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Demographics and Seasonal Diet Composition of Shovelnose Sturgeon (Scaphirhynchus platorynchus Rafinesque) in Wabash River

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DEMOGRAPHICS AND SEASONAL DIET COMPOSITION OF SHOVELNOSE

STURGEON (*SCAPHIRHYNCHUS PLATORYNCHUS* RAFINESQUE) IN WABASH RIVER

(TITLE)

BY

VASKAR NEPAL KC

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ABSTRACT

Shovelnose sturgeon *Schaphirhynchus platorynchus* Rafinesque, one of the only sturgeon species that support a sustainable commercial harvest, are fished in a substantial caviar fishery in the lower Wabash River. However, ecological information on the population is sparse. In this thesis, I present information on the status and seasonal diet characteristics of the population. A 14-year long shovelnose sturgeon monitoring survey conducted by Illinois Department of Natural Resources shows that the population is in relatively good condition, faces low mortality rates, and has a high potential for recruitment. Study of the seasonal composition of diet suggests that shovelnose sturgeon generally get enough food throughout the year, and are thus, in good condition. I found that shovelnose sturgeon are opportunistic benthic invertivores, with Hydropsychidae and Chironomidae as the staple prey taxa for the fish. However, the sex-ratio of the population is highly male-biased, and the proportion of memorable-size fish is decreasing, likely due to the ongoing commercial harvest of ripe-and-running females. This poses potential problems regarding the sustainability of this fishery, and thus, management policies should be conservative until more information on optimal harvest of this fish is available.

Key Words: shovelnose sturgeon, lower Wabash River, demographics, diet, harvest

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INTRODUCTION

Shovelnose sturgeon (*Scaphirhynchus platorynchus* Rafinesque), the smallest and most abundant sturgeon species in North America, is native to the Mississippi and Missouri River drainages (Bailey and Cross 1954, Lee et al. 1980, Pflieger 1997). Typically this potamodromous species is less than 1 meter in length and 3 kg in weight (Pfleiger 1997). Shovelnose sturgeon are usually associated with deep, main channel habitats. However they are not uniformly distributed within the river channel and may show seasonal differences in habitat use (Quist and Guy 1999, Quist et al. 1999). Spawning habitat of shovelnose sturgeon is not well described, but it is believed that spawning occurs in tributary streams or along the borders of main river channels over hard bottoms (Keenlyne 1997, Wilson and McKinley 2005). Mark-recapture studies suggest that shovelnose sturgeon individuals tend to move randomly and multi-directionally, usually over short distances, throughout the river (Moos 1978). Shovelnose sturgeon are largely opportunistic benthic invertivores, feeding on a wide range of prey, including aquatic invertebrates and larval fish (Modde and Schmulbach 1977, Berry 2002, Bock et al. 2011).

Since the 1860s, many species of sturgeons have been harvsted extensively for both caviar and meat for international markets (Boreman 1997, Wilson and McKinley 2005). Overharvesting and habitat loss have caused most sturgeon stocks to be overexploited resulting in a collapse of sturgeon fisheries across the world (Birstein 1993, Boreman 1997, Keenlyne 1997, Quist et al. 2002, Wilson and McKinley 2005, Colombo et al. 2007a, Tripp et al. 2009). These population declines of several sturgeon species in

Europe, and particularly, the decline in populations of lake sturgeon *Acipenser fulvescens* in North America has caused restrictions on international trade in sturgeon products (Raymakers 2002, Pala 2005). Thus, the harvest pressure has shifted towards shovelnose sturgeon (Keenlyne 1997, Quist et al. 2002, Colombo et al. 2007a), which has traditionally been among the least desirable species of North American sturgeons because of its small size. In fact, they were often discarded or even destroyed by some fishermen (Coker 1930). However, today the shovelnose sturgeon is one of the few species that support a viable commercial harvest (Keenlyne 1997, Quist et al. 2002, Colombo et al. 2007b).

Similar to other species of sturgeons, increased exploitation of shovelnose sturgeon has reduced both its range and population size (Keenlyne 1997, Colombo et al. 2007a). Moreover, pallid sturgeon (*S. albus*), a federally endangered species is frequently harvested as bycatch when harvesting shovelnose sturgeon, since the two species are morphometrically similar and sympatric in most of the Mississippi and Missouri River basins (Colombo et al. 2007a, Bettolli et al. 2009, U.S. Fish and Wildlife Service 2010). To protect the pallid sturgeon, the U.S. Fish and Wildlife Service (2010) enacted a law that prevents the harvest of shovelnose sturgeon in areas where it coexists with the pallid sturgeon. This may cause an increase in the harvest pressure in river systems that only contain shovelnose sturgeon (Hintz and Garvey 2012). Shovelnose populations in these rivers need to be constantly monitored to prevent overexploitation.

Shovelnose sturgeon in the Wabash River, under joint jurisdiction of Illinois and Indiana Departments of Natural Resources, are currently being harvested as part of a commercial caviar fishery. The fishery targets only gravid females for the collection of roe. This population is now likely facing increased harvest pressure, yet little is known about its demographics. In 2000, the Illinois Department of Natural Resources started a multi-year mark-recapture survey of shovelnose sturgeon population with the primary objective being to monitor the population. So far, more than 10,000 individuals have been tagged, but information on the population has not been disseminated. Additionally, the Indiana Department of Natural Resources collected shovelnose sturgeon diet samples from the Wabash in 2013 as part of their shovelnose survey. In this thesis, I attempt to describe the population characteristics and seasonal diet composition of shovelnose sturgeon in the Wabash River using these data.

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POPULATION CHARACTERISTICS OF SHOVELNOSE STURGEON IN THE LOWER WABASH RIVER, ILLINOIS

ABSTRACT

Shovelnose sturgeon (*Scaphirhynchus platorynchus*) are one of the few remaining commercially viable sturgeon species. However, habitat destruction and exploitation have caused substantial decreases in the population sizes of this species. Little information is available for shovelnose populations outside of the Mississippi and Missouri Rivers. I studied the demographics of a commercially-exploited shovelnose sturgeon population in the lower 322 km of the Wabash River. During 2001-2013, 10,734 shovelnose sturgeon were captured using dc and ac electrofishing, gill nets, hoopnets, trotlines and benthic trawls. Of these, 399 individuals were recaptured. Electrofishing catch per unit effort was the highest reported for shovelnose sturgeon. Further, relative density of the fish increased over the past decade. Shovelnose sturgeon ranged between 61 and 909 mm fork length (mean 662 ± 0.74 mm, median 671 mm); however relatively few fish less than 500 mm were collected. Although shovelnose were in good condition (Wr = 89.9 ± 0.11), there was a decreasing trend in mean condition over time. Shovelnose sturgeon ranged from ages 0 to 25, with 90% of the fish between ages 8 and 19. This species fully recruited to sampling gear at age 10, and total annual mortality for fish older than 10 was 20.6%. An empirical growth rate of 2.67 mm/year was observed for fish larger than 635 mm, with several fish showing negative growth. In general, shovelnose population in the lower Wabash River is healthy and stable, and has characteristics comparable to the upper Wabash River, with slow growth, large sizes, good condition, and low mortality.

INTRODUCTION

Sturgeons (family Acipenseridae) are among the most threatened families of fishes (Ludwig et al. 2002; Pikitch et al. 2005; IUCN 2010). These fishes grow slowly, mature late, and most of them do not spawn annually (Bemis and Knyard 1997). Because of these life history traits, sturgeon are highly vulnerable to anthropogenic influences, especially harvest (Boreman 1997; Wilson and McKinley 2005). Worldwide, sturgeon populations have declined due to both overharvesting and habitat loss (Birstein 1993; Boreman 1997; Keenlyne 1997; Quist et al. 2002; Wilson and McKinley 2005; Colombo et al. 2007a; Tripp et al. 2009a). With the decline in large-bodied sturgeon species harvest pressure has shifted towards the smaller-bodied shovelnose sturgeon, *Scaphirhynchus platorynchus* Rafinesque (Morrow et al. 1998; Quist et al. 2002; Pikitch et al. 2005; Colombo et al. 2007a).

Shovelnose Sturgeon, currently the most abundant sturgeon species in North America, is native to the Mississippi and Missouri River drainages (Bailey and Cross 1954; Lee et al. 1980; Pflieger 1997). Though shovelnose sturgeon support a commercial fishery in eight states and a recreational fishery in 13 states (Koch and Quist 2010), increased exploitation of this species has caused substantial declines in its range and population size (Coker 1930; Carufel 1953; Hesse and Carreiro 1997; Keenlyne 1997; Colombo et al. 2007a). To protect the federally-endangered pallid sturgeon, *S. albus*, the U.S. Fish and Wildlife Service (2010) restricted the harvest of shovelnose sturgeon in most of Mississippi and Missouri Rivers. Such site-limited protection of the commercially important fish may increase exploitation in unprotected river reaches, such as the Wabash River (Hintz and Garvey 2012). Thus, there is a growing need to monitor shovelnose populations in areas where harvest is still allowed.

The Wabash River, a large tributary of the Ohio River, currently supports a substantial population of shovelnose sturgeon. This is a unique river system because the lower 764 km of this river are unimpounded, making it the largest free-flowing river east of the Mississippi River. As such, the ecological structure and function of the river remains relatively intact compared to other larger rivers in Illinois (i.e. Illinois, Mississippi, etc.). The lower 322 km of the Wabash, under the joint jurisdiction of the Illinois Department of Natural Resources (IDNR) and Indiana Department of Natural Resources (INDNR) supports an active shovelnose sturgeon fishery. Of all the states that allow commercial harvest of shovelnose sturgeon, Illinois has the longest harvest season (1 October to 31 May), and the most licensed commercial shovelnose sturgeon harvesters (95 shovelnose roe taker permits for the state, 35 for the Wabash in 2013). Several studies have been conducted on shovelnose sturgeon in the middle or upper portion of Wabash River where little harvest occurs (e.g. Kennedy et al. 2006, 2007; Kennedy and Sutton 2007; Bock et al. 2011). However, no demographic information on shovelnose sturgeon in the most heavily exploited portion of the river currently exists.

In this paper, I assess the population characteristics of shovelnose sturgeon in the lower Wabash River (LWR). Specifically, I tried to assess size and age structures, gender ratio, growth, mortality, and movement of shovelnose in the LWR. Additionally, I also present information on tag retention rates for different tags used in tagging shovelnose sturgeon. I studied whether the restriction of shovelnose harvest in the Mississippi has negatively affected the shovelnose population in the Wabash. This study provides essential information on demographics of this population, and lays the groundwork for studies on optimal harvest of the fish in the LWR.

METHODS

Sampling

During 2000, IDNR began a mark–recapture study of the shovelnose sturgeon population in the LWR. Several types of gears were used to sample shovelnose sturgeon during this study based on water temperature and season. IDNR sampled sturgeon using alternating current (AC) and direct current (DC) electrofishing, gillnets and driftnets, and Eastern Illinois University Fisheries and Aquatic Research Lab sampled fish using electrified benthic trawls. These were supplemented with sturgeon collected using hoopnets and trotlines by commercial fishermen.

Electrofishing was conducted with three-phase AC electrofishing using an unbalanced array (3 booms with one dropper on each) or DC electrofishing (output: 5 A, 60 pulses s^{-1}, 20 to 50 % range). Both AC and DC electrofishing were conducted mainly in the mid-channel habitats of the LWR. Two netters captured sturgeon for approximately 10 minutes of effort. Monofilament gill nets (30.5 m long and 1.2 or 2.4 m in depth and consisting of 7.6 m panels of 3.8, 5.1, 7.6, and 10.2 cm bar mesh) were used mainly during the winter and spring. Gill nets were set for one hour in depths at least 1.2 meters. I also used these gillnets as driftnets, allowing them to float perpendicular to the river current. Commercial fishermen mainly used overnight sets of double-throated hoop nets (1.2 meters in diameter and 3.7 m long with seven fiberglass/plastic hoops and 3.8 cm bar mesh) to capture shovelnose sturgeon. Trotlines and driftnets were also used intermittently during spring and fall to measure their effectiveness in catching sturgeon.

All captured shovelnose sturgeon were measured to the nearest mm fork length (FL), and weighed to the nearest g. Each fish was tagged with a unique Passive Integrated Transponder (PIT) tag, monel tag and floy tag. In 2013, I visually examined all captured individuals to determine their sex, and estimate the gender ratio of this shovelnose population. Individuals with a soft, swollen abdomen or loose, stretched belly skin and a red vent were classified as gravid females. To confirm identification as female I checked individuals for presence of eggs using a 10 gauge needle. I checked each recaptured fish for the retention of the tag(s), and then released them at the location of capture.

Ageing

During 2013, I collected a 25 mm section of the anterior-most pectoral fin ray from an area proximal to the origin of the ray (N = 306). I allowed fin rays to air-dry for at least 2 weeks before mounting the fin rays in epoxy (Koch and Quist 2007). Multiple 0.7 mm cross-sections of the base of the fin ray were cut using a Buehler Isomet® low speed saw with diamond–cutting blade (Buehler Limited, Lake Bluff, IL). Cross sections were mounted on a glass slide and viewed under a stereomicroscope (≤ 80 X magnification, Leica Microsystems Inc., Buffalo Grove, IL). In a double blind fashion, two independent readers estimated the age of each fish by counting annuli on the cross section of the spine. I also obtained a digital photograph of the best section using a Leica LAS EZ program (Leica Microsystems Inc., Buffalo Grove, IL). Readers resolved discrepancies with a concert read.

Data Analysis

All statistical analyses were performed in statistical program R ver. 3.0.2 (R Development Core Team, 2013). For the analyses, I pooled data from all sampling locations within the LWR. Relative density was quantified as catch per unit hour (CPUE, fish/h) only for DC electrofishing, because this was the only gear consistently used over the years, and accounted for a large proportion of the total catch. I used linear regression on the log-transformed CPUE data for DC electrofishing to assess the change in relative density over the years. The population size of shovelnose sturgeon in the LWR was not estimated because the recapture rate was too low to obtain any ecologically significant information. I calculated the proportion of total catch contributed by each gear, and compared mean FLs of shovelnose caught with each gear using a Kruskal-Wallis rank sum test followed by pairwise comparisons using Wilcoxon-rank sum tests. For this, α was set to 0.0024 based on Dunn-Sidák correction for multiple comparisons.

Size structure of the shovelnose sturgeon population was assessed for each year using length frequency distribution histograms. Additionally, I used size distribution indices to calculate the yearly size structure of shovelnose sturgeon over the years (Anderson and Neumann 1996; Guy et al. 2007). I calculated the proportional size distribution (PSD) as $\mathrm{PSD} = \frac{\text{number of fish} \geq 380\text{ mm}}{\text{number of fish} \geq 250\text{ mm}} * 100$, and relative size distribution as $\mathrm{PSD} = \frac{\text{number of fish} \geq \text{specified length}}{\text{number of fish} \geq 250\text{ mm}} * 100$, with preferred length 510 mm, memorable length 640 mm, and trophy length 810 mm (Quist et al. 1998). I used linear regressions to assess whether PSD values and mean FL of shovelnose changed time.

I used linear regression of natural-log transformed wet weight and FL data to develop the FL-weight relationship. As an index of somatic condition, I calculated mean relative weight (W_r; Anderson and Neumann 1996) of shovelnose by year. Relative weight was calculated as $W_r = (W/W_s) * 100$, where W is the observed weight and W_s is the length specific standard weight for the species. The standard weight of shovelnose sturgeon was estimated by the equation given by Quist et al. (1998): $\log_{10}W_s = -6.287 + 3.330 * (\log_{10}FL)$. I regressed mean relative weight for each year against year determine the trend in the condition of the fish over the years.

I calculated mean length-at-age for all age classes, average percent error (APE) and coefficient of variation (CV = 100·SD/Mean) to assess the precision between readers. Growth was assessed using the von Bertalanffy growth function: $L_t = L_\infty\left[1 - e^{-K(t-t_0)}\right]$ where L_t = the length at time t; L_∞ = the theoretical maximum length; K = Brody growth coefficient (the rate at which the fish approach L_∞); and t_0 = time when length would theoretically equal 0 mm. These parameters can be used to compare growth among populations. Recaptured individuals provided empirical data on growth rates.

Mortality rates were calculated using the Chapman-Robson method using all fish older than the modal age (Dunn et al. 2002; Smith et al. 2012). Robson and Chapman (1961) derived the annual survival estimate ($\hat{S}$) as $\hat{S} = \frac{\sum T}{\sum N + T - 1}$ where T is years since fish fully recruited; and N is the total number of fully recruited fish in the sample. The resulting function for mortality was corrected for over-dispersion and bias as suggested by Smith at al. (2012).

I calculated sex-ratio of shovelnose population based on visual examination of all fish captured during 2013. To ensure that the sex-ratio estimate was conservative, all fish that did not show these characteristics were classified as unidentified. Since the unidentified individuals could be males or females that were not spawning that year, I calculated two sex-ratios: unknown : female, and male : female. Female shovelnose sturgeon are thought to spawn every 2–3 years (Helms 1974; Moos 1978; Kennedy et al. 2006; Tripp et al. 2009b), and so, at any given time, one-half to two–thirds of the mature female population would not be gravid, and, thus, not detectable to us as females. As such, the male: female ratio was calculated by doubling the unknown: female ratio (Kennedy et al. 2007).

RESULTS

A total of 10,734 shovelnose sturgeon was collected from the LWR between 2000 and 2013. Boat DC electrofishing, hoopnets and gillnets contributed 95.02 % of all captures. Boat DC electrofishing, the only gear consistently used in all years, was employed mostly during July, August and September (range May to December) and accounted for the capture of 7,200 of these fish (67.13 % of the total catch). Hoopnets were used mostly during April and May (range March to May) and resulted in 2,520 individuals (23.5 % of total catch, Table 1). Gillnets were used intermittently during spring starting in 2001 and resulted in 471 sturgeon captures (4.39 % of total catch, Table 1). Driftnets were effective at capturing shovelnose sturgeon during periods of low flow, but these nets often got snagged (Les D. Frankland, personal communication), and were discontinued in 2009. The overall catch was highest during August (42.79 % of total catch), followed by April (21.40 % of total catch) and September (14.27 %).

Between 2000 and 2013, there were 436 recaptures from 399 individuals. The recapture data suggested tag retention was significantly different for each tag type (2-sample test for equality of proportion, df = 1, $P < 0.001$). PIT tags had the highest tag retention rate with 89.1 % of tags retained compared to 80 % and 44.8 % respectively for floy and monel tags.

The mean CPUE for shovelnose sturgeon captured using DC electrofishing was 68.26 (± 12.88) fish/h with the highest CPUE of 177.55 fish/h during 2007 and lowest CPUE of 9.76 fish/h during 2003. Although the CPUE increased linearly throughout the study ($F_{1,12}$ = 21.94, R^2 = 0.65, P = 0.0005), CPUE was more stable after 2005 (Figure 1). Mean CPUE from 2005 through 2013 was 95.71 ± 12.31 fish/h. I collected the fewest fish (N = 57) during 2012 due to low water preventing sampling during the major sampling season (July-September).

Shovelnose sturgeon ranged from 61 to 909 mm FL (mean 661.53 ± 0.74 mm FL). Different gears captured sturgeon of different lengths (Kruskal-Wallis χ^2 = 287.97, df = 6, P < 0.0001). On average, benthic trawls collected the smallest fish (mean FL 530.29 ± 8.89 mm), and hoopnets collected the largest fish (mean FL 678.40 ± 1.01 mm, Table 1). Overall, the size structure was negatively skewed (Figure 2), and small size classes were not well represented: only 146 individuals (1.36 % of total catch) < 450 mm FL were collected over the sampling period. The majority of the sturgeon ranged between 550 and 800 mm FL (N = 9957, 92.76 % of total catch, Figure 2). The overall PSD indices for stock (PSD), preferred (PSD-P), memorable (PSD-M) and trophy (PSD-T) size fish were 100, 97, 68 and 1 respectively. There was a significant decrease in PSD-M ($F_{1,\,12}$ = 9.10, R^2=0.43, P = 0.01) and mean FL ($F_{1,\,12}$ = 8.83, R^2=0.42, P = 0.01, Figure 3) over the years. The average weight of shovelnose sturgeon collected was 1194.77 ± 3.74 g. The wet-weight – FL relationship was significant (Log_{10}(wet weight) = 3.217 * Log_{10}(FL) - 6.019, R^2 = 0.91, P < 0.0001, N = 10,695). Mean and median Wr values for shovelnose sturgeon were 89.9 ± 0.11 and 89.0 respectively (Figure 4). However, relative weight decreased linearly over the years (Figure 2; $F_{1,12} = 6.42$, $R^2 = 0.349$, $P = 0.03$).

There was low variability in precision of age estimates for shovelnose sturgeon. Exact agreement between two readers was 70 %; and agreement within 1 year was 94 %. APE in age estimates among readers was 1.7 with a CV of 2.4 %. The age structure of shovelnose sturgeon consisted of 23 age classes between age 0 and 25 years; ages 2, 3 and 4 were not represented (Figure 5). The frequency of fish in each age class increased through age 10 (Figure 4), indicating the sturgeon in the LWR did not fully recruit to the sampling gears until this age. Ninety percent of the collected fish were between ages 8 and 19, and 48 % were between ages 10 and 14. Few captured fish were younger than age 6 (N = 4) or older than age 22 (N = 4).

The von Bertalanffy growth model predicted that the fish grew at a rate of 53.4 mm/y up to age 8 and 17.5 mm/y for ages 9 - 16 (Figure 6). Older individuals (> 17 y) grew at the growth rate of 5.3 mm/year. The predicted mean length of shovelnose sturgeon for the most frequent age class (age 10) was 616.94 mm FL. Empirical growth rates obtained from the recaptured individuals were low and variable (Figure 7). Out of the 353 fish that had been at large for more than 200 days, only 242 fish (68.6 % of total) showed positive growth, while 18 fish (5.1 % of total) showed zero growth, and 93 fish (26.3 % of total) showed negative growth. In fact, two fish in our study that had been at large for 110 and 108 months showed growth of -6 and 4 mm FL respectively. Fish that were 400 - 635 mm FL at the time of tagging had an average annual growth rate of 18.66 mm/year, and fish larger than 635 mm FL grew 2.67 mm/year on average. The total instantaneous mortality from the Chapman-Robson method was 0.23 (95% CI: 0.147 – 0.312), and the total annual mortality was 0.206 (95 % CI: 0.137–0.268).

During 2013 (n = 458) the sex-ratio was skewed towards males. The unknown : female ratio for sexually mature sturgeon was 5.36 : 1 (15.7 % female), and the male : female ratio was 2.18 : 1 (31.4 % female). A total of 380 fish (5.08 %) were found to have egg check marks on their body, although the majority of these egg check wounds were healed. Although some of these fish had more than one egg check mark, I did not quantify the proportion with multiple marks. It could not be determined whether these marks were from one or more encounters. I did not observe any significant relationship between year and the frequency of egg checks (correlation coefficient [r] = 0.27, P = 0.37).

Movement shown by shovelnose sturgeon was variable. I recaptured 273 of the 364 (75 %) recaptured fish at the location of their initial capture, and 327 (90 %) within 4 miles of their initial capture. Only 23 fish (6 %) moved more than 50 miles; a maximum movement of 285 miles was observed for a tagged shovelnose sturgeon with 259 days between captures. The distance travelled by shovelnose sturgeon was significantly correlated to days between captures (r = 0.17, P = 0.001) but not to the length at initial capture (r = -0.02, P = 0.653).

DISCUSSION

The population of shovelnose sturgeon in the LWR was stable and healthy with population characteristics within the range of data reported for shovelnose in other river systems. I observed high CPUE for boat DC electrofishing (68.3 fish/h). The average DC electrofishing CPUE for the LWR was higher than that observed in the upper Wabash River (UWR, upstream of Terre Haute, IN, 24.3 fish/h, Kennedy et al. 2007). Although the relationship between CPUE and year suggests an increase in the population size it may also be attributed to an increase in experience of researchers. As IDNR biologists gained experience with the temporal and spatial habitat use of shovelnose sturgeon during the first few years, they were able to effectively sample Wabash River habitats. This also explains the relative stability in CPUE after 2005. The shovelnose population in the LWR was skewed towards large individuals (for example, PSD = 100, PSD-P = 97), similar to other studies (Quist et al. 1998; Kennedy et al. 2007; Koch et al. 2009). This suggests that the potential for shovelnose sturgeon recruitment in LWR is high. The mean FL (661.5 mm), maximum FL (909 mm) and L_∞ (771 mm) in this study were within the range reported for other systems (maximum FL 693–994 mm, L_∞ 548–907 mm FL, Christenson 1975; Quist et al. 2002; Pierce et al. 2004; Jackson 2004; Anderson 2010). Additionally, the mean Wr (89.9) of shovelnose in this study fell within the target range (80-90) suggested by Quist et al. (1998). These values suggest that shovelnose sturgeon in the LWR were in good condition, and food did not seem to be a limiting factor. Finally, the total annual mortality (A = 20.6 %) for shovelnose in the LWR was lower than most other commercially exploited populations (e.g. 37% Upper Mississippi River, Colombo et al. 2007a; Lower Missouri River, 25% Pierce et al. 2004). Mortality rates of shovelnose sturgeon are likely influenced by anthropogenic factors such as commercial harvest and habitat alterations (Morrow et al. 1998; Quist et al. 2002; Jackson 2004; Anderson 2010). Being a free-flowing river, Wabash River may provide better habitats or spawning sites for shovelnose compared to other channelized systems.

There are also several potential problems in this population. The mean condition, FL and PSD-M of shovelnose sturgeon in the LWR has been decreasing in the recent years. The male : female ratio (2.18 : 1) is highly skewed towards male. A separate destructive study in the LWR showed male : female ratio of 2.25 : 1 (chapter 2). These ratios are highly skewed compared to other systems (e.g. 1.82 : 1 in the UWR, Kennedy et al. 2007; 1 : 1 in Middle Mississippi River, Colombo et al. 2007b), and are potentially problematic. Also, a higher proportion of shovelnose adults had egg check marks (5.1%) in the LWR compared to the UWR (2.4 %). These results suggest harvest pressure towards gravid female shovelnose is higher in the LWR, and might even be increasing in the recent years. Additionally, I captured few individuals smaller than 500 mm, likely because of size-associated gear bias. Hamel and Steffensen (2007) also reported that none of the gears were effective at sampling shovelnose sturgeon less than 380 mm FL in the Missouri River. Although some researchers have reported successful sampling of shovelnose sturgeon of less than 250 mm using otter trawls and trammel nets (Doyle et al. 2008; Plauck et al. 2008; Utrup et al. 2008), none of the gears I used were consistently effective at capturing these individuals. The failure in capturing small individuals may also be due to differential sampling of microhabitats. Juvenile and subadult sturgeon may inhabit microhabitat patches, like shallow sand bars, that are not effectively sampled.

Absence of young/small fish in samples has various possible ramifications for the shovelnose sturgeon population. Such absence of small fish and negative skew in the size structure may be caused by a series of year-class failures in recent years. However, the size distribution of shovelnose sturgeon remained similar over the period of 14 years, suggesting the negative skew in the size structure is related to gear bias and not because of low recruitment. Inability to catch young fish is also problematic when assessing growth. For example, removal of young-of-year fish from my von Bertalanffy model leads to a highly unrealistic estimation of growth parameters (L_∞ = 882 mm FL, K = 0.06, t_0 = -7.6). Management and conservation efforts based on such results may cause more harm than good.

My estimate of K (0.14) is most comparable to the populations in the UWR (0.12; Kennedy et al. 2007) and middle Mississippi River (0.11–0.16; Tripp et al. 2009a). The shovelnose sturgeon populations in most exploited and disturbed rivers have a high K (e.g. 0.24, lower Missouri River, Quist et al. 2002; 0.53 lower Platte River, Anderson 2010). These results imply fish in the Wabash River grew slower than most populations, but were still able to attain large sizes because mortality is comparatively low. Long–term mark–recapture studies of shovelnose sturgeon have reported positive, zero and negative empirical growth during their times at large (e.g. Christenson 1975; Kennedy et al. 2007; Hamel 2013). In particular, growth of sexually mature individuals is low (e.g. -8 to +10 mm FL increase over 58 months, Christenson 1975). My results demonstrated similar patterns, with an average growth of 14.3 mm FL for fish which had been at large for at least 200 days. Several fish which had been at large for more than 24 months showed zero or negative growth. These results suggest that growth stopped once the fish reached sexual maturity. This might be because when sturgeon reach sexual maturity, they likely put most of their energy into reproduction instead of growth.

The mark-recapture study of shovelnose population in LWR has also provided insights into movement and tag retention of the fish. I observed that most fish did not move long distances between captures. However, a few fish (6.3 %) moved more than 50 miles. Shovelnose sturgeon move upstream during spring for spawning, and return to the same site after the spawning season (Curtis et al. 1997; Kennedy et al. 2007; Wellman 2010). Most of the captures and recaptures in this study came from summer and fall, and thus it is highly likely that the fish had moved large distances between captures when they were at large. These findings corroborate the telemetry study done in the Wabash River, in which Wellman (2010) found shovelnose sturgeon showed site fidelity during the spring spawning period, but showed potential to migrate long distances (> 320 kilometers).

I observed differential rates of tag retention in shovelnose, with PIT tags and floy tags showing high tag retention compared to floy tags. Hamel et al. (2012) observed 73–77 % retention of PIT tags when injected along the dorsal fin, and 100 % retention of T-bar anchor tags. While my study showed highest retention for PIT tags, the retention rate of floy tags was not far behind. Floy tags are also generally cheaper than PIT tags, are much easier to view for recreational and commercial fishers, and do not require a specialized reading equipment. Thus, I recommend the use of floy tags as the primary tagging method for shovelnose sturgeon.

The restriction of sturgeon harvest around the world, and particularly the restriction of harvest of shovelnose sturgeon in parts of Mississippi River in the recent years, has likely increased the harvest pressure in the LWR where the harvest is still allowed (Hintz and Garvey 2012). However, this study suggests the shovelnose population in the LWR is in relatively good condition, and experiences low mortality rates. While these fish grow slow, they are able to live longer and attain large sizes. The population seems to be in a stable condition with high potential for recruitment.

However, the sex–ratio seems to be skewed towards male, and the relative weight has decreased over time. Additionally, the proportion of large fish seems to be decreasing in recent years, and without successful recruitment of younger and smaller individuals to gears, I cannot be certain the recruitment is not decreasing. Therefore, we need to continue to monitor the shovelnose sturgeon population closely to ensure the sustainability of the fishery and conservation of this species. Further research should assess the reproductive biology, gender–specific demographics, recruitment trends and optimal harvest strategies of shovelnose sturgeon in the LWR.

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Table 1: Gear-specific catch of shovelnose sturgeon in lower Wabash River between 2000 and 2013. Catch does not represent true efficiency of a particular gear since some gears were used more often than others. Gears that do not share a letter captured shovelnose sturgeon of significantly different mean fork lengths.

Gear	N	Percent of total	Average fork length (mm)
AC Electrofishing	313	2.92	666.17 ab
DC Electrofishing	7200	67.13	657.40 b
Driftnet	138	1.29	673.26 ab
Gillnet	471	4.39	625.38 c
Hoopnet	2520	23.50	678.40 a
Benthic Trawl	14	0.13	530.29 c
Trotline	67	0.62	668.61 ab

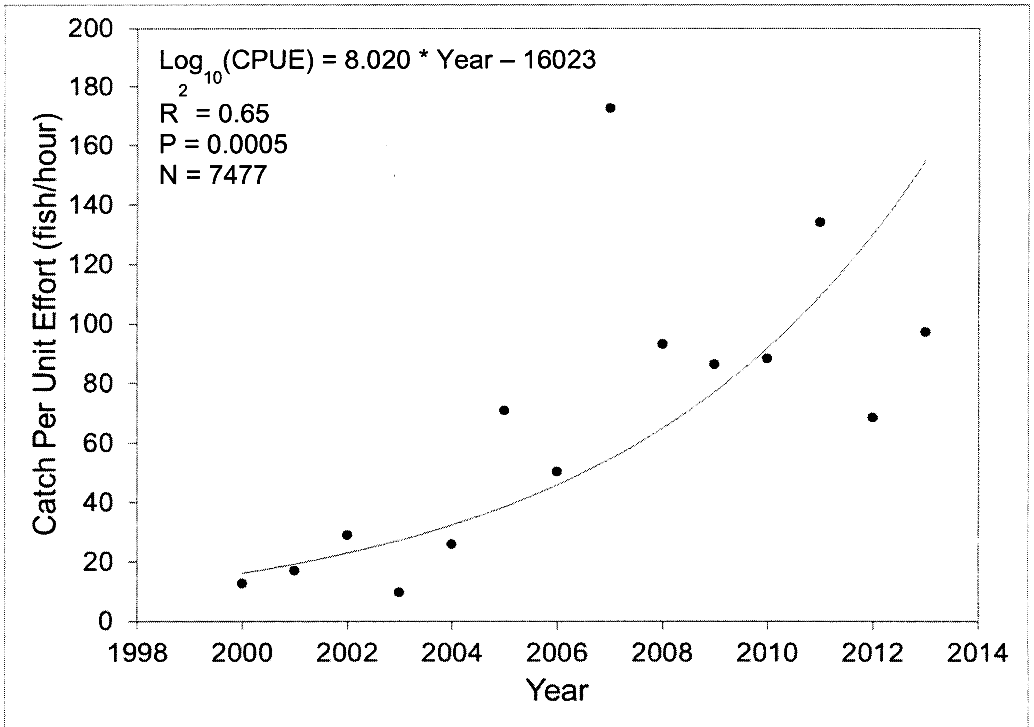

Figure 1: Relative density, represented as catch per unit effort, for shovelnose sturgeon captured in lower Wabash River between years 2000 and 2013 for DC electrofishing.

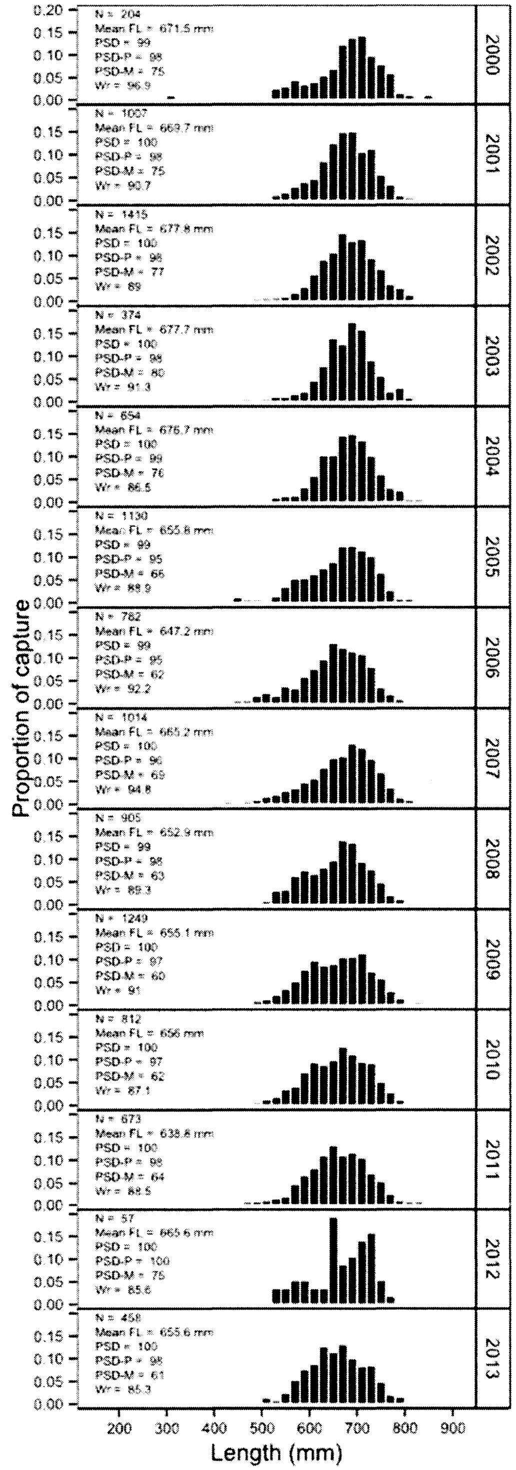

Figure 2: Length-frequency histograms of shovelnose sturgeon sampled in the lower Wabash River between 2000 and 2013. Sample size (N), mean fork length (FL), proportional size distribution (PSD) indices and relative weight (Wr) for each year are also given for each year.

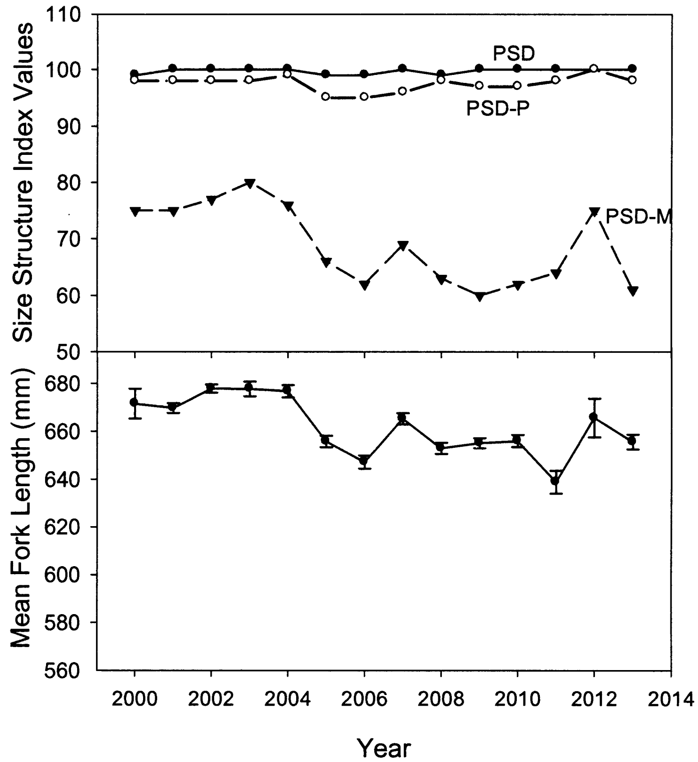

Figure 3: Size Structure Index values and mean fork length (mm) for shovelnose sturgeon population in the lower Wabash River during 2000 - 2013. See text for details on meanings of PSD, PSD-P and PSD-M. Error bars represent one standard error.

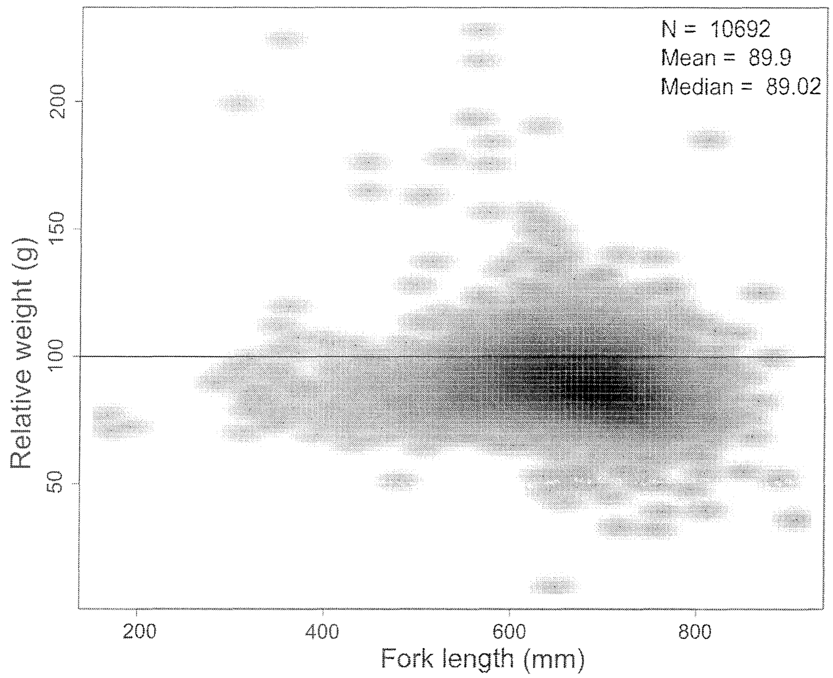

Figure 4: Smooth scatter plot showing the relative weight of shovelnose sturgeon collected from the lower Wabash River between 2000 and 2013. Horizontal line at 100 gives standard relative weight.

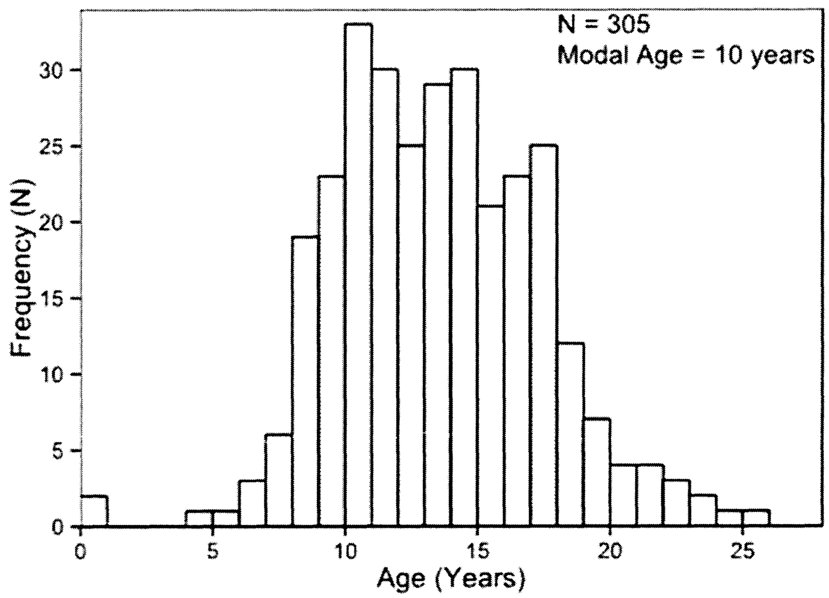

Figure 5: Age structure of shovelnose sturgeon from the lower Wabash River during the year 2013.

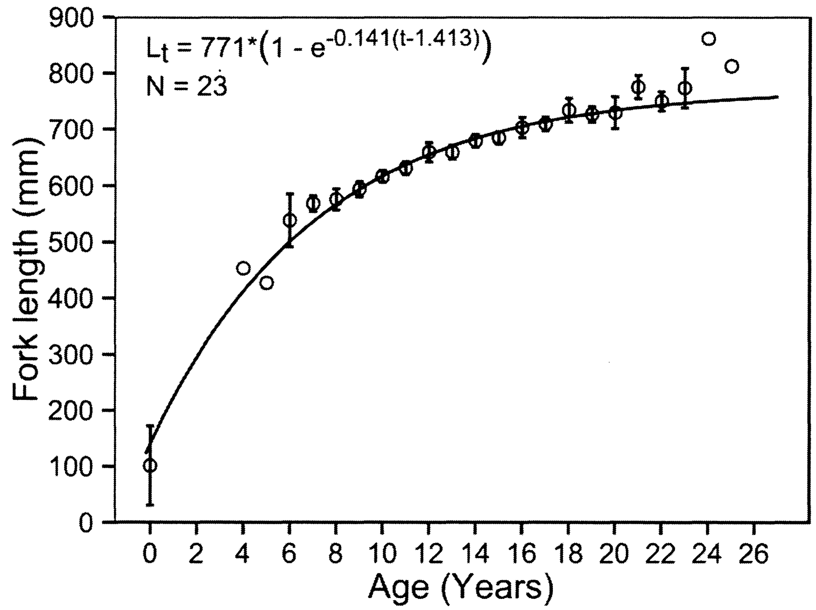

Figure 6: Mean fork length at age for shovelnose sturgeon from the lower Wabash River. Error bars represent 95% confidence intervals. Fitted von Bertalanffy growth function is given as the line and equation.

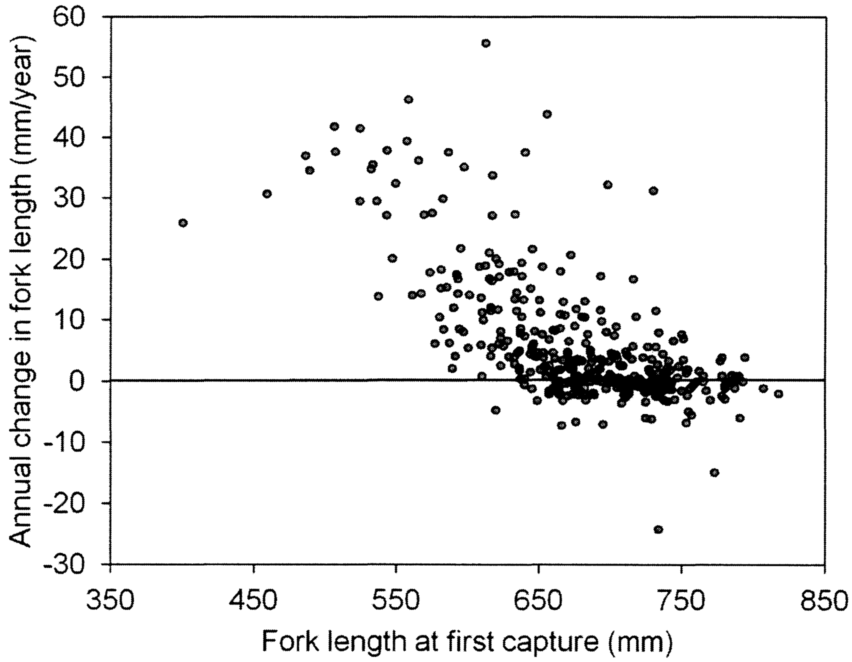

Figure 7: Empirical growth rates of shovelnose sturgeon in the lower Wabash River obtained from mark-recapture of 399 individuals between 2000 and 2013.

SEASONAL PATTERNS IN DIET COMPOSITION OF ADULT SHOVELNOSE STURGEON IN THE WABASH RIVER

ABSTRACT

Shovelnose sturgeon (*Scaphirhynchus platorynchus*) are one of the few remaining commercially-viable sturgeon species, but face increasing danger of overexploitation. Because diet is directly linked to growth, condition, and reproduction, information regarding the diet is essential for commercially-exploited stocks. I analyzed the diets of adult shovelnose collected between January and November 2013 from the lower Wabash River, Indiana/Illinois. Overall, Hydropsychidae, Chironomidae, Potamanthidae and Elmidae were the most important prey taxa for shovelnose sturgeon. Diet composition differed among seasons, with winter, summer and fall samples dominated by Hydropsychidae larvae, and spring samples dominated by Chironomidae larvae. Additionally, fall and winter samples had the highest and lowest proportions of inorganic materials respectively. Remains of bony fish were observed in a few spring and winter samples. I observed a small proportion of individuals (2.2%) with empty stomachs, suggesting that appropriate prey taxa were widely available to shovelnose sturgeon throughout the year. Results of this study are consistent with other studies within the Mississippi and Missouri River drainages, and support the finding that shovelnose sturgeon are opportunistic invertivores with larval Hydropsychidae and Chironomidae comprising the bulk of the total annual diet.

Key Words: Diet, Seasonal, Shovelnose sturgeon, Wabash River

INTRODUCTION

Sturgeon populations have declined substantially across the world due to habitat loss and overharvesting of gravid females to meet demand for caviar (Birstein 1993, Boreman 1997, Keenlyne 1997, Quist et al. 2002, Wilson and McKinley 2005, Colombo et al. 2007a, Tripp et al. 2009a). This decline in sturgeon stocks has shifted harvest pressure towards shovelnose sturgeon, *Scaphirhynchus platorynchus* (Carlson et al. 1985, Keenlyne 1997, Morrow et al. 1998, Quist et al. 2002, Colombo et al. 2007a). This species, native to the Mississippi and Missouri River drainages (Bailey and Cross 1954, Lee et al. 1980, Pflieger 1997), is currently one of the few sturgeon species that supports a viable commercial harvest (Keenlyne 1997, Quist et al. 2002, Kennedy et al. 2007, Kennedy and Sutton 2007, Colombo et al. 2007b).

Although shovelnose sturgeon support a commercial fishery in eight states and a recreational fishery in 13 states (Koch et al. 2010), increased exploitation of this species has caused a range contraction and decreased in local population sizes (Keenlyne 1997, Kennedy et al. 2006, Colombo et al. 2007a). Moreover, the U.S. Fish and Wildlife Service (2010) has recently restricted the harvest of shovelnose in much of the Mississippi and Missouri Rivers to protect the federally endangered pallid sturgeon, *S. albus* (U.S. Fish and Wildlife Service 2010). Such site-limited protection of this commercially important fish may increase exploitation in unprotected river reaches where pallid sturgeon do not occur (Hintz and Garvey 2012), and suggests a need for management of existing shovelnose populations to prevent overexploitation (Colombo et al. 2007ab, Kennedy et al. 2007, Koch et al. 2009). However, most research has focused on shovelnose life history and ecology in the Mississippi and Missouri rivers (e.g. Modde and Schmulbach 1977, Quist et al. 2002, Colombo et al. 2007ab, Koch et al. 2009, Tripp et al. 2009). Since demographics of shovelnose sturgeon may vary greatly among rivers, research on other systems is important (Kennedy et al. 2006).

The Wabash River, a large tributary to the Ohio River, has a substantial shovelnose sturgeon population. This is a unique system because the lower 764 km of this river are unimpounded, making it the longest free-flowing river east of the Mississippi River. Although some research has been conducted on shovelnose sturgeon in the middle or upper portion of the Wabash River (Kennedy et al. 2006, Kennedy et al. 2007, Kennedy and Sutton 2007, Bock et al. 2011), ecological information like population characteristics and diet of shovelnose sturgeon has not been determined in the lower portion of the river. Since the lower Wabash River supports an active roe-fishery, population dynamics of the fish may be very different in this stretch of the river compared to the upper portion, which is not commercially-exploited.

Energy intake affects the survival and growth of a fish. The diet quantity, quality and composition can also influence the condition, and thus, reproduction of a fish. Food and feeding habits determine the trophic position of animals within food webs, and define their ecological niche. Information on diet may provide insight into the behavior, habitat use and inter-and intra-specific interactions of a species. Thus, quantitative information on the diet of a fish is foundational towards effective management and conservation. To address this need, I studied the diet of shovelnose sturgeon in the middle and lower Wabash River, Illinois. Based on the literature, I expected larval Chironomidae and Hydropsychidae to make up the bulk of the shovelnose diet, with seasonal variation in the diet composition of the fish.

METHODS

Fish collection and necropsies

Shovelnose sturgeon were collected every season (winter, spring, summer, fall) from January through October 2013 from three locations in the Wabash River: 1) downstream of Crawleyville, Indiana (38° 17' 26.36" N, 087° 52' 01.15" W), 2) upstream of Mascouten Park (40° 26' 34.33" N, 086° 53' 44.67" W), and 3) upstream of Heron Island (40° 28' 23.91" N, 086° 52' 45.07" W, Figure 1). These locations were chosen because earlier sampling of shovelnose sturgeon had identified these sites as supporting high concentrations of this species. Multifilament gillnets (76 m long, 1.8 m deep, wall panels 5.1 cm bar mesh) were drifted perpendicular to the current for 15 minutes with a targeted maximum distance of 300 m. All individuals were measured (fork length [FL] to nearest mm) and weighed (nearest gram). I performed necropsies on all captured individuals using the process described by Bock et al. (2011). A mid-ventral incision was made from the anus to the gill isthmus, exposing the stomach. The stomach was removed and its contents were flushed and stored in 10% buffered formalin. Food items in the stomachs, mostly invertebrate larvae, were identified to the lowest taxa feasible, using Merritt et al. (2008). After identifying and counting prey items, I dried the contents of each stomach at 100 °C for 5 days, and weighed. The dried contents were then burned in a muffle furnace at 500 °C for 1 h, and reweighed. This allowed me to determine the organic and inorganic content in the diet samples.

Data Analysis

Sturgeon population structure and diet were evaluated using R version 3.0.2 (R Core Development Team 2013). As an index of somatic condition, I calculated mean relative weight (W_r; Anderson and Neumann 1996) of shovelnose for each season for both males and females. Relative weight was calculated as $W_r = (W/W_s) * 100$, where W is the observed weight and W_s is the length specific standard weight for the species. The standard weight of shovelnose sturgeon was estimated by the equation given by Quist et al. (1998): $\log_{10}W_s = -6.287 + 3.330 * (\log_{10}FL)$. Using separate two-way analysis of variance (ANOVA) models, morphometric characteristics (FL and weight) of the fish as well as the inorganic and organic stomach content weights were compared between the sexes and among seasons. I calculated stomach fullness using a regression approach: for different size classes, maximum prey weight was regressed against fish size, and then the ratio of prey weight to predicted maximum prey weight was calculated to give a standardized stomach fullness. I used frequency of occurrence (%F) and % number (%N) as robust measures of diet composition (Baker et al. 2013), because the presence of unidentifiable and inseparable partially digested material prevented complete separation of gut contents into prey categories for quantification of mass. Number of taxa, and total number of prey items were also compared between sexes and among seasons using two-way ANOVA. If season was a significant factor in any of the metrics, I followed the ANOVA with pairwise comparisons using Tukey's Honest Significant Differences procedure.

RESULTS

Sample sturgeon demographics

I assessed diet in 92 shovelnose sturgeon (Table 1). The male:female ratio of this sample was 2.25:1. Shovelnose sturgeon ranged in size between 396 mm FL and 801 mm FL (666.25 ± 7.65; mean ± 1 SE), and 190 and 1900 g wet weight (1080.05 ± 35.98).

Females were longer and heavier than males ($F_{1,83} = 10.233$, $P = 0.002$, and $F_{1,83} = 15.631$, $P < 0.001$). There was a significant difference in wet weights among seasons ($F_{3,83} = 2.92$, $P = 0.039$). Fish in winter had significantly lower mean wet weight (981.82 ± 84.9 g) compared to other seasons, and fish in other seasons did not differ statistically (Table 1). Relative weight of shovelnose ranged between 64.01 and 100.80 (mean =79.76 ± 0.82), with no significant difference in relative weight between the sexes or among the seasons.

Diet analysis

Of the 92 stomach samples processed, 90 (97.8%) had at least one prey item. Both of the empty stomach samples were collected during spring 2013. I collected 54,550 individual prey items from 36 identifiable taxa in the shovelnose sturgeon stomach samples (Table 2). Macroinvertebrate larvae comprised the majority of these prey items. Bony fish (whole *Gambusia* and unidentifiable remains) were also observed in two winter (9.5%) and 1 spring (4.3%) samples. Stomach fullness was significantly higher during fall compared to other seasons ($F_{3,76} = 26.073$, $P < 0.001$, Figure 2). Although the mean number of prey taxa did not differ among seasons ($F_{3,83} = 0.749$, $P = 0.526$), the total number of prey individuals did ($F_{3,83} = 0.16.163$, $P < 0.001$). Fall samples had the highest prey count (1279.69 ± 187.4) and winter samples had the lowest (179.15 ± 60.49, Figure 2). There was no difference in either mean number of prey taxa or the total number of prey individuals between male and female fish ($F_{1,83} = 1.243$, $P = 0.268$, and $F_{1,83} = 0.775$, $P = 0.381$ respectively).

Trichoptera composed the greatest portion of the diets (59.2%), followed by Chironomidae (Diptera, 39.0%), Potamanthidae (Ephemeroptera, 0.4%) and Elmidae

(Coleoptera, 0.4%). Together, Trichoptera and Chironomidae consistently comprised more than 95% of all prey individuals (Table 2). Whereas fall, summer, and winter samples were dominated by Trichoptera, spring samples were dominated by Chironomidae (Table 2). Large proportion of Trichoptera was identified as Hydropsychidae, but a significant proportion of Trichoptera were unidentifiable. Judging by their characteristic shape most of these unidentifiable individuals were likely Hydropsychidae. Proportion of diet comprised by Trichoptera was highest for fall samples (0.86 ± 0.04), and lowest for spring samples (0.13 ± 0.05, $P < 0.05$, Tables 2 and 3). I also observed gender-specific differences in diet composition. Diet of female shovelnose had significantly fewer Chironomidae and more Trichoptera compared to males ($F_{1,81} = 10.176$, $P = 0.002$ and $F_{1,81} = 17.692$, $P < 0.001$). However, there was a significant sex-by-season interaction t for proportion of Chironomidae ($F_{3,81} = 2.759$, $P = 0.047$). Proportion of Chironomidae was higher in diets of females compared to males during fall and spring, but lower during summer and winter (Table 3).

Weight-adjusted prey dry mass for shovelnose sturgeon was significantly higher during fall (2.90 ± 0.28) compared to other seasons ($F_{1,35} = 1.580$, $P < 0.05$, Figure 3); winter samples had the lowest weight-adjusted prey dry mass (0.39 ± 0.11 mg/g fish). In contrast, winter diet samples were largely composed of organic materials (0.63 ± 0.09), whereas the proportions of organic content decreased through the year ($F_{3,35} = 9.550$, $P < 0.001$, Figure 3). There were no difference in prey mass or proportion of organic content between males and females ($F_{1,35} = 1.580$, $P = 0.217$ and $F_{1,35} = 1.525$, $P = 0.225$ respectively).

DISCUSSION

Diets of shovelnose sturgeon in the Wabash River were similar to those reported from other rivers. As expected, larvae of Hydropsychidae and Chironomidae were the dominant prey items. Available literature indicates that these taxa are staple items in shovelnose diets throughout its range (e.g. Modde and Schmulbach 1977, Hoover et al. 2007, Bock et al. 2011). Shovelnose sturgeon exhibited high feeding success in the lower Wabash River as I observed very few sturgeon with empty stomachs (2.2%). This was also consistent with other reports (e.g. Hoover et al. 2007, Bock et al. 2011). Finally, the total number of prey families observed in our study (36) was higher than reports from other river systems (e.g. 21 families in Mississippi River, Hoover et al. 2007; 19 families in Lower Platte River, Rapp et al. 2011; 30 families in Upper Wabash River, Bock et al. 2011). Such large diversity of prey taxa, including the occasional presence of fish in shovelnose diets suggests the shovelnose sturgeon are largely opportunistic benthivores (Modde and Schmulbach 1977, Berry 2002, Wanner et al 2007, Bock et al. 2011).

Diet quantity and composition of shovelnose sturgeon, like other fishes, can vary seasonally (Modde and Schmulbach 1977, Hoover et al. 2007, Wanner et al. 2007, Bock et al. 2011, Seibert et al. 2011). Prey dry mass, stomach fullness, and number of individual prey items were highest in fall, and lowest in winter. Trichoptera was the dominant prey during fall, summer and winter, but Chironomidae was the dominant prey during spring. Such seasonal differences in composition are likely to be related to seasonal environmental conditions and life history patterns of invertebrate prey taxa. While not significant, spring samples had the greatest diversity of prey taxa. This coincides with the massive spawning season of many macroinvertebrates. Additionally, Hydropsychids hatch during spring (April-June), and are likely not as accessible as prey as during other seasons (Mackay 1986, Rutherford and Mackay 1986). This might be the reason why Hydropsychidae was the dominant prey during all seasons except spring. Spring samples were dominated by Chironomids, a result consistent with most other studies (Modde and Schmulbach 1977, Wanner et al. 2007, Bock et al. 2011). This suggests that Chironomids fill the niche left open by the absence of Hydropsychidae during spring.

The total number of prey individuals was highest in fall compared to spring. Further, the two empty stomach samples I observed were both from spring, suggesting low foraging success during spring. These results are not in concert with other reports on diets of shovelnose sturgeon. For example, Bock et al. (2011) reported higher total number of individual prey items during spring compared to fall samples. Seibert et al. (2011) also observed higher percent of shovelnose sturgeon stomachs containing prey items during spring and suggested that this was because of the availability of dislodged benthos as a consequence of drift associated with high river flow during spring. They also reported Hydropsychidae were more numerically abundant than Chironomidae during spring, but less abundant during winter (Seibert et al. 2011). This may be explained by an increase in the water level during my fall sample. This increase in flow might have dislodged benthos and made it available to sturgeon. As such, stomach fullness, weight-adjusted prey dry mass, and total number of individual prey items were highest during fall compared to other seasons. This might also explain the relatively low proportion of organic content in the shovelnose diets during fall. I suspect high turbidity resulting from higher flow during sample collection in the fall and spring might have led to a less discriminate feeding, allowing for inadvertent consumption of inorganic particles like sand (Modde and Schmulbach 1977, Bock et al. 2011). Also, I observed a large proportion of Trichoptera without body parts, likely due to differential digestion of body parts. This can be a major bias in diet analyses; rapidly digested foods are under-represented in stomachs whereas hard parts (like head capsules of insect larvae) are overrepresented. Thus, while the count of Trichoptera individuals in the fall sample was high, the actual mass contributed was not as high, and hence, the lower proportion of organic content.

This study showed that shovelnose sturgeon are opportunistic benthic invertivores with diets composed primarily of aquatic macroinvertebrate larvae of the taxa Trichoptera and Chironomidae. The shovelnose sturgeon also showed a seasonal variation in the prey quantity and composition. These conclusions are also supported by other studies (e.g. Modde and Schmulbach 1977, Keenlyne 1997, Wanner et al. 2007, Bock et al. 2011, Seibert et al. 2011). Additionally, this study is consistent with the findings of other researchers that invertebrate drift caused by high water flow is an energetically important component of the annual shovelnose sturgeon diet (Modde and Schmulbach 1977, Seibert et al. 2011).

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Table 1: Number and mean (± 1 standard error) fork length, somatic weight and relative weight of female and male shovelnose sturgeon captured during winter, spring, summer and fall of 2013 used in this study for diet analyses.

Sex	Season	N	Fork length (mm)	Wet weight (g)	Relative weight
Female	Winter	10	690.60 ± 29.16	1175.00 ± 131.44	76.19 ± 1.55
	Spring	2	701.50 ± 26.50	1462.50 ± 187.50	93.81 ± 0.29
	Summer	7	687.57 ± 20.09	1246.43 ± 133.90	84.43 ± 4.23
	Fall	9	723.67 ± 21.15	1380.56 ± 100.93	79.71 ± 2.79
Male	Winter	12	612.08 ± 24.77	820.83 ± 90.91	79.35 ± 1.83
	Spring	21	672.95 ± 10.21	1092.86 ± 60.41	79.36 ± 1.84
	Summer	16	665.00 ± 10.78	1003.12 ± 52.58	76.52 ± 1.75
	Fall	14	653.36 ± 17.67	1035.71 ± 85.27	82.45 ± 1.72

Table 2: Frequency of occurrence (%F), and % number (%N) of different prey taxa observed in stomach samples from shovelnose sturgeon collected throughout all seasons from the Wabash River between January 2013 and November 2013.

Prey taxa	*Winter*		*Spring*		*Summer*		*Fall*	
	% F	*% N*	*% F*	*% N*	*% F*	*% N*	*% F*	*% N*
Acanthocephala	0	0	4.760	0.361	0	0	0	0
Actinopterygii								
Cyprinodontiformes								
Gambusia	8.700	0.064	0	0	0	0	0	0
Unknown	0	0	4.760	0.011	0	0	0	0
Arachnida								
Araneae								
Araneidae	13.040	0.085	4.760	0.011	4.348	0.008	4.348	0.004
Trombidiformes								
Hydrachnidiae	0	0	0	0	0	0	4.348	0.004
Clitellata								
Haplotaxida								
Lumbricidae	0	0	4.760	0.053	0	0	0	0
Unknown Oligochaeta	0	0	9.520	0.127	8.696	0.051	0	0
Collembola								
Entomobryomorpha								
Entomobryidae	4.350	0.042	4.760	0.011	0	0	0	0
Gastropoda								
Architaenioglossa								
Viviparidae	0	0	0	0	0	0	4.348	0.004
Basommatophora								
Ancylidae	4.350	0.021	0	0	0	0	0	0

Physidae	0	0	4.760	0.032	0	0	4.348	0.004
Neotaenioglossa								
Pleuroceridae	0	0	0	0	0	0	4.348	0.004
Insecta								
Coleoptera								
Elmidae	13.040	0.064	19.050	0.467	8.696	0.017	69.565	0.533
Elmidae adult	0	0	4.760	0.011	0	0	0	0
Unknown	4.350	0.021	0	0	4.348	0.008	4.348	0.004
Diptera								
Athericidae	0	0	4.760	0.011	0	0	0	0
Ceratopogonidae	17.390	0.233	14.290	0.064	0	0	8.696	0.312
Chironomidae	100	39.724	100	85.869	100	34.760	100	25.133
Simuliidae	0	0	28.570	0.138	52.174	0.539	17.391	0.014
Tabanidae	0	0	9.520	0.032	0	0	0	0
Tipulidae	4.350	0.021	19.050	0.085	0	0	0	0
Unknown pupa	17.390	0.170	23.810	0.064	47.826	0.371	52.174	0.091
Ephemeroptera								
Baetidae	0	0	23.810	0.074	52.174	0.253	30.435	0.049
Baetiscidae	0	0	4.760	0.011	4.348	0.008	0	0
Caenidae	0	0	9.520	0.021	0	0	4.348	0.004
Ephemeridae	0	0	4.760	0.053	0	0	0	0
Heptageniidae	8.700	0.085	9.520	0.021	4.348	0.008	4.348	0.004
Polymitarcyidae	0	0	0	0	0	0	4.348	0.004
Potamanthidae	4.350	0.021	42.860	2.292	0	0	8.696	0.014
Unknown	4.350	0.021	23.810	0.074	34.783	0.194	43.478	0.147
Hemiptera								
Belostomatidae	0	0	4.760	0.011	0	0	4.348	0.004
Lepidoptera								

Crambidae	4.350	0.021	4.760	0.011	0	0	0	0
Pyralidae	0	0	4.760	0.011	0	0	0	0
Megaloptera								
Corydalidae	4.350	0.021	0	0	0	0	0	0
Odonata								
Gomphidae	0	0	9.520	0.032	0	0	0	0
Coenagrionidae	0	0	4.760	0.011	4.348	0.008	0	0
Unknown Zygoptera	4.350	0.042	4.760	0.011	0	0	0	0
Orthoptera								
Gryllidae	4.350	0.021	0	0	0	0	0	0
Plecoptera								
Perlidae	39.130	0.657	4.760	0.011	0	0	13.043	0.011
Unknown	17.390	0.212	0	0	0	0	4.348	0.004
Trichoptera								
Head	95.650	52.216	57.140	4.668	100	40.125	100	44.498
Hydropsychidae	73.910	6.214	71.430	5.283	100	23.642	100	29.156
Limnephilidae	0	0	4.760	0.011	0	0	0	0
Unknown	0	0	4.760	0.011	0	0	0	0
Malacostraca								
Amphipoda	0	0	9.520	0.042	4.348	0.008	4.348	0.004
Isopoda								
Asellidae	4.350	0.021	0	0	0	0	0	0

Table 3: Mean (± 1 standard error) proportion of diet composed by the two most frequent and numerically abundant prey taxa observed in shovelnose sturgeon diets collected throughout all seasons from the Wabash River near between January 2013 and November 2013.

Sex	Season	N	Proportion of Trichoptera	Proportion of Chironomidae
Female	Winter	10	0.75 ± 0.07	0.22 ± 0.05
	Spring	2	0.01 ± 0.01	0.99 ± 0.01
	Summer	7	0.74 ± 0.05	0.25 ± 0.05
	Fall	9	0.82 ± 0.10	0.17 ± 0.1
Male	Winter	12	0.59 ± 0.09	0.35 ± 0.08
	Spring	19	0.13 ± 0.05	0.79 ± 0.06
	Summer	16	0.58 ± 0.05	0.41 ± 0.05
	Fall	14	0.87 ± 0.03	0.12 ± 0.03

Figure 1: Location of the shovelnose sturgeon sampling sites in the Wabash River.

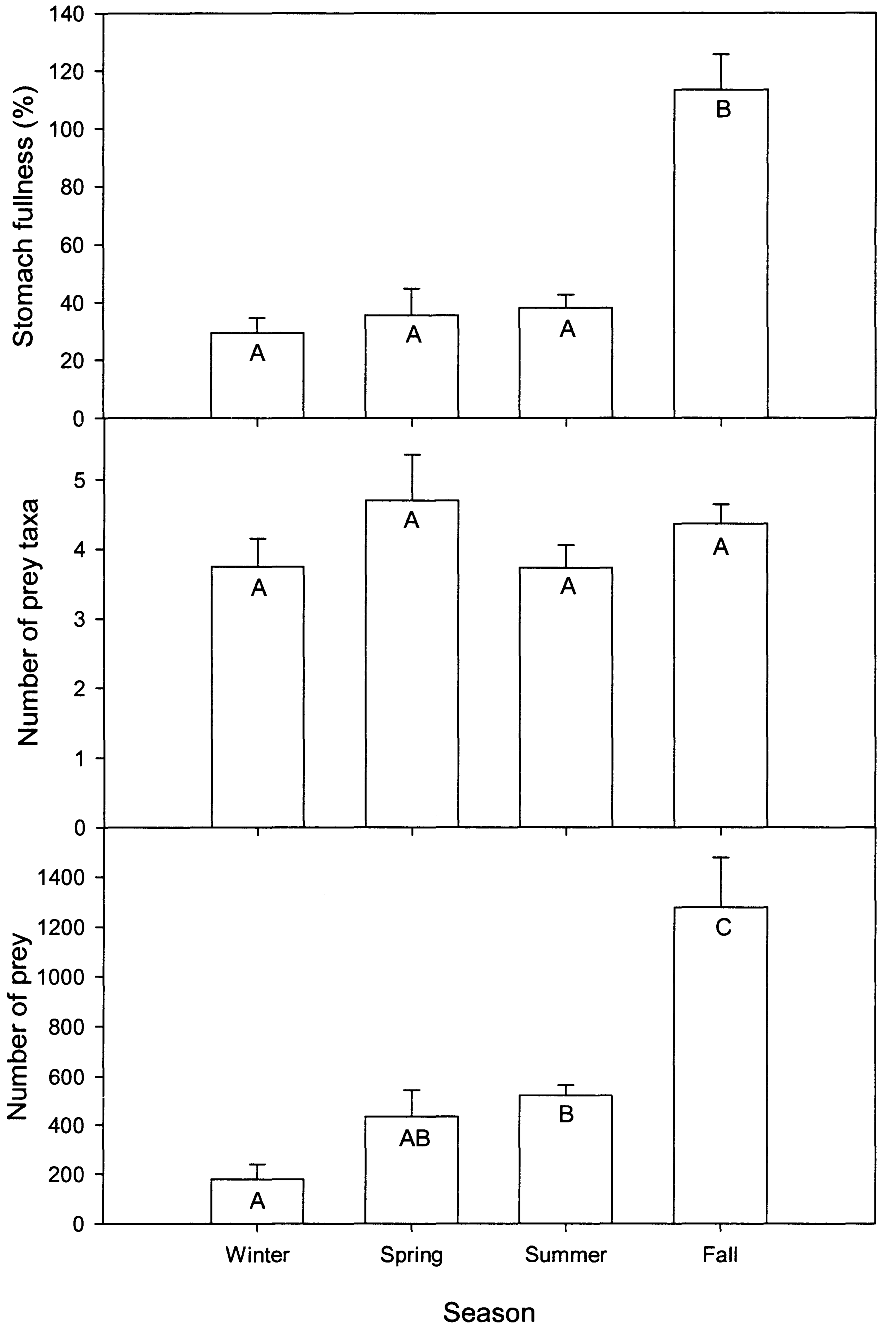

Figure 2: Mean stomach fullness (%), number of prey taxa and number of individual prey items in diet samples of shovelnose sturgeon collected throughout all seasons from the Wabash River between January 2013 and November 2013. Error bars represent 1 standard error; seasons that do not share a letter differ significantly ($P < 0.05$).

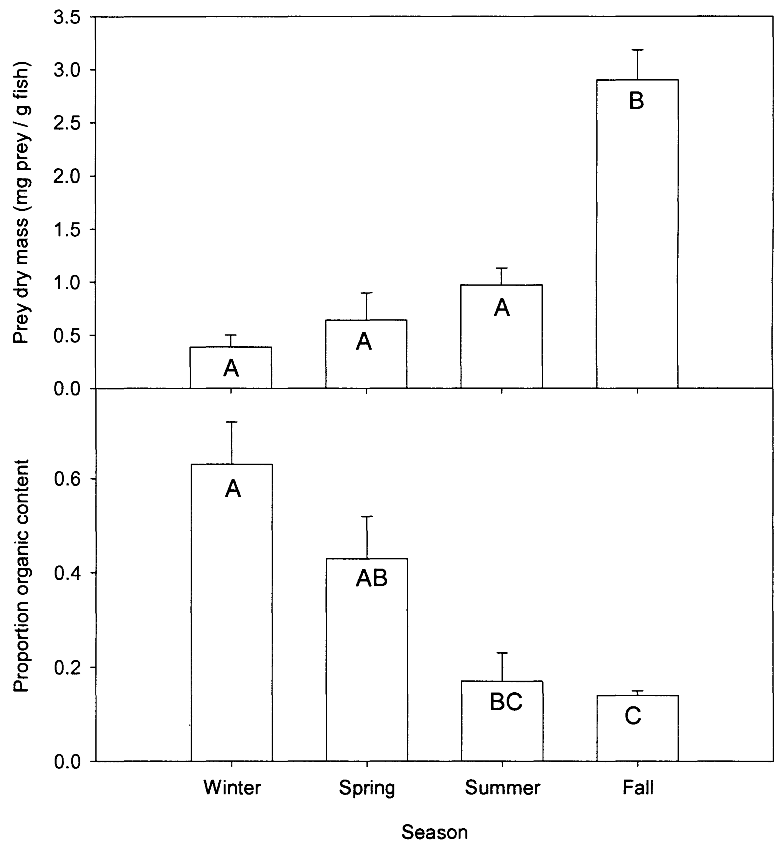

Figure 3: Mean weight-adjusted prey dry mass (mg prey per g of fish) and proportion of organic content in diet samples of shovelnose sturgeon collected throughout all seasons from the Wabash River between January 2013 and November 2013. Error bars represent 1 standard error; seasons that do not share a letter differ significantly ($P < 0.05$).

CONCLUSIONS: PROBLEMS, RECOMMENDATIONS AND FUTURE RESEARCH DIRECTIONS

Sturgeon are particularly vulnerable to harvest because of their life history strategies: they live for many years, mature at a late age and do not spawn annually (Boreman 1997). The shovelnose sturgeon population in the Wabash River, Illinois faces increasing harvest pressure, following the decline of sturgeon fisheries over the world and restriction of shovelnose harvest in the Mississippi River in 2010. This study suggests that the population is in a relatively good condition with low mortality rates and a high potential for future recruitment. The seasonal patterns of prey consumed by shovelnose sturgeon also suggest that most fish get a sufficient amount of food throughout the year. This is likely one of the reasons why shovelnose in the Wabash are in good condition, can grow to large sizes and are potentially able to reproduce and contribute to future generations. However, there are significant problems associated with the population that need to be addressed. Of primary concerns are the observations that the population seems to be highly skewed towards males, and the relative weight, mean fork length of captured fish and proportion of memorable size fish (PSD-M) are decreasing over time. As such, continuation of current management policy should probably be reevaluated to protect the fish from overexploitation. Here I present a few problems associated with the population and the approaches being used to study this population. I also present some recommendations to remedy such problems, and some future research directions.

The biggest problem with the shovelnose sturgeon monitoring survey is the inability to capture small individuals. This is largely associated to gear bias and likely also to repeated sampling of the same habitat patches over the years. While this increases the capture efficiency of the researchers, the increase in relative density it creates is misleading. Gears like the mini-Missouri benthic trawl are cumbersome to use in a free-flowing system like the Wabash River, but may prove useful in catching smaller shovelnose sturgeon (Rayford 2013, this study). Hence, I recommend that future monitoring efforts should include this as a standard gear. Successful recruitment of small individuals to the gears will also assist in development of more accurate growth curves. This is very important, particularly if these growth curves are used in designing harvest management strategies.

Another problem with the study concerned the design of the survey. Sampling is spread out from May to October, which allows collection of a large number of fish, but, is inefficient and violates a number of assumptions of mark-recapture analyses (Williams et al. 2002). Thus, I suggest a more intensive sampling during two or three major time periods. For example, spawning occurs primarily between April and July (Williamson 2003, Kennedy et al. 2006), and thus, I suggest an intensive sampling of multiple locations in the river within a period of a week during April and July. Two more samples evenly spaced between July and October would help in meeting assumptions of mark-recapture analyses, which in turn, would allow estimation of different parameters like population size and survival rate.

Future studies of the shovelnose population in the Wabash should address the micro-habitat use of shovelnose sturgeon in different seasons. Use of telemetry to assess this information can also provide useful information on long-term movement patterns of the fish in the river. This type of study should also prove useful in identifying spawning grounds for shovelnose sturgeon within the Wabash River. Another priority should be to determine the approximate population size of shovelnose sturgeon in the river. Currently, recapture rate is too low to obtain ecologically meaningful estimates of population size. An intensive survey of the population over the next few years is thus important both to obtain more recaptures, and to assess the impacts of the recent closure of the shovelnose harvest in the Mississippi River. Finally, future research should address the gender-specific demographics and optimal harvest strategies of shovelnose in the Wabash. Such information would enable fisheries managers in making informed decisions regarding the optimal management and conservation policies.

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