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Modeling Stocking Suitability at Lake Mcconaughy to Improve Initial Survival of Stocked Walleye (Sander Vitreus) and White Bass (Morone Chrysops)

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MODELING STOCKING SUITABILITY AT LAKE MCCONAUGHY TO IMPROVE INITIAL SURVIVAL OF STOCKED WALLEYE (*SANDER VITREUS*) AND WHITE BASS (*MORONE CHRYSOPS*)

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THESIS ACCEPTANCE

MODELING STOCKING SUITABILITY AT LAKE MCCONAUGHY TO IMPROVE INITIAL SURVIVAL OF STOCKED WALLEYE (*SANDER VITREUS*) AND WHITE BASS (*MORONE CHRYSOPS*)

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Supervisory Committee

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Abstract

Fish stocking continues to be an important and often-used tool in fisheries management. However, hatchery resources are often limited by funding and space. Therefore, survival of stocked fish is important to improve efficiencies and support important fisheries resources. Various strategies to improve survival have been examined over time, whether in the hatchery or in the waterbody. To improve stocking efficiency, managers should consider potential bottlenecks that could limit the survival of stocked products. To date, previous studies that have considered stocking in relation to these bottlenecks have only considered single factors at one time; however, multiple bottlenecks may be acting within a short time frame post-stocking. To my knowledge, no study has combined potential limiting factors to try to predict where to stock fish in order to support greater survival of stocked products. This study was designed to combine three factors – predator risk, zooplankton (food) availability, and measures of habitat – that could be important to the survival of stocked Walleye and White Bass fingerlings (25 – 50 mm total length) in Lake McConaughy, Nebraska, to create a predictive surface to identify optimum stocking locations. The spatial distribution of each factor was modelled using ArcMap 10.7.1 separately. Then, the three layers were combined into a final stocking layer that identified the best 12.8 and 13.9% of the predicted area of Lake McConaughy for stocking Walleye and White Bass, respectively. Both final stocking layers predicted that locations along the southcentral shoreline of Lake McConaughy were optimal for both stocked species. I hypothesized that predicted stocking locations would change between stocking events but found only subtle differences in predicted

stocking locations between the two. Implementation of the conceptual model when making stocking decisions has the potential to increase survival of stocked products and help managers reach population objectives more effectively.

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CHAPTER 1:

INTRODUCTION AND LITERATURE REVIEW

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Introduction

Fish stockings into public and privately owned waters have many purposes, including recreation, ornamentation, and food production (Trushenski et al. 2010), and are often used to introduce, maintain, or supplement sport fish populations (Jennings et al. 2005) and conserve native fish species (Steffensen et al. 2010). Introductory stockings are used in locally extirpated, new, or renovated lakes and reservoirs with the goal of establishing a recreational fishery (Kerr 2011). Maintenance stockings are used in areas that fish naturally occur but no longer have a self-sustaining population (Agostinho et al. 2010). Supplemental stocking programs generally occur in waterbodies that have established populations, but mortality and angler harvest exceed the supply natural recruitment provides (Radomski et al. 2001; Kerr 2011; Hansen et al. 2015). Numbers and sizes of stocked fish and the frequency of stocking differ based on management or conservation goals (Fielder 1992). However, stocking can be an expensive endeavor and results can be variable (Hunt et al. 2017); thus, management agencies often look to optimize survival of stocked fish to improve stocking efficiency (Buckmeier et al. 2003, 2005).

Fish may encounter many bottlenecks that could limit the success of stocking, particularly at fry and fingerling life stages (Agostinho et al. 2010). Concerns when stocking naïve hatchery fish often center around predation (Buckmeier et al. 2005; Lundgren et al. 2014) and their ability to find appropriate food (Jonas and Wahl 1998) and habitat (Hanson and Margenau 1992). To avoid these potential bottlenecks a variety of culture techniques have been employed, including stocking fish at different sizes

(Brooks et al. 2002) and training fish to recognize predators (Kelley and Magurran 2003; Sloychuk et al. 2016) and food that exists within lakes and reservoirs rather than what is available in pellet or flake form (Szendrey and Wahl 1995). Other studies have evaluated stocked fish survival relative to habitat proximity (Taylor and Suthers 2008) and distances from shoreline with consideration of water depth (Weidel et al. 2022). However, few studies have considered multiple bottlenecks together when making stocking decisions (Molony et al. 2003).

Walleye (*Sander vitreus*) are one of the most stocked species in the United States (Freedman et al. 2012) and were stocked in 34 states in 2004 alone (Halverson 2008). Despite substantial stocking efforts, Walleye populations are in decline across many U.S. waters, potentially due to climate change-related impacts to recruitment and available habitat and the introductions of non-native aquatic species such as Zebra Mussels (*Dreissena polymorpha*; Hale et al. 2008; Hansen et al. 2015; Hansen et al. 2022) and Smallmouth Bass (*Micropterus dolomieu*; Van Zuiden and Sharma 2016). Warming temperatures have variable impacts on Walleye recruitment; higher average winter temperatures could negatively impact Walleye gamete development while warmer spring temperatures could positively impact Walleye year-class strength (Colby and Nepszy 1981; DeBoer et al. 2013). Introduction of Zebra Mussels may increase water clarity which could be negatively impacting the overall abundance of Walleye (Hansen et al. 2022) by decreasing feeding efficiency (Vandenbyllaardt et al. 1991). The aggressive territorial behavior of Smallmouth Bass can force Walleye away from littoral zones where they often feed (Galster et al. 2012). Because of these ongoing challenges to

Walleye recruitment, it is likely that the number and frequency of Walleye stocked will continue to increase.

Recruitment of other species, such as White Bass (*Morone chrysops*), have been found to be related to both biotic and abiotic factors as well (DeBoer et al. 2013). White Bass natural recruitment is often erratic (Ahrens et al. 2010) and linked to age-0 total fish CPUE or abundance of adult centrarchids such as Black (*Pomoxis nigromaculatus*) and White Crappie (*P. annularis*; DeBoer et al. 2013; Radigan and Fincel 2022). Abiotic factors such as higher spring precipitation and inflow and warmer air temperatures in June and July have also been tied to increases in White Bass natural recruitment (Beck et al. 1997; DiCenzo and Duval 2002). However, only a few states (four in 2004) stock White Bass to maintain populations for recreational fishing (Halverson 2008).

In Nebraska, Walleye and White Bass are stocked into many reservoirs across the state. In 2016, over 43 million Walleye were stocked across 51 reservoirs and 607,000 White Bass were stocked into two reservoirs (NGPC stocking database). Walleye were most often stocked as fry (40,179,834 fish), followed by fingerlings (25 – 50 mm total length; 3,454,236 fish) and advanced fingerlings (175 – 200 mm total length; 19,519 fish), while White Bass were stocked only as fingerlings (25 – 30 mm total length; 607,872 fish; NGPC stocking database). During 2016, 36% (1,584,717 fish) of Walleye and 95% (578,372 fish) of White Bass fingerling stockings occurred at one waterbody, Lake McConaughy. Fingerling and advanced fingerling production is limited by hatchery pond availability, and costs increase as size of fish increases (Bryan Sweet, NGPC, *personal communication*). The high numbers of fingerlings stocked at Lake McConaughy by the Nebraska Game and Parks Commission (NGPC) provides an opportunity to investigate the most appropriate locations to improve survival of stocked products at their specific life stage.

Problem and Need

At Lake McConaughy (Figure 1), NGPC has designated Walleye and White Bass as priority species with a management goal to maintain 20 and 10 individuals per gill net in standardized fall surveys, respectively (Darrol Eichner, NGPC, *personal communication*). Since 2000, gill-net catch rates for Walleye continue to meet management goals while White Bass have fallen below desired levels (NGPC, *unpublished data*). The NGPC stocks fingerlings between 25–50 mm to limit predation by Alewife (Brooking et al. 1998). From 2014 – 2016, an average of 1,465,209 (±164,267; one standard error) Walleye and 428,365 (±79,886) White Bass (Table 1) fingerlings were released in Lake McConaughy. Evaluations using oxytetracycline (OTC) from 2015 – 2018 indicated that most (91 ± 2%) age-0 Walleye were of hatchery origin (Rowles 2019). Stock contribution by White Bass was evaluated using otolith microchemistry across three years found that anywhere from 8 – 40% of fall age-0 fish were of hatchery origin (Perrion 2016; Rowles 2019). High contributions of stocked Walleye and highly variable contributions of stocked White Bass suggest there may be some differences in the stocking efficacy for both species.

To maximize survival, stocking plans must account for both biotic and abiotic factors that could contribute to stocking success (Agostinho et al. 2010). Specifically, stocking fish in areas with less predators and near food could prevent mortality by limiting predation and increasing growth rates (Jonas and Wahl 1998; Lundgren et al. 2014). Identifying areas with abundant zooplankton that will provide adequate food as Walleye and White Bass begin to make their ontogenetic shift to other prey items post stocking could improve stocking success (Roseman et al. 2005; Perrion 2016). Finally, habitat can be important for fish survival as cover, a feeding location, and to support development (Braekevelt et al. 1989; Hanson and Margenau 1992; Wahl 1995). Habitat needs for Walleye and White Bass are different (Hamilton and Nelson 1984; McMahon et al. 1984) and, thus, will require species-specific identifications of optimal habitat conditions. Water clarity appears to play a factor in Walleye age-0 eye development, feeding, and survival (Braekevelt et al. 1989; Bristow et al. 1996); however, turbidities that are too high can also decrease feeding efficiency (Bulkowski and Meade 1983). Evidence suggests age-0 White Bass feed more efficiently when they are found in an area with shallow sandy substrate adjacent to deep water (Hamilton and Nelson 1984). Considerations of all three factors – predation risk, food availability, and habitat – together for selection of Walleye and White Bass fingerling stocking locations could provide NGPC with new stocking locations that could improve survival of stocked products and provide a blueprint for other waterbodies.

Objectives

The objective of my study was to develop predictive models as layers in GIS for both Walleye and White Bass fingerlings using variables I hypothesized would improve immediate survival of each stocked product at Lake McConaughy. To meet this objective, I quantified predation risk, estimated relative zooplankton density, and measured habitat factors (water transparency and bank slope) for both Walleye and White Bass during their stocking timeframes. I hypothesized that stocking layers developed for Walleye and White Bass would show different suggested stocking locations for each species in areas outside of historic stocking locations. Further, I hypothesized the upper end would have the most optimal stocking locations because of the productivity gradient observed in Lake McConaughy.

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Tables

Table 1. Walleye and White Bass fingerling stockings from 2014 – 2016 at Lake McConaughy, Nebraska.

Year	Walleye	White Bass
2014	1,140,241	305,725
2015	1,670,670	401,000
2016	1,584,717	578,372

Figures

Figure 1. Lake McConaughy located 14 km north of Ogallala, Nebraska.

CHAPTER 2:

APPLYING A CONCEPTUAL MODEL TO DEVELOP A STOCKING MAP USING LAKE MCCONAUGHY, NEBRASKA

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Introduction

Managing freshwater recreational fisheries is increasingly challenging as natural recruitment of many species has declined across their range (Bethke and Staples 2015; Van Zuiden and Sharma 2016; Rypel et al. 2018; Sass et al. 2021) due to factors such as climate change (Hansen et al. 2015a, 2015b), introductions or increases of unwanted species (Carpenter et al. 2011; Hansen et al. 2015b, 2017), and water quality degradation (Feiner and Höök 2015; Feiner et al. 2022). In response, managers have initiated more frequent supplemental stocking programs (Grausgruber and Weber 2020; Rahel 2022). However, stocking of fish requires substantial investments in personnel and hatchery infrastructure (Hunt et al. 2017; Trushenski et al. 2018) and has variable levels of success in producing moderate to strong year classes (Brown and Sauver 2002; Hoxmeier and Wahl 2002; Jennings et al. 2005; Haley and Neal 2021). Identification of factors that support or limit the contributions of stocked fish to the recreational fishery can improve economic efficiency related to management of these resources (Raabe et al. 2020).

Stocked fish face several bottlenecks that limit their survival (Ellison and Franzin 1992; Fielder 1992; Wahl 1999; Agostinho et al. 2010). When first stocked, hatchery raised fish are naïve and do not exhibit natural behaviors that allow them to utilize the new resources available to them and recognize the dangers (i.e., predators) that exist in this new environment (Kopack et al. 2015). As a result, one of the first bottlenecks may be related to predation of the stocked product while those fish are still naïve (Buckmeier et al. 2005; Lundgren et al. 2014). For example, more than a quarter (27.5%) of fingerling Florida Largemouth Bass (*Micropterus salmoides floridanus*) were consumed within the first 12 hours after stocking in Texas (Buckmeier et al. 2005). Lundgren et al. (2014) found that susceptibility of Yellow Perch (*Perca flavescens*) to predation was highest within the first three days post-stocking.

Aside from predation, other bottlenecks for stocked fish that are less understood but could still be important to survival of stocked fish include food (Ellison and Franzin 1992; Kestemont and Baras 2001) and habitat availability (Hanson and Margenau 1992; Wahl 1995). Walleye between 8 – 24 mm will die due to starvation within 6 – 8 days or become vulnerable to predation due to low energy reserves within 6 days post-stocking (Jonas and Wahl 1998). Fish may be stocked near abundant prey resources in order to reduce the energetic cost of searching for food (Taylor and Suthers 2008). Access to cover habitat may assist in predator avoidance (Gotceitas and Colgan 1987; McLean and Godin 1989) or lower predator consumption rates on stocked fish (Carter et al 2010). For example, Muskellunge (*Esox masquinongy*) prefer shallow water (< 3 m) with vegetation (Hanson and Margenau 1992), but survival of stocked fish may only increase when the habitat they selected was not already occupied by predators (Hanson et al. 1986).

Several fish rearing and stocking strategies have been tested in attempts to improve survival and subsequent recruitment of stocked fish (Suboski and Templeton 1989; Brown and Laland 2001). Alternative culture techniques often involve trainings to find fish (Szendrey and Wahl 1995) or invertebrate prey (Reiriz et al. 1998) or recognize predators (Kelley and Magurran 2003; Griffin 2004; Olson et al. 2012; Sloychuk et al. 2016). Other strategies such as the use of different (i.e., older or larger) hatchery products (Brooks et al. 2002; Lawson and Carpenter 2014), stocking at night (Roberts et al. 2009), or stocking away from (Weidel et al. 2022) or near shore (Buckmeier et al. 2005) or into specific habitats (Taylor and Suthers 2008; Taylor et al. 2013) have had variable success (Lantry et al. 2011; Brown et al. 2013). Alternative culture techniques and stocking strategies create added work and costs that would need to be justified by improved survival and year-class contribution to continue (Maynard et al. 1995).

To date, most studies have considered the importance of predator distribution, food, and habitat availability on stocked fish as isolated or individual factors (Pearsons and Hopley 1999; Trushenski et al. 2010; Askey et al. 2013). Inclusion of all these factors simultaneously, along with information on the spatial distributions of such factors within a waterbody could be used to create a predictive surface layer in GIS to help guide stocking decisions. If such layers can be produced for one waterbody for different stocked species with similar but different factors influencing their survival, then the concept could be applied for other species and waterbodies where stocking occurs. To explore development of such a predictive model, I used one early (Walleye) and one later (White Bass) stocked species that have been stocked regularly since 2000 in Lake McConaughy, Nebraska (Darrol Eichner, NGPC, *personal communication*). To create these surfaces, I quantified the spatial distribution of predation risk, zooplankton (prey) densities, and measures of habitat that may influence the survival of stocked Walleye and White Bass.

Methods

Kingsley Dam was completed in 1941 and impounds the North Platte River in Keith County, Nebraska. The construction of the dam created Lake McConaughy, a 14,164-ha irrigation and power reservoir that is owned and operated by the Central

Nebraska Public Power and Irrigation District and was the second largest hydraulic filled dam in the world at the time of completion (Porath et al. 2003; Buettner 2016). Conservation pool elevation of the reservoir is 995.6 m and maximum depth is 43 m (Porath et al. 2003). Water elevation can be variable annually with a maximum observed drawdown exceeding 8 m (Darrol Eichner, NGPC, *personal communication*). The Nebraska Game and Parks Commission (NGPC) manages the fishery in the reservoir. Walleye and White Bass are the two priority species; current management targets for relative abundance of each species are 20 and 10 fish/net, respectively, from annual standard surveys (Darrol Eichner, NGPC, *personal communication*). Alewife (*Alosa pseudoharengus*) were stocked as adults from 1986 – 1988 to provide additional forage and have been the primary prey available to juvenile and adult predators in the system since the 1990s (Porath and Peters 1997). However, Alewife have been shown to consume zooplankton and larval fish (Brooking et al. 1998; Perrion 2016), which could negatively impact recruitment of their predators. In response, NGPC began stocking fingerling (25 – 50 mm TL) Walleye (early June) and White Bass (late June) annually in 1989 and 2000, respectively. In 2017 and 2018, 1,730,985 and 1,808,025 Walleye and 360,226 and 115,815 White Bass were stocked in Lake McConaughy. Stockings historically occurred from shore at four boat ramps or existing lake access points (Figure 1).

To identify locations where stocked Walleye and White Bass short-term survival might be higher relative to other locations across Lake McConaughy, I created a predictive model in GIS that included predation risk, prey availability, and a measure of habitat quality. I hypothesized that the ability of stocked fish to recruit to older life stages is dependent on avoiding predation, finding appropriate food resources, and habitat (Figure 2). Each layer in the GIS model was a separate variable reflecting the potential relative importance of each factor.

To develop the predation risk layer, I identified fish taxa in Lake McConaughy that are known to be piscivorous. Thus, potential predators included Walleye, White Bass, Alewife, Hybrid Striped Bass (*Morone chrysops x M. saxatilis*), Northern Pike (*Esox lucius*), Smallmouth Bass (*Micropterus dolomieu*), Channel Catfish (*Ictalurus punctatus*), Yellow Perch (*Perca flavescens)*, and Black Crappie (*Pomoxis nigromaculatus*). To determine which of these potential predators were more likely to consume Walleye and White Bass, I first identified those predators that consumed each of the stocked products. Potential predators were collected within 1 km of Walleye and White Bass stocking locations no more than 24 h after stocking events in 2017 and 2018. Predators were collected using experimental gill nets with six, 7.6-m panels of 19.1-, 25.4-, 31.8-, 38.1-, 50.8-, and 76.2-mm bar mesh (Zuerlein and Taylor 1985; Schall 2016). Sampling started 1 h prior to dusk and continued until after midnight the next day to capture predators during the crepuscular and nocturnal feeding periods (Willis et al. 2002). Nets were allowed to soak for approximately 1 h before they were pulled to reduce stress on captured fish and prevent food regurgitation (Kocovsky and Carline 2001) and were continuously re-set throughout the night if predators with full stomachs continued to be captured. Supplemental collections were also conducted with a Smith-Root Sr-18 electrofishing boat as time allowed to target near-shore habitats and species that were not vulnerable to capture by gill net (i.e., Smallmouth Bass).

Because food habits can change with length of predators (Hartman 1998), I quantified consumption for each predator by length group (< preferred and ≥ preferred length; Table 1; Gabelhouse 1984). All potential predators collected were measured for total length (TL; mm) and assigned a unique identification number. Stomach contents were collected by pulsed gastric lavage to reduce predator mortality (Lundgren et al. 2014) unless the mouth gape of the predator was smaller than the diameter of the lavage (12 mm). In these cases, the entire stomach was excised from sacrificed fish. Stomach contents for lavaged predators were collected in a 500-µm sieve, placed in a Whirl-Pak bag, and preserved in 90% ethyl alcohol. The goal was to collect stomach contents from at least 20 individuals from each length category for all predators during the stocking of both species. All fish collected were released back into Lake McConaughy immediately after lavaging. Samples were transported to the University of Nebraska at Kearney for processing, and all consumed fish were identified to species when possible and enumerated. Frequency of occurrence (O_i; Bowen 1996) was calculated for each predator length category for 2017 and 2018 based on the number of stomachs with food that also contained at least one Walleye or White Bass fingerling. To quantify the relative risk of each predator species, the total number of Walleye or White Bass fingerlings consumed by that predator was divided by the total number of stomachs with food from those predators during each stocking period (e.g., Walleye or White Bass) across both years.

Each relative risk value was combined with previous predator spatial distribution data (Schall et al. 2019) to create a surface of predator risk for the entire reservoir. Prior gill-net collections across Lake McConaughy occurred in May and July (n = 72 per month) 2015 and 2016 and were set at randomly defined locations divided equally between the north and south shores (see Schall et al. 2019 for details). Relative abundance estimates (number of fish/net) were calculated for each predator length category; however, Smallmouth Bass were not represented in gill-net catches. Thus, nighttime boat electrofishing (described previously) was conducted in June 2019 at each gill-net location by shocking parallel to nearshore habitat for 5 min. Smallmouth Bass catch per unit effort (CPUE) was indexed as the number per 5 min and was used instead of relative abundances of Smallmouth Bass captured in prior gill net collections. Relative abundances from May and July gill-net collections combined with the Smallmouth Bass nighttime electrofishing data were multiplied by the relative risk value for consumption of Walleye and White Bass fingerlings, respectively, at each sampling location. These products were summed to determine a total predation risk for both Walleye and White Bass fingerlings for each stocking timeframe (early and late June).

The second predictive layer for both Walleye and White Bass included zooplankton availability. Juvenile Walleye (Woiak 2014; Uphoff et al. 2019) and White Bass (Miller et al. 2019) have been shown to positively select for *Calanoida* spp. in another Nebraska reservoir. Perrion (2016) found White Bass in Lake McConaughy positively selected for *Calanoida* spp. when they were present but still consumed *Cyclopoida* spp. if they were available. Thus, the combined densities of *Calanoida* and

Cyclopoida spp. were used to represent food resources available for stocked fingerling Walleye and White Bass. Zooplankton collections were conducted every 2 km along the north and south shore starting from Kingsley Dam during both Walleye and White Bass stocking events in 2018. Zooplankton were sampled with a Wisconsin plankton net (80-µm mesh, 0.5-m^2 opening) towed vertically from a depth of 2 m. Each sample was labeled and preserved in a 4% formalin and sucrose mixture (Haney and Hall 1973). Zooplankton were processed following protocol described by Peterson et al. (2005).

The third predictive layer included aspects of habitat for both Walleye and White Bass, but the habitat metric used differed between the two species. The Habitat Suitability Index (HSI) for juvenile Walleye indicated that locations with Secchi disk depths between 1 and 3 m were preferred (McMahon et al. 1984). Transparency was previously measured throughout the reservoir by Schall et al. (2019) at the same spatial locations as predator gill-net collections. Measurements were taken by lowering a Secchi disk from the shaded side of the boat until visibility was lost and then raising the disk until it became visible again (Burns et al. 2005). If the Secchi disk reached the substrate and was still visible, the measurement was attempted again in a deeper location on the same longitudinal plane. All Secchi disk depths were measured to the nearest 5 mm.

The HSI for juvenile White Bass indicated a preference for sandy shoal habitat (Hamilton and Nelson 1984). Because Lake McConaughy is dominated by sandy substrate (Verstraeten et al. 1995), it was not anticipated that this metric varied enough to create a predictive surface. The HSI also indicated depth between 0.5 – 1.5 m is preferred by juvenile White Bass; thus, I selected bank slope as an indicator of depth that would also indicate shoal habitat. Locations with a more gradual slope (i.e., < 2% change in slope) were deemed more suitable than steeper locations (i.e., ≥ 2% change in slope). Bank slopes were calculated from previous data collections (Schall 2019) as the difference in depth from the start to the end of the gill-net set divided by the length of net used (45.7 m).

Data from each of the parameters described above (predation risk, zooplankton availability, and habitat) were used to create four surface layers for each species (one for each parameter and a final predictive layer that combined all three input surfaces) in ArcMap 10.7.1. Ordinary kriging was used to predict the area in between data collection locations due to its ability to handle spatially random data and provide a measure of statistical uncertainty (Murphy et al. 2009). Each layer was run with both a 1st-and 2nd-order trend removal, and cross-validation was used to determine which of the two corrections was most accurate (Nas and Berktay 2010). Cross-validation omits one point at a time to determine how well the model predicts that location using adjacent data (described by Dubrule 1983). Four criteria were used to identify which trend removal most accurately predicted parameter values at known locations: 1) an average error close to zero; 2) a small root mean square prediction error; 3) an average standard error similar to the root mean square prediction error; and 4) a standardized error mean prediction error near zero (Johnston et al. 2001). The trend removal that satisfied the greatest number of these criteria was selected as the best fit for each layer. After cross-validation was completed, layers were converted to ArcMap grids and clipped to the geographic extent of Lake McConaughy. Because all sampling of parameters occurred within 1 km from the shore, the geographic extent of the surface layers was clipped using a 1-km shoreline buffer. The surface layers were then displayed using a quartile classification with four classes (25th, 50th, 75th, and 100th percentiles) for all layers except Secchi depth. This method was chosen due to its ability to represent equal intervals of data (Milic et al. 2019; ESRI 2022).

To identify the top 50% of locations for each of the parameters, the raster grid cells of each surface layer were split into two classes (“Optimal” and “Sub-optimal”) at the natural break identified by ArcMap 10.7.1 near the 50th percentile. Then, grid cells that fell within the top 50% (“Optimal” class) of the raster layer were assigned a “1” while areas outside the top 50% (“Sub-optimal” class) were assigned a ”0” using the Reclassify tool in ArcMap 10.7.1. After reclassification, the Raster Calculator tool was used to multiply the three surface layers for each stocked species together. By multiplying all three surface layers together to produce the stocking layer for Walleye and White Bass, only grid cells with three "1's" fell within the top 50% of all layers. If a “0” was present in any of the three layers, then that grid cell fell outside of the top 50% of all layers. Thus, the final stocking layers for each stocked species that included all three variables identified approximately 12.5% of the sampled area of Lake McConaughy that was expected to support greater immediate post-stocking survival for Walleye and White Bass fingerlings.

Results and Discussion

Predation Risk Layers – Catch was variable between stocking events and years for several predator taxa (Tables 2 and 3). For example, I handled 37 <preferred length

Hybrid Striped Bass during Walleye stocking in 2017 but only 9 in 2018. Similarly, I handled 0 <preferred length Hybrid Striped Bass during White Bass stocking in 2017 and 23 in 2018. The temporal variability in catch may be related to species-specific movement patterns. Various species have been noted to move near or away from shore to spawning locations (Beck and Willis 2000; Jackson and Hightower 2001), seek out suitable water quality (Farquhar and Gutreuter 1989; Zale et al. 1990; Beck and Willis 2000; Prchalová et al. 2009; Henesy et al. 2022), and appropriate prey (Brandt 1980; Olson et al. 2007). Additionally, Walleye and Moronids in this study could be vertically separated due to depth preferences (Van Den Avyle et al. 1983; Willis et al. 2002; Olson et al. 2007; Lincoln et al. 2016). Previous sampling on Lake McConaughy also noted differences in the spatial distribution of different predators, though these differences were noted between seasons (Schall et al. 2019) rather than within the shorter time frame of my collections within each year. The observed spatial and temporal variability in my study amplifies the need to develop time-specific predator maps in this system; similar differences in predator distributions may be found elsewhere (Specziár et al. 2013).

I collected food habits from 472 and 186 predators with food in their stomachs during Walleye and White Bass stocking, respectively (Tables 2 and 3). Every length category of predators was observed consuming either Walleye or White Bass fingerlings, except ≥preferred Channel Catfish (Tables 2 and 3). For most predator length categories, O_i was inconsistent between years and between the two stocking events (Tables 2 and 3). The O_i was higher for stocking events in 2018 compared to 2017. The O_i values were consistently higher during the Walleye stocking period than during the White Bass stocking period. Hybrid Striped Bass, Smallmouth Bass, and White Bass <preferred length had the highest O_i for both stockings. The only occurrences of a larger length category having a higher O_i than the smaller one was Smallmouth Bass during the 2017 Walleye stocking and Walleye during the 2018 White Bass stocking. In both instances, the number of larger predators handled was low which could have influenced the overall calculation of O_i. Taxa with a higher O_i could be selecting for stocked fingerlings when they are introduced, while taxa with a lower O_i could have a preferred food source (i.e., Alewife) that limits fingerling consumption or could be exhibiting opportunistic feeding strategies (Bowen 1996). However, Bowen (1996) warns against over inferring the importance of O_i results as encounter probability could differ among predator taxa. The variety of species found consuming stocked fingerlings confirms the need to evaluate all possible predators within a system to determine which ones are potentially impacting hatchery products.

The predators that consumed both species of stocked fish at the highest rates per individual were Hybrid Striped Bass, Smallmouth Bass, and White Bass (Tables 2 and 3). Which predators are riskier to stocked products may relate to a number of factors, including characteristics of the predators themselves (Graeb et al. 2005; Mihalitsis and Bellwood 2017) and their ability to feed on a variety of prey (Gilliland 1982; Weidel et al. 2000; Schultz et al. 2002; Willis et al. 2002; Schake et al. 2014) or specialize on a specific prey (i.e., stocked fish) (Scheibel et al. 2016). Interestingly, all three top predators are ecomorphologically similar (Edwards et al. 1983; Kilpatrick 2004; Lueckenhoff 2011); body morphology can influence predation rates as it relates to swimming speed and capture efficiency (Videler and Wardle 1991; Videler 1993; Wolter and Arlinghaus 2003; Mihalitsis and Bellwood 2017). However, various ecological aspects of the three species differ. Hybrid Striped Bass and White Bass most often swim in schools within the epipelagic zone (McNaught and Hasler 1961; Hamilton and Nelson 1984; Kilpatrick 2004), whereas Smallmouth Bass often concentrate around habitat structure but do not shoal (Edwards et al. 1983; Miranda et al. 2021). Schooling piscivores, such as Hybrid Striped Bass and White Bass, could have higher capture rates than individual predators when encountering a large group of prey fish (Major 1978). In contrast, solitary predators, like Walleye or Smallmouth Bass, are better suited for capturing individual prey that have broken away from the larger group (Major 1978; Winemiller and Taylor 1987). In addition to feeding habits, the habitat of the predators may also influence predation rates. For example, littoral species such as Smallmouth Bass (Edwards et al. 1983) may already be present around sites where stocking occurs. Other species such as White Bass (Devine and Shiozawa 1984) and Walleye (Kelso 1978) may move into the stocking locations during the crepuscular period. Waterbody specific consideration of which predators are present and what habitats they occupy could help determine where to stock hatchery products.

Relative predation risk for both stocked species were three times higher among the smaller (<preferred) categories when compared to the larger (≥preferred) categories (Tables 2 and 3). Larger predator food habits were largely composed of Alewife (between 150 – 170 mm TL) while smaller categories, when not consuming stocked fingerlings, contained more macroinvertebrates than other fish (Appendix 1). The pattern of increased

consumption of stocked fingerlings by smaller predators may be related to the optimum foraging theory, where energy gained by consuming a prey item is expected to be higher than energy expended (MacArthur and Pianka 1966). While larger prey will provide more energy than smaller prey, larger prey are often more difficult to capture (Boisclair and Leggett 1989). Mouth gape (Schmitt and Holbrook 1984; Slaughter and Jacobson 2008) and swimming speed of predators both increase as fish TL increases, which contributes to higher prey capture efficiency (Webb 1976; Hammer 1995; Domenici 2001; Wolter and Arlinghaus 2003). Smaller predators might not be large enough to capture and consume the larger Alewife that are available during fingerling stockings (Schall 2019). Compared to larger predators, smaller predators do not have as high of total energy demands but their metabolism rates are higher on a per gram basis (Arim et al. 2016). Thus, to meet high metabolic energy demand, the increase in capture efficiency by smaller predators on naïve stocked fingerlings could make these fish a better food source in relation to the optimum foraging theory by decreasing capture time and allowing for higher energy utilization (MacArthur and Pianka 1966).

The ecology of each prey (stocked) species, such as movement rates, may influence their relative predation. For instance, if hatchery fingerlings remain near the location they are stocked, it could influence the number of potential encounters with predators. Parsons and Pereira (1997) found that fingerling Walleye stocked in the fall often stayed near (< 1 – 4 km over multiple lakes) stocking locations for several years. By remaining in the same location, the stocked fish could be exhibiting shoaling (Walleye; Pratt and Fox 2001) or schooling (White Bass; Hamilton and Nelson 1984) behavior, which would leave the fingerlings in larger groups that would favor predators that employed capture techniques more effective at exploiting grouped prey. Similarly, in Iowa, large Walleye fingerings (> 200 mm TL) dispersed more than 400 m within 1 d post-stocking and moved nearly 1,400 m within 13 d (Weber et al. 2020). If movement is more individualized, this behavior could make these fish more vulnerable to some predators (Winemiller and Taylor 1987). Unfortunately, dispersal of smaller Walleye and White Bass fingerlings (< 40 mm TL) is not well understood and needs further investigation. Body size, species preference towards pelagic or demersal habitats (Pratt and Fox 2001; Kilpatrick 2004), and wind (direction and speed) could further influence dispersal from stocking locations (Ellison and Franzin 1992). Thus, consideration into how stocked species disperse once released could be important to the identification of potential stocking locations and development of stocking maps (Radinger and Wolter 2014; Weberg et al. 2020).

Spatial distribution of predicted predation risk varied across Lake McConaughy between Walleye and White Bass stockings (Figures 3 and 4). During Walleye stocking, higher predation risk was concentrated in the middle and lower part of the reservoir, while higher predation risk for stocked White Bass was more concentrated in the upper portion. Changes in predicted predation highlights the need for individualized plans for different stocked species within the same reservoir. Often, stocking plans only consider the specific species being stocked and adjustments focus on the rate (number per hectare) and developmental stage (size) at the time of stocking (Fielder 1992). These blanket strategies are deployed without considering how stocked species and predator needs (e.g., habitat, water quality, food, etc.) vary and could limit stocking success (Molony et al. 2003; Agostinho et al. 2010). For example, adult White Bass can be found near and away from shore, depending on temperature, cloud cover, precipitation, and moon phase (Beck and Willis 2000; Willis et al. 2002). If timing of stockings could be manipulated to avoid times when more predators are near shore, predation on stocked products may be reduced (Buckmeier et al. 2005).

A major limitation of the predation layer was the lack of available adult predator distributions that were collected during each stocking event. Stockings of both Walleye and White Bass typically occur annually in early and late June respectively. I used the best historical spatial distribution data available to me, but it was collected in May and July of 2015 and 2016, respectively. As a result, I introduced variation into the stocking maps (different months and years from food habit collections) that could limit their overall accuracy. Future studies should focus on collecting predator spatial distributions from specific stocking timeframes.

Zooplankton Availability Layers – The density of *Calanoida* and *Cyclopoida* spp. ranged from 9 – 241 individuals/L (mean ± standard error = 80 ± 10 individuals/L) during Walleye stocking and 7 – 154 individuals/L (65 ± 4.8 individuals/L) during White Bass stocking (Appendix 2). Zooplankton density was consistently lower throughout the reservoir during White Bass stocking, just 20 d after Walleye stocking. However, similar spatial patterns were observed between both stocking events, with the highest densities observed around southcentral Lake McConaughy (Figures 5 and 6). Studies at other waterbodies have found similar relative spatial and temporal zooplankton density patterns

(Bernot et al. 2004; Maline et al. 2011). The spatial differences in zooplankton abundances are often greater than temporal variation (Threlkeld 1983) and correlate to phytoplankton spatial distribution (Hart 1988; Striebel et al. 2012), which, in turn, is influenced by several abiotic (e.g., turbidity, wind direction and speed, water temperature) factors (George and Edwards 1976; Grobbelaar 1989; Shuman 1990; Gyllström et al. 2005; Winder and Sommer 2012). The moderate temporal decreases in zooplankton density observed in my study could have been influenced by Alewife (i.e., grazing) (O'Gorman et al. 1991), seasonal drought (Olds et al. 2014), temperature (Kelly et al. 2016), or seasonal succession patterns (Urabe 1989).

Predicted spatial distributions of zooplankton in Lake McConaughy suggest stocking in locations based off convenience could be detrimental to stocking success (Agostinho et al. 2010). Traditionally, stockings in this reservoir have occurred from the upwind side on high wind (> 16 km/h) days to avoid displacing fingerlings out of water as a result heavy wave action (Darrol Eichner, *personal communication*). However, strong wind and wave action can also influence zooplankton distribution (George and Edwards 1976), which might result in stocked fish being released in areas with lower zooplankton densities on those windier days. If stockings could occur near higher abundances of zooplankton, even with high winds, survival and growth of stocked fish may be improved (Houde 1975). This premise is further supported with the match-mismatch hypothesis, which suggests that high growth and survival are expected when young fish overlap spatially and temporally with favorable biotic and abiotic environmental conditions (Cushing 1975). Roseman et al. (2005) found larval Walleye, in mid-June, were more likely to be found in areas where densities of *Calanoida*, *Cyclopoida* and *Cladocera* were at least 40 individuals/L and had strong positive associations to areas with less transparent water and higher relative water temperatures. The observed positive associations to less transparent water and higher relative water temperatures (Roseman et al. 2005) could indicate the appropriateness of including a habitat metric in my conceptual model.

Within my study, the appropriateness of zooplankton as the preferred food for Walleye fingerlings could be scrutinized due to their length being close to the threshold when ontogenetic shifts to different prey items have been reported (Galarowicz et al. 2006). While literature supports both species still consuming zooplankton at this developmental stage (Woiak 2014; Perrion 2016; Miller et al. 2019; Uphoff et al. 2019), food habits are often specific to waterbodies and hatchery products. Further investigation into fingerling food habits post-stocking could provide clarity on the appropriateness of zooplankton as a food source in Lake McConaughy.

Habitat Layers –Secchi disk depth readings during Walleye stocking ranged from 70 – 203 cm (131 ± 3.9 cm). The reservoir was generally less transparent on the west end and became more transparent closer to the dam; the south shore was generally more turbid than the north shore. Overall, the observed transparency pattern followed similar limnological patterns compared to other irrigation reservoir (Soares et al. 2008; Olds et al. 2011). Most Secchi depth readings fell within the optimal range for Walleye (100 – 300 cm; McMahon et al. 1984) except in portions of the west end (< 100 cm). The predicted transparency layer provides some insight into whether historic stocking locations (Figure 1) are the most suitable to support stocking success (Figure 7). Stockings that have occurred from shore in the upper portion of the reservoir were in areas where transparency values were higher than the optimal range (McMahon et al. 1984). Adequate turbidity is necessary for juvenile Walleye retinal tapetum development (Braekevelt et al. 1989; Bristow et al. 1996) and could serve as a form of cover from sight predators such as Smallmouth Bass (Carter et al. 2010). If turbidity is excessive the stocked fingerlings could have negative feeding performance (Bulkowski and Meade 1983). Feeding efficiency has been linked to both the short- and long-term survival of stocked fish (Ersbak and Haase 1983; Vandenbyllaardt et al. 1991; Brown et al. 2003; Hansen et al. 2022).

Bank slopes within Lake McConaughy ranged from 0.2 – 5.7% (2 ± 0.1%). Shallow flats with low percent change were distributed throughout the reservoir (Figure 8) and some historic stocking locations (Figure 1) fell outside of the optimal range. If fish are stocked outside of suitable nursery habitat (shallow littoral areas), they may be more vulnerable to predation and have reduced growth (Beck et al. 2001; Brosse et al. 2007). Research in four Czech Republic reservoirs found that combining substrate and slope together was the most accurate way to identify gentle sloping, sandy areas (Šmejkal et al. 2014), providing evidence of the appropriateness of using bank slope to describe habitat. At Lake McConaughy, White Bass stock contribution has been lower than Walleye stock contribution (Rowles 2019), which could be related to the higher percent slope found at past stocking locations (boat ramps). Stocking White Bass in areas with lower percent slope could positively impact their survival but needs validation in future studies. While

Secchi depth and bank slope were selected for my study, other variables such as water temperature (Peake 1999) or vegetation (Hanson and Margenau 1992) could be more appropriate for other species. Consideration of habitat variables specific to the species being stocked is crucial when developing the habitat layer within the conceptual model.

Stocking Maps –The Walleye stocking map (Figure 9) identified the top 12.8% of the total area of Lake McConaughy that would be expected to support higher post-stocking survival and the White Bass stocking map (Figure 10) identified the top 13.9%. The largest continuous area of optimal stocking locations for both models was concentrated in the middle of the reservoir near the south shoreline. However, there was some variation between the two layers with the White Bass optimal stocking area on the south shoreline extending further west than that of Walleye. Additionally, the Walleye layer identified more locations on the north shoreline than that of White Bass. While some similarities could be related to the overlapping parameters (predation and zooplankton) used, it is surprising the two predicted layers were largely similar, considering the differences observed in each map layer of the conceptual model.

Time and personnel to collect the encompassing amounts of data to model stocking layers using the conceptual model will always be a concern. Fortunately, parameters like zooplankton, habitat, and water temperature are often easily investigated by fishery managers. However, stocked fish interaction, both direct and indirect, with other species, should be considered when selecting conceptual model parameters. For example, Fayram et al. (2005) found Largemouth Bass (*Micropterus salmoides*) predation not only limited the survival of stocked Walleyes, but by stocking Walleyes, Largemouth Bass populations increased. By selecting multiple parameters to model stocking layers with the conceptual model, it leaves each parameter open to interpretation. Managers can have flexibility based on characteristics of specific waterbodies and use only map layers thought to be influential at that location or could elect to use only specific layers instead of the derived stocking layer. For example, managers could decide predation is the only parameter they are worried about, therefore, only use the predation layer when making stocking decisions.

Determining the long-term accuracy of each stocking model could help clarify if the extra time and effort to collect and analyze data for each individual layer comprising the composite model was justified. Without validation of each parameter within Lake McConaughy it will be difficult to determine if using the conceptual model increases the survival of stocked Walleye and White Bass. Ideally, validation of the stocking models could be implemented at Lake McConaughy to determine stocking success related to optimal and sub-optimal stocking locations. However, the economic pressures to be efficient with hatchery products could supersede the desire to validate these layers as the logical development of the final stocking layer could provide enough evidence to fisheries administration. An evaluation might be needed at a different reservoir where the risk of a missing year class does not have the same ramifications as Lake McConaughy.

Despite the lack of current validation, use of the conceptual model to identify important abiotic and biotic factors that could contribute to the mortality of stocked fish can be an improved paradigm for approaching stocking efforts. I recognize there are limitations in this study that will need consideration before developing stocking models for other waterbodies. However, the concept that applies a multitude of factors to the stocking decision making process using logical interpretations of preferred abiotic and biotic conditions has the potential to improve survival and help managers reach relative abundance goals in the waterbodies they oversee.

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Tables

Table 1. Length categories [substock (SS) to preferred (P) and preferred to trophy (T)] used to quantify predator food habits at Lake McConaughy. All sportfish stock size categories are defined from Gabelhouse (1984). Alewife size categories were determined based on length at Age-1 when sexual maturity could occur (O'Gorman et al. 1997). The goal was to collect at least 20 individuals of each taxa and size category with food in their stomachs. Total lengths were chosen to reflect potential ontogenetic diet shifts and gape size differences in predators.

Taxa	Size Category	Total Length (mm)
Alewife	Juvenile	≤100
	Adult	>100
Black Crappie	SS-P	≤250
	P-T	>250
Channel Catfish	SS-P	≤610
	P-T	>610
Hybrid Striped Bass	SS-P	≤380
	P-T	>380
Northern Pike	SS-P	≤710
	P-T	>710
Smallmouth Bass	SS-P	≤350
	P-T	>350
Walleye	SS-P	≤510
	P-T	>510
White Bass	SS-P	≤300
	P-T	>300
Yellow Perch	SS-P	≤250
	P-T	>250

Table 2. Predation impact during Walleye (WAE) stocking in 2017 and 2018 at Lake McConaughy for two length categories: substock to preferred (SS-P) and preferred to trophy (P-T)] (as defined by Gabelhouse 1984). Frequency of occurrence (O_i; %) for each category shows the percentage of predators with food in their stomachs that consumed Walleye fingerlings. Relative risk value divides the total number of fingerlings consumed by the total number of individuals with food in their stomachs for each length category.

		2017				2018				
Species	Length category	# handled	# with food	O_i	# WAE fingerlings consumed	# handled	# with food	O_i	# WAE fingerlings consumed	Relative risk value
Channel Catfish	SS-P	122	43	0	0	48	9	22	15	0.29
	P-T	2	1	0	0	0	0	N/A	0	0.00
Hybrid Striped Bass	SS-P	37	17	65	323	9	9	78	48	14.27
	P-T	46	25	52	543	24	22	23	54	12.70
Smallmouth Bass	SS-P	19	11	18	46	74	27	82	431	12.55
	P-T	3	2	50	5	20	14	29	31	2.25
Walleye	SS-P	350	106	0	0	70	19	5	1	0.01
	P-T	60	30	0	0	27	20	0	0	0.00
White Bass	SS-P	79	19	63	111	2	2	100	53	7.81
	P-T	139	62	16	63	88	20	70	161	2.73
Yellow Perch	SS-P	12	7	29	7	12	7	14	1	0.57
	P-T	0	0	N/A	0	0	0	N/A	0	N/A

Table 3. Predation impact during White Bass (WHB) stocking in 2017 and 2018 at Lake McConaughy for two length categories: substock to preferred (SS-P) and preferred to trophy (P-T)] (as defined by Gabelhouse 1984). Frequency of occurrence (O_i; %) for each category shows the percentage of predators with food in their stomachs that consumed White Bass fingerlings. Relative risk value divides the total number of fingerlings consumed by the total number of individuals with food in their stomachs for each length category.

		2017				2018				
Species	Length category	# handled	# with food	O_i	# WHB fingerlings consumed	# handled	# with food	O_i	# WHB fingerlings consumed	Relative risk value
Channel Catfish	SS-P	8	3	0	0	29	19	16	5	0.23
	P-T	0	0	N/A	0	1	1	0	0	0.00
Hybrid Striped Bass	SS-P	0	0	N/A	0	23	19	47	126	6.63
	P-T	2	2	0	0	2	0	N/A	0	0.00
Smallmouth Bass	SS-P	18	17	41	70	53	22	68	312	9.79
	P-T	1	0	N/A	0	8	5	0	0	0.00
Walleye	SS-P	44	29	3	4	139	20	5	2	0.12
	P-T	5	5	0	0	16	4	50	2	0.22
White Bass	SS-P	1	1	100	9	3	2	100	7	5.33
	P-T	14	12	0	0	72	21	14	39	1.18
Yellow Perch	SS-P	4	1	0	0	7	3	0	0	0.00
	P-T	0	0	N/A	0	0	0	N/A	0	N/A

Figures

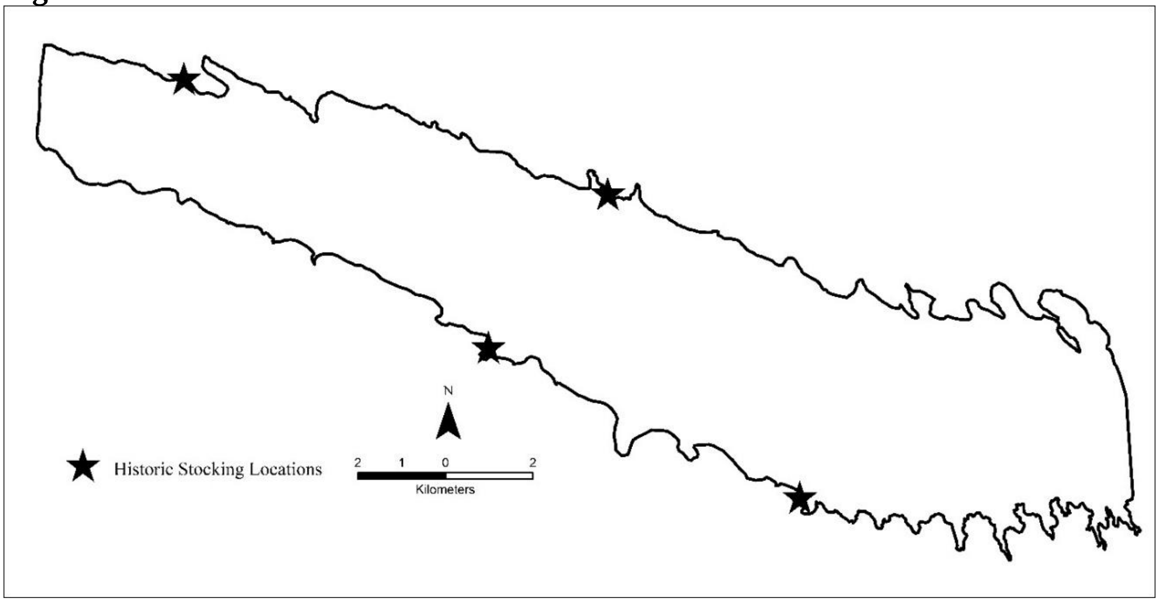

Figure 1. Historic shore stocking locations at Lake McConaughy, Nebraska.

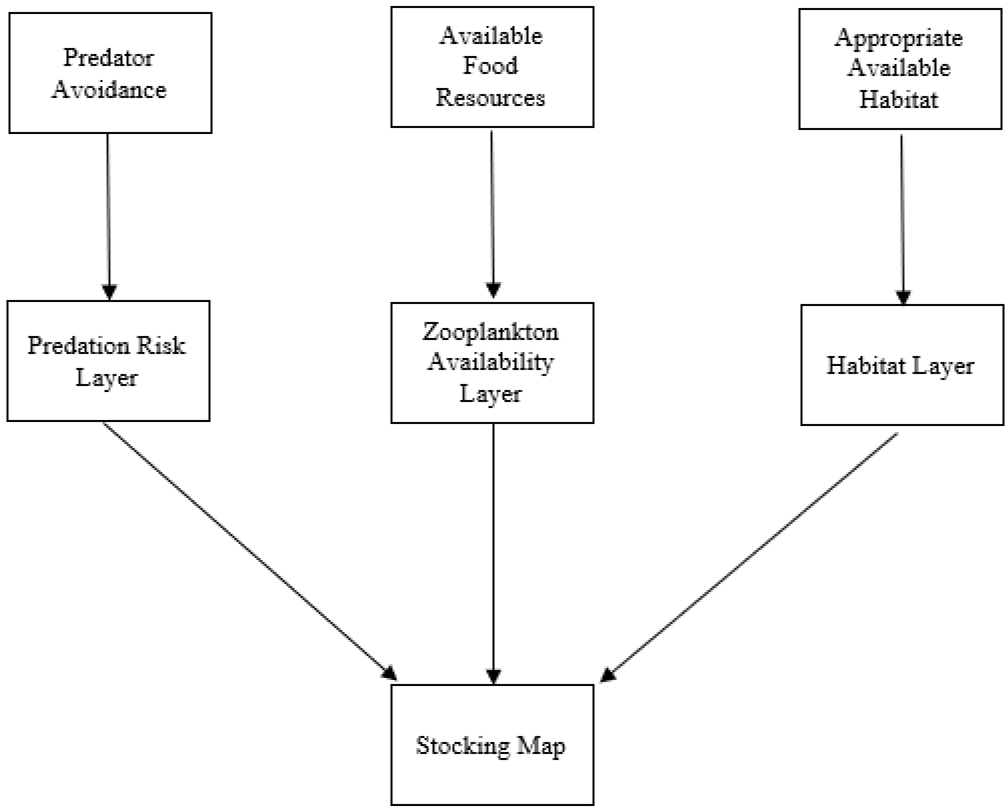

Figure 2. Conceptual model of methodology used to develop GIS stocking layers for Walleye and White Bass in Lake McConaughy.

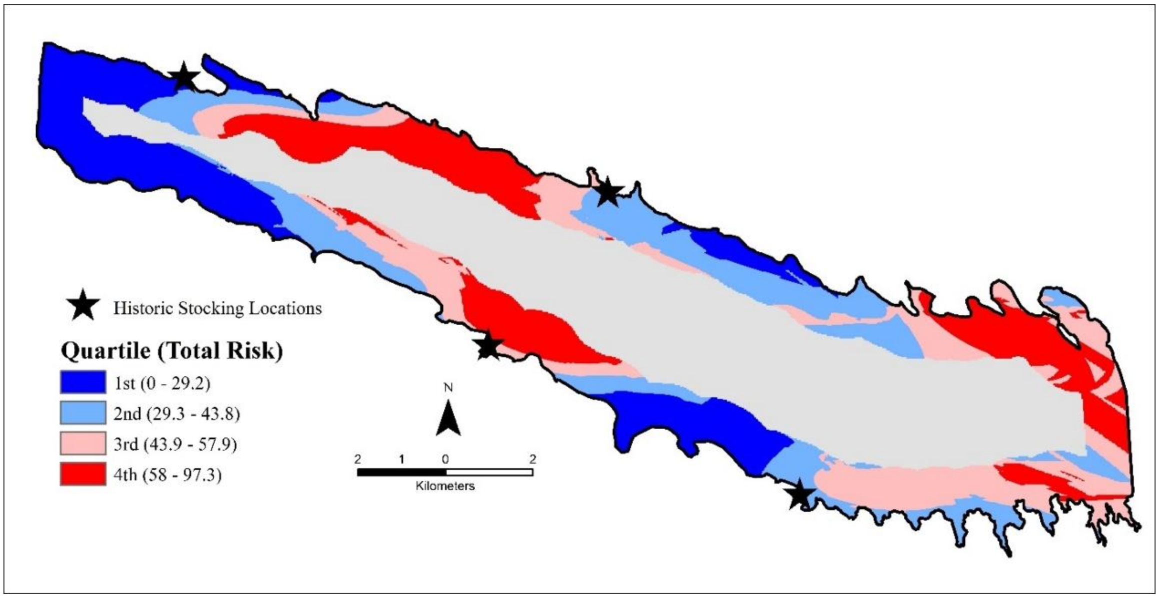

Figure 3. Predicted Walleye fingerling predation risk (summation of relative density multiplied by combined consumption rate of all predators at a given location) within Lake McConaughy. Areas in dark blue represent the lowest probability quartile where Walleye fingerlings are predicted as least susceptible to predation. Dark red areas are the highest quartile where predicted risk of consumption by predators is greatest.

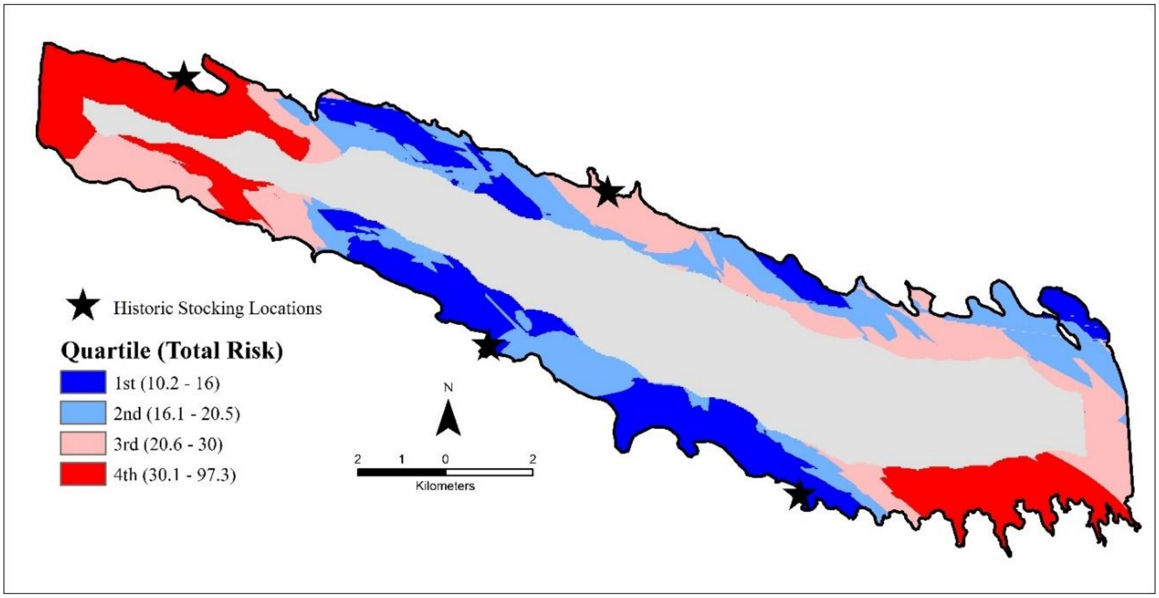

Figure 4. Predicted White Bass fingerling predation risk (summation of relative density multiplied by combined consumption rate of all predators at a given location) within Lake McConaughy. Areas in dark blue represent the lowest probability quartile where White Bass fingerlings are predicted as least susceptible to predation. Dark red areas are the highest quartile where predicted risk of consumption by predators is greatest.

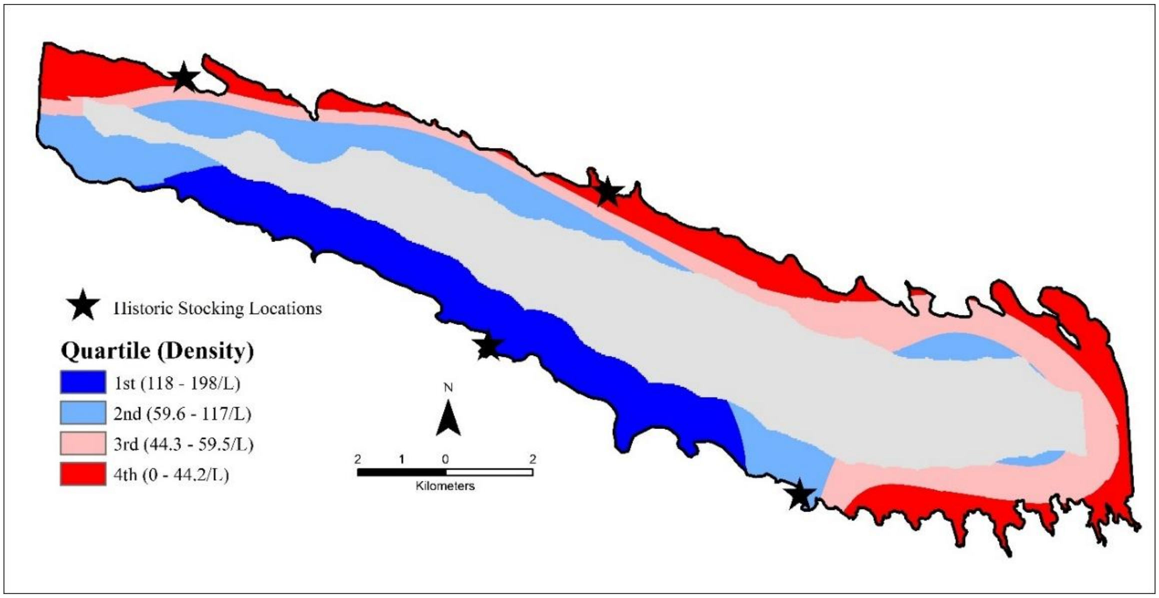

Figure 5. Combined density (number/L) of all *Calanoida* and *Cyclopoida* species collected during Walleye stocking in June 2018. Zooplankton were sampled across 48 sites within Lake McConaughy with an 80-µm Wisconsin plankton net. Dark blue areas highlight the first quartile where density of these two zooplankton genera were highest. Dark red areas are the highest quartile where locations with the lowest density of zooplankton were found.

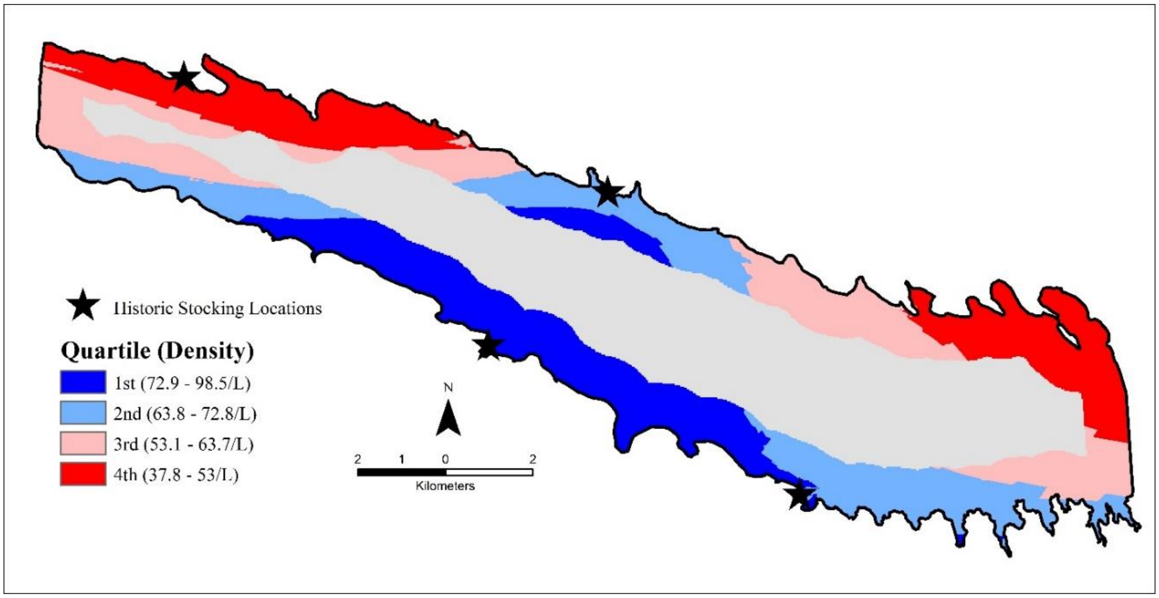

Figure 6. Combined density (number/L) of all *Calanoida* and *Cyclopoida* species collected during White Bass stocking in June 2018. Zooplankton were sampled across 48 sites within Lake McConaughy with an 80-µm Wisconsin plankton net. Dark blue areas highlight the first quartile where density of these two zooplankton genera were highest. Dark red areas are the highest quartile where locations with the lowest density of zooplankton were found.

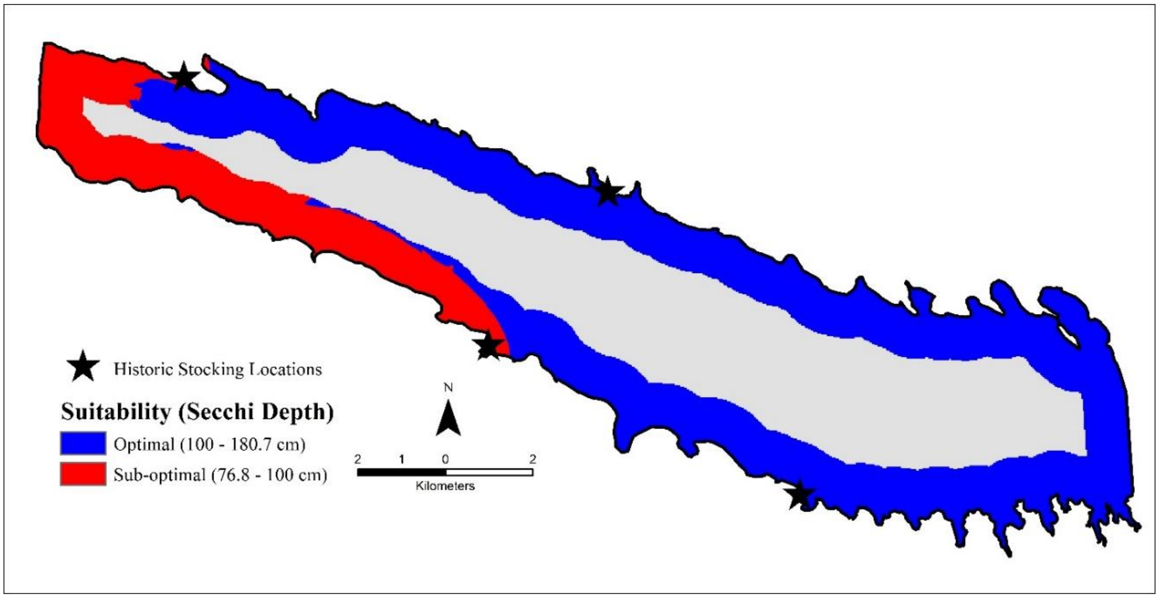

Figure 7. Distributions of Secchi depth (cm) transparencies as measured by Schall (2016). Secchi depth values between 100 – 300 cm were considered optimal for Walleye (McMahon et al. 1984) and are represented in blue. Secchi depths <100 cm was considered too turbid (sub-optimal) and are represented in red.

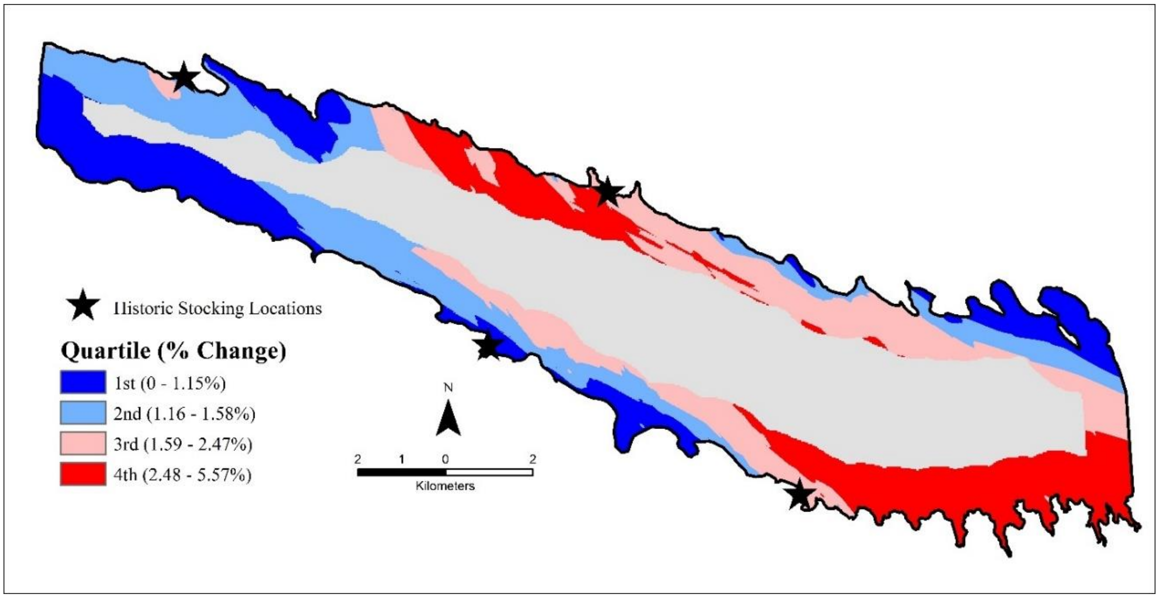

Figure 8. Distributions of bank slope as measured by Schall (2016). Bank slope was calculated using the starting and ending set depth of gill nets at each spatial location. Dark blue areas represent the first quartile where the lowest percent slope was found. Low percent slope indicated the presence of a shallow, sandy shoal preferred by White Bass fingerlings. Dark red areas represent the highest quartile and had the highest percent slope.

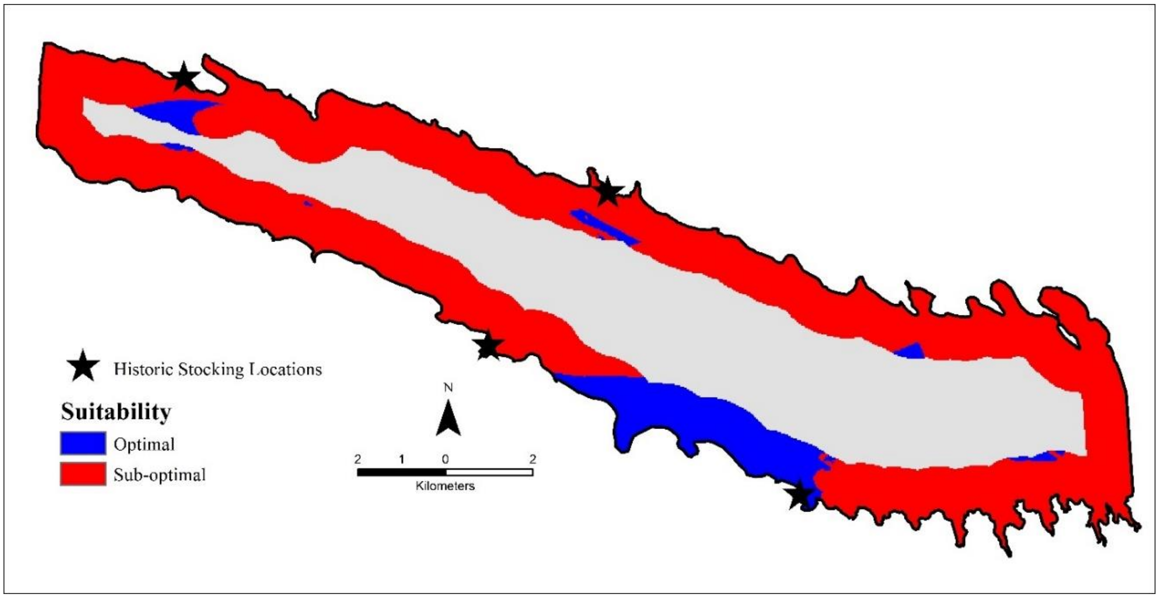

Figure 9. Final map for Walleye stocking that represents the combination of the top 50% of locations for the predation, zooplankton, and turbidity layers. Blue areas highlight the best stocking locations and represent 12.8% of the predicted area of Lake McConaughy. Red areas represent those 87.2% of locations that were not in top 50% of all three layers.

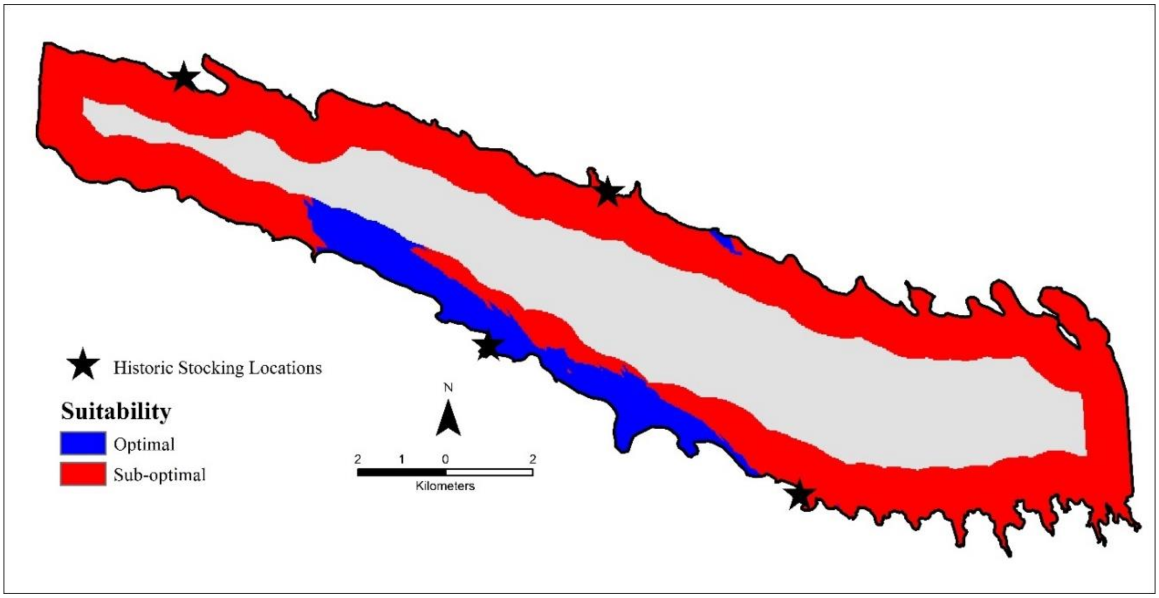

Figure 10. Final map for White Bass stocking that represents the combination of the top 50% of locations for the predation, zooplankton, and bank slope layers. Blue areas highlight the best stocking locations and represent 13.9% of the predicted area of Lake McConaughy. Red areas represent those 86.1% of locations that were not in top 50% of all three layers.

CHAPTER 3:

RESEARCH IMPLICATIONS AND MANAGEMENT RECOMMENDATIONS

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Introduction

Walleye and White Bass populations have struggled to remain sustainable at Lake McConaughy, as catch rates in fall standardized surveys have generally declined over the past 30 years (NGPC, *unpublished data*). In response, an average of 1,465,209 (± 164,267; one standard error) Walleye and 428,365 (±79,886) White Bass fingerlings were supplementally stocked annually by the Nebraska Game and Parks Commission (NGPC) from 2014 – 2016. The numbers of individuals stocked have increased for each species in the previously mentioned three-year period compared to the historical average between 1989 – 2016 for Walleye (1,326,401 ± 170,894) and 2000 – 2016 for White Bass (233,787 ± 48,341). Previous research on Lake McConaughy has focused on understanding the dynamics of Walleye and White Bass recruitment or factors that may support or limit recruitment, including: the spatial and temporal distribution of these species as well as other sportfish (Schall 2016; Schall et al. 2019); descriptions of White Bass juvenile food habits (Perrion 2016); identification of White Bass and Walleye natal origins (Rowles 2019); and age-0 White Bass habitat use (Perrion et al. 2020). Studies of age-0 Walleye and White Bass natal origins have noted that most of the Walleye at that life stage are of hatchery origin; in contrast, the contribution of hatchery White Bass to fall age-0 catches varies widely (Perrion 2016; Rowles 2019; Perrion et al. 2020). Declines in standardized gill-net catches coupled with the high contribution of stocked Walleye and variable contribution by stocked White Bass have highlighted a need for identification of optimal stocking locations that could lead to higher survival of stocked hatchery fish.

Conceptual Model and Stocking Layer Development

Previous research outside of Nebraska has focused on factors such as predation, food and habitat that could be acting as potential bottlenecks for stocked fish (Ellison and Franzin 1992; Fielder 1992; Wahl 1999; Agostinho et al. 2010). However, most of those studies only focused on single factors rather than multiple factors that may act in concert to limit survival of stocked fish. I used a more a holistic approach that incorporated multiple bottlenecks into deciding where to stock fish within a given waterbody. I applied the conceptual model by creating three GIS layers – predation risk, zooplankton (food) availability, and a measure of habitat for each species – that were combined to model optimal stocking locations for fingerling Walleye and White Bass at Lake McConaughy.

Previous research identified predation as a potential source of immediate mortality of stocked products (Stein et al. 1981; Buckmeier et al. 2005; Freedman et al. 2012; Lundgren et al. 2014; Grausgruber and Weber 2020). Thus, I conducted a food habit study to quantify the impact predators had on stocked fingerlings and combined those findings with spatial distribution data collected by Schall et al. (2019). However, predation was only one potential recruitment bottleneck, as stocked fish also need abundant food and suitable habitat within the first few days post-stocking (Jonas and Wahl 1998). I found previous research that identified food and habitat preferences for Walleye and White Bass between 25 – 30 mm total length. Densities of *Calanoida* and *Cyclopoida* spp. were used to index food availability for both species (Woiak 2014; Miller et al. 2019; Uphoff et al. 2019). In terms of habitat, I used water transparency (as indexed by Secchi depth) for identifying optimal stocking locations for Walleye

(McMahon et al. 1984). Availability of locations with appropriate water clarity has been linked to higher feeding rates for Walleye fingerlings (Bulkowski and Meade 1983) and proper retinal tapetum lucidum development (Braekevelt et al. 1989; Bristow et al. 1996). For White Bass, I selected bank slope based on an identified preference for sandy shoal habitat (Hamilton and Nelson 1984).

The differences in the timing of Walleye and White Bass stockings (2 – 4 weeks) within each year allowed me to explore how optimal stocking locations could change through time and for different species. Predation results revealed smaller (<preferred) Hybrid Striped Bass, White Bass, and Smallmouth Bass as the three taxa consuming Walleye and White Bass at the highest rates in 2017 and 2018 for both stocked species. However, predicted predation risk and the locations with the highest risks of predation were different between the two species' stocking periods, highlighting the need to develop stocking layers that use data collected during each stocking period. Additionally, zooplankton density decreased between stocking events in 2018, but patterns of variation remained similar across the entire reservoir between the two stocking periods as areas of higher density were consistent between stocking events. Future studies should investigate this relationship across multiple years to gain a better understanding of how temporal changes influence whether predicted areas of stocking change. Habitat measurements, while not collected during food habit and zooplankton sampling, remained consistent and followed similar patterns between the years they were collected by Schall et al. (2019).

Predation, zooplankton, transparency, and bank slope both showed spatial gradients within Lake McConaughy. Although I measured all variables in a continuous manner, the predicted surfaces relied on changing these variables to a binomial response to identify optimal and sub-optimal locations to stock fish. However, transforming this continuous data to binomial was more difficult for transparency and bank slope than the other two variables because measures of the aforementioned variables were similar across the reservoir. Therefore, transparency and bank slope may not be critical factors that influence the recruitment of stocked Walleye or White Bass in Lake McConaughy. Further investigation into which habitat metrics are acting as bottlenecks for the species being stocked could provide different predictions of optimal and sub-optimal stocking locations. Specifically, evaluating water temperature, cover habitat availability, and dissolved oxygen could provide a better gradient for development of stocking location models (Hamilton and Nelson 1984; McMahon et al. 1984).

Overall, this thesis addressed using GIS layers to predict stocking locations that may support higher survival of stocked Walleye and White Bass fingerlings. My hypotheses that species-specific stocking models would be different because of differences in the resources needed to support survival for each species and reveal optimal stocking locations outside of normal stocking locations were correct. My hypothesis that the upper end (more riverine area) would have a greater proportion of the optimal stocking locations compared to the lower end Lake McConaughy closer to the dam was not supported. The most optimal stocking locations were generally located in the central portion of Lake McConaughy for both species. The productivity gradient that I expected to drive stocking locations did not influence layers in the ways I predicted.

Management Implications and Future Directions

This study had several limitations that should be addressed in future research. First, Lake McConaughy is an irrigation and hydropower reservoir, and changing water levels during floods and drought could alter distributions of predators and zooplankton and change availability of stocking locations. Using a stocking model that captures a snapshot in time will not account for these water-level dynamics. Future projects should develop predictive models at multiple reservoir elevations that could be used as water levels change year to year. Not only is accounting for changing lake elevations important but collecting data during specific stocking timeframes could also change stocking location predictions. For example, the predator distribution data I used (described in Chapter 2) was collected outside of stocking timeframes and could have altered the predictive surfaces for predation risk of each species. Finally, while I hypothesize my final stocking layers identify those locations that support increased survival of stocked products, there is a need for validation to determine if stocking at these locations does lead to more stocked products recruiting to the fishery and will provide additional information on how the conceptual model can be implemented at other waterbodies.

Included as part of this project was an evaluation of predator food habits and zooplankton density and spatial distribution. While both variables were important for the overall development of my stocking models, all the data was not needed for model development. However, I have provided this information in Appendices 1 and 2. Having historical food habit and zooplankton density data could be useful in tracking any changes that could occur at Lake McConaughy in the future. My recommendation would be to sample both food habits and zooplankton more frequently to provide a better understanding of how these factors might change through time.

Overall, I expect that the use of the conceptual model not only at Lake McConaughy, but at other waterbodies will help managers reach, or get closer to, sportfish relative-abundance goals by increasing survival of stocked products. Even a minor improvement in survival has the potential to improve the efficiencies in the use of stocked products. For example, a 1% increase in Walleye survival at Lake McConaughy will result in an additional 16,000 fish in the reservoir for anglers to target, if the fish survive additional bottlenecks at later life stages and make it to harvestable sizes. If NGPC continues to see limited natural recruitment at Lake McConaughy and other waterbodies, the need for an approach to maximize limited hatchery resources will be crucial to the sustainability of these fisheries. Therefore, my recommendation is for NGPC to take the necessary steps to validate the holistic conceptual model approach outlined in this study to determine if implementation of this strategy across multiple waterbodies is a feasible option to address limited recruitment of sportfish.

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APPENDIX 1:

ASSESSMENT OF FISH FOOD HABITS AT LAKE MCCONAUGHY, NEBRASKA IN 2017 AND 2018

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Background and Objectives

In Chapter 2, there was a need to quantify the predation risk of stocked Walleye and White Bass and from which specific predators in Lake McConaughy. To quantify that risk, a food habit study was completed to determine how many fingerlings were consumed per predator (refer to Chapter 2). All potential predators were evaluated. Because specific food habit results were not essential to the development of Chapter 2 in this thesis, it was essential to provide the collected information within this appendix to preserve these findings for future comparisons.

Methods

Sampling locations for predator collections were chosen based on proximity to recent Walleye and White Bass stockings described in Chapter 2. Short-term sets (< 1 hr) of experimental gill nets and a Smith-Root Sr-18 electrofishing boat (supplemental collection as time allowed) were used to capture potential predators of stocked fish. Gastric lavage was selected to collect stomach contents to limit mortality of handled fish. Stomach content identification was completed to the lowest possible taxa, enumerated, and weighed (0.1 mg). Analysis followed methods described in Chapter 2 and included frequency of occurrence (O_i; Bowen 1996) and percent composition by weight and number for each prey taxa and predator length category. Alewife were collected, frozen, and returned to the University of Nebraska for processing to evaluate if they were consuming stocked fish.

Results

Alewife were the most common prey item for all predators combined as indicated by O_i and percent composition by weight and number (Tables 1 – 4). Chironomids were present in nearly every stomach with contents collected during Walleye stocking in 2017 and 2018. However, stomach contents collected during White Bass stocking did not contain Chironomids as often. Similarly, salamanders were present in stomach contents during Walleye stocking but were not observed during White Bass stocking in both years. Crayfish were observed in Smallmouth Bass stomach contents during three of the four sampling events but were not consumed by any other taxa. The Alewife stomach contents processed during this study did not contain any fish.

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Tables

Table 1. Predator food habits following Walleye stocking in 2017 at Lake McConaughy for two length categories; substock to preferred (SS-P) and preferred to trophy (P-T; as defined by Gabelhouse 1984). Frequency of occurrence (O_i; %) indicates the percentage of predators that had food in their stomach that included that prey item. Percent composition by weight (% Weight) and number (% Number) for each prey shows the relative contribution of each prey to the predator food habit. Length categories that were not sampled and data that was unable to be quantified are represented by N/A and were not included in calculations.

Taxa	Length category	N	# with food	Prey	O_i	% Weight	% Number
Channel Catfish	SS-P	122	43	Alewife	9	70.24	0.87
				Chironomid	51	11.77	89.75
				Diptera	5	0.00	0.28
				Hemiptera	26	0.34	4.78
				Orthoptera	9	0.09	0.56
				Unidentified Fish	67	5.74	0.28
				Unidentified Insect	5	0.02	0.42
				Vegetation	19	11.16	N/A
	P-T	2	1	Unidentified Fish	100	100	100
Hybrid Striped Bass	SS-P	37	17	Alewife	18	7.78	1.44
				Chironomid	24	0.02	2.30
				Corixidae	6	0.01	0.29
				Diptera	6	0.01	0.86
				Hemiptera	6	0.00	0.29
				Hymenoptera	12	0.00	0.57
				Odonata	6	0.03	0.29
				Unidentified Fish	35	1.53	1.15
				Walleye	65	90.62	92.82
	P-T	46	25	Alewife	36	35.76	3.94
				Chironomid	20	0.01	9.78
				Diptera	4	0.00	0.16
				Ephemenoptera	4	0.00	0.16
				Hemiptera	4	0.00	0.16
				Unidentified Fish	24	0.81	0.16
				Walleye	52	63.42	85.65
Smallmouth Bass	SS-P	19	11	Alewife	27	22.12	3.45
				Chironomid	45	0.30	35.63
				Diptera	18	0.02	1.15
				Hymenoptera	18	0.19	1.15

Table 1. Continued

				Orthoptera	18	3.54	1.15
				Salamander	9	9.38	1.15
				Unidentified Fish	36	15.03	3.45
				Walleye	18	49.41	52.87
	P-T	3	2	Alewife	50	94.69	25.00
				Chironomid	50	0.44	12.50
				Walleye	50	4.87	62.50
Walleye	SS-P	350	106	Alewife	51	85.27	44.81
				Chironomid	13	0.02	22.08
				Coleoptera	1	0.00	0.65
				Diptera	10	0.01	9.09
				Ephemenoptera	1	0.00	0.65
				Unidentified Fish	50	14.70	22.73
				Unidentified Insect	1	0.00	N/A
	P-T	60	30	Alewife	77	97.50	73.53
				Chironomid	17	0.00	13.24
				Diptera	7	0.00	2.94
				Hymenoptera	3	0.00	1.47
				Unidentified Fish	23	2.48	7.35
				Unidentified Insect	3	0.00	1.47
				Vegetation	3	0.01	N/A
White Bass	SS-P	79	19	Alewife	11	11.08	1.27
				Chironomid	63	0.22	24.05
				Diptera	5	0.01	0.63
				Feather	5	0.02	0.63
				Hemiptera	11	0.06	1.90
				Unidentified Fish	53	3.28	1.27
				Walleye	63	85.33	70.25
	P-T	139	52	Alewife	34	82.12	19.57
				Chironomid	40	0.04	31.52
				Coleoptera	2	0.02	N/A
				Corixidae	5	0.01	2.17
				Diptera	8	0.00	3.80
				Hemiptera	6	0.04	1.63
				Hymenoptera	2	0.00	0.54
				Unidentified Fish	56	12.15	6.52
				Vegetation	5	0.01	N/A
				Walleye	16	5.62	34.24

Table 1. Continued

Yellow Perch	SS-P	12	7	Chironomid	43	10.44	8.83
				Diptera	14	71.86	89.17
				Unidentified Insect	14	0.81	N/A
				Walleye	29	16.89	1.99
	P-T	0	0	N/A	N/A	N/A	N/A

Table 2. Predator food habits following Walleye stocking in 2018 at Lake McConaughy for two length categories; substock to preferred (SS-P) and preferred to trophy (P-T; as defined by Gabelhouse 1984). Frequency of occurrence (O_i; %) indicates the percentage of predators that had food in their stomach that included that prey item. Percent composition by weight (% Weight) and number (% Number) for each prey shows the relative contribution of each prey to the predator food habit. Length categories that were not sampled and data that was unable to be quantified are represented by N/A and were not included in calculations.

Taxa	Length category	N	# with food	Prey	O_i	% Weight	% Number
Channel Catfish	SS-P	48	9	Alewife	67	95.78	2.80
				Coleoptera	22	0.15	1.60
				Diptera	33	0.79	77.20
				Ephemenoptera	11	0.01	0.40
				Hemiptera	22	0.11	10.40
				Hymenoptera	11	0.10	1.60
				Unidentified Fish	22	0.62	0.00
				Unidentified Insect	11	0.09	0.00
				Walleye	22	2.34	6.00
	P-T	0	0	N/A	N/A	N/A	N/A
Hybrid Striped Bass	SS-P	9	9	Alewife	22	55.18	0.67
				Chironomid	22	0.28	21.21
				Diptera	11	3.30	61.95
				Vegetation	11	5.58	N/A
				Walleye	78	35.67	16.16
	P-T	24	22	Alewife	55	92.75	20.24
				Chironomid	9	0.01	11.90
				Salamander	9	2.01	3.57
				Unidentified Fish	45	3.59	N/A
				Walleye	23	1.64	64.29
Smallmouth Bass	SS-P	74	27	Alewife	22	31.69	1.40
				Chironomid	37	0.17	21.64
				Crayfish	4	1.32	N/A
				Hymenoptera	4	0.02	0.17
				Salamander	19	5.46	1.57
				Unidentified Fish	4	0.55	N/A
				Vegetation	7	0.06	N/A
				Walleye	82	60.73	75.22

Table 2. Continued

	P-T	20	14	Alewife	71	97.00	27.66
				Diptera	7	0.00	2.13
				Hemiptera	14	0.02	2.13
				Salamander	7	0.46	2.13
				Unidentified Fish	7	0.13	N/A
				Vegetation	7	0.02	N/A
				Walleye	29	2.38	65.96
Walleye	SS-P	70	19	Alewife	68	95.94	94.12
				Unidentified Fish	37	3.87	N/A
				Walleye	5	0.19	5.88
	P-T	27	20	Alewife	100	99.99	96.15
				Diptera	5	0.00	1.92
				Hemiptera	5	0.01	1.92
White Bass	SS-P	2	2	Walleye	100	100	100
	P-T	88	20	Alewife	60	77.59	7.98
				Chironomid	15	0.01	4.79
				Salamander	10	1.23	1.60
				Unidentified Fish	25	0.84	N/A
				Vegetation	5	0.00	N/A
				Walleye	70	20.32	85.64
Yellow Perch	SS-P	12	7	Chironomid	43	1.33	9.62
				Diptera	43	90.90	89.67
				Trichoptera	14	2.93	0.59
				Walleye	14	4.83	0.12
	P-T	0	0	N/A	N/A	N/A	N/A

Table 3. Predator food habits following White Bass stocking in 2017 at Lake McConaughy for two length categories; substock to preferred (SS-P) and preferred to trophy (P-T; as defined by Gabelhouse 1984). Frequency of occurrence (O_i; %) indicates the percentage of predators that had food in their stomach that included that prey item. Percent composition by weight (% Weight) and number (% Number) for each prey shows the relative contribution of each prey to the predator food habit. Length categories that were not sampled and data that was unable to be quantified are represented by N/A and were not included in calculations.

Taxa	Length category	N	# with food	Prey	O_i	% Weight	% Number
Channel Catfish	SS-P	8	3	Unidentified Fish	100	62.56	N/A
				Vegetation	33	37.44	N/A
	P-T	0	0	N/A	N/A	N/A	N/A
Hybrid Striped Bass	SS-P	0	0	N/A	N/A	N/A	N/A
	P-T	2	2	Unidentified Fish	100	100	100
Smallmouth Bass	SS-P	18	17	Chironomid	18	9.62	50.00
				Crayfish	6	6.88	0.67
				Diptera	12	0.31	1.33
				Hymenoptera	12	1.16	N/A
				Odonata	12	1.91	N/A
				Unidentified Fish	82	47.79	1.33
				Unidentified Insect	6	0.15	N/A
				White Bass	41	32.18	46.67
	P-T	1	0	N/A	N/A	N/A	N/A
Walleye	SS-P	44	29	Alewife	34	65.78	45.16
				Diptera	3	0.01	6.45
				Unidentified Fish	62	33.68	35.48
				Unidentified Insect	3	0.00	N/A
				White Bass	3	0.53	12.90
	P-T	5	5	Alewife	40	59.82	50.00
				Unidentified Fish	60	40.18	50.00
White Bass	SS-P	1	1	Hemiptera	100	1.67	18.18
				Unidentified Fish	100	10.19	N/A
				White Bass	100	88.14	81.82
	P-T	14	12	Alewife	33	70.13	46.67
				Diptera	8	0.00	6.67
				Unidentified Fish	67	29.87	46.67
Yellow Perch	SS-P	4	1	Chironomid	100	100	100
	P-T	0	0	N/A	N/A	N/A	N/A

Table 4. Predator food habits following White Bass stocking in 2018 at Lake McConaughy for two length categories; substock to preferred (SS-P) and preferred to trophy (P-T; as defined by Gabelhouse 1984). Frequency of occurrence (O_i; %) indicates the percentage of predators that had food in their stomach that included that prey item. Percent composition by weight (% Weight) and number (% Number) for each prey shows the relative contribution of each prey to the predator food habit. Length categories that were not sampled and data that was unable to be quantified are represented by N/A and were not included in calculations.

Taxa	Length category	N	# with food	Prey	O_i	% Weight	% Number
Channel Catfish	SS-P	29	19	Alewife	53	88.91	9.70
				Chironomid	5	0.05	33.33
				Diptera	16	0.09	46.41
				Hemiptera	26	0.05	5.91
				Hymenoptera	11	0.01	1.27
				Orthoptera	16	0.11	1.27
				Plastic	5	0.16	N/A
				Unidentified Fish	21	1.96	N/A
				Vegetation	47	8.49	N/A
				White Bass	16	0.17	2.11
	P-T	1	1	Alewife	100	100	100
Hybrid Striped Bass	SS-P	23	19	Chironomid	32	0.88	47.77
				Hemiptera	5	0.01	0.40
				Juvenile Fish	5	1.86	0.81
				Unidentified Fish	21	2.43	N/A
				White Bass	47	94.83	51.01
	P-T	2	0	N/A	N/A	N/A	N/A
Smallmouth Bass	SS-P	53	22	Alewife	23	41.70	1.73
				Crayfish	5	1.18	0.29
				Diptera	18	0.02	2.88
				Hemiptera	9	0.01	0.58
				Hymenoptera	5	0.05	2.59
				Odonata	5	0.03	0.29
				Trichoptera	5	0.06	1.44
				Unidentified Fish	50	10.68	N/A
				White Bass	68	39.05	89.91
				Yellow Perch	5	7.22	0.29

Table 4. Continued

	P-T	8	5	Alewife	80	99.96	75.00
				Diptera	20	0.00	25.00
				Unidentified Fish	20	0.03	N/A
Walleye	SS-P	139	20	Alewife	85	96.77	91.67
				Unidentified Fish	10	2.76	N/A
				White Bass	5	0.47	8.33
	P-T	16	4	Alewife	100	97.07	66.67
				White Bass	50	2.93	33.33
White Bass	SS-P	3	2	White Bass	100	100	100
	P-T	72	21	Alewife	62	86.26	30.36
				Hemiptera	5	0.00	N/A
				Unidentified Fish	43	8.57	N/A
				White Bass	14	5.17	69.64
Yellow Perch	SS-P	7	3	Chironomid	100	84	100
				Unidentified Fish	33	16	N/A
	P-T	0	0	N/A	N/A	N/A	N/A

APPENDIX 2:

ZOOPLANKTON MEAN DENSITY AT LAKE MCCONAUGHY, NEBRASKA, DURING WALLEYE AND WHITE BASS STOCKING IN 2018

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Background and Objectives

In Chapter 2, there was a need to identify the spatial distribution of *Calanoida* and *Cyclopoida* spp. during Walleye and White Bass stocking. To achieve this part of the study, zooplankton were collected during June of 2018. While *Calanoida* and *Cyclopoida* spp. were only needed to develop the conceptual models described in Chapter 2, data was collected on all other zooplankton, and this appendix is an effort to preserve that data for future use.

Methods

To select sampling locations, the reservoir was stratified into six regions (northeast, north central, northwest, southeast, south central, and southwest) following the same regions defined by Schall (2016). Reservoir water elevation was around 3,256.9 feet above sea level during zooplankton collections. Zooplankton were sampled every 2 km on the north and south shore during Walleye and White Bass stocking (described in Chapter 2). A total of 48 locations (24 on the north and south) were sampled during each stocking and combined into 6 regions containing 8 sample sites per region. Zooplankton were collected using a Wisconsin plankton net (80-µm mesh, 0.5-m^2 opening) towed vertically from a depth of 2 m at each location during both stocking periods as described in Chapter 2. Each sample was labeled and preserved in a 4% formalin and sucrose mixture (Haney and Hall 1973). Processing followed protocol described by Peterson et al. (2005). The densities for other zooplankton taxa that were not *Calanoida* or *Cyclopoida* spp. were calculated following the same procedures described in Chapter 2 and averaged for each zone. For patterns of *Calanoida* or *Cyclopoida* spp. densities, please see Chapter 2.

Results

In total, 11 categories of zooplankton were observed during sampling in 2018. Several taxa of zooplankton were rare (i.e., densities < 1 per L) across most regions and sampling events, suggesting they either have a low density in Lake McConaughy or did not occupy the top 2 m of water that was sampled at each location during this study. Overall, zooplankton densities were greater along the south shoreline compared to the north and were on the western side of the reservoir (furthest from Kingsley Dam) compared to the east side (nearer to the dam) for both stocking periods (Tables 1 and 2). Rotifera were the most abundant zooplankton taxa across all regions during Walleye stocking (Table 1). In contrast, *Bosmina* were the most abundant taxa observed during White Bass stocking (Table 2). *Daphnia retrocurva* had the largest increase in abundance between sampling collection periods (Table 1 and 2).

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Tables

Table 1. Zooplankton density (#/L) for six regions of Lake McConaughy during Walleye stocking periods in June 2018. Eight vertical tows were taken in each region, and densities for each tow were averaged. Numbers in parentheses represent one standard error.

Region	*Daphnia pulicaria*	*Daphnia retrocurva*	I-*Daphnia*	*Bosmina*	Chydoridae	*Diaphanosoma*	*Leptodora kindti*	*Ceriodaphnia*	Calanoida-Diatomidae-*Diaptomus*	Cyclopoida-Cyclopoidae-*Cyclops*	I-Nauplii	Rotifera
Northeast	0.00 (0.00)	0.88 (0.75)	0.00 (0.00)	76.63 (9.71)	0.92 (0.34)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	2.04 (0.46)	39.69 (5.70)	51.50 (8.51)	264.02 (23.66)
Northcentral	0.22 (0.13)	0.53 (0.20)	0.00 (0.00)	73.49 (16.10)	0.58 (0.32)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.34 (0.52)	27.13 (6.31)	27.42 (5.52)	223.15 (43.53)
Northwest	0.00 (0.00)	1.90 (0.88)	0.00 (0.00)	253.55 (73.19)	0.70 (0.31)	0.00 (0.00)	0.00 (0.00)	0.08 (0.08)	2.80 (0.93)	49.74 (12.79)	79.75 (30.31)	324.25 (86.76)
Southeast	0.00 (0.00)	0.97 (0.30)	0.00 (0.00)	41.60 (5.86)	0.75 (0.30)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.96 (0.59)	32.96 (5.80)	89.10 (17.72)	253.85 (31.20)
Southcentral	0.00 (0.00)	2.96 (1.19)	0.00 (0.00)	112.66 (10.69)	1.72 (0.43)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	3.45 (0.61)	186.87 (13.55)	178.29 (19.13)	371.18 (21.42)
Southwest	0.00 (0.00)	1.26 (0.26)	0.00 (0.00)	228.23 (65.72)	3.49 (1.21)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.27 (1.39)	128.64 (15.80)	173.00 (17.31)	370.20 (55.45)
Overall mean	0.04 (0.06)	1.42 (0.72)	0.00 (0.00)	131.03 (48.45)	1.36 (0.66)	0.00 (0.00)	0.00 (0.00)	0.01 (0.03)	2.81 (0.90)	77.51 (23.62)	99.84 (26.74)	301.11 (50.81)

Table 2. Zooplankton density (#/L) for six regions of Lake McConaughy during White Bass stocking periods in June 2018. Eight vertical tows were taken in each region, and densities for each tow were averaged. Numbers in parentheses represent one standard error.

Region	*Daphnia pulicaria*	*Daphnia retrocurva*	I-*Daphnia*	*Bosmina*	Chydoridae	*Diaphanosoma*	*Leptodora kindti*	*Ceriodaphnia*	Calanoida-Diatomidae-*Diaptomus*	Cyclopoida-Cyclopoidae-*Cyclops*	I-Nauplii	Rotifera
Northeast	0.00 (0.00)	2.17 (0.58)	0.00 (0.00)	74.69 (15.55)	0.02 (0.02)	0.00 (0.00)	0.00 (0.00)	0.23 (0.09)	0.90 (0.43)	48.46 (10.02)	36.63 (9.00)	21.75 (4.64)
Northcentral	0.00 (0.00)	8.10 (3.48)	0.00 (0.00)	144.35 (21.74)	0.16 (0.16)	0.00 (0.00)	0.00 (0.00)	1.53 (0.54)	1.42 (0.41)	62.82 (15.80)	28.73 (3.89)	22.24 (2.75)
Northwest	0.00 (0.00)	63.96 (13.67)	0.00 (0.00)	115.41 (34.85)	0.16 (0.16)	0.27 (0.18)	0.00 (0.00)	3.55 (0.91)	1.82 (0.34)	43.54 (5.54)	53.15 (5.74)	47.80 (8.29)
Southeast	0.06 (0.06)	11.07 (3.13)	0.14 (0.14)	184.04 (30.70)	0.56 (0.32)	0.00 (0.00)	0.00 (0.00)	3.45 (1.25)	2.47 (0.71)	67.02 (10.48)	57.56 (13.24)	82.04 (25.13)
Southcentral	0.13 (0.13)	22.99 (4.94)	0.00 (0.00)	147.39 (18.97)	0.43 (0.23)	0.00 (0.00)	0.00 (0.00)	4.21 (0.78)	4.77 (1.18)	84.14 (11.75)	64.20 (12.26)	72.12 (10.58)
Southwest	0.00 (0.00)	28.91 (10.58)	0.00 (0.00)	188.54 (32.91)	0.13 (0.13)	0.00 (0.00)	0.06 (0.06)	5.40 (0.92)	3.14 (0.27)	69.55 (9.76)	110.68 (21.55)	116.62 (21.99)
Overall mean	0.03 (0.06)	22.87 (10.24)	0.02 (0.06)	142.41 (28.95)	0.24 (0.19)	0.05 (0.08)	0.01 (0.03)	3.06 (1.00)	2.42 (0.75)	62.59 (11.45)	58.49 (15.01)	60.43 (18.54)