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EVALUATING SPORT FISH USE OF NATURAL AND INTRODUCED HABITATS IN NEBRASKA RESERVOIRS.

A Thesis

Presented to the

Graduate Faculty of the Biology Department

and the

Faculty of the Graduate College

University of Nebraska

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

University of Nebraska at Kearney

By

William M. Schriener

May 2023

THESIS ACCEPTANCE

Acceptance for the faculty of the Graduate College, University of Nebraska, in partial fulfillment of the requirements for the degree Master of Science, University of Nebraska at Kearney.

Supervisory Committee

Name	Department
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Melissa Wuellner
Supervisory Committee Chair

4/26/23
Date

ABSTRACT

Reservoirs are often limited in habitat, and many habitats can be lost through natural decomposition, sedimentation, and as reservoir water elevations changes as reservoirs age. Aquatic managers recognize the importance of maintaining habitat in reservoirs and habitat augmentation projects are common. However, this study was designed to improve understanding surrounding the placement and use of added structures by exploring the following objectives: 1) Quantify the availability of different habitats and how that availability changes under different reservoir elevations; 2) Compare fish assemblages around different habitats; 3) Compare sportfish relative abundance and total lengths between habitats; of Harlan County Reservoir, and 4) Compare fish taxa present between introduced cedar brush piles and Georgia cubes to control sites at Harlan County Reservoir, East Twin Lake, and Red Cedar Reservoir) over three seasons . I was able to estimate that habitat covered 7% of Gremlin Cove in Harlan County Reservoir. Electrofishing efforts over habitat resulted in 22 taxa captured, and a Chi-square test of homogeneity for specific sport fish species showed unequal distributions around habitats ($p \leq 0.03$), suggesting individual species use habitats differently. Finally, during comparison of introduced habitat and control sites, a generalized linear mixed model determined Bluegill was the only species to demonstrate a difference in abundance over different habitats. Fish counts were higher in fall compared to the other seasons. The results of this work suggest that determination of existing habitat distribution can be important before initiating a habitat augmentation project. Additionally, evaluation efforts should consider a multitude of fish taxa and

encompass longer timeframes to conduct these evaluations as differences in use can be noted for fish species and temporally by season.

ACKNOWLEDGMENTS

I would first like to thank my advisors Melissa Wuellner and Keith Koupal for being my advisors and mentoring me through this project. A special thanks to Letty Reichart, Dustin Ranglack, and Rick Holland for being officially or unofficially part of my committee and helping improve this study along the way. I want to thank both Mark Porath and Jeff Jackson for allowing me to pursue this degree while working at the Nebraska Game and Parks Commission (NGPC). I would like to give thanks to the NGPC fisheries managers and biologists who helped to select and provide access to lakes to conduct this project on. A special thanks to the NGPC personnel at the Kearney Service Center who allowed me to use equipment and provided support on this project. Additionally, I would like to thank everyone who helped with sampling on this project, including Josh Kreitman, Logan Dietrich, Thyme Cook, Jenna Ruoss, Blake Logan, Dylan Gravenhof, Logan Zebro, Hayden Wall, Jehnsen Lebsock, Chris Pullano, Bayley Wilmoth, Will Frisch, Nic Fryda, Ellie Morrison, and Jake Ponec.

Lastly, I want to give my appreciation to my friends and family for their support through this period of time. To all the friends that I met along the way here in Kearney, I have enjoyed our time together, from different hunting trips, learning to rock climb, and to the nights downtown or at someone's house; these times will be remembered. To Jenna, I want to thank you for being there for me in more ways than one. To my family, I want to thank them for their support in pursuing higher education and their encouragement all these years.

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Chapter 1:

Background on Reservoir Habitat

Introduction

Reservoirs and their dams are manmade structures that have shaped much of the world's civilization (Ho et al. 2017). In North America, some of the first dams and reservoirs were built as early as the 16th century (Walter and Merritts 2008; Juracek 2015). More than 90,000 dams have been built in the United States, accounting for 11% of dams worldwide (Konijow 2009; Ho et al. 2017), and their reservoirs serve a variety of purposes such as flood control, irrigation, power production, drinking water supply, and recreation (Konijow 2009; Ho et al. 2017). As of 2016, the mean age for these dams in the United States was 66 years old (Konijow 2009; Miranda 2017), but the typical life expectancy for dams is 50 – 100 years (Juracek 2015). Thus, there is nationwide concern about the ongoing functionality of dam infrastructure and a subsequent need to slow the aging process within reservoirs to extend the longevity of these systems (Juracek 2015).

When a dam is built and a reservoir is created, several changes happen above the dam that leads to changes in habitat availability for fish. The water flowing downstream is slowed or stopped, collecting water behind the dam and turning a lotic system to a lentic one (Baxter 1977). Large reservoirs have three denoted zones – riverine, transitional, and lacustrine. As the reservoir transitions from the riverine to the lacustrine zone, there is an increase in depth with a decline in turbidity and productivity (Thornton et al. 1981; Olds et al. 2011). Consequently, fish diversity generally decreases from the riverine to lacustrine zones (Smith and Petrere 2008).

In addition to a longitudinal profile, reservoirs also have more complex depth profiles than rivers, providing both pelagic and littoral habitats (Northcote and Atagi

1997; Miranda 2017). The littoral zone of a reservoir is often composed of riparian vegetation that was flooded when the reservoir was first created (Kimmel and Groeger 1986; Northcote and Atagi 1997). This terrestrial vegetation, including both woody and soft vegetation such as grasses, can become important nursery, feeding, and cover habitat for fish in the years immediately following reservoir construction (Godshalk and Barko 1985; Northcote and Atagi 1997). These habitats also add important nutrients that support trophic upwelling (June 1974). This trophic upwelling can lead to increased growth rates of fish during those early years of impoundment (Patriarche and Campbell 1958; June 1974).

The storage and management of water within the reservoir can exacerbate external and internal sediment loading and prevent new habitats from forming (Juracek 2015). Soft vegetation decomposes within 1 to 2 years of impoundment, and there is a time lag before the aquatic vegetation seed bank can be established (Northcote and Atago 1997). Further complicating the establishment of vegetation stands is reservoir water management, which can lead to desiccation of existing stands or higher turbidity levels that limit the establishment of aquatic vegetation (Godshalk and Barko 1985). Harder materials such as coarse woody debris and rock will remain in the reservoir for a longer period of time, but sedimentation from reservoir flow and lateral drift along newly established shorelines may compromise the integrity of interstitial spaces (Gatch et al. 2020) and limit access to these habitats (Mason 2021; Ruoss et al. 2023). Additionally, sedimentation can reduce substrate firmness and lead to the decline of reservoir depth and storage area (Baxter 1977; Juracek 2015; Miranda 2017).

As the habitat within a reservoir degrades due to natural processes and reservoir aging, fisheries management agencies look for solutions to potentially regain habitat complexity to sustain or improve fisheries (Krogman and Miranda 2016; Miranda 2017). Because the aging process within a reservoir is more accelerated than the successional processes observed within natural lakes (Batxer 1977) managers should anticipate the inflow of water and sediment may be greater than in natural lentic systems (Benson 1982). Some states have implemented programs to fund and execute habitat restorations in impounded waters (Pegg et al. 2015). A variety of restoration practices have been employed to create, restore, and maintain habitat in reservoirs, but many typically come at a high cost, and the outcomes from these projects are rarely evaluated (Allen et al. 2014; Pegg et al. 2015). Options include, but are not limited to: shoreline protection, dredging, water-level management, and the addition of physical habitats constructed from natural or artificial materials (Willis 1986; Pegg et al.2015). In many cases, habitat restorations are frequently more focused on angler access and slowing reservoir aging rather than just the habitat needs of fish (Pegg et al. 2015; Miranda 2017).

The practice of adding habitat in reservoirs has been used in the United States since the 1930s (Hazard 1937; Bolding et al. 2004). Many different materials have been employed over time (Bolding et al. 2004; Allen et al. 2014; Miranda 2017). Initially, greater emphasis was placed on using natural materials such as rock, hardwood trees, and softwood trees to create habitats (Rold et al. 1996; Bolding et al. 2004; Magnelia et al. 2008; Allen et al 2014). However, many of these structures degrade or lose their complexity (e.g., tree branching, interstitial spacing variation) within a few years

(Bolding et al. 2004). As an alternative, structures composed of artificial materials (e.g., tires, concrete, polyvinyl chloride tubing) have been developed (Magnelia et al. 2008; Santos et al. 2008; Feger and Spier 2010; Driscoll et al. 2020). Configurations of such structures are many and include Georgia cubes (Houser 2007), Porcupine cribs (Houser 2007), and floating plats (Santos et al. 2008), to name a few (Bolding et al. 2004, Magmelia et al. 2008; Santos et al. 2008; Feger and Spier 2010; Driscoll et al. 2020). Much of the research evaluating these structures demonstrates that they can concentrate various sizes of fish and increase angler catch rates (Magmelia et al. 2008; Santos et al. 2008; Feger and Spier 2010; Driscoll et al. 2020). However, most evaluation efforts have been performed as a single event on a single lake, and few studies have compared fish use of structures composed of natural or artificial structures between seasons or years after structure implementation (Magmelia et al. 2008; Santos et al. 2008; Feger and Spier 2010; Driscoll et al. 2020).

An additional concern with habitat augmentation projects is appropriate placement within the reservoir. Management of water within reservoir systems results in dynamic changes in water elevation within and among years, especially in reservoirs managed for irrigation or flood control (Daugherty et al. 2015). Placement of physical structures is static in nature. These structures would not fulfill habitat needs for different life stages of fish if they were out of water or potentially too deep (Miranda 2017). Previous research has shown that fewer fish use deeper structures compared to shallower structures (Allen et al. 2014; Miranda 2017). For reservoirs that have higher water-level elevation changes, habitat placement can be just as important as type of habitat (Miranda 2017)

The dynamics and changes in reservoir habitat are major concerns as reservoirs age. The Nebraska Game and Parks Commission (NGPC) has developed and funded an aquatic habitat program designed to combat reservoir aging. A component of this program has been focused on adding physical habitat structures to benefit fish and recreational fishing. Most evaluations of the program thus far have focused on angler catch rates and fish population structure and dynamics (Spirk et al. 2008; Martin and Pope 2011; Spurgeon et al. 2016). However, other information is necessary to evaluate previous projects and plan for future ones, including which species of fish use different kinds of structure across seasons and where to place physical structures in order to maximize their availability as reservoir elevation varies over time. Thus, the objectives of my research are:

1) Quantify the availability of coarse woody habitat, docks, and rock habitats and how that availability changes under different reservoir elevations within one cove (Gremlin) in Harlan County Reservoir;
2) Compare fish assemblages around different habitats in two coves (Gremlin and Patterson Harbor) of Harlan County Reservoir;
3) Compare sportfish relative abundance and total lengths between habitats in two coves (Gremlin and Patterson Harbor) of Harlan County Reservoir; and

4) Compare fish taxa present between introduced cedar brush piles and Georgia cubes to control sites at Harlan County Reservoir, East Twin Lake, and Red Cedar Reservoir) over spring, summer, and fall in 2021.

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Chapter 2:

Availability and Fish Use of Habitat in Hydrodynamic Coves in One Nebraska Reservoir

Introduction

Reservoirs are artificial impoundments that typically have less available habitat compared to natural lakes (Baxter 1977). Initially, the majority of habitat in a newly created reservoir results from flooded terrestrial vegetation and landscape features (i.e., slopes, exposed rock, soil type) which lose their integrity and function over time (Baxter 1977; Northcote and Atagi 1997). Reservoir aging processes accelerate the loss of habitat by breaking down large woody debris, filling in interstitial spaces of rock habitat with sediment, and increasing turbidity which subsequently reduces the photic zone and vegetation development (Baxter 1977; Godshalk and Barko 1985; Northcote and Atagi 1997; Juracek 2015; Miranda 2017). Oscillation of water levels associated with natural hydro-cycles are enhanced by dam operations associated with the primary reservoir purpose (i.e., irrigation and power production), which can also lead to further reductions in available habitat (Godshalk and Barko 1985; Northcote and Atagi 1997). These oscillations can disconnect coves and leave habitat out of water in many cases (Daughtery et al. 2015: Mason 2021; Ruoss et al., 2023; Schriener et al. 2023).

Coves, bays, and the shallow inlets of tributaries are features that provide unique littoral habitats within reservoirs (Meals and Miranda 1991; Mason 2021; Ruoss et al. 2023). Coves are frequently shallow and protected from wind, which can result in improved water clarity and, consequently, vegetation development (Smart et al. 1998; Miranda 2017). Further, the isolated nature and small size of coves have made them a focal point of access and habitat improvement projects (Smart et al. 1998; Miranda 2017). Coves have also been shown to support certain life stages and unique fish assemblages (Meals and Miranda 1991; Ruoss et al., 2023) by providing habitats for spawning, protection, and feeding (Barwick 2004; Sass et al. 2006; Fisher et al. 2012; Smejkal et al. 2014; Miranda 2017). For example, young-of-the-year Bluegill (*Lepomis macrochirus*), Gizzard Shad (*Dorosoma cepedianum*), and Walleye (*Sander vitreus)* have been shown to be more abundant and grow faster in coves compared to the main reservoir (Meals and Miranda 1991; Roseman et al. 2005). Woody debris with interstitial spacing increases habitat complexity to provide protection for species such as Black Crappie (*Pomoxis nigromaculatus*) and Bluegill (Sass et al. 2006; Allen et al. 2014). Largemouth Bass (*Micropterus salmoides*) and Northern Pike (*Esox lucius*) use vegetation that can be found in littoral zones of coves for feeding (Savino and Stein 1989). Rock habitat can provide important spawning habitat for species such as Walleye (Katt et al. 2012), Smallmouth Bass (*Micropterus dolomieu*; Bozek et al. 2002; Musch 2007), and Rock Bass *(Ambloplites rupestris*; Gross and Nowell 1980; Musch 2007). Understanding which species and sizes of fish are present around or on different habitat types can inform habitat projects that are focused on supporting particular species.

Because reservoir habitat is lost over time, habitat improvement projects within reservoirs are becoming more prevalent and expensive (Pegg et al. 2015). The Nebraska Game and Parks Commission (NGPC) initiated a habitat improvement program in 1997 (NGPC 1997), and other states have developed similar programs since that time (IDNR 2021; AZGF 2022). Single-reservoir projects involve substantial planning, permitting, and cooperation with other stakeholders and rarely evaluate outcomes (Pegg et al. 2015). Costs for these projects can run into the millions of dollars and come with a watchful public eye that anticipates improved fisheries shortly after the project completion (Pegg et al. 2015). Thus, fishery managers need improved understanding of the relationship between fish and habitat along with the impacts of water elevation on the availability of habitat. Therefore, I propose to examine the following objectives:

1) Quantify the area of coarse woody habitat, docks, and rock habitats and how that availability changes under different reservoir elevations within Gremlin cove in Harlan County Reservoir.
2) Compare fish assemblages around coarse woody debris, rock, dock, and bare substrate habitats Gremlin and Patterson Harbor coves of Harlan County Reservoir.
3) Compare sport fish abundance and total lengths between coarse woody debris, rock, dock, and bare substrate habitats in two coves (Gremlin and Patterson Harbor) of Harlan County Reservoir.

Methods

Study Area

Harlan County Reservoir is a flood control reservoir located in south-central Nebraska between the towns of Alma and Republican City (Figure 1). The dam on the mainstem of the Republican River was completed in 1957. The reservoir serves multiple purposes, including flood control, providing irrigation water to two states, and supporting recreational boating and fishing (USACE 1991). The normal water elevation for the lake is 593 msl, storing 28,493 ha of water with a mean depth of 4 m (USACE 1991). Water level may vary from year to year; the lowest water elevation observed to date was 586 msl in 2005 (USBOR 2020; Mason 2021).

For this study, I focused on two coves on Harlan County Reservoir – Patterson Harbor and Gremlin (Figure 1). Both coves are located on the lower end of the reservoir near the dam and have public boat ramps, marinas, and residential or camping areas. The coves differ in surface area (Gremlin = 13 ha and Patterson Harbor = 25 ha) but had similar mean depths (3.3 and 3.8 m, respectively). Cove water elevations may temporarily increase with intermittent inflows from the creeks that feed into each, but elevations mostly depend on water levels in the reservoir. While sedimentation does occur at the mouths of both coves, each has a constant connection to the main body of the reservoir due to periodic hydraulic dredging by the United States Army Corps of Engineers (USACE). An aquatic habitat project by NGPC in 2013 included dredging beyond the normal boating channel. Additionally, a breakwater was constructed at both cove mouths to provide wind protection and prevent shoreline erosion from berm formation between the cove and main reservoir.

Mapping

I used side-scan sonar (Humminbird® Series Helix 7 CHIRP MEGA, Racine, Wisconsin) in summer 2021 to map different habitats within Gremlin Cove. The process for mapping and quantifying the area of habitat followed similar protocols for Patterson Harbor (see Schriener et al., *in review*). Briefly, water depths were recorded every 2 s and used to create a bathymetric map with 0.5-m contours within ArcGIS Pro (ESRI 202, version 2.8.1). Side-scan images were also processed through the Sonar TRX-SI_Pro v

18.1 software (Leraand Engineering, Inc., Honolulu, Hawaii) to be used in ArcGIS Pro. Images were used to create polygons around different types of habitats. I focused on physical habitats that were classified into three categories: rock, docks, and coarse woody debris (CWD). Definitions of habitat types followed those used in Patterson Harbor, and the total amount of surface area for each of the habitat types was calculated following the procedures described by Schriener et al. (*in review*). The habitat layer was then overlayed with the bathymetric layer to quantify the area of habitat that would remain in water as reservoir elevations decreased by 0.5-m increments. These calculations were completed for all habitat types except for docks as they do not decrease with water level change unless pulled out by the marina personnel not associated with the USCAE or NGPC. For that reason, only the initial surface area of docks was reported.

Fish sampling

The fish communities in both coves were sampled using boat-mounted DC electrofishing (Smith-Root® electrofishing Boat GPP) over two days in early October 2021. Sampling began 1 hr before sunset and was completed by 0300 the following morning. I randomly selected 10 locations from available CWD, rock, dock, and open (bare sediment that acted as a control) habitat that was identified in the vertical habitat distribution maps described above. In Gremlin Cove, only 3 CWD locations were available, so all were sampled. Each sampling location was at least 15 m away from others to maintain independence between locations. At each location, the boat was moved next to or over the sampling location and the generator was turned on for 30 s. Two netters at the front of the boat collected as many fish as possible during this period. All fish collected were identified to species, enumerated, and measured for total length (TL; mm).

Fish count and TL data were combined between the two coves as both have similar fish communities (Mason et al. 2022; Ruoss et al., *2023*). I calculated species richness (S) and Shannon-Wiener diversity (H; Shannon 1948) for each habitat type. A chi-square test of homogeneity was performed on count data to compare abundances of those specific sportfish species that met test assumptions (≥ 5 individuals per habitat type; McHugh 2013) between habitat types. I adjusted the expected number to account for the unequal sampling of CWD compared to the other habitat types. A Bonferroni correction was used to account for multiple comparisons (3 comparisons) and conserve the overall risk of a Type I error. Differences in mean TL by habitat type for species selected for the chi-square test were evaluated using a Kruskal-Wallis followed by a Dunn's test (Dunn 1964). Significance for all analyses was determined at $\alpha = 0.10$.

Results

Mapping and elevation

Surface area loss was not linear and decreased between 3,306 and 18,981 m^2 as water elevation decreased every 0.5 m (Figure 2A). All habitats combined covered a total area of 137,106m^2 (approximately 7.5% of cove area) at conservation pool in Gremlin Cove and predominantly consisted of rock (5,181 m^2) or docks (5,108 m^2); CWD only accounted for 0.3% of the total area. Habitat availability differed by habitat type as elevations decreased. Brush habitat was left entirely out of the water when water elevations decreased by 1.5 m (Figure 2C). The majority of rock habitat was in the top 2 m at conservation pool, but 0.1% remained even as water elevations decreased by 6 m (Figure 2B).

Fish sampling

I collected 5,305 fish representing 20 species and two hybrid taxa. Gizzard Shad comprised the majority (82%) of fish captured, and seven species were represented by fewer than five individuals (Table 1). Over twice as many individuals were caught around docks as compared to rock habitat (Table 1). Species richness was highest at rock and open sites (S = 15), followed by CWD (S = 11) and docks (S = 10). The highest species diversity was observed over rock habitat (H = 1.52) and the lowest was around docks (H = 0.30); bare habitat had higher diversity (H = 0.98) than CWD (H = 0.42).

Black Crappie, Bluegill, and White Bass were the only species that met the requirements for comparisons of abundances and TLs between habitat types. Counts of all three species differed between habitat types (Table 2). Black Crappie and Bluegill were both more abundant over rock habitat, and White Bass were more abundant over open habitat than the other types (Figure 3). Mean TLs of each of the three species were different between habitats (all p-values < 0.01, Figure 4). Black Crappie collected over rock habitats were larger than those captured over the other three habitat types (Table 3; Figure 4). Bluegill collected over rock habitats were larger than those collected over open habitats, but no other differences were noted among the other habitat types (Table 3; Figure 4). Mean TL of White Bass collected over open habitats were smaller than those collected over rock habitat and around docks, and White Bass collected over CWD were smaller than those collected over rock habitat and around docks (Table 3; Figure 4).

Discussion

The presence of physical habitat in reservoirs is important to support fish diversity and sustain quality recreational fisheries (Miranda 2017). Because of habitat limitations in reservoirs, adding habitat to these waters over time has become a priority for many state agencies (Pegg et al. 2012). Planning for habitat additions or supplementation requires knowing where to place structures so that they are available for fish as water levels change over time and what fish are using these habitats (Miranda 2017). Most studies of habitat projects have focused on fish use of different habitat types, but very few have examined the vertical distribution of habitats within a reservoir to my knowledge (Schriener et al., 2023). In this study, I examined and compared not only fish use of different habitats but also projected which habitats may be lost and by how much due to water level change in an irrigation reservoir. Further, I compared how these habitats may influence fish size by comparing total lengths of individual species between habitat types.

The vertical distribution of habitats in Gremlin Cove appears to be uneven as different habitats became more or less relatively available as reservoir elevations decreased. Similar patterns have been noted in reservoirs in Texas (Daugherty et al. 2015) as well as in Patterson Cove on Harlan County Reservoir (Schriener et al., 2023). In Texas, littoral areas, coarse substrates, and aquatic vegetation habitat were moderately to highly sensitive to water-level changes in terms of the percent area lost (Daugherty et al. 2015). On Harlan County Reservoir, Patterson Cove lost most of the available habitat in the first 2 m of water-level declines, and all habitat was lost between 3.5 and 4.0 m of water-level decline (Schriener et al., 2023). Both Gremlin and Patterson Harbor coves have had multiple alterations to improve access, increase depth, and provide added habitat structure. The alterations might have changed the area and relative proportion of habitat types (rock, artificial structure, etc.) within these coves but most likely has not changed the access to these habitats as water levels decrease. In other words, placement of habitat has not accounted for water elevation losses in many cases. Other coves on Harlan County Reservoir without similar alterations are disconnected from the main reservoir within 2 to 3 m of water level change from conservation pool (Mason 2021; Ruoss et al. 2023). As the unaltered coves disconnect, most habitats within coves on Harlan County Reservoir are not accessible to the main reservoir, which may be a more pressing issue in terms of providing aquatic habitat needed for fish communities, as an entire cove worth of habitat can be unavailable for fish use.

Boat-mounted electrofishing was chosen as the only sampling method in this study, and sampling only occurred over one season. The use of electrofishing is effective for sampling relatively small areas and is the standard sampling for expected species, including many Centrarchidae (Miranda and Boxrucker 2009). Although sampling with additional gears and at different times of the year may have captured additional species or the same fish at different catch rates (Miranda and Boxrucker 2009), I believe that my sampling protocol provided information that is similar to previous research of these coves on Harlan County Reservoir. Twenty-four fish taxa have been previously identified in these coves via the use of multiple gears (trap nets, shoreline seines) and across multiple seasons (spring, summer, and fall; Mason 2021, Ruoss et al., 2023). In comparison, I captured nearly the same number of taxa (n = 22), and most (91%) were the same as those identified in previous research. Future research might examine whether richness, diversity, and fish use differ between seasons in these coves as research on other littoral zones indicates seasonal differences in fish communities (Hatzenbeler et al. 2000).

Not surprisingly, various species in my study used habitats differently. Fish use of different habitats will depend on their ecology, life stage, and tolerance (Miranda 2017). Some species used habitats as I expected based on previous research, but others did not. For example, I found that White Bass were more abundant in open-water habitats than other habitat types and were larger near rock and dock habitats, both of which are frequently found in deeper parts of both coves (*personal observation*). White Bass are often located in deep water and typically not associated with physical habitat structure unless feeding in littoral zones (Lincoln et al. 2016). In contrast, I found that Bluegill and Black Crappie were more abundant and larger over rock habitats. Other studies have found that Bluegill and Black Crappie are often negatively associated with rocky structure and positively associated with CWD or vegetation (Paukert et al.2004; Weimer 2004; Gosch et al. 2006; Allen et al. 2012). However other studies have found rock habitat may serve as an alternative habitat, fulfilling some role for protection or feeding to support Bluegill (Barwick 2004; Purcell et al. 2013), especially larger individuals with less risk of predation. (Mittelback 1981; Werner et al. 1983; Johnson et al. 1988). Use of different habitats compared to previous studies may be related to the availability of quality habitats in my coves. Most of the CWD in Patterson Harbor and Gremlin coves are older than 50 years and likely function as standing logs as the complexity of the structure has broken down over time and vegetation has been limited (Schriener et al.

2023). Thus, habitat use might be dependent on the availability and quality of habitat and food resources.

Management Implications

Fisheries managers who want to add habitat into reservoirs need to understand the vertical distribution of existing habitats and the influence of water fluctuation on habitat availability. Water storage patterns at each reservoir need to be considered when adding habitat. Habitat might be plentiful at conservation pool elevations, but more limiting with seemingly slight changes in elevation (< 2m) as they were for Gremlin and Patterson coves in Harlan County Reservoir. As natural aging processes reduce depths in specific areas such as coves, greater depths (> 2 m) may not be present and specific habitat types could be lacking. Fish communities have been shown to be more diverse when they maintain connection to the main reservoir (Mason et al. 2022). Thus, a focus of habitat work for Nebraska reservoirs should include dredging for connection and depth and introduction of deep-water habitat. Another option is to place deep water habitat just outside of the cove to provide a cover refuge in areas that may require less maintenance costs compared to coves that are more sensitive to sedimentation (Miranda 2017).

A second consideration for managers is to prioritize the amount, habitat type and habitat placement to best fit management goals or objectives for the reservoir. Variability in cove habitat conditions and connectivity have been related to various sportfish, nuisance fish, and native fish taxa (Mason et al. 2022). Additionally, specific sportfish taxa have been observed in greater abundance surrounding different habitat types at different depths (Allen et al. 2014). Knowing which species use one or multiple habitat types can be helpful for planning restoration projects to support management goals for that reservoir. Results from my work would suggest that rock habitat was an optimal habitat type for sportfish communities, however the rocky areas in this study were located in the top section of the cove and might not be best for deeper water. Other habitat such as trees might be better as vertical height in structures might be needed to extend the life of the structures at depths. Regardless of the final habitat plans that are developed, a paramount concern would be to ensure that conflict with navigation and recreation activities are not elevated as a result of habitat management.

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Table 1: Species of fish, total number collected (n) across all sampling events, and the total number caught over coarse woody debris (CWD), docks, open (bare), and rock habitats in two coves (Gremlin and Patterson Harbor) of Harlan County Reservoir. All fish were captured in fall 2021 using boat-mounted electrofishing. Count data were combined for both coves.

Common name	Scientific name	n	CWD	Docks	Open	Rock
Black Crappie	*Pomoxis nigromaculatus*	155	31	25	40	59
Bluegill	*Lepomis macrochirus*	294	25	2	86	181
Bluegill X Green Sunfish hybrid	*Lepomis macrochirus* x *L. humilis*	1	0	0	0	1
Bigmouth Shiner	*Notropis dorsalis*	5	0	0	5	0
Brook Silverside	*Labidesthes sicculus*	10	2	4	4	0
Channel Catfish	*Ictalurus punctatus*	7	2	0	3	2
Common Carp	*Cyprinus carpio*	19	2	0	3	14
Flathead Catfish	*Pylodictis olivaris*	3	2	0	0	1
Freshwater Drum	*Aplodinotus grunniens*	68	4	1	40	23
Gizzard Shad	*Dorosoma cepedianum*	4333	1024	1770	1088	451

Common name	Scientific name	n	CWD	Docks	Open	Rock
Golden Shiner	*Notemigonus crysoleucas*	1	0	1	0	0
Green Sunfish	*Lepomis cyanellus*	9	0	0	0	9
Largemouth Bass	*Micropterus salmoides*	47	5	0	4	38
Northern Pike	*Esox lucius*	1	0	1	0	0
Orange spotted Sunfish	*Lepomis humilis*	13	0	0	4	9
Quillback	*Carpiodes cyprinus*	1	0	0	1	0
River Carpsucker	*Carpiodes carpio*	10	0	0	10	0
Red Shiner	*Cyprinella lutrensis*	1	0	0	1	0
Walleye	*Sander canadense*	4	0	1	0	3
White Bass	*Morone chrysops*	303	16	63	159	65
White Bass X Striped Bass	*Morone chrysops* x *M. saxatilis*	3	0	0	0	3
White Crappie	*Pomoxis annularis*	17	1	10	5	1

Table 2. Results of the Chi-square tests of homogeneity to determine whether Black Crappie, Bluegill, and White Bass counts were similar or different between habitat types. Significance was determined at $\alpha = 0.03$ after Bonferroni correction.

Species	# collected	χ^2	p
Black Crappie	155	14.18	0.003
Bluegill	294	216.53	<0.001
White Bass	303	104.99	<0.001

Table 3. Results of Dunn test (z) to compare total lengths (mm) of Black Crappie, Bluegill, and White Bass between habitat types [coarse woody debris (CWD), dock, open, and rock]. Significance was determined using a Bonferroni adjusted level of significance at $\alpha = 0.0167$.

Species	Habitat	z	p
Black crappie			
	Open x Rock	-6.63	<0.001
	Open x Dock	-0.30	0.974
	Open x CWD	0.95	0.341
	Rock x Dock	-5.72	<0.001
	Rock x CWD	-5.10	<0.001
	Dock x CWD	0.87	0.380
Bluegill			
	Open x Rock	-3.44	<0.001
	Open x Dock	0.55	0.579
	Open x CWD	0.39	0.693
	Rock x Dock	-0.07	0.939
	Rock x CWD	-1.69	0.090
	Dock x CWD	-0.41	0.675
White Bass			
	Open x Rock	-4.75	<0.001
	Open x Dock	6.29	<0.001
	Open x CWD	-0.13	0.089
	Rock x Dock	1.33	0.185
	Rock x CWD	-2.62	0.009*
	Dock x CWD	-3.46	<0.001

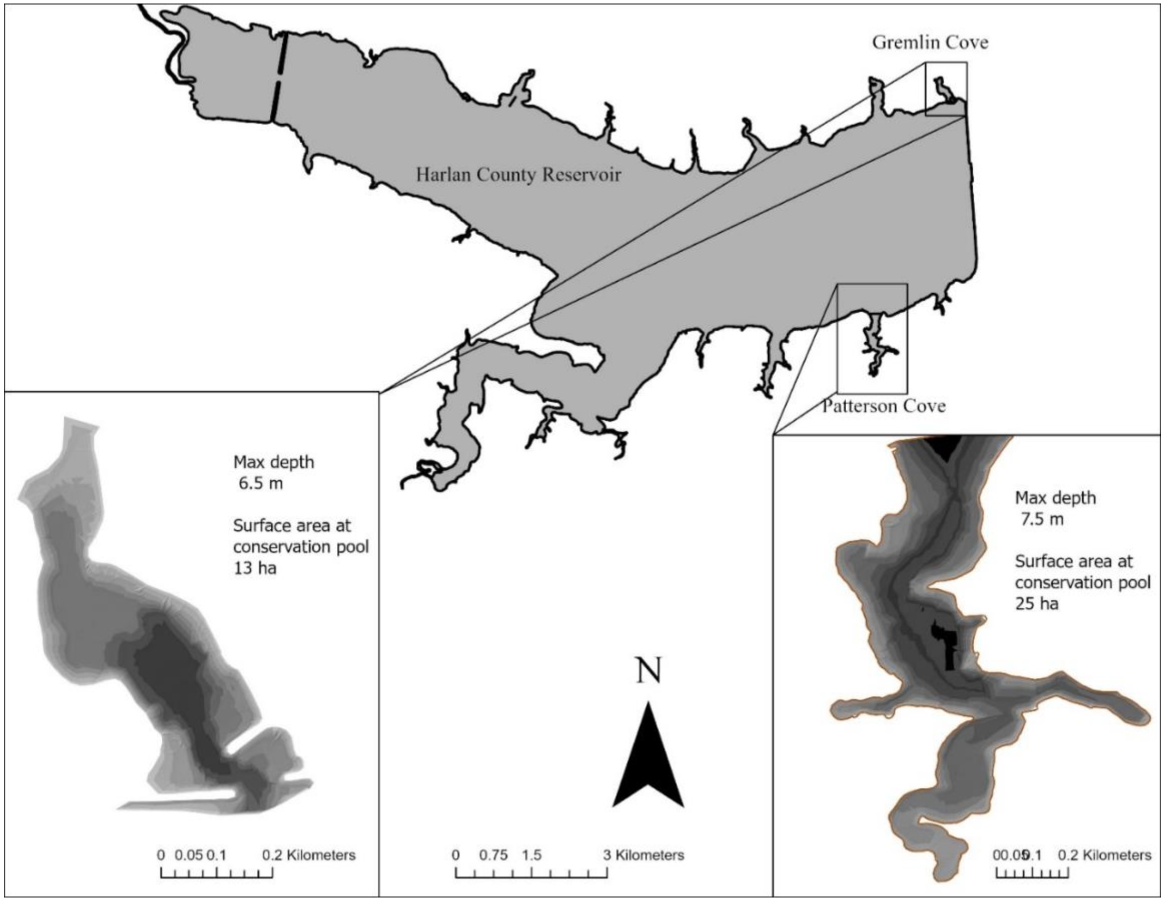

Figure 1. Map of Harlan County Reservoir (adapted from aerial imagery taken by the USDA-NRCS July 13, 2016; surface water elevation approximately 591 msl) with locations of the two coves (Gremlin and Patterson Harbor) and their depth profiles. Shades of grey denote 1 m of change.

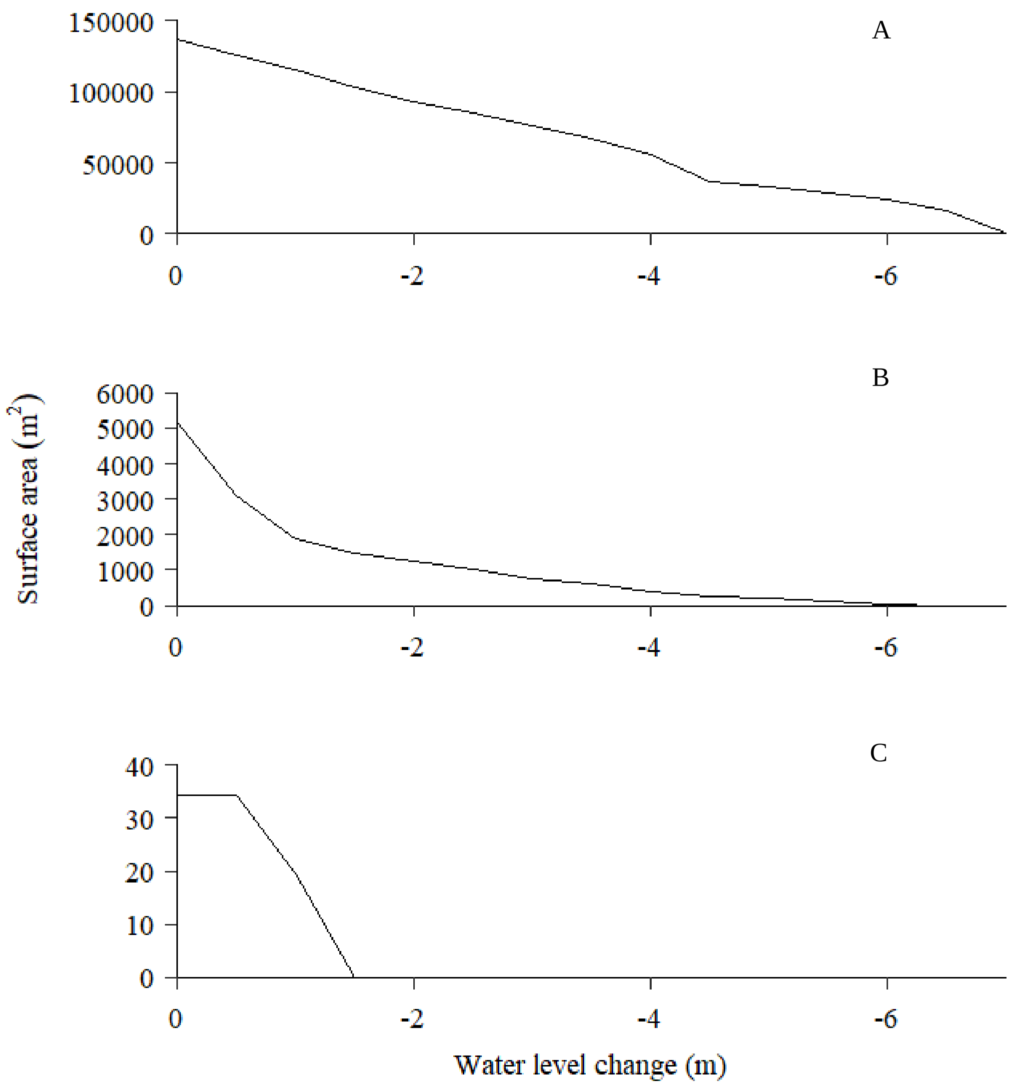

Figure 2. Predicted changes in surface area (panel A) and areas of rock (panel B) and tree (panel C) habitats due to water elevation changes in Gremlin Cove, Harlan County Reservoir, Nebraska. Zero represents the elevation at full conservation pool (593 msl).

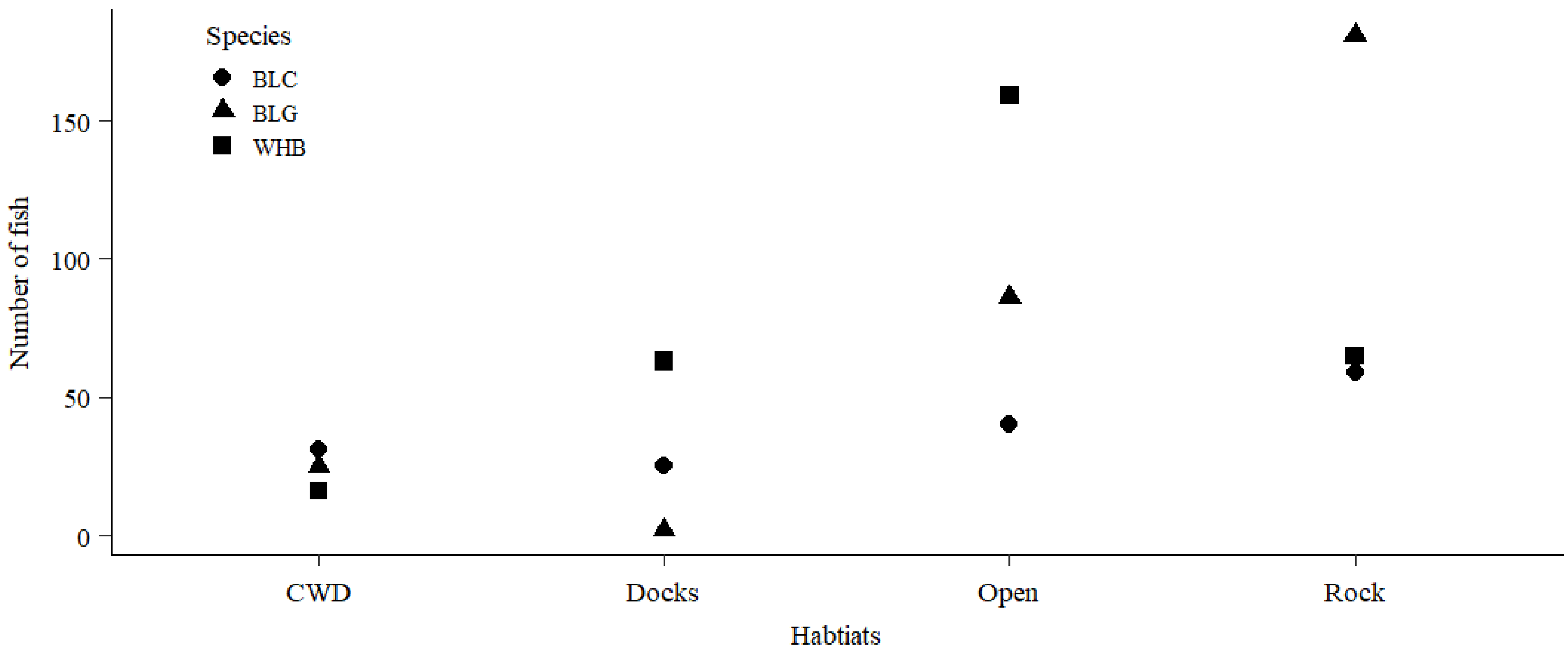

Figure 3. Total number of Black Crappie (BLC), Bluegill (BLG), and White Bass (WHB) over each habitat type [coarse woody debris (CWD), docks, open, and rock)] in Gremlin and Patterson Harbor coves of Harlan County Reservoir. All fish were collected using boat-mounted electrofishing in fall 2021.

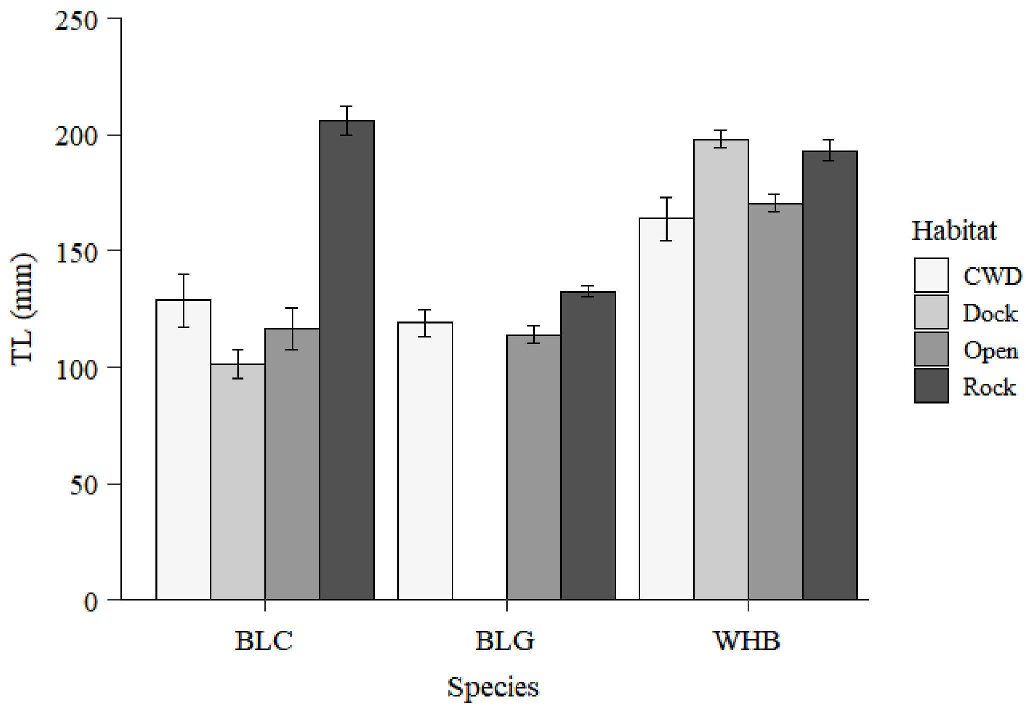

Figure 4. Mean total length (TL) of Black Crappie (BLC), Bluegill (BLG), and White Bass (WHB) for each habitat type [coarse woody debris (CWD), docks, open and rock] in Gremlin and Patterson Harbor coves of Harlan County Reservoir. No Bluegill were collected near docks. All fish were collected using boat electrofishing in fall 2021. Error bars represent one standard error.

Chapter 3:

Comparisons of Fish Presence Around Introduced Structures in Three Nebraska Reservoirs

Introduction

Constructed reservoirs often have a paucity of available habitat due to the removal of trees and materials in the construction process (Northcote and Atagi 1997; Willis et al. 2010). Natural structures or features that do remain after initial reservoir construction can be reduced over time as sedimentation and decay processes cover or break down remaining habitat (Northcote and Atagi 1997; Nilsson and Berggren 2000; Miranda 2017). The loss and reduction in habitat are a concern to fisheries biologists managing these systems (Sass et al. 2006; Miranda 2017) as physical habitat structure provides refuge and feeding opportunities for many species of fish and macroinvertebrates (Hatzenbeler et al. 2000; Sass et al. 2006). Additionally, the lack of habitat can hinder productivity of aquatic communities (Rold et al. 1996; Northcote and Atagi 1997; Sass et al. 2006; Smokorowski and Pratt 2007).

To address the lack of available habitat, managing agencies have initiated aquatic habitat programs that dedicate money and resources to improve or maintain habitat integrity (Pegg et al. 2015). A common approach is to use natural materials such as trees or rocky material to create new habitats or enhance existing habitat availability (Bolding et al. 2004; Allen et al. 2014; Miranda 2017). Structures comprised of natural materials are hypothesized to benefit fish communities by providing cover, feeding, and spawning substrates (Rold et al. 1996; Bolding et al. 2004; Magnelia et al. 2008; Allen et al. 2014). While many studies have documented fish attraction around these added structures (Rold et al.1996; Bolding et al. 2004; Magnelia et al. 2008; Allen et al. 2014), the longevity of the hypothesized benefits may be limited (Bolding et al. 2004). Woody materials break down in a few years, and the interstitial spaces of rock piles can be filled in with sediment (Rold et al.1996; Bolding et al. 2004; Magnelia et al. 2008; Allen et al. 2014; Baetz et al. 2020). While the use of larger trees and rocks can prolong the integrity of habitats constructed from natural materials, the placement of these larger structures require specialized equipment, which can increase costs, and in some cases makes them infeasible(Allen et al. 2012; Miranda 2017).

To address concerns related to longevity, several management agencies have begun to use artificial materials for habitat structures. Plastic in the form of polyvinyl chloride (PVC) and high-density polyethylene are common materials used in many configurations (Rold et al. 1996; Magnelia et al. 2008; Feger and Spier 2010; Driscoll et al. 2020). Plastic materials do not break down as quickly as wood and can be constructed in such a manner to offer a greater variety in interstitial spacing compared to rock habitats, thus potentially avoiding sedimentation issues (Rold et al. 1996; Magnelia et al. 2008; Feger and Spier 2010; Driscoll et al. 2020). Like structures composed of natural materials, PVC structures have been shown to concentrate fish such as Largemouth Bass (*Micropterus salmoides*) and Bluegill (*Lepomis macrochirus*; Rold et al. 1996; Magnelia et al. 2008; Feger and Spier 2010; Driscoll et al. 2020). However, most studies evaluating the use of PVC structures have been done on either one lake (Rold et al. 1996; Magnelia et al. 2008; Feger and Spier 2010; Driscoll et al. 2020), at one time of the year (Magnelia et al. 2008) or have not compared fish use to more common structures made from natural material available within the same reservoir (Feger and Spier 2010; Driscoll et al. 2020). Thus, my objective was to compare fish presence and assemblages on introduced structures composed of either wood (cedar brush piles or plastic material (Georgia cubes) to nearest existing available habitat and a site with no apparent habitat structures across three reservoirs (East Twin Lake, Red Cedar Lake, and Harlan County Reservoir) over spring, summer, and fall 2021.

Methods

Study Area

Three Nebraska reservoirs were selected (East Twin Lake, Red Cedar Lake, and Harlan County Reservoir) based on their inclusion in the Nebraska Game and Parks Commission (NGPC)-approved aquatic habitat list and recommendations by the district fisheries biologists. East Twin Lake, located in southeastern Nebraska (40.828621°, -96.944338°), is an 85-ha flood-control reservoir (maximum depth = 6 m) owned by NGPC. The fish community in this lake consists of Bluegill, Largemouth Bass, crappie (*Pomoxis* spp.), and Walleye (*Sander vitreus*). Red Cedar Lake (surface area = 20 ha; maximum depth = 4 m) is a flood-control reservoir owned by the Lower Platte South Nebraska Natural Resource District and is located southwest of Weston, Nebraska (41.16545689º, -96.8772168º). The fishery includes Bluegill, Largemouth Bass, and Channel Catfish (*Ictalurus punctatus*). Harlan County Reservoir is the third largest reservoir (5,260 ha) in Nebraska and is located in the southcentral portion of the state (40.070753º, -99.212203º). The dam is operated by the U.S. Army Corps of Engineers for the purposes of flood control and irrigation. The fishery is managed by NGPC and includes Bluegill, Largemouth Bass, crappie, Walleye, catfishes, White Bass (*Morone chrysops*), and Hybrid Striped Bass (*Morone chrysops* x *M. saxatilis*) along with 24 other species (Ruoss et al., 2023). Coves on Harlan County Reservoir provide access to boat anglers and have been the focus of previous research on the influence of connectivity to aquatic communities in the reservoir and the addition of habitat (Mason et al. 2022; Ruoss et al., 2023: Schriener et al., 2023). To provide similar fish community comparisons, all study sites were located within Patterson Harbor at Harlan County Reservoir. Patterson Harbor is located on the south end of the lower reservoir and has an area of 21 ha and a maximum depth of 7 m at full pool (Figure 1).

Habitat Structures

Cedar brush piles and Georgia cubes were selected to be added as representative structures constructed from natural and artificial materials, respectively. All added structures were placed in the three study reservoirs in October 2020. Cedar brush piles were constructed by harvesting trees located near each reservoir. Trees were tied with rope to two cement blocks (16 kg) to anchor structures to the substrate. Georgia cube frames were constructed of 3.81-cm (1 ½“) diameter PVC and assembled into 1-m^3 cubes (Figure 2). Prior to deployment, the PVC sections were filled with 7 kg of pea gravel, and a minimum of ten, 8-mm diameter holes were drilled to allow air to escape when sinking. Ten pieces of 10.16-cm high-density polyethylene corrugated irrigation pipe were drilled and fitted across the PVC frames to enhance structure complexity. Three cubes were arranged into a triangle shape and tied together with 7 mm rope to create one cube complex that laid flat on the substrate. The area and volume of both added structures were similar.

The added habitats were placed in an area devoid of existing habitat and separated by a minimum of 15 m from other habitats. Depth of placement was 1.5 – 2.0 m and the substrate around the structure was mostly sand or sediment. Three similarly sized areas devoid of any natural or added habitat were selected at least 15 m away and served as a negative control (hereafter, referred to as "open habitats”). A positive control was also selected near each added habitat and represented any existing physical structure of similar size and volume. Existing habitat was identified using depth and assumed available for a minimum of five years prior to the initiation of the study (October 2020). Thus, the study design had three lakes with three locations that included four habitat types (total number of habitats sampled = 12 per lake)

Fish Sampling and Analysis

Fish were sampled over all 12 habitats sampled at each lake once during spring (late May and early June), summer (July), and fall (October) in 2021 using a boat-mounted DC electrofishing unit (Smith-Root® electrofishing Boat GPP) with a target output of 8 A. Sampling began within 1 hr of sunset and followed methods established by Feger and Spier (2010) consisting of 30 s shock time over each habitat. All fish collected were identified, enumerated, and measured for total length (TL; mm).

I calculated species richness (S) and Shannon-Wiener diversity by lake (H; Shannon 1948) for each habitat type by combining locations within a lake across all seasons combined. To compare fish use between the four habitat types by season, I performed a generalized linear mixed model (GLMM) on count data for select sport fish taxa. The taxa included Bluegill, Largemouth Bass, Channel Catfish, and crappie (Black

Crappie *Pomoxis nigromaculatus* and White Crappie *P. annularis*, combined). The two crappie species were not separated in the analysis as both are managed under a similar bag regulation (15 daily bag limit) in all three reservoirs. For some species, several zeros existed in the data and, thus, data distributions were not normal. Therefore, I transformed the count for all species data by calculating the log of the counts added to 10. Models were run for each species within each lake, and season and habitat type were treated as fixed variables. Significance was determined at $\alpha = 0.10$. If any of the GLMM results were significant, then a Tukey's test was performed to identify specific differences.

Results

A total of 1096 fish were caught across all lakes and sampling periods. The highest abundance of fish captured was in Harlan County Reservoir (n = 292), representing 18 species (Table 1). Catch numbers were lowest for abundance and species richness in Red Cedar Lake (n = 369; S = 6; Table 1). Fish abundance and species richness were intermediate in East Twin Lake (n = 435; S = 10; Table 1). Species richness was highest around the nearest existing habitat and lowest over open habitats (Table 1). In one lake, species richness was equal between added habitat constructed from artificial materials and the nearest existing habitat; however, richness was lower around added habitat constructed from artificial materials compared to nearest existing habitat in the other two lakes. Fish species richness captured at added habitat constructed from natural materials was intermediate to open and habitats constructed from artificial materials (Table 1). Shannon diversity was highest for two lakes around nearest existing habitat, but diversity was higher around added structures constructed from artificial materials compared to existing habitat at the third lake. Additionally, more fish were sampled in fall (n =665, spring n = 162, summer = 269) and over nearest existing habitat (n = 410) compared to added habitat constructed from natural materials (n = 273), added habitat constructed from artificial materials (n =223) and open habitat (n = 90).

The following counts of Largemouth Bass (n = 40), Channel Catfish (n = 14), crappie (n = 232) and Bluegill (n = 327) were found in all lakes. No consistent differences in season or habitat were noted for any species across all three lakes (Figures 3 – 6). In Harlan County Reservoir, catches were higher in the fall for crappie and Bluegill (Table 1; Figures 5 and 6) but no differences in habitat type were found for any of the four species (Figures 3 – 6). In contrast, habitat differences were found in Red Cedar Lake for Bluegill where counts were higher over nearest existing habitat (Table 1; Figure 6), but no seasonal differences were noted for any of the four species (Figures 3 – 6). For East Twin Lake, catches of all species except Largemouth Bass were higher in the fall than in the other seasons; no seasonal differences were found for bass (Table 1; Figures 3 – 6). However, counts for only one species (i.e., Bluegill) differed by habitat type with higher counts over nearest existing habitat (Table 1; Figure 6).

Discussion

In this study, I found a wide array of different species present on various sampled habitats (18) of which 15 taxa were present across both added structures. Addition of structures constructed from natural or artificial materials to augment existing habitat is a common fisheries management practice in reservoirs (Rold et al. 1994; Bolding et al. 2004; Feger and Spier 2010; Allen et al. 2012). However, the efforts to evaluate the response of fish communities to placement of habitat structures has primarily focused on a single species. Previous evaluations of habitat enhancement projects have focused on Largemouth Bass (Rold et al. 1994; Magmelia et al. 2008; Feger and Spier 2010; Allen et al. 2012; Driscoll et al. 2020); crappies (black and white; Feger and Spier 2010; Allen et al. 2012); and Bluegill **(**Rold et al. 1994; Magmelia et al. 2008; Feger and Spier 2010; Driscoll et al. 2020). The use of placed structures by Channel Catfish has not been highlighted specifically in previous literature, but other studies have examined habitat selection in this species **(**Braaten and Berry 1997; Kelsch and Wendel 2004). While my comparisons of habitat use of structures across seasons only focused on four taxa, the variety of taxa present at placed structures indicates that proper evaluation of habitat augmentation projects should consider more species in the future. The use and benefits to sportfish may be the priority for many habitat augmentation projects, but the indirect benefits to ancillary taxa within the community could impact population dynamics of the target sportfish species (Michaletz 1998; Wolfe et al. 2009).

Understanding fish community use of habitats over time is important, but responses of individual species may differ. In my study, Bluegill were the only species to show differences between habitat types. Bluegill have relatively smaller home ranges **(**Fish and Savitz 1982; Paukert et al. 2004**)** than have been reported for crappie (Markham et al. 1991; Guy et al. 1994; Fryda et al. 2008). Largemouth Bass and Channel Catfish have demonstrated similar home ranges as Bluegill (Fish and Savitz 1982; Fisher et al. 1999). However, Largemouth Bass have been noted to move between habitats more frequently. (Fish and Savitz 1982). Another possible explanation for the results I found maybe that the benefit Bluegill receive from structure may be more related to increased availability of prey (which may take time to develop) as compared to cover protection. Since Bluegill have shown a proclivity for different habitat types (Paukert and Willis 2002; Paukert et al. 2004; Weimer 2004), perhaps it is more related to the length of time and potential food production that has developed from habitat rather than available interstitial spaces for cover. The results from this study may suggest to managers that they have an opportunity to manipulate design and placement of structures to optimize benefits to specific species, but greater understanding of these relationships needs to be developed.

In addition to examining individual fish species presence around structures, examining patterns of the timing of use across individual or multiple species can provide useful information for planning and evaluating habitat enhancement projects. For example, crappies (black and white) have been noted to spawn in 1 m of water during the spring but then retreat to deeper waters during the summer (Garner 1995). Similarly, other centrarchid species like Bluegill may spawn multiple times, which would place them in shallow water for most of the summer that is typically surrounded by vegetation (Paukert and Willis 2002; Paukert et al. 2004; Weimer 2004). Because of seasonal fish movement patterns, it would be ideal to evaluate habitat augmentation projects for consecutive time periods (e.g., Paukert and Willis 2002; Weimer 2004), or for multiple years (e.g., Allen et al. 2014). In many cases, time and money may not be available for this length of evaluation effort. Thus, I would recommend considering a seasonal timeframe for use of habitat structures or selecting the most appropriate season for priority species. In this study, I recorded higher abundance for multiple fish species in the fall. Therefore, I would recommend fall as the most appropriate single season for assessment efforts.

Habitat studies have shown results that structure made from natural (Rold et al. 1996; Magmelia et al. 2008) and artificial material (Feger and Spier 2010; Driscoll 2020) can aggregate different fish species at different concentrations. This study design took a general look at the response of fish taxa to placement of these added structures. While evaluation efforts have certainly been conducted in other waters in Nebraska and elsewhere, there is a need for greater understanding of how time and money spent to improve habitat impacts the fish community (Tugend et al. 2002). The design of this study was intended to develop better questions and evaluation methods for on-going use of added structures, whether composed of natural or artificial materials. The type of sampling and timeframe for evaluations, along with how fish interacted between added and existing habitat are all factors that need to be considered. The hope is that the results from this study can be used to improve study designs for needed evaluations of management activities.

Management Implications

The complexity of habitat needs by fish is variable between species and life stages (Hatzenbeler et al. 2000). And as such there were limited patterns of fish presence surrounding the habitat locations sampled in this study. Generally, there was greater presence of fish surrounding cover habitat during the fall, which may be associated with reduced water levels in irrigation reservoirs or a decline in macrophyte availability. The sporadic patterns of cover use by varying species through time suggest that there is not a single most appropriate habitat type to introduce to Midwest reservoir systems. Rather a diversified approach of providing a variety of cover habitat types that can be available at multiple depths (Schreiner et al. 2023). Structures can be added to promote fishing and provide opportunity to anglers. The choice of structures for any individual project should be driven by the initial cost, longevity of added structures, replacement costs and perception of the structure for public use.

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Table 1: Total species caught (n), species richness (S), and Shannon diversity index (H) by habitat type for East Twin Lake, Red Cedar Lake, and Harlan County Reservoir, in Nebraska. Numbers represent all species captured across all seasons (spring, summer, and fall) in 2021.

Lake	Habitat type	n	S	H
East Twin	Cedar trees	146	7	1.27
	Cubes	110	9	1.53
	Nearest existing	104	9	1.55
	Open	75	5	1.26
Red Cedar	Cedar trees	43	4	0.79
	Cubes	16	3	0.89
	Nearest existing	307	5	0.67
	Open	3	2	0.43
Harlan	Cedar trees	84	8	1.51
	Cubes	97	10	1.18
	Nearest existing	99	16	2.36
	Open	12	6	1.37

Table 2: Results of the generalized linear mixed models used to test whether counts of each species listed differed between season or habitat type across three reservoirs. Significance was determined at $\alpha = 0.10$ and noted with an asterisk.

Species	Reservoir	Variable	F-value	p- value
Largemouth Bass	East Twin	Seasons	1.50	0.243
		Habitat	0.50	0.685
		Season X habitat	0.50	0.802
	Red Cedar	Seasons	1.25	0.304
		Habitat	1.45	0.253
		Season X habitat	0.76	0.609
	Harlan	Seasons	2.33	0.118
		Habitat	0.78	0.178
		Season X habitat	1.44	0.239
Channel Catfish	East Twin	Seasons	3.37	0.051*
		Habitat	0.57	0.640
		Season X habitat	1.14	0.369
	Red Cedar	Seasons	1.00	0.383
		Habitat	0.33	0.801
		Season X habitat	1.00	0.448
	Harlan	Seasons	1.00	0.383
		Habitat	1.22	0.323
		Season X habitat	0.56	0.761
Crappie	East Twin	Seasons	3.83	0.036*
		Habitat	2.03	0.136
		Season X habitat	0.76	0.609
	Red Cedar	Seasons	1.00	0.383
		Habitat	1.00	0.410
		Season X habitat	1.00	0.448
	Harlan	Seasons	6.73	0.005*
		Habitat	1.89	0.158
		Season X habitat	2.01	0.104
Bluegill	East Twin	Seasons	4.17	0.019*
		Habitat	2.42	0.091*
		Season X habitat	1.07	0.408
	Red Cedar	Seasons	0.22	0.803
		Habitat	30.5	<0.001*

	Season X habitat	0.94	0.486
Harlan	Seasons	9.29	0.001*
	Habitat	1.76	0.181
	Season X habitat	3.62	0.010*

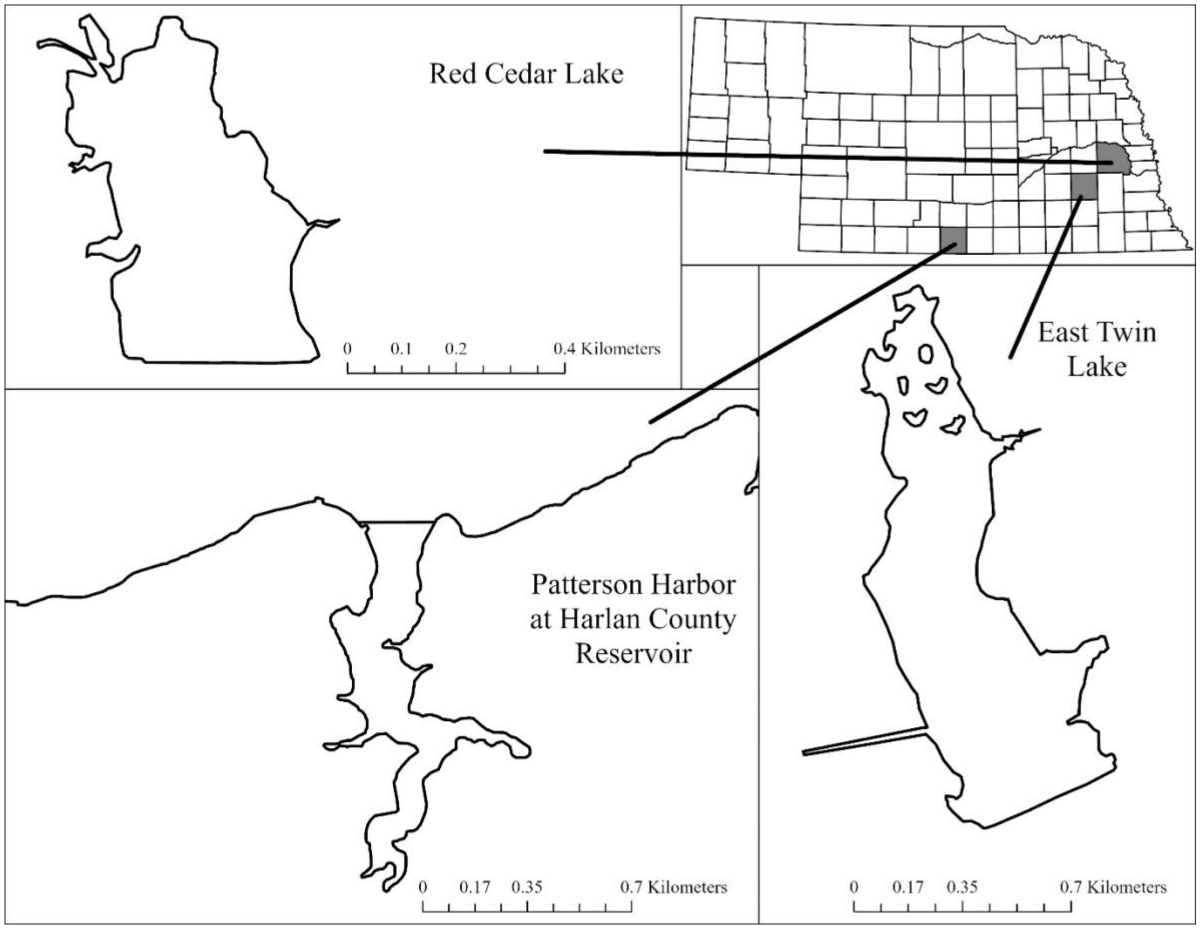

Figure 1: Locations and maps of East Twin Lake in Seward County, Red Cedar Lake in Saunders County, and Patterson Harbor at Harlan County Reservoir in Harlan County, Nebraska.

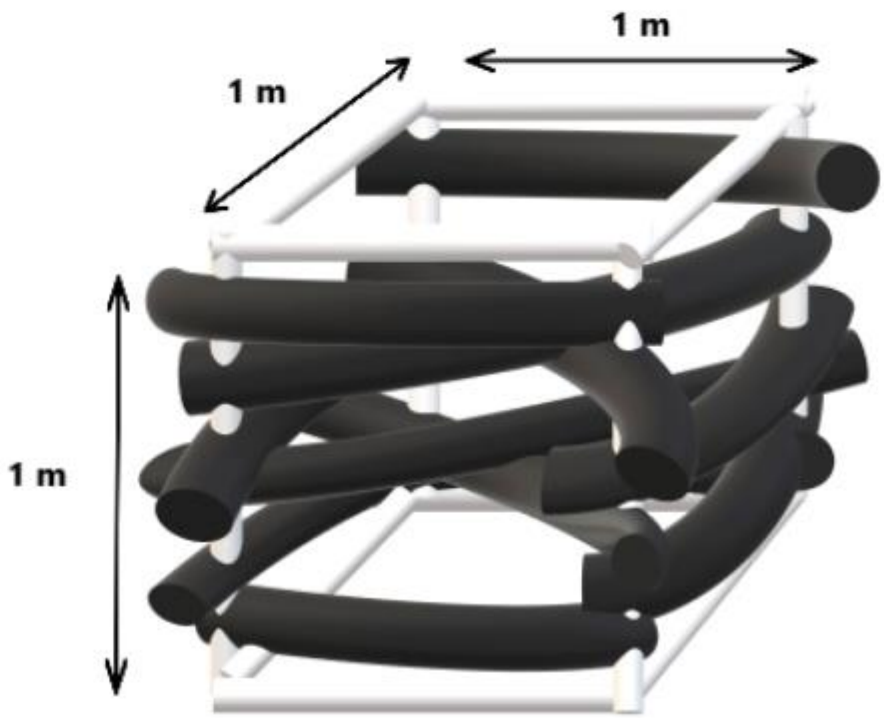

Figure 2. Georgia cube design used in this study. Frames were composed of 3.81-cm (1 ½") diameter polyvinyl chloride pipe and ten, 10.16-cm high-density polyethylene corrugated pipe fitted across the frame

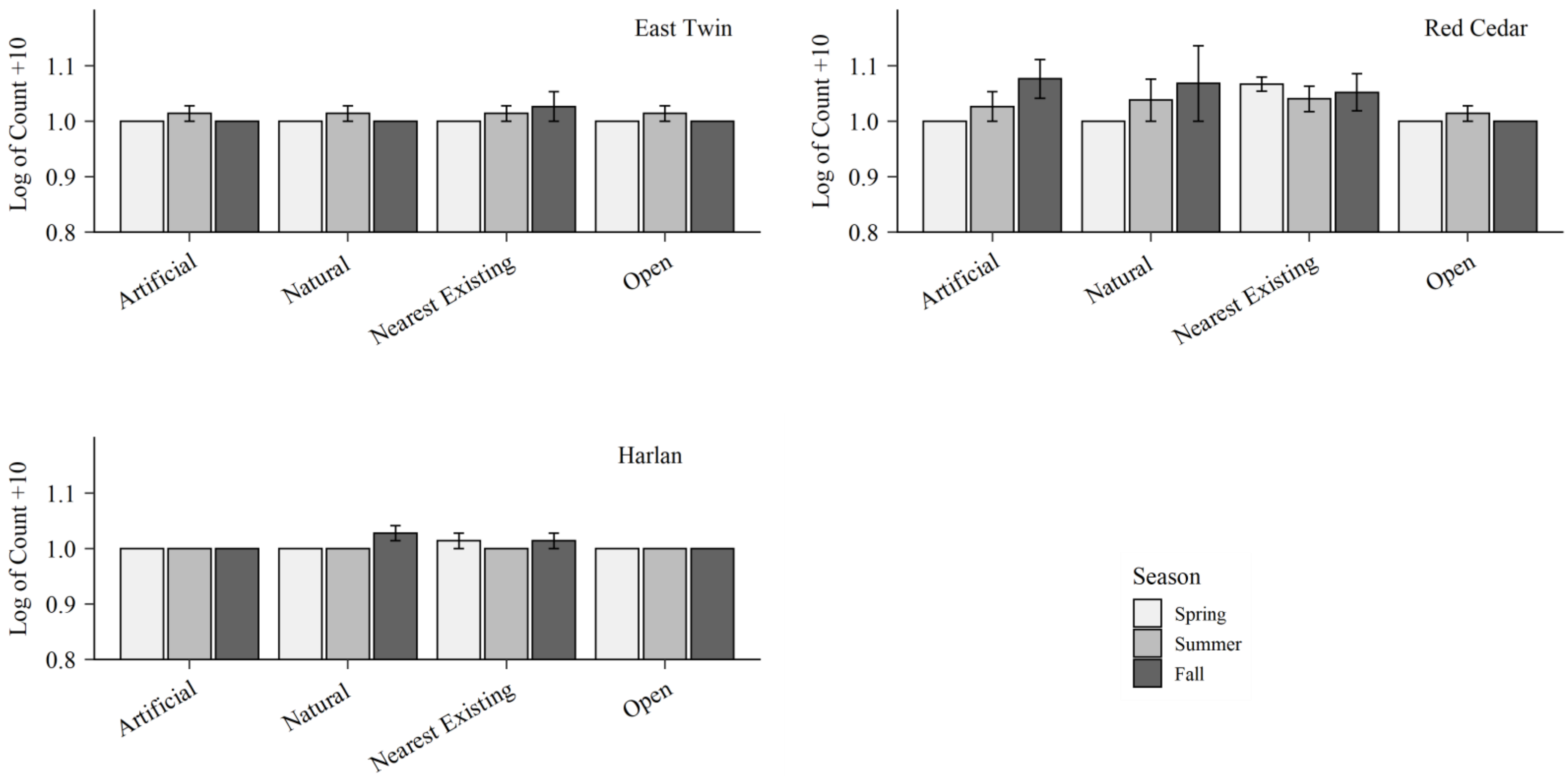

Figure 3. Transformed count data [$\log_{10}$(count +10)] for Largemouth Bass collected by electrofishing during spring, summer, and fall over different habitat types (artificial, natural, nearest existing habitat, and open habitat) in 2021 across three reservoirs. No differences in numbers of Largemouth Bass were denoted across season or habitat type. Error bars denote one standard error.

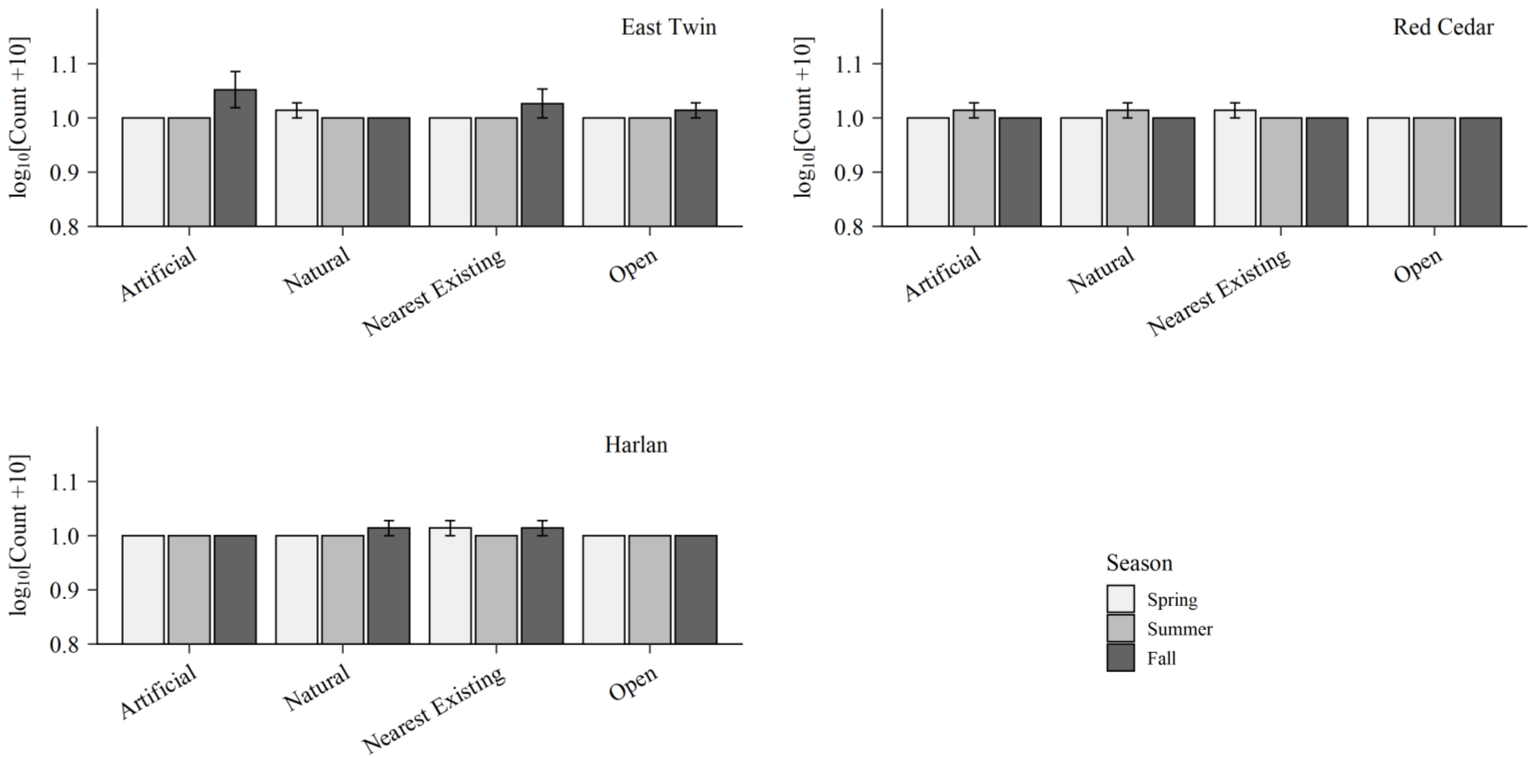

Figure 4. Transformed count data [$\log_{10}$(count +10)] for Channel Catfish collected by electrofishing during spring, summer, and fall over different habitat types (artificial, natural, nearest existing habitat, and open habitat) in 2021 across three reservoirs. East Twin Lake had significantly higher counts over fall than other seasons. No differences in numbers of Channel Catfish were denoted across habitat type. Error bars denote one standard error.

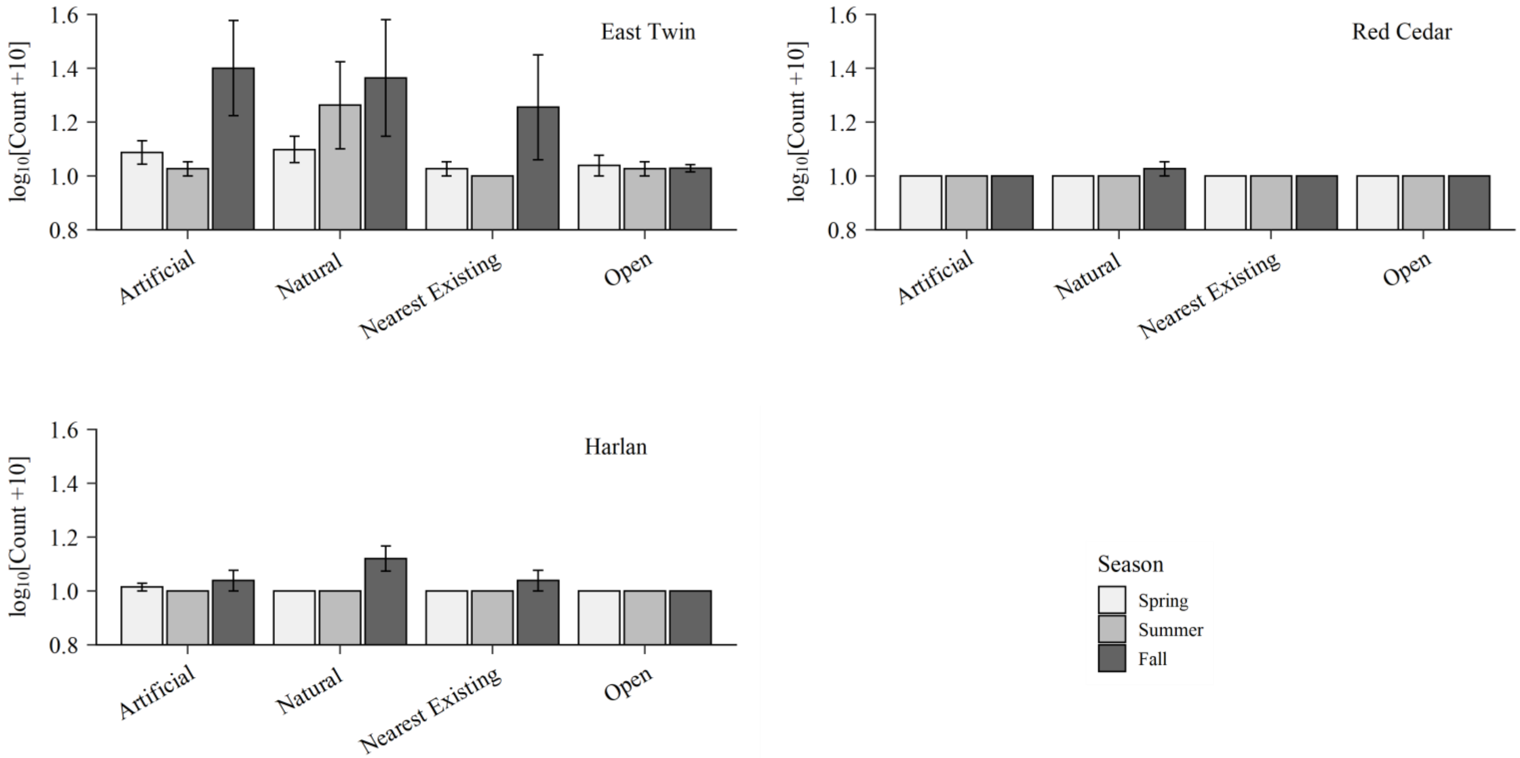

Figure 5. Transformed count data [$\log_{10}$(count +10)] for crappie (Black and White Crappies combined) collected by electrofishing during spring, summer, and fall over different habitat types (artificial, natural, nearest existing habitat, and open habitat) in 2021. No differences in numbers of Crappies were denoted across habitat type. East Twin and Harlan County Reservoir had significantly higher counts in fall over other seasons. Error bars denote one standard error.

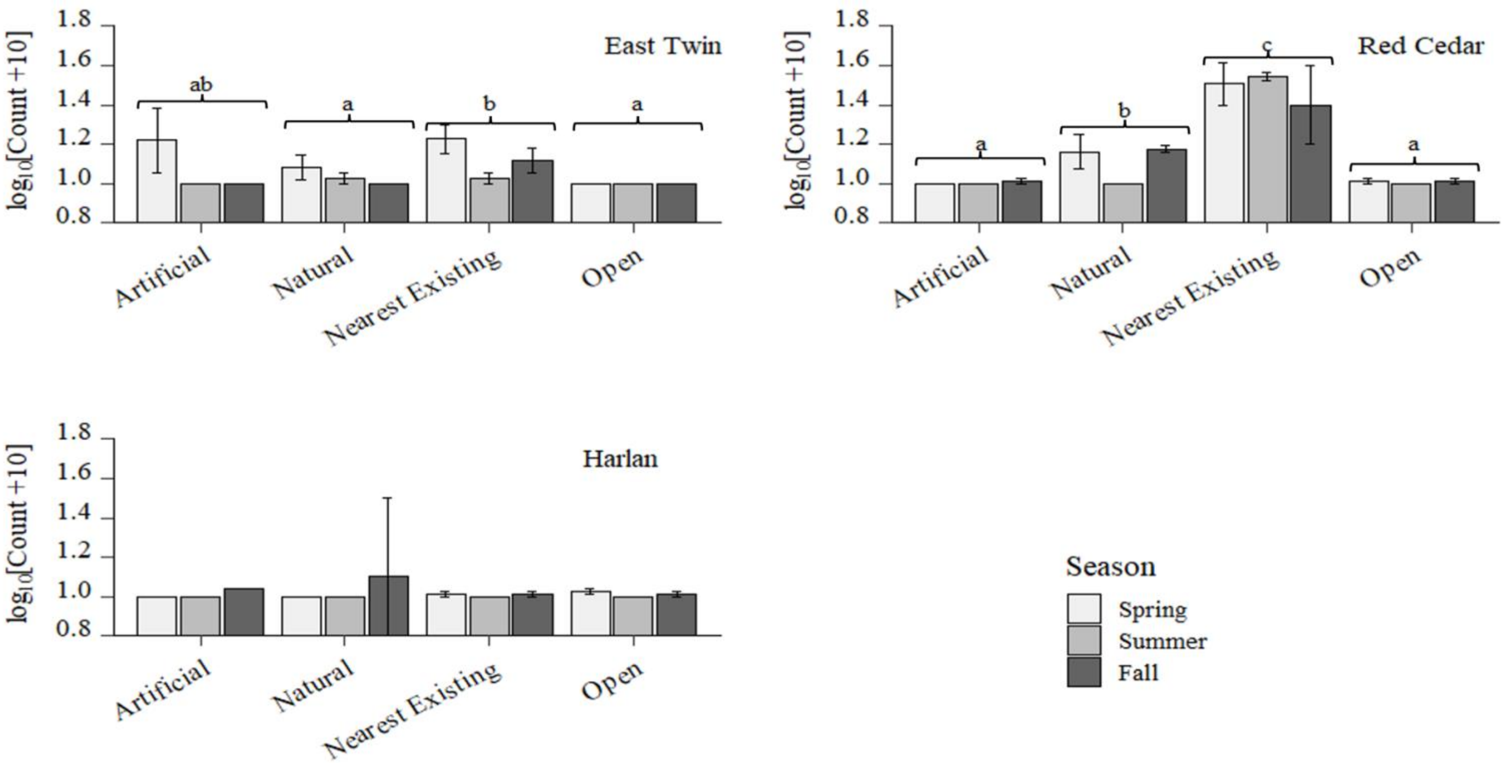

Figure 6. Transformed count data [$\log_{10}$(count +10)] for Bluegill collected by electrofishing during spring, summer, and fall over different habitat types (artificial, natural, nearest existing habitat, and open habitat) in 2021. Letters denote differences between habitats. East Twin and Harlan County Reservoir had significantly higher counts in fall. Error bars denote one standard error.

Chapter 4:

Management Implications

Introduction

The Nebraska Game and Parks Commission established an aquatic habitat program in 1997, which has led to the implementation of more than 130 projects to improve available aquatic habitat and access (NGPC 1997). In many cases, these NGPC projects have added habitat for the direct use by fish as habitat or as a secondary benefit (e.g., algal and invertebrate colonization) to benefit fish as the physical structures that are added to provide access to anglers or stabilize banks against erosion can be utilized by fish or other biota in many cases. To date, only minimal evaluations related to the habitat program have been completed, and most have only examined the possible benefits to anglers or aquatic communities (Pape 2004; Spirk et al. 2009; Spurgeon et al. 2016). No studies have evaluated how habitat is distributed within Nebraska lakes in relation to fluctuating water levels or compared fish presence around common structure types used to my knowledge. The objectives addressed in my research can provide important information to Nebraska and other state agencies as they plan and implement habitat projects.

One factor often not discussed when designing and installing habitat in reservoirs is how water levels can influence the availability of added habitat. Reservoirs in Nebraska and elsewhere can be highly dynamic, depending on their primary purpose, and habitats may be in shallow or no water with only a relatively small change in reservoir elevation (Daugherty et al. 2015). Irrigation reservoirs, such as Harlan County Reservoir, may be subject to greater variations in water level compared to municipal or flood-control reservoirs (Arfi 2005; Olds et al. 2011; Mason 2021; Ruoss et al., 2023; Schriener et al., *2023*). As noted in Chapter 2, habitat within lakes may not be evenly distributed throughout the water column. However, habitat may be set too deep or too shallow for some species (Bolding et al. 2004; Miranda 2017) or become unavailable at certain water levels (Schriener et al., *2023*). For instance, vegetation growing in the littoral zone can be unavailable with only a few meters of change (Daugherty et al. 2015). Given unique operating parameters of each reservoir, it is important to understand how water-level variations interact with the distribution of different habitat types.

A tool that was helpful to my evaluation of habitat distribution in reservoirs was side-scan sonar. This technology is widely available for use by state agencies and can be readily coupled with geographic information systems (GIS). The use of side-scan sonar has been used to assess the area of habitats such as vegetation, rock, and coarse woody debris in both lentic and lotic systems (Kaeser and Litts 2008; Bennett et al. 2020). Side-scan sonar has also been used to model changes in available habitat and public access to water in response to water-level changes (Daugherty et al. 2015; Schriener et al., 2023). Given this, I recommend that state agencies map out existing habitat structures, whether those structures are constructed from natural or artificial material, that are available at current and projected elevation levels prior to developing specific habitat augmentation plans.

In addition to assessing habitat availability, my study also examined fish presence around habitats, both for existing and introduced structures. Fish presence around structures might depend on many factors such as species habitat preferences, life stage, or needs, the type of habitat added, and the availability of existing habitats (Rold et al. 1996;

Bolding et al. 2004; Allen et al. 2014). Some species may take time to find and begin using new habitats following introduction (Santos et al. 2011). Thus, evaluations of newly added habitat may not represent the eventual use of those structures by all possible members of the fish community. Continuous evaluation of structure over multiple years may provide a different patterns of fish use than what was shown within the one year of my study. However, long-term studies may need to balance the amount of sampling within and between years (Santos et al. 2011; Allen et al. 2014). If time and monetary constraints prohibit sampling multiple times in one year, my results suggest that the fall may be the most appropriate single season to sample. However, other studies have also recommended summer sampling due to higher observed catch rates during this time (Rold et al.1995).

Future Research

Side-scan sonar equipment was used in this and previous efforts to quantify the amount of habitat available in a waterbody (Daugherty et al. 2015; Schriener et al., 2023). While the information collected from side-scan sonar efforts is useful, some gaps of information may still exist. To date, previous studies (including this one)(Bennett et al. 2020) have reported habitat in terms of the lateral area covered by specific habitat types. However, the function and benefits of habitat can occur in three dimensions, so considerations of habitat volume covered should be explored. Additionally, the quality of data from shallow areas (<0.5 m) produced by side-scan sonar collections is relatively diminished, and additional ground truthing is sometimes required. Certainly, many advances are happening within the electronic industry, and fisheries should consider alternative collection methods of habitat data in the future.

Future research may also consider using other gears besides boat-mounted electrofishing to assess fish presence. Electrofishing can be useful for sampling a variety of species in relatively shallow water (< 2 m depth), but efficiency is reduced in deeper waters (Miranda and Boxrucker 2009). As a result of my gear choice, I could only sample fish on habitat structures that were in shallower waters. Sampling structures at different depths could result in different species or numbers caught (Allen et al. 2014). In addition, certain species such as Channel Catfish (*Ictalurus punctatus*) might be sampled at lower electrical frequencies not used in our study (Miranda and Boxrucker 2009) or with other approaches such as angling, scuba, or underwater cameras (Bolding et al. 2004; Allen et al. 2014; Miranda 2017). Sampling multiple times within a season can also provide a more complete response of fish presence to introduced habitat, including quantifying how quickly fish begin to use newly added structures. Ultimately, improvements in sampling design may expand evaluation efforts to incorporate multiple species and multiple life stages over longer periods of time within and between years following additions of habitat structures.

The introduction of habitat structures has been used in U.S. lakes and elsewhere since before the 1930s (Hazzard 1937). New structures made from artificial materials are growing in use by fisheries managers, although natural materials are still used widely (Bolding et al. 2004; Allen et al. 2014; Magmelia et al. 2008). The longevity of structures composed of artificial materials is enticing, but other factors such as boat wakes, angler snagging, and natural waves may affect the longevity of these structures in other ways (Bolding et al. 2004; Miranda 2017). If debris from artificial structures dislodges, the broken pieces could cause issues with clogging of water intake system and dam operations (Miranda 2017). Additionally, many stakeholders may be concerned that structures composed of plastic materials could leach microplastics but limited studies have been done to assess these potential risks to date (Bolding et al. 2004; Alford et al. 2020). Lastly, artificial structure may be viewed as litter in aquatic systems by the public and other biologists (Cooke et al. 2023).

Adequate and appropriate habitat is essential to maintain fish populations and support recruitment and survival (Northcote and Atagi 1997; Miranda 2017). As more agencies initiate dedicated programs to maintain and improve habitat conditions in reservoirs (Pegg et al. 2015), care must be taken to ensure these efforts are economically efficient. From the culmination of time and effort I spent working on this evaluation, I would recommend that project managers assess the total amount of existing habitat available prior to developing a management plan for any waterbody. A habitat map should consider vertical distribution of the existing habitat as well as projections for water elevation changes anticipated within the reservoir. References to habitat available and habitat lift should, when possible, use volumetric dimensions. Additionally, the advantages of adding habitat need to be considered for the entire community and not centered on single species. Because the fisheries industry is at the infancy of developing habitat programs, continuous evaluations of habitat projects is imperative to ensure that managers can plan which habitats and which locations are best suited to meet their management goals.

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