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EXPLOITATION OF CHANNEL CATFISH IN NEBRASKA FLOOD-CONTROL RESERVOIRS

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EXPLOITATION OF CHANNEL CATFISH IN NEBRASKA FLOOD-CONTROL RESERVOIRS

By

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EXPLOITATION OF CHANNEL CATFISH IN NEBRASKA

FLOOD-CONTROL RESERVOIRS

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Channel catfish *Ictalurus punctatus* is a popular sportfish in North America, and is the third most-sought fish species in Nebraska. Exploitation rates of channel catfish populations have been estimated to be substantial in states neighboring Nebraska. Despite the popularity of channel catfish, little is known about the exploitation of channel catfish populations in Nebraska. The objectives of this study were to estimate the exploitation rates of channel catfish populations, identify the length bias of angling for channel catfish, and identify the self-imposed length limits for channel catfish at flood-control reservoirs of Nebraska. The software package Program Mark was used to analyze mark-recapture data for channel catfish captured with tandem-set hoop nets to estimate channel catfish population sizes at ten reservoirs during 2011-2012. Angler catch and harvest of channel catfish was estimated at eight reservoirs during 2011-2012 using data collected from angler interviews. Exploitation rates were estimated by dividing the number of channel catfish harvested by the number of channel catfish available in the population. Estimates of exploitation rate ranged from 0% at three reservoirs to 73% at one reservoir. Given the imprecision associated with the estimates of channel catfish population size and angler harvest of channel catfish, we suggest the investigation of

other approaches to estimate exploitation rates of channel catfish populations in the future. Recreational angling was length biased, with angling selecting intermediate lengths of channel catfish regardless of harvest regulations or sizes of channel catfish available in the population. I determined self-imposed length limits for channel catfish by modeling probability of harvest of captured channel catfish based on length using a generalized linear mixed model. I determined that an interaction between whether an angler was angling from a boat or the bank and angling during the night or during the day was the most appropriate model for explaining self-imposed length limits for channel catfish. Self-imposed length limits for channel catfish ranged from 63 cm total length for anglers angling during the day from the bank to 90 cm total length for anglers angling during the night from a boat.

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Chapter 1. Introduction

Recreational angling in the U.S.A. is an activity that contributes substantially to the economy, with 30 million anglers spending $42 billion dollars on fishing-related expenses during 2006 (USFWS 2007). Recreational anglers are an important stakeholder in the management of North America's natural resources (McMullin and Pert 2010), providing the majority of funds for the management of fish populations through the purchase of licenses and taxes paid on the purchase of angling gear (Moffitt et al. 2010). Ictaluridae represent an important target species for anglers in the U.S.A., with seven million anglers targeting Ictaluridae during 98 million fishing days during 2006 (USFWS 2007). Channel catfish *Ictalurus punctatus* is a fish species native to North America and popular with recreational anglers throughout the U.S.A. (Michaletz and Dillard 1999; USFWS 2007). Channel catfish are popular with recreational anglers in Nebraska (Hurley and Duppong Hurley 2002), and received the third greatest amount of angler effort in water bodies included in the Nebraska statewide creel surveys statewide during 2011. The contribution of expenses made during the pursuit of channel catfish and popularity of channel catfish make the management of channel catfish a priority in the U.S.A. and Nebraska.

Providing opportunities for angling of channel catfish has value because of the popularity of channel catfish with anglers. Natural recruitment of channel catfish is often limited or nonexistent in small reservoirs (Marzolf 1957) because predatory fish (e.g., largemouth bass *Micropterus salmoides*) limit recruitment (Mestl and Maughan 1993). However, the stocking of large juvenile (200-250 mm) channel catfish has been identified as a method to maintain populations of channel catfish in small reservoirs with relatively

high densities of predator fish (e.g., largemouth bass) (Jackson and Francis 1999). Thus, the stocking of large juvenile channel catfish into small reservoirs has become a common practice throughout the U.S.A. and Nebraska (Michaletz and Dillard 1999; Chizinski 2012). Given limitations on the natural recruitment of channel catfish in these small reservoirs, the stocking of juvenile channel catfish is continued at regular intervals to maintain populations. The cost of stocking juvenile channel catfish ($3.00/kg of juvenile channel catfish [Brader 2008]) places a substantial amount of financial burden on management agencies.

Stock enhancement using hatchery-produced fish can be used with the goal of stocking for mitigation, enhancement, restoration, or the creation of new fisheries (Cowx 1994). The stocking of large juvenile channel catfish could be viewed as the creation of a new fishery. Without the regular addition of these hatchery-raised large juvenile channel catfish, populations of channel catfish would not exist in small reservoirs. Channel catfish are stocked as large juveniles as a strategy identified as put-grow-take (Eder and McDannold 1987). This strategy is similar to the strategy used to provide trout fisheries in reservoir and tailrace habitats where they would otherwise be nonexistent due to the lack of natural recruitment (Dillon and Jarcik 1994; Magnelia 2004).

Given the need to evaluate the success of any stock enhancement project (Cowx 1994; Molony et al. 2003), substantial research has been conducted to determine population dynamics and the success of stockings of large juvenile channel catfish throughout the U.S.A. and in Nebraska (Irwin et al. 1999; Michaletz and Travnichek 2011; Chizinski 2012). Previous research on channel catfish populations in Nebraska has identified exploitation of channel catfish populations as a potential source of the

irregularities in population dynamics observed across lentic ecosystems (Chizinski 2012). Further, variation in exploitation rates across water bodies has been identified as a complicating factor regarding the interpretation of stocking evaluations (Michaletz and Travnichek 2011; Chizinski 2012).

Exploitation is the removal of individuals from a population as a result of being harvested by resource users. Exploitation rate is the percent of a population harvested during a given period (Ricker 1975). Exploitation can reduce fish population abundance and alter fish population size and age structures (Coble 1988; Murawski and Idoine 1992). Estimates of exploitation rates of channel catfish populations maintained by stocking large juvenile channel catfish are valuable because the relative success of the put-grow-take stocking strategy for maintaining channel catfish is often assessed based on the number or weight of fish harvested following stocking (Eder and McDannold 1987; Shaner et al. 1996). Stocking rates can then be adjusted based on whether exploitation is relatively low or high (Michaletz et al. 2008).

Anglers are inherently size-selective for fish and use terminal tackle that excludes undesired sizes of fish (Orsi 1987; Wilde et al. 2003). If exploitation is not selective for channel catfish at the size they are stocked (large juvenile channel catfish ~ 23 cm; Jackson and Francis 1999), then it would take time for channel catfish to grow to sizes at which they are more likely to be exploited. Exploitation of crappie (*Pomoxis spp*.) and flathead catfish (Pylodictus olivaris) is size-selective for intermediate length individuals of both species (Miranda and Dorr 2000; Travnichek 2011). Thus, exploitation may be size selective for intermediate-size channel catfish. However, the length bias of recreational angling is unknown.

Once a fish is caught and available for harvest, an immediate decision (assuming this angler is abiding by regulations forbidding "high-grading") must be made whether to harvest the fish or to release the fish back into the water. Anglers elect to harvest select species and sizes of captured fish for practical, economic, and regulatory reasons, and the decision of an angler to harvest a captured fish is likely influenced by previous and current angling catch rates, previous and current angling effort, current motivating factors for participating in recreational angling, and current social normative pressures (Hunt et al. 2002; Beardmore et al. 2011). The sum of harvest decisions by anglers can create a self-imposed length limit in the absence of an official minimum length limit (Chizinski et al. in press). This self-imposed length limit coupled with size-selectivity of recreational angling could make some individuals in a channel catfish population more vulnerable to harvest, thus making exploitation of channel catfish size selective.

Little is known about the exploitation of channel catfish populations in Nebraska (Chizinski 2012). Exploitation rates of channel catfish populations varied across waterbodies in neighboring states (Mitzner et al. 1989; Santucci et al. 1994; Michaletz et al. 2008). Thus, exploitation should be assessed in the flood-control reservoirs of Nebraska to supplement previous the assessments of stocking strategies and management practices for channel catfish (Chizinksi 2012).

Goal

The goal of my research is to describe exploitation of channel catfish in Nebraska flood-control reservoirs.

Objectives

1) Estimate exploitation rates of channel catfish populations at eight Nebraska flood-control reservoirs.
2) Determine if recreational angling was length biased for channel catfish at two Nebraska flood-control reservoirs.
3) Describe angler size-selective harvest by defining the self-imposed length limit for channel catfish at seven Nebraska flood-control reservoirs.

Study Site and Reservoirs

Salt Creek Watershed

The thirteen reservoirs selected for various portions of this thesis were all flood-control reservoirs located in the Salt Creek watershed of Nebraska. The Salt Creek watershed is located in southeastern Nebraska. Salt Creek flows in a general southwest to northeast direction and empties into the Platte River near Ashland, Nebraska. Portions of this watershed are urban (e.g., Lincoln, Nebraska), whereas other portions are rural. The rural areas are primarily used for row-crop agriculture and pastureland.

Branched Oak Lake

Branched Oak Lake is located in Lancaster County, Nebraska and is managed by the Nebraska Game and Parks Commission (NGPC). The reservoir covers 728 ha at conservation pool. Branched Oak Lake supports populations of bluegill *Lepomis macrochirus*, blue catfish *Ictalurus furcatus*, channel catfish, common carp *Cyprinus carpio*, black crappie *Pomoxis nigromaculatus*, flathead catfish *Pylodictus olivaris*, hybrid striped bass *Morone chrysops x saxatilis*, largemouth bass, walleye *Sander vitreus*,

white crappie *Pomoxis annularis,* and white perch *Morone americana*. The harvest of channel catfish is regulated with a 5-fish daily bag limit at Branched Oak Lake.

Conestoga Lake

Conestoga Lake is located in Lancaster County, Nebraska and is managed by the NGPC. The reservoir covers 93 ha at conservation pool. Conestoga Lake supports populations of black crappie, bluegill, channel catfish, common carp, flathead catfish, freshwater drum *Aplodinotus grunniens*, hybrid striped bass, largemouth bass, walleye, and white crappie. The harvest of channel catfish is regulated with a 5-fish daily bag limit at Conestoga Lake.

East Twin Lake

East Twin Lake is located in Seward County, Nebraska and is managed by the NGPC. The reservoir covers 109 ha at conservation pool. East Twin Lake supports populations of black crappie, bluegill, black bullhead *Ameiurus melas*, channel catfish, common carp, largemouth bass, walleye, white bass *Morone chrysops*, white crappie, and yellow bullhead *Ameiurus natalis*. The harvest of channel catfish is regulated with a 5-fish daily bag limit at East Twin Lake.

Holmes Lake

Holmes Lake is located in Lancaster County, Nebraska and is managed by the city of Lincoln. The reservoir covers 40 ha at conservation pool. Holmes Lake supports a fish community of bluegill, channel catfish, largemouth bass, and walleye. Holmes Lake is also stocked with rainbow trout *Oncorhynchus mykiss* every winter. The harvest of channel catfish is regulated with a 5-fish daily bag limit at Holmes Lake.

Meadowlark Lake

Meadowlark Lake is located in Seward County, Nebraska and is managed by the Lower Platte South Natural Resources District (LPSNRD). The reservoir covers 22 ha at conservation pool. Meadowlark supports a fish community of black crappie, bluegill, channel catfish, largemouth bass, and white crappie. The harvest of channel catfish is regulated with a 5-fish daily bag limit at Meadowlark Lake.

Merganser Lake

Merganser Lake is located in Lancaster County, Nebraska and is managed by the LPSNRD. The reservoir covers 16 ha at conservation pool. Merganser Lake supports a fish community of bluegill, channel catfish, and largemouth bass. The harvest of channel catfish is regulated with a 5-fish daily bag limit at Merganser Lake.

Olive Creek Lake

Olive Creek Lake is located in Lancaster County, Nebraska and is managed by the NGPC. The reservoir covers 70 ha at conservation pool. Olive Creek Lake supports a fish community of bluegill, channel catfish, and largemouth bass. The harvest of channel catfish is regulated with a 5-fish daily bag limit at Olive Creek Lake.

Pawnee Lake

Pawnee Lake is located in Lancaster County, Nebraska and is managed by the NGPC. The reservoir covers 300 ha at conservation pool. Pawnee Lake supports a fish community of black crappie, bluegill, channel catfish, common carp,, flathead catfish, freshwater drum, largemouth bass, sauger *Sander canadensis*, walleye, white bass, white

crappie, and white perch. The harvest of channel catfish is regulated with a 5-fish daily bag limit at Pawnee Lake.

Stagecoach Lake

Stagecoach Lake is located in Lancaster County, Nebraska and is managed by the NGPC. The reservoir covers 78 ha at conservation pool. Stagecoach Lake supports a fish community of black crappie, bluegill, channel catfish, common carp, hybrid striped bass, largemouth bass, walleye, and white crappie. The harvest of channel catfish is regulated with a 5-fish daily bag limit at Stagecoach Lake.

Wagon Train Lake

Wagon Train Lake is located in Lancaster County, Nebraska and is managed by the NGPC. The reservoir covers 127 ha at conservation pool. Wagon Train Lake supports a fish community of bluegill, channel catfish, hybrid striped bass, muskellunge *Esox masquinongy*, redear sunfish *Lepomis microlophus*, and walleye. The harvest of channel catfish is regulated with a 5-fish daily bag limit at Wagon Train Lake.

Wild Plum Lake

Wild Plum Lake is located in Lancaster County, Nebraska and is managed by the LPSNRD. The reservoir covers 6 ha at conservation pool. Wild Plum supports a fish community of bluegill, channel catfish, and largemouth bass. The harvest of channel catfish is regulated with a 5-fish daily bag limit at Wild Plum Lake.

Wildwood Lake

Wildwood Lake is located in Lancaster County, Nebraska and is managed by the LPSNRD. The reservoir covers 41 ha at conservation pool. Wildwood Lake supports a

fish community of black crappie, bluegill, channel catfish, largemouth bass, walleye, and white crappie. The harvest of channel catfish is regulated with a catch-and-release regulation at Wildwood Lake.

Yankee Hill Lake

Yankee Hill Lake is located in Lancaster County, Nebraska and is managed by the NGPC. The reservoir covers 84 ha at conservation pool. Yankee Hill Lake supports a fish community of bluegill, channel catfish, largemouth bass, and walleye. The harvest of channel catfish is regulated with a 5-fish daily bag limit at Yankee Hill Lake.

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Chapter 2. Exploitation Rates of Channel Catfish Populations at Eight Nebraska Flood-Control Reservoirs

Introduction

Channel catfish *Ictalurus punctatus* is a popular sportfish in the U.S.A. Ictalurids ranked as the third-most sought sportfish group in the U.S.A. during a 2006 survey (USFWS 2007). A 2002 return-mail survey indicated that channel catfish was the third most preferred fish species by anglers who purchased a Nebraska fishing license (Hurley and Duppong Hurley 2002). Channel catfish received the third greatest amount of angler effort in water bodies included in the Nebraska statewide creel surveys statewide during 2011.

Management agencies stock channel catfish for anglers because channel catfish recruitment is often limited or nonexistent in small reservoirs (Marzolf 1957). However, the success of supplemental stockings of channel catfish fry and small fingerlings is negatively correlated with predator densities (Mestl and Maughan 1993). Thus, the stocking juvenile (> 200 mm) channel catfish is necessary to maintain catchable populations of channel catfish in small reservoirs with relatively high densities of predators (Jackson and Francis 1999).

The popularity of channel catfish and cost of stocking ($3.00/kg of juvenile channel catfish [Brader 2008]) have motivated management agencies to monitor channel catfish population dynamics (Richters and Pope 2011). Channel catfish population dynamics are monitored using multi-panel monofilament gill nets in Nebraska lentic systems; however, inefficiency of gill nets for capturing channel catfish often results in

sample sizes insufficient for estimating channel catfish population dynamics (Richters and Pope 2011). Without estimates of channel catfish population dynamics and angler harvest, it is difficult to determine the success of channel catfish stocking practices in Nebraska's flood control reservoirs (Richters 2012).

Angler harvest estimates of channel catfish are available for selected reservoirs each year in Nebraska from creel surveys. However, results from creel surveys provide little insight into the exploitation rates of channel catfish populations without estimates of population size. Exploitation rates of channel catfish may be high in Nebraska reservoirs because anglers who prefer channel catfish are more harvest-oriented than anglers seeking other species (Hurley and Duppong Hurley 2002). Further, although exploitation rates of channel catfish have been estimated to be high in some reservoirs in the Midwest (Mitzner 1989; Michaletz et al. 2008), rates have not been estimated for channel catfish in Nebraska reservoirs.

Historically, biologists have estimated angler exploitation rates using the tag-return method (e.g., Larson et al. 1991; Schultz and Robinson 2002; Travnichek 2011) outlined by Ricker (1975). This method requires a known number of fish to be marked and released into a water body, after which the number of marked fish harvested by anglers is estimated either by a creel survey or reported by anglers seeking to collect rewards associated with the tags (Ricker 1975). Exploitation rate is estimated as the percentage of returned tags (Miranda et al. 2002). The assumptions made by the tag-return method for estimating exploitation rate are: 1) no loss of tags; 2) no tagging mortality; 3) the ratio of tagged and untagged fish remains unchanged from immigration and emigration; 4) no recruitment; 5) no differential natural mortality between marked

and unmarked fish; 6) full reporting compliance; and 7) equal vulnerability to angling between marked and unmarked fish (Ricker 1975). Many studies using the tag-return method have employed strategies to estimate and correct violations of these assumptions (Miranda et al. 2002). However, uncertainty associated with these correction strategies, the number of potential sources of uncertainty, and the effort and cost associated with estimating the exploitation rate using tag-return studies led Miranda et al. (2002) to encourage the use of other methods for estimating the exploitation rates of fish populations.

One alternative to the tag-return method is to directly estimate the exploitation rate of a fish population (Miranda et al. 2002). Directly estimating an exploitation rate relies on two components: a population census or survey that estimates the number of fish at the beginning of a season, and an angler census or survey that estimates the number of fish harvested from that population by anglers. This method has been suggested for small water bodies with relatively small fish populations and low angler harvest (Miranda et al. 2002). Historically, fish population size has been estimated using the Petersen or Schnabel estimators with various statistical correction techniques (Serns 1982; Edwards et al. 1997; Pyron et al. 2001). The Petersen estimator requires two samples to be taken: the first sample to capture and mark a known number of individuals, and the second sample to capture and record the capture history (whether an individual has been captured or not) of a known number of individuals. The Schnabel estimator modifies the Petersen estimator for use in a multiple-mark, multiple-recapture approach. The assumptions made by the Petersen and Schnabel estimators are: 1) marked individuals do not lose their marks prior to the last recapture period; 2) marked

individuals are not overlooked in the recapture sample(s); 3) marked and unmarked individuals are equally likely to be captured in each sample; 4) marked and unmarked individuals have equal mortality rates during the interval between marking and recapture samples; and 5) there are no additions to the population during the sample interval (Van Den Avyle and Hayward 1999).

The assumption of equal vulnerability of marked and unmarked individuals to capture by sampling gear is likely invalid (Seber 1970; Pollack et al. 1990; Pradel 1993). Violation of this assumption could cause extreme bias if trap-happy (the event of capture makes an individual more likely to be captured in future samples) or trap-shy (the event of capture makes an individual less likely to be captured in future samples) individuals are present in the population (Pollack et al. 1990). Trapping-bias from the presence of trap-happy or trap-shy individuals is most likely when baited traps are used to sample the population (Pradel 1993). Given observations of trap-bias, models used to estimate population size from data collected using baited traps should not assume equal vulnerability of marked and unmarked individuals.

A baited sampling gear (tandem-set hoop nets) has been recommended for use sampling channel catfish in reservoirs in several states (e.g., Michaletz and Sullivan 2002; Flammang and Schultz 2007; Chizinski 2012). If captured of channel catfish by tandem-set hoop nets influences the probability of these channel catfish being captured in the future (i.e., trap bias), it may influence the results of studies monitoring the relative abundance of channel catfish with tandem-set hoop nets. For example, if channel catfish become trap-shy following capture by tandem-set hoop nets and a population is sampled multiple times, either within a year or across years, catch rates of channel catfish may

decrease even if channel catfish population density does not, thus indices of catch-per-unit-effort will not reflect changes in channel catfish population abundance. Further, if trap-bias is observed for channel catfish caught by tandem-set hoop nets, it would suggest the need to use population estimation approaches that can account for trap bias.

Exploitation rates of channel catfish populations have been estimated directly in Iowa (Mitzner 1989). Estimates of population size and angler harvest are accompanied with accepted methods for obtaining variance about the mean (Ricker 1975; Otis et al. 1978; Malvestuto 1996). However, no method for estimating variance about direct estimates of exploitation rates has been utilized. Estimates of exploitation rates cannot be compared for differences without measures of variance about the means. The delta method has been suggested as a method for approximating variance when combining two parameter estimates to calculate another parameter (Powell 2007). The delta method combines the existing parameter estimates and associated variances to estimate the variance about the third parameter being estimated by combining the two existing parameter estimates. Thus, the delta method may be appropriate for estimating variance about exploitation rates, a parameter that is estimated by combining estimates of the parameters population size and number of channel catfish harvested.

The objective of my study was to estimate exploitation rates of channel catfish from eight reservoirs in the Salt Creek watershed of Nebraska. We directly estimated exploitation rate for each channel catfish population during a three-month period by estimating the channel catfish population size at the beginning of a three-month period and the number of channel catfish harvested by anglers during that three-month period.

Results from this study will assist managers in future decision-making processes regarding the management of channel catfish populations in the Salt Creek watershed.

Methods

Population Estimate - Sampling Schedule

Channel catfish population sizes were estimated for eight small (< 130 ha) flood-control reservoirs of the Salt Creek watershed during 2011 or 2012 (Table 2-1). We grouped the reservoirs in two pairs during each year. We sampled each reservoir pairing every other week for ten weeks, with five capture occasions for each reservoir during June-August. We deviated from this format for Merganser Lake and Wild Plum Lake during 2011; we sampled this reservoir pairing for eight weeks, with four capture occasions for each reservoir.

Population Estimate - Gear

We used baited, tandem-set hoop nets (hereafter referred to as hoop nets) to capture channel catfish for the mark-recapture population estimates. Hoop-net surveys were conducted in accordance with methodology established for small impoundments in Missouri and Iowa (Michaletz and Sullivan 2002; Flammang and Schultz 2007). Hoop nets consisted of three nets, attached bridle to cod end, an anchor, and two weights. A 6.8-kg winged anchor was attached to the rear net, and a 4.5-kg concrete weight was attached between the front and middle nets to reduce buoyancy. An additional 4.5-kg weight was attached to the bridle of the front net to prevent the series from collapsing. Nets were baited with soybean cake pellets as a fish attractant (Flammang and Schultz 2007). Hoop nets measured approximately 3.4 m in length and were constructed of #15

twine with 25.4-mm bar mesh and seven fiberglass hoops, the largest of which was 0.8 m in diameter and equipped with a bridle of 1-m rope. Two-fingered crow-foot throats were attached to the second and fourth hoops. To reduce escapement from the cod end, the rear throat was constricted with plastic zip ties (Porath et al. 2011).

Hoop nets were set parallel to the shoreline above the thermocline and at a depth of 1-6 m. Using bathymetric maps developed from the Nebraska Game and Parks Commission Lake Mapping Program, sampling sites were randomly selected for each sampling event from points marked at 20-m intervals along the perimeter of the water body. Randomly selected sites with steep slopes, heavy vegetation, or substantial development (i.e., docks or swimming beaches) were substituted with other randomly selected sites. Hoop nets were fished undisturbed for approximately 72 h. Previous batch marks were recorded and total length (cm) were measured for each channel catfish following capture.

Population Estimate - Batch Marks

Captured channel catfish were marked with capture period-specific batch marks. We used a combination of fin clips and hot brands as batch marks. Channel catfish captured during the first sampling period were marked by clipping the left pelvic fin. Channel catfish captured during the second sampling period were marked by clipping the right pelvic fin. Channel catfish captured during the third sampling period were marked by a hot brand on the left side of the fish or by clipping from the upped caudal fin. Hot brands were used only for the first 47 channel catfish marked at Holmes Lake during the third sampling event, then abandoned due to concern about the time taken to process samples using hot brands. Channel catfish captured during the fourth sampling period

were marked by clipping from the lower caudal fin. Channel catfish captured during the fifth sampling period were marked by clipping from the anal fin.

Population Estimate - Data Analysis

We removed the capture histories of channel catfish < 28 cm TL from our dataset before estimating population size because research suggests that hoop nets catch channel catfish ≥ 28 cm equal to their availability in the population (Michaletz and Sullivan 2002; Buckmeier and Schlechte 2009). Thus our estimate of population size is for stock-length channel catfish (channel catfish ≥ 28 cm; Anderson 1980).

We used the closed captures design (Otis et al. 1978) in Program MARK (White and Burnham 1999) to estimate channel catfish population size, capture probability (the probability a previously unmarked individual is captured), and recapture probability (the probability a previously marked individual is captured) in the eight reservoirs included in this study. The assumptions of the closed capture design in Program Mark are 1) no loss of marks; 2) no fish leave or enter the study area during the study period; 3) all marks are correctly identified when a fish is captured. Two candidate models were constructed *a priori*. Both models were constructed to account for variability in capture probability across capture periods. We allowed capture probability (p) and recapture probability (c) and to be calculated independently for each capture period (Table 2-2; Table 2-3). Therefore, an estimate of capture probability and recapture probability was made for each capture period. One model assumed that capture probability and recapture probability were equivalent. The second model assumed that capture probability and recapture probability were independent. The strength of this approach was the ability to compare a

model that accounted for trap bias and a model that did not account for trap bias, while accounting for temporal variation in capture and recapture probabilities.

However, this model failed to reach converge on a value of population size for all eight populations included in this analysis. The failure of this model to converge on a value of population size was likely due to relatively small sample sizes of channel catfish captured during the final capture periods (Appendix C.1.). In response to this model failing to converge on a value of population size, we constructed a *post hoc* set of candidate models to account for the small sample sizes of channel catfish captured during certain capture periods (Table 2-2; Table 2-3). We pooled data across capture periods in a step-wise manner, estimating a single capture probability and recapture probability for the pooled capture periods (Table 2-2; Table 2-3).

We used Akaike's information criterion (AIC) to compare candidate models (Burnham and Anderson 2002). I report AIC scores with a second-order correction for small sample size (AIC_c). We removed candidate models that did not converge on parameter values, or that produced erroneous confidence intervals around estimates of population size, capture probability, and recapture probability.

We used full model averaging (Lukacs et al. 2009) to estimate values of population size, capture probability, and recapture probability. Model-averaged parameter estimates are derived as a weighted average where the individual parameter estimates from a candidate model are weighted based on the corresponding Akaike weight for that model (Symonds and Moussalli 2011). The Akaike weight is a value between zero and one, with the sum of Akaike weights of all models in the candidate set being one (Symonds and Moussalli 2011). The Akaike weight can be interpreted as the

probability that a given model is the best approximating model from a set of candidate models (Symonds and Moussalli 2011).

Harvest Estimate - Sampling Frame

Angler harvest was estimated using access point interviews and roving pressure counts. The sampling frame consisted of monthly periods from June to August 2011 and June to August 2012. The sampling frame included three eight-hour shifts (00:00-08:00 [early], 08:00-16:00 [mid], and 16:00-24:00 [late]) per date.

Harvest Estimate - Sample Selection

Creel survey days and times were chosen following a stratified multi-stage probability sampling regime (Malvestuto 1996). Merganser Lake and Wild Plum Lake, during 2011, and Meadowlark Lake and Wildwood Lake, during 2012, were assigned 12 samples each month.

Holmes Lake and Yankee Hill Lake, during 2011, and Olive Creek Lake and Wagon Train Lake, during 2012, were assigned 24 samples each month. All monthly samples were split equally into six categories (weekday-early, weekday-mid, weekday-late, weekend-early, weekend-mid, and weekend-late). Weekday sample days were selected from all non-holiday Monday-Friday days within each month, and weekend sample days were selected from all Saturday-Sunday days and all U.S.A. federal holidays within each month. All available sampling periods within each month were assigned a random date from within the available sampling frame.

Each creel technician was assigned to two samples from each sampling category listed above (e.g., weekend-early) for a total of twelve samples per month. Two creel technicians were assigned to 2 reservoirs and randomly assigned creel periods on those

reservoirs. One creel technician was assigned the additional twelve sampling periods per month conducted at the two pairings of reservoirs (Holmes Lake and Yankee Hill Lake during 2011, and Olive Creek Lake and Wagon Train Lake during 2012) that received double sampling effort.

Two pressure-count times per water body were randomly chosen within the sampling period. Creel technicians moved between reservoirs within each pair to attain pressure counts at the randomly assigned times. Angler interviews were conducted when creel technicians were not conducting pressure counts.

Harvest Estimate – On-site Creel Survey

On-site creel surveys consisted of a roving count to estimate effort and access-point interviews to estimate harvest. Roving counts were conducted from vehicles and high points to estimate angling effort. Creel technicians intercepted anglers at access points and conducted interviews to gather information about trip duration and harvest. All interviews were conducted following completed fishing trips. All harvested fish were identified to species, weighed, and measured by the creel technician at the end of the interview.

Harvest Estimate - Data Analysis

Monthly estimates of harvest of channel catfish and associated variance were calculated as described by Malvestuto et al. (1978). The basic process of the extrapolations is as follows. First, fishing pressure for each survey day was calculated by multiplying the angler count by the number of hours in the survey period adjusted by the probability (0.33 for this study) of the daily period. The mean daily pressure for each stratum (weekday and weekend/holiday) was then calculated for the month and these two

mean values were weighted by the proportion of the day types per month and summed. This daily pressure estimate was then multiplied by the number of days per month to calculate monthly pressure. Then the daily harvest per unit effort (HPUE) for each survey day was calculated by dividing total harvest for surveyed anglers that day by the total recorded trip lengths of surveyed anglers that day. Sub-stock-length channel catfish were removed from this analysis to remain consistent with our channel catfish population estimates. The harvest for that day was then calculated by multiplying the daily HPUE by daily effort (effort of time period extrapolated out to the day). The mean daily catch for each stratum (weekday and weekend/holiday) was then calculated for the month, and these two mean values were weighted by the proportion of the day types per month and summed, and this daily harvest estimate was then multiplied by the number of days per month to obtain an estimate of monthly catch. Monthly estimates were derived for boat, bank, and all (boat + bank) anglers, and differentiated among species caught. We added the monthly estimates and corresponding standard errors from June, July, and August for each reservoir to calculate summer harvest of channel catfish.

Exploitation Rate Estimate

We defined the exploitation rate as the percent of a channel catfish population harvested by anglers from June 1 to August 31. Exploitation rate was calculated by dividing the number of channel catfish harvested by anglers (harvest estimate) by the number of channel catfish available in the population (population estimate). We calculated the standard error and corresponding 95% confidence intervals of exploitation rate using the delta method (Seber 1982). When the lower bound of the 95% confidence interval of exploitation rate was less than 0%, we truncated to 0%. Similarly, when the

upper bound of the 95% confidence interval of exploitation rate was greater than 100%, we truncated to 100%. We truncated the 95% confidence interval to these values because values of exploitation rate outside that range are impossible.

Results

Holmes Lake

During 2011, 1,385 channel catfish were captured in hoop nets deployed at Holmes Lake during five separate capture periods. We encountered 254 previously batch marked channel catfish during the final four capture periods. Total lengths of captured channel catfish ranged from 28 to 77 cm. Model averaging was used to estimate population size (N), capture probabilities (p), and recapture probabilities (c) of the channel catfish population (Table 2-4; Table 2-5).

The model-averaged estimate (95% confidence interval) of channel catfish population size was 1,470 (1,446 - 1,503) (Table 2-6). The estimate (95% confidence interval) of the number of channel catfish harvested by anglers was 690 (231 - 1,149) (Table 2-6). Given these estimates of angler harvest of channel catfish and channel catfish population size, the exploitation rate (95% confidence interval) of channel catfish was estimated to be 47% (16 - 78%) (Table 2-7).

Merganser Lake

During 2011, 46 channel catfish were captured in hoop nets deployed at Merganser Lake during four separate capture periods. We encountered 10 previously batch marked channel catfish during the final three capture periods. Total lengths of captured channel catfish ranged from 48 to 62 cm. Model averaging was used to estimate

population size (N), capture probabilities (p), and recapture probabilities (c) of the channel catfish population (Table 2-8; Table 2-5).

The model-averaged estimate of channel catfish population size was 91 (75 - 112) (Table 2-6). The estimate of the number channel catfish harvested by anglers was 32 (9 - 63) (Table 2-6). Given these estimates of angler harvest of channel catfish and channel catfish population size, the exploitation rate of channel catfish was estimated to be 35% (0 - 73%) (Table 2-7).

Wild Plum Lake

During 2011, 4 channel catfish were captured in hoop nets deployed at Wild Plum Lake during four separate capture periods. We encountered 1 previously batch marked channel catfish during the final three capture periods. Total lengths of captured channel catfish ranged from 62 to 77 cm. Model averaging was used to estimate population size (N), capture probabilities (p), and recapture probabilities (c) of the channel catfish population (Table 2-9; Table 2-5).

The model-averaged estimate of channel catfish population size was 5 (4 - 22) (Table 2-6). The estimate of the number channel catfish harvested by anglers was 0 (0 - 0) (Table 2-6). Given these estimates of angler harvest of channel catfish and channel catfish population size, the exploitation rate of channel catfish was estimated to be 0% (0 - 0%) (Table 2-7).

Yankee Hill Lake

During 2011, 839 channel catfish were captured in hoop nets deployed at Yankee Hill Lake during five separate capture periods. We encountered 86 previously batch marked channel catfish during the final four capture periods. Total lengths of captured

channel catfish ranged from 28 to 62 cm. Model averaging was used to estimate population size (N), capture probabilities (p), and recapture probabilities (c) of the channel catfish population (Table 2-10; Table 2-5).

The model-averaged estimate of channel catfish population size was 1,593 (1,126 - 2,822) (Table 2-6). The estimate of the number channel catfish harvested by anglers was 0 (0 - 0) (Table 2-6). Given these estimates of angler harvest of channel catfish and channel catfish population size, the exploitation rate of channel catfish was estimated to be 0% (0 - 0%) (Table 2-7).

Meadowlark Lake

During 2012, 43 channel catfish were captured in hoop nets deployed at Meadowlark Lake during five separate capture periods. We encountered 11 previously batch marked channel catfish during the final four capture periods. Total lengths of captured channel catfish ranged from 42 to 68 cm. Model averaging was used to estimate population size (N), capture probabilities (p), and recapture probabilities (c) of the channel catfish population (Table 2-11; Table 2-5).

The model-averaged estimate of channel catfish population size was 68 (44 - 194) (Table 2-6). The estimate of the number channel catfish harvested by anglers was 11 (3 - 27) (Table 2-6). Given these estimates of angler harvest of channel catfish and channel catfish population size, the exploitation rate of channel catfish was estimated to be 16% (0 - 41%) (Table 2-7).

Olive Creek Lake

During 2012, 481 channel catfish were captured in hoop nets deployed at Olive Creek Lake during five separate capture periods. We captured 15 previously batch

marked channel catfish during the final four capture periods. Total lengths of captured channel catfish ranged from 28 to 75 cm. Model averaging was used to estimate population size (N), capture probabilities (p), and recapture probabilities (c) of the channel catfish population (Table 2-12; Table 2-5).

The model-averaged estimate of channel catfish population size was 1,313 (563 - 8,947) (Table 2-6). The estimate of the number channel catfish harvested by anglers was 63 (24 - 102) (Table 2-6). Given these estimates of angler harvest of channel catfish and channel catfish population size, the exploitation rate of channel catfish was estimated to be 5% (0 - 14%) (Table 2-7).

Wagon Train Lake

During 2012, 480 channel catfish were captured in hoop nets deployed at Wagon Train Lake during five separate capture periods. We captured 14 previously batch marked channel catfish during the final four capture periods. Total lengths of captured channel catfish from ranged from 28 to 79 cm. Model averaging was used to estimate population size (N), capture probabilities (p), and recapture probabilities (c) of the channel catfish population (Table 2-13; Table 2-5).

The model-averaged estimate of channel catfish population size was 1,305 (504 - 28,997) (Table 2-6). The estimate of the number channel catfish harvested by anglers was 959 (504 - 1,410) (Table 2-6). Given these estimates of angler harvest of channel catfish and channel catfish population size, the exploitation rate of channel catfish was estimated to be 73% (0 - 100%) (Table 2-7).

Wildwood Lake

During 2012, 219 channel catfish were captured in hoop nets deployed at Wildwood Lake during five separate capture periods. We captured 13 previously batch marked channel catfish during the final four capture periods. Total length of captured channel catfish ranged from 42 to 78 cm. Model averaging was used to estimate population size (N), capture probabilities (p), and recapture probabilities (c) of the channel catfish population (Table 2-14; Table 2-5).

The model-averaged estimate of channel catfish population size was 668 (356 – 1,951) (Table 2-6). The estimate of the number channel catfish harvested by anglers was 0 (0 - 0) (Table 2-6).Given these estimates of angler harvest of channel catfish and channel catfish population size, the exploitation rate of channel catfish was estimated to be 0% (0 - 0%) (Table 2-7).

Discussion

Two groups of reservoirs were identified in this study with regard to the exploitation rates of channel catfish populations. The first reservoir group contained three reservoirs with exploitation rates of channel catfish populations of 0% during the study period (Table 2-7). The second reservoir group contained four reservoirs with mean exploitation rates of channel catfish between 5 and 73% (Table 2-7).

Harvest of channel catfish occurred outside of our study period and would have increased annual exploitation rate at Olive Creek Lake, Wagon Train Lake, and Yankee Hill Lake (Appendix D.2.). Further, the majority of the channel catfish caught during 2011 at Yankee Hill Lake and 2012 at Olive Creek Lake were caught outside of our study period (Appendix D.1.). Thus, comparison of our estimates of exploitation rates of

channel catfish populations should be made with the caveat that we did not estimate an annual exploitation estimate, and that the majority of annual harvest did not occur during the study period at each reservoir (Appendix D.2.).

Estimates of angler exploitation rates of channel catfish at Wild Plum Lake, Wildwood Lake, and Yankee Hill Lake were not within the range of any exploitation rates of channel catfish observed in the literature (1-85%) (Eder and McDannold 1987; Mitzner 1989; Hubert 1999). This observation may be based on the differences in scales between this study and previous studies of exploitation rates of channel catfish because exploitation rates are generally estimated on an annual basis. However, estimates of exploitation rates of 0% during the summer (June-August) at Wild Plum Lake and Wildwood Lake may be representative of the annual exploitation rates of channel catfish from these populations because there were no observations of harvest of channel catfish outside of our study period (June-August) during the years we assessed exploitation rates of these populations. However, the annual exploitation rate of the channel catfish population at Yankee Hill Lake would have been greater than 0% because an estimated 101 channel catfish were harvested during 2011 outside of the study period (June-August) (Appendix D. 2.). Estimates of exploitation rates of zero at Wildwood Lake, Wild Plum Lake, and Yankee Hill Lake during our study period were not unreasonable given the management strategies and channel catfish population characteristics at these reservoirs. The harvest of channel catfish population at Wildwood Lake was managed with a catch-and-release regulation. We observed no violations of this regulation during all interviews during 2012 (Appendix D. 2.), so an estimate of the exploitation rate of the channel catfish population at Wildwood Lake may be reasonable. Wild Plum Lake had a

relatively small channel catfish population (4-28 channel catfish) (Table 2-6), making the capture and subsequent harvest of channel catfish by anglers unlikely. Further, no harvest of channel catfish was encountered outside of the study period during 2011 (Appendix D. 2.) so this estimate of the exploitation rate of the channel catfish population at Wild Plum Lake may be reasonable as an estimate of annual exploitation. Our estimate of zero harvest of channel catfish by anglers at Yankee Hill Lake is reasonable given that angler effort for channel catfish was low (3.51 hours/ha) during the summer 2011 (D. Martin, personal communication). A fish kill during the summer 2010 may have removed most of the channel catfish at Yankee Hill Lake that had been stocked prior to the fall of 2010 (J. J. Jackson, personal communication) and contributed to the low level of angler effort for channel catfish during 2011.

For reservoirs of the first group based on exploitation rates of channel catfish populations, lack of exploitation was caused by a catch-and-release regulation, lack of channel catfish fish large enough to have a high probability of being harvested given capture, or low channel catfish population density and subsequent low probability of encounter by anglers. Catch-and-release regulations are not implemented with the goal of increasing exploitation rates of a population so we do not recommend the alteration of the established catch-and-release regulation at Wildwood Lake based on the lack of exploitation of the channel catfish population at Wildwood Lake. The channel catfish population at Yankee Hill Lake, where there are few channel catfish long enough to have a relatively high likelihood of being harvested if caught by anglers, may be a special case regarding the exploitation of channel catfish. A fish kill at Yankee Hill Lake the year prior to this study (2010) removed many fish from the population and likely reduced

angler effort for channel catfish. We suggest continued monitoring of angler effort for and harvest of channel catfish as well as channel catfish abundance and size structure at Yankee Hill Lake to determine if the exploitation rate increases once channel catfish in the population have grown larger. Exploitation of the channel catfish population at Wild Plum Lake was nonexistent due to the small channel catfish population at Wild Plum Lake (5 individuals). Wild Plum Lake had not been stocked with channel catfish in over ten years and natural reproduction was likely non-existent (there were no channel catfish < 60 cm in total length). Merganser Lake is a reservoir with similar surface area (16 ha), and fish community to Wild Plum Lake and is only 5 km away from Wild Plum Lake. The exploitation rate of channel catfish from Merganser Lake was between 0 and 73%. Also, angling intensity (angler hours/ha) was greater at Wild Plum Lake than Merganser during 2011 (D. Martin, personal communication), so anglers would likely exploit channel catfish at Wild Plum Lake at rates comparable to Merganser Lake if channel catfish were stocked at Wild Plum Lake.

Estimates of exploitation rates of channel catfish populations at Holmes Lake, Merganser Lake, Meadowlark Lake, Olive Creek Lake, and Wagon Train Lake fell within the range of previous estimates of exploitation rates of channel catfish populations (1-85%) (Eder and McDannold 1987; Mitzner 1989; Hubert 1999) (Table 2-7). However, only one previous study used a direct estimation approach (estimating number of channel catfish harvested and channel catfish population size) for estimating exploitation rates of channel catfish populations (Mitzner 1989). This study did not provide measures of variance about estimates of exploitation rates but exploitation rates estimates ranged from 19-85% (Mitzner 1989). The exploitation rate of the channel

catfish population at Olive Creek Lake was estimated to be less than 14%. However, harvest of channel catfish occurred outside of our study period and would have increased annual exploitation rate at Holmes Lake, Merganser Lake, Olive Creek Lake, and Wagon Train Lake from the rates we observed during our study period (Appendix D.2.). Thus, the annual exploitation rate of the channel catfish population at Olive Creek Lake may have fallen within the ranges of exploitation rates reported in the study by Mitzner (1989).

Exploitation rates of fish populations have been assessed for other catfish species in North America. Exploitation rates of flathead catfish *Pylodictus olivarus* populations have estimated ranges of 4.1-9.6% in the Missouri River, Missouri (Travnichek 2011), 5-13% at Lake Wilson, Alabama (Marshall et al. 2009), and 14-25% from the Flint River, Georgia (Quinn 1993). These ranges of exploitation rates for flathead catfish populations were estimated using tag-return approaches for estimating exploitation. However, comparison of the ranges of exploitation rates of channel catfish populations to exploitation rates of flathead catfish populations indicate that exploitation rates of flathead catfish populations may be lower than those of channel catfish populations. Previous research illustrates that anglers seeking trophy fish prefer flathead catfish instead of channel catfish (Arternburn et al. 2002) and anglers are willing to tolerate the relatively low catch rates of hook-and-line angling for flathead catfish for the chance to land a large individual (Mayhew 1969). Thus, exploitation rates of flathead catfish populations may fall below exploitation rates of most channel catfish populations due to angler targeting of trophy individuals when targeting flathead catfish. However, the low exploitation rate of flathead catfish from the Missouri River may be due to the fact that

the study was conducted in lotic habitats. Previous research conducted on channel catfish populations in lotic habitats report exploitation rates of 1.7-7.4% for anglers using terminal tackle (Timmons 1999). Exploitation rate of a blue catfish *Ictalurus furcatus* population was estimated to be 17.1% in the Kentucky Lake, Kentucky and Tennessee (Timmons 1999), which was greater than the exploitation rate of a channel catfish population in the same system (Timmons 1999). Further comparisons between the exploitation of blue catfish and channel catfish populations must be made before trends can be identified. However, exploitation rates of channel catfish populations were highly variable across the reservoirs included in this study and other studies (e.g., Table 2-7; Eder and McDannold 1987; Mitzner 1989; Hubert 1999) suggesting the concept of a "normal" exploitation rate of channel catfish populations in small reservoirs may not exist.

Given the imprecision associated with our estimates for exploitation rates of channel catfish populations (Table 2-7), differentiation of exploitation rates of channel catfish populations are difficult to make due to confidence interval overlap. Thus, we suggest the consideration of alterations to this approach or the use of other approaches for future estimates of exploitation rates of channel catfish populations to reduce uncertainty. The uncertainty about our estimates of exploitation rates warrants comment and the recommendation for future direct estimates of exploitation rates.

Catch rates of channel catfish decreased dramatically during our sampling periods, with catch rates being highest during the initial capture periods and decreasing dramatically during each subsequent sampling period (Appendix C.1.). Thus, estimates of capture probability and recapture probability for the final capture periods were based

on small sample sizes of channel catfish. This was a likely source of high levels of uncertainty (95% confidence interval 0-100%) for estimates of channel catfish population size. The dramatic decrease in catches of channel catfish during our study periods may have been caused by gear bias (fish becoming less likely to enter a trap following being captured), channel catfish escaping the nets (Porath et al. 2011), or spawning activity influencing probabilities of capture. Given observed that estimates of capture probability were generally higher recapture probability (Table 2-5), it is likely that we observed some form of trap avoidance. Several states use baited hoop nets as a standard gear for sampling channel catfish (e.g., Michaletz and Sullivan 2002; Flammang and Schultz 2007). If channel catfish remain trap-biased for periods of a year or longer, it could bias indices of relative abundance based on catch-per-unit-effort by making some individuals less likely to be captured than others.

We used a closed-population model for estimating channel catfish population size with a short, three month period to reduce violation of the closure assumption. Harvest of channel catfish occurred outside of the study period used by this study in five of the eight reservoirs studied (Appendix D. 2.). One alteration to the methods used in this study would be to use the robust design approach (Kendall 1999) to estimate channel catfish population size. The use of the robust design approach would allow for the study period to be elongated because the robust design does not require the assumption of closure for the entire duration of the study (Kendall and Nichols 1995; Kendall 1999). The robust design approach to estimating population size does not make the assumption of population closure and would allow for a longer study period. Another advantage of the robust design approach is the ability to estimate the parameter individual survival rate

(Kendall et al. 1999). Survival and mortality can be assumed to be additive (Muoneke 1994), thus mortality (A) can be calculated from an estimate of survival (S) by the formula: $A = 1 – S$ (Muoneke 1994). Thus, comparisons of exploitation rate and mortality rate could be made to determine whether natural mortality or exploitation is having a greater influence on the total mortality rate of a channel catfish population. We recommend the use of the robust design approach for estimating channel catfish population size because of the ability to lengthen the study period and estimate total mortality during the study period.

Channel catfish populations managed as a put-grow-take fishery may be unique with regard to exploitation rates when compared to exploitation rates of flathead catfish and blue catfish populations. Exploitation rates of flathead catfish and blue catfish populations estimated by other studies were lower than 25%. However, given the uncertainty of exploitation rates of channel catfish populations estimated by this study, it is unclear how exploitation rates of channel catfish populations vary from those observed for flathead catfish and blue catfish. We urge future research to investigate methods that may reduce uncertainty of estimates of exploitation rates of channel catfish populations.

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Table 2-1. Channel catfish population estimation schedule for reservoirs of the Salt Creek watershed in Nebraska during 2011 and 2012. An “X” indicates that a water body was sampled June through August during the respective year with tandem-set baited hoop-nets.

Reservoir	2011	2012
Holmes	X	
Meadowlark		X
Merganser	X	
Olive Creek		X
Wagon Train		X
Wildwood		X
Wild Plum	X	
Yankee Hill	X	

Table 2-2. Explanation of models used to estimate channel catfish population size at Holmes Lake and Yankee Hill Lake during 2011, and Meadowlark Lake, Olive Creek Lake, Wagon Train Lake, and Wildwood Lake during 2012.

Model	Explanation
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5}$, $c_{i=2}c_{i=3}c_{i=4}c_{i=5}$	p and c independent; p variable across all five capture periods, c variable across the last four capture periods
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45}$, $c_{i=2}c_{i=3}c_{i=45}$	p and c independent; p variable across capture periods 1, 2, 3, and then grouped capture periods 4 and 5; c variable across capture periods 2, 3, and then grouped across capture periods 4, and 5
N, $p_{i=1}p_{i=2}p_{i=345}$, $c_{i=2}c_{i=345}$	p and c independent; p variable across capture periods 1 and 2 and then grouped capture periods 3, 4, and 5; c variable across capture period 2 and then grouped across capture periods 3, 4, and 5
N, $p_{i=1}p_{i=2345}$, $c_{i=2345}$	p and c independent; p variable across capture period 1 and then grouped capture periods 2, 3, 4, and 5; c grouped across capture periods 2, 3, 4, and 5
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5} = c_{i=2}c_{i=3}c_{i=4}c_{i=5}$	p and c dependent; variable across all five capture periods
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45} = c_{i=2}c_{i=3}c_{i=45}$	p and c dependent; p and c variable across capture periods 1, 2, 3, and then grouped across capture periods 4 and 5
N, $p_{i=1}p_{i=2}p_{i=345} = c_{i=2}c_{i=345}$	p and c dependent; p and c variable across capture periods 1 and 2 and then grouped capture periods 3, 4, and 5
N, $p_{i=1}p_{i=2345} = c_{i=2345}$	p and c dependent; p and c variable across capture period 1 and then grouped capture periods 2, 3, 4, and 5

Table 2-3. Explanation of models used to estimate channel catfish population size at Merganser Lake and Wild Plum Lake during 2011.

Model	Explanation
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}$, $c_{i=2}c_{i=3}c_{i=4}$	p and c independent; p variable across all four capture periods, c variable across the last three capture periods
N, $p_{i=1}p_{i=2}p_{i=34}$, $c_{i=2}c_{i=34}$	p and c independent; p variable across capture periods 1 and 2 and then grouped across capture periods 3, and 4; c independent for capture period 2, and then grouped across capture periods 3 and 4
N, $p_{i=1}p_{i=234}$, $c_{i=234}$	p and c independent; p variable across capture period 1 and then grouped capture periods 2, 3, and 4; c grouped across capture periods 2, 3, and 4
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4} = c_{i=2}c_{i=3}c_{i=4}$	p and c dependent; variable across all five capture periods
N, $p_{i=1}p_{i=2}p_{i=34} = c_{i=2}c_{i=34}$	p and c dependent; p and c variable across capture periods 1 and 2; and then grouped across capture periods 3, and 4
N, $p_{i=1}p_{i=234} = c_{i=234}$	p and c dependent; p variable across capture period 1 and then p and c grouped across capture periods 2, 3, and 4

Table 2-4. Comparison of models used to describe channel catfish population size in Holmes Lake during the summer (June-August) 2011. Parameters estimated were population size (N), capture probability for capture period(s) *i* (p_i), and recapture probability for capture period(s) *i* (c_i). Subscripts indicate the groupings of capture periods used to describe capture and recapture probability. Models were ranked using corrected Akaike's information criterion (AIC_c) from the lowest scoring (highest-ranked model) to the highest scoring (lowest-ranked model), where ΔAIC_c is the difference between a model's AIC_c value and that of the highest-ranked model, $WAIC_c$ is the Akaike weight for that model (sum of all weights = 1.00), and K is the number of parameters associated with each model. Models with the superscript "a" did not achieve convergence. Remaining models were averaged based on AIC_c weight to determine channel catfish population size at Holmes Lake during the summer 2011.

Model	AIC_c	ΔAIC_c	$WAIC_c$	K
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45}$, $c_{i=2}c_{i=3}c_{i=45}$	-11924.2	0.0	0.59	8
N, $p_{i=1}p_{i=2}p_{i=345}$, $c_{i=2}c_{i=345}$	-11923.5	0.7	0.41	6
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5} = c_{i=2}c_{i=3}c_{i=4}c_{i=5}$	-11896.3	27.9	0.00	6
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45} = c_{i=2}c_{i=3}c_{i=45}$	-11885.9	38.3	0.00	5
N, $p_{i=1}p_{i=2}p_{i=345} = c_{i=2}c_{i=345}$	-11862.1	62.1	0.00	4
N, $p_{i=1}p_{i=2345}$, $c_{i=2345}$	-11848.4	75.8	0.00	4
N, $p_{i=1}p_{i=2345} = c_{i=2345}$	-11083.1	841.1	0.00	3
[a]N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5}$, $c_{i=2}c_{i=3}c_{i=4}c_{i=5}$				

Table 2-5. Model averaged estimates of capture period-specific capture probability (p_i), and recapture probability (c_i) with associated standard error (SE) for channel catfish from Holmes Lake, Merganser Lake, Wild Plum Lake, and Yankee Hill Lake during the summer (June-August) 2011, and Meadowlark Lake, Olive Creek Lake, Wagon Train Lake, and Wildwood Lake during the summer 2012. Subscripts indicate the capture period for the corresponding capture and recapture probability.

Reservoir	N (SE)	p_1 (SE)	p_2 (SE)	p_3 (SE)	p_4 (SE)	p_5 (SE)
Holmes	1470 (33)	0.212 (0.117)	0.644 (0.233)	0.392 (0.043)	0.421 (0.064)	0.420 (0.070)
Merganser	91 (21)	0.209 (0.065)	0.264 (0.077)	0.075 (0.029)	0.057 (0.024)	NA
Wild Plum	5 (1.0)	0.200 (0.179)	0.800 (0.179)	0.800 (0.179)	0.800 (0.179)	NA
Yankee Hill	1593 (602)	0.480 (0.225)	0.187 (0.218)	0.047 (0.077)	0.058 (0.109)	0.058 (0.109)
Meadowlark	68 (12)	0.371 (0.078)	0.293 (0.075)	0.312 (0.075)	0.247 (0.056)	0.242 (0.054)
Olive Creek	1313 (1252)	0.471 (0.377)	0.030 (0.043)	0.075 (0.116)	0.075 (0.122)	0.075 (0.122)
Wagon Train	1305 (1862)	0.502 (0.207)	0.272 (0.123)	0.496 (0.226)	0.544 (0.263)	0.543 (0.265)
Wildwood	668 (447)	0.126 (0.090)	0.467 (0.355)	0.267 (0.289)	0.261 (0.295)	0.260 (0.295)

Table 2-5 (Continued).

Reservoir	c_2 (SE)	c_3 (SE)	c_4 (SE)	c_5 (SE)
Holmes	0.129 (0.019)	0.067 (0.006)	0.056 (0.004)	0.056 (0.004)
Merganser	0.264 (0.077)	0.075 (0.029)	0.057 (0.024)	NA
Wild Plum	0.100 (0.095)	0.100 (0.095)	0.100 (0.095)	NA
Yankee Hill	0.065 (0.010)	0.017 (0.004)	0.018 (0.003)	0.018 (0.003)
Meadowlark	0.137 (0.050)	0.119 (0.040)	0.054 (0.021)	0.049 (0.019)
Olive Creek	0.008 (0.004)	0.008 (0.003)	0.009 (0.003)	0.009 (0.003)
Wagon Train	0.008 (0.005)	0.012 (0.005)	0.009 (0.003)	0.008 (0.004)
Wildwood	0.137 (0.044)	0.015 (0.006)	0.008 (0.004)	0.008 (0.004)

Table 2-6. Estimates of channel catfish population size with corresponding standard errors and 95% confidence intervals for each population. Estimates of the number of channel catfish harvested with corresponding standard errors and 95% confidence intervals for each reservoir. Holmes, Merganser, Wild Plum, and Yankee Hill were sampled during the summer (June- August) of 2011. Meadowlark, Olive Creek, Wagon Train and Wildwood were sampled during the summer 2012.

Reservoir	Population Size	Population Size 95 % C. I.	Harvest	Harvest 95 % C. I.
Holmes	1,470 ± 36	1446 - 1503	690 ± 234	231 - 1149
Merganser	91 ± 21	75 - 112	32 ± 16	1 - 63
Wild Plum	5 ± 2	4 - 22	0 ± 0	0 - 0
Yankee Hill	1,593 ± 602	1126 - 2822	0 ± 0	0 - 0
Meadowlark	68 ± 22	44 - 194	11 ± 8	0 - 27
Olive Creek	1,313 ± 1,252	563 - 8947	63 ± 20	24 - 102
Wagon Train	1,305 ± 1,862	504 - 28997	959 ± 231	504 - 1410
Wildwood	668 ± 447	356 - 1951	0 ± 0	0 - 0

Table 2-7. Estimates of exploitation rates of channel catfish populations with corresponding standard errors and 95% confidence intervals for each estimate. When the lower bound of the 95% confidence interval of exploitation rate was less than 0%, we truncated to 0%. Similarly, when the upper bound of the 95% confidence interval of exploitation rate was greater than 100%, we truncated to 100%. Estimates of exploitation rates of exploitation with truncated 95% confidence intervals are denoted by the superscript “a”. Holmes Lake, Merganser Lake, Wild Plum Lake, and Yankee Hill Lake were sampled during the summer (June-August) 2011. Meadowlark Lake, Olive Creek Lake, Wagon Train Lake, and Wildwood Lake were sampled during the summer 2012.

Reservoir	Exploitation rate	Exploitation 95 % C.I.
Holmes	47 ± 16	16 - 78
Merganser	35 ± 19	0 - 73[a]
Wild Plum	0 ± 0	0 - 0
Yankee Hill	0 ± 0	0 - 0
Meadowlark	16 ± 13	0 - 41[a]
Olive Creek	5 ± 5	0 - 14[a]
Wagon Train	73 ± 106	0 - 100[a]
Wildwood	0 ± 0	0 - 0

Table 2-8. Comparison of models used to describe channel catfish population size in Merganser Lake during the summer (June-August) 2011 Parameters estimated were population size (N), capture probability for capture period(s) *i* (p_i), and recapture probability for capture period(s) *i* (c_i). Subscripts indicate the groupings of capture periods used to describe capture and recapture probability. Models were ranked using corrected Akaike's information criterion (AIC_c) from the lowest scoring (highest-ranked model) to the highest scoring (lowest-ranked model), where ΔAIC_c is the difference between a model's AIC_c value and that of the highest-ranked model, $WAIC_c$ is the Akaike weight for that model (sum of all weights = 1.00), and K is the number of parameters associated with each model. Models with the superscript "b" were deleted due to the presence of erroneous confidence intervals around the estimate. Remaining models were averaged based on AIC_c weight to determine channel catfish population size at Merganser Lake during the summer 2011.

Model	AIC_c	ΔAIC_c	$WAIC_c$	K
N, $p_{i=1}p_{i=2}p_{i=34} = c_{i=2}c_{i=34}$	-84.5	0.0	0.58	4
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4} = c_{i=2}c_{i=3}c_{i=4}$	-83.8	0.7	0.42	5
N, $p_{i=1}p_{i=234} = c_{i=234}$	-67.3	17.2	0.00	3
[b]N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}$, $c_{i=2}c_{i=3}c_{i=4}$				
[b]N, $p_{i=1}p_{i=2}p_{i=34}$, $c_{i=2}c_{i=34}$				
[b]N, $p_{i=1}p_{i=234}$, $c_{i=234}$				

Table 2-9. Comparison of models used to describe channel catfish population size in Wild Plum Lake during the summer (June-August) 2011. Parameters estimated were population size (N), capture probability for capture period(s) *i* (p_i), and recapture probability for capture period(s) *i* (c_i). Subscripts indicate the groupings of capture periods used to describe capture and recapture probability. Models were ranked using corrected Akaike's information criterion (AIC_c) from the lowest scoring (highest-ranked model) to the highest scoring (lowest-ranked model), where ΔAIC_c is the difference between a model's AIC_c value and that of the highest-ranked model, $WAIC_c$ is the Akaike weight for that model (sum of all weights = 1.00), and K is the number of parameters associated with each model. Models with the superscript "b" were deleted due to the presence of erroneous confidence intervals around the estimate. The model (N, $p_{i=1}p_{i=234}$, $c_{i=234}$) was selected to determine channel catfish population size at Wild Plum Lake during the summer 2011 because it carried > 0.90 of the $WAIC_c$.

Model	AIC_c	ΔAIC_c	$WAIC_c$	K
N, $p_{i=1}p_{i=234}$, $c_{i=234}$	14.4	0.0	0.92	3
N, $p_{i=1}p_{i=234} = c_{i=234}$	20.4	6.0	0.05	3
N, $p_{i=1}p_{i=2}p_{i=34} = c_{i=2}c_{i=34}$	21.7	7.3	0.02	4
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4} = c_{i=2}c_{i=3}c_{i=4}$	25.3	10.9	0.00	5
[b]N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}$, $c_{i=2}c_{i=3}c_{i=4}$				
[b]N, $p_{i=1}p_{i=2}p_{i=34}$, $c_{i=2}c_{i=34}$				

Table 2-10. Comparison of models used to describe channel catfish population size in Yankee Hill Lake during the summer (June-August) 2011. Parameters estimated were population size (N), capture probability for capture period(s) *i* (p_i), and recapture probability for capture period(s) *i* (c_i). Subscripts indicate the groupings of capture periods used to describe capture and recapture probability. Models were ranked using corrected Akaike's information criterion (AIC_c) from the lowest scoring (highest-ranked model) to the highest scoring (lowest-ranked model), where ΔAIC_c is the difference between a model's AIC_c value and that of the highest-ranked model, $WAIC_c$ is the Akaike weight for that model (sum of all weights = 1.00), and K is the number of parameters associated with each model. Models with the superscript "b" were deleted due to the presence of erroneous confidence intervals around the estimate. Remaining models were averaged based on AIC_c weight to determine channel catfish population size at Yankee Hill Lake during the summer 2011.

Model	AIC_c	ΔAIC_c	$WAIC_c$	K
N, $p_{i=1}p_{i=2}p_{i=345}$, $c_{i=2}c_{i=345}$	-7689.7	0.0	0.35	6
N, $p_{i=1}p_{i=2}p_{i=345} = c_{i=2}c_{i=345}$	-7689.4	0.3	0.30	4
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45} = c_{i=2}c_{i=3}c_{i=45}$	-7688.1	1.6	0.16	5
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45}$, $c_{i=2}c_{i=3}c_{i=45}$	-7687.7	2.0	0.13	8
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5} = c_{i=2}c_{i=3}c_{i=4}c_{i=5}$	-7686.3	3.4	0.06	6
N, $p_{i=1}p_{i=2345}$, $c_{i=2345}$	-7638.4	51.2	0.00	4
N, $p_{i=1}p_{i=2345} = c_{i=2345}$	-7557.4	132.3	0.00	3
[b]N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5}$, $c_{i=2}c_{i=3}c_{i=4}c_{i=5}$				

Table 2-11. Comparison of models used to describe channel catfish population size in Meadowlark Lake during the summer (June-August) 2012. Parameters estimated were population size (N), capture probability for capture period(s) *i* (p_i), and recapture probability for capture period(s) *i* (c_i). Subscripts indicate the groupings of capture periods used to describe capture and recapture probability. Models were ranked using corrected Akaike's information criterion (AIC_c) from the lowest scoring (highest-ranked model) to the highest scoring (lowest-ranked model), where ΔAIC_c is the difference between a model's AIC_c value and that of the highest-ranked model, $WAIC_c$ is the Akaike weight for that model (sum of all weights = 1.00), and K is the number of parameters associated with each model. Models with the superscript "b" were deleted due to the presence of erroneous confidence intervals around the estimate. Remaining models were averaged based on AIC_c weight to determine channel catfish population size at Meadowlark Lake during the summer 2012.

Model	AIC_c	ΔAIC_c	$WAIC_c$	K
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45} = c_{i=2}c_{i=3}c_{i=45}$	-52.6	0.0	0.41	5
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5} = c_{i=2}c_{i=3}c_{i=4}c_{i=5}$	-51.2	1.4	0.20	6
N, $p_{i=1}p_{i=2345}$, $c_{i=2345}$	-51.1	1.5	0.20	4
N, $p_{i=1}p_{i=2}p_{i=345}$, $c_{i=2}c_{i=345}$	-50.8	1.8	0.17	5
N, $p_{i=1}p_{i=2}p_{i=345} = c_{i=2}c_{i=345}$	-45.7	6.9	0.01	4
N, $p_{i=1}p_{i=2345} = c_{i=2345}$	-43.1	9.5	0.00	3
[b]N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5}$, $c_{i=2}c_{i=3}c_{i=4}c_{i=5}$				
[b]N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45}$, $c_{i=2}c_{i=3}c_{i=45}$				

Table 2-12. Comparison of models used to describe channel catfish population size in Olive Creek Lake during the summer (June-August) 2012. Parameters estimated were population size (N), capture probability for capture period(s) *i* (p_i), and recapture probability for capture period(s) *i* (c_i). Subscripts indicate the groupings of capture periods used to describe capture and recapture probability. Models were ranked using corrected Akaike's information criterion (AIC_c) from the lowest scoring (highest-ranked model) to the highest scoring (lowest-ranked model), where ΔAIC_c is the difference between a model's AIC_c value and that of the highest-ranked model, and $WAIC_c$ is the Akaike weight for that model (sum of all weights = 1.00, $WAIC_c$ is the Akaike weight for that model (sum of all weights = 1.00), and K is the number of parameters associated with each model. Models with the superscript "a" did not achieve convergence. Models with the superscript "b" were deleted due to the presence of erroneous confidence intervals around the estimate. Remaining models were averaged based on AIC_c weight to determine channel catfish population size at Olive Creek Lake during the summer 2012.

Model	AIC_c	ΔAIC_c	$WAIC_c$	K
N, $p_{i=1}p_{i=2}p_{i=345}$, $c_{i=2}c_{i=345}$	-4313.1	0.0	0.36	6
N, $p_{i=1}p_{i=2345} = c_{i=2345}$	-4312.5	0.6	0.27	3
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45} = c_{i=2}c_{i=3}c_{i=45}$	-4311.9	1.2	0.19	5
N, $p_{i=1}p_{i=2345}$, $c_{i=2345}$	-4310.5	2.6	0.10	4
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45}$, $c_{i=2}c_{i=3}c_{i=45}$	-4310.1	3.0	0.08	8
[a]N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5} = c_{i=2}c_{i=3}c_{i=4}c_{i=5}$				
[a]N, $p_{i=1}p_{i=2}p_{i=345} = c_{i=2}c_{i=345}$				
[b]N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5}$, $c_{i=2}c_{i=3}c_{i=4}c_{i=5}$				

Table 2-13. Comparison of models used to describe channel catfish population size in Wagon Train Lake during the summer (June-August) 2012. Parameters estimated were population size (N), capture probability for capture period(s) *i* (p_i), and recapture probability for capture period(s) *i* (c_i). Subscripts indicate the groupings of capture periods used to describe capture and recapture probability. Models were ranked using corrected Akaike's information criterion (AIC_c) from the lowest scoring (highest-ranked model) to the highest scoring (lowest-ranked model), where ΔAIC_c is the difference between a model's AIC_c value and that of the highest-ranked model, $WAIC_c$ is the Akaike weight for that model (sum of all weights = 1.00), and K is the number of parameters associated with each model. Models with the superscript "b" were deleted due to the presence of erroneous confidence intervals around the estimate. Remaining models were averaged based on AIC_c weight to determine channel catfish population size at Wagon Train Lake during the summer 2012.

Model	AIC_c	ΔAIC_c	$WAIC_c$	K
N, $p_{i=1}p_{i=2}p_{i=345}$, $c_{i=2}c_{i=345}$	-3690.3	0.0	0.49	6
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45}$, $c_{i=2}c_{i=3}c_{i=45}$	-3689.5	0.8	0.33	8
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5} = c_{i=2}c_{i=3}c_{i=4}c_{i=5}$	-3688.2	2.1	0.17	6
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45} = c_{i=2}c_{i=3}c_{i=45}$	-3673.2	17.1	0.00	5
N, $p_{i=1}p_{i=2345}$, $c_{i=2345}$	-3673.0	17.3	0.00	4
N, $p_{i=1}p_{i=2}p_{i=345} = c_{i=2}c_{i=345}$	-3635.6	54.7	0.00	4
N, $p_{i=1}p_{i=2345} = c_{i=2345}$	-3632.0	58.3	0.00	3
[b]N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5}$, $c_{i=2}c_{i=3}c_{i=4}c_{i=5}$				

Table 2-14. Comparison of models used to describe channel catfish population size in Wildwood Lake during the summer (June-August) 2012. Parameters estimated were population size (N), capture probability for capture period(s) *i* (p_i), and recapture probability for capture period(s) *i* (c_i). Subscripts indicate the groupings of capture periods used to describe capture and recapture probability. Models were ranked using corrected Akaike's information criterion (AIC_c) from the lowest scoring (highest-ranked model) to the highest scoring (lowest-ranked model), where ΔAIC_c is the difference between a model's AIC_c value and that of the highest-ranked model, $WAIC_c$ is the Akaike weight for that model (sum of all weights = 1.00), and K is the number of parameters associated with each model. Models with the superscript "b" were deleted due to the presence of erroneous confidence intervals around the estimate. Remaining models were averaged based on AIC_c weight to determine channel catfish population size at Wildwood Lake during the summer 2012.

Model	AIC_c	ΔAIC_c	$WAIC_c$	K
N, $p_{i=1}p_{i=2}p_{i=345}$, $c_{i=2}c_{i=345}$	-1390.4	0.0	0.45	6
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45} = c_{i=2}c_{i=3}c_{i=45}$	-1390.0	0.4	0.38	5
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5} = c_{i=2}c_{i=3}c_{i=4}c_{i=5}$	-1388.3	2.1	0.16	6
N, $p_{i=1}p_{i=2}p_{i=345} = c_{i=2}c_{i=345}$	-1383.0	7.4	0.01	4
N, $p_{i=1}p_{i=2345} = c_{i=2345}$	-1094.3	296.1	0.00	3
[b]N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5}$, $c_{i=2}c_{i=3}c_{i=4}c_{i=5}$				
[b]N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45}$, $c_{i=2}c_{i=3}c_{i=45}$				
[b]N, $p_{i=1}p_{i=2345}$, $c_{i=2345}$				

Chapter 3. Length Biases of Recreational Angling for Channel Catfish at Two Nebraska Flood-Control Reservoirs

Introduction

Channel catfish *Ictalurus punctatus* diet composition changes as they grow (Hill et al. 1995), which possibly alters their vulnerability to angling. Further, the techniques (i.e., angling gear used and habitat selected for angling) used during recreational angling can alter exclude certain fish based on length (Wilde et al. 2003). These two concepts could influence the vulnerability of a fish to recreational angling, resulting in recreational anglers not catching fish in proportion to their availability in the population based on length. Thus, recreational angling would be length biased. Length biased recreational angling has been observed for crappie *Pomoxis spp*. (Miranda and Dorr 2000) and flathead catfish *Pylodictus olivaris* (Travnichek 2011). However, the length bias of recreational angling for channel catfish is unknown.

Regulations for the harvest of a fish species can alter angler effort at a water body (Beard et al. 2003). A catch-and-release regulation is a method for both controlling exploitation (eliminating exploitation if non-compliance with regulation is absent) and providing a unique angling experience on a regional scale (Martin and Pope 2011). It is unknown how a catch-and-release regulation would influence the length-bias of angler catch of channel catfish. Given that some anglers prefer to catch channel catfish for consumptive purposes and are more concerned with the number of channel catfish caught than the size of channel catfish caught (Hurley and Duppong Hurley 2002), a catch-and-release regulation for channel catfish may only attract anglers that are targeting larger channel catfish. Thus, recreational angling may have a stronger length bias against small

channel catfish for population managed with a catch-and-release regulation than a population without a catch-and-release regulation.

The goal of this study was to determine if the length-frequency distributions of channel catfish available in two populations were different from the length-frequency distributions of angler-caught channel catfish at two flood-control reservoirs of the Salt Creek watershed. We further compared the length-frequency distributions of the channel catfish populations to determine if the length-frequency distributions of channel catfish available at the two reservoirs were different. We further compared the length-frequency distributions of the channel catfish caught by anglers to determine if the length-frequency distributions of channel catfish caught by anglers at the two reservoirs were different. Results from this study will provide insight into the length bias of recreational angling for channel catfish.

Methods

Channel Catfish Population Size Structure - Sampling Schedule

We surveyed channel catfish populations to estimate length-frequency distributions using baited, tandem-set hoop nets (hereafter referred to as hoop nets at Wagon Train Lake and Wildwood Lake during summer (June- August) 2012. We sampled each reservoir every other week during a period of ten weeks, with five capture occasions for each reservoir.

Channel Catfish Population Size Structure - Gear

Hoop net surveys were conducted in accordance with methodology established for small impoundments in Missouri and Iowa (Michaletz and Sullivan 2002; Flammang and Schultz 2007). Hoop nets consisted of three nets, attached bridle to cod end, an anchor,

and two weights. A 6.8-kg winged anchor was attached to the rear net, and a 4.5-kg concrete weight was attached between the front and middle nets to reduce buoyancy. An additional 4.5-kg weight was attached to the bridle of the front net to prevent the series from collapsing. Nets were baited with soybean cake pellets as a fish attractant (Flammang and Schultz 2007). Hoop nets measured approximately 3.4-m in length and were constructed of #15 twine with 25.4-mm bar mesh and seven fiberglass hoops, the largest of which was 0.8-m in diameter and equipped with a bridle of 1-m rope. Two-fingered crow foot throats were attached to the second and fourth hoops. To reduce escapement from the cod end, the rear throat was constricted with plastic zip ties (Porath et al. 2011).

Hoop nets were set parallel to the shoreline above the thermocline and at a depth of 1-6 m. Using existing bathymetric maps, sampling sites were randomly selected for each sampling event from points marked at 20-m intervals along the perimeter of the water body. Randomly selected sites with steep slopes, heavy vegetation, or significant development (i.e., docks or swimming beaches) were substituted with other randomly selected sites. Hoop nets were fished undisturbed for approximately 72 h.

This study was conducted concurrently with a mark-recapture population estimate, so we used marks to identify channel catfish previously caught during our study. We removed these previously marked channel catfish from the analysis to prevent channel catfish from being counted twice in our length-frequency distribution. Sub-stock length channel catfish (channel catfish < 28 cm total length; Anderson 1980) were excluded from this analysis because hoop nets are known to bias catch of these smaller channel catfish (Michaletz and Sullivan 2002).

Angler-Caught Channel Catfish Size Structure - Sampling Frame

Access-point interviews were used to estimate the length-frequency distributions of angler-caught channel catfish from Wagon Train Lake and Wildwood Lake. The sampling frame consisted of monthly periods from June 2012 to August 2012. The sampling frame included three eight-hour shifts (00:00-08:00 [early], 08:00-16:00 [mid], and 16:00-24:00 [late]) per day.

Angler-Caught Channel Catfish Size Structure - Sample Selection

Creel survey days and times were chosen following a stratified multi-stage probability sampling regime (Malvestuto 1996). Wagon Train Lake received 24 samples each month. Wildwood Lake received 12 samples each month. These samples were split evenly into six categories (weekday-early, weekday-mid, weekday-late, weekend-early, weekend-mid, and weekend-late). Weekday sample days were selected from all non-holiday Monday-Friday days within each month and weekend sample days were selected from all Saturday-Sunday days plus all federal holidays within each month. All available sampling periods within each month were assigned a random date from within the available sampling frame.

Angler-Caught Channel Catfish Size Structure - On-Site Creel Survey

Anglers intercepted at access points by technicians following completed trips to gather information on catch and harvest of channel catfish. Angler-reported species and length of released fish were recorded. Species, length, and weight of all harvested fish were measured and recorded at the end of the interview.

Data analysis

A Kolmogorov-Smirnov (KS) test (α = 0.05) was used to test for differences between the length-frequency distributions of channel catfish available in the population and angler-caught channel catfish at Wagon Train Lake and Wildwood Lake. A *post hoc* analysis was conducted in an attempt to explain why the results of our analysis were not consistent with our hypotheses. We used the KS test to test for differences between the length-frequency distributions of hoop net-caught channel catfish at Wagon Train Lake and Wildwood Lake. We also used the KS test to test for differences between the length-frequency distributions of angler-caught channel catfish at Wagon Train Lake and Wildwood Lake. Analyses were completed using R (R Development Core Team, 2012).

Results

During the course of this study, 480 and 219 channel catfish were caught in hoop nets at Wagon Train Lake and Wildwood Lake, respectively. Total lengths of hoop net-caught channel catfish at Wagon Train Lake ranged from 28 to 79 cm, and those at Wildwood Lake ranged from 42 to 78 cm.

During the course of this study, 195 and 58 channel catfish were caught by anglers that were interviewed at Wagon Train Lake and Wildwood Lake, respectively. Total lengths of angler-caught channel catfish at Wagon Train Lake ranged from 28 to 87 cm, and those at Wildwood Lake ranged from 42 to 78 cm.at Wildwood Lake ranged from 30 to 79 cm.

The length-frequency distributions of the channel catfish available in the population and channel catfish caught by anglers were different (D = 0.49, $P < 0.01$) at Wagon Train Lake and Wildwood Lake (D = 0.50, $P < 0.01$). The length-frequency

distributions of channel catfish available in the populations at Wagon Train Lake and Wildwood Lake were different (D = 0.76, $P < 0.01$), with the channel catfish population at Wildwood Lake having a greater proportion of larger individuals than the channel catfish population at Wagon Train Lake. However, the length-frequency distributions of angler caught channel catfish at Wagon Train Lake and Wildwood Lake were not different (D = 0.21, $P = 0.05$).

Angler catch of channel catfish was length biased at both Wagon Train Lake and Wildwood Lake, with length-frequency distributions of channel catfish caught by anglers being dissimilar from those available in the population (Figure 3-1; Figure 3-2). Although the length-frequency distributions of channel catfish available at each reservoir were different, the length-frequency distributions of channel catfish captured by anglers were not significantly different between the reservoirs (Figure 3-1; Figure 3-2). Thus, even though recreational angling was length biased for channel catfish at each reservoir, the length-frequency distributions of angler-caught channel catfish were similar at each reservoir.

Discussion

The length bias of recreational angling may be constant across these two reservoirs, with recreational angling catch selecting for intermediate-sized channel catfish in these systems. This length bias would be consistent with the observation of length bias of angling for crappie (Miranda and Dorr 2000). The techniques (i.e., angling gear used and habitat selected for angling) used during recreational angling can alter the sizes of fish caught (Arterburn and Berry 2002; Wilde et al. 2003). Recreational anglers prefer to catch larger fish (Petering et al. 1995) and can use gear or techniques that exclude small

fish based on gape size (Orsi 1987; Wilde et al. 2003). However, as fish grow the size of their prey increases (Ball and Kilambi 1973; Serns and Kempinger 1981), therefore leading to a slower evacuation rate of food items (Miranda and Muncy 1991) and a subsequent reduction in feeding frequency. Thus, it is likely that fish vulnerability to capture is likely to increase with length until fish are at the size that is no longer excluded from being caught based on gaped size. Then fish vulnerability to capture is likely to decrease once the fish reaches a size that its frequency of feeding decreases, leading to intermediate length fish being most vulnerable to angling.

Catch rates of fish decrease following periods of catch-and-release angling, suggesting that fish are conditioned to avoid lures and baits after being caught-and-released (Askey et al. 2006; Klefoth et al. 2012). It is possible that the larger channel catfish in Wildwood Lake, having been exposed to catch-and-release angling, could have a lower vulnerability to being caught by recreational anglers. This combined with reduced feeding frequency of larger fish could explain the fact that the length-frequency distributions of channel catfish caught by anglers were not different between reservoirs even though the length-frequency distributions of channel catfish available to anglers were different between reservoirs.

The catch-and-release regulation for channel catfish at Wildwood is unique to reservoirs of the Salt Creek watershed, and could be used in other regions to provide a unique channel catfish fishery if the channel catfish population size structure is unique from other channel catfish populations in the area (Martin and Pope 2011). Given the results of our study, the catch-and-release regulation for channel catfish at Wildwood Lake was effective for producing a population dominated by memorable-length channel

catfish (≥ 71 cm; Anderson 1980). The size structure of this channel catfish population was unique when compared to the size structure of channel catfish populations throughout the Salt Creek watershed (Appendix B). Anglers have a diversity of desires about angling for channel catfish (Hurley and Duppong Hurley 2002). Catch-and-release regulations for channel catfish could be used on a regional scale to provide a unique channel catfish population that subsequently provides a unique angling opportunity.

There are caveats associated with our study. We used angler-provided total lengths of channel catfish caught and released for this analysis. Anglers do not identify fish species and length with 100% accuracy (Prior and Beckley 2007; Bowlby and Savoie 2011; Page et al. 2012). Whether the bias associated with angler mis-identification of fish species and length would be expected to be constant across reservoirs is relatively unknown. Anglers were able to identify channel catfish to the correct family group ("catfish") 98.1% of the time in a study of Ohio fishing license holders (Page et al. 2012). Channel catfish and black bullheads *Ameriurus melas* were the only Ictaluridae sampled from Wagon Train Lake and Wildwood Lake. Black bullhead rarely attain lengths longer than 40 cm TL in the Midwest (Pflieger 1997). We observed angler-caught channel catfish < 40 cm TL at Wildwood Lake even though we caught no channel catfish < 40 cm TL in hoop nets at Wildwood Lake. If anglers misidentify black bullhead as channel catfish, it may explain the angler-reported channel catfish < 40 cm TL at Wildwood Lake (Figure 3-2). Also, we used the length-frequency distribution of channel catfish captured in hoop nets to represent the channel catfish available to anglers at Wagon Train Lake and Wildwood Lake. Hoop nets catch channel catfish 28 to 55 cm in proportion to their

abundance in the population (Michaletz and Sullivan 2002). However, the length bias of hoop nets for catching channel catfish > 55 cm TL has not been assessed.

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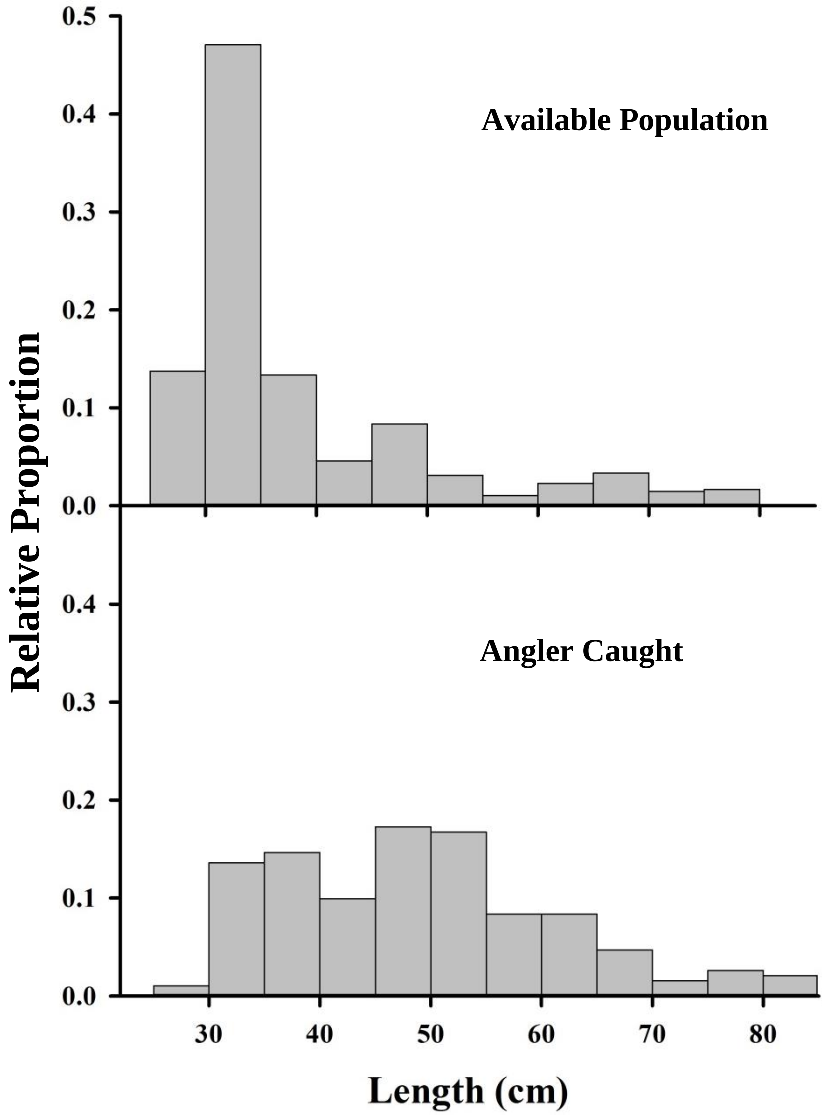

Figure 3-1. Length-frequency distributions of stock-length channel catfish available in the population and caught by anglers at Wagon Train Lake during the summer (June-August) of 2012.

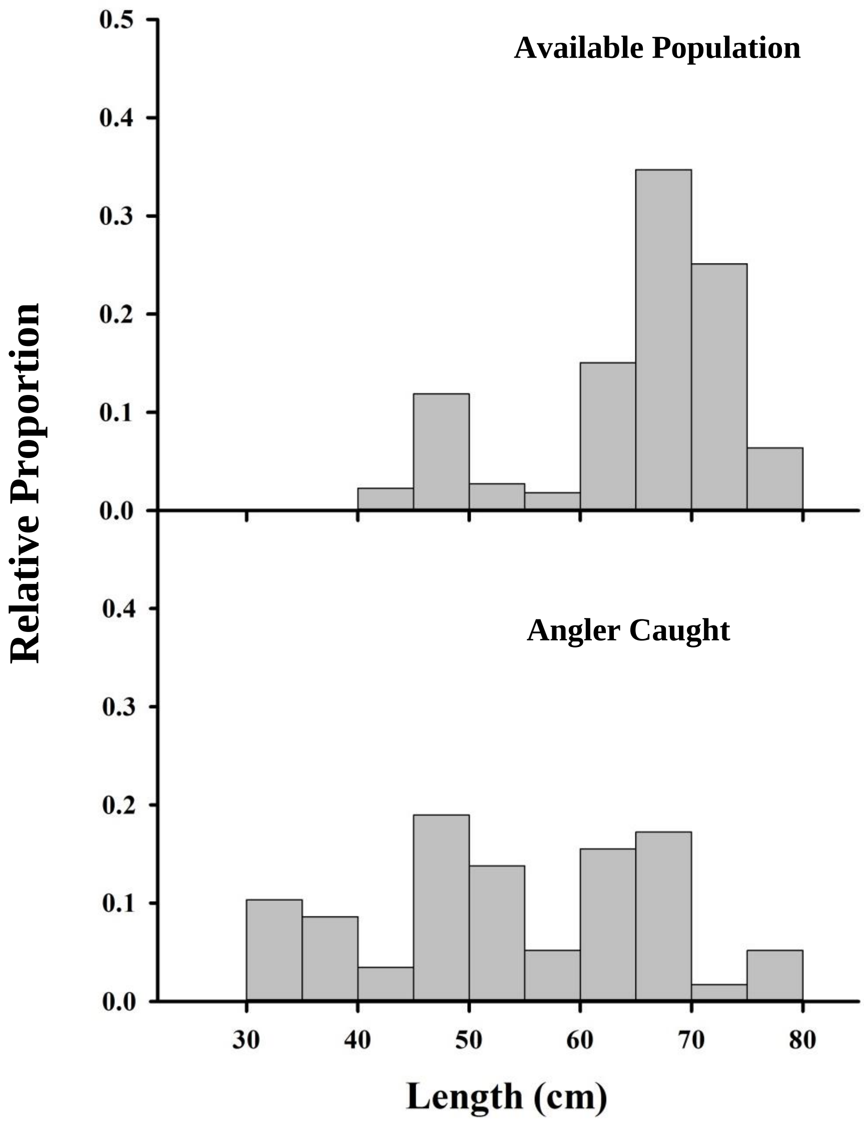

Figure 3-2. Length-frequency distributions of stock-length channel catfish available in the population and caught by anglers at Wildwood Lake during the summer (June-August) 2012.

Chapter 4. Self-Imposed Length Limits for Channel Catfish in Nebraska Flood-Control Reservoirs

Introduction

A self-imposed length limit is the length at which anglers release the majority of fish shorter than that length upon capture when no length limit has been enacted by a management agency (Steward and Ferrell 2003; Chizinski et al. in press). Anglers elect to harvest select species and sizes of captured fish for practical, economic, and regulatory reasons. The decision of an angler to harvest a captured fish is likely influenced by previous and current angling catch rates, previous and current angling effort, current motivating factors for participating in recreational angling, and current social normative pressures (Hunt et al. 2002; Hutt and Bettoli 2007; Beardmore et al. 2011). Therefore, the decision to harvest or release a captured fish is dependent on the attitudes and characteristics of the angler and is influenced by regulations and the species and size of fish (Chizinski et al. in press).

The self-imposed length limit and angler gear size-selectivity are the two primary components determining the sizes of fish harvested by anglers from populations that are regulated with bag limits and no length limit. Channel catfish *Ictalurus punctatus* are a popular sportfish (Hurley and Duppong Hurley 2002; USFWS 2007) and exploitation rates of channel catfish populations can be high, with estimated exploitation rates exceeding 50% in some reservoirs (Mitzner 1989; Table 2-7). Further, channel catfish are often managed with bag limits but rarely with length limits of any kind in North

America (Michaletz and Dillard 1999). Thus, the self-imposed length limit could be a source of size-selectivity for exploitation of channel catfish.

A study of six water bodies across Nebraska determined the self-imposed length limits for six fish species (Chizinski et al. in press). The distance between the lengths corresponding to the 20% and 80% probabilities of harvest given capture for channel catfish was broad when compared to other species (bluegill *Lepomis macrochirus*, crappie *Pomoxis spp.* (black *Pomoxis nigromaculatus* and white crappie *Pomoxis annularis* grouped), white bass *Morone chrysops*, and yellow perch *Perca flavescens*) in this analysis (Chizinski et al. in press). A narrow distance between the 20% and 80% probabilities of harvest given capture implies that the self-imposed length limit for a species was similar across anglers, whereas a broad distance between the 0.2 and 0.8 probabilities of harvest given capture implies that the self-imposed length limit for a species was dissimilar across anglers. Given that the self-imposed length limit of an angler is based on the attitudes and characteristics of the angler (Chizinski et al. in press), the broad distance between the 0.2 and 0.8 probabilities of harvest given capture for channel catfish may indicate that anglers have more diverse attitudes about the harvest of channel catfish than about the harvest of other species.

Anglers that prefer channel catfish are considered to be more harvest oriented than anglers that prefer other fish species (Wilde and Ditton 1991; Hurley and Duppong Hurley 2002; Reitz and Travnichek 2006). Thus anglers seeking channel catfish may harvest the majority of captured fish, and in turn release fewer small fish, in an effort to produce more meat from their catch, whereas anglers seeking other species may release the majority of captured catfish because these anglers are not as harvest oriented as

anglers seeking channel catfish (e.g., anglers seeking largemouth bass *Micropterus salmoides*) (Meyers et al. 2008; Gaeta et al. 2013). The distance between the lengths that corresponded to 0.2 and 0.8 probability of harvest could have been the result of differences between the harvest practices of anglers seeking other species.

Harvest practices have been linked to angler specialization, with highly specialized anglers being primarily catch-and-release oriented and lesser specialized anglers being primarily harvest oriented (Bryan 1977; Hutt and Bettoli 2007). Further, harvest practices and angler specialization have been linked to the method of presentation (e.g., the gear an angler uses and whether an angler fishes in open water or through the ice) (Margenau et al. 2003; Isermann et al. 2005; Hutt and Bettoli 2007). Angling from a boat instead of angling from the bank may be a reflection of angler specialization. Thus, anglers angling from a boat and anglers angling from the bank may have different attitudes and harvest preferences given differences in angler specialization.

Angler harvest of channel catfish is known to be different at night than during the day (Eder and Mcdannold 1987; Parrett et al. 1999). Further, catch rates of channel catfish differ from day to night, likely altering angler perception of the number of channel catfish available (Eder and Mcdannold 1987; Parrett et al. 1999). Angler perception of the number of channel catfish available can influence harvest decisions (Hunt et al. 2002; Beardmore et al. 2011) and may have an influence on the self-imposed length limit for channel catfish. Also, similar to the use of a boat, the action of angling at night may be a representation of angler specialization. Given this, anglers angling at night may have a different self-imposed length limit for channel catfish than anglers angling during the day.

The objective of this study was to improve the understanding of the self-imposed length limit for channel catfish. For this analysis we determined whether grouping anglers by those that sought channel catfish or not, by anglers that fished from the bank or from a boat, and by anglers that fished at night or during the day had the most influence estimates self-imposed length limits. Further, we constrained our analysis to the Salt Creek watershed, Nebraska to reduce the spatial variability in the self-imposed length limit for channel catfish.

Methods

Anglers were interviewed during 2009, 2010, 2011, and 2012 to document angler participation patterns, angling pressure, catch and harvest at reservoirs across the Salt Creek watershed in Nebraska. Interviews took place at Branched Oak Lake, Conestoga Lake, Holmes Lake, Olive Creek Lake, Pawnee Lake, Wagon Train Lake, and Yankee Hill Lake between 1 January and 31 December (Table 4-1). A stratified multi-stage probability sampling regime (Malvestuto 1996) was used to determine days of interviews. Totals of 12 or 24 days were surveyed per month at each reservoir depending on logistical constraints. These samples were split evenly into six categories (weekday-early (00:00-08:00), weekday-mid (08:00-16:00), weekday-late (16:00-00:00), weekend-early, weekend-mid, and weekend-late). Weekday sample days were selected from all non-holiday Monday-Friday days within each month, and weekend sample days were selected from all Saturday-Sunday days and all federal holidays within each month. During the interview process, harvested fish were measured by creel clerks and lengths of released fish were recorded as specified by the angler.

Data were combined across reservoirs and years for analyses. Anglers angling through ice were excluded from this analysis due to the small number of anglers of using this technique interviewed. Mixed-effects logistic regression (Venables and Dichmont 2004) was used to predict whether the probability of harvest for a captured channel catfish given its total length (Length), reservoir from which it was captured (Reservoir), year during which it was captured (Year), month during which it was captured (Month), whether it was captured by an angler from a boat or the bank (Bank_Boat), whether it was captured by an angler during a night trip or a day trip (Day_Night), whether it was captured by an angler seeking channel catfish (Sppsought) using the *lme4* package (Bates et al. 2012) in program R (R Development Core Team 2012). In this analysis, we treated Reservoir, Year, and Month as random effects to account for variation of these variables in the model. We treated Length, Bank_Boat, Day_Night, Sppsought, Day_Night+Bank_Boat, Day_Night+Sppsought, Bank_Boat+Sppsought, the interaction between Day_Night and Bank_Boat, the interaction between Bank_Boat and Sppsought, and the interaction between Day_Night and Sppsought were used as fixed effects to estimate their influence on the parameter estimate probability of harvest given capture. Ten candidate models were constructed with all random effects and different combinations of fixed effects (Table 4-2). Model selection is underpinned by a philosophical view that understanding can best be approached by simultaneously weighing evidence for multiple working hypotheses (Hilborn and Mangel 1997, Burnham and Anderson 2002). We used Akaike's information criterion (AIC) to compare evidence for the candidate models (Burnham and Anderson 2002). We used model averaging if the top model did not carry > 0.90 of the AIC weight (Burnham and

Anderson 2002). Probabilities of harvest and 95% confidence intervals were calculated across the channel catfish length range using the coefficient values and standard errors from fixed effects.

A *post hoc* analysis was conducted to determine differences between the catch rates and length-frequency distributions of channel catfish caught by the four groups that were identified to have different self-imposed length limits for channel catfish. This portion of our analysis used data from angler interviews included in the analysis, thus included only angling parties that caught at least one channel catfish during the angling trip. We estimated the catch-per-unit-effort (CPUE) of all species and of channel catfish by anglers angling during the day from the bank, anglers angling during the night from the bank, anglers angling during the day from a boat, and anglers angling during the night from a boat. We also compared the length-frequency distributions, two at a time, of channel catfish caught by anglers angling during the day from the bank, anglers angling during the night from the bank, anglers angling during the day from a boat, and anglers angling during the night from a boat using a Kolmogorov-Smirnov (KS) test ($\alpha = 0.05$).

Results

Data for this study were collected from 25,653 interviews conducted during 2009, 2010, 2011, and 2012. Length and fate (harvested or released) information was collected on 1,658 channel catfish (8-88 cm TL) (Table 4-1). The model with Length+Bank_Boat+Day_Night+ Bank_Boat:Day_Night fixed effects was selected as the top model, carrying > 0.90 of the AIC weight (Table 4-2). Variance attributed the random effects were 0.43 for month, 0.53 for reservoir, and 11.49 for year.

The probability of harvest given that a channel catfish was caught increased as channel catfish total length increased (Figure 4-1, Table 4-3). Further, the model Length+Bank_Boat+Day_Night+ Bank_Boat:Day_Night carried > 0.90 of the AIC weight (Table 4-3), suggesting that these two factors and their interaction explained more variance in the self-imposed length limit for channel catfish than any of the other models we assessed (Table 3). The length ranges that encompassed 20% to 80% probability of harvest for channel catfish were 55-125 cm for day boat anglers (50% = 90 cm), 43-113 cm for night boat anglers (50% = 78 cm), 28-98 cm for day bank anglers (50% = 63 cm), and 37-107 cm for night bank anglers (50% = 72 cm). The lengths at which a channel catfish had an 80% probability of being harvested given capture were greater than the largest channel catfish observed by this study.

Anglers angling during the day from the bank caught channel catfish at the same rate as anglers angling during the day from a boat (Table 4-4). Anglers angling during the night from the bank caught channel catfish at a lower rate than anglers angling during the night from a boat (Table 4-4). Anglers angling during the day from the bank caught channel catfish at a greater rate than anglers angling during the night from the bank (Table 4-4). Anglers angling during the day from the bank caught channel catfish at the same rate as anglers angling during the night from a boat (Table 4-4). Anglers angling during the day from a boat caught channel catfish at the same rate as anglers angling from a boat during the night (Table 4-4).

The length-frequency distributions of channel catfish caught by anglers angling during the day from a boat and anglers angling during the night from a boat were different (D = 0.26, $P < 0.01$), with anglers angling during the night from a boat catching

a greater proportion of larger channel catfish than anglers angling during the day from a boat (Figure 4-2). The length-frequency distributions of channel catfish caught by anglers angling during the night from the bank and anglers angling during the day from a boat were not different (D = 0.08, *P* = 0.41). The length-frequency distributions of channel catfish caught by anglers angling during the day from the bank and anglers angling during the day from a boat were different (D = 0.28, *P* < 0.01), with anglers angling during the day from a boat catching a greater proportion of larger channel catfish than anglers angling during the day from the bank (Figure 4-2). The length-frequency distributions of channel catfish caught by anglers angling during the night from the bank and anglers angling during the night from a boat were different (D = 0.30, *P* < 0.01), with anglers angling during the night from a boat catching a greater proportion of larger channel catfish than anglers angling during the night from the bank (Figure 4-2). The length-frequency distributions of channel catfish caught by anglers angling during the day from the bank and anglers angling during the night from a boat were different (D = 0.50, *P* < 0.01), with anglers angling during the night from a boat catching a greater proportion of larger channel catfish than anglers angling during the day from the bank (Figure 4-2). The length-frequency distributions of channel catfish caught by anglers angling during the day from the bank and anglers angling during the night from the bank were different (D = 0.25, *P* < 0.01), with anglers angling during the night from the bank catching a greater proportion of larger channel catfish than anglers angling during the day from the bank (Figure 4-2).

Discussion

Harvest orientation, preferences, and actions of anglers have been linked to specialization, a metric of skill and experience (Bryan 1977; Hutt and Bettoli 2007). Further, skill and experience have been closely linked to the approach used by anglers (e.g., natural bait vs. artificial flies or angling from the bank vs. angling in the water using waders) (Bryan 1977; Hutt and Bettoli 2007). The use of a boat or angling from the bank influences the habitats available to an angler and could be linked to angler specialization. Also, angling during the night or during the day can be viewed as two different presentations, tying these two approaches to specialization as well. The link between angling from a boat or the bank, and angling during the night or day with angler specialization is unknown. However, our results clearly link these two approaches to explaining differences in self-imposed length limits for channel catfish (Figure 4-1).

Results from a return-mail survey of Nebraska licensed anglers showed the presence of four groups of anglers that indicated preference for channel catfish (Hurley and Duppong Hurley 2002; K. Hurley, personal communication). These four groups illustrated differences among anglers that prefer channel catfish regarding approval of length limits, preference for size and numbers of channel catfish, preference for consumption of fish, use of boats, and income (Hurley and Duppong Hurley 2002; K. Hurley, personal communication). The “opportunistic” catfish anglers used boats the most often, had the highest mean income, and were the most preferential for large fish (Hurley and Duppong Hurley 2002; K. Hurley, personal communication). The “lawn-chair” catfish anglers were the most preferential for harvest, and indicated the lowest skill. The “casual” catfish anglers used boats the least and valued the size and number of

channel catfish equally (Hurley and Duppong Hurley 2002; K. Hurley, personal communication). The “avid” catfish angler had the lowest income, displayed a dichotomy over preference for length limits, and used the Missouri river more often than anglers of the other four groups (Hurley and Duppong Hurley 2002; K. Hurley, personal communication).

Characteristics of the “opportunistic” angler group suggest that anglers from this group may be best represented by anglers that fish from boats during the day, practicing selective harvest by harvesting larger individuals and releasing small individuals as indicated by our modeling of the self-imposed length limit. Inspection of length-frequency histograms indicates that anglers angling from boats during the day catch larger channel catfish than do anglers angling from the bank during the day (Figure 4-2). Characteristics of the “lawn-chair” angler group suggest that anglers from this group may be best represented by anglers that fish from the shore during the day. Anglers that fished from the shore during the day had the smallest self-imposed length limit for channel catfish, suggesting a greater willingness to harvest smaller channel catfish. The harvest of smaller fish is likely the result of the desire to harvest more fish during a given trip. The “lawn-chair” anglers indicated the lowest specialization of the four survey groups, and thus likely fish from the bank. Characteristics of the “casual” angler group suggest that anglers from this group may be best represented by anglers angling from the bank, regardless if the angling trip is during the day or during the night. Anglers of the “Avid” angler group had the strongest preference for catching large channel catfish. Anglers angling during the night from a boat caught larger channel catfish than anglers angling during the day from a boat or anglers angling at any time from the bank. Thus,

the "Avid" angler group may be best represented by anglers angling during the night from a boat.

Biologists often use regulations to restrict the harvest of populations that are over-exploited. Harvest of channel catfish is generally regulated with bag limits (Michaletz and Dillard 1999). However, bag limits are not as effective at reducing exploitation rates as length limits (Van Poorten et al. 2013). Populations likely to benefit from length limits tend to exhibit a combination of moderate to rapid growth, low natural mortality, and high exploitation rates (Colvin 1991a, 1991b; Allen and Miranda 1995). Given the concern about the exploitation rates of channel catfish from the flood-control reservoirs of the Salt Creek watershed, minimum length limits may be appropriate for reducing harvest from highly exploited populations (e.g., Wagon Train). However, research indicates that growth and mortality rates are variable across the channel catfish populations of the Salt Creek watershed (Chizinski 2012). Therefore, further research should be conducted to ensure that channel catfish population dynamics are consistent with those that are generally successful for minimum length limits (e.g., moderate to rapid growth, and low natural mortality).

Given that there appears to be groups of the angling population in this region that have different self-imposed length limits, the future implementation of a minimum length limit will influence the harvest practices of these groups of anglers differently. For example, the harvest practices of anglers angling during the day from the bank will be influenced more than anglers angling during the day from a boat because anglers angling during the day from the bank were more likely to harvest small channel catfish than other anglers. Further, given that "lawn-chair" and "casual" anglers are more harvest-oriented

and likely to fish from the bank (Hurley and Duppong Hurley 2002; K. Hurley, personal communication), these anglers will be most influenced by a minimum length limit.

There are some caveats that may have influenced the results of this study. First, sizes of released fish were based on angler recollection of the size and number of released fish by species, and thus subject to recall bias (Pollock et al. 1994). It is unlikely that recall bias was an important factor given that the recollection period was relatively short (<12 hours) as anglers were interviewed while preparing to depart from the reservoir (completed trips). Second, the premise of this study is grounded on the fact that an angler must make a decision to harvest a fish at the point of catch. Though it is possible that some anglers may do this illegally, current regulation dictates that "any fish that is not to be counted in the daily creel limit must be returned immediately to the water with as little injury as possible. Culling and high-grading is not allowed" and thus, not a major concern for our study.

Conclusions

It is evident that the approach used by anglers influences the self-imposed length limits for channel catfish. Anglers commonly group themselves by species sought and managers frequently use these groups during data analysis. However, these groups do not appear to explain the harvest actions of anglers for channel catfish as well as the approach used (herein, angling during the day or during the night, and angling from a boat or from the bank). Given that angler approach has been cited as a reflection of angler specialization, which has been tied to angler harvest practices, this finding is not surprising. We urge future research to further determine the influence of angling

approach on harvest practices in an attempt to better explain the harvest actions of anglers.

We used previous research in our speculation about how angler specialization may explain the four groups with different self-imposed length limits for channel catfish. However, there is no research that defines a link between specialization and an angler's self-imposed length limit for channel catfish. We urge further research to link angler attitudes, preferences, and specialization to observed harvest actions, such as the self-imposed length limit. Such research will help predict the influence future management actions, such as length limits for channel catfish, will have on certain groups of anglers.

We observed differences in self-imposed length limits for channel catfish. We further observed differences in the sizes of channel catfish caught by anglers using different approaches. Given these observations and the fact that anglers vary in preference for harvest of channel catfish, an official minimum length limit for channel catfish would influence the harvest practices of anglers differently. An official minimum length limit is set for smaller channel catfish may not reduce harvest substantially because these fish are unlikely to be harvested if captured. Increasing the range of length protected by a minimum length limit for channel catfish may eventually be met with opposition if the harvest practices of a group of anglers are restricted, and they are no longer able to harvest enough channel catfish to maintain satisfaction with the resource being provided.

Finally, our findings should be considered during the planning of future creel surveys. Methodology that does not collect a representative sample from anglers angling during the day or night and bank or boat will likely introduce bias due to the differences

in harvest actions of channel catfish by these four groups. Current methodology of many creel surveys excludes anglers angling at night, thus not collecting a representative sample of the angling population. We urge biologists to create creel surveys with the consideration for collecting a representative sample from these four angler groups in order to reduce bias in estimates of channel catfish total harvest and the length-distributions of channel catfish harvested.

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Table 4-1. Sample sizes for reservoir and year used in the analysis of channel catfish fate as a function of total length and year of capture species during 2009, 2010, 2011, and 2012 in the Salt Creek reservoirs. An "NA" indicates that the reservoir was not sampled during that year.

Reservoir	Fate	2009	2010	2011	2012	Total
Branched Oak	Released	206	143	36	126	511
	Harvested	20	48	24	12	104
Conestoga	Released	128	NA	NA	NA	128
	Harvested	13	NA	NA	NA	13
Holmes	Released	23	NA	70	NA	93
	Harvested	3	NA	35	NA	38
Olive Creek	Released	NA	NA	NA	34	34
	Harvested	NA	NA	NA	22	22
Pawnee	Released	15	21	NA	NA	36
	Harvested	1	6	NA	NA	7
Wagon Train	Released	NA	NA	79	298	377
	Harvested	NA	NA	56	138	194
Yankee Hill	Released	NA	97	NA	NA	97
	Harvested	NA	4	NA	NA	4

Table 4-2. Comparison of models used to describe self-imposed length limits for channel catfish at seven reservoirs in the Salt Creek watershed during 2009-2012. Models include the fixed effects of channel catfish length at capture (Length), the species sought (Sppsought), whether the channel catfish was captured by an angler on the bank (Bank) or on a boat (Boat), whether the channel catfish was captured by an angler angling at night or during the day (Day), the interaction between Day and Boat (Day:Boat), the interaction between species sought and boat (Bank_Boat:Sppsought), and the interaction between Day and Sppsought (Day:Sppsought). Models were ranked using corrected Akaike's information criterion (AIC_c) from the lowest scoring (highest-ranked model) to the highest scoring (lowest-ranked model), where ΔAIC_c is the difference between a model's AIC_c value and that of the highest-ranked model, and $WAIC_c$ is the Akaike weight for that model (sum of all weights = 1.00). We chose the top model based on this model carrying ≥ 0.90 the $WAIC_c$.

Model	K	AICc	Delta AICc	WAICc
Day_Night:Bank_Boat	8	1818.82	0.00	0.94
Bank_Boat	6	1826.02	7.20	0.03
Day_Night.Bank_Boat	7	1826.45	7.64	0.02
Bank_Boat.Sppsought	7	1827.88	9.06	0.01
Bank_Boat:Sppsought	8	1829.81	11.00	0.00
Day_Night	6	1852.51	33.69	0.00
Length	5	1853.66	34.84	0.00
Day_Night.Sppsought	7	1853.88	35.06	0.00
Spp.sought	6	1855.58	36.76	0.00
Day_Night:Sppsought	8	1855.88	37.07	0.00

Table 4-3. Results of mixed-effects logistic regression for total length (cm) of channel catfish as a function of fate (released or harvested) that was determined by anglers angling at reservoirs across the Salt Creek watershed, Nebraska during 2009-2012. Reservoir, month, and year were included as random effects in model and fixed effects are shown below.

Coefficient	Estimate	SE	z value	Prob > |z|
Intercept	-3.56	0.43	-8.18	<0.001
Length	0.04	0.00	8.58	<0.001
Day_Night	0.47	0.16	2.88	0.004
Bank_Boat	1.08	0.18	6.13	<0.001
Day_Night:Bank_Boat	-0.86	0.27	-3.14	0.002

Table 4-4. Mean and standard error catch-per-unit-effort (CPUE) of channel catfish and all species. Anglers were grouped based on whether they fished during the day from the bank (Day_Bank), during the day from a boat (Day_Boat), during the night from the bank (Night_Bank), and during the night from a boat (Night_Boat). This analysis was confined to anglers from the analysis of self-imposed length limits for channel catfish in the reservoirs of the Salt Creek watershed of Nebraska during 2009-2012.

Group	Channel catfish	All species
Day_Bank	0.45 ± 0.04	1.53 ± 0.13
Day_Boat	0.51 ± 0.06	0.88 ± 0.03
Night_Bank	0.37 ± 0.06	0.80 ± 0.12
Night_Boat	0.51 ± 0.07	0.58 ± 0.07

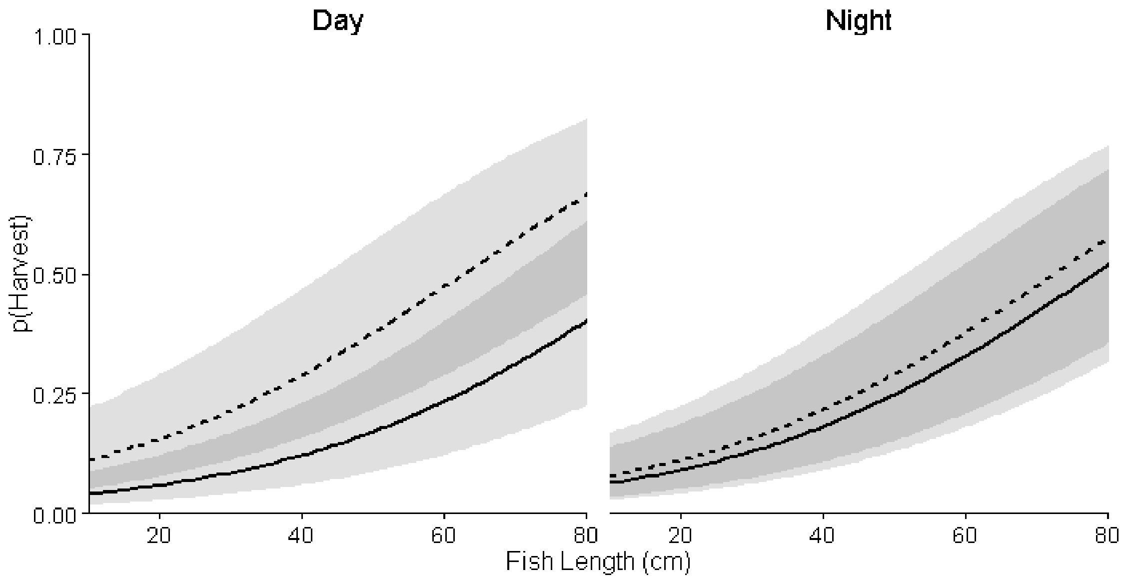

Figure 4-1. Predicted probabilities that captured channel catfish were harvested by anglers angling either during the day or night and either from the bank (dashed lines) or a boat (solid lines) with 95% confidence intervals (gray ribbons) in seven Salt Creek watershed reservoirs during 2009, 2010, 2011, and 2012.

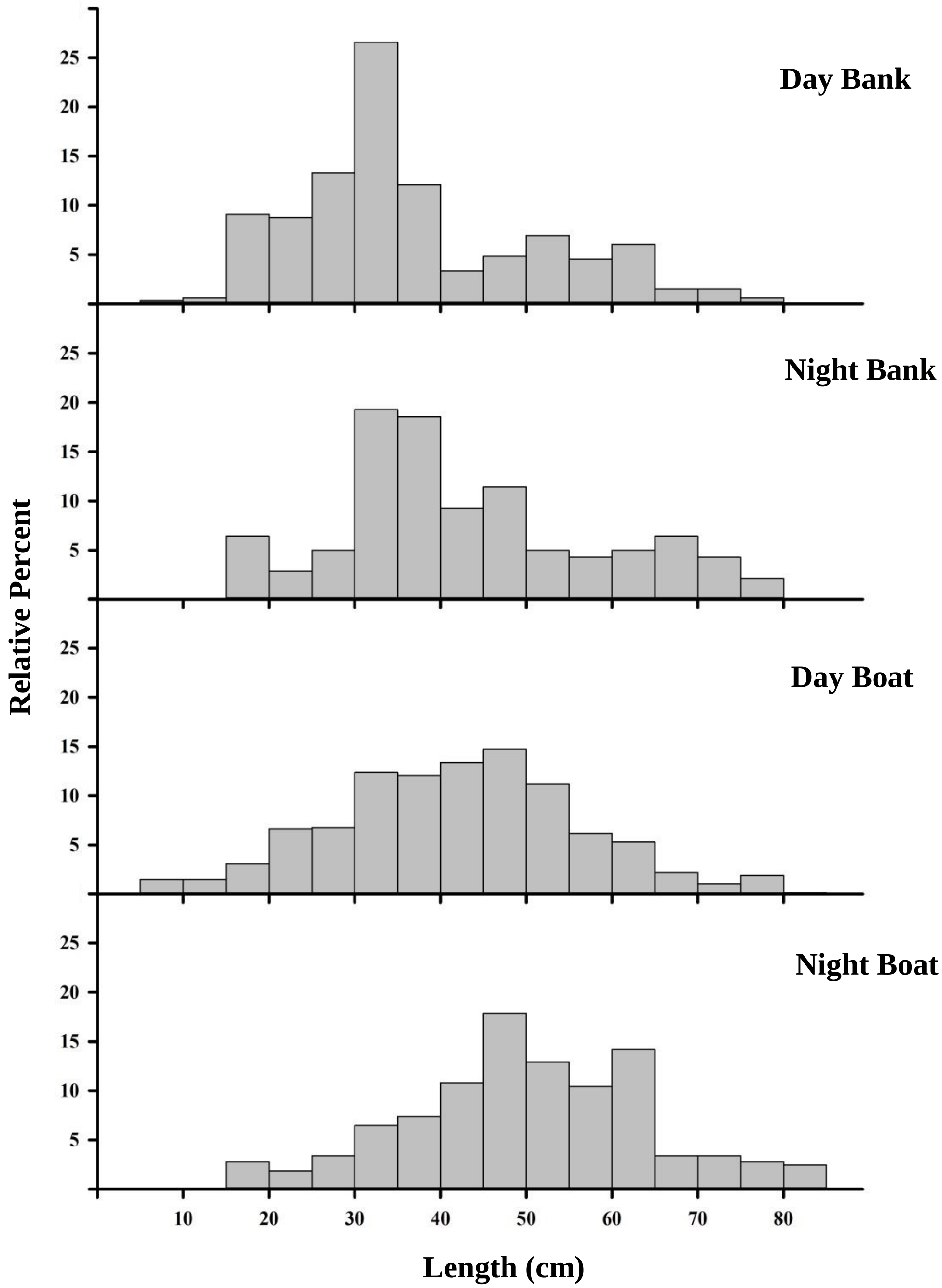

Figure 4-2. Length-frequency distributions of channel catfish caught by anglers angling during the day from the bank (Day_Bank), anglers angling during the night from the bank (Night_Bank), anglers angling during the day from a boat(Day_Bank), and anglers angling during the night from a boat (Night_Boat). This analysis was confined to anglers from the analysis of self-imposed length limits for channel catfish in the reservoirs of the Salt Creek watershed of Nebraska during 2009-2012.

Chapter 5. Management Implications and Future Research

Channel catfish *Ictalurus punctatus* is a popular sportfish species in Nebraska and throughout the U.S.A. (Hurley and Duppong Hurley 2002; USFWS 2007). Given the popularity of channel catfish with recreational anglers, management agencies regularly stock channel catfish in reservoirs. Stocking channel catfish in small reservoirs places a particularly large financial burden on management agencies due to the need to stock large fingerling channel catfish (Marzolf 1957; Mestl and Maughan 1993). Despite the importance of channel catfish to management agencies very little is known about the exploitation of channel catfish populations. This is especially true in Nebraska where exploitation rates of channel catfish populations have not been estimated. Exploitation rates of channel catfish populations can be greater than 80% annually, as indicated by studies in Iowa and Missouri (Mitzner 1989; Michaletz et al. 2008), and may be high in some Nebraska reservoirs as well given the popularity of channel catfish with Nebraska anglers. Also, exploitation of channel catfish populations has been identified as a major source of uncertainty for determining the differences in channel catfish population characteristics across ecosystem types (Chizinski 2012). Therefore, the primary objective of this study was to estimate exploitation rates of channel catfish populations from flood-control reservoirs of Nebraska. Additionally, a secondary objective of this study was to estimate the potential size-selectivity of exploitation of channel catfish populations by assessing the size bias of angling and size-selective harvest by anglers.

Exploitation Rates of Channel Catfish Populations

Two groups of reservoirs were identified in this study with regard to the exploitation rates of channel catfish populations. The first reservoir group contained three reservoirs with exploitation rates of channel catfish populations of 0% during the study period (Table 2-7). The second reservoir group contained four reservoirs with mean exploitation rates of channel catfish between 5 and 73% (Table 2-7).

The exploitation rates of channel catfish populations at Wildwood Lake, Yankee Hill Lake, and Wild Plum Lake were zero, and were not within the range of previous estimates of exploitation rates of channel catfish populations at other reservoirs (Mitzner 1989). Harvest of the channel catfish population at Wildwood Lake was managed with a catch-and-release regulation. It can be inferred that a catch-and-release regulation is implemented to reduce exploitation, and the current exploitation rate of the channel catfish population at Wildwood Lake is 0%. The channel catfish population at Yankee Hill Lake, where there are few channel catfish long enough to have a relatively high likelihood of being harvested if caught by anglers (Appendix B. 5.; Figure 4-1), may be a special case regarding the exploitation of channel catfish. A fish kill at Yankee Hill Lake the year prior to this study (2010) removed many fish from the population and likely reduced angler effort for channel catfish. We suggest continued monitoring of angler effort for and harvest of channel catfish as well as channel catfish abundance and size structure at Yankee Hill Lake to determine if the exploitation rate increases once larger channel catfish become available in the population. Exploitation of the channel catfish population at Wild Plum Lake was nonexistent due to the small channel catfish population at Wild Plum Lake (4-28 channel catfish). Wild Plum Lake had not been

stocked with channel catfish in over ten years and natural reproduction was likely non-existent (there were no channel catfish < 60 cm in total length). Results of previous research indicated that infrequent stocking was appropriate for maintaining channel catfish populations in flood-control reservoirs (Chizinski 2012). There was exploitation of the channel catfish population at Merganser Lake, a reservoir with similar surface area (16 ha) and fish community to Wild Plum Lake that is only 5 km away from Wild Plum Lake. Also, angling effort for channel catfish was observed at Wild Plum Lake during 2011 (D. Martin, personal communication), so anglers would likely exploit channel catfish at Wild Plum Lake at rates comparable to Merganser Lake if channel catfish were stocked at Wild Plum Lake.

The exploitation rates of channel catfish populations at Holmes Lake (16-78%, Table 2-7), Meadowlark Lake (0-41%, Table 2-7), Merganser Lake (0-73%, Table 2-7), Olive Creek Lake (0-14%, Table 2-7), and Wagon Train Lake (0-100%, Table 2-7) were varied, but were within the range of previous estimates of exploitation rates of channel catfish populations (Mitzner 1989; Hubert 1999). The exploitation rate of the channel catfish population at Olive Creek Lake was lower than the exploitation rates of the channel catfish population at Holmes Lake (Table 2-7). Holmes Lake is in an urban setting, whereas Olive Creek Lake is in a rural setting, which may have contributed to the greater levels of angler effort observed at Olive Creek Lake (D. Martin, personal communication). Given the uncertainty about our estimates of exploitation rates of channel catfish we are unable to determine further differences in this second group of reservoirs.

Given the problems associated with tag-return studies (Miranda et al. 2002), and the uncertainty associated with estimates of exploitation rates of channel catfish populations made by this study, there is a substantial amount of work to be done to determine methods for estimating exploitation rates of fish populations. We estimated exploitation rates of channel catfish directly by dividing the number of channel catfish harvested during a three month period by the channel catfish population estimate during that time period. Thus, uncertainty associated with estimates of exploitation rates of channel catfish populations originated from both the estimate of channel catfish population size and number of channel catfish harvested.

The assumption that a population is closed to emigration and immigration is rarely true for a natural biological population (Otis et al. 1978). The assumption of population closure "can be met at least approximately" with proper study designs (Otis et al. 1978). We used a closed population approach (Otis et al. 1987) to estimate channel catfish population size during short, 3-month period to reduce violation of the closure assumption. The use of a robust design (Kendall 1999) would allow for a longer study period because this method does not make the assumption of closure for the entire duration of the study period. The specific application of the robust population size method to channel catfish would require modification of the methods we used in this study. We used hoop nets set for 72 hours (Michaletz and Sullivan 2002, Flammang and Schultz 2007) in an effort to maximize catch rates of channel catfish. Given the short (3-5 day) duration of the closed periods used by the robust design model, we recommend the continued use of hoop nets set for 72 hours, but pulled and reset every 24 hours to increase the number of sets per closed period. Channel catfish population sizes have

been estimated using the robust design in the Platte, Nebraska (Blank 2012), but have not been used to estimate channel catfish population size in lentic systems.

Another advantage of the use of the robust design approach is the ability to estimate emigration and mortality (Kendall et al. 1999). Survival and mortality can be assumed to be additive (Muoneke 1994), thus mortality (A) can be calculated from an estimate of survival (S) by the formula: $A = 1 - S$. Thus, comparisons of exploitation rate and mortality rate could be made to determine if natural mortality or exploitation is having a greater influence on the total mortality of a channel catfish population. We suggest that future estimation of exploitation rates utilize the robust design because of the reduction of assumption violations associated with this approach, the subsequent ability to obtain estimates of exploitation rates during a longer study period, and the ability to estimate emigration and survival of channel catfish during the study period.

We observed a dramatic decrease in catches of channel catfish during our study periods (Figure 2-1). This trap avoidance may have been caused by gear bias (fish becoming less likely to enter a trap following being captured), channel catfish escaping the nets, or spawning activity influencing probabilities of capture. Given that observed estimates of capture probability were generally higher than recapture probability (Table 2-5), it is likely that we observed some form of trap avoidance. Several states use baited hoop nets as a standard gear for sampling channel catfish (e.g., Michaletz and Sullivan 2002, Flammang and Schultz 2007). If channel catfish remain trap-biased for periods of a year or longer, it could bias indices of relative abundance based on catch-per-unit-effort by making some individuals less likely to be captured than others. We used a study period of three months, so it would be beneficial to determine if there is evidence of

channel catfish being trap-biased by baited hoop nets for longer periods. We suggest that future research should investigate the cause and duration of the trap avoidance for channel catfish following capture by baited hoop nets.

Length-Biased Catch of Channel Catfish by Recreational Angling

If hoop nets catch channel catfish in proportion to their availability in the population then recreational angling may be length biased for channel catfish (Figure 3-1; Figure 3-2). The length-frequency distributions of channel catfish caught at Wagon Train Lake and Wildwood Lake were not different even though length-frequency distributions of channel catfish available in the two populations were different. This observation suggests that recreational angling selects for intermediate sizes of channel catfish, an observation consistent with preconceived notions of fish vulnerability to angling gear and previous studies of exploitation rates of fish populations (Miranda and Dorr 2000; Travnichek 2011). This observation may explain the delay between large juvenile channel catfish being stocked and being harvested by anglers in other put-grow-take channel catfish fisheries (Santucci et al. 1994).

Self-Imposed Length Limits for Channel Catfish

A self-imposed length limit for a fish is the length at which the majority of fish are released instead of being retained by the angler for harvest. The self-imposed length limit is a potential link between preconceived desires and preferences of anglers and the actual harvest actions that directly influence a fish population. Analysis of the self-imposed length limit for channel catfish in the Salt Creek regional fishery indicated the presence of two different self-imposed length limits imposed by anglers. One limit is imposed by anglers fishing from the bank during the day, whereas the other limit is

imposed by anglers fishing from the bank during the night, and fishing from a boat during the day or during the night. Not all anglers catch channel catfish at the same rate, with anglers fishing from the bank during the night catching channel catfish at a lower rate than anglers fishing from the bank during day and anglers fishing from the boat during the night or day.

Currently the methods used by the creel surveys used to sample Nebraska water bodies outside of the Salt Creek watershed in Nebraska only sample the hours from sunrise to sunset using access-point interviews. It is unknown if access-point interviews intercept anglers fishing from the bank and from a boat in proportion to their availability. It is known that daytime access-point interviews do not intercept anglers fishing at night in proportion to their availability. If the objective of creel surveys in Nebraska is to describe differences in participation levels and associated harvests among water bodies and among generic angling groups then night-time survey periods should be included in methodological approaches for conducting creel surveys because the differences in self-imposed length limits for channel catfish observed by this study. Failure to do so will lead to estimates that do not accurately describe difference in participation levels and associated harvests among water bodies and among generic angling groups. Further research should be conducted to determine if access point interviews intercept boat and bank anglers in proportion to their availability. We recommend the continued use of creel surveys using a 24-hour sampling frame in the Salt Creek watershed and investigation of implementing a 24-hour sampling frame for all creel surveys conducted in Nebraska.

Management Recommendations

Estimates of exploitation rates of channel catfish populations assists with assessment of stocking strategies in standing waters (Chizinski 2012). However, objectives for the management of channel catfish populations in flood-control reservoirs are unclear. These channel catfish are managed as a put-grow-take fishery (Eder and McDannold 1987), a common practice for providing angling opportunities for channel catfish in the U.S.A. (Michaletz and Dillard 1999). Channel catfish populations managed using a put-grow-take management strategy are stocked as large (20-25 cm) juveniles, which provides a financial burden on management agencies due to the increased time needed to raise these individuals. Thus, a measure of use is valuable for illustrating the contribution of stocked channel catfish to angler catch and harvest, and for comparison of channel catfish stocking strategies.

Stocking strategies should be evaluated based on whether or not clear objectives were met (Cowx 1994; Molony et al. 2003). Unfortunately, there are no clear objectives set for the exploitation rates of channel catfish populations in the put-grow-take channel catfish fisheries of the Salt Creek watershed. Recommendations for alterations of current stocking strategies could be made if objectives were in place to evaluate the success of put-grow-take channel catfish fisheries of the Salt Creek watershed with regard to exploitation rates of the channel catfish populations. As a hypothetical example, if the objective of stocking channel catfish was to provide a put-grow-take fishery with an exploitation rate of between 50 and 60%, then we would recommend the continuation of current stocking practices and harvest regulations at Holmes Lake, Merganser Lake, and Wagon Train Lake because the 95% confidence intervals for exploitation rate of channel

catfish fall within the range specified by this hypothetical management objective; we would also recommend a reduction in stockings, in either density or frequency, at Olive Creek Lake and Meadowlark Lake because stocked channel catfish are not being harvested at high enough rates for this hypothetical management objective.

Exploitation rate is the measure of channel catfish harvested during a period and provides a metric for quantifying use. However, until management objectives for the exploitation rates of channel catfish populations from reservoirs in the Salt Creek watershed a simple evaluation of current stocking strategies is not possible. Thus, we recommend that specific management objectives be developed and explicitly stated for the exploitation rates of channel catfish populations in the Salt Creek watershed.

The estimated exploitation rate of the channel catfish population at Wild Plum Lake was 0%. The channel catfish population at Wild Plum was relatively small (4-28 channel catfish) and yet we still encountered anglers seeking channel catfish during our study period (D. Martin, personal communication). Even without explicitly stated management objectives, we believe there are two potential courses of action for management of channel catfish at Wild Plum Lake. Continue to not stock channel catfish and provide a bluegill and largemouth bass fishery or begin stocking channel catfish infrequently (once every 2-4 years [Chizinski 2012]) to provide a bluegill, channel catfish, and largemouth bass fishery. We recommend the stocking of large juvenile channel catfish in Wild Plum Lake at a rate of 74 individuals per hectare every three years to provide a channel catfish fishery at Wild Plum Lake.

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Appendices

Appendix A. Estimates of channel catfish population sizes from two Nebraska flood-control reservoirs. Channel catfish population size was estimated using methods consistent with methods used to estimate channel catfish population size in Chapter 2.

Appendix A.1. Comparison of models used to describe channel catfish population size in East Twin Lake during the summer (June-August) 2011. Parameters estimated were population size (N), capture probability (p_i) for capture period(s) *i*, and recapture probability (c_i) for capture period(s) *i*. Subscripts indicate the groupings of capture periods used to describe capture and recapture probability. Models were ranked using corrected Akaike's information criterion (AIC_c) from the lowest scoring (highest-ranked model) to the highest scoring (lowest-ranked model), where ΔAIC_c is the difference between a model's AIC_c value and that of the highest-ranked model. $WAIC_c$ is the Akaike weight for that model (sum of all weights = 1.00), and K is the number of parameters associated with each model. Models with the superscript "b" were deleted due to the presence of erroneous confidence intervals around the estimate. Remaining models were averaged based on AIC_c weight to determine channel catfish population size at East Twin Lake during the summer 2011.

Model	AIC_c	ΔAIC_c	$WAIC_c$	K
N, $p_{i=1}p_{i=234}$, $c_{i=234}$	-359.41	0.00	0.65	4
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4} = c_{i=2}c_{i=3}c_{i=4}$	-358.22	1.20	0.36	5
N, $p_{i=1}p_{i=2}p_{i=34} = c_{i=2}c_{i=34}$	-343.29	16.12	0.00	4
N, $p_{i=1}p_{i=234} = c_{i=234}$	-327.70	31.71	0.00	3
[b]N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}$, $c_{i=2}c_{i=3}c_{i=4}$				
[b]N, $p_{i=1}p_{i=2}p_{i=34}$, $c_{i=2}c_{i=34}$				

Appendix A.2. Comparison of models used to describe channel catfish population size in Stagecoach Lake during the summer (June-August) 2012. Parameters estimated were population size (N), capture probability (p_i) for capture period(s) *i*, and recapture probability (c_i) for capture period(s) *i*. Subscripts indicate the groupings of capture periods used to describe capture and recapture probability. Models were ranked using corrected Akaike's information criterion (AIC_c) from the lowest scoring (highest-ranked model) to the highest scoring (lowest-ranked model), where ΔAIC_c is the difference between a model's AIC_c value and that of the highest-ranked model/ $WAIC_c$ is the Akaike weight for that model (sum of all weights = 1.00), and K is the number of parameters associated with each model. Models with the superscript "b" were deleted due to the presence of erroneous confidence intervals around the estimate. Remaining models were averaged based on AIC_c weight to determine channel catfish population size at Stagecoach Lake during the summer 2012.

Model	AIC_c	ΔAIC_c	$WAIC_c$	K
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45}$, $c_{i=2}c_{i=3}c_{i=45}$	-15161.28	0.00	1.00	8
N, $p_{i=1}p_{i=2}p_{i=345}$, $c_{i=2}c_{i=345}$	-15095.35	65.94	0.00	6
N, $p_{i=1}p_{i=2}p_{i=3}p_{i=45} = c_{i=2}c_{i=3}c_{i=45}$	-15073.51	87.78	0.00	5
N, $p_{i=1}p_{i=2345}$, $c_{i=2345}$	-15061.90	99.38	0.00	4
N, $p_{i=1}p_{i=2}p_{i=345} = c_{i=2}c_{i=345}$	-15050.24	111.04	0.00	4
[a]N, $p_{i=1}p_{i=2345} = c_{i=2345}$				
[a]N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5}$, $c_{i=2}c_{i=3}c_{i=4}c_{i=5}$				
[a]N, $p_{i=1}p_{i=2}p_{i=3}p_{i=4}p_{i=5} = c_{i=2}c_{i=3}c_{i=4}c_{i=5}$				

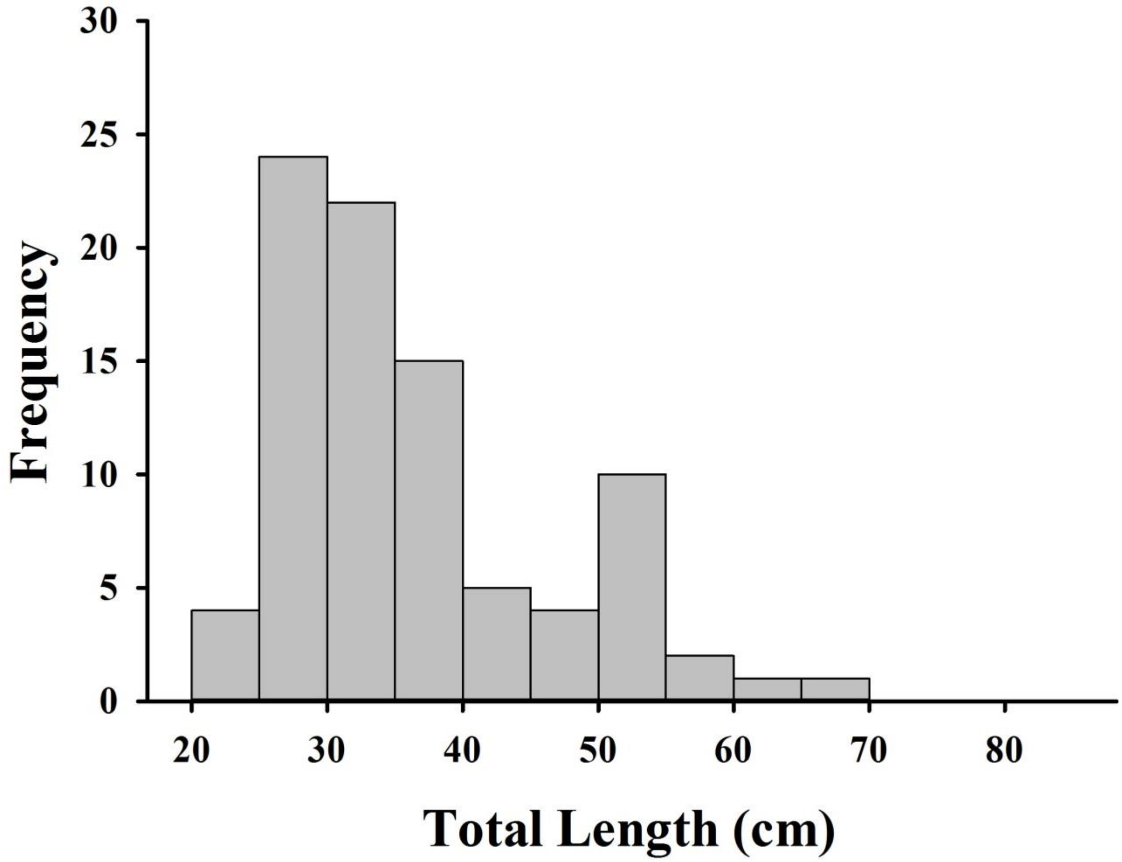
Appendix A.3. Model averaged estimates of time-period specific capture probability (p_i), and recapture probability (c_i) with associated unconditional standard error (SE) for channel catfish at East Twin Lake and Stagecoach Lake. Subscripts indicate the capture period for the corresponding capture and recapture probability.

Reservoir	N (SE)	p_1 (SE)	p_2 (SE)	p_3 (SE)	p_4 (SE)	p_5 (SE)
East Twin	300 (340)	0.136 (0.032)	0.424 (0.055)	0.416 (0.051)	0.405 (0.046)	NA
Stagecoach	2057 (37)	0.220 (0.009)	0.381 (0.015)	0.283 (0.018)	0.542 (0.042)	0.542 (0.042)

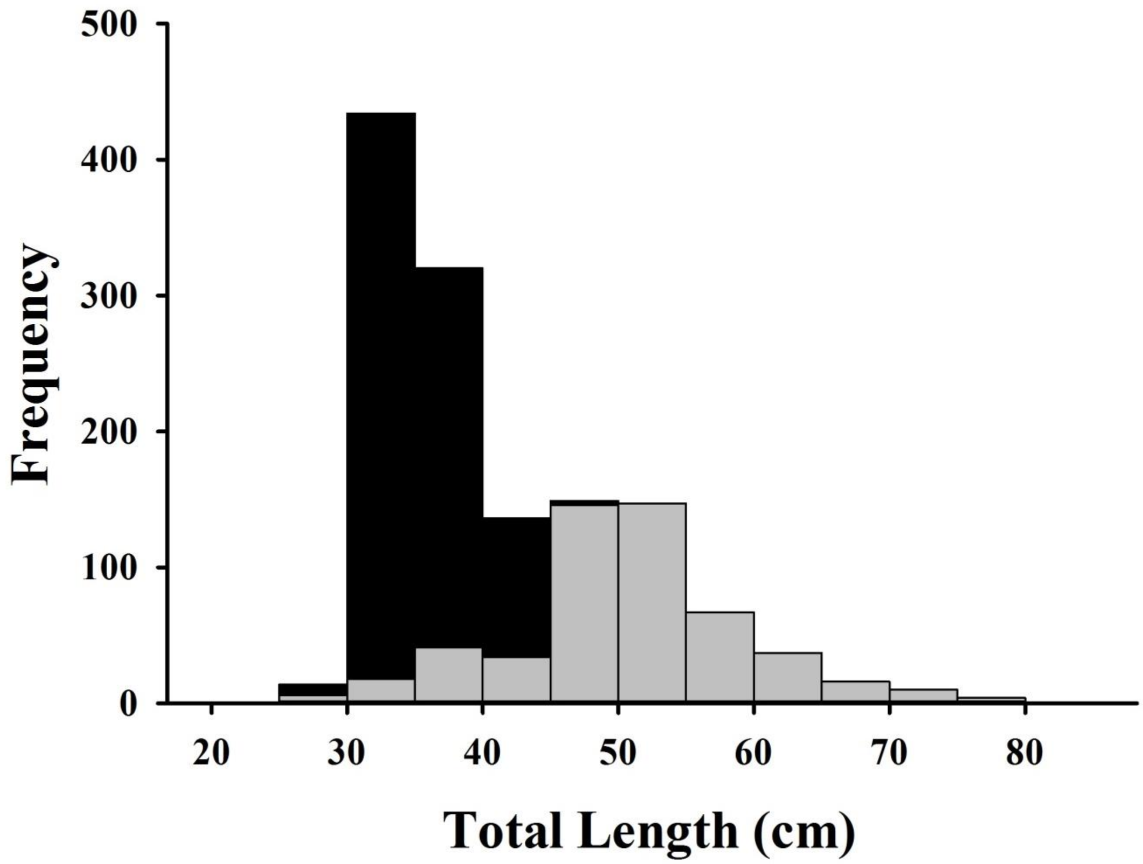
Appendix A.3. (Continued)

Reservoir	c_2 (SE)	c_3 (SE)	c_4 (SE)	c_5 (SE)
East Twin	0.038 (0.019)	0.030 (0.015)	0.018 (0.010)	NA
Stagecoach	0.093 (0.014)	0.136 (0.011)	0.176 (0.006)	0.176 (0.006)

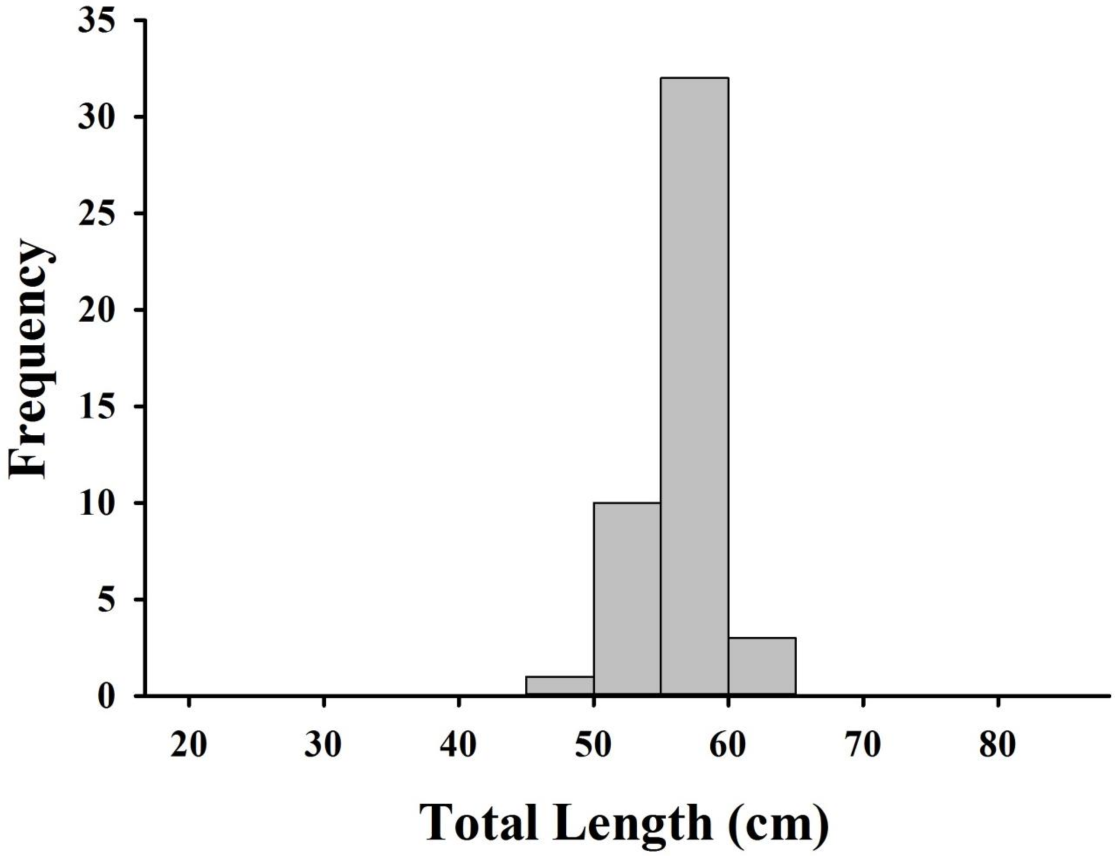
Appendix B. Length-frequency distributions of channel catfish captured in hoop nets during the summer (June-August) 2011 and 2012 at ten Nebraska flood-control reservoirs. Previously marked channel catfish were excluded to prevent channel catfish from being counted twice. Channel catfish with clipped adipose fins are represented by black bars and channel catfish without clipped adipose fins are represented by black bars. Adipose fins were clipped from all channel catfish stocked during 2009-2011.



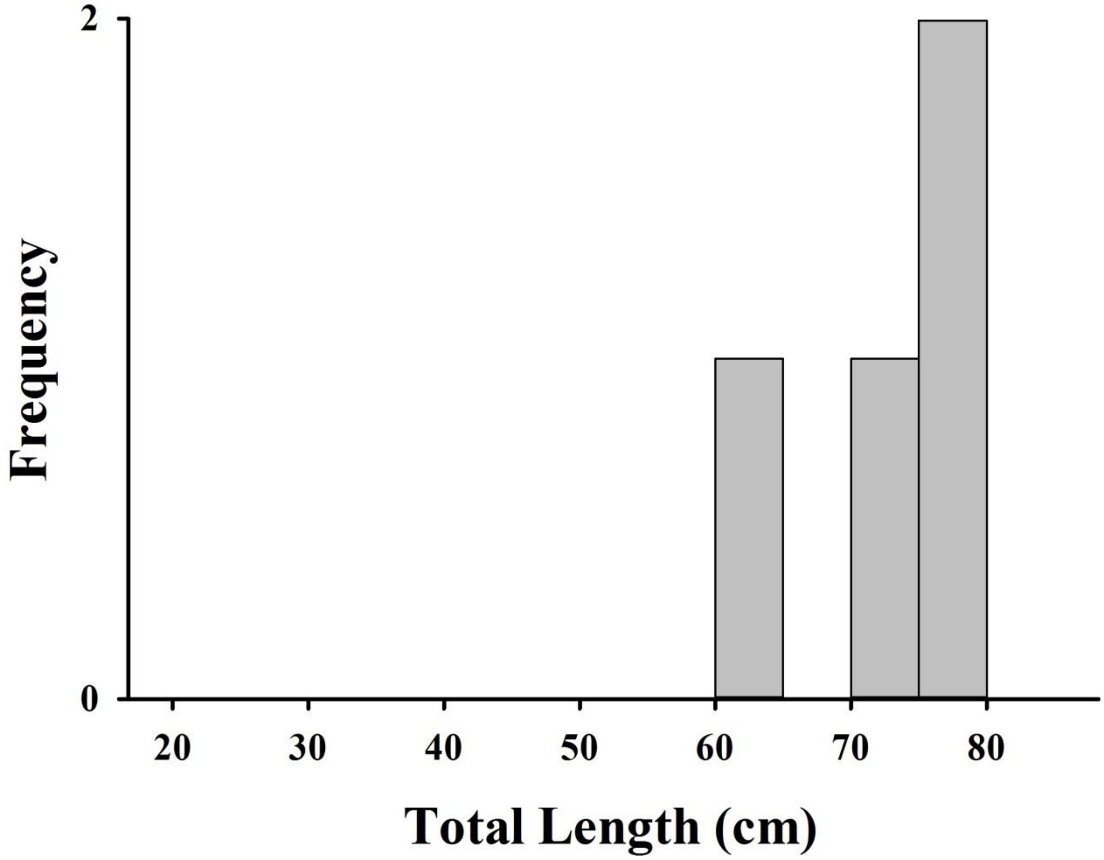
Appendix B.1. Length-frequency distribution of channel catfish captured in hoop nets during the summer (June-August) 2011 at East Twin Lake. Previously marked channel catfish were excluded to prevent channel catfish from being counted twice. Channel catfish with clipped adipose fins are represented by black bars and channel catfish without clipped adipose fins are represented by grey bars.



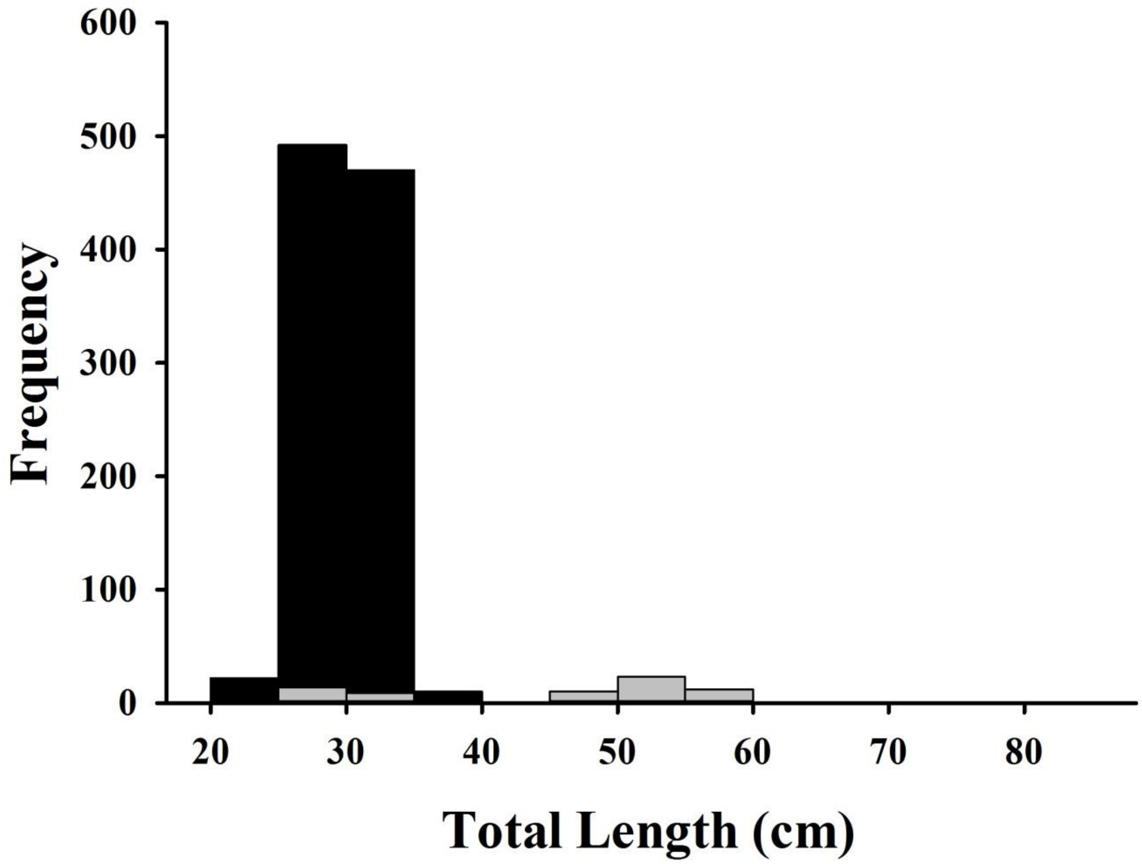
Appendix B.2. Length-frequency distribution of channel catfish captured in hoop nets during the summer (June-August) 2011 at Holmes Lake. Previously marked channel catfish were excluded to prevent channel catfish from being counted twice. Channel catfish with clipped adipose fins are represented by black bars and channel catfish without clipped adipose fins are represented by grey bars.



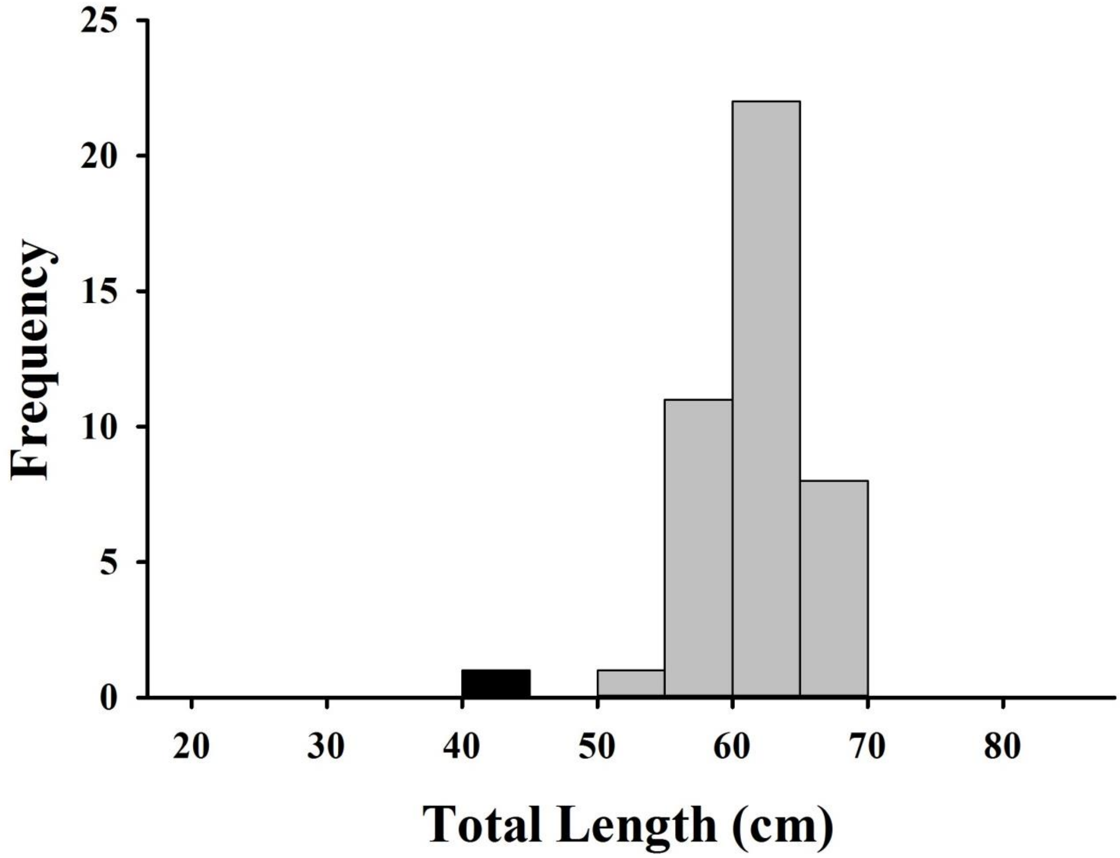
Appendix B.3. Length-frequency distribution of channel catfish captured in hoop nets during the summer (June-August) 2011 at Merganser Lake. Previously marked channel catfish were excluded to prevent channel catfish from being counted twice. Channel catfish with clipped adipose fins are represented by black bars and channel catfish without clipped adipose fins are represented by grey bars.



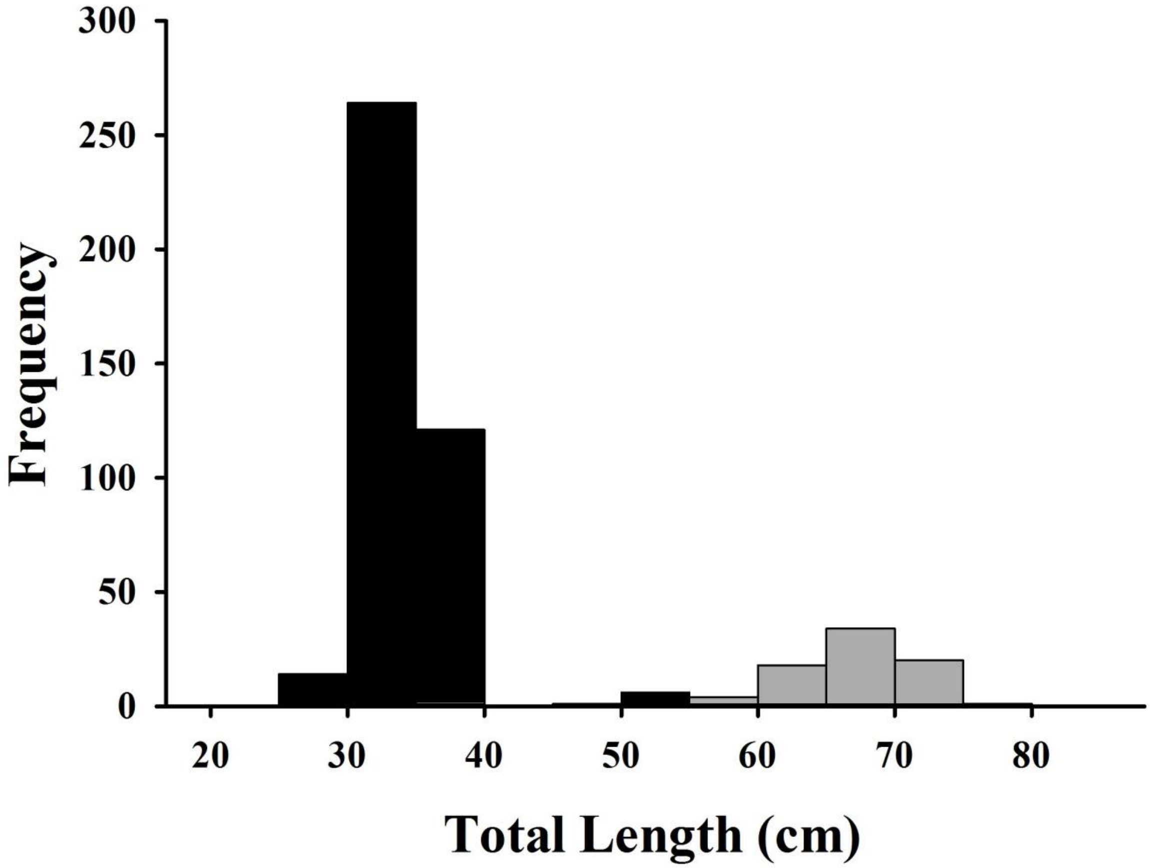
Appendix B.4. Length-frequency distribution of channel catfish captured in hoop nets during the summer (June-August) 2011 at Wild Plum Lake. Previously marked channel catfish were excluded to prevent channel catfish from being counted twice. Channel catfish with clipped adipose fins are represented by black bars and channel catfish without clipped adipose fins are represented by grey bars.



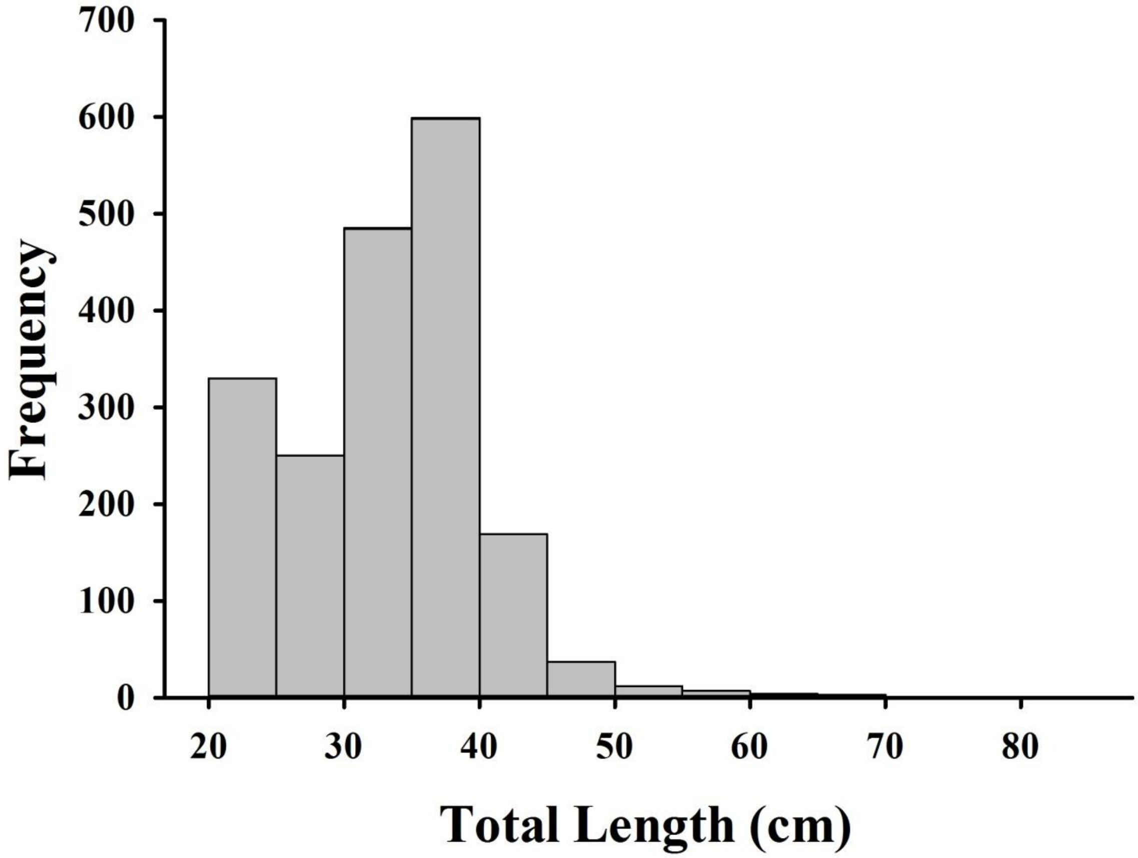
Appendix B.5. Length-frequency distribution of channel catfish captured in hoop nets during the summer (June-August) 2011 at Yankee Hill Lake. Previously marked channel catfish were excluded to prevent channel catfish from being counted twice. Channel catfish with clipped adipose fins are represented by black bars and channel catfish without clipped adipose fins are represented by grey bars.



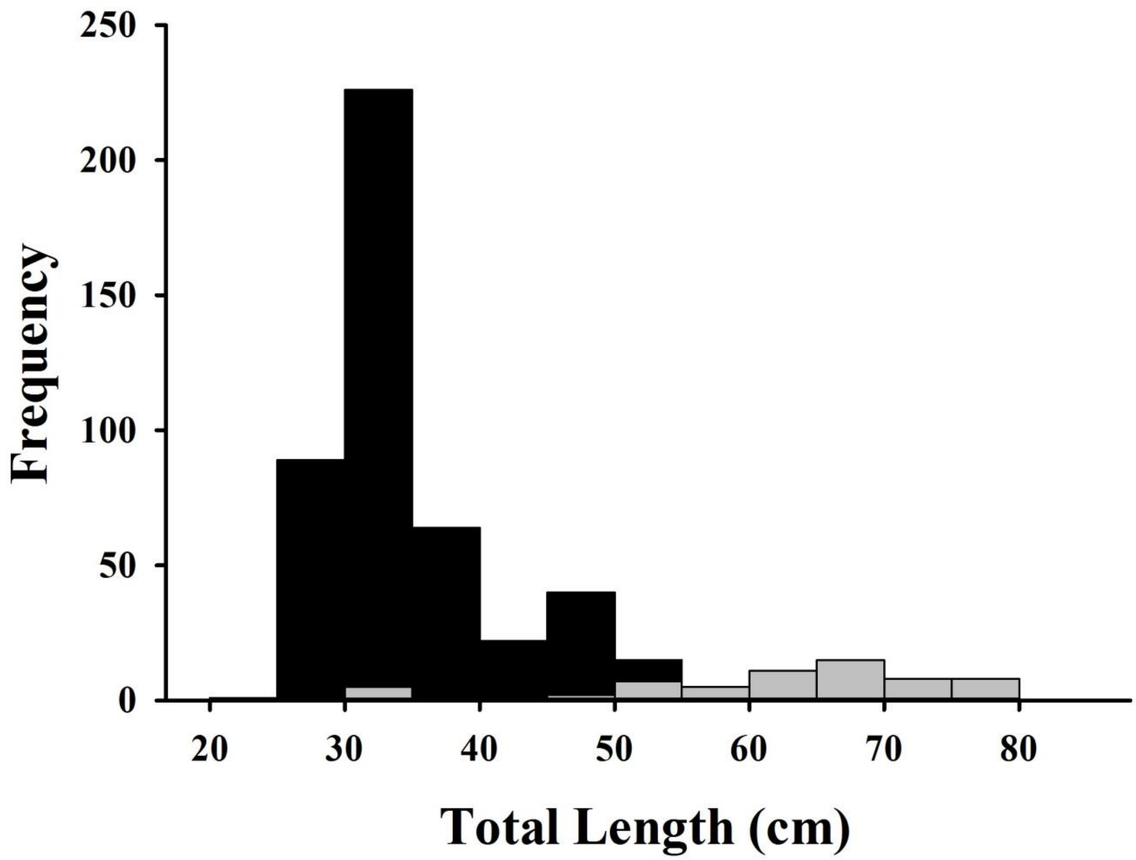
Appendix B.6. Length-frequency distribution of channel catfish captured in hoop nets during the summer (June-August) 2012 at Meadowlark Lake. Previously marked channel catfish were excluded to prevent channel catfish from being counted twice. Channel catfish with clipped adipose fins are represented by black bars and channel catfish without clipped adipose fins are represented by grey bars.



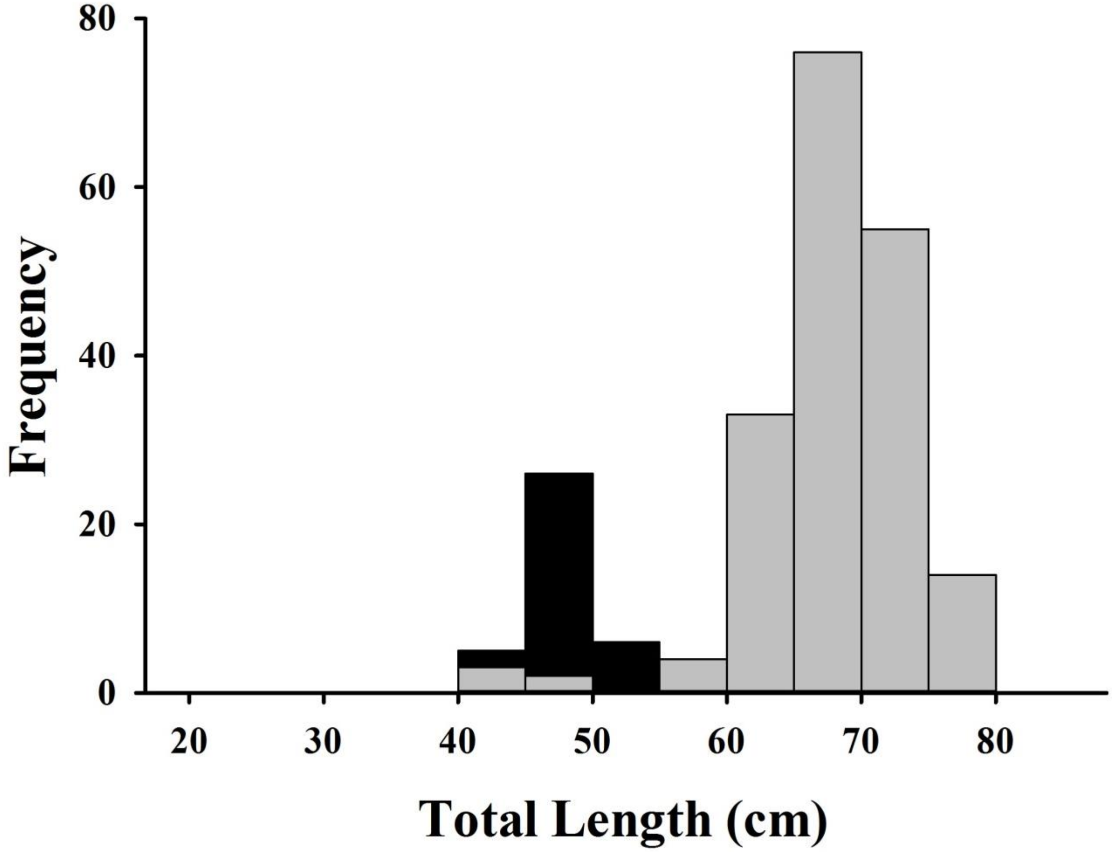
Appendix B.7. Length-frequency distribution of channel catfish captured in hoop nets during the summer (June-August) 2012 at Olive Creek Lake. Previously marked channel catfish were excluded to prevent channel catfish from being counted twice. Channel catfish with clipped adipose fins are represented by black bars and channel catfish without clipped adipose fins are represented by grey bars.



Appendix B.8. Length-frequency distribution of channel catfish captured in hoop nets during the summer (June-August) 2012 at Stagecoach Lake. Previously marked channel catfish were excluded to prevent channel catfish from being counted twice. Channel catfish with clipped adipose fins are represented by black bars and channel catfish without clipped adipose fins are represented by grey bars.

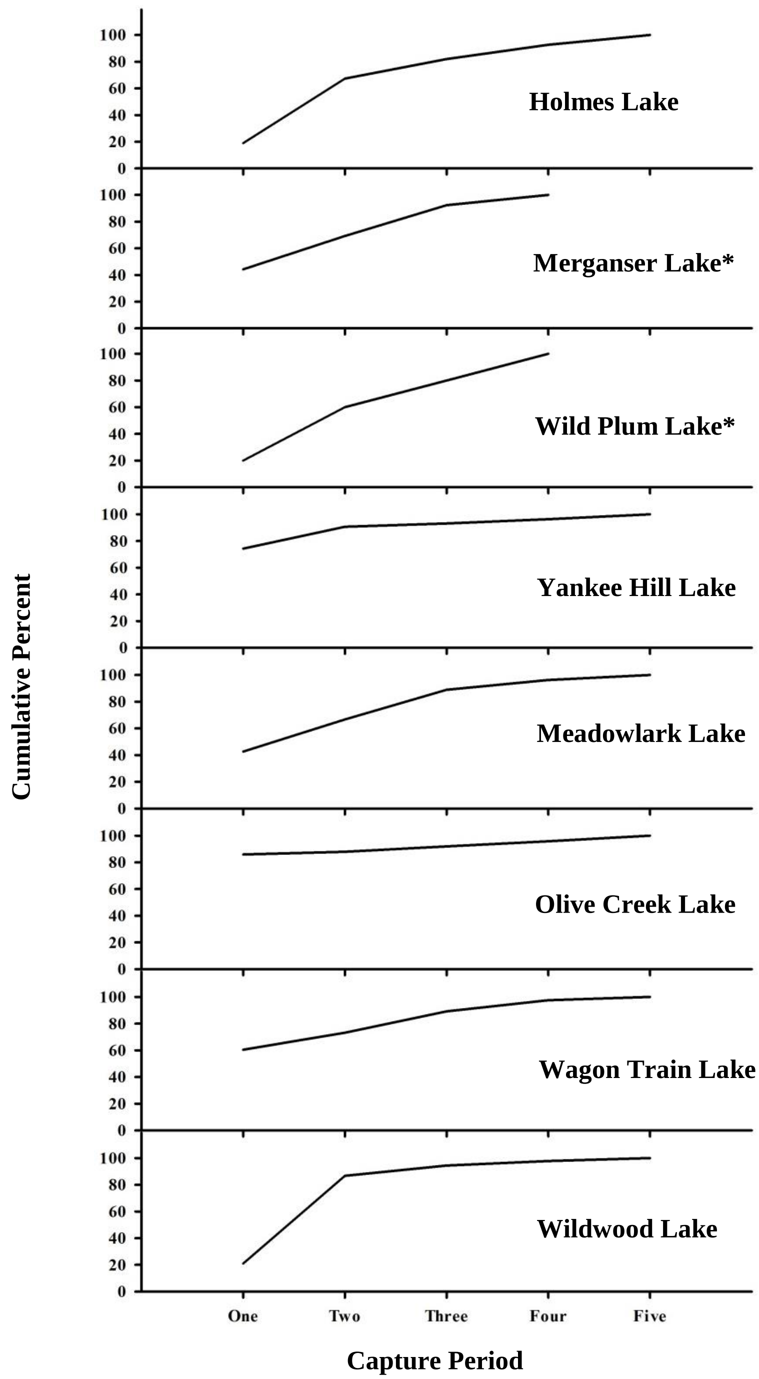


Appendix B.9. Length-frequency distribution of channel catfish captured in hoop nets during the summer (June-August) 2012 at Wagon Train Lake. Previously marked channel catfish were excluded to prevent channel catfish from being counted twice. Channel catfish with clipped adipose fins are represented by black bars and channel catfish without clipped adipose fins are represented by grey bars.



Appendix B.10. Length-frequency distribution of channel catfish captured in hoop nets during the summer (June-August) 2012 at Wildwood Lake. Previously marked channel catfish were excluded to prevent channel catfish from being counted twice. Channel catfish with clipped adipose fins are represented by black bars and channel catfish without clipped adipose fins are represented by grey bars.

Appendix C. Cumulative percent (percent of total catch) of channel catfish caught with hoop nets from eight Salt Creek reservoirs during the summers (June-August) of 2011 and 2012.



Appendix C.1. Cumulative percent (percent of total catch) of channel catfish caught with hoop nets from eight Salt Creek reservoirs during 2011 and 2012. Each bar represents the total number of channel catfish caught as of that sampling period divided by the total number of channel catfish caught at the corresponding reservoir during all capture periods.

Appendix D. Estimates of the percent of the annual catch and harvest of channel catfish that occurred during each month of the study period for exploitation.

Appendix D.1. Estimates and associated standard errors of the total number of channel catfish caught by anglers during the year studied (Annual Total) and each month (January-December) at Holmes Lake (lake code # 5745), Merganser Lake (5480), Wild Plum Lake (5495), and Yankee Hill Lake during 2011 and at (5265) Meadowlark Lake (5520), Olive Creek Lake (5120), Wagon Train Lake (5135), Wildwood Lake (5485) during 2012.

	Reservoir							
Period	5745	5520	5480	5120	5135	5495	5485	5265
January	0	0	0	0	0	0	0	0
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
February	0	0	0	0	0	0	0	0
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
March	0	0	0	0	784	0	0	0
	(0)	(0)	(0)	(0)	(401)	(0)	(0)	(0)
April	0	0	11	28	728	0	0	0
	(0)	(0)	(8)	(14)	(46)	(0)	(0)	(0)
May	59	0	0	235	1176	0	57	142
	(0)	(0)	(0)	(94)	(140)	(0)	(0)	(0)
June	326	23	22	143	848	0	61	721
	(80)	(0)	(14)	(13)	(21)	(0)	(0)	(0)
July	907	50	6	75	1355	0	405	64
	(46)	(0)	(0)	(7)	(111)	(0)	(0)	(0)
August	1210	11	0	85	1614	8	664	102
	(131)	(8)	(0)	(7)	(100)	(0)	(0)	(0)
September	58	0	0	15	441	0	22	180
	(0)	(0)	(0)	(0)	(15)	(0)	(0)	(36)
October	646	0	0	9	315	0	227	104
	(86)	(0)	(0)	(3)	(71)	(0)	(0)	(3)
November	0	0	0	0	109	0	0	0
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
December	0	0	0	0	0	0	0	0
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Annual Total	3207	84	39	591	7370	8	1435	1312
	(342)	(8)	(22)	(138)	(904)	(0)	(0)	(40)
Summer Total	2443	84	28	304	3817	8	1130	887
	(256)	(8)	(14)	(27)	(232)	(0)	(0)	(0)
%	76	100	72	51	52	100	79	68

Appendix D.2. Estimates and associated standard errors of the total number of channel catfish harvested by anglers during the year studied (Annual Total) and each month (January-December) at Holmes Lake (lake code # 5745), Merganser Lake (5480), Wild Plum Lake (5495), and Yankee Hill Lake during 2011 and at (5265) Meadowlark Lake (5520), Olive Creek Lake (5120), Wagon Train Lake (5135), Wildwood Lake (5485) during 2012.

	Reservoir							
Period	5745	5520	5480	5120	5135	5495	5485	5265
January	0	0	0	0	0	0	0	0
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
February	0	0	0	0	0	0	0	0
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
March	0	0	0	0	536	0	0	0
	(0)	(0)	(0)	(0)	(401)	(0)	(0)	(0)
April	0	0	11	28	251	0	0	0
	(0)	(0)	(8)	(14)	(46)	(0)	(0)	(0)
May	0	0	0	212	437	0	0	0
	(0)	(0)	(0)	(94)	(137)	(0)	(0)	(0)
June	199	0	22	41	203	0	0	0
	(86)	(0)	(14)	(13)	(21)	(0)	(0)	(0)
July	96	0	0	7	421	0	0	0
	(48)	(0)	(0)	(0)	(111)	(0)	(0)	(0)
August	329	11	0	0	334	0	0	0
	(148)	(8)	(0)	(0)	(100)	(0)	(0)	(0)
September	0	0	0	0	50	0	0	91
	(0)	(0)	(0)	(0)	(15)	(0)	(0)	(36)
October	302	0	0	9	96	0	0	10
	(102)	(0)	(0)	(3)	(71)	(0)	(0)	(3)
November	0	0	0	0	0	0	0	0
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
December	0	0	0	0	0	0	0	0
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Annual Total	925	11	32	312	2328	0	0	101
	(342)	(8)	(22)	(131)	(901)	(0)	(0)	(40)
Summer Total	623	11	22	63	41	0	0	0
	(282)	(8)	(14)	(20)	(232)	(0)	(0)	(0)
%	99	100	67	20	41	0	0	0