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[Management Brief]

Abundance of Adult Saugers across the Wind River Watershed, Wyoming

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Abstract.—The abundance of adult saugers *Sander canadensis* was estimated over 179 km of continuous lotic habitat across a watershed on the western periphery of their natural distribution in Wyoming. Three-pass depletions with raft-mounted electrofishing gear were conducted in 283 pools and runs among 19 representative reaches totaling 51 km during the late summer and fall of 2002. From 2 to 239 saugers were estimated to occur among the 19 reaches of 1.6–3.8 km in length. The estimates were extrapolated to a total population estimate (mean ± 95% confidence interval) of 4,115 ± 308 adult saugers over 179 km of lotic habitat. Substantial variation in mean density (range = 1.0–32.5 fish/ha) and mean biomass (range = 0.5–16.8 kg/ha) of adult saugers in pools and runs was observed among the study reaches. Mean density and biomass were highest in river reaches with pools and runs that had maximum depths of more than 1 m, mean daily summer water temperatures exceeding 20°C, and alkalinity exceeding 130 mg/L. No saugers were captured in the 39 pools or runs with maximum water depths of 0.6 m or less. Multiple-regression analysis and the information-theoretic approach were used to identify watershed-scale and instream habitat features accounting for the variation in biomass among the 244 pools and runs across the watershed with maximum depths greater than 0.6 m. Sauger biomass was greater in pools than in runs and increased as mean daily summer water temperature, maximum depth, and mean summer alkalinity increased and as dominant substrate size decreased. This study provides an estimate of adult sauger abundance and identifies habitat features associated with variation in their density and biomass across a watershed, factors important to the management of both populations and habitat.

Saugers *Sander canadensis* are widely distributed in North America. They are native to the Mississippi–Missouri, Great Lakes, and Hudson Bay drainages (Pflieger 1975). Saugers occur naturally in large rivers and the lower portions of their tributaries (Hesse 1994), and adult saugers have been described as preferring turbid river segments that have deep, low-velocity pools and runs with sand or silt substrates and cover features that provide refuge from currents (Ali et al. 1977; Crance 1988; Vallazza et al. 1994; Gangl et al. 2000; McMahon and Gardner 2001). Summer thermal preferences of saugers are 20–28°C (Dendy 1948), and it is likely that relatively warm temperature needs govern the northern and western boundaries of the species' range (Braaten and Guy 2002; Amadio et al. 2005).

Recent surveys suggest that sauger populations are declining throughout much of their native range (Nelson and Walburg 1977; Scott 1984; Yeager and Siao 1992; Hesse 1994; Maceina et al. 1998; McMahon and Gardner 2001). Many sauger populations in the Great Plains have declined in association with the construction of reservoirs that have inundated long reaches of rivers and affected downstream habitat. Relatively little is known about the habitat associations of saugers in small, high-elevation rivers in the upper Missouri River watershed (McMahon and Gardner 2001; Welker et al. 2002a, 2002b; Amadio et al. 2005). Due to the large size of rivers where most saugers occur, there has been little research attempting to estimate sauger numbers, density, or biomass. We are aware of no published estimates of sauger abundance in lotic systems or assessments of relationships between sauger density or biomass and variation in habitat factors across watersheds or over long segments of rivers.

Amadio et al. (2005) identified factors affecting the occurrence of adult saugers throughout the Wind River basin upstream from Boysen Reservoir on the periphery of the species' natural distribution in Wyoming. They found a contiguous distribution of saugers over 179 km of streams among four rivers in the watershed and determined that upstream boundaries were formed by low summer water temperatures, high channel slopes, and water diversion dams that created

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barriers to upstream movement. We used the same data set as Amadio et al. (2005) to address questions regarding abundance of saugers within their distribution in the Wind River watershed upstream from Boysen Reservoir. Our objectives were to estimate the abundance of adult saugers in the watershed, describe variation in adult sauger density (fish/ha) and biomass (kg/ha) across the watershed, and identify basin-scale and instream habitat features influencing this variability across the watershed. Based on previous studies of sauger ecology, we hypothesized that sauger biomass would be positively associated with the availability of deep, low-gradient pools and high summer water temperature, turbidity, and nutrient levels (Hesse 1994; Pegg et al. 1997; Vallazza et al. 1994; Maceina et al. 1996; Gangl et al. 2000; Welker et al. 2002a).

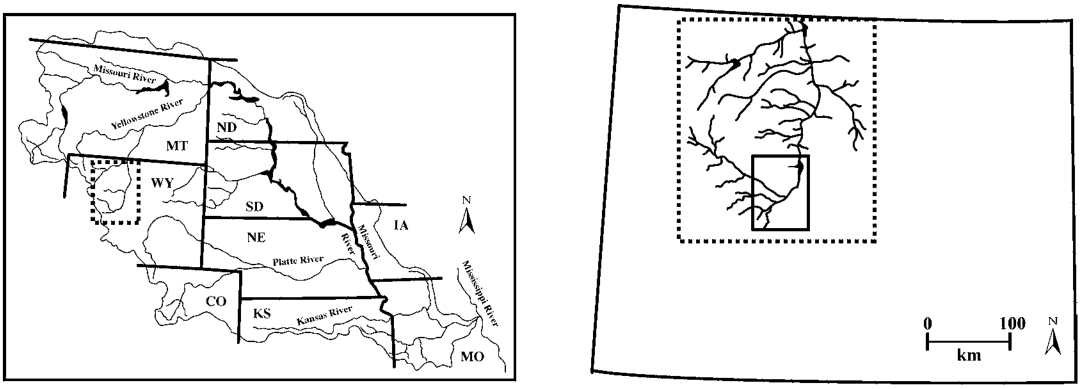
Methods

The study area comprised the 179 km of perennial rivers in the Wind River watershed upstream from Boysen Reservoir where saugers were found by Amadio et al. (2005) and included 58 km of the Wind River immediately upstream from Boysen Reservoir, 59 km of the Little Wind River, 38 km of the Popo Agie River, and 24 km of the Little Popo Agie River (Figure 1). The approaches to the sampling of habitat and saugers are described in detail by Amadio et al. (2005). One reach that was representative of the habitat was established in each river segment (Figure 1). The elevation above mean sea level, channel gradient, and sinuosity of each reach were estimated from U.S. Geological Survey 1:24,000-scale topographic maps. Water temperature and water quality were monitored at 14 sites across the watershed to estimate mean daily summer water temperature and mean summer total alkalinity for each reach in 2002. Within each reach, habitat features in all pools and runs that were at least one channel width long were measured between 9 July and 12 August 2002, when the rivers were near base flows. Water surface area, maximum depth, and dominant substrate were determined for each pool and run. Additionally, the water surface area with underlying silt or sand substrate, areas of water greater than 1.0 and 1.5 m deep, and areas of woody debris or boulder cover were determined for each pool and run. We also measured water surface areas with combinations of these habitat features. Substrate was classified as silt (<0.06 mm), sand (0.06–2.0 mm), gravel (2.1–64.0 mm), cobble (64.1–256.0 mm), or boulder (>256 mm).

We sampled adult saugers in all pools and runs in each reach between 23 August and 25 October 2002 using raft-mounted, pulsed-DC electrofishing gear. A three-pass removal method was used in individual pools and runs, but we did not isolate individual pools and runs with block nets during depletion efforts. We identified all saugers greater than 300 mm total length (TL) as adults, because sexual maturity is generally attained at 250–300 mm TL (Priegel 1969; Gebken and Wright 1972; Maceina et al. 1998). Captured adult saugers were weighed (g) and measured (mm TL), and the number of fish collected on each pass was recorded. The software program CAPTURE (White et al. 1978) was used to calculate abundance estimates, the SEs of the estimates, and capture probabilities for each pool and run by use of the model M_{R1}. Abundance estimates (N) for each pool and run sampled in a reach were summed to obtain an abundance estimate for the reach. Similarly, the SE of the estimate for the reach was estimated from the SE for each pool and run and was computed as $\sqrt{}(\mathrm{SE}^2)$. Reach estimates of abundance and SEs were extrapolated for each segment ([segment length/reach length] × N or SE). Abundance estimates and SEs for the entire study area were obtained by summing the estimates for each segment, and the 95% confidence interval (CI) was computed. Density and biomass estimates were calculated for each pool and run by use of the abundance estimate, the mean weight of saugers in the pool or run, and measured water surface area.

Habitat features that may account for variation in sauger biomass in pools and runs were assessed with multiple-regression analysis and the information-theoretic approach (Burnham and Anderson 1998; Anderson et al. 2000). Sauger biomass (B) was $\log_e$ transformed (i.e., $\log_e[B + 1]$). Proportional independent variables were arcsine-transformed.

A subset of uncorrelated independent variables was included in a global model representing our a priori hypotheses. The fit of candidate models was assessed with Akaike's information criteria corrected for small-sample bias (AIC_c), and AIC_c weights (w_i) were used to rank the models (Burnham and Anderson 1998; Anderson et al. 2000). Pearson's product-moment correlations were calculated for each pair of independent variables, and only uncorrelated variables were included in candidate models. Among the correlated habitat features (correlation coefficient $r \geq 0.195$, $P \leq 0.05$), the single-variable model with the highest w_i was selected for inclusion in the global model. The set of models that included all possible combinations of independent variables in the global model was assessed, and models with w_i values that were 10% or more of the w_i for the top-ranked model were considered to be competing models. The relative importance of individual variables in the set of competing models was assessed by comparing the sum of the w_i values for each variable across all models



Missouri River Watershed with Bighorn-Wind River Watershed in Wyoming (box)

Bighorn-Wind River Watershed in Wyoming with Study Area in smaller box

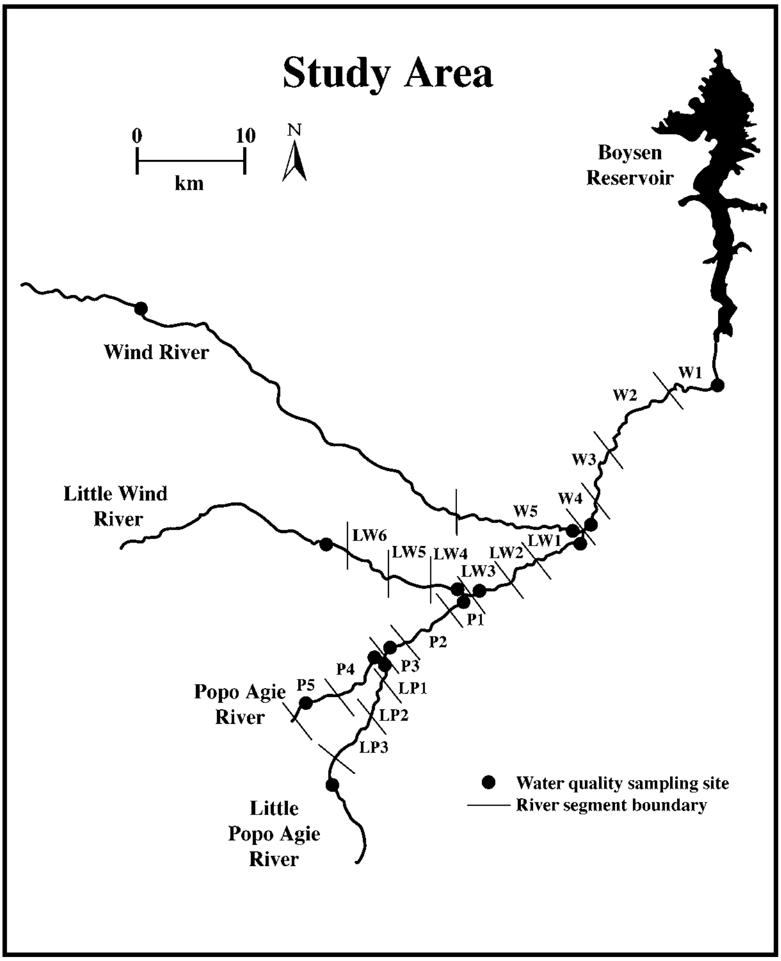


FIGURE 1.—Location of study segments in the Wind (W), Little Wind (LW), Popo Agie (P), and Little Popo Agie (LP) rivers, Wyoming. Temperature and water quality sampling sites are also indicated.

TABLE 1.—Estimates of adult sauger abundance in each reach sampled in the Wind River watershed, Wyoming, with expansions to river segments and the entire watershed. Rivers in the watershed include the Wind (W), Little Wind (LW), Popo Agie (PA), and Little Popo Agie (LPA) rivers.

		Sampled reach				Extrapolations to segment			Pools and runs	
River	Segment	Length (km)	Number of pools and runs sampled	Estimated number of fish	SE	Length (km)	Estimated number of fish	SE	Mean density (fish/ha)	Mean biomass (kg/ha)
W	1	3.67	9	17	1.6	15.09	70	6.6	1.1	0.7
	2	3.45	10	83	9.5	12.91	311	35.6	6.1	4.1
	3	3.41	10	82	2.3	7.36	177	5.0	7.0	5.8
	4	2.98	12	36	3.5	4.74	57	5.6	3.5	2.2
	5	2.66	11	12	1.9	18.30	83	13.1	1.4	0.9
LW	1	2.79	13	239	5.5	9.56	819	18.9	32.5	16.8
	2	3.84	14	90	1.1	9.19	215	2.6	10.8	5.5
	3	3.12	17	175	9.2	9.00	505	26.5	16.7	8.2
	4	2.36	16	75	1.4	9.70	308	5.8	21.9	12.6
	5	1.91	13	20	0.7	13.16	138	4.8	5.2	3.6
	6	1.74	14	29	0.6	8.28	138	2.9	6.3	6.5
PA	1	2.97	15	91	1.4	6.34	194	3.0	18.5	7.5
	2	2.55	16	102	5.9	11.52	461	26.7	17.0	8.8
	3	2.73	16	103	3.9	3.79	143	5.4	20.9	11.9
	4	1.92	15	56	25.4	11.00	321	145.5	15.5	11.3
	5	1.91	15	21	2.9	5.52	61	8.4	6.1	5.1
LPA	1	1.62	23	17	0.0	3.57	37	0.0	10.6	6.9
	2	1.75	23	2	0.0	12.85	15	0.0	1.0	0.5
	3	2.41	21	19	0.0	7.88	62	0.0	7.2	5.4

that included that variable. We used multi-model averaging and calculated averaged estimates of the coefficients and their SEs among competing models to address model selection uncertainty. Model parameters and their SEs were weighted by the associated w_i values for each model and were summed across all competing models (Burnham and Anderson 1998). The sums of the averaged coefficients and SEs were divided by the summed w_i values for all competing models to calculate weighted averages and SEs for each independent variable in the model set. Pearson's product-moment correlations and linear regression analyses were used to describe the relationship between density and biomass estimates among pools and runs. Analyses were conducted in Minitab release 13.1 (Minitab, Inc. 2000).

Results

Sampling of saugers and habitat in pools and runs was conducted in 19 river segments; representative reaches in each segment ranged from 1.6 to 3.8 km (Table 1). A total of 1,258 saugers greater than 300 mm TL were collected. Saugers were captured in 160 of the 283 pools and runs sampled. Population estimates were obtained for 158 of the 160 pools and runs. We were unable to achieve depletions in one pool and one run, and these habitats were omitted from the length of the reach sampled when estimating abundance in the reach. Among the 158 pools and runs where abundant estimates were obtained, capture probabilities ranged from 0.23 to 1.00; 94% of the capture probabilities exceeded 0.50.

Estimates of adult sauger abundance varied from 2 to 239 fish among the 19 reaches, and these estimates were extrapolated to 15–819 fish among the 19 segments (Table 1). The total number of adult saugers in the study area was estimated to be 4,115 (95% CI = ±308). However, 72% (i.e., 2,979 fish) of the total number of adult saugers were estimated to occur in 39% (70 km) of the study area within the three downstream segments of the Little Wind and Popo Agie rivers (Table 1).

Mean density estimates of adult saugers in individual pools and runs ranged from 1.0 to 32.5 fish/ha, and mean biomass estimates ranged from 0.5 to 16.8 kg/ha. Density and biomass were greatest in the downstream-most segments of both the Little Wind and Popo Agie rivers (Table 1).

No saugers were found in 39 pools or runs with maximum water depths of 0.6 m or less, so these pools and runs were excluded from further analysis. Among the remaining 244 pools and runs, density and biomass estimates were correlated. The relationship was described by linear regression (coefficient of determination $r^2 = 0.94$) as follows: $D = 1.01 + 1.55B$, where D is density (fish/ha) and B is biomass (kg/ha). Because of this strong relationship, modeling was conducted with only biomass as the response variable.

Before models accounting for the variation in adult sauger biomass among pools and runs were computed,

TABLE 2.—Competing regression models accounting for the variation in biomass of adult saugers among pools and runs in the Wind River watershed, Wyoming. The global model included mean daily summer water temperature (T), maximum depth of pool or run (D), habitat type (H), mean summer alkalinity (A), and dominant substrate rank (S). See text for more details. Models were ranked according to Akaike weights (w_i) computed from Akaike's information criterion modified for small sample size (AIC$_c$; $n = 244$), the number of estimated parameters (K), the residual sum of squares (RSS), and the difference in AIC$_c$ (Δ_i). Competing models with w_i values that were 10% or more of the maximum w_i are included in the table.

Rank	Model	K	RSS	AIC$_c$	Δ_i	w_i	R^2
1	T, D, H, A	6	247.645	15.97	0.00	0.609	0.356
2	T, D, H, A, S	7	246.751	17.21	1.24	0.328	0.358

correlations of measured habitat variables were examined to identify a subset of variables to include in the global model. Three sets of habitat features were significantly correlated. Water temperature, turbidity, channel gradient, sinuosity, the pool-to-run ratio, and elevation were all correlated ($r \geq 0.25$). Among the six simple linear regression models accounting for variation in sauger biomass with each of these variables, mean daily summer water temperature had the highest value of w_i (0.99) and was selected for inclusion in the global model. The second set of correlated basin-scale variables included alkalinity and total dissolved solids ($r \geq 0.51$). Mean summer alkalinity had the higher w_i and was selected for inclusion in the global model. Instream cover habitat variables were also correlated. Maximum depth of pools and runs and all water surface area estimates of deep, low-velocity areas were highly correlated ($r \geq 0.65$). The maximum depth model had the highest w_i (0.99), so maximum depth was selected for inclusion in the global model.

Five uncorrelated habitat features were included in the global model: mean daily summer temperature, mean summer alkalinity, maximum depth, dominant substrate class, and pool or run habitat type. Among the 244 pools and runs in the data set, mean daily summer temperature ranged from 18.6°C to 20.9°C, mean summer alkalinity ranged from 80 to 156 mg/L, maximum depth ranged from 0.61 to over 2.0 m, dominant substrate ranks ranged from 1 to 5, and biomass estimates ranged from 0.0 to 16.8 kg/ha. Among the set of 31 multiple-regression models that were computed based on all possible combinations of variables from the global model, two competing models were identified (Table 2). The top-ranked model ($w_i = 0.609$) included maximum depth, mean daily summer water temperature, pool or run habitat type, and mean summer alkalinity. The second-ranked model ($w_i = 0.328$) was the global model. The averaged model (Table 3) identified the manner in which each variable affected biomass of adult saugers in pools and runs. Sauger biomass was greater in pools than in runs. As mean daily summer temperature, maximum depth, and alkalinity increased, so did biomass. Dominant substrate rank had a lesser influence than the other variables, but as substrate size declined the biomass of adult saugers tended to increase.

Discussion

We estimated that there were about 4,100 adult saugers over 179 km of four rivers in the Wind River watershed upstream from Boysen Reservoir in the late summer and fall of 2002. The Wind River watershed is not isolated from Boysen Reservoir by barriers to upstream movement, and saugers occur in the reservoir (Krueger et al. 1997). It is not known whether the adult saugers found in the Wind River watershed are a fluvial population, a fluvial–adfluvial population, a combination of the two, or a population with routine move-

TABLE 3.—Averaged model variables, estimated model coefficients and SEs (in parentheses), and sums of corrected Akaike information criterion (AIC$_c$) weights for a model averaged between the two competing models accounting for the variation in adult sauger biomass ($\log_e [B + 1]$, where B = biomass [kg/ha]) among 244 pools and runs in the Wind River watershed, Wyoming. The sums of AIC$_c$ weights identify the relative importance of each variable in the averaged model.

Model variable	Averaged coefficient	Sum of AIC$_c$ weights
Constant	−16.491 (2.361)	
Mean daily summer water temperature (°C)	0.686 (0.104)	0.937
Maximum depth (m)	1.156 (0.163)	0.937
Habitat type (0 = run, 1 = pool)	0.523 (0.149)	0.937
Mean summer total alkalinity (mg/L)	0.017 (0.006)	0.937
Dominant substrate rank[a]	−0.016 (0.017)	0.328

[a] 1 = silt, 2 = sand, 3 = gravel, 4 = cobble, and 5 = boulder; see text for more details.

ments of individuals among lotic and lentic portions of the watershed. However, our sampling in late summer and fall reduced the probability that we sampled a portion of a fluvial–adfluvial population that had migrated into the river system to spawn.

Mean summer water temperature, maximum depth, habitat type (i.e., pool or run), mean summer total alkalinity, and substrate size accounted for the variation in the biomass of adult saugers across the Wind River watershed. These were the same variables that Amadio et al. (2005) identified as predicting the likelihood of occurrence of adult saugers in pools and runs within their distribution in the Wind River watershed. Both mean daily summer temperature and mean summer total alkalinity were reach-scale habitat features that appeared to have substantial influence on adult sauger biomass. Maximum depth was the instream habitat feature that exerted the greatest influence on biomass, but biomass also tended to be greater in pools than in runs. As the size of the dominant substrate declined, the biomass of adult saugers tended to increase, but small substrates were probably a secondary characteristic of low-velocity pools. Overall, our findings corroborate previous research suggesting that adult saugers prefer warm, deep pools and runs with low current velocities (Ali et al. 1977; Crance 1988; Vallazza et al. 1994; Gangl et al. 2000).

The limitations of our study included the inability to isolate individual pools and runs while conducting depletion electrofishing; electrofishing primarily in the thalweg but not in shallow water; sampling habitat and estimating sauger abundance at different times; and using the mean biomass of fish sampled in individual pools and runs when estimating biomass. It is possible that saugers may have fled from individual pools and runs during electrofishing, leading to biased abundance estimates. However, we generally captured saugers when electrofishing in the deepest water with instream cover (i.e., large woody debris or boulders), which suggests that they fled to deep water with instream cover if they carried out a flight response. The failure to capture any saugers in pools or runs with a maximum depth of 0.6 m or less further suggests that saugers avoided shallow water during the day; however, it is possible that some fish in shallow water were not vulnerable to capture. Sampling of habitat (9 July–12 August 2002) occurred prior to sampling of saugers (23 August–25 October 2002), and abundance estimates were made over a 2-month period. It is possible that redistribution of saugers from summer into fall may have biased our attempt to identify relationships between biomass and habitat features. However, a subsequent study of adult sauger movements in the Wind River basin during 2004–2005 has identified little movement of fish outside of the spring spawning period (Kuhn 2005). It is possible that our use of sauger mean weights in samples from individual pools and runs to estimate biomass in those habitats may have biased these estimates, but the weight distributions of saugers in samples from individual pools and runs were highly variable.

Our results suggest that the adult sauger population in the Wind River watershed is not large, but it does not appear to be in jeopardy due to inbreeding or stochastic processes (Soule 1987; Reiman and McIntyre 1993). However, variation in the biomass of adult saugers across the watershed suggests that their overall abundance in the Wind River watershed is largely affected by high summer water temperatures and alkalinity along with the abundance of deep pool habitat in the downstream segments of the Little Wind and Popo Agie rivers. Preservation of high-quality habitat in this portion of the Wind River watershed and prevention of population fragmentation are probably critical to the long-term management and preservation of saugers in this system.

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