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[Article]

Population Characteristics of Shovelnose Sturgeon in the Upper Wabash River, Indiana

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Abstract.—Shovelnose sturgeon *Scaphirhynchus platorynchus* support a commercial fishery throughout much of the Mississippi and Missouri River drainages. There is concern that harvest closures for Eurasian sturgeons (Acipenseridae) may result in increased exploitation of shovelnose sturgeon to meet global demands for caviar. Population attributes of shovelnose sturgeon were examined in the upper Wabash River, Indiana, from April 2003 through November 2004 between Wabash and Terre Haute. Fish ($N = 4{,}849$) were captured by direct current electrofishing, experimental gill nets, and benthic trawls. Electrofishing catch per unit effort varied on a temporal basis, being highest for both reaches from March through May. The fork length of captured fish ranged from 273 to 858 mm, but few fish less than 550 mm were captured. Median fork length and wet weight were 683 mm and 1,208 g, respectively (ranges = 273–858 mm and 52–3,381 g). Shovelnose sturgeon ranged from ages 2 to 30, with 95% of the fish between ages 9 and 20. Total annual mortality for fish between ages 13 and 18 was 20%. Empirical growth rates derived from recaptured fish were slow; 74% of the fish exhibited negative or no growth. The population characteristics of shovelnose sturgeon in the upper Wabash River were within the ranges reported for other river systems, but fish attained a larger body size, reached older age-classes, and experienced lower mortality rates than did some other populations. The results from this study will allow for the detection of shifts in abundance, size and age structure, and gender ratio in response to harvest or natural perturbations and promote the development of appropriate management actions to ensure the sustainability of this species and its fishery.

There has been a global decline of sturgeon (Acipenseriformes) stocks, with many species currently classified as threatened or endangered (Birstein et al. 1997). Population declines of sturgeons have been attributed to overharvest, poaching, dam construction, and pollution (Beamesderfer and Farr 1997; Birstein et al. 1997; Boreman 1997; Keenlyne 1997). Although some sturgeon stocks are supplemented by artificial propagation, stocking programs are typically viewed as a short-term solution (Birstein et al. 1997; Khodorevskaya et al. 1997). The maintenance and restoration of naturally reproducing, self-sustaining sturgeon populations will require efforts to determine appropriate harvest levels, learn more about their life history, identify and protect critical habitats (e.g., spawning and nursery areas), and improve water quality.

Shovelnose sturgeon *Scaphirhynchus platorynchus* is a small-bodied, North American sturgeon that inhabits large river systems throughout the Mississippi and Missouri River drainages (Bailey and Cross 1954; Lee et al. 1980). This long-lived (up to 43 years) species is typically less than 1 m in length and seldom exceeds a weight of 3 kg (Pflieger 1997; Everett et al. 2003). Although shovelnose sturgeon are one of the most abundant sturgeon species in North America, alterations to large river habitats and overharvest by commercial roe fishers has reduced their abundance and distribution (Birstein 1993; Boreman 1997; Curtis et al. 1997; Keenlyne 1997; Morrow et al. 1998). Historically, shovelnose sturgeon were considered undesirable by commercial fishers and were often discarded because of their small size (Coker 1930; Carlander 1954; Helms 1974a). However, as lake sturgeon *Acipenser fulvescens* populations in North America declined in the early 20th century, shovelnose sturgeon began to increase in popularity as a commercial species (Helms 1974a; Quist et al. 2002).

Shovelnose sturgeon currently support a commercial fishery in 7 states (and recreational fishery in 12 states), but steady population declines over the past 100 years have raised concern about the continued harvest of this

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species (Keenlyne 1997). Because shovelnose sturgeon are one of the few species that support a sustained commercial harvest and because the importation of sturgeon caviar has become more strictly regulated, this fishery has experienced increased pressure to meet the demands of the global market (Carlson et al. 1985; Keenlyne 1997; Morrow et al. 1998; Quist et al. 2002). For example, commercial harvest of shovelnose sturgeon in Missouri waters of the Mississippi River during 1999, 2000, and 2001 was 30, 51, and 87% greater, respectively, than the mean for the previous 10 years (i.e., 1988–1998; V. Travnichek, Missouri Department of Conservation, unpublished data).

The Wabash River, Indiana, supports a viable commercial fishery for shovelnose sturgeon. Most harvest occurs between mid-October and late May, with the peak harvest occurring during the spawning migration (April through May; R. Maher, Illinois Department of Natural Resources, personal communication). This fishery focuses on gravid females that provide black roe that is processed into caviar. Commercial fishing activities in the Wabash River are restricted to the reach downstream from the State Road 26 (SR 26) bridge near Lafayette, Indiana (hereafter referred to as the lower reach), to its confluence with the Ohio River (Figure 1). Hoop nets are the only legal commercial fishing gear in the Wabash River, and there are no length restrictions or closed seasons for shovelnose sturgeon. The reach from SR 26 extending upstream to the J. Edward Roush Lake dam near Huntington, Indiana, serves as a refugia from commercial fishing (hereafter referred to as the upper reach). However, recreational harvest of shovelnose sturgeon, including the use of one set line ($\leq$50 hooks) per angler, is permitted throughout the entire river.

The objectives of this study were to determine the relative abundance, size and age structure, growth, mortality rate, condition, and gender ratio of shovelnose sturgeon from the upper Wabash River, Indiana. These data were used to determine the status of the shovelnose sturgeon population in this system and to increase our understanding of the biology of this species. These results provide baseline data against which to measure population-level changes in the future.

Study Site

The Wabash River is 764 km in length, courses southwest across northern Indiana, and becomes the

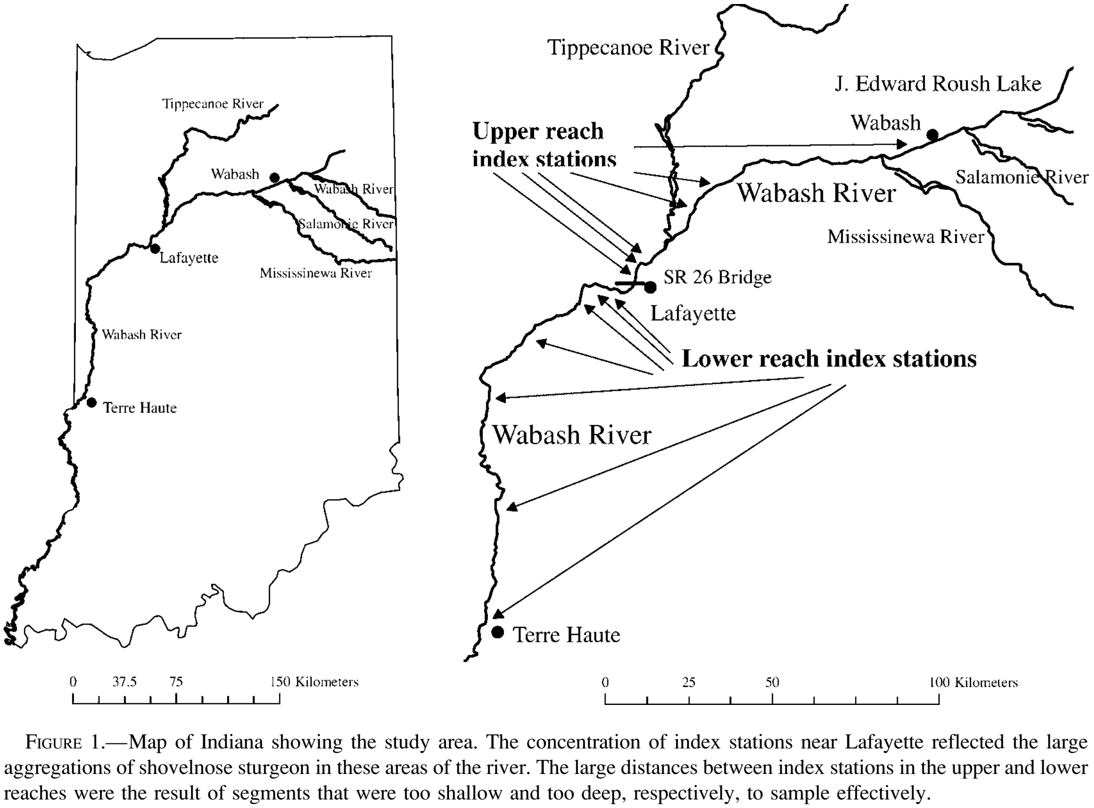

FIGURE 1.—Map of Indiana showing the study area. The concentration of index stations near Lafayette reflected the large aggregations of shovelnose sturgeon in these areas of the river. The large distances between index stations in the upper and lower reaches were the result of segments that were too shallow and too deep, respectively, to sample effectively.

portion of the east–west boundary between Indiana and Illinois before reaching its confluence at the Ohio River (Figure 1). The river has a large (85,500 km^2) drainage area, which includes 62,000 km^2 of Indiana, 22,540 km^2 of Illinois, and 740 km^2 of Ohio. The Wabash River is the twelfth largest river in the USA and contains the longest free-flowing section of river in the eastern United States (662 km; Gammon 1998). The hydrograph of the river is highly variable and is only slightly moderated by its one main-stem reservoir (J. Edward Roush Lake, Huntington, Indiana; 364 ha) and the impoundments associated with its major tributaries (e.g., the Mississinewa, Salamonie, and Tippecanoe rivers). Shovelnose sturgeon were collected from the upper Wabash River between Wabash and Terre Haute, Indiana (Figure 1). This 295-km reach lies entirely within Indiana and consists of two distinct reaches: the 121-km upper reach between Wabash and Lafayette and the 174-km lower reach between Lafayette and Terre Haute. The upper section was characterized by shallow water depths (range, <3 m), associated with sand, gravel, cobble, and bedrock substrates. The lower section of the study reach was deeper (range, 0.5–15 m), with a mixture of clay, sand, and gravel substrates. Land use throughout the study reach was primarily row-crop agriculture. Although riparian zone buffer strips were present in some areas, water conditions were generally turbid (visibility range, 0–1 m in depth).

Methods

Fish collection.—Shovelnose sturgeon were collected from April 2003 through November 2004 by a combination of boat electrofishing, gill nets, and benthic trawls. Hoop nets were used to sample during a pilot study, but proved to be less effective than other gears and so were not used for this study. Sampling was conducted during periods when sampling was deemed to be effective, defined by river stage resting at or below a maximum gauge height defined for that sampling location. As a general guideline, boat electrofishing surveys occurred when the river discharge was less than 170 m^3 (range, 54–212 m^3/s) and gill nets were used at river levels at or below flood stage for the Lafayette gauging station (487 m^3/s; range, 113–708 m^3/s). Trawling was conducted at a variety of water levels throughout the upper and lower reaches (range, 85–263 m^3/s).

Fish were collected by daytime electrofishing using 4- to 6-A direct current with 30 pulses per second and a 20–50% range of pulse width. Six electrofishing index stations (approximately 1 km in length) were established in the upper reach, whereas the lower reach contained seven stations of similar length (Figure 1). Each index station consisted of three passes in a downstream direction. The initial pass occurred within the third of the river closest to the left bank descending, the second pass was within the middle third of the river, and the third pass was within the third of the river closest to the right bank descending. Data were collected from all captured fish after each pass of the index station to identify that third (i.e., right, middle, or left) of the river from which each fish was collected. Additional electrofishing "spot" sampling occurred outside the index stations in an attempt to locate shovelnose sturgeon, increase the number of tagged fish in the system, and sample the river along a continuum. Catch per unit effort (CPUE) for both electrofishing approaches was reported as the number of shovelnose sturgeon captured per hour.

To reduce conflict with commercial fishers, gill nets were not used in the lower reach. Each net was 30.5 m in length, 1.2 or 2.4 m in depth, and contained four 7.6-m panels of 38-, 51-, 76- and 102-mm-bar mesh. Gill nets were oriented perpendicular to the river flow and drifted downstream over gravel bars (depth range, 1–4 m) for 1–6 min. Catch per unit effort was defined as the number of shovelnose sturgeon captured per 5 min that the net was drifted (i.e., the average length of a net drift).

Benthic trawling was conducted in both the upper and lower reaches using a nylon shrimp trawl (headrope: 3.6 m; trawl body: 38-mm-bar mesh; cod end: 31-mm-bar mesh; towing warp: 30-m polypropylene rope, diameter = 10 mm) with paired wooden otter doors (30.5 cm × 61 cm). The trawl was attached to the stern of the boat and towed in a downstream direction at a speed slightly greater than the current (mean speed = 7 km/h). The duration of each trawl tow ranged from 2 to 7 min (mean = 4 min). Catch per unit effort was reported as the number of shovelnose sturgeon captured per minute of trawling.

All captured shovelnose sturgeon were measured for fork length (FL) to the nearest 1 mm and wet weight to the nearest 1 g, except for 75 fish that could not be weighed because of equipment failure. A 25-mm segment of the left pectoral fin ray was removed from each fish and dried in the laboratory for subsequent age analysis (Helms 1974b). All fish were inspected for an egg check (i.e., scars on the abdomen of fish as a result of an incision made by commercial fishers to determine if the fish contained marketable roe). Incisions are presumably made with a pocket knife, ranging from 10 to 20 mm in length (or more). Although conditions are not aseptic and the incisions are not sutured, healing and subsequent scarring are evident. When feasible, gravid females were identified externally (i.e., swollen abdomen during the spawning season). Before release, each fish was examined for the presence of a tag and, if none was present, we implanted a passive integrated transponder (PIT) tag (Biomark, Inc., Boise, Idaho; 2003 sampling season) or t-bar anchor tag (Floy Tag, Inc., Seattle, Washington; 2004 sampling season) at the base of the dorsal fin or pectoral girdle, respectively.

Laboratory analysis.—In the laboratory, cross sections of the base of the marginal pectoral fin ray were cut at a thickness of 0.7 mm with a Buehler Isomet low-speed saw outfitted with a diamond-cutting blade (Buehler, Ltd., Lake Bluff, Illinois). Cross sections were placed on a glass slide and viewed over transmitted light with a stereomicroscope (1.6× magnification) to which a digital camera (Diagnostic Instruments, Sterling Heights, Michigan) was attached. Readers counted the number of translucent bands to estimate fish age. Age estimations were made by two independent readers examining identical images of each cross section; discrepancies between readers were resolved with a subsequent concert read. Discrepancies between readers were reported as the percent of fish for which age estimates were less than 1, 2, and 3 years.

Three hundred thirty-eight fish (7% of the total catch) were subsampled for age analysis by using a length-stratified random sampling approach. Thirty fish per 25-mm group (15 fish per 25-mm group per reach) were randomly selected and aged to ensure representation of fish captured throughout the entire study area (DeVries and Frie 1996). For FL groups within a reach that contained less than 15 individuals, individuals from the other reach were incorporated to increase sample size. The coefficient of variation (CV; 100·SD/mean) for age estimations was calculated for each fork length-group (range, 7.4–23.0%; mean = 18.2%). An additional 20 individuals were aged for the length category with the highest CV (700-mm-FL group; CV = 23.0%) to determine the effect of subsample size on estimating the age structure of the population. Because the CV for the 700-mm-FL group declined by only 3.3% when the sample size was increased to 50, we decided 30 fish per 25-mm group was an appropriate sample size.

Data analyses.—Movement data (L. Frankland and R. Maher, Illinois Department of Natural Resources, unpublished data; T.M.S. and A.J.K., unpublished data) suggested that shovelnose sturgeon in the Wabash River moved long distances (up to 280 km) and consistently crossed the demarcation of the upper and lower reaches. As a result, the upper and lower reach were referenced to identify a general portion of the study area for CPUE analyses. However, for all other analyses, data from both reaches were pooled, and the results represent the entire study area.

The size structure of shovelnose sturgeon was examined with length-frequency distributions and two stock-density indices. Length-frequency distributions were reported as the percent of the total catch composed of each 25-mm group. Proportional stock density (PSD) was estimated as the ratio of the number of fish greater than or equal to the species' quality length (380 mm) to the number of fish greater than or equal to the designated stock length (250 mm; Gabelhouse 1984). Relative stock density (RSD) was estimated as the ratio of the number of fish greater than or equal to a specified length to the number of fish greater than or equal to the designated stock length (Wege and Anderson 1978; Gabelhouse 1984). Quist et al. (1998) reported minimum lengths for shovelnose sturgeon RSD categories as: stock (RSD-S) = 250 mm FL, quality (RSD-Q) = 380 mm FL, preferred (RSD-P) = 510 mm FL, memorable (RSD-M) = 640 mm FL, and trophy (RSD-T) = 810 mm FL.

A von Bertalanffy growth model was constructed for the population by using Fishery Analyses and Simulation Tools software (FAST; Slipke and Maceina 2000). The model was calculated as

$$l_t = L_\infty\left[1 - e^{-K(t-t_0)}\right],$$

where l_t was fish body length (FL) at time t, L_∞ was the theoretical maximum fish length, K was the rate at which length approaches L_∞, and t_0 was the time when fish body length was equal to 0 mm (Van Den Avyle 1999). The data used to calculate L_∞, K, and t_0 were the age and mean length at age.

A wet weight–FL relationship was developed by using linear regression of $\log_e$ transformed weight and length data. Body condition was examined in terms of estimates of relative weight (W_r) based on the following length-specific standard weight equation:

$$\log_{10} W_s = -6.287 + 3.330 \cdot \log_{10}\mathrm{FL},$$

where W_s was the length-specific standard weight and FL was as previously defined (Quist et al. 1998).

Total instantaneous mortality (Z) was estimated using catch-curve analysis (Ricker 1975). The number of fish captured in each age-class was plotted versus age to detect the age at which shovelnose sturgeon fully recruited to the sampling gear. Age-classes that were not fully recruited to the gear and those that contained fewer than five individuals were excluded from further analysis. Annual survival (S) and mortality (A) rates were derived from the total instantaneous mortality rate (Van Den Avyle 1999).

Because older age-classes of shovelnose sturgeon are difficult to age accurately (Helms 1974b; Jackson 2004) and because the catch for ages 19–24 ranged from 8 to 361 individuals, we also calculated mortality rates using Heincke's method (Ricker 1975). This approach required that only the youngest age-class fully recruited to the sampling gear was aged accurately. Total annual mortality by this method was calculated as

$$A = 1 - [(n - n_0)/n],$$

where n was the sum of the frequencies of each age-class fully recruited to the sampling gear and n_0 was the frequency of the youngest age fully recruited to the sampling gear.

Gender ratio was determined from fish captured during the 12-week period between 17 March and 8 June 2004. Although male and female shovelnose sturgeon are indistinguishable during most of the year, stage-5 and −6 females (i.e., gravid and spent, respectively) could be identified by way of external characteristics (i.e., soft, swollen abdomen or loose, stretched belly skin and red vent, respectively; Moos 1978) during the spawning season. To ensure that the gender ratio reflected a conservative estimate of the female component of the catch, fish that could not be confidently identified as females were given a gender assignment of "unknown." Thus, the unknown category contained all male fish from the sample and females that were not spawning that year (i.e., stages 2–4) and reflects the observed percentage of the catch that was female. As a result, two gender ratios were reported; the ratio of unknown to female fish (unknown : female) and the male to female ratio (male : female). Because female shovelnose sturgeon have been reported to spawn every 2 to 3 years (Helms 1974a; Moos 1978), the estimated male : female ratio was derived by doubling the unknown : female ratio. Both of these ratios were calculated only from the catch that represented the sexually mature population (i.e., FL $\geq$ 600 mm; Kennedy et al. 2006).

Results

A total of 4,849 shovelnose sturgeon were captured from 29 May 2003 through 22 November 2004. Sampling occurred on 127 d during the study period, with every month being represented by at least 1 d (range, 1–17 d; median = 7 d) except January and October 2004. Boat electrofishing was done on 109 of those days and accounted for the capture of 3,816 shovelnose sturgeon (79% of the total catch). Gill nets were used on 25 d and resulted in the capture of 993 fish (20% of the total catch), and benthic trawls were used on 7 d, capturing 40 fish (1% of the total catch). Because of the low recapture rate of marked fish (4.5%; 215 recaptures/4,789 marked fish) during the study period, we did not calculate an absolute population abundance estimate.

Catch per unit effort for boat electrofishing was greater for the upper reach (range, 5–90 fish/h) from

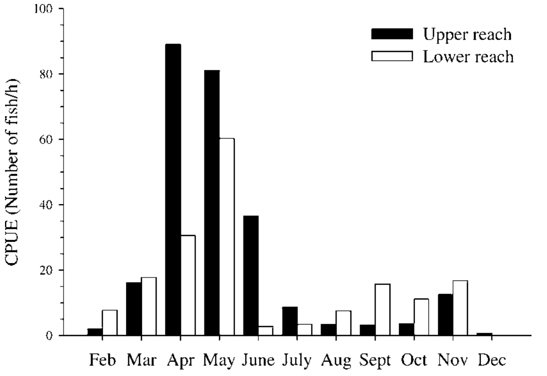

FIGURE 2.—Catch per unit effort (CPUE) at shovelnose sturgeon electrofishing index stations by month for the upper and lower reaches of the upper Wabash River, Indiana.

April through July, whereas the lower reach had a higher CPUE from August through February (range, 4–12 fish/h greater; Figure 2). During March, CPUE was similar for each reach. Catch per unit effort was as high as 478 fish/h in the upper reach for spot-sampling efforts over shallow gravel bars (i.e., suspected spawning locations) in late April and early May (i.e., during the spawning season), whereas CPUE in the lower reach during this time was 89 fish/h. For all electrofishing efforts combined (i.e., index stations and spot sampling, upper and lower reaches), CPUE was 24.3 fish/h. Forty-eight percent of shovelnose sturgeon were captured in the middle of the river (i.e., the second electrofishing pass); 24% and 28% were captured near the right and left bank descending, respectively.

Catch per unit effort for drifted experimental gill nets was 2.8 fish/min during spring (i.e., March through June). With benthic trawls, CPUE was 3.5 fish/min, but 33% of the total number of fish captured using this method were caught during a single, 1.5-min tow. Benthic trawling efforts were discontinued as a result of the high frequency with which the trawl became snagged on the bottom of the river.

Shovelnose sturgeon ranged from 273 to 858 mm FL (Figure 3). Mean FL and wet weight were 683 mm and 1,208 g, respectively. Most fish captured ranged from 600 to 799 mm fork length (N = 4,587 fish; 94.6%), 1.3% (N = 61 fish) of the catch being greater than 800 mm FL. Small size-classes (i.e., <550 mm) were not well represented, accounting for only 0.2% (N = 10 fish) of the total catch. The wet weight–FL relationship for shovelnose sturgeon was significant ($r^2 = 0.84$, $P <$ 0.001; Figure 4). Median relative weight of shovelnose sturgeon in the upper Wabash River was 82.

The precision of age estimates for shovelnose sturgeon was variable. Although only 13% of age

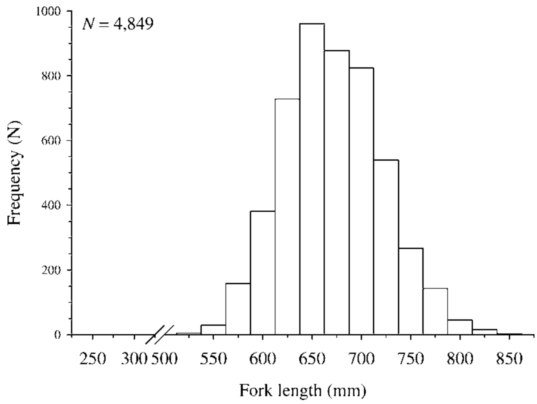

FIGURE 3.—Length-frequency distribution for shovelnose sturgeon from the upper Wabash River, Indiana. The 250-mm and 275-mm groups each contained only one fish, so the bars for these categories are not visible.

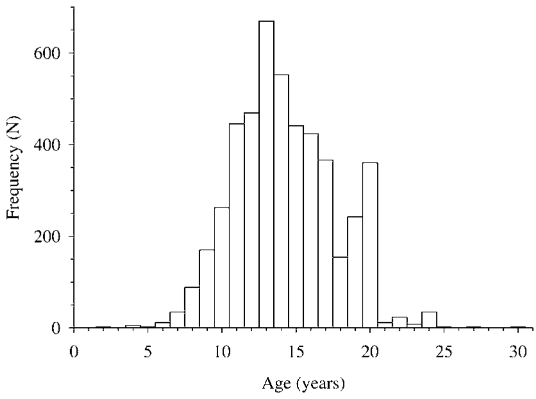

FIGURE 5.—Age structure of shovelnose sturgeon from the upper Wabash River, Indiana, extrapolated from a length-stratified subsample ($N = 338$ fish).

estimations made by each reader were in agreement, 40% of the estimates were within 1 year of each other. Further, 61% and 73% of age estimations were within 2 and 3 years, respectively, of each other. The mean and median discrepancies in age estimates between readers were 2.7 and 2 years, respectively.

The age structure of shovelnose sturgeon comprised fish from 24 age-classes (range, ages 2–30; Figure 5). The frequency of fish in each age-class increased through age 13, which indicated that shovelnose sturgeon did not fully recruit to the sampling gears until this age. Ninety-five percent of the fish captured were between age 9 and age 20 with 55% between age 13 and age 18. Few fish captured were younger than age 6 ($N = 4$ fish) or older than age 24 ($N = 4$ fish).

The annual growth rates of shovelnose sturgeon predicted by the von Bertalanffy growth model declined with age (Figure 6). The mean predicted growth rates for shovelnose sturgeon ages 2–9 and 10–19 were 39 and 13 mm per year, respectively. Growth rates of older age-classes of shovelnose sturgeon (i.e., ages 20–29) were lower, with a mean predicted growth rate of 4 mm per year. The predicted mean length of shovelnose sturgeon for the most frequent age-class (age 13) was 693 mm FL. Shovelnose sturgeon were recruited to the commercial fishery (i.e., reached sexually maturity) by age 9 (approximately 600 mm FL). Empirical growth rates derived from mark–recapture data were low, with mean differences in FL between mark and recapture being −2 mm and 10 mm for fish that had been at large for 6–12 months or for 1–3 years, respectively.

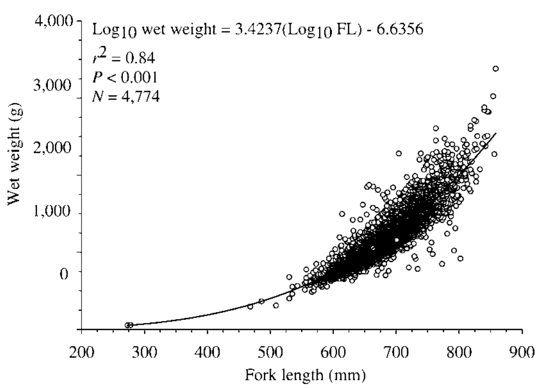

FIGURE 4.—Weight–length relationship for shovelnose sturgeon from the upper Wabash River, Indiana. The estimated line represents wet weight as a power function of FL.

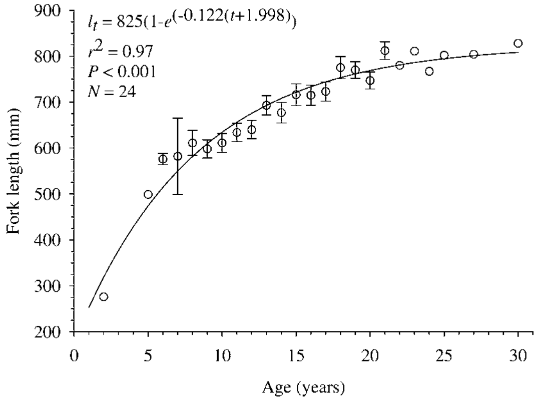

FIGURE 6.—Mean length at age for shovelnose sturgeon from the upper Wabash River, Indiana. Error bars represent 95% confidence intervals; confidence intervals were not calculated for age-classes with fewer than five fish. The line is the fitted von Bertalanffy growth function.

Further, 74% of recaptures exhibited zero or negative growth regardless of time at large.

The size structure of the shovelnose sturgeon population was skewed towards large fish (>600 mm FL). Proportional stock density was 100 (i.e., all fish were greater than the minimum stock length of 250 mm FL), and more than 99% of the fish captured were of preferred length (510 mm FL). The relative stock density for the memorable size-class (640 mm FL) was 81, but few trophy fish (810 mm FL) were captured (RSD-T < 1).

Mortality estimates were calculated for shovelnose sturgeon between ages 13 and 18 by using catch-curve analysis and for ages 13–24 by Heincke's method. Total instantaneous mortality from the catch-curve analysis was 0.247 (95% confidence interval [CI], 0.209–0.284). The annual mortality estimated from the catch curve was 0.219 (95% CI, 0.158–0.247). The annual mortality rate estimated using Heincke's method was 0.204 (95% CI, 0.197–0.211), and the total instantaneous mortality rate was 0.228 (95% CI, 0.221–0.235).

The gender ratio of shovelnose sturgeon was skewed toward male fish. The unknown : female ratio for sexually mature shovelnose sturgeon was 4.5:1 (18.2% female), and the estimate of the male : female ratio was of 1.8:1 (36.4% female). Fish less than 600 mm FL were not included in this analysis because few fish less than this size would be sexually mature.

A total of 103 shovelnose sturgeon (range, 610–856 mm FL) exhibited egg checks, which represented 2.4% of the total catch of fish greater than 600 mm FL (i.e., that portion of the population recruited to the commercial fishery; Table 1). Multiple egg checks (range, 2–5) were observed for eight fish (0.18% of the total catch) and 7.8% of fish that had egg checks displayed multiple scars. We could not determine whether fish that displayed multiple egg-check scars had received them during a single capture event or had been captured on multiple occasions and received one check each time. Female shovelnose sturgeon composed 8.5% of the fish that had an egg check. The mean FL of shovelnose sturgeon with an egg check was 718 mm, and fish greater than 775 mm FL were 3.5 times more likely to display an egg check than individuals smaller than this length.

TABLE 1.—Frequency of shovelnose sturgeon with egg checks (scars) by fork length (FL, mm) group in the upper Wabash River, Indiana.

FL group[a]	Sample size	Number of egg checks: 1	Number of egg checks: >1	% With egg checks
600	370	3	0	0.8
625	694	4	0	0.6
650	926	13	1	1.4
675	837	14	0	1.7
700	788	23	1	2.9
725	515	23	2	4.5
750	258	10	2	3.9
775	133	9	2	6.8
800	43	3	0	7.0
825	15	0	0	0.0
850	3	1	0	33.3
Total	4,582	103	8	2.4

[a] The 600-mm group includes fish ranging from 600 to 624 mm in length, the 625-mm group fish ranging from 625 to 649 mm, and so forth.

Discussion

Electrofishing CPUE for the upper Wabash River (24.3 fish/h) was greater than that reported for the lower Wabash River (i.e., below Terre Haute, Indiana; 15.2 fish/h) by Jackson (2004). Temporal trends in CPUE between the upper and lower reach suggest seasonal differences in the distribution of shovelnose sturgeon throughout the Wabash River. Relative abundance of shovelnose sturgeon was greater in the upper reach during spring, which was most likely attributable to upstream migrations associated with spawning activities, as hypothesized by Curtis et al. (1997) for the Mississippi River. By mid- to late summer (i.e., August), fish moved back downstream, as indicated by an increase in CPUE in the lower reach. Higher relative abundance of shovelnose sturgeon in the upper reach during the spawning period suggests that this reach contains suitable shovelnose sturgeon spawning habitat (i.e., gravel bars in riffle habitats; Pflieger 1997) and may have a significant role in sustaining this population by acting as a spawning refugia. Electrofishing CPUE data for shovelnose sturgeon outside of the Wabash River are not available, which precluded comparisons of relative abundance across river systems.

The size structure of shovelnose sturgeon populations throughout their geographic distribution is highly variable (Jackson 2004); most populations are skewed toward large fish as a result of sampling gear biases. For example, Quist et al. (1998) reported that all but 1 of 32 populations of shovelnose sturgeon examined from the Mississippi and Missouri drainages had PSD values greater than 79. The size structure of shovelnose sturgeon in this study was also skewed toward large fish (e.g., PSD = 100; RSD-M = 81); few small fish were captured. The lack of small fish in our sample was probably the result of size bias associated with gill-net mesh size and boat electrofishing. However, the presence of few small fish in our sample may also be the result of larval shovelnose sturgeon drifting downstream beyond the lower end of our sampling area (Terre Haute) and residing in these areas until they are ready to spawn, at which time they would move upstream into our study area. Both of the fish less than 300 mm FL captured in this study were located near Montezuma, Indiana (near the lower bound of our sampling reach); several others have been captured near Terre Haute (L. Frankland, Illinois Department of Natural Resources, personal communication). Although the potential for shovelnose sturgeon recruitment in the Wabash River is high (i.e., there is a large adult population), a series of year-class failures over the past several years could also explain the lack of small fish in our sample.

Longevity, mean length, and maximum length of shovelnose sturgeon vary substantially within and among river systems (Helms 1974a, 1974b; Morrow et al. 1998; Everett et al. 2003). Quist et al. (2002) used different estimates for maximum age for each of three different sections of the Missouri River. In addition, the maximum age reported in the literature ranges from 16 to 43 (Helms 1974b; Morrow et al. 1998; Everett et al. 2003). Similarly, the mean and maximum length reported for shovelnose sturgeon ranged from 611 to 689 mm and 693–994 mm FL, respectively, and estimates of L_∞ ranged from 660 to 842 mm (Christenson 1975; Morrow et al. 1998; Quist et al. 2002; Everett et al. 2003; Jackson 2004). Maximum age of shovelnose sturgeon in this study (age 30) fell within the reported range for this species, but few individuals older than age 24 were captured. The mean FL for shovelnose sturgeon in the upper Wabash River (683 mm FL) was greater than reported for populations throughout the Mississippi and Missouri rivers (range, 611–681 mm FL; Helms 1974a; Morrow et al. 1998; Everett et al. 2003; Jackson 2004). The Yellowstone River contained the only population that had a greater reported mean FL (689 mm) than the upper Wabash River (Everett et al. 2003). The maximum observed length (858 mm FL) and L_∞ (825 mm) for shovelnose sturgeon in the upper Wabash River were also within the range reported for this species and were most comparable with those in the Yellowstone River. These results suggest that size and age structure estimates of shovelnose sturgeon in the upper Wabash River were near the upper range observed for other systems. The sources of variation in body size and age structure among river systems are not well understood, but differences in abundance, exploitation rates, and mean water temperature have been hypothesized to be potential contributing factors (Everett et al. 2003).

Shovelnose sturgeon are notoriously difficult to age because of their closely spaced and false annuli (Helms 1974a; Morrow et al. 1998; Jackson 2004; Whiteman et al. 2004). Reader agreement for this study (13%) was less than the 18% reported for shovelnose sturgeon, 17–31% for lake sturgeon, and 37% for white sturgeon *A. transmontanus* (Brennan and Calliet 1989; Rien and Beamesderfer 1994; Whiteman et al. 2004). However, mean reader discrepancy for this study was 2.7 years, which was similar to the 1.6–4.3 years reported for shovelnose sturgeon by Whiteman et al. (2004). Further, age estimates by each reader in this study were within 3 years of each other for 73% of age estimates (247/338), a proportion similar to those reported for shovelnose, lake, white, and pallid sturgeon *S. albus* (Brennan and Calliet 1989; Rien and Beamesderfer 1994; Hurley et al. 2004; Whiteman et al. 2004).

No size-dependent trends in CV values for age estimations for shovelnose sturgeon were detected. These results are in contrast to reports for shovelnose sturgeon by Whiteman et al. (2004) that suggested age estimates were more variable between readers for older fish. This difference may be because the shovelnose sturgeon aged during this study were larger than those examined from the Missouri River by Whiteman et al. (2004). Larger fish have larger fin rays and thus annuli separation may have been more apparent on older (700–850 mm FL) fish in this study than for older fish (<700 mm FL) from the Missouri River.

The shovelnose sturgeon in this study did not fully recruit to the sampling gears until age 13 (approximately 670 mm FL). However, each age-class greater than age 5 (ages 6–24) was represented in the catch, which indicated that recruitment occurred on an annual basis until 1998. The age at which fish in this study fully recruited to the sampling gear was 5 and 6 years later than reported for populations of shovelnose sturgeon in the middle and lower Mississippi River, respectively (Morrow et al. 1998; Jackson 2004). This was probably because shovelnose sturgeon in the Wabash River exhibited slower growth rates than those in the Mississippi River. Further, the sampling gears used in this study (i.e., gill nets and electrofishing) were selective for large-bodied (older) fish (Hubert 1996; Reynolds 1996). This study could not determine whether the absence of young age-classes of shovelnose sturgeon reflected low recruitment rates or biases associated with sampling gear and habitat use. However, the frequency of each age-class greater than age 5 increased, which suggests that the low number of fish at younger age-classes was due to sampling gear bias or to not sampling in the appropriate habitats rather than to low recruitment.

The total annual mortality rate for shovelnose sturgeon from ages 13 to 24 in the upper Wabash River was 20%, which suggests that exploitation in the study area was low. However, no tag returns were received from commercial or recreational anglers to allow determination of exploitation rates. This estimate of total annual mortality is similar to reports for the Mississippi River by Morrow et al. (1998) and falls within the range reported for other systems (3–42%; Morrow et al. 1998; Quist et al. 2002; Jackson 2004). Jackson (2004) reported that the total annual mortality rate for shovelnose sturgeon ages 8 and older for the lower Wabash River was 31% and suggested that harvest was the cause for this high mortality rate. Although mortality in the lower Wabash River may be greater than in the upper river, their estimate was based on a limited sample size ($N = 118$) and on fish caught during primarily during summer. Mortality estimates derived for the upper Wabash River incorporated fish captured during all seasons ($N = 338$), most of the large fish (i.e., older fish >800 mm FL) being captured during fall or spring months. As a result, the difference between mortality estimates between the upper and lower Wabash River may result from biases associated with sampling season and sample size rather than exploitation.

Growth rates of shovelnose sturgeon derived from long-term mark–recapture studies have reported minimal, negative, or no growth for fish during their time at large (e.g., Helms 1973; Christenson 1975). Christenson (1975) reported length differences of −8 to +10 mm for shovelnose sturgeon that had been at large for 7–58 months in the Chippewa–Red Cedar River. Further, a shovelnose sturgeon recaptured in the Missouri River that had been at large for over 20 years had grown only 25 mm (V. Travnichek, personal communication). The empirical growth rates of shovelnose sturgeon in this study were also minimal; the mean increase in FL for fish at large for 6–12 months was −2 mm (range, −7 to +4 mm). These reports suggest that, once shovelnose sturgeon approach their maximum length, growth in length becomes negligible. The von Bertalanffy Brody growth coefficient (K) estimated for this study (0.122) was less than was reported for shovelnose sturgeon in the Mississippi (0.213, Morrow et al. 1998; 0.30, Jackson 2004), Missouri (0.273, 0.168, and 0.191; Quist et al. 2002), and lower Wabash River (0.22, Jackson 2004). These results suggest that growth rates of shovelnose sturgeon in the upper Wabash River were generally less than in other rivers for all length classes. Despite slow growth rates, fish were still able to attain large body sizes (i.e., >800 mm FL), which probably happened because fish in this study reached ages greater than those reported for most populations in the Mississippi, Missouri, and lower Wabash rivers.

We were unable to make comparisons of egg-check frequency across river systems and exploitation rates because these data are not available for other systems. However, the frequency of fish with egg checks in the lower Wabash River from 2001 to 2004 ranged from 5% to 6% (L. Frankland, Illinois Department of Natural Resources, unpublished data), greater than the 2.4% observed in this study. These differences may result from greater commercial fishing pressure in the lower Wabash River (i.e., below Terre Haute) relative to the lower reach in this study (i.e., Lafayette to Terre Haute). Furthermore, the majority of fish captured in this study were from the upper reach, which does not experience commercial harvest. The majority of egg checks observed on shovelnose sturgeon in the upper Wabash River were healed and did not appear to have deleterious effects on the fish.

Gravid female shovelnose sturgeon composed 18% of the total catch in the upper Wabash River. Carlson and Pflieger (1981) and Moos (1978) reported that 18% and 29%, respectively, of their catch in the Missouri River were gravid females. Because identification of gravid female shovelnose sturgeon is subjective, individuals for which gender determination was questionable in our study were not reported as females. Kennedy et al. (2006) reported that all 49 fish visually identified as gravid females and subsequently sacrificed for fecundity estimates were indeed gravid females (i.e., 100% accuracy), which suggests that external identification of females for this study was also accurate. Christenson (1975) and Moos (1978) reported ovaries in different stages of development throughout the year and suggested that shovelnose sturgeon spawn every 2 to 3 years. Similarly, a sample of fish sacrificed for study by Kennedy et al. (2006) during April 2004 contained sexually mature female fish with ovaries in various stages of development. The presence of known females with egg checks ($N = 8$) within the sample of egg-checked fish suggests that female shovelnose sturgeon in the Wabash River do not spawn every year. As a result, doubling the percent of the catch that was female should yield a conservative estimate of the percent of the population that was female. The estimated percentage of the upper Wabash River population consisting of female fish was 36% (i.e., male to female ratio = 1.8:1). Although the gender ratio was skewed towards male fish, as expected for a species supporting a gender-specific (female) commercial fishery, the low male : female ratio suggests that this population experienced low rates of exploitation.

This study suggests that population characteristics of shovelnose sturgeon in the upper Wabash River are within the range reported for other river systems. Although growth rates and relative weight were lower than observed for many river systems, shovelnose sturgeon in the Wabash River attained a larger body size, reached older age classes, and appeared to experience lower mortality rates than elsewhere. Aggregations of fish in spawning condition during April and May and the collection of several spent females suggest that this species was spawning, and many of these aggregations were located on shallow gravel bars in the upper reach. The large number of fish observed ($N = 4{,}849$) and a gender ratio that is only slightly skewed towards males suggests that the potential for recruitment was high, although sampling methods for this study were unable to detect recruitment to young age-classes (i.e., ages 1–5). As a result, this study described only the population characteristics and status of adult (i.e., >600 mm FL) shovelnose sturgeon. This qualifier must be considered when using the population parameters reported in this study to evaluate the status and viability of shovelnose sturgeon in the upper Wabash River. Future studies should attempt to evaluate spawning success and quantify recruitment to increase our understanding of population dynamics and facilitate the development of appropriate management actions that will ensure the sustainability of this species and its fishery.

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