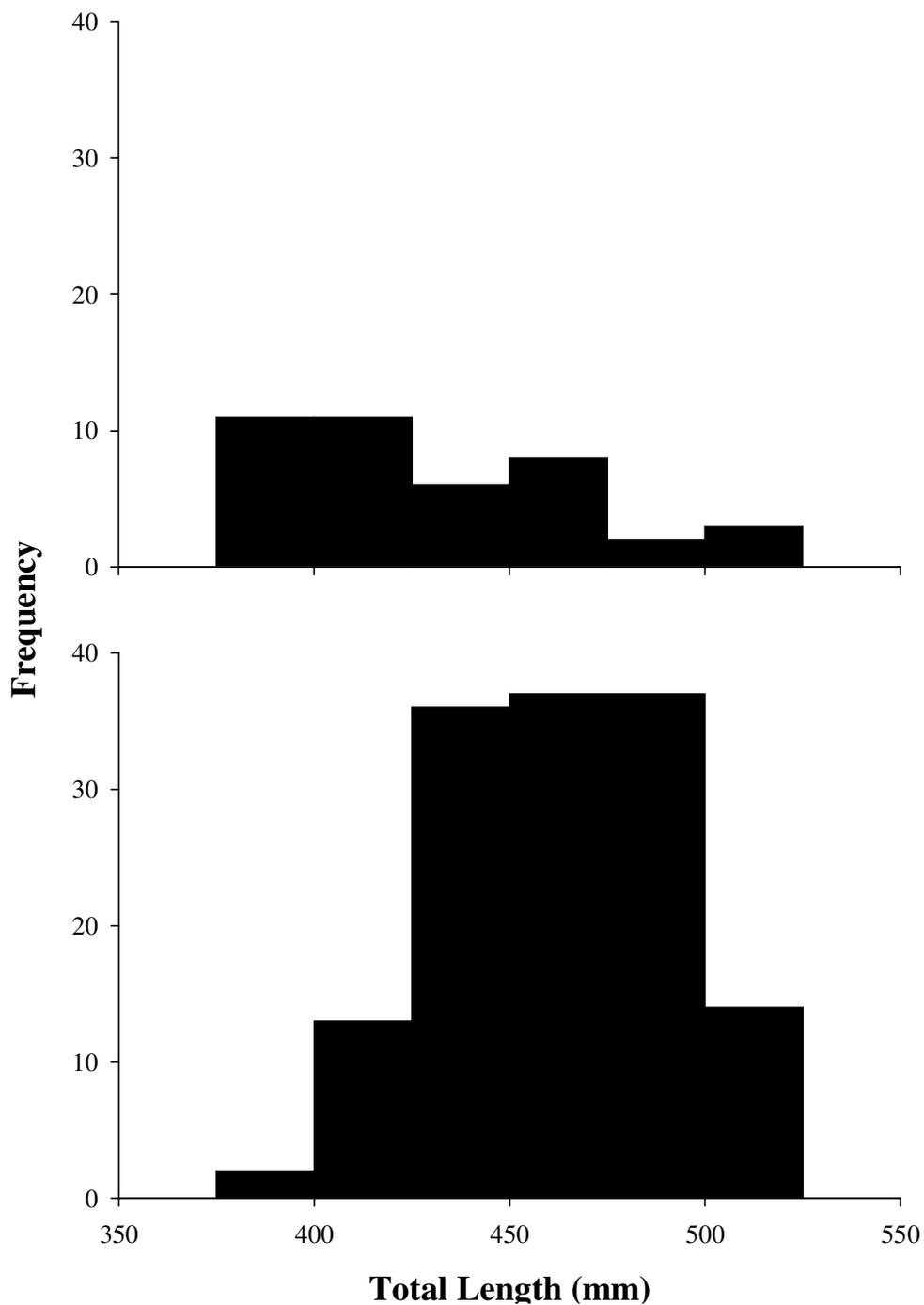
Figure 4-4. Length-frequency distribution of female walleye collected at Sherman Reservoir, Nebraska by Nebraska Game and Parks Commission (NGPC) biologists (top) during September and October 2009 and 2010 and from fish harvested by anglers (bottom) during May-July 2009 and 2010.

**Chapter 5.  A model of a sexually size dimorphic species' response to different**

**length limits**

**Introduction**

Fishing in general is a selective process, where anglers target specific species, sizes, or areas during specific times of the year.  This selectivity can be compounded by management actions such as a length limit or seasonal closures, thus harvested fish populations pose an interesting experimental unit in life-history evolution of selective harvest, which is comprised of three groups: 1) fishery managers that set patterns of selection, 2) anglers applying the mortality, and 3) the fish stocks as recipients of the selective mortality (Law 2000).  Most of the studies focusing on selective harvest have focused on commercial harvest of marine stocks (Gulland 1983, Goodyear 1993) and only recently has attention been applied to recreational angler harvest on fish populations (Post et al., 2002; Lewin; et al., 2006; Arlinghaus et al. 2010).

Traditional fisheries management encourages the exploitation of larger individuals through the implementation of length limits.  This has a truncation effect on the fish population reducing the density of larger more fecund individuals.  This theory predicts that the reduction in density of larger fish reduces the energetic demand of the population, allowing for more per capita energy available for young fish resulting in greater growth to the exploitation size.  What this traditional theory neglects is the evolutionary impacts of this size-selective harvest, which often has consequences of lowering the age-at-maturity and potentially destabilizing the population (Conover and Munch 2002; Jorgensen et al. 2007).  Additionally, this fails to incorporate any of the

potential effects on a sexually size dimorphic fish species.  Typically in sexually size dimorphic fish the sex that is larger has the potential to be exploited greater than the other sex, because of the size-selective nature of angler harvest.  This could have profound effects on the short-term and long-term dynamics of the fish population.

Walleye *Sander vitreus* the largest member of the Percidae family in Nebraska (Scott 1967), is a highly sought after sportfish found throughout North America (Scott and Crossman 1973; Colby et al. 1979).  Walleye are a sexually dimorphic fish species that express sex-specific growth rates and maturation ages.  Female walleye attain faster growth rates, larger maximum size, and later maturation presumably to increase fecundity and overall reproductive success (Henderson et al. 2003).  As a result of its popularity, walleye harvest is managed through a multitude of minimum length limits, protected slot limits and harvestable slot limits. For example, in the state of Nebraska, USA walleye regulations include: 381-mm minimum, 559-mm minimum, 381 to 508-mm harvestable slot and a 457 to 610-mm protected slot (NGPC 2011).  Male walleye typically mature at ages 2 through 5 (259-384 mm) and females at ages 5 through 7 (439 – 500 mm) (Priegel 1969) and thus, the type of regulation imposed on a population not only will affect the male and females differently, but could also affect reproductively viable individuals within a population differently.

The objectives of this paper were to examine the short-term dynamics associated with various harvest regulations used to manage a sexually size dimorphic species. Specifically the objectives were to 1) to create a hypothetical walleye population model based on parameters from populations in the Midwestern USA and 2) use the model to explore the influence of minimum, protected slot, and harvested slot length limits on the

population abundance, sex ratio, and length-frequency distributions of the hypothetical population of walleye. We predict a shift towards a male-biased population as the length of minimum length limit increases. Additionally we predict female-biased population under simulations of harvest slots between 381-mm and 559-mm. We predict that trend to reverse under a harvest slot between 559-mm and 661-mm. We predict an equal distribution of males and females under any protected slots.

**Methods**

We developed an age-structured walleye simulation model with multidimensional density-dependence on the vital rates of walleye. The model was modified from a model developed for walleye (Venturelli et al. 2010) and for northern pike (Arlinghaus et al. 2010). The model focused only on the short-term ecological dynamics of the population and thus neglected any of the longer-termed evolutionary dynamics associated with size-selective harvest. The parameters used in the model (Table 5-1) represent a prototypical Midwestern USA population of walleye exploited by recreational fisheries. No study was available that reported all the information needed, therefore population parameters were collected from different sources (citations). Below we will describe specifics of the model development and parameters used.

*Population dynamics*

To determine the effect of length limits on the population of a sexually size dimorphic fish species we developed a stochastic, density dependent, stage within age matrix population model (Rose et al. 2003, Venturelli 2010) for each sex. Briefly, a stage

within age matrix population model uses a stage-based model for the first year of life using a daily time step, and models later stages with an age-based model of adults (Caswell 1989), using an annual time step. For ages 1+ we modeled the population following a Leslie matrix model, where the changes in the age structure and density of the population are described by

$$
\begin{pmatrix} N_1(t+1) \\ N_2(t+1) \\ N_3(t+1) \\ \dots \\ N_{a_{max}}(t+1) \end{pmatrix} = \begin{pmatrix} f_1 & f_1 & f_1 & \dots & f_1 \\ s_1 & 0 & 0 & \dots & 0 \\ 0 & s_1 & 0 & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & s_{a_{max}-1} & 0 \end{pmatrix} \times \begin{pmatrix} N_1(t) \\ N_2(t) \\ N_3(t) \\ \dots \\ N_{a_{max}}(t) \end{pmatrix}
$$

The vector N(t) represents the abundance of walleye per hectare in year t across all age groups a=1, …, $a_{max}$. The model was run such that the census occurred at the beginning of each season (prior to breeding). The vital rates for fecundity at age $a$ (i.e., number of eggs produced per female) and survival $S_a$ (i.e., probability of surviving age $a$ to age +1) were functions of total population density (male and females combined) and thus vary with time t. In each time step, the survival of individuals in age group $a_{max}$ (i.e., maximum age) was zero.

Early life stages were modeled differently from the adult as these were modeled using a stage-based approach (Caswell 2001). There were four stages for the first year of life (egg, larva, early juvenile, late juvenile) with durations of 30, 60, 90, and 180 days. These stages are designated the subscripts $0_1$, $0_2$, $0_3$, $0_4$, respectively. Within each stage there was an associated probability of surviving the time step but staying within a stage, $P$, and a probability of surviving a time-step and moving to the next life stage, $G$, (Caswell 2001)

$$\begin{pmatrix} N_{0_1}(t+1) \\ N_{0_2}(t+1) \\ N_{0_3}(t+1) \\ N_{0_4}(t+1) \\ N_1(t+1) \end{pmatrix} = \begin{pmatrix} P_{0_1} & 0 & 0 & 0 & 0 \\ G_{0_1} & P_{0_2} & 0 & 0 & 0 \\ 0 & G_{0_2} & P_{0_3} & 0 & 0 \\ 0 & 0 & G_{0_3} & P_{0_4} & 0 \\ 0 & 0 & 0 & G_{0_4} & P_1 \end{pmatrix} \times \begin{pmatrix} N_{0_1}(t) \\ N_{0_2}(t) \\ N_{0_3}(t) \\ N_{0_4}(t) \\ N_1(t) \end{pmatrix}$$

There were two dynamic sources of mortality within these stages. We included a density dependent component into the early juvenile stage because both predation and competition for resources are highly density dependent at the onset of exogenous feeding (Cowan et al. 2000). As the density of early juveniles increased so did juvenile mortality, given by

$$Z' = Z \times (\lambda \times D_{0_3} + 1)$$

Where natural mortality is Z, $\lambda$ is the parameter that defines the sensitivity of Z to the number of early juvenile ($D_{0_3}$). This equation is part of the Ricker stock-recruitment model family (Hilborn and Walters 1992). There appears to be fairly frequent degrees of recruitment variability of walleye in Nebraska, so we included this component as well. During each annual time step run, we randomly selected whether recruitment variability occurred (~ 1 in 4 years). If recruitment variability was to occur, we randomly selected one of the four age 0 stages and decreased survival at that stage by 5, 10, 25, or 50%.

*Biological Processes*

The length at age for males and females was modeled separately according to the biphasic growth model by Lester et al. (2004). This model explicitly considers the annual energetic demand imposed by reproduction, which is assumed to be constant across mature age groups and follows the von Bertalanffy growth equation of postmaturation

somatic growth in freshwater fish. Alternatively, until maturation occurs growth is almost linear. The length-at-age is represented as:

$$La = \frac{3}{3 + g_a}(L_{a-1} + h),$$

$$L_1 = h(1 - t_1)$$

where $g_a$ is annual reproductive investment at age $a$ (i.e., the surplus energy devoted to reproduction), and $h$ is the annual length increment of immature fish (Lester et al. 2004). As $g_a = 0$ until the age of maturation, immature growth is linear with the annual increment h. In our model, age at maturation for males and females was static and based on information collected in the field. The age of first spawning occurred one year after reaching maturity.

We converted length at age to mass at age using an empirical allometric equation:

$$W_a = \alpha_1(L_a)^3$$

where $W_a$ is somatic weight at age $a$ and $\alpha_1$ are empirical parameters defining the relationship for walleye. The biomass of the population at time $t$, is simply the sum of biomasses across all age groups and sexes,

$$D = \left(\sum_{a=1}^{a_{max}} W_{Ma} N_{Ma}\right) + \left(\sum_{a=1}^{a_{max}} W_{Fa} N_{Fa}\right)$$

Growth in fish is often density-dependent due to increased competition for food with increasing density (Lorenzen and Enberg, 2002). Thus the effect of density dependence on incremental growth was modeled using:

$$h = \frac{h_{max}}{1 + \beta_1(D)^{\beta_2}}$$

where $\beta_1$ and $\beta_2$ define the shape of this relationship and $h_{max}$ is the maximum annual length increment without the effect of density dependence (i.e., $D = 0$).

The number of ova produced by female walleye was assumed to be a function of body mass:

$$f_a = W_{Fa} \times 52000$$

The number of ova produced in time step $t$ by a fish in age group $a$ were released at the onset of time step $t + 1$. Estimates of fecundity per female mass (kg) were obtained from Baccante and Colby (1996). Modeling ova produced in this manner ensured that ova production was a function of conditions present during ova development rather than conditions at the time of ova release. It was assumed that 1:1 male: female sex ratio existed.

Annual survival rates $S_a$ at age are calculated by combining age-specific instantaneous natural mortality rates $M_a$ with instantaneous fishing mortality rates $F_a$,

$$S_a = \exp\left(-(M_a + F_a)\right).$$

The value of $M_a$ was kept constant at 0.10 while $F_a$ varied depending on the size structure and population density at time $t$. For further details, see below.


*Recreational angling processes*

Fish have a size-dependent relationship to their vulnerability to angling, thus we modeled the vulnerability of an age group to angling using a sigmoid relationship with length that was scaled from 0 (completely invulnerable) to 1 (completely vulnerable):

$$V_a = (1 - \exp(-\eta L_a))^\theta$$

where $V$a is the vulnerability of fish age a with $\eta$ and $\theta$ describe the shape of the

relationship (Paul et al 2003, Arlinghaus et al. 2010). We determined the shape

parameters by fitting the curve to walleye angler catch (catch and release) in 2009 at

Sherman and Merritt reservoirs. The total density of vulnerable fish at time t was given

as:

$$N_v = \sum_{a=1}^{a_{max}} V_a N_a$$

Post et al. (2003) suggested that a reasonable expectation of angler behavior to the quality

of the fishery could be described by a sigmoid numerical response. Angler effort

increases with a corresponding increase in the number of vulnerable fish. We modeled

angler effort to the number of vulnerable walleye as:

$$E = u \left( p + \frac{N_v^{\xi}}{N_{v,1/2}^{\xi} + N_v^{\xi}} (1 - p) \right)$$

Where $u$ is the maximum effort per ha, $p$ is the proportion of $u$ that is always present,

$N_{v,1/2}$ is the density of fish that elicits one-half of the variable effort density, and $\xi$ is an

exponent that characterizes the steepness of the effort response curve (Post et al. 2003,

Arlinghaus et al 2010).

We developed several different length-based regulations to explore the effect on

male and female walleye. The first type of regulations was minimum length limits ($\geq$ 381

mm, $\geq$ 457 mm, $\geq$ 559 mm, and $\geq$ 711 mm), where fish with lengths greater than the

limit were vulnerable to harvest. The second type of regulations was harvestable slots ($\geq$

381mm & $\leq$ 508 mm, $\geq$ 451 mm & $\leq$ 584 mm, $\geq$ 508 mm & $\leq$ 635 mm), where fish with

lengths that fell within the slot were vulnerable to harvest. The third type of regulations

was protected slots (≤381mm & ≥508 mm, ≤ 451 mm & ≥ 584 mm, ≤ 508 mm & ≥ 635

mm), where fish with length that fell outside of the slot were vulnerable to harvest. In

this model, anglers release protected fish, some of which die from hooking mortality

(Arlinghaus et al. 2007). Walleye fishing is typically a harvest-orientated activity, where

vulnerable fish that were caught were removed from the population. The number of dead

fish $d_a$ at age $a$ is given as (Arlinghaus et al. 2009):

$$d_a = \begin{cases} V_a N_a [1 - exp(-qE)], \text{if } L_a \text{ is harvestable,} \\ V_a N_a [1 - exp(-UqE)], \text{if } L_a \text{ is protected,} \end{cases}$$

where $q$ is a constant catchability coefficient, $E$ is angling effort density, and $U$ is the

proportion of protected fish that experience hooking mortality. The instantaneous

angling mortality $F_a$ at age $a$ is then:

$$F_a = -\ln\left(1 - \frac{d_a}{N_a}\right).$$

*Modeling Outline*

Initial models were run to identify when the population reached equilibrium (t

=24) without the effect of harvest on the population. We ran the model for an additional

75 time steps and initiated harvest at $t = 100$ and completed each model run at $t = 200$.

Each regulation scenario was evaluated with 200-year population projection generated

through Monte Carlo simulation (1000 iterations) to account for the stochasticity

associated with recruitment failure. The mean and 95% confidence interval (percentile)

for $L$a and $N$a at t for males and females were calculated for each regulation scenario.

Results were presented in order of the regulations that had the least effect to the most

effect on $N$a at t=200.

**Results**

Simulations of minimum length limits indicated that as the length of a minimum length limit increases, the number of mature (age 4 and older) walleye increases (Figure 5-1; Figure 5-2). Approximately 5 mature walleye per hectare were in the population regulated with a 381-mm minimum length limit, whereas approximately 12 mature walleye per hectare were in the population regulated with a 711-mm minimum length limit. Simulations of minimum length limits indicated that as the length of a minimum length limit increases, the female to male ratio of mature walleye increases (Figure 5-3). The female to male ratio for a 381-mm minimum length limit was 0.98 : 1.00 whereas the ratio for a 711-mm minimum length limit was 1.00 : 1.00.

Simulations of protected slot length limits indicated that as the lengths of protected fish increases, the number of mature (age 4 and older) walleye decreases (Figure 5-1; Figure 5-2). Approximately 7 mature walleye per hectare were in the population regulated with a 381-mm to 508-mm protected slot length limit, whereas approximately 5 mature walleye per hectare were in the population regulated with a 508-mm to 635-mm protected slot length limit. Simulations of protected slot length limits indicated that as the lengths of protected fish increases, the female to male ratio of mature walleye remains constant (Figure 5-3). The female to male ratio for 381-mm to 508-mm, 457-mm to 581-mm, and 508-mm to 635-mm protected slot length limits was 0.97 : 1.00.

Simulations of harvest slot length limits indicated that as the lengths of harvested fish increases, the number of mature (age 4 and older) walleye increases (Figure 5-1; Figure 5-2). Approximately 6 mature walleye per hectare were in the population under a 381-mm to 508-mm harvest slot length limit, whereas approximately 9 mature walleye

per hectare were in the population regulated with a 508-mm to 635-mm harvest slot

length limit. Simulations of harvest slot length limits indicated that as the lengths of

harvested fish increases, the female to male ratio of mature walleye increases slightly

(Figure 5-3). The female to male ratio for a 381-mm to 508-mm harvest slot length limit

was 0.98 : 1.00 whereas the ratio for a 508-mm to 635-mm harvest slot length limit was

1.00 : 1.00.


**Discussion**

Length limits are extensively used as a method to manage harvest of the popular

sportfish, walleye. Multiple types (e.g., minimum, slot, and maximum) and lengths (e.g.,

382 mm, 457 mm, and 720 mm) of limits have been employed in an effort to adequately

protect populations from overharvest and create quality fisheries. When length limits are

employed, managers create objectives they hope the length limit will help the fish

population achieve (e.g., PSD = 60, or angler catch rate of at least 2.5 fish/hr). Previous

studies have revealed instances where the length limit employed did not lead to

achievement of *a-priori* objectives (Wilde 1997). A possible explanation for some of

these failures is the lack of consideration of different growth rates between male and

female walleye (i.e., sexual-size dimorphism). The walleye model in this study used

separate growth rates for male and female walleye to determine the interaction between a

length limit and subsequent harvest of male versus female walleye.

All length limits that were assessed in this paper caused a decline in the overall

number of fish in the population. The decline in population abundance was a direct result

of the modeling procedures we used, which started with a population at equilibrium with

no harvest. Typical observations with implementation of length limits are increases, no change, and decreases in abundance on fish populations that are currently being harvested (Munger and Kraai 1997; Fayram et al. 2001; Munger 2002; Stone and Lott 2002). Even so, our model outputs provided insights into the relative outcomes of various harvest regulations. A 711-mm minimum length limit, which we used because it essentially is a "catch and release" length limit, had the least decline in the number of fish in the population. Alternatively, a 381-mm minimum length limit had the greatest decline in the number of fish in the population. Similar to the trend across minimum length limits, the harvest slot that targeted the largest sized fish had the least decline in the number of fish in the population and harvest slots that targeted the smallest size fish had the greatest decline. In contrast to the trends across minimum and harvest slot length limits, the protected slot that targeted the largest adults had the greatest decline in the number of fish in the population and the protected slot that targeted the smallest adults had the least decline in the number of fish in the population.

The modeling procedures we used included numerous assumptions and limitations. For this exercise, we started with populations at equilibrium without harvest and then implemented harvest with defined regulations. In reality, harvest regulations are implemented on fish populations that are already depressed by harvest, which means some inherent residuals for the harvest already in place that was unaccounted by our modeling procedure. For this exercise, we also assumed anglers were mobile and would move in response to number of harvestable-sized fish, similar to the modeling approach taken by Carpenter and Brock (2004). In reality, anglers are mobile but they respond to numerous factors other than abundance of harvestable-size fish such as travel costs

(Milon 1988) and associated amenities (Adamowicz et al. 1994; Haab et al. 2008). For this exercise, we assumed a constant natural mortality rate of 10% for all age groups. In reality, there is evidence that natural mortality rates vary with age and size (Hampton 2000) and sex (this study). For this exercise, we assumed 100% compliance with the simulated regulations. In reality, compliance is seldom 100% for any publicly managed fish population, and non-compliance with regulations can negate the intended effects of a harvest regulation (Pierce and Tomcko 1998). For this exercise, we held catch and release mortality rate constant at 5%. In reality, catch and release mortality rate varies with water temperature, season, size of fish, and species (Muoneke and Childress 1994; Bartholomew and Bohnsack 2005).

Contrary to our *a-priori* predictions, the models suggested none of the length limits examined would cause a significant change in the male to female ratio of a walleye population. We contribute this result to catch-and-release mortality. That is, as a greater proportion of one sex was harvested under a certain length limit, the sex ratio shifted towards the other sex, but as there became more of one sex in the population, that sex experienced greater catch rates and thus greater catch and release mortality, which brought the population back to essentially a 1:1 sex ratio. This counter pressure to return to a 1:1 sex ratio is directly related to catch and release mortality rate, which varies across populations and species. Concerns have been expressed that skewed sex ratios in fish populations could disrupt spawning behavior and reduce spawning success (Smith and Jamieson 1991; Wilderbuer and Turnock 2009). Given our conceptualization, these concerns for recreational and commercial fisheries may be overstated if catch and release mortality rates are excessive; alternatively these concerns may be understated if catch and

release is non-existent or if catch-and-release mortality is near zero. As such, there is great need to understand the spatial and temporal magnitude in catch-and-release mortality.

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Table 5-1.  Life history parameters for male and female walleye exploited by a recreational fishery.  Parameters are arranged according to biological and recreational angling processes.

| Symbol | | Value | Source |
|---|---|---|---|
| | | Biological processes | |
| Age-1+ model | | | |
| $a_{max}$ | Maximum age (yr) | 12 | This study |
| $t_1$ | Growth trajectory | -2.42466 | Quist et al. (2003) |
| $a_{mat}$ | Age at maturity (yr) | 5 (female) | This study |
| | | 3 (male) | |
| $g_a$ | Energy allocated to reproduction | 0.20 (female) | Shuter et al. (2005) |
| | | 0.25 (male) | |
| $\alpha_1$ | Relationship of length(mm) to weight (kg) | $9.5 \times 10^{-6}$ | Lester et al. (2000) |
| $h_{max}$ | Maximum annual juvenile growth increment (mm) | 200 | Baccante and Colby (1996) |
| $\beta_1$ | Density-dependent growth | 1.077 | Sass et al. (2004) |
| $\beta_2$ | Density-dependent growth | 0.161 | Sass et al. (2004) |
| Age-0 model | | | |
| $Z$ | Instantaneous daily mortality | 0.150 ($Z_{0_1}$) | Venturelli 2010 |
| | | 0.009 ($Z_{0_2}$) | |
| | | 0.009 ($Z_{0_3}$) | |
| | | 0.009 ($Z_{0_4}$) | |
| $\lambda$ | Density dependent parameter for early juvenile mortality | 0.0025 | This study |
| | | Angling processes | |
| $\eta$ | Vulnerability | 0.0185 | This study |
| $\theta$ | Vulnerability | 500 | This study |
| $u$ | Maximum angling effort | 75 | This study |
| $p$ | Proportion of angling effort always present | 0.2 | This study |
| $N_{v,1/2}$ | Numerical response of angling effort to fish availability | 10 | This study |
| $\xi$ | Numerical response of angling effort to fish availability | 5 | This study |
| $q$ | Catchability | 0.01 | Newby et al. (2000) |
| $U$ | Hooking mortality | 0.05 | This study |
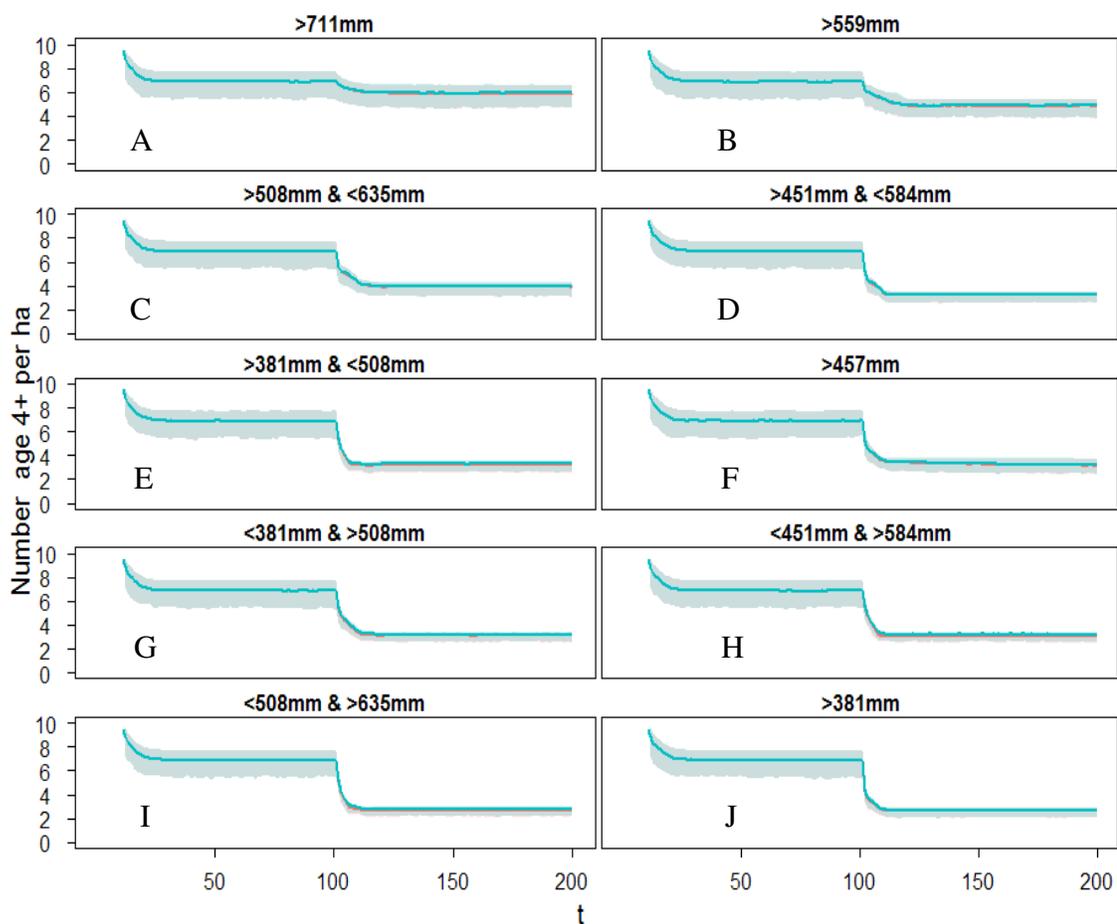
Figure 5-1. Mean density (number per ha) with 95% confidence intervals projected (1000 iterations of the model) for adult (age 4 and older) male (blue) and female (pink) walleye regulated with minimum (panels A, B, F and J), slot (panels C, D and E) and protected slot (panels G, H and I) length limits beginning in year 100.
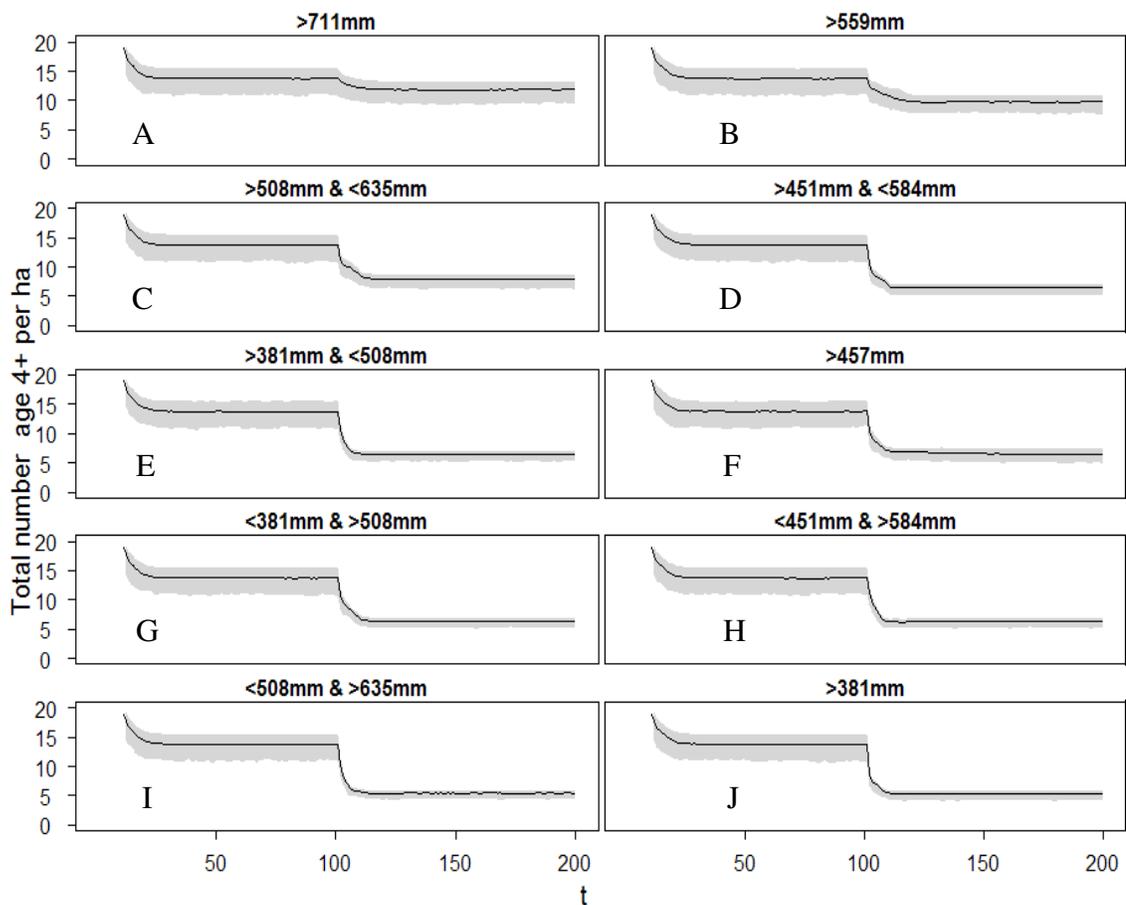
Figure 5-2. Mean density (number per ha) with 95% confidence intervals projected (1000 iterations of the model) for adult (age 4 and older) walleye regulated with minimum (panels A, B, F and J), slot (panels C, D and E) and protected slot (panels G, H and I) length limits beginning in year 100.
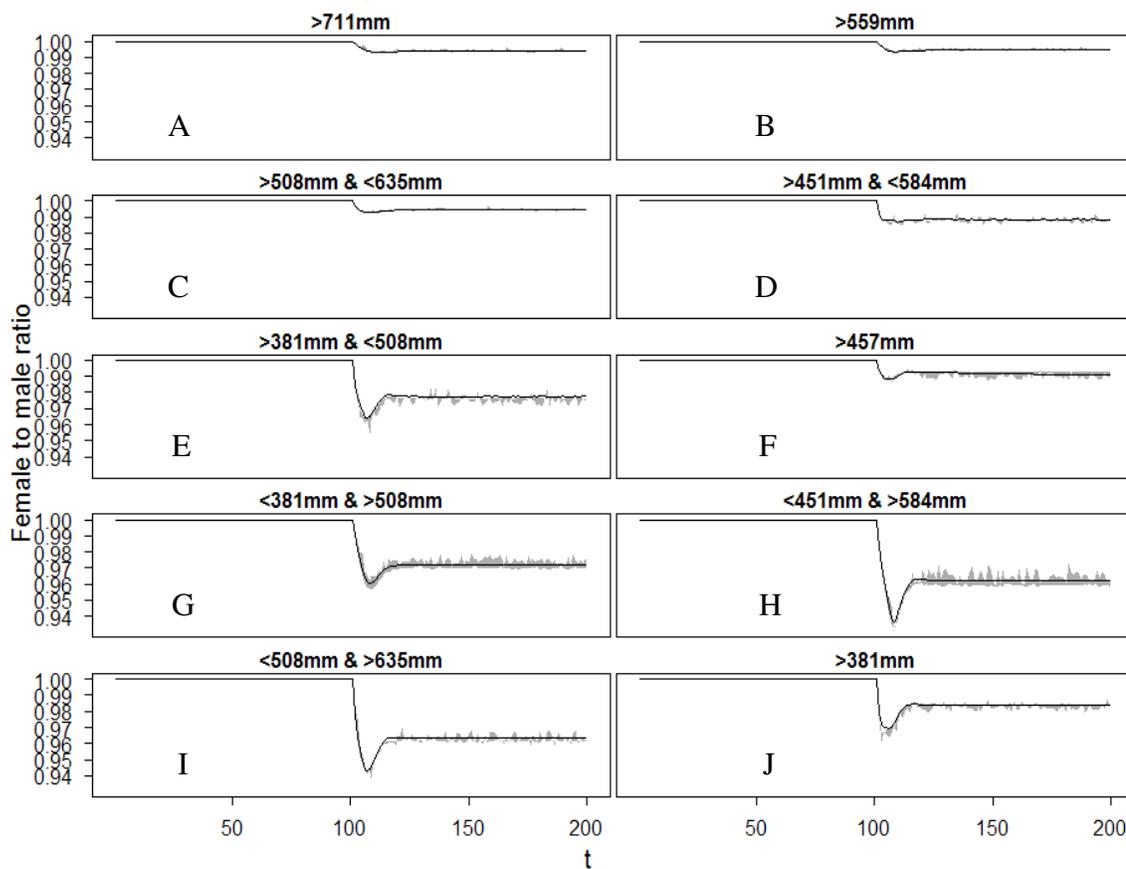
Figure 5-3. Ratio of female to male walleye with 95% confidence intervals projected (1000 iterations of the model) for walleye regulated with minimum (panels A, B, F and J), slot (panels C, D and E) and protected slot (panels G, H and I) length limits beginning in year 100.
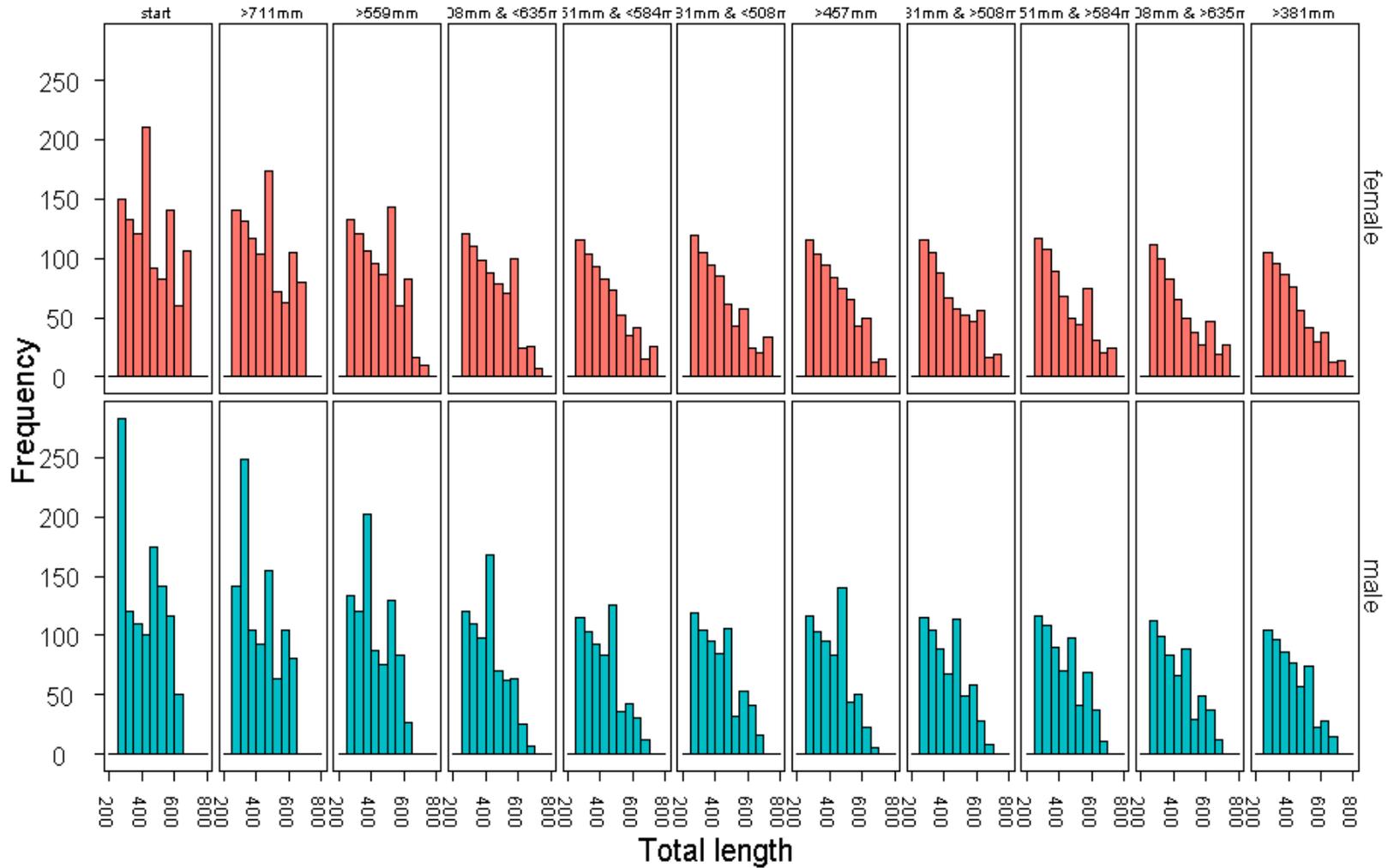
Figure 5-4. Mean length frequency for a hypothetical 100-ha waterbody for male and female walleye under various length limits (based on 1000 iterations of the model). The first panel represents the distribution prior to angling activity at t = 99 and the remaining panels are at t = 120.

## Chapter 6.  Management Implications and Future Research

White crappie, white bass, and walleye are popular sportfish in Nebraska.  All three are in the top five most sought after fish species in Nebraska.  Additionally, each consistently rank among the most harvested species in the state each year.  Thus, management of all three species is of great concern to biologists in Nebraska.

The Nebraska Game and Parks Commission (NGPC) spends valuable time and money each year managing fish populations present in public waters.  Length limits are a common tool used by NGPC for fishery management.  Although length limits are not sex specific, many managed sportfish (including white crappie, white bass, and walleye) exhibit sex-specific dynamics.  Therefore, understanding the effects that length limits have on sexually size dimorphic fishes is critical to achieve success with length limits.

*Observations From Sampling*

Though not an original objective of my study, I made two observations while sampling that are worthy of note.  First, the protocol of the Nebraska Game and Parks Commission standardized sampling calls for an 80% confidence on abundance estimates which generally results in 4 to 5 gillnet-nights per reservoir for white bass and walleye.  I believe that sampling effort is insufficient to quantify these fish populations because total catch is generally limited to less than 100 fish per species and furthermore is greatly influenced by variability in weather and fish behavior.  I recommend that the Nebraska Game and Parks Commission carefully evaluate the cost-benefit tradeoff of increasing sampling effort to include multiple visits in different weeks.  I recognize that something

must be given up to increase sampling effort with gillnets.  Second, the protocol of the

Nebraska Game and Parks Commission standardized sampling calls for the use of scales

to estimate age of fish.  I believe that scales are insufficient for accurate age estimation.

During this study, I had the opportunity to compare age estimates that were derived from

both scales and otoliths for some fish, and developed strong confidence in using otoliths

to estimate age and lost all previous confidence I had in using scales to estimate age.

During this study, we had greater than 99% agreement on otolith age estimates.  Otolith

readers disagreed on only 2 otoliths, which after we reviewed those 2 otoliths together,

we were able to agree on an age estimate for both fish.  Thus, no age estimates from

otoliths had to be discarded during this research project.  I recommend that the Nebraska

Game and Parks Commission adopt the use of otoliths in all instances for which age

estimates are required.  I recognize that this requires killing fish, which has the potential

for negative public reaction.  Even so, I believe the need for accurate data outweighs this

concern; in instances where it does not, no age data are better than inaccurate age data.


*Male and Female Differences*

An analysis of male versus female growth, size structure, age structure, and

condition was used to determine the extent of sexual dimorphism displayed by white bass

and walleye in Sherman Reservoir, Nebraska.  Sexual-size dimorphism exists in

populations of white bass and walleye in Sherman Reservoir.  Male and female white

bass had similar growth rates, although females were slightly longer.  Male walleye grew

slower and attained shorter maximum sizes than their female counterparts.  No

differences in size structure, age structure and condition between males and females were

observed for either white bass or walleye. No sex information is gathered under the current sampling protocol for Nebraska reservoirs. However, I believe that differences between males and females could affect information collected for standardized surveys such as age and growth. Therefore, I recommend that the Nebraska Game and Parks Commission alter their sampling protocol to include the collection of sex data for all species that are routinely monitored. Caution must be exercised when analyzing these data; adequate sample sizes must have been collected for sex-specific assessments.

*Observations From Harvested Fish*

Sampling of angler-harvested fish was completed at two reservoirs, Calamus and Sherman Reservoirs to determine if anglers harvested fish of a single sex in greater proportion than harvest of the other sex. Harvest of white crappie and white bass was female biased in 2009 and 2010. Conversely harvest of walleye was close to 1:1 for both years. The Nebraska Game and Parks Commission currently utilizes creel (angler) surveys to determine information about angler harvest. These surveys do not incorporate gathering of sex information from surveyed fish. My results suggest sex-biased harvest is occurring at reservoirs in Nebraska, therefore I recommend that the Nebraska Game and Parks Commission alter their sampling protocol to include collection of sex information when sampling angler-harvested fish.

*Selective Harvest*

Comparisons were completed between males caught during standardized surveys and males sampled from angler harvest to determine if size-, sex-, or age- selective

harvest was occurring for white bass and walleye populations in Sherman Reservoir.

Comparisons were also completed for females of each species. Female white bass

displayed sex-selective harvest by anglers. Harvest of walleye was size selective.

Additionally, harvest of walleye was age selective during one year but not the other.

Some research has been completed on the differences in energetic demand between the

sexes for percids (Schoenebeck and Brown 2012). I would recommend further research

investigating differences in energetic demand or behavior between male and female white

bass to gain a better understanding of why female white bass displayed sex-selective

harvest. I believe the finding of size- and age-selective harvest displayed by walleye is

closely related to the differences in angler success between 2009 and 2010. I would

recommend further research to determine how angler success influences the sex ratio of

harvested fish.


*Modeling of Different Length Limits*

Comparisons were completed between minimum-, harvest slot-, and protected

slot- length limits to determine potential population responses of a sexually size

dimorphic species to various regulations. Less restrictive regulations resulted in a greater

decrease in fish abundance than more restrictive regulations, though these differences

were minimal. More restrictive regulations resulted in a greater skew in sex ratios of fish

than did less restrictive regulations, though these differences were mitigated by catch-

and-release mortality. The Nebraska Game and Parks Commission has limited

information on catch-and-release mortality rates, especially for white crappie, white bass,

and walleye. Our results indicate that catch-and-release mortality is a counter pressure to

the sex-selective-harvest pressure, therefore I recommend that the Nebraska Game and Parks Commission initiate studies to quantify temporal and spatial catch-and-release mortality rates for primary sportfishes.

**Literature Cited**

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