EFFECT OF SHALLOW-WATER HABITAT QUANTITY ON YOUNG-OF-YEAR SHOVELNOSE STURGEON PREY USE AND CONDITION ALONG A LONGITUDINAL GRADIENT

By

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Abstract: The lower Missouri River has been highly modified and it is hypothesized that the loss of shallow-water habitat (SWH) has decreased prey availability, negatively affecting young-of-year (YOY) sturgeon. Young-of-year sturgeon (*Scaphirhynchus* spp.) from five reaches of the lower Missouri River that varied in amount of SWH (47 to 295 ha) were sampled bi-monthly from May through October in 2014 and 2015. For each site, I analyzed prey use and condition in relation to the amount of SWH along a longitudinal gradient of the river. I analyzed 506 YOY shovelnose sturgeon in 2014 and 569 in 2015 (14 to 120 mm FL) and found diet items were restricted to three macroinvertebrate orders: diptera, ephemeroptera, and trichoptera. In 2015, YOY shovelnose sturgeon consumed nearly twice as many prey as in 2014 and had many fewer instances of empty stomachs. Regarding the predominant prey type, number of diptera larvae eaten peaked at middle reaches and moderate amounts of SWH in 2014 and high numbers were consumed at sites further downstream and as SWH increased in 2015. The number of diptera larvae consumed grew exponentially with length, however, in 2015, rate of diptera larvae consumed was least in high amounts of SWH. Prey quantity did not appear to be limited and factors beyond amounts of SWH appear to be affecting prey use and survivorship of YOY shovelnose sturgeon. The highest percent lipid (i.e. body condition) for YOY shovelnose sturgeon was at lengths ≤40mm, attributed to assimilation of the yolk sac. Condition was best explained by location along the river continuum, increasing with increased distance upstream ($r^2 \leq 0.27$). An interannual influence was observed with average percent lipid in lengths 41-120mm being lower in 2014 than in 2015. Emaciated and healthy control YOY shovelnose sturgeon were acquired to compare to the condition of wild-caught fish. In 2014, length categories >41mm were not statistically different from emaciated specimens and, in 2015, only length category 101-120mm differed from control specimens ($P \leq 0.05$). These results provide the first description of YOY sturgeon prey use and condition at a large spatial scale along the lower Missouri River.

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CHAPTER I

INTRODUCTION

Rivers and streams have long been manipulated by humans such as for transportation routes when roads were few in the early settlement days of the United States and as a source of power in the boom of the Industrial Revolution (NRC, 1992). Beginning in the 20th century, there was an escalation of river engineering initiatives in the attempt to harness the power of rivers and streams. With growing populations and urban development along rivers there was a demand for flood control, water supply, hydropower and recreation. The growth of agricultural and mineral production industries created a need for irrigation and navigable waterways for transportation of goods. All these initiatives shaped the physical structure and function of rivers currently.

The Mississippi River is emblematic of these systems being the world's second largest drainage basin as well as being heavily altered. The basin has a total watershed of 4.8 million square-km, encompassing more than 90 major river systems (Hesse *et al.*, 1993), including the Ohio, Platte and Missouri Rivers (Figure 1), all of which have been altered to varying degrees. The prevailing influence of industrial activity in urban areas to the east, agricultural practices in the rural areas to the west, and a demand for navigable channels across the nation has constrained waterways and transformed the dynamic riverscape. Degradation of the Ohio River, for example, occurred shortly after colonization, initially as a result of logging in the upper reaches of the river buffered by hardwood forests. But, as population increased so did agriculture and mining leading to wide-spread pollution in the river (Thomas *et al.*, 2004). In 2013, the Ohio River ranked number one for pollution discharge with over ten thousand four hundred metric tons of chemicals dumped into the river (Environmental Protection Agency, 2015). Additionally, to sustain a navigation channel, twenty high-lift dams have been constructed (Emery *et al*., 2003). Fragmentations of rivers suppress biotic diversity, inhibit passage of organic matter, and affect seasonal flows (Ward and Stanford, 1983). The Platte River system has had much of its water diverted to create reservoirs for domestic needs in large cities and water supply for agriculture use in the plains (Strange *et al*., 1999). These actions have increased the risk for population extinctions of native fish fauna by altering thermally suitable habitat in this once cold-water high-elevation stream (Rahel *et al*., 1996; Strange *et al.*, 1999).

Recently, however, there are ongoing efforts in many of the large watersheds of the Mississippi River Basin to restore certain characteristics that have been lost from anthropogenic alterations. Restoration efforts in the upper Mississippi River Basin (above the confluence with the Missouri River) are guided by a master plan developed by the Upper Mississippi River Basin Commission (UMRBC, 1982); a multi-agency and stakeholder cooperation to address policy and program priorities to create a healthier and more resilient ecosystem (USACE, 2015a). Construction of setback levees allow the river to meander in a prescribed floodplain and dredged diversions create backwater refugia for aquatic organisms (Gore and Shields, 1995). In addition, Ten National Fish and Wildlife Refuges have been established along the upper Mississippi River to contribute to the preservation of floodplain and riparian land (NRC, 1992).

Regulatory and management actions of the U.S. Fish and Wildlife Service (USFWS) in particular have guided restoration activities to benefit threatened and endangered species in the Mississippi River corridor. The 2000 Water Resource Development Act delegated funds for projects within the Mississippi River basin to evaluate and better protect, restore and create aquatic and related habitat. Actions in the Ohio and Platte River watersheds such as barrier removal at low water crossings, riparian habitat plantings, timed releases from reservoirs to create vegetation-free sand bars, acquiring habitat complexes to shield main-channel and interconnected side channels are implemented to restore ecological functions to benefit threatened and endangered species.

The Missouri River, however, is the largest of the Mississippi River basins and has one of the longest histories of river engineering. As early as 1832, there had been interest in channel modifications on the Missouri River for transportation of goods; mainly the removal of obstacles to ease passage of steamboats, finally made possible by the 1912 Bank Stabilization and Navigation Project. Further modified by the Rivers and Harbors Act of 1945, these acts congressionally authorized the U.S. Army Corps of Engineers (USACE) to maintain a navigation channel for commercial transport (USFWS, 2000). These anthropogenic influences have led to a loss of habitat diversity on the Missouri River (USFWS, 2000; USFWS, 2003), shifting from a meandering, shallow, turbid river into a channelized, deep, clear waterway.

Channelization of the Missouri River has altered an estimated 1.2 M ha of natural river habitat, eliminated the reproduction of native cottonwood trees *Populus deltoides*, and reduced aquatic insect abundance by seventy percent (USACE, 2009). Furthermore, many native fish species have declined (NRC, 2011) and, in response, the USFWS issued a Biological Opinion (BiOp) on the USACE operation of the Missouri River to prevent jeopardy of threatened and endangered species. The Missouri River Recovery Program (MRRP) was created to implement the reasonable and prudent alternatives of the BiOp to restore the Missouri River to a semblance of its original dynamic riverscape and physical processes. Restoration activities are conducted in an adaptive management framework and include improving floodplain connectivity, constructing chutes or side channels, implementing a natural flow regime, and creating sandbar habitat (USFWS, 2000; USFWS, 2003).

One critical restoration goal of the MRRP is the reestablishment of shallow-water habitat

(SWH). Shallow-water habitat is created by the modification of existing river control structures and construction of off-channel chutes. In a regulatory context, SWH is defined as water less than 1.5 m deep and a flow velocity less than 0.6 m/s (USACE, 2015b). Examples of SWH include backwaters, depositional sandbars detached from the bank, and low-lying depositional areas adjacent to shorelines (USFWS, 2003). The SWH construction goal is 8-12 ha per 1.61 km (2,833 ha to 8,094 ha total) on the channelized lower Missouri River, below Gavins Point dam near Yankton, South Dakota to Saint Louis, Missouri 2024 (USFWS, 2000; USFWS 2003).

Shallow-water habitat is critical for young and small-bodied fishes by providing low velocity nursery zones for growth and development (Schiemer *et al*., 2001). Shallow-water may encourage increased forage opportunities for fishes by retaining higher rates of organic matter, phytoplankton, and zooplankton (Knowleton and Jones, 2000; Brown and Coon, 1994). Shallow-water habitat also provides a refuge in the channelized areas of the river for drifting larval fishes growth and development (Schiemer *et al*., 2001).

Two long-lived river sturgeon species occur in the lower Missouri River Basin, both with similar life history traits (Wildhaber *et al*., 2007). The pallid sturgeon *Scaphirhynchus albus* is rare and endangered in most of its range (Colombo *et al*., 2007) and is one of the species for which the BiOp was written prompting habitat restoration along the lower Missouri River. The shovelnose sturgeon *S. platorynchus*, the more common of the two, is listed as threatened when sympatric with pallid sturgeon due to similarity of appearance. Because pallid sturgeon are rarely captured, shovelnose sturgeon is often considered a surrogate for pallid sturgeon.

Early life stages of shovelnose sturgeon depend on nursery habitat availability that slows larval drift, increases retention of food sources and provides habitat conditions for recruitment to age-1 (i.e., SWH) (Braaten *et al*., 2008). The transition from the yolk sac to exogenous feeding is important for survival of young-of-year (YOY) sturgeon, so an abundance of benthic macroinvertebrates, their main prey source (Sechler *et al*., 2012), is critical. While the creation of more SWH may provide areas favorable to fishes and macroinvertebrate production (Schiemer *et* *al*., 2001; Sechler *et al*., 2012), it is currently unknown if SWH restoration is providing the hypothesized benefits to support early life stages of YOY sturgeon. For example, YOY sturgeon were more likely to have empty stomachs in SWH within constructed chutes compared to SWH in mainstem habitats of the lower Missouri River (Gosch *et al*., 2016; T. Starks, Oklahoma State University, unpublished data). The goal of this research is to identify whether SWH restoration affects YOY sturgeon prey use and body condition in the lower Missouri River at a large spatial scale.

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FIGURE 1. Map of the Mississippi River Basin and select major tributaries.

CHAPTER II

EFFECT OF HABITAT QUANTITY ON YOUNG-OF-YEAR SHOVELNOSE STURGEON PREY USE ALONG A LONGITUDINAL GRADIENT

Introduction

Anthropogenic influences have led to a loss of habitat diversity on the lower Missouri River (USFWS, 2000; USFWS, 2003), engineered from a meandering, shallow, slow-moving river into a channelized, deep, swift-moving waterway. An estimated 90 percent of historical shallow, slow-moving aquatic habitat has been lost due to construction, operation, and maintenance of structures to improve boat navigation (USFWS, 2000). Since 2000, restoration actions have been directed at the reestablishment of shallow-water habitat (SWH) through modification of existing river structures and construction of off-channel chutes. The regulatory definition of SWH was defined as water less than 1.5 m deep and a flow velocity of less than 0.6 m/s and includes backwaters, depositional sandbars detached from the bank, and low-lying depositional areas adjacent to shorelines (USFWS, 2000; USFWS, 2003; USFWS 2009). As of 2014, there were 45,367 ha of SWH created throughout the entire Missouri River (USACE, 2014). Shallow-water habitat is thought to benefit the early-life stages of small bodied fish, especially, federally endangered pallid sturgeon *Scaphirhynchus albus* and its ecologically similar relative - shovelnose sturgeon *Scaphirhynchus platorynchus* (Braaten *et al*,. 2007, 2012; Gosch *et al*., 2015). Most sturgeon captured on the lower Missouri River in 2014 and 2015 were genetically confirmed shovelnose sturgeon (E. Heist, Southern Illinois University, unpublished data) which is the focus of this study.

Whether constructed SWH benefits river sturgeon and their early life stages has only recently been investigated. The SWH restoration is under the umbrella of the Missouri River Recover Program and is set in an adaptive management framework that uses the best available science to make management decisions (USFWS, 2003; USACE, 2014). Current monitoring attempts to assess system-wide responses for long-term recruitment of pallid sturgeon and the short-term responses to SWH creation, such as increased retention of YOY sturgeon and increased food availability (USACE, 2012). The early life stages of *Scaphirhynchus* species are thought to depend on SWH as nursery areas (Colombo *et al*., 2007; Wildhaber *et al*., 2007) where larvae fall out of the drift in areas of high food source retention improving survival (Braaten *et al.*, 2008).

A link between macroinvertebrate density in SWH and *Scaphirhynchus* recruitment is hypothesized to be the bottleneck to sturgeon population viability in the lower Missouri River (Wildhaber *et al.*, 2007; Steffensen *et al.*, 2014). In large rivers, slow water velocities and high concentrations of silt and organic matter coincide with an increase in productivity and availability of macroinvertebrate prey (Schiemer *et al*., 2001; Schiemer *et al*., 2002; Galat *et al*. 2005; Ning *et al*., 2010; Benke and Cushing, 2011; O'Neil and Thorp, 2011; Sechler *et al*., 2012). Longitudinal, as well as lateral connectivity to adjacent shallow water areas benefits river fishes through input of nutrients and prey sources (Humphries *et al.*, 1999; Wildhaber *et al.*, 2007; Schiemer *et al*., 2002). An abundance of benthic macroinvertebrates, the main prey source for young-of-year (YOY) *Scaphirhynchus*, is a determinant of survival during the transition from the yolk sac to exogenous feeding (Gisbert and Williot, 1997; Deng *et al.*, 2003; Wildhaber *et al.*, 2007; Braaten *et al*. 2012).

Successful feeding at initiation of exogenous feeding and an increase in prey use as they grow and develop is closely linked to survival at this critical period in YOY *Scaphirhynchus* life history. Dietary studies of YOY shovelnose sturgeon in the lower Missouri River are sparse (Gosch *et al*. 2015), but have been conducted more extensively in the middle Mississippi River (Sechler 2012, 2013), lower Mississippi River (Harrison *et al.*, 2014), and the upper Missouri River (Braaten *et al.*, 2007). In these studies, YOY shovelnose sturgeon rarely had incidences of empty stomachs (Braaten *et al*., 2007; Sechler *et* al., 2012; Harrison *et al.*, 2014), suggesting abundant prey, with diets dominated by two macroinvertebrate orders: diptera and ephemeroptera (Braaten *et al*., 2007; Sechler *et al.*, 2012, 2013; Harrison *et al.*, 2014; Gosch *et al.*, 2016). In addition, an exponential increase in prey consumption was observed concomitant with fish sizes (Braatan *et al*., 2007, Sechler *et al*., 2012, 2013).

With the restoration goal of creating SWH, the hypothesis is that an increase in SWH will increase production and retention of food sources increasing YOY river sturgeon prey use, ultimately leading to greater YOY shovelnose sturgeon survival. The objective of this study is to examine prey use and stomach fullness of YOY shovelnose sturgeon at a large spatial scale along a linear gradient of the lower Missouri River.

Methods

Study site. - The geographic extent of the SWH restoration includes the main-stem lower Missouri River and main-stem connected side channel chutes from Ponca, Nebraska to the confluence with the Mississippi River in Saint Louis, Missouri (USACE, 2015; Figure 1). The lower Missouri River is channelized from self-dredging powered by dikes and revetments constricting the thalweg and directing flow toward the middle of the river (Jacobson and Galat, 2006). Five reaches of the lower Missouri River between Kansas City and Saint Louis that varied in amount of cumulative SWH (47 to 295 ha) were sampled bi-monthly from May through October in 2014 and 2015 when river conditions permitted (Table 1).

Sampling Design. - Sampling was conducted by the U.S. Army Corps of Engineers (reach 1 and 2) and the U.S. Fish and Wildlife Service (reach 3, 4, and 5; Figure 1) using a bow-mounted or stern-mounted otter trawls (OTO4) in accordance with the Missouri River Standard Operating Procedures for Fish Sampling and Data Collection (Welker and Drobish, 2012). The OTO4 is a 4 mm mesh nylon net with a 4.88 m opening that is pulled with the river current along the riverbed and spread open by two, 91.4 cm by 38.1cm boards (a.k.a. doors). The OTO4 was used to catch YOY shovelnose sturgeon in benthic habitats between 1.5 and 5 m deep with a trawling distance from 75 to 300 m and between 1 and 1.5 m deep with a trawling distance from 15 to 150 meters. When three or more YOY shovelnose sturgeon were captured in a single trawl, an additional two trawls were conducted in the same location. If ten or more YOY shovelnose sturgeon were captured in either additional trawl, one duplicate trawl was conducted for a maximum of five trawls in the same location. Repeated sampling of habitats was necessary to achieve the desired sample size in each length category.

Captured YOY sturgeon were measured for fork length (FL) or total length (TL), depending on presence of the heterocercal tail filament. Fin clips were sent to Southern Illinois University to verify species identity through genetic analysis. Young-of-year shovelnose sturgeon were kept at -18ºC and preserved in ethanol to minimize oxidative decomposition and slow deterioration. After each sampling season was complete, up to 20 YOY shovelnose sturgeon were randomly selected from each of the six separate length categories (0-20, 21-40, 41-60, 61-80, 81-100, 101-120 mm) for gut content analysis (Table 2).

Diet quantification. - The lower esophagus and stomach of YOY shovelnose sturgeon were removed in the laboratory, blotted dry and weighed (0.0001g), gut contents removed, and the stomach reweighed. By subtraction, this provided stomach content weight (plus unidentifiable material and fluid) to give a proportion of prey items relative to gut size (percent stomach fullness) (Terry, 1976; Hyslop, 1980; Hintz *et al.*, 2015). Gut contents were then enumerated under a Nikon SMZ800 microscope and identified to order (family for diptera) and sub-sampled if prey items exceed 250. Sub-sampling was conducted by spreading the gut contents out in gridded tray (mm^2) counting items in three randomly selected grids to count, which were averaged, and multiplied by the number of filled grids to estimate the total number of prey items (Hayslip, 2007). A search for large and rare organisms was also conducted before sub-sampling.

Statistical methods. - Trends of percent fullness by length category in relation to the amount of SWH (ha) and distance from the mouth of the Missouri River (i.e. river kilometer (rkm) along a longitudinal gradient) was examined with quadratic regression analysis in SigmaPlot 12 statistical software. The number of each major prey type consumed by each length category in relation to the amount of SWH and location along the river (RKM) was analyzed with zero inflated negative binomial regression and zero inflated Poisson regression, depending on convergence and model fit, in 2014 and 2015 using SAS 9.4 software. To separate the influence of location from SWH quantity, the residuals of the number of prey eaten and percent fullness for the RKM models were extracted and plotted against the amount of SWH (ha).

The rate of change in prey consumed with YOY shovelnose sturgeon length and age (ontogenetic diet shift) for each study site, was examined with exponential regression using SigmaPlot version 12 statistical software. Young-of-year shovelnose sturgeon age (days) was estimated by quantifying post-hatch length-increases as a function of water temperature (Braaten and Fuller, 2007) using data from the USGS National Water Information System in approximate location to the five study reaches (Table 1). Slope estimates (±95% CI) of the regression models were plotted against quantity of SWH and river location (rkm) for each year to investigate how these two variables affected the rate of prey consumption as a function of YOY shovelnose sturgeon length and age.

Results

A total of 506 YOY sturgeon in 2014 and 569 YOY sturgeon in 2015 were randomly selected, but not all length categories were represented by the goal of 20 individuals (Table 2). Genetic analysis confirmed that all YOY sturgeon used for this analysis were shovelnose sturgeon. Diet items were restricted to mainly two macroinvertebrate orders: diptera (larvae and pupae) and ephemeroptera (nymphs). Cyclopoid copepods and trichopterans were rarely consumed and excluded from further analysis (Table 3). I identified 80909 diet items from 506 individual YOY shovelnose sturgeon in 2014 (Table 5); 21 fish had empty stomachs (Table 4). In 2015, I identified 197344 diet items from 569 YOY shovelnose sturgeon (Table 6) and only 8 were empty (Table 4). The number of prey items consumed in 2015 was over twice as many as in 2014, paralleling to the number of empty stomachs (Table 4). Diptera larvae was the most frequently encountered prey item (88% in 2014 and 93% in 2015), followed by diptera pupae (46% and 49%) and ephemeroptera (29% and 19%; Table 3).

In 2014, percent fullness was significantly and non-linearly related to river location (distance from mouth; rkm) for all length categories of YOY shovelnose sturgeon <80 mm (4 categories) (Figure 2; left column), whereas only 2 length categories (0-20 and 60-80 mm) exhibited significant models as a function of SWH quantity (Figure 2; middle and right columns). For the smallest YOY shovelnose sturgeon category, percent fullness peaked farthest away from the river mouth and in areas with the least amount of SWH. For larger-sized YOY shovelnose sturgeon, percent fullness peaked at moderate distances from the mouth and moderate amounts of SHW. After accounting for the effect of river location, percent fullness, when significant, peaked at low amounts of SWH. However, explanatory ability of these models was fairly low ($r^2 \leq 0.21$).

In 2015, percent fullness was significantly and non-linearly related to RKM and amount of SWH (Figure 3), but different from 2014. Significant relationships between percent fullness and distance from mouth, as well as amount of SWH, were found for larger-sized YOY shovelnose sturgeon (60-80, 80-100, and 120-140 mm). Young-of-year shovelnose sturgeon from 60-80 mm had peak stomach fullness at both ends of the variables (far and near the mouth; low and high SWH). In contrast, length categories 80-100 mm and 120-140 mm had peak stomach fullness far from the mouth and in areas with lower amounts of SWH (Figure 3; left and middle columns). Adjusting for river location, only YOY shovelnose sturgeon 41-60 mm exhibited a significant relationship with amount of SWH, peaking at the lower quantities. Similar to 2014, however, these models all exhibited low explanatory power ($r^2 \leq 0.27$).

In 2014, SWH was significantly related to the number of each prey type consumed; however, it depended on YOY shovelnose sturgeon length. Not including the smallest length category (0-20mm), there were peak numbers of diptera larvae and diptera pupae consumed at sample sites with moderate amounts of SWH (Figure 4). The 0-20mm YOY shovelnose sturgeon had more diptera larvae and pupae consumed at low amounts of SWH (Figure 4; diptera larvae $P = 0.01$, $r^2 = 0.54$ and diptera pupae $P=0.01$, $r^2=0.47$). Ephemeroptera, for the statistically significant models, were consumed more at high and low amounts of SWH (Figure 4; right column).

The 2015 analysis for number eaten in relation to the amount of SWH was significantly related but with varying results based on prey type. Diptera larvae did not show as strong of a peak as in 2014, but more of a slight increase in consumption as the amount of SWH increased (Figure 5; left column). For diptera pupae, YOY shovelnose sturgeon > 20 mm consumed more of this prey type at sites in the moderate range of SWH ($P = 0.01$, $r^2 \geq 79$). All but one model was statistically significant for the ephemeroptera prey type and the trend showed an increase in number eaten for YOY shovelnose sturgeon 21-40 mm ($P = 0.05$, $r^2 = 47$) and > 61 mm ($P \leq 0.02$, $r^2 \geq 51$) in the reach with the highest amount of SWH (Figure 5; right column).

The spatial relationship of distance from mouth (rkm) and number of prey type consumed depended on the year sampled and the prey type. In 2014, there were strong relationships in the number of diptera larvae and diptera pupae eaten ($P \leq 0.05$, $r^2 \geq 0.43$; Figure 6 left and middle column) with site location. In 2014, peak number of diptera larvae and diptera pupae consumed occurred at areas mid-distance from the mouth. The number of ephemeroptera consumed peaked at sites furthest upstream from the mouth (Figure 6; right column). The 2015 results tended to explain more of the statistical variation between distance from mouth (rkm) and number of prey type eaten ($P \leq 0.05$, $r^2 \geq 0.53$) than in 2014. RKM had a significant influence on the number of diptera larvae eaten with higher numbers consumed at sites closer to the mouth of the Missouri River (Figure 7; left column). Similar to 2014, there were more diptera pupae present in the gut in the middle sample reaches in 2015 forming a peak in the mid-reaches (Figure 7; middle column). In 2014 and 2015, there were more ephemeroptera consumed in reach 1 (Table 5 and 6).

The residual number of prey eaten in relation to amount of SWH analysis models all exhibited low explanatory power ($r^2 \leq 0.17$) and few instances of significance (Figure 8 and Figure 9). For the statistically significant models in 2014, diptera larvae consumption peaked at moderate amounts of SWH and a declining slope in relation to amount of SWH for diptera pupae. No significant models were produced in 2015 (Figure 9).

Young-of-year shovelnose sturgeon exhibited exponential increases in number of prey consumed (predominately diptera larvae) as a function of size and age at all study reaches. Comparatively, across all reaches, there was a trend for exponential models to have greater explanatory power in upstream reaches (1 and 2) in both years (Figure 10 and Figure 11). The rates at which YOY shovelnose sturgeon consumed diptera larvae was not a function of distance from mouth or amount of SWH in 2014 (Figure 12). However, in 2015, the lowest rate of consumption was at the site with the most amounts of SWH, near the mouth of the Missouri River (Figure 13). Additionally in 2015, there was an indication for the highest rate of prey consumption to occur at the site with the least amount of SWH.

Discussion

It is evident that the influence of SWH on prey use (i.e. fullness, by prey type, and ontogenetically) depends on year, fish length, and prey type. However, YOY shovelnose sturgeon appeared to consume adequate amounts of prey throughout the sample reaches in comparison to published studies in other areas. In the upper Missouri River, YOY shovelnose sturgeon consumed an average of 4655 diet items per individual, with one percent incidence of empty stomachs (Braaten *et al*., 2007). In the middle Mississippi River, there was a one percent incidence of empty stomachs out of 404 YOY *Scaphirhynchus* captured (Sechler *et al.* 2013). Although instances of empty stomachs was greater in the lower Missouri River, they coincided with the smallest length categories, when these fish transition from endogenous yolk to exogenous feeding on invertebrate prey (Snyder, 2002), suggesting chance captures during the transition period rather than a failure to feed (Sechler *et al*., 2013). Whether my results from the lower Missouri River are indicative of this section of river compared to the upper Missouri River or Mississippi River is occluded by the differences between years. YOY sturgeon in 2015 consumed nearly twice as many prey as in 2014 and had many fewer instances of empty stomachs, suggesting that environmental variability influenced feeding. Water levels and temperatures were greater in 2015 than 2014, but it is unknown how these two variables might have affected feeding by YOY sturgeon. Plausibly, higher water levels would influence productivity, increasing prey availability for YOY sturgeon. Additionally, higher water temperatures could have led to increased activity and consumption rates by YOY sturgeon (Phelps *et al.*, 2010). Either of these hypotheses would require additional studies to identify the causative role that these variables would exert on YOY sturgeon prey use.

Shallow-water habitat was defined for regulatory purposes at a medium August flow (USACE, 2014) and remained fixed at that cumulative amount for analyses. In reality, the amount of SWH fluctuates over time; by annual releases from reservoirs through dams as well as rainfall and snowmelt through tributaries that change temperature and discharge in the river seasonally. The lower Missouri River historically had more SWH overall (USFWS, 2000; USFWS, 2003); however, under current modified river conditions, SWH is believed to be maximized during extremely low flows (Jacobson and Galat, 2006). Water level (i.e. discharge) likely influenced the available prey and the amount of SWH available for feeding by YOY sturgeon in my study. Although intermittent rises in river stage likely increases prey available by washing prey into settling areas (Harrison, 2012) SWH would generally be scarce during seasons of higher water levels (Jacobson and Galat, 2006). In 2015, when water levels were higher, relationships between amount of SWH and prey use were more evident, suggesting that SWH was more important when it was less abundant.

Factors beyond amounts of SWH appear to affect prey use by YOY shovelnose sturgeon. Longitudinal factors, for instance, are likely major drivers of shovelnose sturgeon prey use. Gavins Point Dam, the first dam on the Missouri River, acts as an ecological reset for conditions downstream (Ward and Stanford, 1983). In this stretch below the dam, the channel is sinuous and braided, promoting the production of collector and predatory insects that dominate the macroinvertebrate assemblage (i.e. diptera and ephemeroptera) (Vannote *et al.*, 1980) and this was exemplified in the peak trend in number of prey eaten and greater incidences of ephemeroptera at the upstream reach.

The use of the best available science to implement restoration actions (i.e. SWH creation) on the lower Missouri River is imperative to the adaptive management framework that is being used to manage the lower Missouri River (USFWS, 2000; USFWS, 2003). Only recently have restoration projects involving the creation of SWH in the lower Missouri River been conducted to determine their effect. In 2012 and 2013, richness of age-0 fishes differed between created chute SWH and mainstem SWH (Starks *et al.*, 2014) as well as lower probability of catching exogenously feeding YOY shovelnose sturgeon in habitats that meet SWH criteria (Ridenhour *et* *al*.,2011; Gemeinhardt *et al*., 2015; Gosch *et al*., 2015). Based on these findings, the role of habitat on YOY sturgeon feeding and ultimate survivorship is in need of further study. The results of this study provide the first description of YOY shovelnose sturgeon prey use at a large spatial scale along the lower Missouri River and suggests that prey quantity is not limited; other factors that affect sturgeon survivorship may exist and should be investigated (e.g., body condition).

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TABLE 1. A description of each sample site including the length, cumulative amount of shallow-water habitat, approximate location of USGS water gauge location used to gather data, average water temperature by water year, and annual discharge for 2014 and 2015. (* incomplete data).

	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
Distance from mouth (river kilometer)	494 – 526	346 – 381	253 – 290	151 – 177	53 - 87
Amount of shallow-water habitat (hectares)	47	191	137	58	295
Approximate stream gauge location	Kansas City, MO	Glasgow, MO	Jefferson City, MO	Hermann, MO	Saint Charles, MO
2014 Annual water temperature (Celsius)	15.62	14.24	13.94	15.95	22.91*
2015 Annual water temperature (Celsius)	13.34	16.67	14.49	14.61	15.61
2014 Annual discharge (cubic meters/second)	1378	1561	1631	1770	1879
2015 Annual discharge (cubic meters/second)	1872	2275	2401	2877	3194

TABLE 2. Goal set for the number of individuals to be sampled within five reaches on the lower Missouri River.

Length Category	**Number of Individuals**	**Reaches**
0 – 20 mm	20	All (1-5)
21 – 40 mm	20	All (1-5)
41 – 60 mm	20	All (1-5)
61 – 80 mm	20	All (1-5)
81 – 100 mm	20	All (1-5)
101 – 120 mm	20	All (1-5)
Total	120	600

TABLE 3. Metrics for all prey types in the gut of 506 young-of-year shovelnose sturgeon from sample year 2014 and 569 young-of-year shovelnose sturgeon from sample year 2015 sampled in the lower Missouri River.

Metric	**Diptera Larvae**		**Diptera Pupae**		**Ehemeroptera**		**Trichoptera**		**Cyclopoida**	
Sample year	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**
Frequency of occurrence (%)	88	93	46	49	29	19	4	1	0	<1
Median number per gut	37	166	0	0	0	0	0	0	0	0
25% Quartile	3	7	0	0	0	0	0	0	0	0
75% Quartile	174	540	4	7	1	0	0	0	0	0
Minimum number per gut	0	0	0	0	0	0	0	0	0	1
Maximum number per gut	1345	2363	475	756	16	21	11	3	0	1

TABLE 4. Number of empty guts from 2014 (n=506) and 2015 (n=569) by location and length.

Year	**Metric**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**
2014	Length (mm)	19, 20, 20	17,17,19,19,22	15,15,17,17,18,18,19	-	15,17,17,18,18,20
	Total	3	5	7	0	6
2015	Length (mm)	18, 18, 20	18,19	17	-	19, 21
	Total	3	2	1	0	2

TABLE 5. Number of certain prey type by reach and the percent of the total diet for 2014.

Prey Type	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Total**	**Percent of Diet**
Ephemeroptera	154	42	31	53	81	361	0.45%
Diptera larvae	9765	11114	23534	19667	11614	75694	93.55%
Diptera pupae	215	1167	1313	1868	253	4816	5.95%
Trichoptera	16	0	1	3	18	38	0.05%
Cyclopoida	0	0	0	0	0	0	0.00%
Total	10150	12323	24879	21591	11966	80909	

TABLE 6. Number of certain prey type by reach and the percent of the total diet for 2015.

Prey Type	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Total**	**Percent of Diet**
Ephemeroptera	118	29	46	15	23	231	0.12%
Diptera Larvae	51627	47803	50567	27207	10889	188093	95.31%
Diptera Pupae	566	2288	1016	4743	401	9014	4.57%
Trichoptera	0	3	2	1	0	6	< 0.01%
Cyclopoida	0	0	1	0	0	0	< 0.01%
Total	52311	50123	51631	31966	11313	197344	

FIGURE 1. Map of the lower Missouri River including sample reach and approximate stream gauge location (red dot).

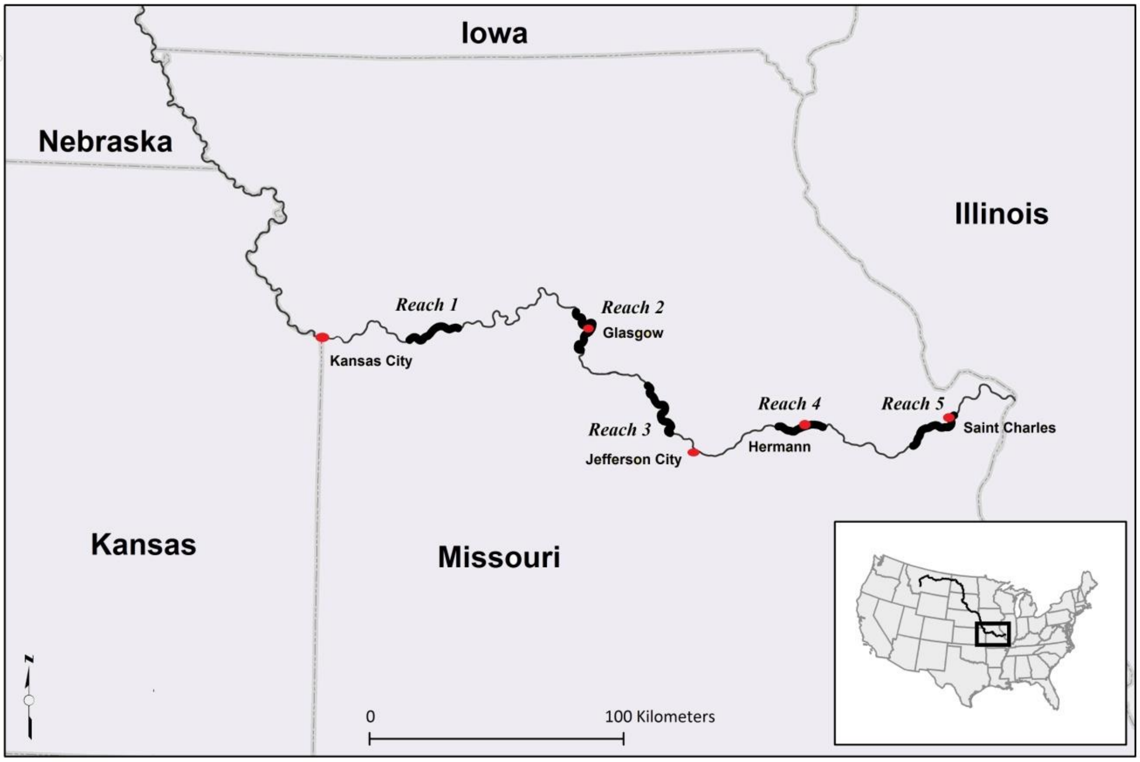


Figure 1: Map of the lower Missouri River including sample reach and approximate stream gauge location.

FIGURE 2. 2014 percent fullness in relation to the distance from mouth (rkm), amount of shallow-water habitat (ha), and residual percent fullness as it relates to amount of shallow-water habitat (ha). Each row is a different length category decreasing from top to bottom (0-20, 21-40, 41-60, 61-80, 81-100, 101-120mm).

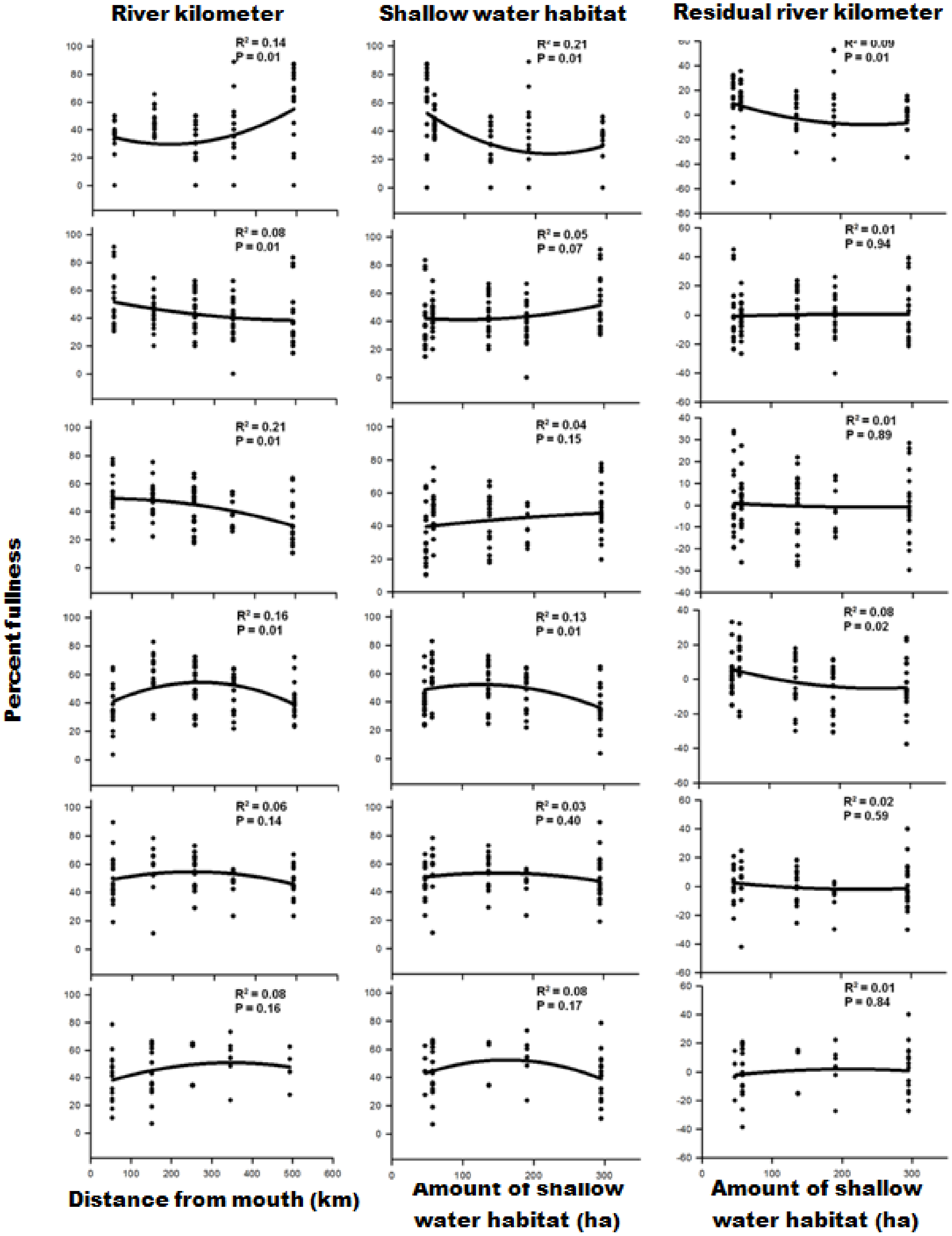


FIGURE 3. 2015 percent fullness in relation to the distance from mouth (rkm), amount of shallow-water habitat (ha), and residual percent fullness as it relates to amount of shallow-water habitat (ha). Each row is a different length category decreasing from top to bottom (0-20, 21-40, 41-60, 61-80, 81-100, 101-120mm).

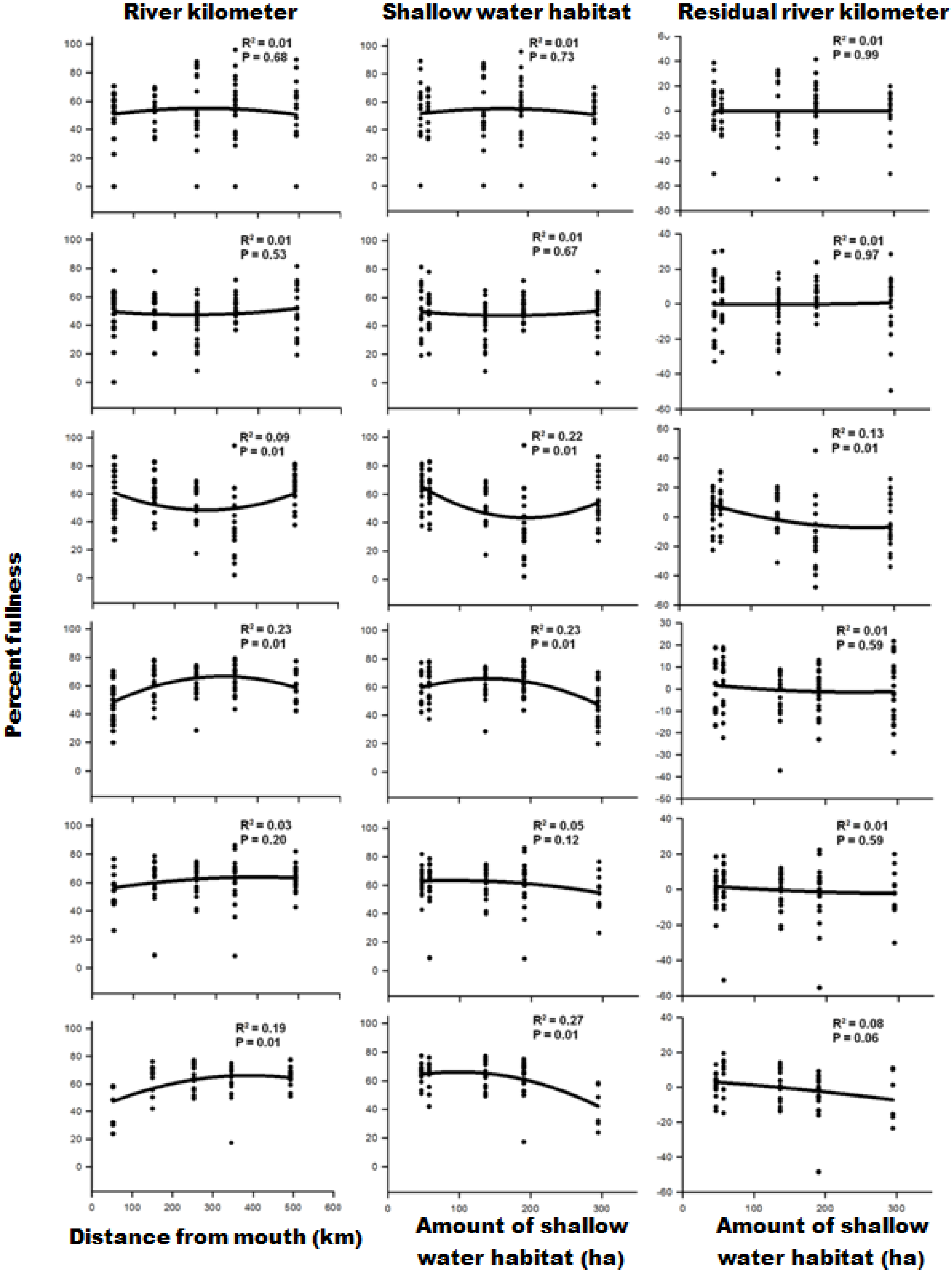


FIGURE 4. 2014 number eaten of three main macroinvertebrate prey types in relation to the amount of shallow-water habitat (ha). Letters A-F are length categories (0-20, 21-40, 41-60, 61-80, 81-100, 101-120mm)

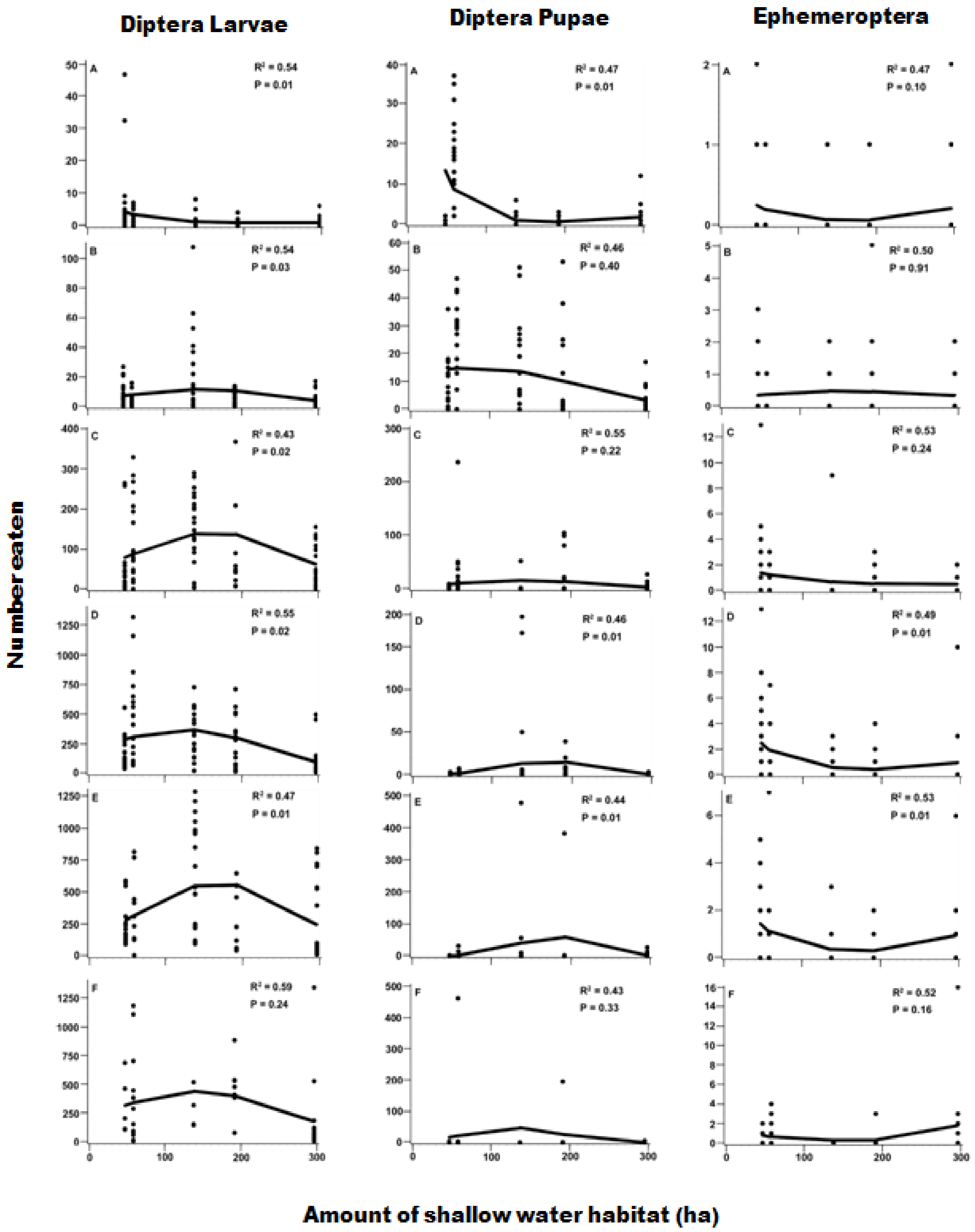


FIGURE 5. 2015 number eaten of three main macroinvertebrate prey types in relation to the amount of shallow-water habitat (ha). Letters A-F are length categories (0-20, 21-40, 41-60, 61-80, 81-100, 101-120mm)

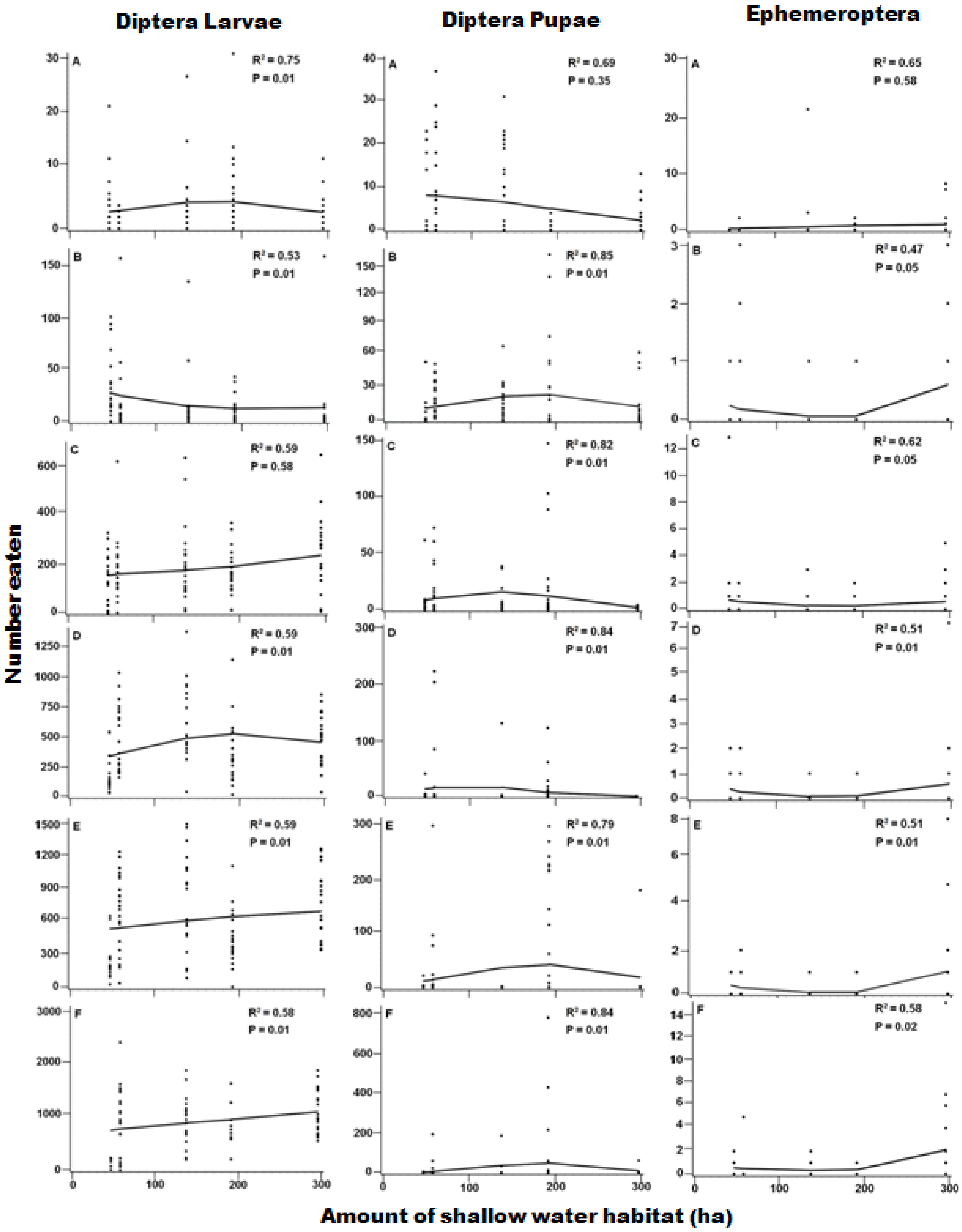


FIGURE 6. 2014 number eaten of three main macroinvertebrate prey types in relation to the distance from mouth (rkm). Letters A-F are length categories (0-20, 21-40, 41-60, 61-80, 81-100, 101-120mm)

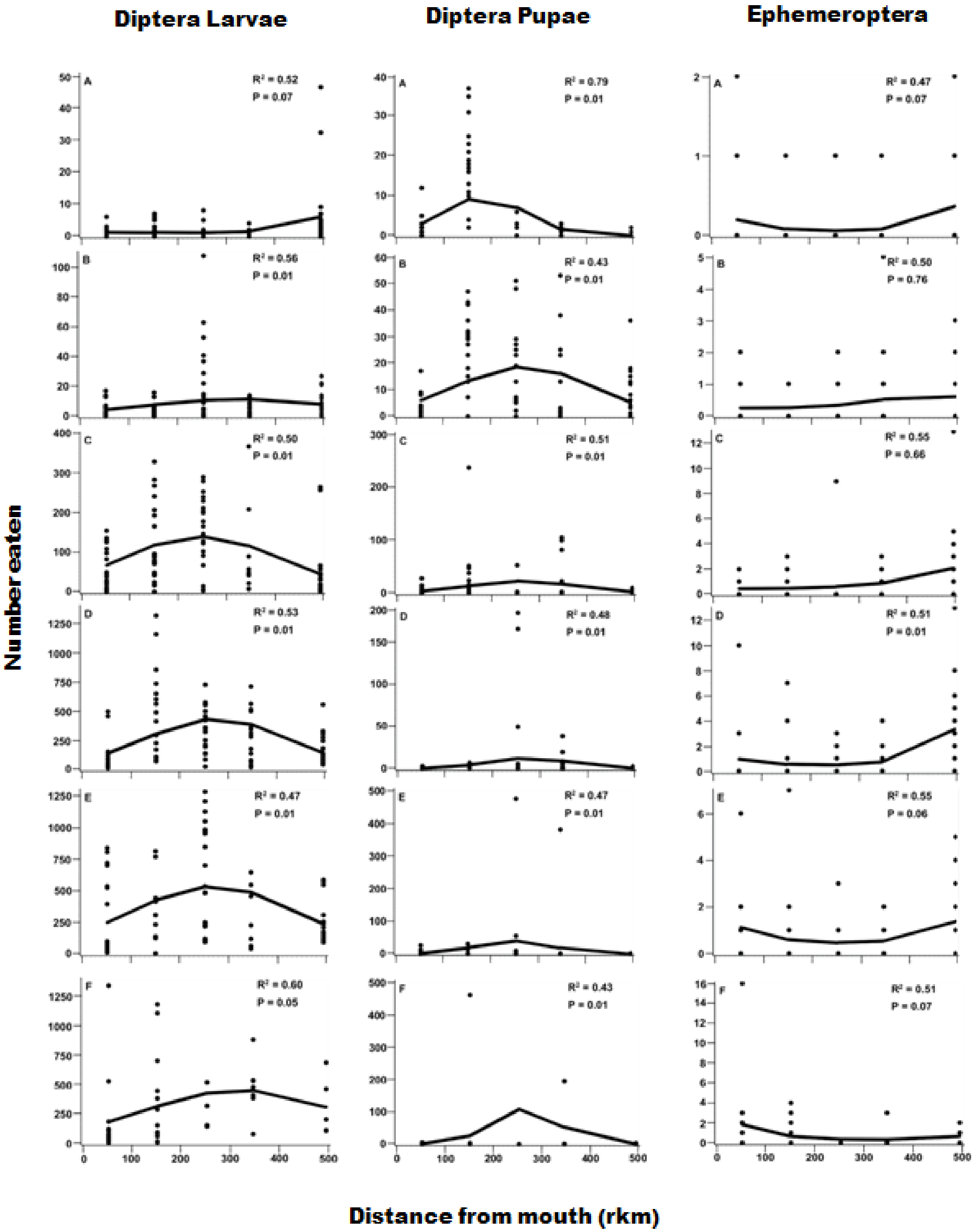


FIGURE 7. 2015 number eaten of three main macroinvertebrate prey types in relation to the distance from mouth (rkm). Letters A-F are length categories (0-20, 21-40, 41-60, 61-80, 81-100, 101-120mm)

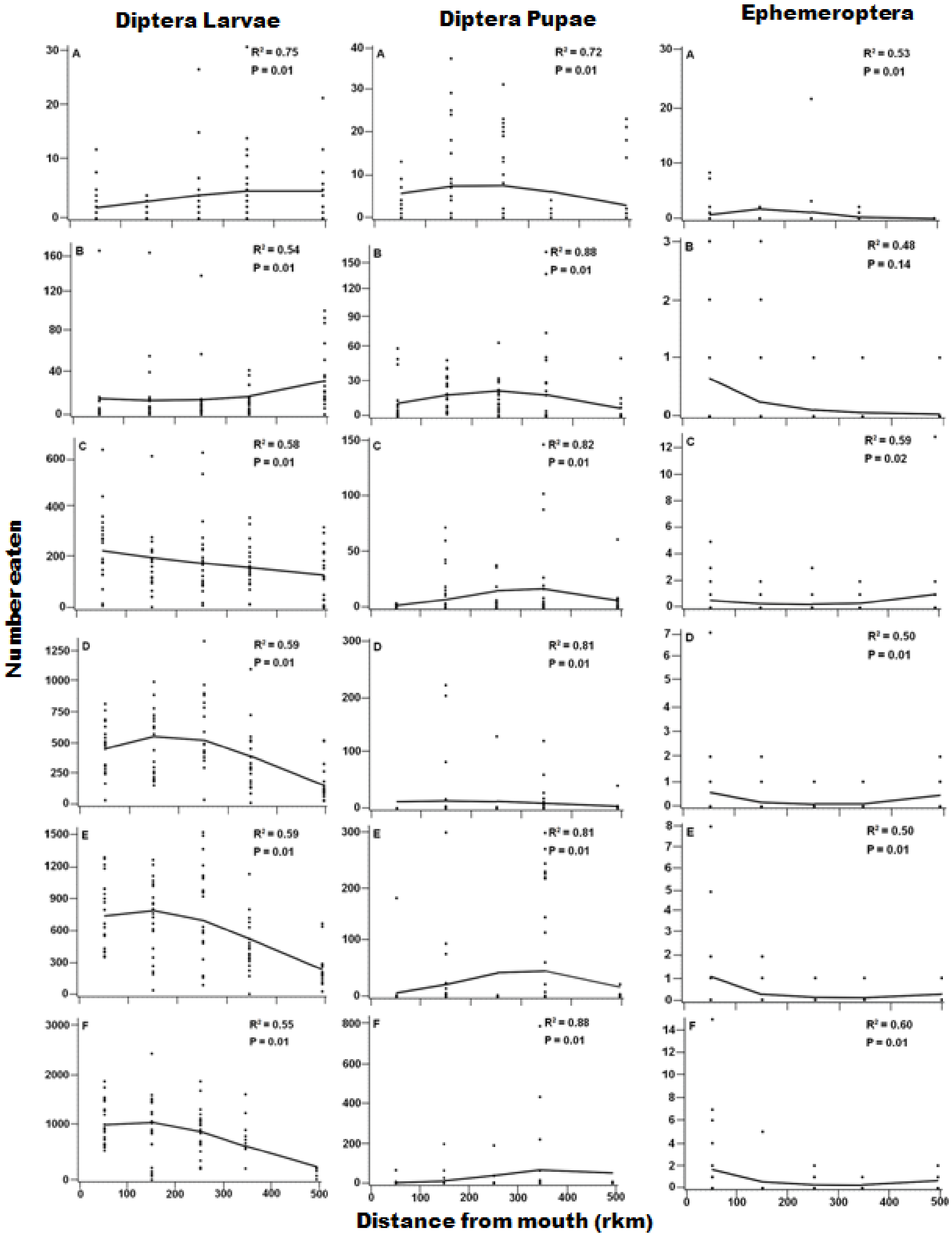


FIGURE 8. 2014 residual number eaten of three main macroinvertebrate prey types in relation to the amount of shallow-water habitat (ha). Letters A-F are length categories (0-20, 21-40, 41-60, 61-80, 81-100, 101-120mm)

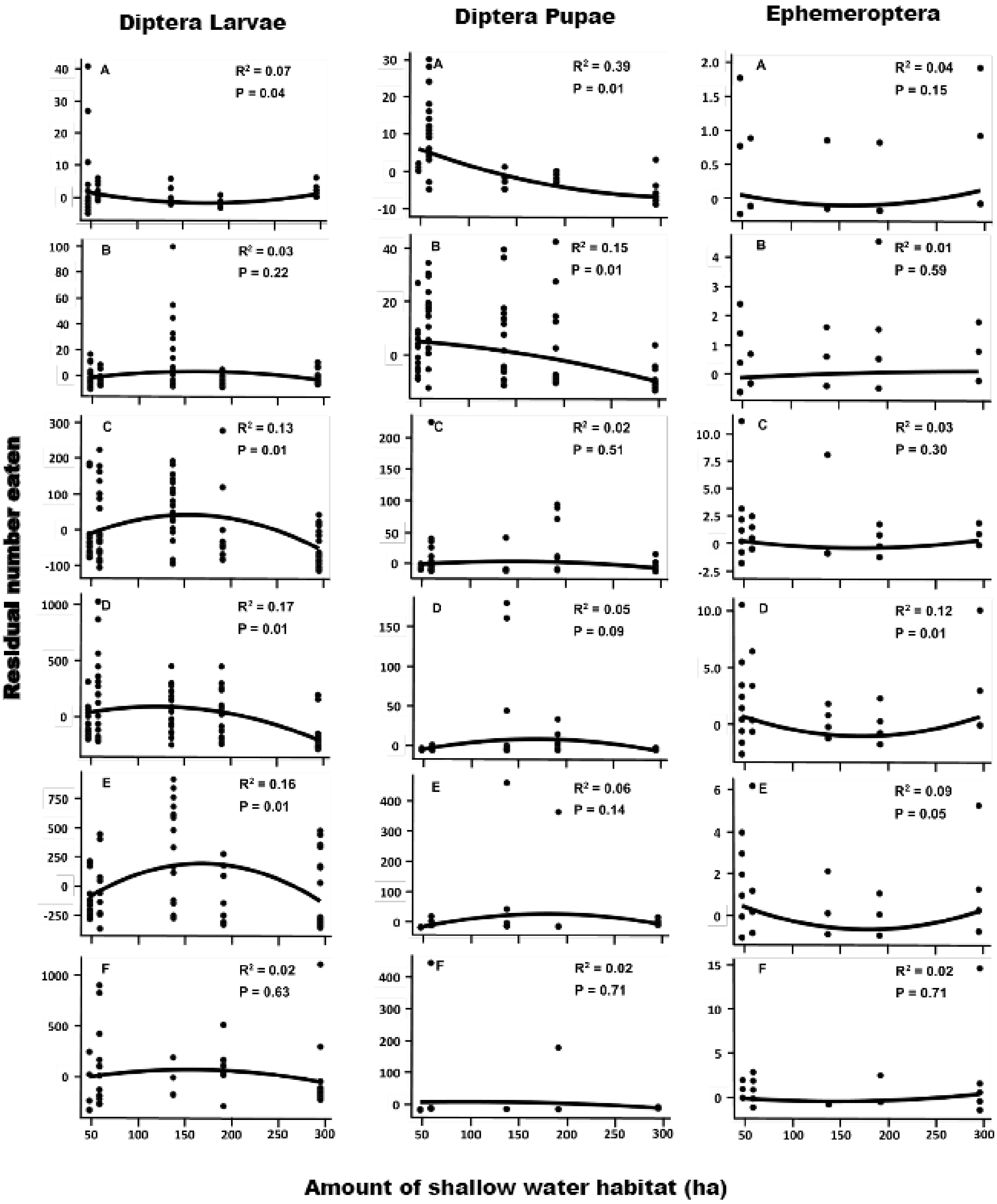


FIGURE 9. 2015 residual number eaten of three main macroinvertebrate prey types in relation to the amount of shallow-water habitat (ha). Letters A-F are length categories (0-20, 21-40, 41-60, 61-80, 81-100, 101-120mm).

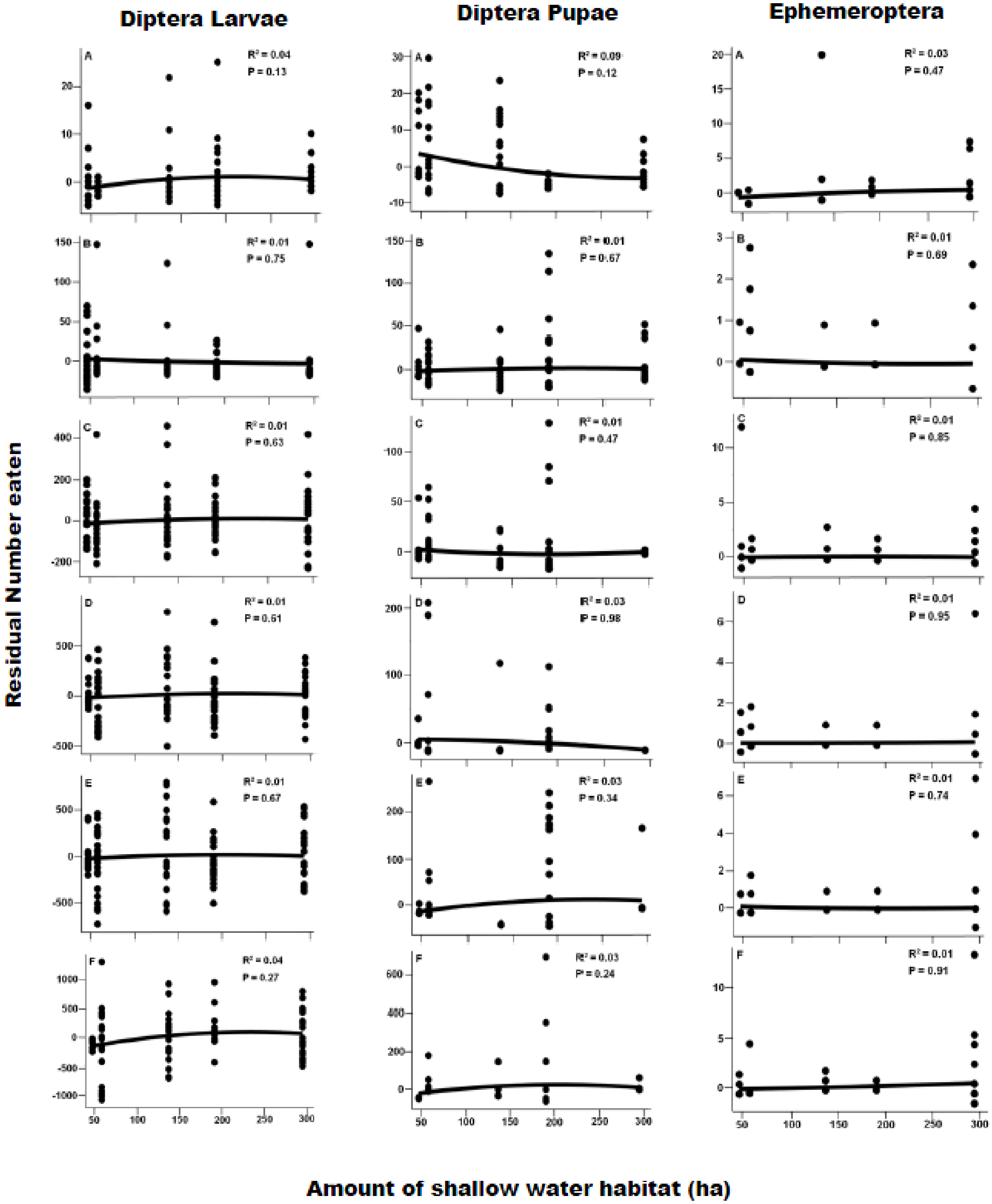


FIGURE 10. Exponential models of diptera larvae eaten by young-of-year shovelnose sturgeon as a function of length and age in five locations of the lower Missouri River in 2014. Numbers 1-5 are sample reach locations moving downstream to the mouth.

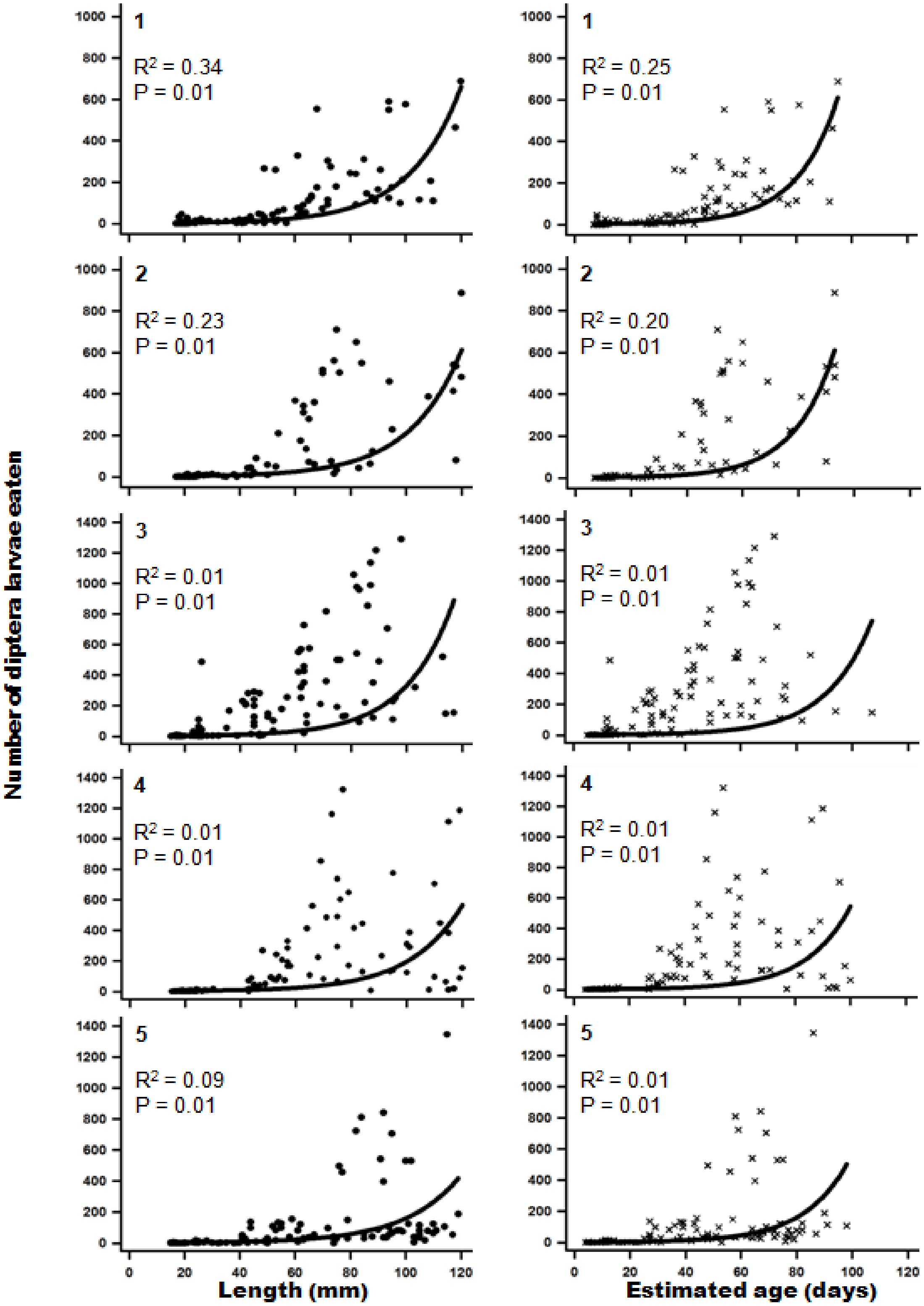


FIGURE 11. Exponential models of diptera larvae eaten by young-of-year shovelnose sturgeon as a function of length and age in five locations of the lower Missouri River in 2015. Numbers 1-5 are sample reach locations moving downstream to the mouth.

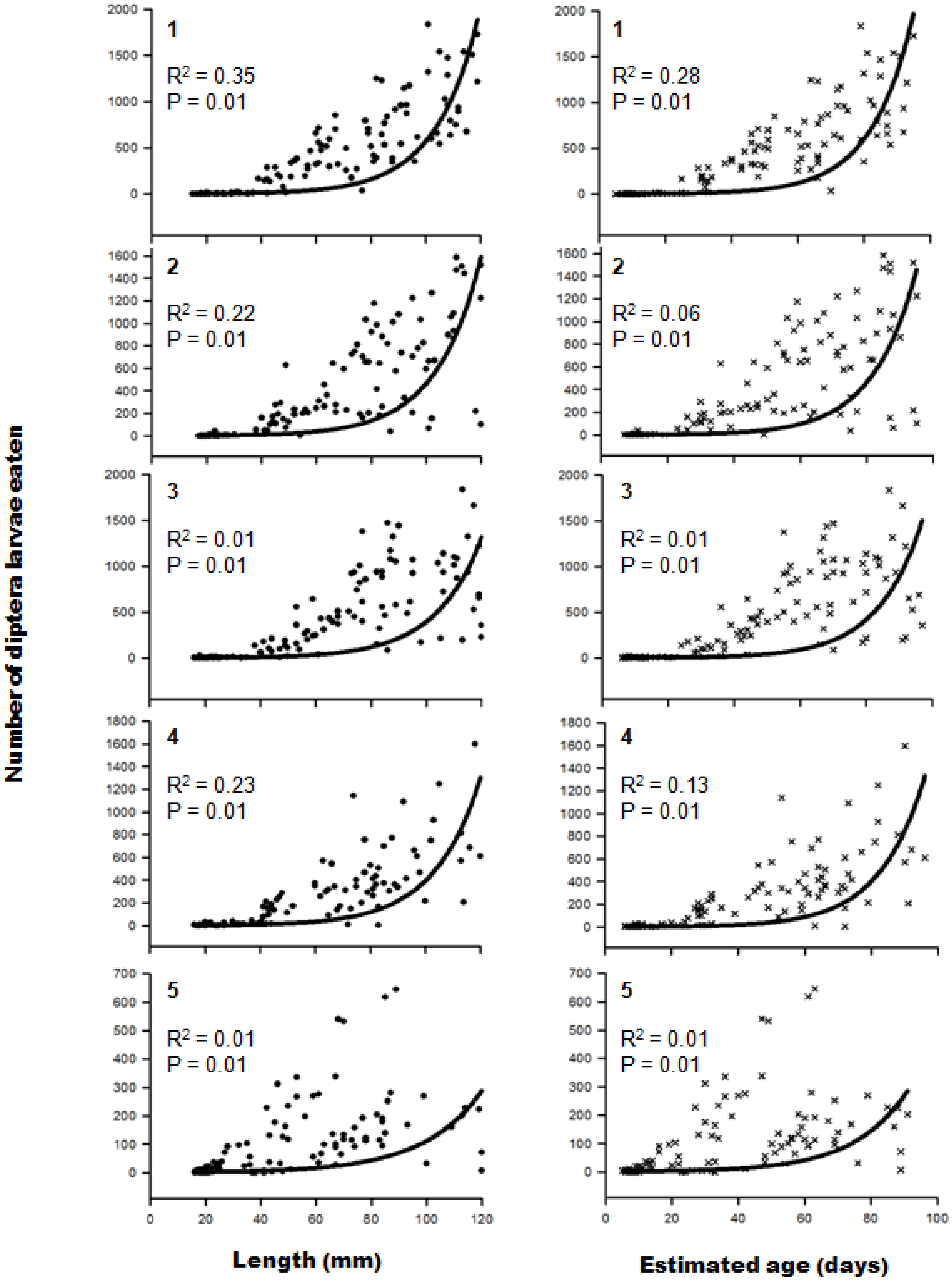


FIGURE 12. The slope values or rate of increase of diptera larvae eaten with ± 95% confidence intervals for both length and daily age of young-of-year shovelnose sturgeon from 2014 captured at 5 sample sites along the lower Missouri River

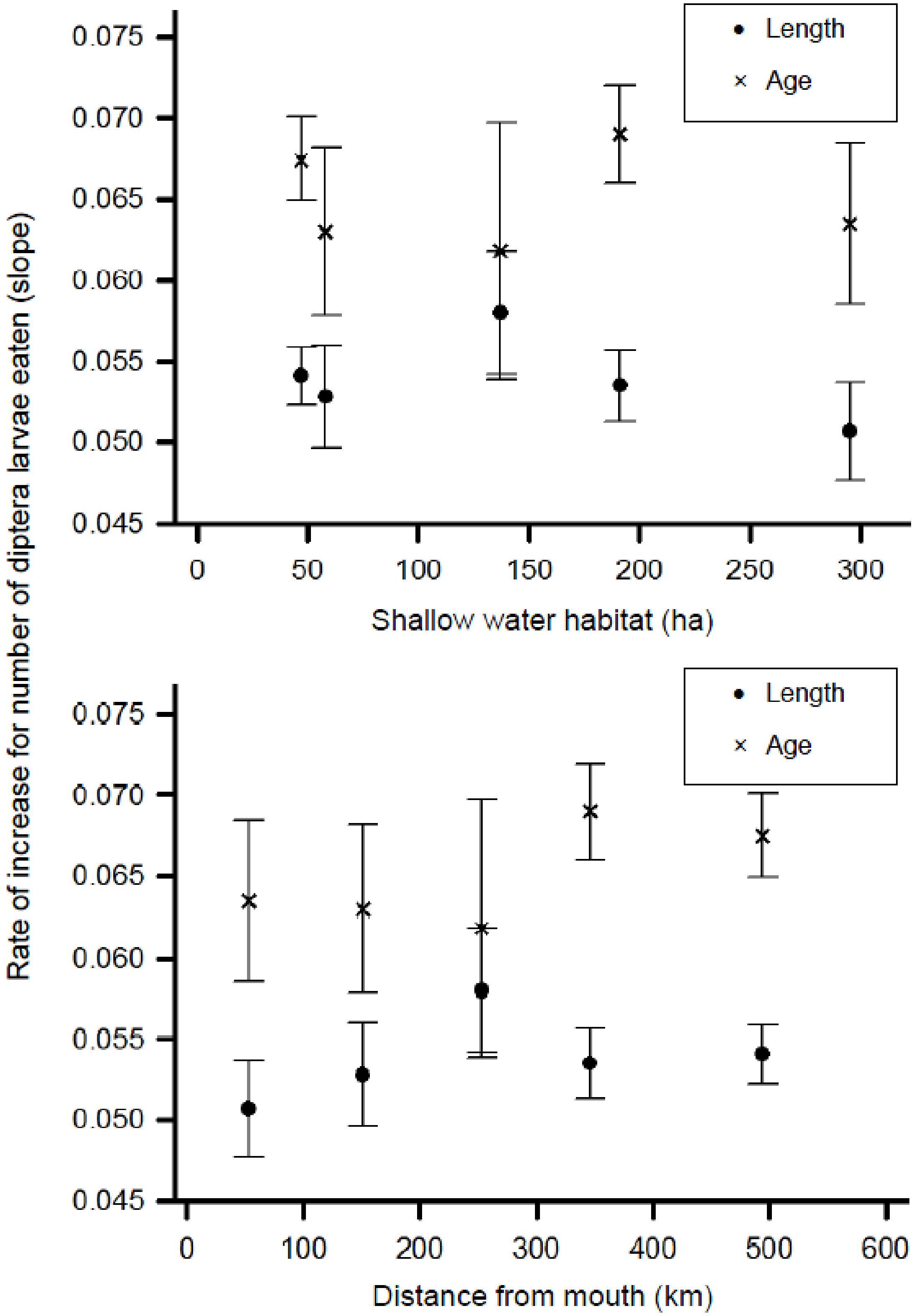
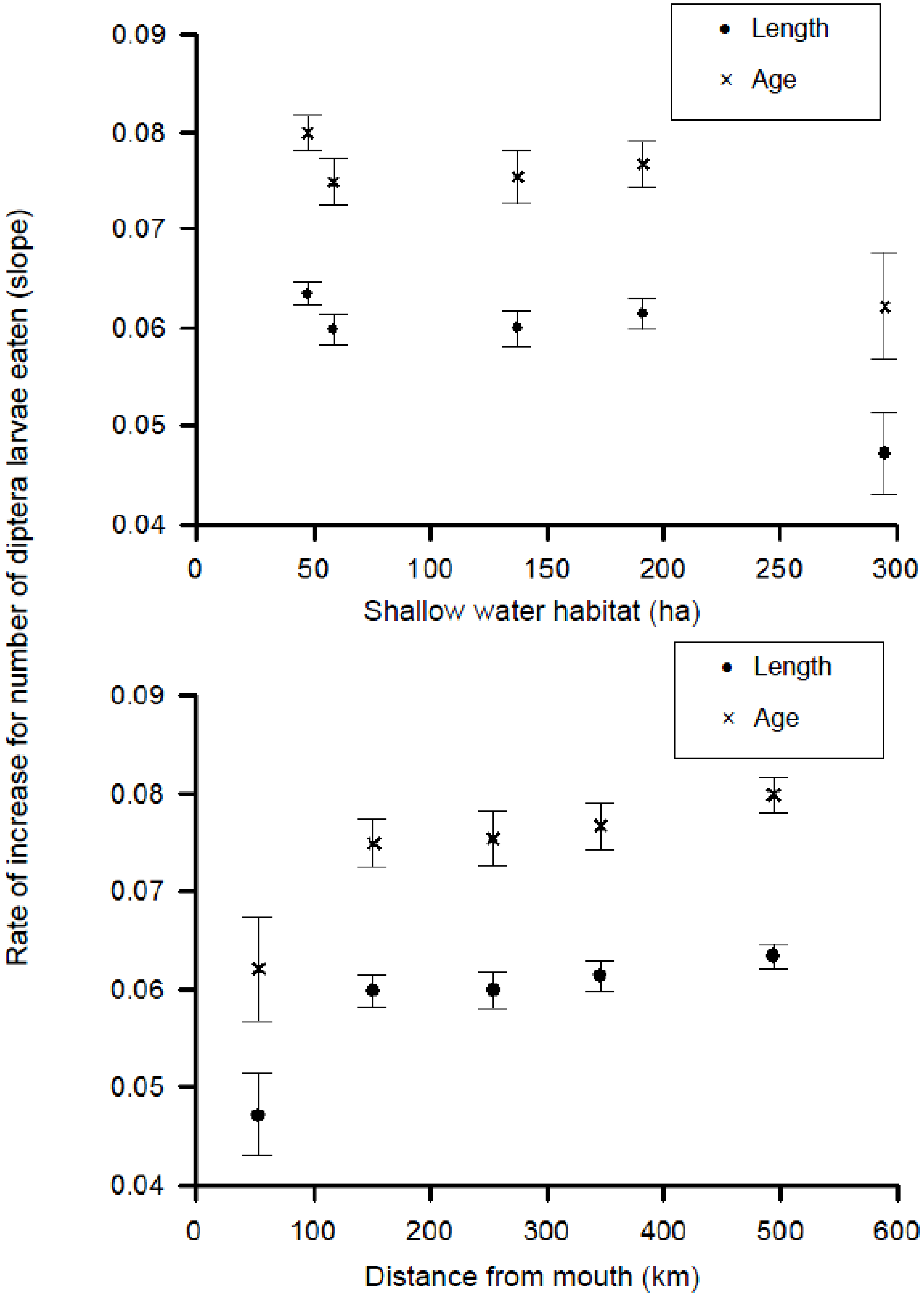


FIGURE 13. The slope values or rate of increase of diptera larvae eaten with ± 95% confidence intervals for both length and daily age of young-of-year shovelnose sturgeon from 2015 captured at 5 sample sites along the lower Missouri River



CHAPTER III

EFFECT OF HABITAT QUANTITY ON YOUNG-OF-YEAR SHOVELNOSE STURGEON CONDITION ALONG A LONGITUDINAL GRADIENT

Introduction

As early as 1832, there had been interest in channel modifications on the Missouri River for transportation of goods; mainly the removal of obstacles to ease passage of steamboats, finally made possible by the 1912 Bank Stabilization and Navigation Project. Further modified by the Rivers and Harbors Act of 1945, these acts congressionally authorized the U.S. Army Corps of Engineers (USACE) to maintain a navigation channel for commercial transport (USFWS, 2000). These anthropogenic influences have led to a loss of habitat diversity on the Missouri River (USFWS, 2000; USFWS, 2003), shifting from a meandering, shallow, turbid river into a channelized, deep, more clear waterway.

Channelization of the Missouri River has altered an estimated 1.2 M ha of natural river habitat, eliminated the reproduction of native cottonwood trees *Populus deltoids* in some areas, and reduced aquatic insect abundance by seventy percent (USACE, 2009). Furthermore, many native fish species have declined (NRC, 2011) and, in response, the U.S. Fish and Wildlife

Service issued a Biological Opinion (BiOp) on the USACE operation of the Missouri River to prevent jeopardy of threatened and endangered species. The Missouri River Recovery Program (MRRP) was created to implement the reasonable and prudent alternatives of the BiOp to restore the Missouri River to a semblance of its original dynamic riverscape and physical processes. Restoration activities are conducted in an adaptive management framework and include improving floodplain connectivity, constructing chutes or side channels, implementing a natural flow regime, and creating sandbar habitat (USFWS, 2000; USFWS, 2003).

One critical restoration goal of the MRRP is the reestablishment of shallow-water habitat (SWH). Shallow-water habitat is created by the modification of existing river control structures and construction of off-channel chutes. In a regulatory context, SWH is defined as water less than 1.5 m deep and a flow velocity less than 0.6 m/s (USACE, 2015b). Examples of SWH include backwaters, depositional sandbars detached from the bank, and low-lying depositional areas adjacent to shorelines (USFWS, 2003). Shallow-water habitat is critical for young and small-bodied fishes by providing low velocity nursery zones for growth and development (Schiemer *et al*., 2001). Shallow water may encourage increased forage opportunities for fishes by retaining higher rates of organic matter, phytoplankton, and zooplankton (Knowleton and Jones, 2000; Brown and Coon, 1994). Shallow water habitat also provides a refuge in the channelized areas of the river for growth and development of drifting larval fishes (Schiemer *et al*., 2001), particularly *Scaphirhynchus* sturgeon (pallid sturgeon *S. albus* and shovelnose sturgeon *S.platorynchus)*.

There is a hypothesized link between the creation of SWH and its influence on YOY sturgeon survival during the transition from the yolk sac to exogenous feeding during the first year of life (USFWS, 2000; USFWS 2003;Wildhaber *et al*., 2007). Fish survival or well-being is quantified by indices of condition that attempt to perceive growth rates, energy storage, reproductive potential, and overall fitness (Adams, 1999). On the lower Missouri River, prey quantity did not appear to be limited and factors beyond amounts of SWH appear to affecting prey use and ultimately survivorship by YOY shovelnose sturgeon (Chapter 2). Quantifying condition can also provide insight into characterizing the aquatic habitat, including prey availability, and whether the ecological and physiological processes are ideal for survival at the population scale (Pope and Kruse, 2007; Adams, 1999).

Condition is often measured mathematically with weight-length relationships (Anderson and Neumann,1996), but a more direct measure of physiological parameters, such as energy stores, yields a more accurate representation(Copeland *et al.*, 2008), especially for juvenile and YOY fish species (Patrick, 1992). Energy density of fish can be measured directly using a calorimeter (Sechler *et al*., 2012), but this method is expensive and tedious. Analysis of whole-lipid content is an alternative to energy density and is relatively inexpensive. Lipids represent the long-term storage of energy that fish need for basic metabolic needs as well as the vital energy needed to sustain during periods of low food intake (Adams, 1999). The quantity of lipids extracted allow for an indication of health to be quantified for many individuals, which can help evaluate population dynamics (Henderson and Tocher, 1987; Adams 1999).

With the restoration goal of creating SWH, there is an inherent hypothesis that an increase in SWH will increase production and retention of food sources leading to improved condition and survival of YOY shovelnose sturgeon. The objective of this study is to examine the influence SWH on the condition of YOY shovelnose sturgeon at a large spatial scale along a linear gradient of the lower Missouri River.

Methods

Study site. - The geographic extent of the SWH restoration includes the main-stem lower Missouri River and main-stem connected side channel chutes from Ponca, Nebraska to the confluence with the Mississippi River in Saint Louis, Missouri (USACE, 2015; Figure 1). The lower Missouri River is channelized by dikes and revetments constricting the thalweg and directing flow toward the middle of the river (Jacobson and Galat, 2006). Five reaches of the lower Missouri River between Kansas City and Saint Louis (Figure 1) that varied in amount of cumulative SWH (47 to 295 ha) were sampled bi-monthly from May through October in 2014 and 2015 when river conditions permitted.

Sampling Design. - Sampling was conducted by the U.S. Army Corps of Engineers (reach 1 and 2) and the U.S. Fish and Wildlife Service (reach 3, 4, and 5; Figure 1) using a bow-mounted or stern-mounted otter trawls (OTO4) in accordance with the Missouri River Standard Operating Procedures for Fish Sampling and Data Collection (Welker and Drobish, 2012). The OTO4 is a 4 mm mesh nylon net with a 4.88 m opening that is pulled with the river current along the riverbed and spread open by two, 91.4 cm by 38.1cm boards (a.k.a. doors). The OTO4 was used to catch YOY shovelnose sturgeon in benthic habitats between 1.5 and 5 m deep with a trawling distance from 75 to 300 m and between 1 and 1.5 m deep with a trawling distance from 15 to 150 meters. When three or more YOY shovelnose sturgeon were captured in a single trawl, an additional two trawls were conducted in the same location. If ten or more YOY shovelnose sturgeon were captured in either additional trawl, one duplicate trawl was conducted for a maximum of five trawls in the same location. Repeated sampling of habitats was necessary to achieve the desired sample size in each length category.

Captured YOY sturgeon were measured for fork length (FL) or total length (TL), depending on presence of the heterocercal tail filament. Young-of-year shovelnose sturgeon were kept at -18ºC and preserved in ethanol to minimize oxidative decomposition and slow deterioration. After each sampling season was complete, up to 20 YOY shovelnose sturgeon were randomly selected from each of the six separate length categories (0-20, 21-40, 41-60, 61-80, 81-100, 101-120 mm) for lipid content analysis (Table 1).

Condition quantification. - A broad measure of condition was obtained by performing a modified Folch lipid extraction that measures energy reserves within the tissue (Folch *et al.*, 1957). The Folch *et al.*(1957) extraction utilizes a 2:1 ratio of organic solvents (chloroform and methanol) to remove virtually all lipids from the specimen and is the preferred methodology for fish tissue (Cabrini *et al.*, 1992; Iverson *et al.*, 2001). The modification included the substitution of ethanol for methanol (J. Truschenski, University of Southern Illinois, personal communication), which was verified using pure vegetable oil (i.e., 100 percent lipid) with an average of 97.3 ± 1.7 percent recovery (n=16) of lipid material determined gravimetrically. After weighing, the specimen's body was kept in the original storage vial of ethanol to ensure all lipid content was retained. Individual specimens within each length category (Table 1) were homogenized separately and a 2:1 ratio of chloroform and ethanol was confirmed by adding chloroform to the original ethanol and then vortexed. The sample was placed into the freezer (-20ºC) for one hour and removed before adding 0.88g of 0.88% potassium chloride (KCl) aqueous wash to aide in phase separation. The sample was placed back in the freezer for five minutes then centrifuged at 1500 RPM for five minutes. The bottom layer of the partitioned mixture that contained the purified lipid was transferred through a sodium sulfate filter (to remove contaminating material) into an aluminum weigh pan and placed on a hot plate at medium heat until evaporation of the solvent was complete. Lipid content as a percentage of body weight was then determined gravimetrically (Folch *et al*., 1957).

To allow comparison to the YOY shovelnose sturgeon condition captured in the wild, I worked with biologists at the U.S. Geological Survey, Columbia Environmental Research Center (CERC) to raise two groups of YOY shovelnose sturgeon that were representative of healthy and starved groups (Table 1). Two hundred and forty hatchery-reared individuals were raised to similar size length categories as wild fish and fed ad libitum a diet of live *Artemia* sp. and *Lumbriculus* sp., frozen foods including *Artemia* sp. and *Chironomus* sp., and prepared rations of Otohime Fish Diet. One-half of the individuals were separated into a healthy 'control' group that were not isolated from food prior to collection and preservation. The other half were isolated from food until they became moribund or deceased, representing the 'emaciated' group. Hatchery specimens were obtained out under an animal care and use protocol developed and approved by CERC as part of other related sturgeon research. These two groups provided opposing levels of condition to compare with the YOY shovelnose sturgeon captured in the wild.

Statistical methods. - Linear regression was used to identify differences in lipid percentage from each length category in 2014 and 2015 in relation to the amount of SWH (ha) and distance from mouth (RKM). To separate the influence of location from SWH quantity, the residuals of the percent lipid for the RKM models were extracted and plotted against the amount of SWH (ha). Box plots of percent lipids for each sturgeon length category were used to compare years of wild-caught fish, control, and emaciated YOY. Two-way analysis of variance (ANOVA) and the arcsine square root transformation of YOY shovelnose sturgeon lipid percentage was used to determine statistical differences among length categories and group (sample year of wild-caught fish and the opposing condition levels of hatchery-reared fish). A Tukey's post-hoc test was used to determine the factors influencing the significant results in each treatment group. All statistical procedures were analyzed using SigmaPlot 12 statistical software.

Results

A total of 493 YOY sturgeon in 2014 and 537 YOY sturgeon in 2015 were used for lipid analysis, but not all length categories were represented by the goal of 20 individuals in each reach (Table 2). Genetic analysis confirmed that all YOY sturgeon used for this analysis were shovelnose sturgeon (E. Heist, Southern Illinois University, unpublished data). Of the six length categories, the ≤ 40mm YOY shovelnose sturgeon had the highest percent lipid (Figure 5). The control group consistently had a higher median percent lipid regardless of length (Figure 5). There was a statistically significant interaction between effects of length category and group (sample year of wild-caught fish, and hatchery-reared control or emaciated) on the lipid percentage of YOY shovelnose sturgeon ($F = 4.6$, $P = 0.01$). Tukey's post-hoc analysis indicated, for wild fish, YOY shovelnose sturgeon captured in 2014 had significantly lower average percent lipid than 2015 for all length categories >41mm (*P* $\leq$ 0.04). In 2014, the length categories >41mm were not statistically different from the emaciated specimens (*P* > 0.05). In 2015, only the 101-120mm length category significantly differed in lipid percentage from the control specimens (*P* = 0.01).

Models of lipid percentage as a function of SWH had low explanatory power ($r^2 \leq 0.07$) for each length category in 2014, but were comparatively higher in 2015 ($r^2 \leq 29$; Figure 2). In 2014, the smallest length category (0-21mm) showed a positive relationship with lipid percentage and amount of SWH while the large length categories (61-100mm) had a negative relationship with amount of SWH. In 2015, the one statistically significant model had a negative relationship exhibiting a decrease in condition as the amount of SWH increased (*P* = 0.01, $r^2 = 29$). The percent of individuals below the maximum starvation condition (shaded gradient) from each length category steadily increased in 2014 as the YOY shovelnose sturgeon length category increased (Table 4). In 2015, the percent of individuals below the maximum starvation condition stayed rather constant in the smaller three length categories and actually decreased as length categories increased (right column). The percent of individuals above the maximum control condition was higher in 2015 than in 2014 (left column).

The spatial variable of RKM had more statistically significant models in 2014 and 2015 than the SWH variable (Figure 3). In 2014, all but the smallest length category (0-21mm) exhibited an increase in percent lipid with increasing distance upstream ($r^2 \leq 0.27$). In 2015, the 61-80mm and 81-100mm length categories decreased in condition with increasing distance upstream, however, the relationships were comparatively weak ($r^2 = 0.08$).

The residual percent lipid in relation to amount of SWH exhibited few instances of significance (Figure 4). In 2014, the 41-60mm length category showed a significant and positive relationship in the residual percent lipid with SWH. Similar to the percent lipid analysis related to SWH, the smallest length category for both 2014 and 2015 had an increase in percent lipid as

SWH increased ($P \leq 0.03$, $r^2 \leq 0.08$). In addition, the 2015 statistically significant models had a negative relationship exhibiting a decrease in condition as the amount of SWH increased.

Discussion

The ability to quantify condition of YOY shovelnose sturgeon has provided the means to extend the period to which we can infer the health of year classes and the population as a whole. From this measurement of body condition, where lipids represent long-term energy storage, YOY shovelnose sturgeon in 2014 were similar to those starved of food. This is the most surprising result of the study due to the fact YOY shovelnose sturgeon that had consumed prey and were captured in the wild were in similar condition to the emaciated specimens raised in the laboratory. Based upon prey use alone, an adequate amount of prey was consumed in both sample years and in all sample reaches (Chapter 2). However, prey use doubled in 2015 which translated to condition levels above starvation levels, closer to well-fed control individuals. These results provide reference to how much prey improves condition in the wild and suggest interannual differences in hydrology (e.g., stage, discharge, water temperature) might affect condition.

Percent lipid decreased with increasing size, attributed to the transition from endogenous yolk-sac feeding to exogenous feeding (Gershanovich, 1991; Schiemer *et al*., 2002), suggesting that lipid percentage of larger-sized YOY shovelnose sturgeon are more indicative of habitat suitability. Furthermore, differences of 1-3 percent lipid content in these larger YOY shovelnose sturgeon, which appear minor, may be significant. The early life stages of large river fishes are most sensitive to environmental stressors (Schiemer *et al*., 2001) that could preclude YOY shovelnose sturgeon from finding, consuming and digesting prey. Habitats that promote foraging success and provide shelter are all important for maximizing allocation of energy from prey sources to lipid storage (i.e. better survival) (Adams, 1999). Shallow-water habitat was a poor variable affecting lipid concentration and often showed a negative trend, suggesting it has little influence on sturgeon body condition. Factors other than strict amounts of SWH appear to affect the percent lipid of YOY shovelnose sturgeon on the lower Missouri River, but which of the potentially other myriad of variables that may be important would require additional research.

Shallow-water habitat is measured for regulatory purposes at a medium August flow (USACE, 2014) and was fixed at that cumulative amount for analyses. In reality, the amount of SWH fluctuates over time; by annual releases from reservoirs through dams as well as rainfall and snowmelt through tributaries that change temperature and discharge in the river seasonally. The lower Missouri River historically had more SWH overall (USFWS, 2000; USFWS, 20003); however, under currently modified river conditions, SWH is believed to be maximized during extremely low flows (Jacobson and Galat, 2006). Abiotic influences on aquatic habitats such as water velocity as well as temperature (Deslauries *et al.*, 2016; Heironimus, 2014) can dictate YOY shovelnose sturgeon condition. In 2015, the relationships between prey use and body condition with SWH were more evident; suggesting that SWH was more important when it was less abundant. Anthropogenic influences, such as channelization on the lower Missouri River, have altered the temperature regime, benthic habitats, and water velocity in which sturgeon species have had to adapt to survive (USFWS, 2003; Bergman *et al.*. 2008). However, SWH by its current definition does not appear to affect body condition to a large degree, but variables related to location along the river continuum appear to be important. Research from reaches farther upstream in the lower Missouri River would help better understand the role that location might play in the early life stages of river sturgeon.

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TABLE 1. Goal set for the number of individuals to be sampled within five reaches on the lower Missouri River and for specimens received from USGS Columbia Environmental Research Center (Emaciated (E) and Control (C)).

Length Category	**Number of Individuals**	**Reaches**	**Standard Groups**
0 – 20 mm	20	All (1-5)	E + C
21 – 40 mm	20	All (1-5)	E + C
41 – 60 mm	20	All (1-5)	E + C
61 – 80 mm	20	All (1-5)	E + C
81 – 100 mm	20	All (1-5)	E + C
101 – 120 mm	20	All (1-5)	E + C
Total	120	600	240

TABLE 2. A description of each sample site including the length, cumulative amount of shallow-water habitat, approximate location of USGS water gauge location used to gather data, average water temperature by water year, and annual discharge for 2014 and 2015. (* incomplete data available).

	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
Distance from mouth (river kilometer)	494 – 526	346 – 381	253 – 290	151 – 177	53 - 87
Amount of shallow-water habitat (hectares)	47	191	137	58	295
Approximate water gauge location	Kansas City, MO	Glasgow, MO	Jefferson City, MO	Hermann, MO	Saint Charles, MO
2014 Annual water temperature (Celsius)	15.62	14.24	13.94	15.95	22.91*
2015 Annual water temperature (Celsius)	13.34	16.67	14.49	14.61	15.61
2014 Annual discharge (cubic meters/second)	1378	1561	1631	1770	1879
2015 Annual discharge (cubic meters/second)	1872	2275	2401	2877	3194

TABLE 3. Values are means and standard errors for percent lipid of each length category from each treatment group. Means in a row without a common superscript letter differ ($P < 0.05$) as analyzed by two-way ANOVA and the TUKEY post-hoc test.

Length Category	Control	2014	2015	Emaciated
1	12.9 ± 0.8^{a}	13.3 ± 0.3^{a}	11.8 ± 0.3^{a}	6.7 ± 0.8^{b}
2	5.4 ± 0.8^{a}	4.9 ± 0.3^{a}	4.6 ± 0.4^{a}	2.1 ± 0.9^{b}
3	3.3 ± 0.8^{a}	1.5 ± 0.4^{b}	2.2 ± 0.4^{ac}	1.6 ± 0.9^{bc}
4	2.5 ± 0.8^{ab}	1.6 ± 0.4^{a}	2.3 ± 0.3^{b}	1.4 ± 0.8^{ab}
5	3.2 ± 0.8^{a}	1.5 ± 0.4^{b}	2.1 ± 0.4^{a}	1.3 ± 0.8^{ab}
6	3.8 ± 0.8^{a}	1.1 ± 0.5^{b}	2.3 ± 0.4^{c}	1.2 ± 0.9^{bc}

TABLE 4. Percent of each length category that falls above the minimum control percent lipid and under the maximum emaciated percent lipid by year.

		Length Category					
		1	2	3	4	5	6
Control	2014	76.3	57.0	6.5	27.5	18.8	2.1
	2015	76.5	65.2	18.6	51.0	39.9	21.1
Emaciated	2014	42.3	43.4	69.9	60.0	53.6	80.9
	2015	44.9	34.8	44.2	20.4	14.1	11.3

FIGURE 1. Map of the lower Missouri River including sample reach and approximate stream gauge location (red dot).

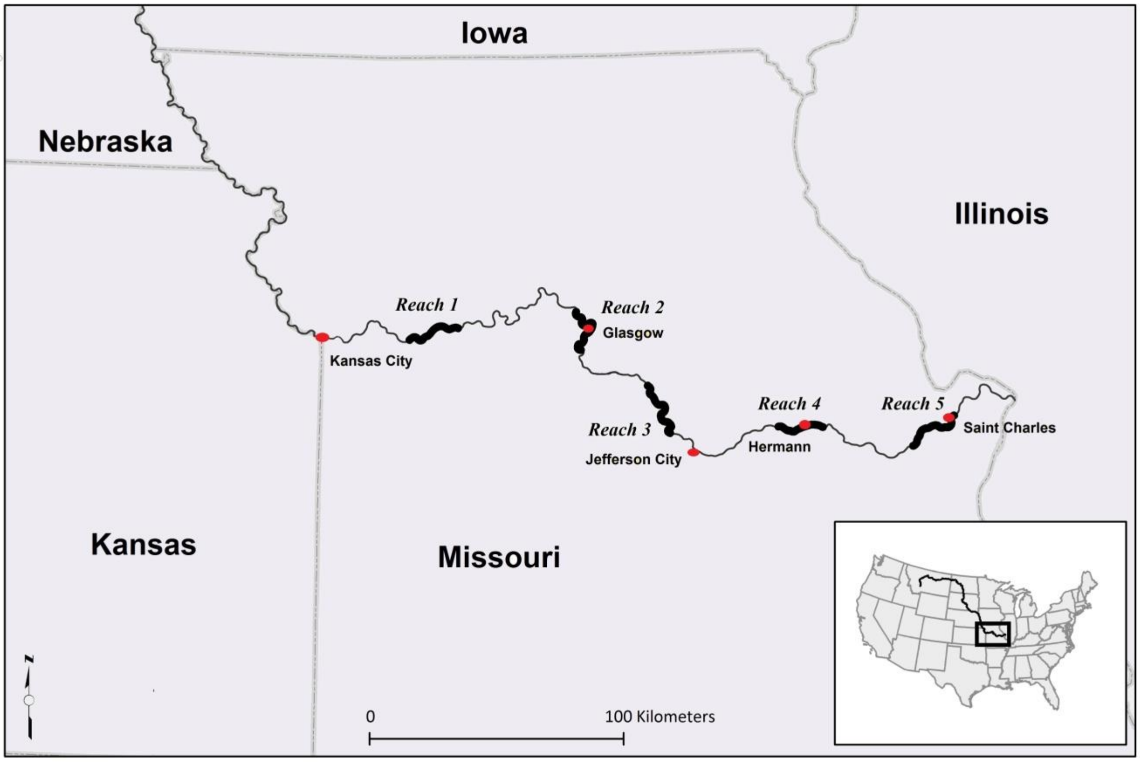


Figure 1: Map of the lower Missouri River including sample reach and approximate stream gauge location.

FIGURE 2. Influence of the amount of SWH (ha) on the percent lipid on six length categories increasing in length from the top to bottom (0-20, 21-40, 41-60, 61-80, 81-100, 101-120) in 2014 and 2015. Emaciated average lipid percentage is depicted by the dashed line and the gradient in color increases in darkness as you move from the maximum to the minimum percent lipid of emaciated YOY shovelnose sturgeon.

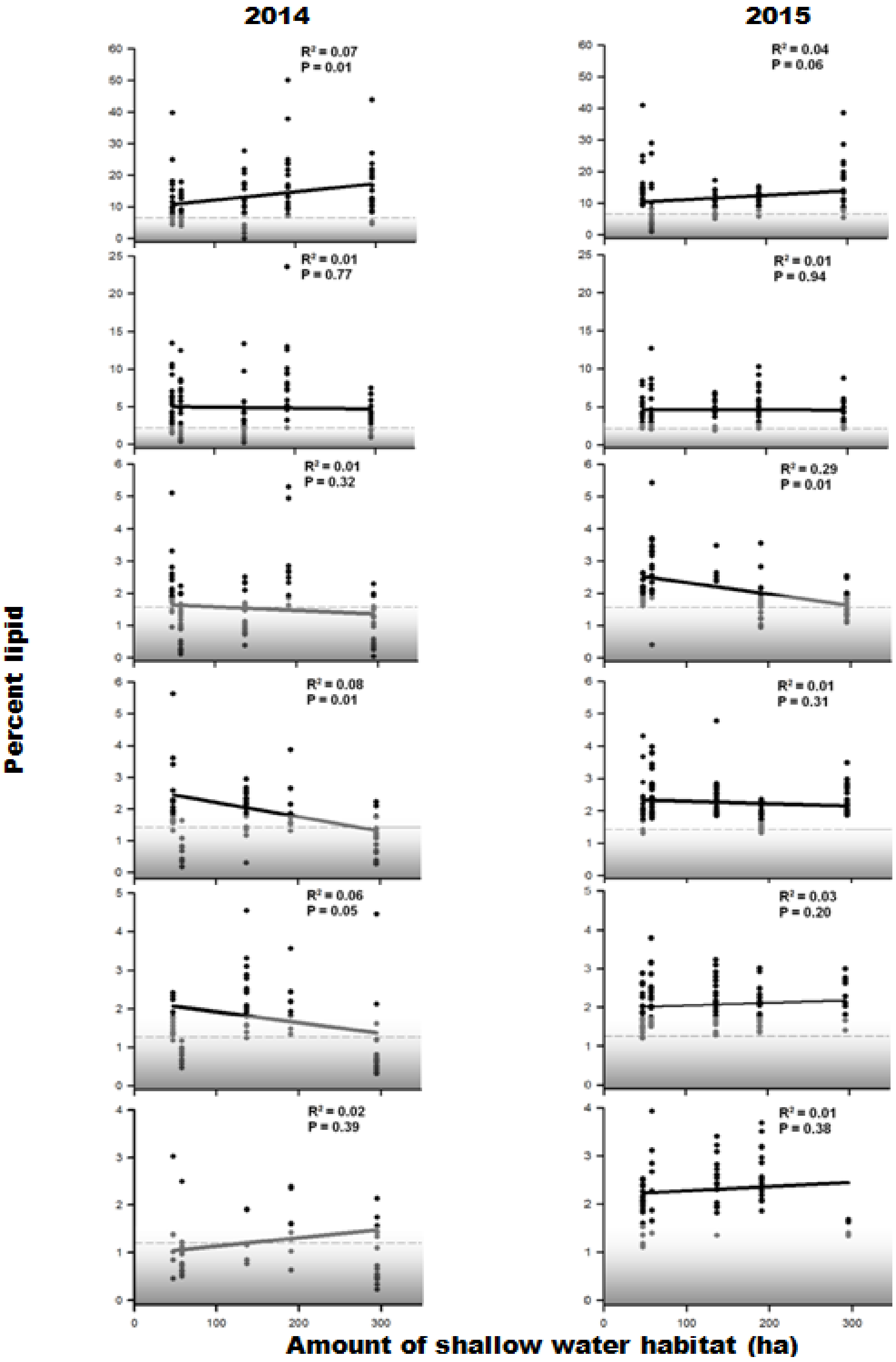


FIGURE 3. Influence of distance from mouth (rkm) on the percent lipid on six length categories increasing in length from the top to bottom (0-20, 21-40, 41-60, 61-80, 81-100, 101-120) in 2014 and 2015. Emaciated average lipid percentage is depicted by the dashed line and the gradient in color increases in darkness as you move from the maximum to the minimum percent lipid of emaciated YOY shovelnose sturgeon.

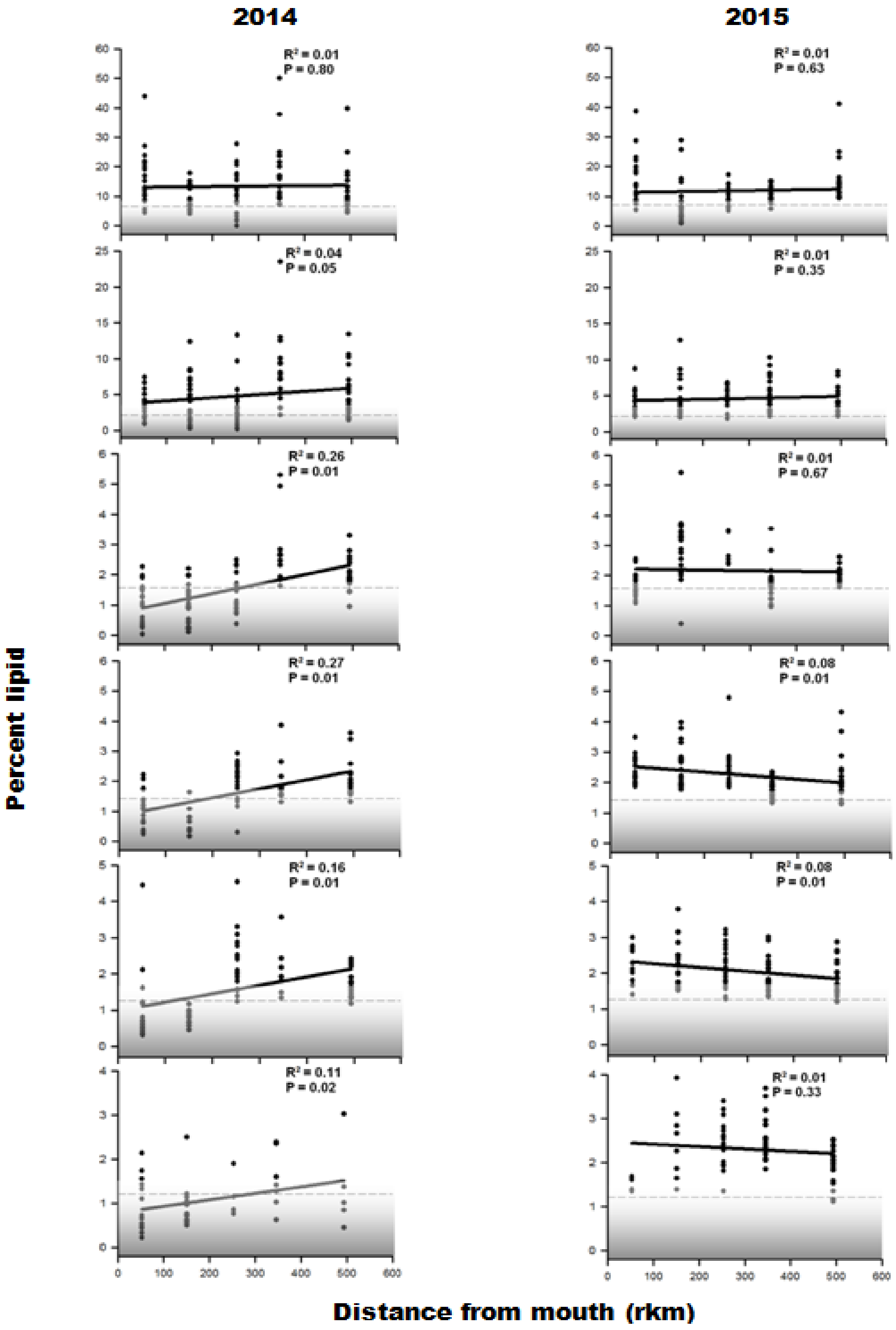
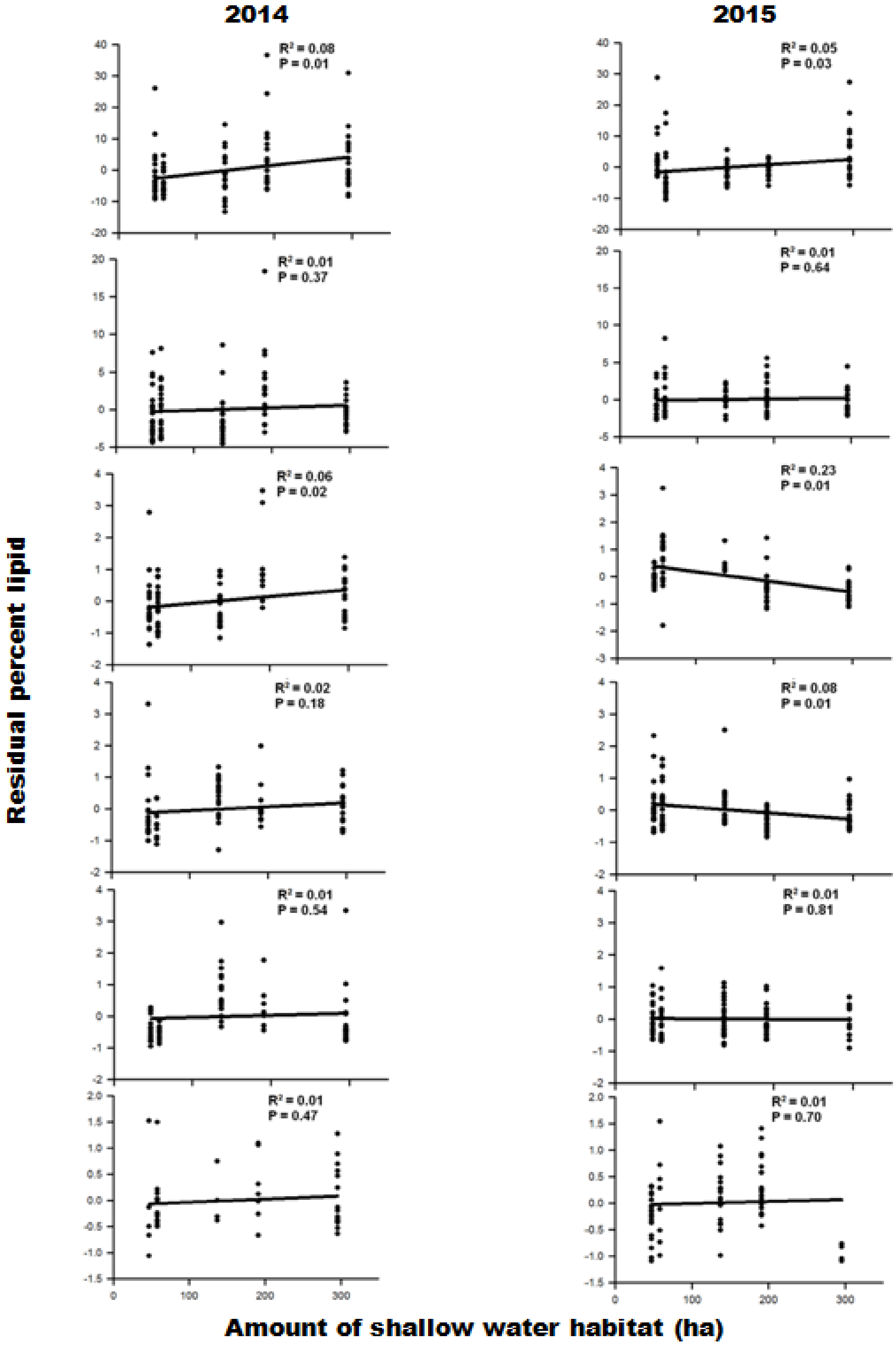
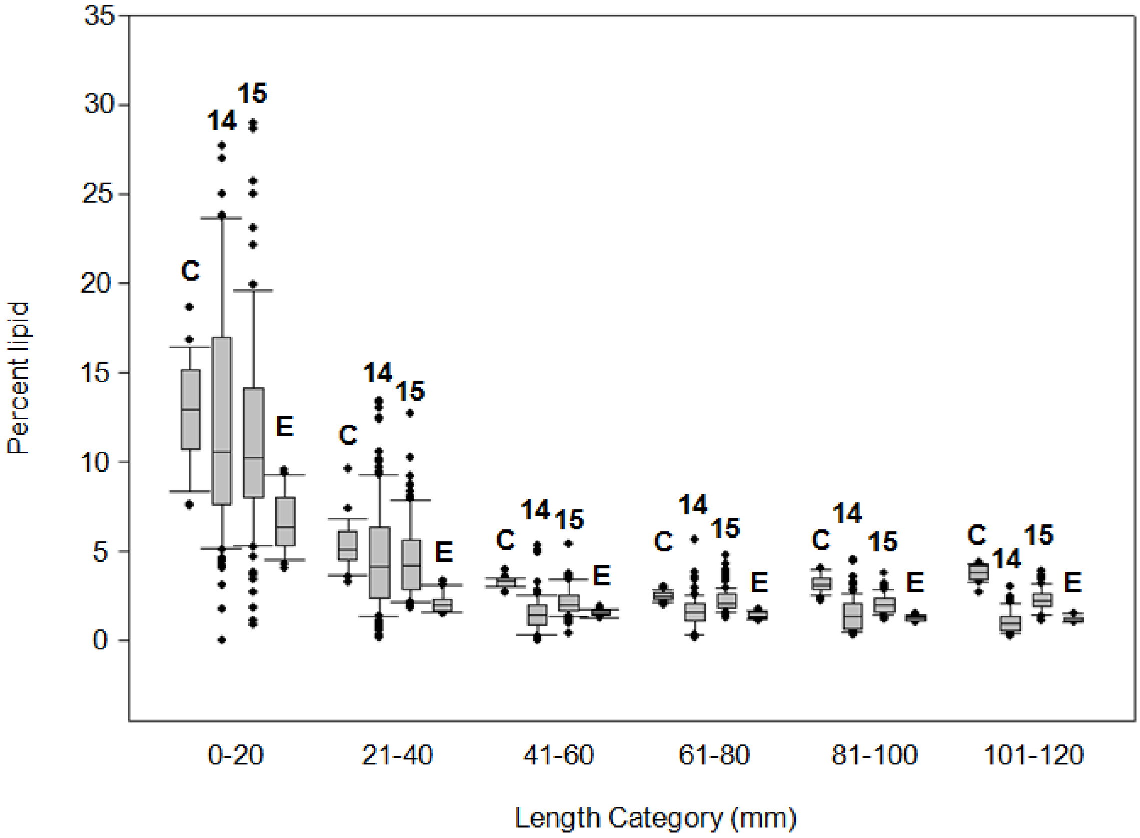


FIGURE 4. Influence of the amount of SWH (ha) on the residual percent lipid of six length categories increasing in length from the top to bottom (0-20, 21-40, 41-60, 61-80, 81-100, 101-120) in 2014 and 2015.



Box plots of percent lipid by length category. The letter or number above each box designates the group Control (C), 2014 (14), 2015 (15), Emaciated (E).



VITA

Anthony P. Civiello

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF SHALLOW-WATER HABITAT QUANTITY ON YOUNG-OF-YEAR SHOVELNOSE STURGEON PREY USE AND CONDITION ALONG A LONGITUDINAL GRADIENT

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