FISH ASSEMBLAGE STRUCTURE RESPONSE TO SILVER CARP INVASION IN THE WABASH RIVER

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Abstract

Impacts of environmental stressors on river ecosystems are frequently identified using abundance and diversity data for fish assemblages to assess the impact of environmental stressors on river ecosystems. However, biomass is less frequently used. We created a random variable linear mixed model using the biomass data from a large boat electrofishing database to investigate the fish assemblage structure of the Wabash River Indiana. We tested for the temporal effects of silver carp on biomass of six trophic guilds of the Wabash River assemblages for pre-establishment and post-establishment of silver carp in 2004. An increase in biomass from pre- to post- establishment was detected for benthic invertivores and general invertivores, and a decrease in the biomass from pre- to post establishment was detected for omnivores. We suggest that there is value in adding biomass as a variable to consider in assessing riverine fish assemblages, and that combining these data with abundance, diversity, and food web data could provide more insight into the effects that stressors such as silver carp have.

Introduction

Fish assemblages

Anthropogenic impacts on river ecosystems impact fish assemblage structure (Pyron et al. 2016), including environmental stressors such as climate change and dam operations that modify lotic hydrology (Poff and Allen, 1995). Biomass data can provide information for fish assemblage status and basic river ecosystem functions that are valuable for conservation and management efforts in response to environmental stressors and anthropogenic impacts (Cohen, 1991; Takahara et al., 2012). Biomass data for fishes inform body size and predator-prey interactions in food webs (Cohen, 1991; Zhang et al., 2016; Kramer et al., 2019). Biomass diversity indices are a proxy for aquatic ecosystem stability (Aoki and Mizushima, 2001), and are part of production calculations across aquatic ecosystems (Randall and Minns 2000; McClanahan et al. 2016).

We used biomass data from annual collections to assess temporal trends of fish assemblages on the Wabash River where previous studies have used abundance (Pyron et al., 2006; Pyron et al., 2011, Broadway et al. 2015). Pyron et al. (2006) found variability in temporal fish assemblages from 1974-1998 for river km 272-530, but relatively little change in abundance values. Broadway et al. (2015) expanded upon this with a community size spectrum model based on fish body size and abundance. They found a shift in dominant functional feeding guilds (FFG) in the Wabash fish assemblage from a system dominated by planktivores and omnivores to the current status with benthic invertivores dominating the system (Broadway et al. 2015).

Invasive Silver Carp

The introduction of nonnative species frequently disturbs ecosystems by altering trophic positions, changing interactions among native species, and impacting fish assemblage structure (Sampson et al., 2009; Pongruktham et al., 2010; Zhang et al., 2016; Nelson et al. 2017; Pyron et al., 2017; Minder and Pyron, 2018; Kramer et al., 2019). Silver carp (*Hypophthalmichthys molitrix*) are invaders of freshwater rivers and lakes in North America with large body mass and high growth rates, with maximum weight and fecundity around 27 kg and 500,000 eggs respectively (Varble et al., 2007). Silver carp potentially alter fish assemblage structure by direct and indirect competition with native fishes for food resources (Irons et al., 2007; Sampson et al., 2009; Pyron et al. 2017; Minder and Pyron, 2018), through modifications of plankton community composition (Pongruktham et al., 2010), or potentially shifting carbon flow via undigested plankton in fecal pellets (Yallaly et al., 2015).

Invasive silver carp were introduced to the Wabash River in the late 1990's and were established by 2004 (Coulter et al., 2013), resulting in silver carp diet overlap with native gizzard shad (Minder and Pyron, 2018) Our study utilized biomass data to investigate the fish assemblage structure of the Wabash River ecosystem between 1974 and 2008. We evaluated trends during this period as evidence for silver carp as an invasive stressor. We used linear mixed modelling to evaluate these temporal trends in our highly variable data. We expect a similar shift between pre- and post- establishment biomass values for six FFG as was found in abundance values in Broadway et al. (2015) where benthic invertivores became the dominant FFG.

Methods

Site description

The Wabash River is a large tributary of the Ohio River, US with a watershed of 85,000 km² (Pyron et al. 2017) (Figure 1). Stressors on the Wabash River ecosystem include agricultural runoff, urban development, hydrological alterations, and invasive species such as the bigheaded carp that have impacted overall abundance and diversity of fish assemblages (Gammon, 1998; Pyron et al., 2006; Pyron et al. 2020). Recent fish assemblage surveys of diversity and abundance found recovery by sensitive fish species that were attributable to the Clean Water Acts regulation of point-source pollution in the 1970s and the adoption of better agricultural practices. (Pyron et al., 2006; Pyron et al. 2020).

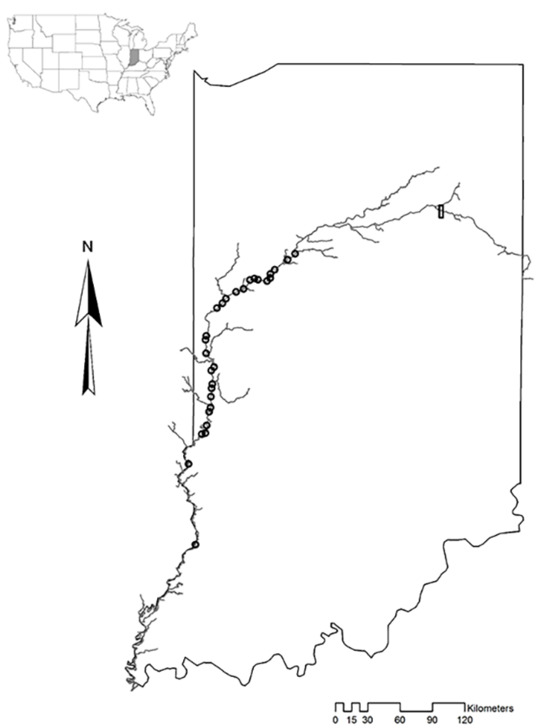

Figure 1. Location of annual electrofishing surveys on the Wabash River Indiana, USA

Field Analyses

Many freshwater fishes are opportunistic feeders with flexibility in their diets (Vander Zanden et al., 1997). This allows fish species to be categorized into FFG as an alternative method to analyze fish assemblage structure (Poff and Allen, 1995). For this study, we grouped fish species into six FFG: benthic invertivores, general invertivores, herbivore-detritivores, omnivores, piscivores, and planktivores (Pyron et al., 2006; Broadway et al. 2015). Functional feeding guilds for parasites had extremely low values in the database and were used in total biomass calculations but were excluded from individual FFG comparisons. We used biomass (g) data from a large database of boat electrofishing data on the Wabash River (Broadway et al. 2015). We converted this into g per 0.5 km, because site distances for collections were all 0.5 km. This database was started by Gammon (1998) for the years 1974-1998 and continued by Pyron et al. (2020) for the years 2004-2008. We used only data from river km 298-494, where sites were sampled regularly. Due to inconsistent sampling efforts, individuals less than 10 mm total length or 10 g were eliminated from analyses. A list of taxa and associated functional feeding guilds are in Broadway et al. (2015).

Statistical Analyses

To assess the impact of silver carp introduction on fish biomass, we created a random intercept linear mixed model using the *lme*4 package (Bates, Maechler & Bolker, 2012) in R statistical software. Linear mixed models use a “mixing” of fixed effects and random effects for the use of data with high variation and allows use of data that is not truly independent without the loss of data through subsetting. We implemented the lmer function using a residual maximum likelihood (REML) estimate, setting the log-transformed biomass (g) of catch data as the response variable and pre- and post- establishment groupings of each of our six FFG’s as a categorical fixed effect. We also used year (n = 30) as a random effect to account for variation in our biomass in the likelihood of sampling the same fishes from the same sites between years. Inspections of a residual plot showed no distinct patterns, so assumptions of homoscedasticity and linearity were met. Collinearity and normality of residuals assumptions were also met using vif function and inspections of histogram of residuals and Q-Q plots. To compare average biomass between pre- and post- establishment of each FFG, we ran our linear mixed model through the emmeans function in the emmeans package (Length et al., 2021) to produce estimated marginal mean values for each factor of the fixed effects. This confint function package in R also provided probability values for contrast comparisons among factors and 95% confidence interval.

An additional linear mixed model was created with the same parameters except with a fixed effect of categorization of pre-establishment or post-establishment. This was done to find any observable effects in the overall biomass in the fish assemblage. Assumptions for this model were all met using the same methods as described above. For this model we

Results

Estimated marginal means for each FFG for pre- and post- establishment with lower and upper 95% confidence intervals are shown in table 1. Additionally, additive contrast comparisons are shown in table 2 between estimated marginal means of pre- and post- establishment factors of similar FFG's, with lower and upper 95% confidence intervals. Our model with establishment as a fixed effect, did not result in a significant difference between pre- and post- establishment. For the main model with a fixed effect of pre- and post- establishment categories for each FFG resulted in an effect between pre- and post- establishment benthic invertivores, general invertivores, and omnivores with estimates of 0.789 [0.363, 1.215], 0.484 [0.055, 0.912], and -

0614 [-1.043, -0.186] respectively (Tables 1 and 2). Year as a random effect accounted for approximately 14% of the variation in this model.

Table 1: Estimated marginal means of our fixed effects with lower and upper 95 % confidence intervals (CI), from a random intercept linear mixed model with 95% confidence interval range. Trophic groups were fixed effects and are listed from before

Trophic Groups	Emmean	Lower 95% CI	Upper 95 % CI
Pre-establishment			
Benthic Invertivore	3.60	3.50	3.69
General Invertivore	2.81	2.71	2.91
Herbivore/Detritivore	3.07	2.97	3.17
Omnivore	3.82	3.73	3.92
Piscivore	3.21	3.11	3.30
Planktivore	3.03	2.94	3.13
Post-establishment			
Benthic Invertivore	4.38	4.15	4.62
General Invertivore	3.29	3.06	3.53
Herbivore/Detritivore	2.77	2.43	3.11
Omnivore	3.21	2.97	3.45
Piscivore	3.27	3.04	3.51
Planktivore	3.43	3.19	3.69
Benthic Invertivore	4.38	4.15	4.62

Table 2: Change in biomass in FFG from before and after silver carp establishment. The estimate column is the result of additive comparisons via subtraction. LCL and UCL represent the lower and upper confidence level of a 95% confidence interval of this estimate.

Trophic groups comparisons	Estimate	Lower 95% CI	Upper 95% CI	P
Post Benthic Invertivore – Pre Benthic Invertivore	0.789	0.363	1.215	<0.001
Post General Invertivore - Pre General Invertivore	0.484	0.055	0.912	0.012
Post Herbivore/Detritivore - Pre Herbivore/Detritivore	-0.294	-0.886	0.297	0.9
Post Omnivore - Pre Omnivore	-0.614	-1.043	-0.186	0.0002
Post Piscivore - Pre Piscivore	0.065	-0.362	0.492	1
Post Planktivore - Pre Planktivore	0.399	-0.030	0.829	0.098

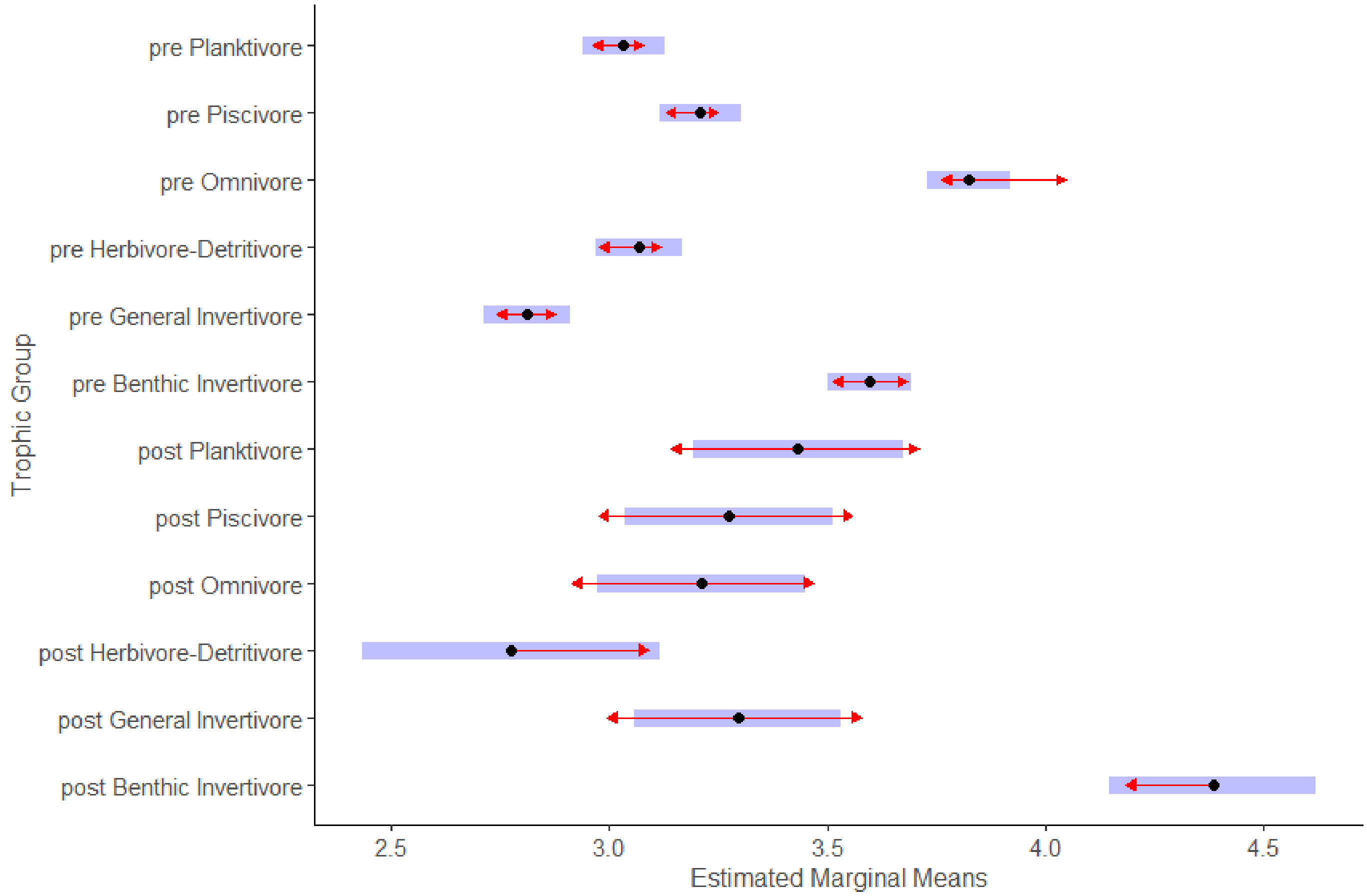

Figure 1 – Estimated marginal means (emmean) for trophic factors in model that are listed for before and after silver carp establishment. Blue bars indicate 95% confidences intervals and red lines indicate a schema for comparisons among groups. Where red lines overlap there is no significant difference between those groups

Discussion

We did not find significant differences in average biomass levels between just establishment groups. The Wabash River has been subjected to hydrological alterations and numerous point source pollution sources that caused large fish kills in the 1970s and 1980s (Gammon, 1998). We suggest that a time-lag recovery for the post-establishment fish assemblage extends further than 2008 data. This lag may result from regulations of point-source pollutants and improved agricultural techniques (Pyron et al. 2006, Pyron et al. 2020) that have led to improved water quality. Additional data past 2008 may reveal trends in mean biomass and year of collections for the post-establishment assemblage.

Although we found no significant difference in biomass from before and after silver carp establishment, we found pre- and post- establishment coefficients differed for benthic invertivores, general invertivores, and omnivores with an increase in the average biomass of benthic invertivores and general invertivores and a decrease in the general biomass of omnivore from pre- to post- establishment years. These results support the results of Broadway et al. (2015) who found a shift in FFG dominance: planktivores, omnivores, and piscivores were replaced by benthic invertivores. The effects among FFG's could result from variation in biological responses. For example, observed rapid growth and high fecundity of silver carp may have resulted in increased average biomass of planktivores in the post-establishment assemblage. (Varple et al. 2007). This biological variation may also be present at different magnitudes within trophic groups. The general Invertivore trophic group, for example, includes taxa such as the small-bodied centrarchid sunfish and large-bodied buffalo species. These two fish taxa have very different ecological roles and biological responses. It is because of this variation that there may be value in further investigation into shifts in life history traits or other biological pathways such as age at maturity, fecundity, or growth rate responses between fish taxa. Fish taxa have different responses to stressors in the form trade-offs to maximize their reproductive capabilities (Winemiller, 2005). These variations may lead to faster or slower recovery rates after a stressor event. There are likely still numerous stressors on the fish assemblages of the Wabash River, such as nutrient loading from agricultural runoff and the establishment of invasive carp in 2004.

These biological variables would also be valuable in pinpointing environmental stressors by utilizing an expected fish assemblage response (Fox, 1994). Silver carp invasion resulted in reduced body condition of native planktivorous competitors in the Illinois River (Irons et al. 2007) and could drive such a shift in feeding habits in the Wabash River fish assemblages. Yallaly et al. (2015) explored the transfer of nutrients from the water column to the benthos in the form of undigested plankton in silver carp fecal pellets. Yallaly et al. (2015) found that juvenile omnivorous catfish survived on fecal pellets, which may indicate the possibility of the establishment of alternative food sources in a river ecosystem.

We are unable to attribute the invasion of silver carp as the sole stressor driving fish assemblage shifts. Silver carp likely provide an additive, subtractive, or compensatory factor to other stressors on the Wabash River ecosystem (Jackson et al., 2016). Biomass data for a comparable river that lacks silver carp as a stressor might provide an interesting contrast to this study. This could reveal the effects of other potential environmental stressors on the fish assemblages and, indirectly, reveal ecosystem effects of silver carp invasion. We suggest that biomass data for fish assemblages are valuable when combined with abundance, diversity, and food web analyses. At large scale this information could provide the variables required for predictive modelling as in Lake Erie (Zhang et al., 2016) or the Mississippi River (Kramer et al., 2019). At smaller scales, these data provide increased understanding, and potential predictions for the effects of silver carp on river ecosystems (Baxter et al. 2004)

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