A comparison of fish communities between coves of varying connection to Harlan County Reservoir, Nebraska

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ABSTRACT
Sediment berms of various heights have developed in the mouths of several coves within Harlan County Reservoir due to a combination of sediment deposition and lateral drift of eroded sediments. These berms can isolate coves from the main reservoir if the berm height is greater than the water elevation of the reservoir. Previous research in other reservoirs has shown that fish communities may differ in coves based on their connection histories. This study examines similarities and differences in fish assemblages between several disconnected coves and connected coves in Harlan County Reservoir. Connected coves had greater species richness and diversity compared to disconnected coves. Fish communities between cove types were relatively similar based on presence-absence data but notably different based on species abundance. Nonmetric multidimensional scaling ordination showed that fish communities were distinct between cove types. Eleven fish species were indicators of connected coves, and two species were indicators of disconnected coves. Disconnected coves had higher abundances of understudied native species rarely found in the main reservoir, such as Orangespotted Sunfish, Green Sunfish and Black Bullhead. Further research evaluating the influence of water quality, food availability, and duration of isolation is needed to understand the effect of cove disconnection on fish communities. Managers can use this information when planning cove renovations by weighing the costs and benefits of either maintaining ecologically distinct coves versus connecting coves and improving habitat accessibility for reservoir fishes.

ARTICLE HISTORY
Received 8 August 2022
Accepted 1 October 2022

KEYWORDS
Reservoir coves; reservoir bays; connectivity; disconnection; reservoir aging; sediment berm; sedimentation; aquatic community

Introduction
Coves are common features within reservoir systems and are typically formed by the flooding of former tributaries when water levels are elevated following dam construction (Miranda et al. 2014). Cove habitats often encompass a notable proportion of the limited shallow littoral area within reservoir systems (Miranda et al. 2014). Physical, chemical,
and biological attributes of coves are often different compared to those within the main reservoir (Meals and Miranda 1991; Mason 2021). Aquatic macrophytes are more likely to establish in coves compared to other areas of the reservoir due to water level stability and protection from wave and wind action (Marsh and Langhorst 1988; Slipke et al. 2005; Dagel and Miranda 2012).

The unique characteristics of cove habitats within a reservoir can impact fish communities that utilize them (Ferrer-Montaño and Dibble 2002). Many centrarchid species such as Bluegill (*Lepomis macrochirus*), crappie (*Pomoxis* spp.) and Largemouth Bass (*Micropterus salmoides*) often use coves for spawning and nursery habitat (Meals and Miranda 1991; Warren 2009), and higher recruitment to age 0 has been reported for centrarchids within cove habitats compared to main reservoir shoreline due to the protection that coves offer from wind and wave action (Meals and Miranda 1991). Additionally, fish may be more abundant and species richness may be higher in coves compared to the main reservoir (Gido and Matthews 2000). In fact, some species, such as Brook Silverside (*Labidesthes sicculus*) are typically only found within coves (Matthews 1998). Thus, coves may add to the overall fish diversity in reservoir systems.

As reservoirs age, coves can become disconnected from their parent reservoir due to sediment accumulation at the cove mouth. Cove isolation can occur by lateral drift of shoreline sediments (Marsh and Langhorst 1988; Mueller 1995) or by backfill of sediments from the main lake (Slipke et al. 2005; Slipke and Maceina 2007). The development of sediment berms restricts or eliminates exchange of surface water between coves and the...
main lake (Marsh and Langhorst 1988; Slipke and Maceina 2005). As a result, fish within isolated coves may be confined to this habitat alone, depending on water depth (Slipke and Maceina 2005; Slipke et al. 2005). This isolation could restrict access to critical resources for fish either located within other coves or the main reservoir. For example, cove isolation could lead to the restriction of available spawning habitat within coves for species within the main reservoir that utilize these areas (Meals and Miranda 1991). Additionally, fish in disconnected coves may lack access to high-quality food resources found within the main reservoir, such as large annual year classes of bait fish including Gizzard Shad (*Dorosoma cepedianum*; Sullivan et al. 2011). Because of the potential restrictions of habitat and resources caused by cove disconnection, the fish communities and population dynamics for both disconnected coves and the main reservoir, may be impacted over time to better adapt to the altered habitat (Patton and Lyday 2008; Gilbert and Pease 2019).

Harlan County Reservoir, Nebraska, has numerous coves located throughout the reservoir (Figure 1). Sediment berms of various heights have developed in the mouths of several coves within this reservoir due to a combination of sediment deposition and lateral drift of eroded shoreline sediments. Some berms have minimal sediment accumulation and are often submerged either consistently or periodically throughout the year (e.g. Bone and Prairie Dog); other berms are often as high as or higher than the annual maximum water level (e.g. Methodist, Tipover and Indian Hill). Due to high variations in water elevation within Harlan County Reservoir, it is difficult to define cove disconnection to the main reservoir. Shorter berms increase the likelihood for connection to the main reservoir within and between years. The highest berms, however, reduce or eliminate surface water exchange between the two areas for longer periods of time (Figure 2). Routine dredging for navigational purposes has allowed Patterson and Gremlin coves to maintain consistent connectivity over time, but no actions have been undertaken to maintain connections between other coves and the main reservoir (U.S. Army Corps of Engineers (USACE) 1991; Diffendal et al. 2002). The objective of this study is to describe fish assemblages within coves of Harlan County Reservoir, Nebraska, and to compare those assemblages

**Figure 2.** Elevation of the sediment berms disconnecting coves from the main reservoir, compared to end of month water level elevation of Harlan County Reservoir since January 1990. The grey line indicates the water elevation of the main reservoir, recorded at the dam spillway (U.S. Bureau of Reclamation (USBOR) 2020). Horizontal black lines indicate minimum water level required for connection (heights of sediment berm plus 1 meter) for each corresponding cove. Vertical dotted lines indicate January 1st of the year labeled below. Initial berm height was calculated by Flatwater Group Inc., 2017.
between coves connected to the main reservoir and those that have experienced isolation due to berm formation.

**Methods**

**Study area**

Harlan County Reservoir is operated by the U.S. Army Corps of Engineers and is located in southcentral Nebraska near the Kansas border (Figure 1). Initiation of dam construction began in 1946, and the dam currently operates for the primary purposes of flood control on the Republican River and to hold water for irrigation use (USACE 2011). At full conservation pool, Harlan County Reservoir has a surface area of approximately 5,400 ha and a storage capacity of approximately 1 billion m$^3$ (USACE 2011). Mean depth of the reservoir at full conservation pool is 4 m and maximum depth is 18 m (Uphoff et al. 2013). Water elevation, however, can vary up to 3 m on an annual basis due to seasonal changes in precipitation and irrigation demands (Diffendal et al. 2002). Thermal stratification rarely occurs due to the reservoir’s westward orientation and its long fetch distance (Olds et al. 2011; Uphoff et al. 2013).

For the purpose of this study, disconnected coves were defined as coves having <1 m of water connection at the berm saddle point (i.e. the lowest point atop the berm crest; Hanslow et al. 2000) at any time throughout the study. All other coves were classified as connected. Depth of connection was based on measurements of the sediment berms for each cove, taken by Flatwater Group, Incorporated in 2017, compared to the main reservoir water elevation recorded on the dam spillway (Figure 2). All connected coves within Harlan County Reservoir (Bone, Gremlin, Patterson and Prairie Dog Coves) were included in the study.Disconnected coves (Indian Hill, Methodist, and Tipover Coves) were selected based on their candidacy for future renovation projects to reconnect coves to the main reservoir. All disconnected coves had been isolated from the main reservoir for 4 years or longer at the beginning of this study, with Indian Hill, Methodist, and Tipover coves being disconnected from the main reservoir since September 1993, February 2012, and June 2012, respectively, assuming sediment berm heights have remained similar since their last connection event (USBOR 2020; Figure 2). None of the coves included in this study changed in classification from their original connection designation over the course of this study. Physical characteristics and water quality parameters varied within and between cove types, but disconnected coves were generally smaller, shallower in depth, had higher turbidity, lower Secchi depth, and lower dissolved oxygen compared to connected coves (Mason 2021; Table 1).
Fish sampling

Fish were sampled during the spring (May), summer (July), and fall (September–October) of 2017 and 2018. During fall and spring, four 137 × 93 cm-frame, single-throat modified fyke nets [two 16-mm mesh and two 19-mm mesh] with a maximum lead length of 15 m, were deployed overnight within each cove. During summer, a 15.25 × 1.22-m beach seine with 0.63-cm bar mesh netting were pulled in quarter-arcs at four locations within each cove (Pope et al. 2009; Miller et al. 2018). The location of the four fyke net sets and seine hauls were equally spaced throughout each cove and were maintained for the entirety of the project or moved to the nearest possible location if water level fluctuations and gear restrictions prevented adequate sampling in a specified location. All fish collected during this study were identified to species and released.

Data analysis

To examine differences in fish communities between disconnected and connected coves, species richness and Shannon’s diversity index (Shannon 1948) was calculated for each of the two cove types. Additionally, indices of similarity in fish communities between cove types included Jaccard’s similarity index (Jaccard 1901) and Renkonen percent similarity index (Renkonen 1938). Both measures of similarity were included in our analyses, as Renkonen percent similarity index is based on the relative abundance of fish instead of presence/absence data as used in the Jaccard’s index. Species data was combined across cove type and years for all richness, diversity, and similarity analysis.

To examine species associations with connected or disconnected coves, we used a non-metric multidimensional scaling (NMDS) ordination, using Bray-Curtis distance metrics, calculated from species abundances from each cove during each season. A one-way

| Table 2. Percent composition of the total assemblage of fish species collected within connected and disconnected coves of Harlan County Reservoir. |
|-----------------------------|---------------|---------------|---------------|---------------|
| **Family**                  | **Species**   | **Common name** | **Name code** | **Connected**  |
| Atherinidae                 | *Labidesthes sicculus* | Brook Silverside | BSS | 0.06 (2) 0.12 (3) |
| Catostomidae                | *Carpiodes carpio* | River Carpsucker | RCS | 0.64 (22) – |
| Centrarchidae               | *Lepomis cyanellus* | Green Sunfish | GSF | 0.35 (12) 2.68 (68) |
|                             | *Lepomis humilis* | Orangespotted Sunfish | OSS | 0.53 (18) 11.70 (297) |
|                             | *Lepomis macrochirus* | Bluegill | BLG | 6.80 (233) 7.45 (186) |
|                             | *Lepomis macrochirus x cyanellus* | Hybrid Sunfish | HSF | 0.09 (3) 0.16 (4) |
| Clupeidae                   | *Dorosoma cepedianum* | Gizzard Shad | GZS | 47.61 (1631) 4.37 (111) |
| Cyprinidae                  | *Cyprinella lutrensis* | Red Shiner | RES | 3.74 (128) 0.47 (12) |
|                             | *Cyprinus carpio* | Common Carp | COC | 3.42 (117) 15.45 (392) |
|                             | *Notropis atherinoides* | Emerald Shiner | EMS | 0.44 (15) – |
| Cyprinidae                  | *Esox lucius* | Northern Pike | NOP | 0.38 (13) – |
| Ictaluridae                 | *Ameiurus melas* | Black Bullhead | BBH | 0.09 (3) 36.84 (935) |
|                             | *Ictalurus punctatus* | Channel Catfish | CCF | 0.61 (21) 0.04 (1) |
|                             | *Pylodictis olivaris* | Flatehead Catfish | FCF | 0.03 (1) – |
| Lepisosteidae              | *Lepisosteus osseus* | Longnose Gar | LNG | 0.03 (1) – |
|                             | *Lepisosteus platostomus* | Shortnose Gar | SNG | 5.60 (192) 0.24 (6) |
| Moronidae                   | *Morone chrysops* | White Bass | WHB | 5.28 (181) – |
|                             | *Morone chrysops x saxatilis* | Hybrid Striped Bass | HSB | 0.58 (20) – |
| Percidae                    | *Sander vitreus* | Walleye | WAE | 1.17 (40) – |
| Poeciliidae                 | *Gambusia affinis* | Western Mosquitofish | WMF | 0.73 (25) 0.04 (1) |
| Sciaenidae                  | *Aplodinotus grunniens* | Freshwater Drum | FWD | 12.69 (92) 0.04 (1) |

Collection took place during the spring, summer and fall of 2017 and 2018. Counts are indicated within parentheses. Dash marks indicate the non-detection of the corresponding species.
analysis of similarity (ANOSIM, 999 permutations) was used to determine if fish communities differed between connected and disconnected cove habitats \( (\alpha = 0.05; \text{Clarke} \ 1993) \). Ordination and ANOSIM calculations were generated using the ‘vegan’ and ‘MASS’ packages in R (R Core Team 2020) version 4.0.0. Finally, an indicator species analysis (Dufrene and Legendre 1997) was conducted to further identify species that are commonly associated with either connected or disconnected coves. The resulting indicator values are a function of a species relative abundance and relative frequency within either connected or disconnected coves. Species were considered indicators of a respected habitat if their indicator values were \( > 25 \) (Miranda et al. 2014) and \( p \leq 0.1 \). Indicator species analysis was conducted using the ‘indval’ function from the ‘labdsv’ package of program R (R Core Team 2020).

**Results**

A total of 5,964 fish (3,426 within four connected coves; 2,538 within three disconnected coves), representing 24 species, were collected between all coves included in this study across the two years. Eight species of fish were collected only within connected coves.
while disconnected coves had no unique species (Table 2). Species richness was lower in disconnected versus connected coves (16 versus 24, respectively). Diversity was higher in connected ($H' = 1.96$) than disconnected coves ($H' = 1.45$). Species assemblages between the two cove types were similar ($J = 66.67$) based on presence/absence data. However, similarities based on species abundance indicated more dissimilarity between cove types ($PS = 0.32$). Abundance differences were highest between cove types for Gizzard Shad, Black Bullhead ($Ameiurus melas$), and Orangespotted Sunfish ($Lepomis humilis$) (Table 2).

Nonmetric multidimensional scaling ordination showed that fish communities were distinct between cove types (Figure 3) and significantly different from each other (stress $= 0.15$; ANOSIM $R = 0.29$, $p < 0.01$). Fish communities in connected coves did appear to differ by gear type whereas fish communities in disconnected coves differed more by individual cove than gear type (Figure 3). Indicator species analysis suggested that several species were associated with connected coves, including White Bass ($Morone chrysops$), Freshwater Drum ($Aplodinotus grunniens$), Channel Catfish ($Ictalurus punctatus$), Gizzard Shad, River Carpsucker, Walleye ($Sander vitreus$), Shortnose Gar ($Lepisosteus platostomus$), Largemouth Bass, Northern Pike ($Esox lucius$), Red Shiner ($Cyprinella lutrensis$), and Hybrid Striped Bass ($Morone chrysops x saxatilis$) were indicator species of connected coves (Figure 4). In contrast, only Common Carp and Black Bullhead were indicator species of disconnected coves (Figure 4).
Discussion

Lateral connectivity of isolated waterbodies to their parent source can play an important role in determining fish assemblages within these habitats (Ellis et al. 1979; Tockner et al. 1999; Miranda et al. 2014; Gilbert and Pease 2019). Connected reservoir coves likely have species assemblages with high degrees of similarity to each other, as fish can freely navigate and be exchanged between them and the main reservoir (Patton and Lyday 2008). In contrast, waterbodies in isolated systems can lose the external contribution of fish for long stretches of time, preventing the replacement of any fish species lost due to mortality and poor recruitment in cove habitat (Patton and Lyday 2008). The loss of cove habitats due to disconnection could further impact the reservoir fish community, as coves are a vital component of the mosaic of habitats (Slipke and Maceina 2005). Previous studies examining fish communities of disconnected and connected coves and other backwater habitats both support and differ with the results of this study. Slipke and Maceina (2005) found that diversity was similar between connected and disconnected backwater habitats of Demopolis Reservoir, AL, however, disconnected backwaters had slightly lower species richness compared to connected waters. Patton and Lyday (2008) found similar species richness and diversity between disconnected and connected habitats in Lake Texoma, OK.

Species composition of fish communities within disconnected and connected habitats have also shown documented differences. Slipke and Maceina (2005), found similarly high abundances of Gizzard Shad and centrarchid species within both connected and disconnected coves, but disconnected coves had significantly higher abundances of Bluegill, Redear Sunfish (Lepomis microlophus), and Spotted Gar (Lepisosteus oculatus). Connected coves, on the other hand, had significantly higher abundances of Largemouth Bass and White Crappie (Pomoxis annularis), indicating connection may play an important role for these species within cove habitats (Slipke and Maceina 2005). Disconnected habitats within Lake Texoma had more variable fish assemblages between individual locations but generally separated into two groups: those with assemblages with higher abundances of White Crappie, Channel Catfish, and River Carpsucker (Carpiodes carpio), and those with higher abundances of Freshwater Drum and Blue Catfish (Ictalurus furcatus) (Patton and Lyday 2008). Furthermore, White Bass and Striped Bass had a consistently higher affinity to connected habitats (Patton and Lyday 2008). Similar to the finding in this study on Harlan County Reservoir, previous studies have documented reductions or absences of moronids within disconnected habitats compared to connected, perhaps indicating reductions in long-term survival and/or recruitment within small, isolated systems for these species (Slipke and Maceina 2005; Patton and Lyday 2008). Low recruitment and survival in disconnected habitats may also be driving the absence of other species in disconnected coves of Harlan County Reservoir, such as Walleye, Northern Pike, River Carpsucker and Emerald Shiner (Notropis atherinoides).

Species assemblages within disconnected habitats may be linked to the length of time of disconnection. Patton and Lyday (2008) indicated that the distinct assemblage groupings noted within fragmented habitats were likely related to the duration of disconnection, as the site containing abundant Blue Catfish and Freshwater Drum was more recently connected to the main reservoir than the other fragmented habitats in their study. Disconnected coves of Harlan County Reservoir also exhibit two distinct patterns of assemblage: two coves (Methodist and Tipover) consist mainly of numerous centrarchid species and Black Bullhead, and the other cove (Indian Hill) was composed entirely of Common Carp. The latter cove had been disconnected from the main reservoir for approximately 24 years at the beginning of this study, whereas the other two had only been disconnected for approximately 5 years. Patterns of changes in fish assemblages over
time have also been observed in oxbow lakes of the Mississippi River, where lakes with more advanced stages of disconnection have fish assemblages containing higher abundances of species tolerant of low DO and high turbidity (Ellis et al. 1979; Miranda 2005). The relationship between species assemblage and timeframe of isolation within disconnected coves of Harlan County Reservoir could indicate that Indian Hill Cove is more advanced in its species assemblage succession than the more recently disconnected coves, supporting only a single generalist species. Additionally, several droughts had occurred over Indian Hill Cove’s period of isolation, causing low water levels within the main reservoir (Figure 2) and possibly exacerbating any extreme conditions within disconnected coves. Winter ice cover of disconnected coves could also restrict the available DO in the waterbody for extended intervals of time (Greenbank 1945; Magnuson et al. 1985). These periods may have accelerated the transition of the fish assemblage to only extremely tolerant species within Indian Hill Cove, while coves with less developed sediment berms experienced reconnection events after low periods and were likely replenished with species from the main reservoir.

Another reason that fish assemblages may have differed between cove type may be related to water quality. Ongoing analyses have indicated that disconnected coves within Harlan County Reservoir had higher water turbidity, lower Secchi depth, and potentially limited dissolved oxygen compared to connected coves (Mason 2021). Some species such as Common Carp, Black Bullhead, and Orangespotted Sunfish are highly tolerant to these conditions (Zambrano et al. 2001; Novomeská and Kováč 2009; Warren 2009), and, thus, may be better able to survive and reproduce in disconnected coves compared to other species. Tolerant fish may also exclude other species due to their abundance and biological activity. For example, benthivorous fish, such as Common Carp, may further increase turbidity and productivity in disconnected coves by resuspending solids with their feeding behavior (Zambrano et al. 2001). High turbidity may also help tolerant species avoid predation, thus, increasing their density and supporting additional increases in turbidity (Miranda 2005).

Fish communities and water quality parameters within coves also likely impact the zooplankton assemblages of coves. Zooplankton taxa with high tolerance to turbidity, such as rotifers, have been more abundant within these habitats, while others such as Daphnia and Calanoida were reduced (Mason 2021). This difference in zooplankton assemblage between the different cove types could help explain the observed differences in fish community. For example, Daphnia and Calanoida are the preferred food source for larval Walleye and White Bass (Beck et al. 1998; Miller et al. 2019; Uphoff et al. 2019) and the absence of this food source within disconnected coves may lead to lower survival for these species. Alternatively, larval Pomoxis spp. have been shown to select for smaller zooplankton (Dubuc and DeVries 2002) such as those taxa found in disconnected coves (Mason 2021); thus, crappie and other centrarchids may have an abundant food source in these habitats early in their development.

Overall, this study of Harlan County Reservoir provides information regarding differences in fish assemblages between cove types that may be useful for fisheries managers to consider for other reservoirs across the U.S. with similar habitats. Assemblages within disconnected coves may be impacted by the duration of isolation from the parent reservoir. These assemblage changes may also impact the water quality and zooplankton communities within disconnected coves, however more research is needed for clarification. Reservoir managers may find value in reconnecting disconnected cove habitats, as connected coves had higher diversity and species richness and higher association with sportfish species, such as White Bass, Walleye, Northern Pike, and Largemouth Bass.
Alternatively, disconnected coves may offer unique ecological and recreational potential by harboring distinct fish assemblages compared to connected coves and the main reservoir. Within Harlan County Reservoir, some native fish species (e.g. Orangespotted Sunfish, Green Sunfish (*Lepomis cyanellus*), and Black Bullhead; Sowa et al. 2006) that have limited presence within connected coves and the main reservoir are found in higher abundance in disconnected coves. Thus, disconnected coves could be potential sources of diversity for the main reservoir during years of high water, as connection would allow these species to move to other coves and recolonize other areas of the reservoir where local extirpation may have occurred (Ruoss et al. in press). If disconnected coves remain isolated, however, they may require additional ongoing maintenance to help alleviate potentially low DO, improve water clarity, and control measures of potentially nuisance benthivorous fish. These measures could extend the successional longevity of disconnected coves and prevent the development of fish assemblages composed of only the most tolerant species. Managers may also benefit from the unique fish assemblages by providing angling opportunities for the higher concentrations of centrarchid species within disconnected coves, or even from microfishing opportunities for native fish taxa. Additionally, when managers plan cove renovations, they should weigh the costs and benefits of either maintaining ecologically distinct coves, versus connecting coves and improving habitat accessibility for some fishes.

**Acknowledgements**

We thank the personnel with the Kearney office of the Nebraska Game and Parks Commission and the Army Corp of Engineers office at Harlan County Reservoir who assisted with the planning and execution of this project. Additional appreciation is extended to Josh Kreitman, Tony Long, William Frisch, Sam Wallick, Garrett Rowles, Thyme Cooke, Luke Rogers, Amanda Medaries, William Schriener, Christine Ruskamp, Jessica Davis, Sean Farrier, Brett Miller and Charles Mordhorst for their assistance with field sampling and laboratory processing.

**Disclosure statement**

The authors of this study assert that we have no conflicts of interest, financial or otherwise, related to this specific research.

**Funding**

This project was funded through Federal Aid in Sport Fish Restoration (Grant: F-16-R, Study Number: F19AF00082) administered through the Nebraska Game and Parks Commission. This research protocol was approved by the University of Nebraska - Kearney Institutional Animal Care and Use Committee Approval #032918

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**Data availability statement**

The data that the findings of this study are based is openly available in Mendeley Data at [https://data.mendeley.com/datasets/xcpkf5t5j](https://data.mendeley.com/datasets/xcpkf5t5j) (doi:10.17632/xcpkf5t5j.1).
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