North American Journal of Fisheries Management 30:12–25, 2010

DOI: 10.1577/M07-221.1

[Management Brief]

Comparison of Green and White Mesh Trammel Nets and Gill Nets to Assess the Fish Community in a Large River

GREG A. WANNER,* ROBERT A. KLUMB, AND DANE A. SHUMAN
U.S. Fish and Wildlife Service, Great Plains Fish and Wildlife Conservation Office, 420 South Garfield Avenue, Suite 400, Pierre, South Dakota 57501, USA

KIRK STEFFENSEN
Nebraska Game and Parks Commission, 2200 North 33rd Street, Lincoln, Nebraska 68503, USA

SAM STUKEL
South Dakota Department of Game, Fish, and Parks, 31247 436th Avenue, Yankton, South Dakota 57078, USA

NICHOLAS J. UTRUP[1]
U.S. Fish and Wildlife Service, Columbia National Fish and Wildlife Conservation Office, 101 Park DeVille Drive, Suite A, Columbia, Missouri 65203, USA

Abstract.—Standardized monitoring programs in great rivers need to identify and minimize the bias in the estimates of fish population characteristics to enable fishery managers to make informed decisions. We compared the effectiveness of green and white mesh in drifted trammel and anchored gill nets in capturing fish in the Missouri River from downstream of Fort Randall Dam, South Dakota, to the mouth of the river near St. Louis, Missouri. Sampling occurred from March to November 2006 and from April to May 2007. Paired green and white trammel net drifts ($N = 383$) caught 28 fish species from 12 families. Pairs of anchored gill nets set overnight ($N = 193$) caught 24 fish species from 12 families. Chi-square tests indicated that for most species there were no significant differences in occurrence between mesh colors in both the trammel and gill nets. However, occurrence was significantly higher in white mesh nets for goldeye *Hiodon alosoides* and blue sucker *Cycleptus elongatus* in trammel nets and for river carpsucker *Carpiodes carpio* and walleye *Sander vitreus* in gill nets. Despite turbidities in the Missouri River that ranged over two orders of magnitude, analysis of covariance indicated that water clarity had no significant effect on capture rates between green and white meshes. The majority of the variance in mean catch per unit effort (CPUE) of these species in both gears was spatial or temporal. In general, CPUE and precision were either similar or higher for white nets, making it unnecessary to dye nets green, which saves time and money. Because turbidity did not significantly affect catch rates between green and white mesh nets, the variations in CPUE can more confidently be attributed to localized changes in the actual relative abundance throughout the Missouri River.

* Corresponding author: greg_wanner@fws.gov
[1] Present address: U.S. Fish and Wildlife Service, Wisconsin Ecological Services Office, 2661 Scott Tower Drive, New Franken, Wisconsin 54229, USA.

Received December 14, 2007; accepted September 7, 2009
Published online December 21, 2009

Trends in abundance of fish populations can effectively be monitored with long-term data sets from standardized sampling programs. Whether sampling for fish with passive or active gear, bias is evident for various species, sizes, and habitats (Hayes et al. 1996; Hubert 1996). Understanding interactions among gear and seasonal biases and how they affect sampling data are important to a monitoring program (Pope and Willis 1996). A well-designed program that uses strict gear specifications, deployment techniques, and accounts for seasons will obtain precise estimates of fish population characteristics and reduce gear biases (Allen et al. 1999). This standardization will then allow for direct comparisons of catch statistics from different water bodies and analysis of trends through time (Burkhardt and Gutreuter 1995; Bonar and Hubert 2002). Thus, there is a need to identify sampling gears that minimize variation and reduce bias associated with different sampling techniques.

The U.S. Army Corps of Engineers, along with other federal and state agencies, developed a standard operating procedure (SOP) for long-term monitoring of pallid sturgeon *Scaphirhynchus albus* and the fish community in the Missouri River (Drobish 2007). These SOPs were adapted from the benthic fish study in the Missouri and Yellowstone rivers (Berry et al. 2004) and the Long-Term Resource Monitoring Program in the Mississippi River (Gutreuter et al. 1995). As part of the SOP, multifilament drifted trammel nets and anchored gill nets are used to capture fish. However, there was no mention in the SOP for the color of twine used in nets (U.S. Army Corps of Engineers 2002). Because of low turbidity levels in the Missouri River downstream of Fort Randall Dam,

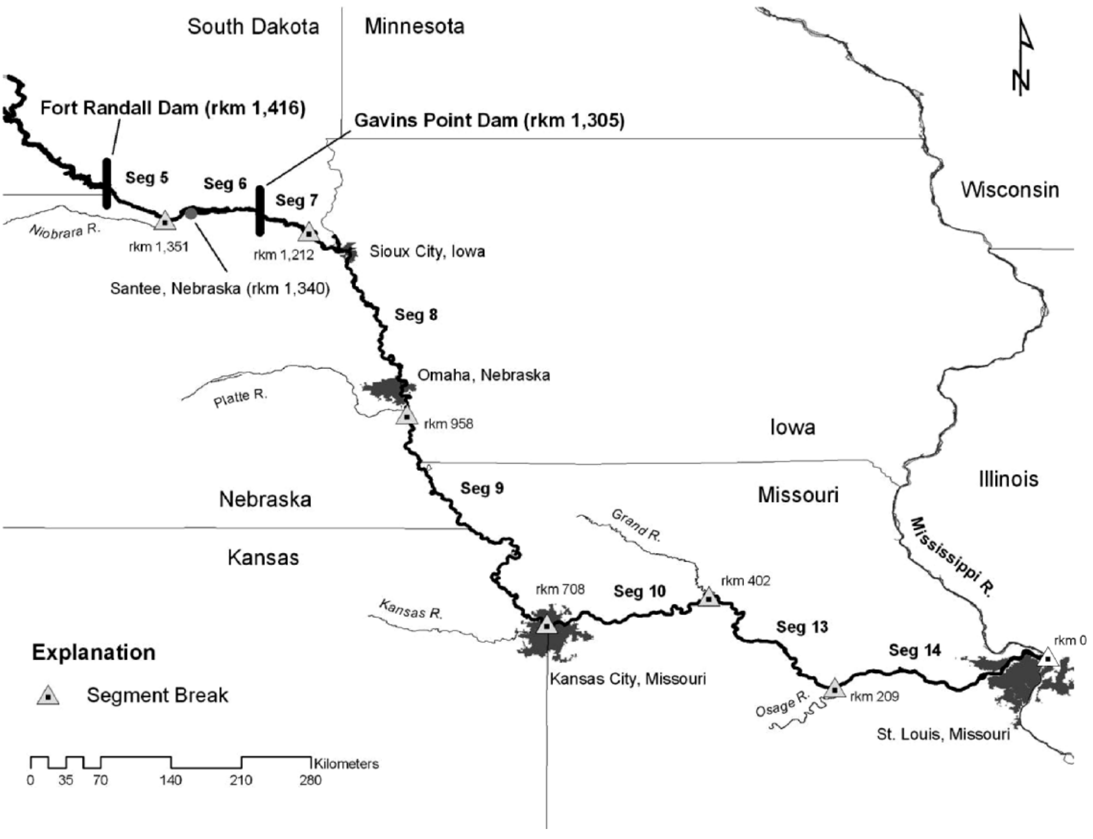

FIGURE 1.—Map of the Missouri River from Fort Randall Dam, South Dakota, to its confluence with the Mississippi River near St. Louis, Missouri, depicting river segments, major tributaries, and urban areas.

trammel and gill nets were dyed green under the hypothesis that this would increase gear efficiency by reduced visibility to fish. Green color was chosen under the hypothesis that it would be camouflaged with algae and other aquatic vegetation in the clear water downstream of Fort Randall Dam. However, other state and federal agencies have used undyed white nets throughout the Missouri River because there was not a concern for net color due to high turbidity levels. Some reaches of the Missouri River (such as downstream of Fort Peck and Gavins Point dams) also have low turbidity levels. Variable turbidity in the Missouri River makes the issue of net color paramount to achieving a standardized protocol that samples the fish community in an unbiased fashion to enable riverwide comparisons of fish abundance and size structure.

The objective of this study was to determine the effectiveness of green and white trammel and gill nets in sampling the Missouri River benthic fish community. Since twine color was initially overlooked while establishing standardized gears, we needed to know if this affected catch per unit effort (CPUE) and our ability to compare CPUE between twine colors throughout the Missouri River and other rivers. We hypothesized that mean CPUE would be higher in green nets at low turbidity levels with no differences in mean CPUE at higher turbidity levels. We also hypothesized no differences in length frequency distributions of fish species would exist for the two twine colors since mesh size was constant. Knowledge of the effectiveness between the two twine colors will enable fisheries biologists to more effectively sample the relative abundance of fish populations in river systems and refine standardized gears as part of long-term monitoring programs.

Study Area

The study site encompassed the Missouri River from Fort Randall Dam near Pickstown, South Dakota (river kilometer [rkm] 1,416) to its confluence with the Mississippi River near St. Louis, Missouri (rkm 0; Figure 1). The Missouri River was divided into segments based on hydrological characteristics and the influences of large tributaries (Drobish 2007).

Segment 5 (rkms 1,416–1,351), which extends from Fort Randall Dam to the confluence with the Niobrara River, meanders and its turbidity is relatively low due to hypolimnetic releases from the dam (Table 1; Shuman et al. 2007). Segment 6 (rkms 1,351–1,340), which extends from the Niobrara River confluence to the headwaters of Lewis and Clark Lake near Santee, Nebraska, is highly braided with an aggraded streambed (i.e., delta) and its turbidity is higher than that of segment 5 (Shuman et al. 2007). Segment 7 (rkms 1,305–1,212) extends from Gavins Point Dam to Ponca, Nebraska, and is highly braided with reduced turbidity due to dam releases (Stukel et al. 2007). Segment 8 (rkms 1,212–958) extends from Ponca, Nebraska, to the confluence of the Platte River, where the river becomes highly engineered by channelization with increased turbidity (Hamel and Steffensen 2007). Segment 9 (rkms 958–708), which extends from the Platte River to the confluence of the Kansas River, has a more natural hydrograph and increased turbidity due to tributary discharges (Steffensen and Hamel 2007). Segment 10 (rkms 708–250), from the Kansas to the Grand River (rkm 250), and segment 11, the Kansas River, were not sampled during this study. The remaining segments in the state of Missouri are delineated by major tributaries. Segment 12 was eliminated and combined with segment 13 (rkms 250–130; Drobish 2007); it extends from the Grand River to the Osage River confluence (Plauck et al. 2007). Segment 14 (rkms 130–0) extends from the Osage River to the mouth of the Missouri River (Utrup et al. 2007).

TABLE 1.—Mean nephelometric turbidity units, SD, and range in each Missouri River segment from Gavins Point Dam, South Dakota–Nebraska, downstream to St. Louis, Missouri, during 2006.

River segment	Mean	SD	Range	Reference
5	6.3	2.2	2–9	Shuman et al. (2007)
6	24.3	9.8	13–37	Shuman et al. (2007)
7	19.4	4.4	11–27	Stukel et al. (2007)
8	68.0	47.2	29–155	Hamel and Steffensen (2007)
9	85.9	53.1	35–216	Steffensen and Hamel (2007)
13	69.2	49.0	12–192	Plauck et al. (2007)
14	88.1	43.7	32–190	Utrup et al. (2007)

Methods

Sampling.—Trammel nets were 38 m long. Their outside wall panels were 2.4 m deep and constructed with 15.2-cm bar mesh (number 9 nylon twine). The inside wall panels were 1.8 m deep and constructed with 2.5-cm bar mesh (number 139 nylon twine). Float lines were 1.3-cm polyurethane foam core, and lead lines were 22.7-kg lead core (22.7 kg/91.4 m of line). Sampling with paired green and white multifilament trammel nets was done from April through September 2006. Trammel nets were orientated perpendicular to the river current and drifted along the bottom. The distance for each drift, targeted to be 300 m, was measured using a Global Positioning System (GPS) receiver. Typical duration of a drift was 2–15 min, depending on water velocity and presence of snags (e.g., submerged trees, cobble, and boulders). Nets were immediately retrieved upon being snagged, and distance drifted was recorded. One undyed white and one dyed green trammel net were drifted on the same date, usually within 1 h of each other. Nets were deployed either adjacent to or in line with the other. Nets deployed in line with one another always had drifts with different GPS coordinates (i.e., they never drifted through the exact same area). Mean distance between paired trammel net drifts was 360 m (SD = 434.6; range = 10–2,677 m). The color of the net deployed first was randomly selected.

Gill nets were set in March, April, October, and November in 2006, and March and April in 2007 only in segments 5–7 when water temperatures remained below 12.8°C to prevent stress-induced mortality. In segment 7, experimental multifilament gill nets were 30.4 m long and 1.8 m deep, with four 7.6-m long panels with bar mesh sizes, in order, of 3.8, 5.1, 7.6, and 10.2 cm, composed of number 139 nylon twine. To target smaller fish in segments 5–6, an additional 7.6-m panel with 2.5-cm bar mesh was attached to the gill net, for a total of length of 38 m. Float lines were 1.3-cm polyurethane foam core, and lead lines were 22.7 kg lead core. Gill nets were set parallel to the flow of the river in pairs with one undyed white and one dyed green. Paired nets were deployed either adjacent to or in line with one another. Mean distance between paired nets was 101 m (SD = 80.1; range = 12–492 m). The color of the net deployed first was randomly selected.

To ensure that the only difference in the net specifications was twine color, all trammel and gill nets used throughout the study were either manufactured by Memphis Net and Twine Company (Memphis, Tennessee), or by H. Christenson (Duluth, Minnesota). The net twine, float and lead lines, and bar mesh sizes were identical between the two net manufacturing companies. Between sets, each net was inspected for damage. If more than 25% of the mesh was damaged, the net was discarded; otherwise, the net was mended.

All river bends in each segment were numbered, and then about 15–32% were randomly selected for sampling. A minimum of four paired deployments (i.e., subsamples) for trammel nets occurred in each randomly selected bend. A minimum of 10 paired gill nets were set in each bend. Depth (m), water temperature (°C), bottom water velocity (m/s), and surface water turbidity (NTUs) were measured at the transect midpoint of the drifted trammel net after the drift was completed and measured at the set location immediately after gill nets were retrieved (Drobish 2007). Bottom water velocity was recorded to the nearest 0.1 m/s using a Marsh-McBirney Flo-Mate portable flowmeter, Model 2000 (Marsh-McBirney, Frederick, Maryland). Turbidity was measured using a Hach Turbidimeter, Model 2100P (Hach Company, Loveland, Colorado).

Statistical analysis.—Because the goal of the long-term Missouri River monitoring program was to assess changes in distribution and relative abundance of the fish community, differences in occurrence of individual fish species between the paired green and white mesh nets were assessed using chi-square tests for equal proportions. Similar analyses of individual species were done by Herzog et al. (2005) for sampling the fish community in the Mississippi River with otter trawls. We used the Yates correction for continuity (Zar 1999) due to our comparison of only two colors (i.e., categories). Chi-square tests were only performed when a minimum of 10 fish were captured for each species to better meet chi-square assumptions (Conover 1999). Probabilities were adjusted using the Holm procedure (Neter et al. 1996) to accord multiple simultaneous comparisons.

Relative abundance of the most commonly caught species in the families Acipenseridae, Hiodontidae, Catostomidae, Ictaluridae, and Percidae was compared for green and white mesh nets. Mean CPUE for each drifted trammel net was calculated as number of fish/100 m, while gill net mean CPUE was calculated as number of fish per overnight set. The mean CPUE data were checked for normality. The data were not normally distributed; therefore, we $\log_{10}(\text{CPUE} + 1)$ transformed the data, and normality improved based on residual and normal probability plots of the residuals (Neter at al. 1996). We then used the coefficient of variation ($\text{CV} = 100 \times \text{SD/mean}$) to compare the relative precision for mean CPUE estimates between net colors.

We used an analysis of covariance (ANCOVA), with turbidity set as the covariate, to test for differences in mean $\log_{10}(\text{CPUE} + 1)$ data between the paired green and white nets. We used a general linear model (GLM; Hintze 2006) in which the dependent variable was modeled as a function of net color, river bend, and their interaction for trammel nets. Because gill nets were set in 2 years, an additional term assessed interannual variation in the GLM; the interaction of river bend and year was also assessed. The interaction term tests for homogeneity of slopes, and, if not significant, the reduced model (without the interaction term) was run to test for differences in the intercepts. When the turbidity covariate was not significant, a paired *t*-test was used to test for differences in mean $\log_{10}(\text{CPUE} + 1)$ between colors. When turbidity was significant, an F-test checked the ANCOVA assumption of equality of slopes between green and white nets.

If significant differences in mean CPUE existed between net colors, predictive regression models were developed that converted the lower mean CPUE data (with the lower relative precision [high CV]) to the gear with the higher mean CPUE and relative precision. The net color with the highest mean CPUE and relative precision would be a more appropriate choice for a standardized gear. Because model error would increase the variance of converted data, only models with relatively high coefficients of determination (e.g., $r^2 > 0.65$) were used (Prairie 1996). Finally, we used a geometric mean functional regression to develop a predictive model (Ricker 1984) to convert the lower mean CPUE data to the mesh color with the higher mean CPUE because it is "robust" (Ricker 1984) and provides the best estimate available for short series with moderate or large variability (Ricker 1973).

For each gear a Kolmogorov–Smirnov test was used to compare length frequency distributions of fish species captured in the two twine colors. All fish were measured to total length to the nearest millimeter except sturgeons, which were measured to fork length (FL), and paddlefish *Polyodon spathula*, which were measured from eye to FL. Only the most abundant fish species from the families Acipenseridae, Hiodontidae, Catostomidae, Ictaluridae, and Percidae were used for length frequency distribution comparisons. All analyses of normality, mean CPUE, and length frequency distributions were performed with Number Cruncher Statistical Software (NCSS; Hintze 2006). Significance was determined at α equal to 0.05 for all tests.

Results

Trammel Nets

Three hundred eighty-three paired trammel nets were drifted in 72 river bends during this study. We sampled at depths that ranged from 0.8 to 9.5 m, at bottom water velocities of 0.1–1.5 m/s and at turbidities of 3–551 NTU. We sampled 28 species of fish and one hybrid from 12 families; 916 fish were captured in green trammel nets and 1,169 fish with white nets. Chi-square tests indicated that most species occurred similarly in both mesh; however, goldeye *Hiodon alosoides* and blue sucker *Cycleptus elongatus* occurred significantly more often in white trammel nets

TABLE 2.—Fish species captured by paired green and white mesh trammel nets drifted in the Missouri River during 2006. Mean CPUE is the number of fish per 100-m drift. Chi-square tests with the Yates correction for continuity were used to compare differences in the occurrence of fish captured between mesh colors (performed only when ≥10 fish were captured for each species). Probabilities were adjusted to accommodate simultaneous testing using the Holm procedure (in parentheses); only original probabilities less than adjusted probabilities are significant at $\alpha = 0.05$.

	Green mesh				White mesh					
Family and species	*n*	Mean	SE	CV	*n*	Mean	SE	CV	χ^2	*P*
Acipenseridae										
Lake sturgeon *Acipenser fulvescens*	1	0.001	0.001	1,957	0					
Pallid sturgeon *Scaphirhynchus albus*	6	0.008	0.004	944	7	0.013	0.005	825	0	1.000 (0.05)
Shovelnose sturgeon *S. platorynchus*	401	0.856	0.119	271	407	0.938	0.125	260	0.03	0.860 (0.0125)
Polyodontidae										
Paddlefish *Polyodon spathula*	2	0.003	0.002	1,741	1	0.002	0.002	1,957		
Lepisosteidae										
Longnose gar *Lepisosteus osseus*	5	0.010	0.005	978	9	0.024	0.009	739	0.64	0.422 (0.005)
Shortnose gar *L. platostomus*	6	0.020	0.008	794	5	0.016	0.007	875	0	1.000 (0.05)
Hiodontidae										
Goldeye *Hiodon alosoides*	72	0.202	0.039	374	156	0.443	0.057	252	30.21	<0.001 (0.003)
Clupeidae										
Skipjack herring *Alosa chrysochloris*	1	0.002	0.002	1,957	0					
Gizzard shad *Dorosoma cepedianum*	1	0.003	0.003	1,957	9	0.027	0.017	1,240	4.90	0.027 (0.004)
Cyprinidae										
Grass carp *Ctenopharyngodon idella*	1	0.002	0.002	1,957	5	0.012	0.006	910		
Common carp *Cyprinus carpio*	3	0.009	0.005	1,167	2	0.006	0.004	1,387		
Silver carp *Hypophthalmichthys molitrix*	2	0.004	0.004	1,591	1	0.003	0.003	1,957		
Bighead carp *H. nobilis*	4	0.009	0.006	1,327	5	0.012	0.006	1,100		
Catostomidae										
River carpsucker *Carpiodes carpio*	19	0.044	0.013	576	22	0.051	0.012	458	0.10	0.755 (0.007)
Highfin carpsucker *C. velifer*	2	0.003	0.003	1,525	4	0.008	0.004	1,046		
Quillback *C. cyprinus*	9	0.020	0.008	832	7	0.017	0.007	766	0.06	0.802 (0.008)
Blue sucker *Cycleptus elongatus*	200	0.515	0.080	306	315	0.840	0.107	250	25.24	<0.001 (0.003)
Bigmouth buffalo *Ictiobus cyprinellus*	1	0.002	0.002	1,957	4	0.011	0.005	997		
Smallmouth buffalo *I. bubalus*	14	0.034	0.011	665	16	0.040	0.012	579	0.03	0.855 (0.010)
Shorthead redhorse *Moxostoma macrolepidotum*	42	0.088	0.026	579	35	0.083	0.031	728	0.47	0.494 (0.006)
Ictaluridae										
Blue catfish *Ictalurus furcatus*	21	0.025	0.007	545	23	0.037	0.013	702	0.02	0.880 (0.017)
Channel catfish *I. punctatus*	83	0.189	0.031	327	90	0.191	0.034	350	0.21	0.648 (0.006)
Flathead catfish *Pylodictis olivaris*	1	0.001	0.001	1,957	1	0.003	0.003	1,957		
Percichthyidae										
White bass *Morone chrysops*	0				1	0.002	0.002	1,957		
Centrarchidae										
Smallmouth bass *Micropterus dolomieu*	0				4	0.006	0.003	999		
Percidae										
Sauger *Sander canadensis*	14	0.021	0.007	639	25	0.030	0.010	631	2.56	0.109 (0.004)
Walleye *S. vitreus*	4	0.009	0.005	1,043	10	0.010	0.004	724	1.79	0.181 (0.005)
Saugeye (sauger × walleye)	0				1	0.001	0.001	1,957		
Sciaenidae										
Freshwater drum *Aplodinotus grunniens*	1	0.003	0.003	1,957	4	0.007	0.004	1,244		
All species	916	2.083	0.183	172	1,169	2.831	0.226	157	30.46	<0.001 (0.003)
No fish in net	152				112				5.76	0.016 (0.004)

(Table 2). Additionally, the total number of fish captured was significantly higher in white nets compared with green nets which improved relative precision (CV) for CPUE (Table 2). The number of empty nets did not significantly differ between colors. Compared with white trammel nets, no fish species were captured more often in green nets.

Based on ANCOVA, turbidity was not a significant factor affecting mean CPUE for shovelnose sturgeon, goldeye, blue sucker, channel catfish, and sauger in green and white mesh trammel nets (Table 3). The interaction of net color and river bend was insignificant for all species, so the reduced GLM was used. For all species, scatter plots of mean $\log_{10}$(CPUE + 1) on turbidity for each mesh color had similar slopes for both green and white nets, and coefficients of determination were all low (<0.01; Figure 2). For all species except sauger, mean relative abundance (adjusted for differing turbidity) significantly differed among river bends. There were insufficient numbers of fish captured from families Polyodontidae, Lepisosteidae, Clupeidae, Cyprinidae, Esocidae, Percichthyidae, Centrarchidae, and Sciaenidae for further mean CPUE analyses. After adjusting for varying turbidity, white mesh trammel nets caught significantly more fish than green nets for goldeye ($t = -5.10$; $P < 0.001$) and blue

TABLE 3.—Analysis of covariance for trammel net catch per unit effort (with turbidity as a covariate) assessing net color and spatial variation (river bend) for the most commonly caught species of Acipenseridae, Hiodontidae, Catostomidae, Ictaluridae, and Percidae in the Missouri River during 2006. No net color × river bend interactions were significant.

Source	df	Mean square	F	P[a]
Shovelnose sturgeon				
Turbidity	1	0.0001	0.00	0.97
Net color	1	0.0142	0.23	0.63
River bend	45	0.2003	3.24	<0.01*
Error	718	0.0618		
Goldeye				
Turbidity	1	0.0281	1.12	0.29
Net color	1	0.4863	19.41	<0.01*
River bend	45	0.1128	4.50	<0.01*
Error	718	0.0250		
Blue sucker				
Turbidity	1	0.1720	3.54	0.06
Net color	1	0.4650	9.56	<0.01*
River bend	45	0.1913	3.93	<0.01*
Error	718	0.0487		
Channel catfish				
Turbidity	1	0.0028	0.19	0.66
Net color	1	0.0012	0.09	0.77
River bend	45	0.0639	4.40	<0.01*
Error	718	0.0145		
Sauger				
Turbidity	1	0.0001	0.06	0.81
Net color	1	0.0008	0.35	0.55
River bend	45	0.0024	1.12	0.28
Error	718	0.0021		

[a] Asterisks indicate significance at $P < 0.01$.

sucker ($t = -3.17$; $P = 0.002$). Attempts to adjust green trammel net CPUE for goldeye and blue sucker to white trammel CPUE were significant, but coefficients of determination were low for both goldeye ($r^2 = 0.03$) and blue sucker ($r^2 = 0.18$). Therefore, no predictive models were developed.

The size structure of shovelnose sturgeon, goldeye, blue sucker, and sauger caught with green and white trammel nets did not significantly differ (Figure 3). Significantly shorter channel catfish were captured in white trammel nets. The difference in mean length of channel catfish between the two colors was less than 22 mm.

Gill Nets

In spring 2006, fall 2006, and spring 2007, a total of 193 paired green and white mesh gill nets were set overnight in 20 river bends. Gill nets were anchored at depths from 0.9 to 12.5 m, at bottom water velocities of 0.0–0.9 m/s, and at turbidities of 3–244 NTU. We sampled 24 species of fish from 12 families; 772 fish were caught in green gill nets with 972 fish caught in white gill nets. Chi-square tests indicated that occurrences of most fish species did not significantly differ between gill net mesh colors (Table 4). However, occurrences of river carpsucker and walleye were significantly higher in white gill nets. The total catch of all species was significantly higher in white nets; however, no significant differences were found in the occurrence of empty nets between twine colors—41% for green nets and 39% for white nets. Coefficients of variation were generally lowest for white mesh gill nets.

Based on ANCOVA, turbidity was a covariate affecting mean CPUE of goldeye but not shovelnose sturgeon, river carpsucker, channel catfish, and walleye for green and white mesh gill nets (Table 5). The interactions of net color and river bend as well as river bend and year were insignificant for all species, so the reduced GLM was used. For all species, scatter plots of mean $\log_{10}(\text{CPUE} + 1)$ on turbidity for each mesh color had similar slopes for both green and white nets, and coefficients of determination were all low (<0.09; Figure 4). For all five species, mean relative abundance, adjusted for differing turbidity, significantly differed among river bends, while only walleye CPUE significantly differed among years. There were insufficient numbers of fish captured from families Polyodontidae, Lepisosteidae, Clupeidae, Cyprinidae, Esocidae, Percichthyidae, Centrarchidae, and Sciaenidae for further mean CPUE analyses.

The size structure of goldeyes, river carpsuckers, and walleyes caught with green and white trammel nets did not significantly differ (Figure 5). Significantly shorter shovelnose sturgeon were captured in white gill nets, but the mean difference in length was 22 mm.

Discussion

The results of our study did not support our hypothesis of higher capture rates in green nets at low turbidity levels. Overall, there was a general lack of significant differences in occurrence, relative abundance, and relative precision between green and white mesh for both drifted trammel nets and anchored gill nets for most fish species. Although the Missouri River is fragmented by six large dams that greatly reduce turbidity immediately downstream, water clarity did not influence capture rates between the two colors. This indicates that standardized trammel net and gill net catches can be compared across large river systems.

Sampling in a paired design controlled for additional confounding by environmental factors such as seasonal changes in water temperature and discharge. Given the chi-square results for occurrence and the results for relative abundance of the most commonly caught species, both showed that color had a minimal effect. The majority of variance in CPUE was spatial for

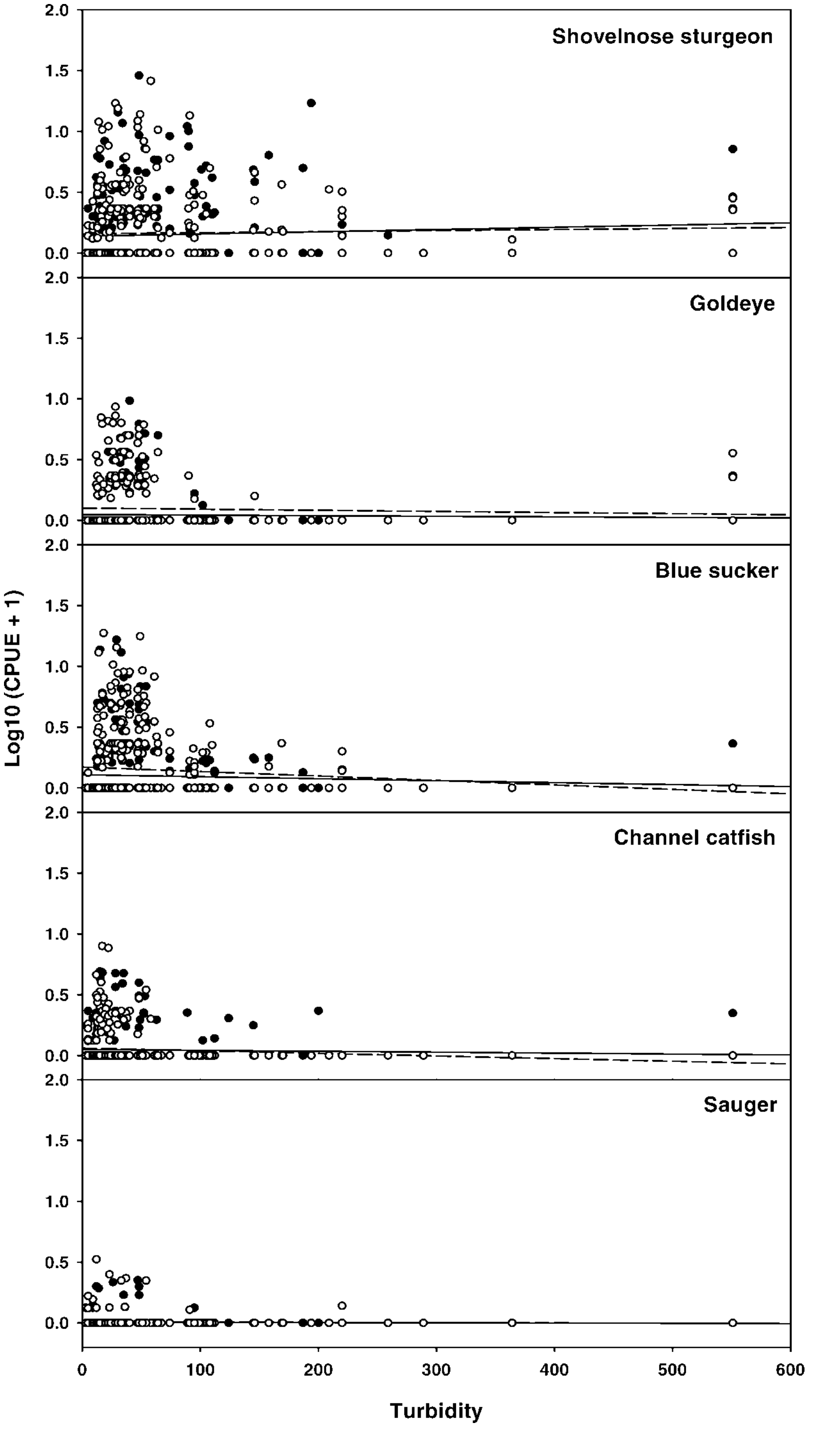

FIGURE 2.—Scatterplots comparing the trammel net $\log_{10}$(CPUE + 1) for green (black circles) and white mesh nets (white circles) with turbidity levels for five fish species in the Missouri River in 2006. The slopes for the green nets are depicted by solid lines, those for white nets by dashed lines.

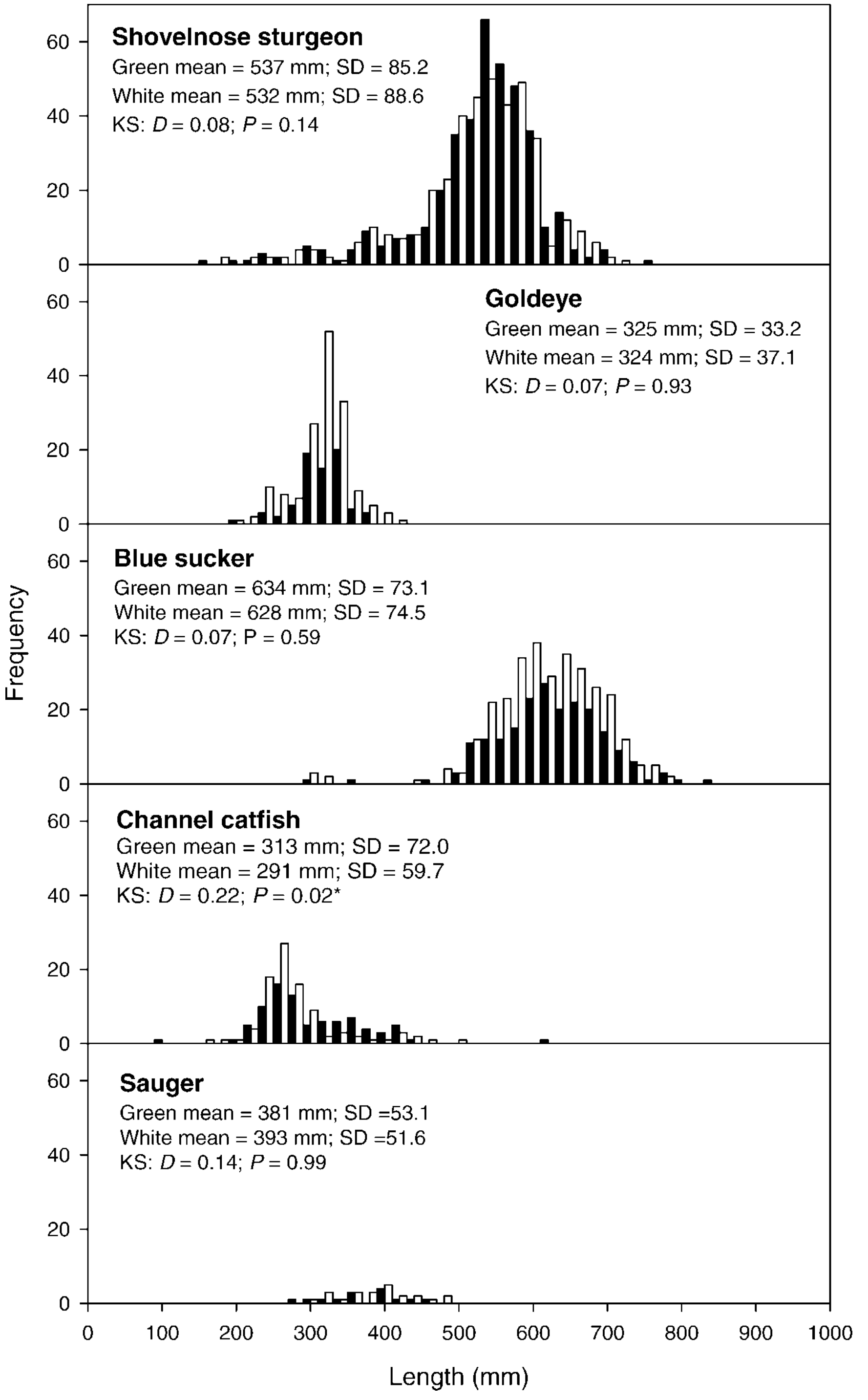

FIGURE 3.—Length frequency distributions of five fish species (20-cm length-groups) caught in green (black bars) and white mesh (white bars) drifted trammel nets in the Missouri River in 2006; the abbreviation KS refers to the Kolmogorov–Smirnov test.

TABLE 4.—Fish species captured by paired green and white mesh gill nets anchored in the Missouri River during 2006–2007. See Table 2 for additional details.

Family and species	Green mesh *n*	Mean	SE	CV	White mesh *n*	Mean	SE	CV	χ^2	*P*
Acipenseridae										
Pallid sturgeon	17	0.088	0.033	515	14	0.073	0.023	433	0.13	0.719 (0.010)
Shovelnose sturgeon	323	1.679	0.305	252	354	1.829	0.393	298	1.16	0.249 (0.005)
Polyodontidae										
Paddlefish	9	0.047	0.021	630	12	0.062	0.029	649	0.19	0.662 (0.008)
Lepisosteidae										
Shortnose gar	3	0.016	0.012	1,033	8	0.041	0.018	595	1.45	0.228 (0.004)
Hiodontidae										
Goldeye	46	0.238	0.121	704	45	0.233	0.112	667	0	1.00 (0.05)
Clupeidae										
Gizzard shad	14	0.073	0.032	605	3	0.016	0.009	798	5.88	0.015 (0.003)
Cyprinidae										
Common carp	9	0.047	0.028	827	7	0.036	0.015	588	0.06	0.803 (0.017)
Bighead carp	0				2	0.010	0.010	1,389		
Catostomidae										
River carpsucker	56	0.290	0.093	443	123	0.637	0.193	421	24.34	<0.001 (0.003)
Highfin carpsucker	1	0.005	0.005	1,389	10	0.052	0.043	1,144	5.82	0.016 (0.003)
Quillback	2	0.010	0.007	980	8	0.041	0.016	541	2.50	0.114 (0.004)
Blue sucker	33	0.171	0.086	700	44	0.228	0.086	522	1.30	0.254 (0.005)
Bigmouth buffalo	4	0.021	0.016	1,097	9	0.047	0.021	630	1.23	0.267 (0.006)
Smallmouth buffalo	29	0.150	0.058	541	51	0.264	0.082	431	5.51	0.019 (0.003)
Shorthead redhorse	35	0.181	0.037	283	42	0.218	0.044	283	0.47	0.494 (0.006)
Ictaluridae										
Channel catfish	54	0.280	0.060	300	50	0.259	0.070	377	0.09	0.769 (0.013)
Flathead catfish	1	0.005	0.005	1,389	0					
Esocidae										
Northern pike *Esox lucius*	8	0.041	0.019	644	5	0.026	0.011	615	0.31	0.579 (0.007)
Centrarchidae										
Smallmouth bass	4	0.021	0.013	847	3	0.016	0.009	798		
Rock bass *Ambloplites rupestris*	0				2	0.010	0.007	979		
Percidae										
Sauger	17	0.088	0.023	362	26	0.135	0.042	437	1.49	0.222 (0.004)
Walleye	58	0.301	0.108	497	102	0.528	0.174	456	11.56	<0.001 (0.003)
Saugeye	3	0.016	0.009	798	1	0.005	0.005	1,389		
Sciaenidae										
Freshwater drum	0				1	0.005	0.005	1,389		
All species	726	3.767	0.551	203	922	4.772	0.672	196	22.71	<0.001 (0.003)
No fish in net	80				76				0.06	0.810 (0.025)

trammel nets and spatial and temporal for gill nets. Large rivers are dynamic with changes in habitat (e.g., sand bars, pools, island tips, and converging flow) over short distances. Fish are not randomly distributed across the river, and a net may be drifted or placed in an area where fish are migrating through or using as a feeding or refuge area. Even though green and white nets were paired and set at random, one net may capture a large number of fish, while another net a short distance away may capture zero fish. For example, one white gill net in this study captured 24 walleyes, while its paired green net captured only three. Even though all necessary steps were taken to randomly set the paired samples, given the dynamic nature and heterogeneity of large rivers, it is difficult to accurately determine if samples were truly "paired."

Fishes native to the Missouri River are especially adapted to the turbid river and are generally characterized by having reduced eyes. No discernable trends in capture rates were found between green and white mesh for fish species (e.g., pallid sturgeon, shovelnose sturgeon, paddlefish, and channel catfish) that rely on sensory structures other than vision, such as barbels (Miller 2005) and electrosensory organs (Wilkens et al. 2002; Gibbs and Northcutt 2004). Fish species (e.g., walleye, sauger, smallmouth bass, goldeye, gars, and freshwater drum) that have large eyes and rely on their keen eyesight to detect prey and their environment appeared to be more susceptible to capture by white nets. Surprisingly, native fish from the family Catostomidae were captured more often in white trammel and gill nets. Although catostomids are well adapted to turbid river conditions with a benthic feeding behavior (Pflieger 1997), they appear to rely on their vision to interpret their environment. Jester (1973) reported that catostomids, such as smallmouth buffalo and river carpsucker, were captured at higher rates in white nets compared with seven other colors of nets. This

TABLE 5.—Analysis of covariance for gill-net CPUE (with turbidity as a covariate) assessing net color, spatial variation (river bend), and interannual variation for the most commonly caught species of Acipenseridae, Hiodontidae, Catostomidae, Ictaluridae, and Percidae in the Missouri River during 2006 and 2007. No net color × river bend or river bend × year interactions were significant.

Source	df	Mean square	F	P[a]
Shovelnose sturgeon				
Turbidity	1	0.0185	1.95	0.16
Net color	1	0.0118	0.12	0.72
River bend	16	0.3665	3.86	<0.01*
Year	1	0.0057	0.06	0.81
Error	366	0.0949		
Goldeye				
Turbidity	1	0.1862	9.31	<0.01*
Net color	1	0.0010	0.05	0.82
River bend	16	0.0806	4.03	<0.01*
Year	1	0.0361	1.81	0.18
Error	366	0.0200		
River carpsucker				
Turbidity	1	0.0362	2.04	0.15
Net color	1	0.0561	3.16	0.08
River bend	16	0.5626	31.73	<0.01*
Year	1	0.0070	0.40	0.53
Error	366	0.0177		
Channel catfish				
Turbidity	1	0.0476	3.35	0.07
Net color	1	0.0064	0.45	0.50
River bend	16	0.2168	15.26	<0.01*
Year	1	0.0697	4.90	0.03*
Error	366	0.0142		
Walleye				
Turbidity	1	0.0043	0.13	0.72
Net color	1	0.0476	1.44	0.23
River bend	16	0.1401	4.23	<0.01*
Year	1	1.0409	31.45	<0.01*
Error	366	0.0331		

[a] Asterisks indicate significance at $P < 0.01$.

evidence suggests that catostomids are able to detect different colors at various levels of turbidity. Previous studies reported that fish were able to distinguish colors and lights at various intensities (Brown 1937; Hurst 1953), and several species of fish have been reported to have a broad range of spectral sensitivity to light (Douglas and Djamgoz 1990). Additionally, teleost fishes have adapted vision for ultraviolet light which human eyes cannot detect, which makes it difficult to understand the visual aspects of fish behavior (Losey et al. 1999).

One observation during this study was that after the first deployment of a white net, the twine would become stained a light tan color from the suspended particles in the river. The stained white nets may have become more camouflaged, which may have reduced their detection by fish. Jester (1973) reported that catostomids and carps were caught in higher numbers in brown nets, while game fish catches were higher in white nets (which may partially explain the higher capture rates of catostomids in white gill nets in this study). Green nets generally maintained their color throughout the study. Our hypothesis that green nets would be camouflaged with the surrounding environment of algae and other plants in the river downstream of a large dam was not supported. Further studies may be needed to investigate use of red nets because red light wavelengths are the first color in the light spectrum absorbed by water (Wetzel 1983).

With significant differences between green and white trammel net mean CPUE for goldeye and blue sucker, we attempted to convert the green mean CPUE data to white mean CPUE data, but coefficients of determination were low ($r^2 \leq 0.24$). The low coefficients of determination suggested other environmental factors besides turbidity probably affected CPUE, such as seasonal movement patterns or behavior, discharge, water temperature, photoperiod, and prey availability (Pope and Willis 1996; Linløkken and Haugen 2006; Gabr et al. 2007). Wanner et al. (2007) reported that trammel net mean CPUE increased in August for pallid sturgeon despite the relatively high gear efficiency of drifting trammel nets (Guy et al. 2009). Sampling in this study occurred over 1.5 years, so variation in CPUE may be explained more by seasonal changes in vulnerability of capture due to behavior and movement, and not simply by net color.

Surprisingly, the length frequency distribution analysis revealed that smaller channel catfish were captured in white trammel nets and smaller shovelnose sturgeon were captured in white gill nets compared with their green counterpart. Salmonids and goldfish *Carassius auratus* have been reported to exhibit an ontogenetic loss of ultraviolet sensitivity (Douglas 1989; Hawryshyn et al. 1989), while visual acuity increased proportionately with fish length for Pacific saury *Cololabis saira* (Hajar et al. 2008). Information is lacking on the ontogenetic changes in vision for both channel catfish and shovelnose sturgeon, but there may be changes in color vision as these fish grow. However, because channel catfish and shovelnose sturgeon have reduced eyes, rely on other sensory structures (i.e., barbels and rostrum) to detect their environment, and the mean length difference was 22 mm or less, the significant differences in length frequency distribution between mesh colors may not be because of ontogeny but rather because of a type I error.

Although a small detail such as mesh color was overlooked as part of development of a long-term monitoring program, lack of significant differences in relative abundance (under various turbidity levels) indicated that overall trend data in the Missouri River

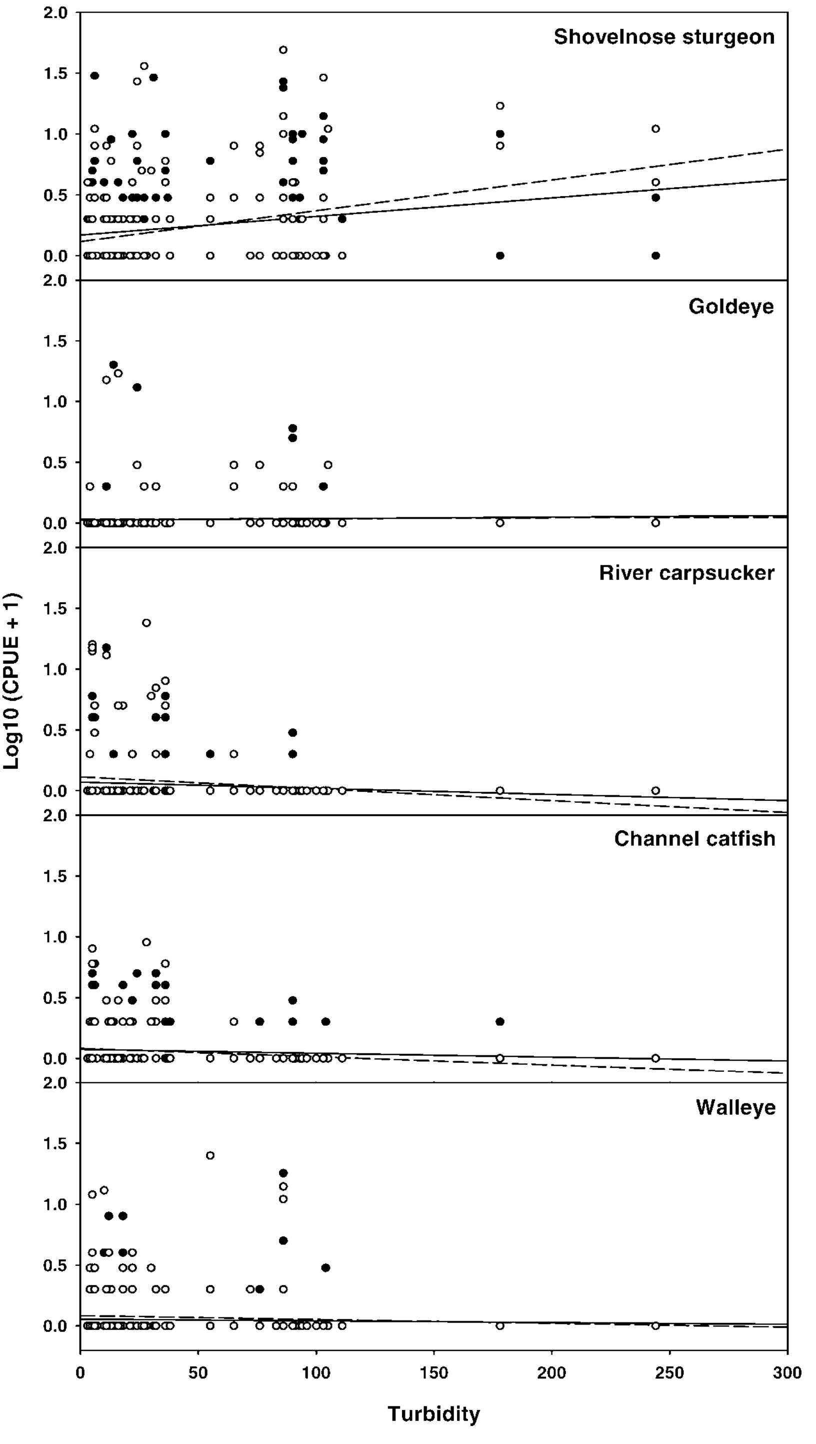

FIGURE 4.—Scatterplots comparing the gill-net $\log_{10}(\text{CPUE} + 1)$ for green (black circles) and white mesh nets (white circles) with turbidity levels for five fish species in the Missouri River in 2006 and 2007. The slopes for the green nets are depicted by solid lines, those for the white nets by dashed lines.

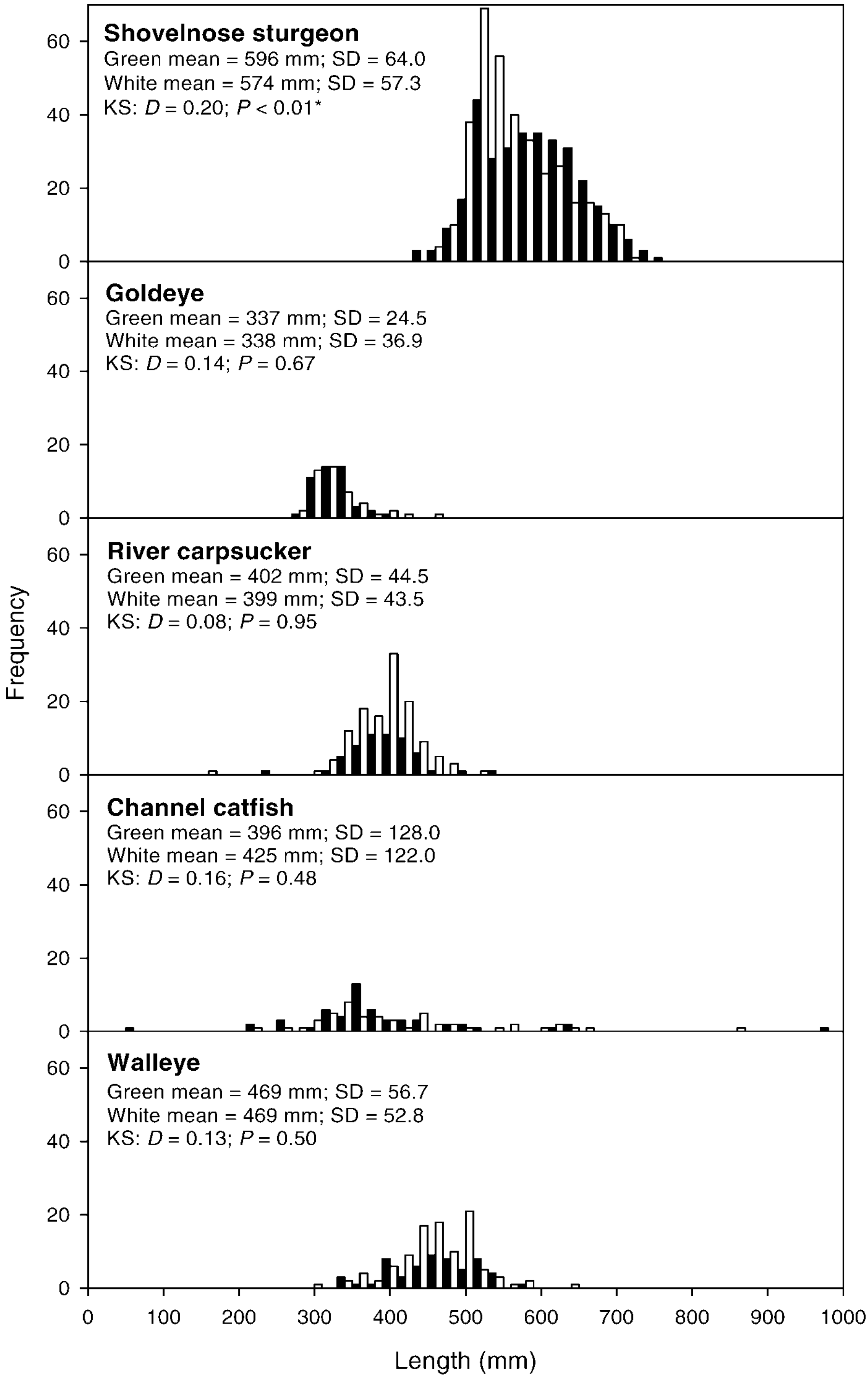

FIGURE 5.—Length frequency distributions of five fish species (20-cm length-groups) caught in green (black bars) and white mesh (white bars) gill nets in the Missouri River in 2006 and 2007; the abbreviation KS refers to the Kolmogorov–Smirnov test.

was not affected. We conclude that it was not necessary to dye nets green and recommend use of white nets due to higher overall catches and higher relative precision (low CV). Additionally, savings of time and money are realized by not needing to dye nets. Green and white net captures were both equally representing the fish populations; therefore, fishery managers may combine mean CPUE data from green and white mesh trammel nets and gill nets. A well-defined standardized monitoring program will allow fishery managers to compare fish population characteristics across large geographic areas over time in response to management actions.

Acknowledgments

We thank the many biologists and technicians from the U.S. Fish and Wildlife Service (USFWS) Great Plains Fish and Wildlife Conservation Office; Nebraska Game and Parks Commission; South Dakota Department of Game, Fish, and Parks; and USFWS Columbia National Fish and Wildlife Conservation Office for assisting with field collections. We also thank the Missouri Department of Conservation for database management. Funding was provided by the U.S. Army Corps of Engineers and USFWS. Reference to trade names does not imply endorsement by the U.S. Government.

References

Allen, M. S., M. M. Hale, and W. E. Pine III. 1999. Comparison of trap nets and otter trawls for sampling black crappie in two Florida lakes. North American Journal of Fisheries Management 19:977–983.

Berry, C. R. Jr., M. L. Wildhaber, and D. L. Galat. 2004. Fish distribution and abundance, volume 3. Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone rivers. U.S. Geological Survey, Cooperative Fish and Wildlife Research Units, South Dakota State University, Brookings.

Bonar, S. A., and W. A. Hubert. 2002. Standard sampling of inland fish: benefits, challenges, and a call for action. Fisheries 27(3):10–16.

Brown, F. A. Jr. 1937. Responses of largemouth black bass to colors. Illinois Natural History Survey Bulletin 21:33–55.

Burkhardt, R. W., and S. Gutreuter. 1995. Improving electrofishing catch consistency by standardizing power. North American Journal of Fisheries Management 15:375–381.

Conover, W. J. 1999. Practical nonparametric statistics, 3rd edition. Wiley, New York.

Douglas, R. H. 1989. The spectral transmission of the lens and cornea of the brown trout (*Salmo trutta*) and goldfish (*Carassius auratus*): effect of age and implications for ultraviolet vision. Vision Research 29:861–869.

Douglas, R., and M. Djamgoz, editors. 1990. The visual system of fish. Chapman and Hall, New York.

Drobish, M. R., editor. 2007. Missouri River standard operating procedures for sampling and data collection, volume 1.2. U.S. Army Corps of Engineers, Yankton, South Dakota.

Gabr, M., Y. Fujimori, S. Shimizu, and T. Miura. 2007. Trawling experiment in a circular water tank to assess the effects of towing speed, light intensity, and mesh shape on active escape of undersized fish. Fisheries Science 73:557–564.

Gibbs, M. A., and R. G. Northcutt. 2004. Development of the lateral line system in the shovelnose sturgeon. Brain, Behavior, and Evolution 64:70–84.

Gutreuter, S. J., R. Burkhardt, and K. Lubinski. 1995. Long-term resource monitoring program procedures: fish monitoring. National Biological Service, LTRMP 95-P002-1, Onalaska, Wisconsin.

Guy, C. S., E. W. Oldenburg, and P. C. Gerrity. 2009. Conditional capture probability of *Scaphirhynchus* spp. in drifting trammel nets. North American Journal of Fisheries Management 29:817–822.

Hajar, M. A. I., H. Inada, M. Hasobe, and T. Arimoto. 2008. Visual acuity of Pacific saury *Cololabis saira* for understanding capture process. Fisheries Science 74:461–468.

Hamel, M., and K. Steffensen. 2007. 2006 annual report: pallid sturgeon population assessment and associated fish community monitoring for the Missouri River—segment 8. Prepared for the U.S. Army Corps of Engineers. Omaha District, Yankton, South Dakota. Nebraska Game and Parks Commission, Lincoln.

Hawryshyn, C. W., M. G. Arnold, D. J. Chaisson, and P. C. Martin. 1989. The ontogeny of ultraviolet photosensitivity in rainbow trout (*Salmo gairdeneri*). Visual Neuroscience 2:247–254.

Hayes, D. B., C. P. Ferreri, and W. W. Taylor. 1996. Active fish capture methods. Pages 193–220 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Herzog, D. P., V. A. Barko, J. S. Scheibe, R. A. Hrabik, and D. E. Ostendorf. 2005. Efficacy of a benthic trawl for sampling small-bodied fishes in large river systems. North American Journal of Fisheries Management 25:594–603.

Hintze, J. 2006. NCSS, PASS, and GESS. Number Cruncher Statistical Software, Kaysville, Utah.

Hubert, W. A. 1996. Passive capture techniques. Pages 157–192 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Hurst, P. M. Jr. 1953. Can fish see color? Progressive Fish-Culturist 15:95.

Jester, D. B. 1973. Variations in catchability of fishes with color of gill nets. Transactions of the American Fisheries Society 102:109–115.

Linløkken, A., and T. O. Haugen. 2006. Density and temperature dependence of gill-net catch per unit effort for perch, *Perca fluviatilis*, and roach, *Rutilus rutilus*. Fisheries Management and Ecology 13:261–269.

Losey, G. S., T. W. Cronin, T. H. Goldsmith, D. Hyde, N. J. Marshall, and W. N. McFarland. 1999. The UV visual world of fishes: a review. Journal of Fish Biology 54:921–943.

Miller, M. J. 2005. The ecology and functional morphology of feeding of North American sturgeon and paddlefish. Pages 87–102 *in* G. T. O. LeBreton, F. W. H. Beamish, and R. S. McKinley, editors. Sturgeons and paddlefish of North America. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. 1996. Applied linear statistical models, 4th edition. WCB McGraw-Hill, Boston.

Pflieger, W. L. 1997. Fishes of the Missouri River, revised edition. Missouri Department of Conservation, Jefferson City.

Plauck, A., N. Utrup, W. Doyle, P. Herman, and T. Hill. 2007. 2006 annual report: pallid sturgeon population assessment and associated fish community monitoring for the Missouri River—segment 13. Prepared for the U.S. Army Corps of Engineers, Omaha District, Yankton, South Dakota. U.S. Fish and Wildlife Service, Columbia, Missouri.

Pope, K. L., and D. W. Willis. 1996. Seasonal influences on freshwater fisheries sampling data. Reviews in Fisheries Sciences 4:57–73.

Prairie, Y. T. 1996. Evaluating the predictive power of regression models. Canadian Journal of Aquatic Sciences 53:490–492.

Ricker, W. E. 1973. Linear regression in fishery research. Journal of the Fisheries Research Board of Canada 30:409–434.

Ricker, W. E. 1984. Computation and uses of central trend lines. Canadian Journal of Zoology 62:1897–1905.

Shuman, D. A., G. A. Wanner, R. A. Klumb, and W. J. Stancill. 2007. 2006 annual report: pallid sturgeon population assessment and associated fish community monitoring for the Missouri River—segments 5 and 6. Prepared for the U.S. Army Corps of Engineers, Omaha District, Yankton, South Dakota. U.S. Fish and Wildlife Service, Pierre, South Dakota.

Steffensen, K., and M. Hamel. 2007. 2006 annual report. Pallid sturgeon population assessment and associated fish community monitoring for the Missouri River: segment 9. Prepared for the U.S. Army Corps of Engineers Omaha District, Yankton, South Dakota. Nebraska Game and Parks Commission, Lincoln.

Stukel, S., J. Kral, and S. LaBay. 2007. 2006 annual report: pallid sturgeon population assessment and associated fish community monitoring for the Missouri River—segment 7. Prepared for the U.S. Army Corps of Engineers, Omaha District, Yankton, South Dakota. South Dakota Department of Game, Fish, and Parks, Yankton.

U.S. Army Corps of Engineers. 2002. Pallid sturgeon and fish community assessment plan for Missouri River habitat. U.S. Army Corps of Engineers, Yankton, South Dakota.

Utrup, N., A. Plauck, W. Doyle, P. Herman, and T. Hill. 2007. 2006 annual report: pallid sturgeon population assessment and associated fish community monitoring for the Missouri River—segment 14. Prepared for the U.S. Army Corps of Engineers, Omaha District, Yankton, South Dakota. U.S. Fish and Wildlife Service, Columbia, Missouri.

Wanner, G. A., D. A. Shuman, M. L. Brown, and D. W. Willis. 2007. An initial assessment of sampling procedures for juvenile pallid sturgeon in the Missouri River downstream of Fort Randall Dam, South Dakota and Nebraska. Journal of Applied Ichthyology 23:529–538.

Wetzel, R. G. 1983. Limnology, 2nd edition. Saunders, New York.

Wilkens, L. A., M. H. Hofmann, and W. Wojtenek. 2002. The electric sense of the paddlefish: a passive system for the detection and capture of zooplankton prey. Journal of Physiology 96:363–377.

Zar, J. H. 1999. Biostatistical analysis, 4th edition. Prentice-Hall, Upper Saddle River, New Jersey.