Channel catfish and freshwater drum population demographics across four large Midwestern rivers

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ABSTRACT
Channel catfish (Ictalurus punctatus) and freshwater drum (Aplodinotus grunniens) are two commercially and recreationally important species in large rivers of the Midwestern United States. Understanding their population demographics is essential to managing sustainable populations. In this study, we determined and compared the size structure, individual growth, and mortality estimates of channel catfish and freshwater drum among the Illinois River and sections of the Mississippi, Ohio, and Wabash rivers to provide a current baseline for managing these populations. Results suggest that both fishes differed in size structure among rivers. Compared to all other rivers, the Mississippi River freshwater drum growth rate was the highest and the theoretical maximum length was the lowest, and the Ohio River annual mortality was lowest. Channel catfish growth did not differ among rivers, but annual mortality was significantly higher in the Mississippi River compared to the Wabash River. Given the importance of these two fishes, better understanding of their population demographics in these systems is essential to improving current and future fisheries management programs.

Introduction

Channel catfish (Ictalurus punctatus) and freshwater drum (Aplodinotus grunniens) are two species commonly found in North American rivers, including in the Mississippi and Ohio river basins of the Midwestern United States (Michaletz and Dillard 1999). They are long-lived, benthic generalists and are recognized as recreationally and commercially important...
species (Pitlo 1997; Michaletz and Dillard 1999; Maher 2019). Channel catfish is a highly sought-after game fish comprising about one third of the United States’ commercial freshwater fish harvest (Quinn 2011), and recreational angling and interest in management of channel catfish populations continues to increase throughout the United States (Arterburn et al. 2002; USFWS 2011, 2016). Freshwater drum is listed as a non-game fish in most states but are frequently harvested recreationally and commercially because of their abundance and potential to reach a large body size (Becker 1983; Maher 2019). Management of channel catfish in large river systems is typically governed by length-based harvest regulations, but freshwater drum is largely unregulated (Michaletz and Dillard 1999). Despite the popularity and prevalence of these two fishes, limited population demographic data (i.e. recruitment, growth, and mortality)—essential to the characterization and management of fish populations (Guy and Brown 2007)—exists for some populations of channel catfish (Michaletz and Dillard 1999) and freshwater drum inhabiting large river systems (Blackwell et al. 1995).

The literature on population demographics of channel catfish in large floodplain rivers of the Midwestern USA and neighboring states is more abundant and has increased considerably in the second half of the twentieth century and early twenty-first century (Kwak et al. 2011; Porath et al. 2021) compared to freshwater drum (Blackwell et al. 1995; Jacquemin and Pyron 2013). Multiple articles have documented the capture efficiency and size selectivity of sampling gears as well as age estimation techniques used to calculate catfish (order Siluriformes) population demographics in both lotic and lentic habitats (see Kwak et al. 2011). In general, channel catfish growth has been found to be variable within systems (Barada and Pegg 2011; Sindt 2021) and across different systems and regions (Hubert 1999; Rypel 2011; Stewart et al. 2016), but growth does follow a latitudinal gradient with northern populations having faster growth rates (Rypel 2011). Similar to growth, channel catfish mortality estimates for large rivers can be highly variable, affected by multiple factors such as harvest regulations and pressure (e.g. Oliver et al. 2021). For example, three articles on the Wabash River estimated channel catfish annual mortality ranged from 18–35% (Colombo et al. 2008; Donabauer 2009; Colombo et al. 2010), which was lower than the commercially harvested Middle Mississippi River at 43% (Bueltmann and Phelps 2015) and sections of the non-commercially harvested Missouri River ranging from 46–56% (Eder et al. 2016; Hamel et al. 2021). The size structure of channel catfish populations, which reflects the interaction of population demographics, is highly specific to sampling gear and habitat, but length distributions or mean lengths are often reported in association with other population demographics and in examination of harvest regulations (e.g. Barada and Pegg 2011; Eder et al. 2016). Population demographics of freshwater drum in large rivers are understudied (especially relative to channel catfish), with published descriptions of population demographics only existing for growth (Butler 1965; Rypel et al. 2006; Rypel 2007; 1992–1996 data, Abner and Phelps 2018) and length distribution (Rypel 2007).

Within four large river systems that dominate the Midwestern landscape (i.e. the Illinois, Mississippi, Ohio, and Wabash rivers), there are limited recent population demographic studies (2000s) that can be used to inform harvest regulations and monitoring decisions for both channel catfish and freshwater drum (see Colombo et al. 2008, 2010; Abner and Phelps 2018; DeBoer et al. 2021; Gainer et al. 2021; Oliver et al. 2021). These large rivers also span multiple jurisdictions that lead to differences in recreational and commercial harvest regulations for channel catfish; there are no harvest regulations for freshwater drum (Table 1). Therefore, there is a need to establish a baseline for understudied and more-recent assessments of population demographics, which includes channel
catfish size structure in the Illinois and Ohio rivers, growth in the Mississippi River, and mortality in the Illinois and Mississippi rivers. For freshwater drum, estimates of growth and mortality are needed for all four rivers and size structure for the Illinois, Ohio, and Wabash rivers. Additionally, the determination of current channel catfish and freshwater drum population demographics for these four large rivers would add to the growing body of literature to make inter-river comparisons for evaluating and applying various fishery management options (e.g. harvest regulations, Oliver et al. 2021) and river conservation approaches (e.g. varying hydrological patterns, Erickson et al. 2021; Sindt 2021) to improve and conserve these fishes.

Long-term monitoring programs are effective at providing ecological system descriptions and temporal trends over decadal timescales (Carpenter 1998; Lindenmayer et al. 2012), but importantly, the existing data collection framework of long-term monitoring programs can be leveraged to gain insight into additional ecological questions within or across basins (Lindenmayer et al. 2012; Counihan et al. 2018). Recently, long-term data sets are more accessible in many countries worldwide; however, few standardized studies (i.e. long-term monitoring and assessment programs) are conducted on large floodplain river systems. The Long-term Survey and Assessment of Large River Fishes in Illinois (LTEF—historically known as the Long-Term ElectroFishing project) is a standardized electrofishing sampling program that began in 1957 on the Illinois River, USA and expanded to include pools of the Upper Mississippi River (UMR) in 2009 and pools of the Ohio River and portions of the lower Wabash River in 2010. The existing data collection format of the LTEF program provided an opportunity to address knowledge gaps related to channel catfish and freshwater drum population demographics across these four large Midwestern river systems.

In this paper, we used data collected by the LTEF program during a two-year period to quantify population demographics (i.e. size structure, individual growth, and mortality) of channel catfish and freshwater drum from the Illinois River and portions of the Mississippi, Ohio, and Wabash rivers. Our objectives were to: 1) document and assess population demographics over a large geographical area; 2) identify whether differences exist in freshwater drum and channel catfish population demographics among four large Midwestern rivers; 3) and examine channel catfish population demographics in relation to commercial and recreational fishing regulations.

### Materials and methods

#### Study area

A total of twenty-two reaches of four large floodplain rivers, the Illinois, Mississippi, Ohio, and Wabash, were sampled in this study (Brown et al. 2005; Delong 2005; Pyron et al. 2020; White et al. 2005; Figure 1; Table 2). The Illinois River flows approximately 439 river kilometers (rkm) through five lock and dam structures (six navigation pools)}
from the confluence of the Des Plaines and Kankakee rivers, 77 km southwest of Chicago, Illinois, to Grafton, Illinois where it meets the UMR (Delong 2005). The UMR is defined as the 1,374 rkm section of river between St. Anthony Falls, Minnesota and Cairo, Illinois and consists of impounded reaches and open-river reaches. In this study, the impounded UMR reaches bordering the state of Illinois from Rock Island, Illinois to Winfield, Missouri were sampled (navigation pools 16–17, 19–21, and 25). Two open-river reaches that flow from the Missouri-Mississippi river confluence to the Ohio-Mississippi river
confluence were sampled, the Chain of Rocks and Kaskaskia reaches. The three lowest pools and one reach of the Ohio River (Smithland Pool, Pool 52, Pool 53, and the open river reach downstream of Lock and Dam 53) were sampled from the mouth of the Wabash River to the confluence with the Mississippi River (214 rkm). The lower unimpounded section of the Wabash River was sampled in five open-river reaches from Terre Haute, Indiana to the confluence with the Ohio River.

These large rivers are impacted by aquatic invasive species in all river sections sampled, such as bigheaded carps (silver carp Hypophthalmichthys molitrix and bighead carp H. nobilis), common carp (Cyprinus carpio), and zebra mussels (Dreissena polymorpha), although in differing densities (Angradi et al. 2011). Additionally, each river has had a history of modifications at varying levels such as land-use practice, urbanization, hydrological alterations, and restoration and conservation (Brown et al. 2005; Delong 2005; White et al. 2005; Pyron et al. 2020). Midwestern large river ecosystems, including these rivers, have had complex responses to both anthropogenic impacts and restoration and conservation efforts (DeBoer et al. 2019, 2022; Pyron et al. 2020).

Data collection

Channel catfish and freshwater drum were surveyed in 2017–2018 through collaboration between Eastern Illinois University, the Illinois Natural History Survey’s Illinois River Biological Station and Great Rivers Field Station, Southern Illinois University, and Western Illinois University under the LTEF program. This program follows a standardized direct-current (DC) electrofishing protocol sampling across three, six-week periods from June 15-October 31 (see Fritts et al. 2017). Effort per river is allocated randomly by

| Table 2. Pools and reaches of the Illinois, Mississippi, Ohio, and Wabash rivers sampled by LTEF pulsed-DC electrofishing surveys during 2017–2018 with river kilometers (RKM), the number of sampling locations within each sample region (N), whether each pool/reach is impounded by a lock and dam (Y/N), and mean (± SE) annual discharge with gauging station. |
|---------------------------------|-----------------|----------------|----------------|-----------------|-----------------|
| River                          | Year            | Pool/Reach     | RKM            | Size (RKM)      | N               | Impounded (Y/N) | Mean annual discharge (millions of m³)a |
| Illinois                       | 2017–2018       | Pools 3–8      | 460.3–0.0      | 334.7           | 174             | Y              | 0.3 ± 0.02, La Grange Lock & Dam, IL |
| Mississippi                    | 2017            | Pool 16        | 777.3–735.8    | 41.5            | 15              | Y              | 1.2 ± 0.07, Lock & Dam 22, IL/MO      |
|                                | 2018            | Pool 17        | 735.8–703.4    | 32.4            | 12              | Y              |                                       |
|                                | 2017–2018       | Pools 19–21    | 660.6–522.9    | 137.7           | 51              | Y              |                                       |
|                                | 2017–2018       | Pool 25        | 440–388.5      | 51.5            | 18              | Y              |                                       |
|                                | 2017–2018       | Chain of Rocks | 322.7–266.3    | 56.4            | 21              | N              |                                       |
|                                | 2017–2018       | Kaskaskia Reach| 266.3–188.3    | 78              | 30              | N              |                                       |
| Ohio                           | 2017–2018       | Smithland Pool | 1478.2–1364.7  | 113.5           | 42              | Y              | 3.1 ± 0.1, Metropolis, IL             |
|                                | 2017–2018       | Pool 52        | 1364.7–1511.2  | 33              | 12              | Y              | Period 2002–2018.                     |
|                                | 2017–2018       | Pool 53        | 1511.2–1549.0  | 37              | 15              | Y              |                                       |
|                                | 2017–2018       | Mississippi    | 1549.0–1578.8  | 18.5            | 12              | N              |                                       |
| Wabash                         | 2017–2018       | Terra Haute, IN| 783.8–715.4    | 68.4            | 15              | N              | 0.4 ± 0.02, Mt. Carmel, IN           |
|                                | 2017–2018       | Palestine, IL  | 715.4–663.1    | 52.3            | 21              | N              |                                       |
|                                | 2017–2018       | Vincennes, IN  | 633.1–620.4    | 12.7            | 18              | N              |                                       |
|                                | 2017–2018       | Mt. Carmel, IL | 620.4–564.9    | 55.5            | 27              | N              |                                       |
|                                | 2017–2018       | New Harmony, IN| 564.9–507.7    | 57.2            | 21              | N              |                                       |
one sample site, one 15-min electrofishing run, per five river miles (see DeBoer et al. 2017; Moody-Carpenter et al. 2020). All fishes were measured for total length (mm) in the field. For ageing, freshwater drum sagittal otoliths (hereafter ‘otoliths’) were removed and one pectoral spine per channel catfish was disarticulated in the field before releasing the channel catfish alive (Colombo et al. 2010). Channel catfish <250 mm and freshwater drum <200 mm were not collected for this study due to electrofishing size selectivity (Buckmeier and Warren Schlechte 2009; Reynolds and Kolz 2012).

In the laboratory, all freshwater drum otoliths and channel catfish spines were fixed in Envirotex Lite epoxy (Environmental Technology, Inc, Fields Landing, CA). Freshwater drum otoliths and channel catfish spines were sectioned with a Buehler Isomet low-speed saw (Illinois Tool Works (ITW), Lake Bluff, IL) into 800–1000 μm sections. Otoliths were sectioned along the transverse plane through the nucleus, and spines were sectioned at the basal processes. Sectioned otoliths and spines were then coated with pure glycerin and photographed for aging with a Leica DMC2900 camera mounted on a Leica S8AP0 microscope (Leica Biosystems Inc., Buffalo Grove, IL). Otolith and spine images were independently aged by counting annuli for each fish by two experienced readers to gain a consensus age, with a third reader consulted for any disagreements.

**Statistical analyses**

Data from individual rivers in 2017 and 2018 were pooled across years for all analyses for each species to increase sample sizes. Size structure (i.e. distribution of lengths) differences were assessed using length-frequency histograms for each fish species and river combination (Neumann and Allen 2007). Kolmogorov-Smirnov tests (K-S test) were used to determine whether the distribution of lengths differed between river combinations within species, and p-values were adjusted with a Bonferroni correction for multiple comparisons (Neumann and Allen 2007).

The von Bertalanffy growth function was used to model fish growth for each species by river, \( L_t = L_\infty (1 - e^{-K(t-t_0)}) \) where \( L_t \) is total length (mm) at age \( t \) (years), \( L_\infty \) is theoretical maximum total length of an individual within the population, \( K \) is the growth coefficient for the population, and \( t_0 \) is the theoretical age when the total length is zero (von Bertalanffy 1938; Isely and Grabowski 2007). Mean growth coefficient estimates (i.e. \( L_\infty, K, \) and \( t_0 \)) and their 95% confidence intervals were used to identify differences in indicated parameters among rivers by nonoverlapping 95% confidence intervals for each species.

Instantaneous total annual mortality rate (\( Z; 1/\text{year} \)) and annual mortality (\( A \)) were calculated for each river using the weighted catch-curve regression method (Miranda and Bettoli 2007; Ogle 2016), where the slope of a regression line is fitted to the descending limb of a weighted catch-curve using age-frequency data obtained from aged samples for each river. The ascending left limb and dome of the catch curve represent age-groups that are under sampled by the sampling gear and were not used in each analysis. The channel catfish catch-curve analyses included age-5 and older for the Illinois and Mississippi rivers, age-4 and older for the Ohio and Wabash river. For the freshwater drum catch-curve analyses, age-1 and older were used for the Illinois and Mississippi rivers and age-2 and older were used for the Wabash and Ohio rivers. A one-way analysis of covariance (ANCOVA) was used to identify differences between the instantaneous total mortality rate, which was derived from the negative slope of the descending limb of the catch-curve analyses, between two rivers at a time for each species (Pope and Kruse 2007; Ogle 2016). To compensate for multiple comparisons, the Bonferroni correction method was applied...
to the p-values (Ogle 2016). Both channel catfish and freshwater drum data used in mortality analyses met assumptions of normality and homogeneity of variances based on residual plots.

All statistical analyses were performed using R statistical environment (version 4.0.3; R Core Team 2020). Size structure, individual growth, and mortality analyses were conducted using FSA: Fisheries Stock Analysis Package (version 0.3.32; Ogle et al. 2021). von Bertalanffy growth model start values were generated by using the vbStarts() function, parameters were estimated using the nls() function and 95% confidence intervals were generated using the nlsBoot() function. Mortality analyses were completed with the anova() function for each comparison. Significance was determined at $\alpha = 0.05$ with adjusted p-values using p.adjust() where the p-value is multiplied by the number of comparisons.

**Results**

**Channel catfish**

Overall, 720 channel catfish were collected during 2017–2018 from the Illinois, Mississippi, Ohio, and Wabash rivers. After removing fish without an assigned age and channel catfish <250 mm total length due to under sampling of small fish, 635 channel catfish were used for the size structure analyses and 706 channel catfish for the individual age and mortality analyses. Mean lengths of channel catfish from the four rivers ranged from 430–454 mm (Figure 2). Fewer (total catch) but longer channel catfish between 250–490 mm were observed on both the Ohio and Mississippi rivers compared to the Illinois and Wabash rivers. The Ohio and Mississippi rivers contained larger fish overall with 50% of channel catfish shorter than 450 mm and 50% shorter than 420 mm and 430 mm for the Illinois and Wabash rivers, respectively. The size structure of channel catfish differed between the Illinois and Ohio rivers (K-S Test; $D = 0.200, p < 0.05$) and the Illinois and Mississippi rivers ($D = 0.188, P < 0.05$) with a higher proportion of smaller channel catfish collected in the Illinois River. The channel catfish size structure also differed between the Mississippi and Wabash rivers (K-S Test; $D = 0.204, p < 0.05$) with the Wabash River having a higher proportion of smaller fish.

Channel catfish mean coefficient estimates among rivers were not different, as indicated by overlapping 95% confidence intervals (Table 3, Figure 3). Instantaneous total mortality rate ($Z$) was significantly different between channel catfish in the Mississippi and Wabash rivers (ANCOVA; $DF = 1, F = 12.057, p < 0.05$) but not between other rivers. Total annual mortality (95% confidence intervals) was estimated at 40.7% (30.5–49.5%) for the Illinois River, 54.4% (42.1–64.1%) for the Mississippi River, 47.4% (18.3–76.6%) for the Ohio River, and 30.6% (16.2–42.4%) for the Wabash River (Table 4, Figure 4).

**Freshwater drum**

A total of 890 freshwater drum were collected in the four rivers sampled through LTEF. We used 784 freshwater drum in the size structure analyses and 885 fish in the individual growth and mortality analyses. Freshwater drum mean lengths ranged from 308–399 mm (Figure 5). Fifty percent of freshwater drum were shorter than 410 mm on the Ohio River, 300 mm for both the Illinois and Mississippi rivers, and 310 mm on the Wabash River. The size structure differed between the Ohio River and all other rivers (K-S Test, all $p < 0.001$) with the Ohio River having fewer (total catch) and longer fish overall.
(280–650 mm), but the maximum length of freshwater drum was similar among the Illinois, Ohio, and Wabash rivers. The Mississippi River also had a different size structure than the Wabash River with a higher proportion of smaller freshwater drum collected in the Wabash River ($D = 0.139, p < 0.001$).

Freshwater drum from the Mississippi River had a significantly lower $L_\infty$ and a higher $K$ than the other three rivers, and the Mississippi River had a significantly higher $t_0$ than the Illinois and Wabash rivers (Table 3, Figure 6). Instantaneous total mortality rate differed between the Ohio River and the Illinois (ANCOVA; $Df = 1, F = 13.580, p < 0.05$), Mississippi ($Df = 1, F = 21.173, P < 0.001$), and Wabash rivers ($Df = 1, F = 15.902, p < 0.05$). Total annual mortality was estimated at 7.6% (95% confidence intervals, 3.5–11.6%) for the Ohio River, 18.9% (15.2–22.4%) for the Illinois River, 29.4% (22.7–35.5%) for the Mississippi River, and 19.0% (11.8–25.6%) for the Wabash River (Table 4, Figure 7).
Discussion

We observed variability in size structure, individual growth, and annual mortality of channel catfish and freshwater drum populations from the Illinois River and sections of the Mississippi, Ohio, and Wabash rivers. Channel catfish was generally longer in the Ohio and Mississippi rivers compared to the Illinois and Wabash rivers, while freshwater drum from the Ohio River were fewer but longer compared to the other three rivers. Growth did not significantly differ among rivers for channel catfish, but the Ohio River had the highest $K$ and the lowest $L_{\infty}$ and inversely the Illinois River had the lowest $K$ and the highest $L_{\infty}$. Freshwater drum $K$ was significantly higher and $L_{\infty}$ lower in the Mississippi River compared to all other rivers. Channel catfish annual mortality was significantly higher in the Mississippi River compared to the Wabash River, and freshwater drum annual mortality was lower than all other rivers. These findings provide a current snapshot of channel catfish and freshwater drum population dynamics in these four large rivers that serve as a baseline or updated reference for evaluating current management regulations and identifying future management and research needs.

Management of channel catfish using length-based recreational and commercial harvest regulations has been shown to decrease fishing mortality, prevent or slow growth overfishing and recruitment overfishing (Pitlo 1997; Slipke et al. 2002; Stewart et al. 2016), and alter population demographics (e.g. Pitlo 1997; Eder et al. 2016). Harvest regulations for channel catfish differ among our four study rivers; state harvest regulations for the impounded Wabash River are reported at the river scale, while regulations in impounded rivers are reported by pool (e.g. UMR; Table 1). Recreational and commercial harvest occurs in all sampled pools and reaches of our four study rivers except commercial harvest is not permitted in the upper portion (pools 3–5) of the Illinois River (Table 1). The Ohio River is managed for a trophy fishery by placing greater restrictions on the harvest of large channel catfish (vs. smaller channel catfish) with a length-based harvest slot limit ($\geq 330.2$ mm to $\leq 711.2$ mm); these regulations permit harvest of one fish $\geq 711.2$ mm per
day by regular permit holders and four fish \( \geq 711.2 \text{ mm} \) per day by trophy permit holders (15 trophy permits granted each year downriver of the Cannelton Lock and Dam) to protect trophy fish from being over harvested (KDFW 2021; Oliver et al. 2021; Table 1). The other three rivers are managed by minimum length-based restrictions (Table 1).

Under these harvest regulations, our data indicates that the Ohio and Mississippi rivers have larger channel catfish overall, but the Ohio River has a lower maximum length than the other three rivers (von Bertalanffy growth model; Figure 3) and a lower proportion of larger fish (Figure 5). Similarly, Gainer et al. (2021) reported a larger proportion of UMR channel catfish total catch in length bins between 350–500 mm, but the proportion of fish identified at each length was higher and mean length lower in their study. The Wabash and Ohio rivers have the same channel catfish harvest slot limit, but unlike the Ohio River, the Wabash River is comprised of smaller channel catfish overall (does not have a low proportion of larger channel catfish) and size structure that significantly differed from the Mississippi River. These results suggest that although the Ohio and Wabash rivers are regulated with the same harvest slot limit, they have different size structures and potentially could be managed more effectively through population-specific harvest regulations. Recently, modeling by Oliver et al. (2021) showed that the Ohio River harvest slot limit, implemented in 2013–2014, was unlikely to impact the channel catfish population demographics or fishery yield, despite the fishery being previously unregulated. The Wabash River harvest regulations also changed in 2015 from commercial (254 mm in Indiana; 381 mm in Illinois) and recreational (254 mm in Indiana; no regulation in Illinois) minimum length limits to the same Ohio River slot limit, citing concerns over increased fishing mortality and harvest of immature channel catfish (Colombo 2007; Donabauer 2009). Our data show that the Wabash River channel catfish theoretical maximum length, growth, and mortality has remained relatively unchanged under the harvest slot limit regulation when compared to Colombo et al. (2008) AC electrofishing data, but electrofishing is known to under sample small channel catfish (Colombo et al. 2008) and may lack the resolution to show a change in the population (Table 2).

Channel catfish exhibit varying growth potential among fisheries and lack general geographical patterns, making statewide harvest regulations ineffective at managing all channel catfish populations within a state (Hubert 1999; Slipke et al. 2002; Stewart et al. 2016);
Figure 4. Catch curves for channel catfish sampled with DC electrofishing during 2017–2018 in the Illinois River and sections of the Mississippi, Ohio, and Wabash rivers. Ages used for regression are shown in Table 4 (Illinois $r^2 = 0.95$; Mississippi $r^2 = 0.96$; Ohio $r^2 = 0.79$; Wabash $r^2 = 0.92$).

Figure 5. Length frequency histograms (10 mm total length bins) for freshwater drum that were collected during 2017–2018 in the Illinois River and sections of the Mississippi, Ohio, and Wabash rivers. Total fish collected (N) and mean total length for each river.
however, we did not find conclusive evidence of growth differences among the four sampled rivers. These results are similar to recent findings in the Illinois River channel catfish population where limited spatial variability in growth was observed (DeBoer et al. 2021), but our mean coefficient estimates for $L_\infty$ and $t_0$ were lower and $K$ was higher for all four rivers in comparison compared to the North American river average (Jackson et al. 2008). Channel catfish is a slow growing long-lived fish but can mature quickly (ages 2–4; Helms 1975; Graham and Deisanti 1999; Hubert 1999; Slipke et al. 2002) and reach 300–375 mm at maturity (Hubert 1999; Shephard and Jackson 2005). In relation to current harvest regulations and general age and length at maturation, our data suggests channel catfish would become legal to harvest before reaching maturity in the Ohio and Wabash rivers but would reach maturity and become eligible for harvest at the same time in the Illinois and Mississippi rivers, thus potentially protecting them more from recruitment overfishing. Additionally, length-based slot limit regulations may be more effective in systems with rapid fish growth (Stewart et al. 2016) where fish outgrow the upper end of the slot limit and become protected. With a long-lived, slow-growing fish like channel catfish (Hubert 1999), the Ohio River might be a good candidate for slot regulations, which increases fish growth, with its current growth rate higher than the other three rivers (Table 3).

Estimated channel catfish annual mortality in our four sampled rivers differed from some Midwestern rivers with our constricted channel catfish age range and single gear used. Channel catfish ages ranged from 0–12 years in most of our sampled rivers and ages used to calculate annual mortality were between 4–12 years (Table 4). In comparison, Oliver et al. (2021) estimated 27% (Bayesian derived 95% credible intervals; 11–37) annual mortality of channel catfish for the Ohio River collected using multiple gear types, with ages ranging from 0–23 years, which was lower than our mortality estimate of 47.4%. Similarly, annual mortality estimates calculated in two sections of the non-commercially harvested Minnesota River used ages ranging from 5–17 years and 7–20 years collected in hoop nets (Sindt 2021). However, our Wabash River channel catfish mortality estimate (30.6%) was similar to estimates by Colombo et al. (2008 [1–15 years; $A = 31%$], 2010 [2–17 years; $A = 33%$]) calculated using only electrofishing data, and Donabauer (2009 [18–35%]) calculated from hoop net data. Current comparative data for our selected pools of the UMR and the Illinois River are lacking, and our data could serve as a baseline to
The UMR channel catfish had documented overexploitation before harvest regulations were changed in 1984–1985 from a minimum length limit of 330.2 mm to 381 mm; at that time annual mortality estimates ranged from 61–91% (Pitlo 1997) which is higher than our current estimate (54.4%) and Bueltmann and Phelps (2015) Middle Mississippi River estimate (43%).

Despite freshwater drum lacking harvest regulations, they are a key contributor to many recreational and commercial fisheries and more states are beginning to re-examine the importance of nongame fish species, increasing the value of baseline population demographics for individual systems. For example, in the UMR and its tributaries (including the Illinois River), freshwater drum comprised 5.4% of the total commercial fishing value and harvest averaged 1.29 million pounds annually from 2001–2005 (U.S. Army Corps of Engineers 2012). Freshwater drum are also harvested through bowfishing (harvesting fish with a bow and arrow or crossbow), a growing sport; although, freshwater drum is not heavily targeted like other nongame fish such as common carp (Cyprinus carpio) and buffalo fishes (Ictiobus spp.; Scarnecchia and Schooley 2020). Even with this commercial harvest and recreational interest, mortality rates of freshwater drum are relatively low in Midwestern rivers. The annual mortality estimates for this study ranged from 7.6–29.4%, with the Ohio River having a significantly lower mortality rate than the other three study rivers. Among the study rivers, the Mississippi River freshwater drum had the highest mortality rate (29.4%) and significantly lower $L_{\infty}$ and higher $K$; but our estimate might have been impacted by a truncated age range in our sample (Table 3). Our Mississippi River mortality estimate of 29.4% was higher than the estimate by Abner and Phelps (2018; pools 13–16/open river, 1992–1996 data) at 15%–25% but similar to HDR Engineering (2021) that reported pool 14 annual mortality at 33.8% for 2020.

Freshwater drum have complex age-at-length relationship patterns across their North American range, highlighting the need to establish population dynamics for individual systems to inform potential future harvest regulations (Rypel 2007; Jacquemin and Pyron 2013). For example, Butler and Smith (1950) documented freshwater drum age-at-maturity for males between 3–6 year of age and 279.4–355.6 mm and females between 5–6 years of age and 330.2–381 mm in the UMR. These ages and lengths are older and larger than reported for mature males (3–4 years, 61–480 mm) and mature females (3–4 years, and 156–584 mm) for rivers in Alabama, USA (Rypel 2007). Additionally, freshwater drum...
exhibits growth sexual dimorphism in older fish (>5 years; females reach a larger body size than males; Rypel 2007) potentially exposing females to preferential harvest resulting in differential mortality. Freshwater drum in our study ranged in ages from 0–29 years with the majority of fish being 1–3 years of age. Additional research should incorporate sex-specific growth differences in population demographics of freshwater drum for our four study rivers.

Biases (i.e. unequal probability of sampling individuals of a population) associated with individual sampling gears have been documented to influence population metrics (e.g. size structure, growth, and mortality; Colombo et al. 2008; Reynolds and Kolz 2012), and comparisons of population demographics made among different gear types should be interpreted with caution. Pulsed-DC electrofishing is size selective, effectively sampling catfishes 250–850 mm but under-sampling catfishes <200 mm and is considered less effective at capturing catfish than other large river sampling gears (e.g. hoop net; Buckmeier and Warren Schlechte 2009; Gainer et al. 2021). Additionally, it was necessary in this study to combine both sexes of freshwater drum to achieve suitable sample sizes in this study, so any comparison to our growth and mortality analyses for freshwater drum do not account for known differences due to sexual dimorphism (Rypel et al. 2006; Rypel 2007). Lastly, fish were pooled across each river in our study to increase sample size, so we made the assumption that growth and mortality rates were the same within multiple pools of each river. Future demographic studies should strive to account for sex-specific growth differences and reduce sampling bias by using multiple gear types to provide the best available data for managers to analyze the impact of fishery management and environmental health regulations.

**Conclusion**

This study provides a snapshot of current channel catfish and freshwater drum population demographics across four large Midwestern rivers where relatively limited population demographic research exists. Outcomes of this study increase our understanding of channel catfish and freshwater drum populations in these rivers and identifies potential knowledge gaps for future research needed to monitor these populations. We learned that channel catfish population demographics in the Ohio, and Wabash rivers vary among systems under the same harvest regulations, and the Wabash River channel catfish population demographics are similar to those documented by Colombo et al. (2008) before the implementation of the current harvest regulations. Additionally, although freshwater drum harvest is unregulated and their population demographics vary among rivers, their mortality is relatively low. Thus, future studies should focus on determining channel catfish reach specific population demographics as variation within or between systems could have ramifications from statewide harvest regulations, freshwater drum sex-specific population demographics, and biological factors driving population demographics in these large Midwestern rivers to inform future management strategies.

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followed in accordance with the University of Illinois Institutional Animal Care and Use Committee (EIU, 16-003; INHS, 17018; SIU, 16-008; WIU, 16-09).

**Disclosure statement**

The authors report there are no competing interests to declare.

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**Data availability statement**

The data that support the findings of this study are available on request from the corresponding author, ALW.

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