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Distribution and habitat use of sturgeon chubs (*Macrhybopsis gelida*) and sicklefin chubs (*M. meeki*) in the Missouri and Yellowstone Rivers, North Dakota

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Abstract

Sampling was conducted on the Missouri and Yellowstone rivers, North Dakota to obtain information on the distribution, abundance and habitat use of the sturgeon chub (*Macrhybopsis gelida*) and sicklefin chub (*M. meeki*) (Family Cyprinidae), two declining benthic fish species native to the Missouri River basin. The study area consisted of three distinct river segments, the Missouri River near Williston, the Missouri River near Bismarck (below Garrison Dam), and the Yellowstone River near its confluence with the Missouri River. Both species of chub were collected, mainly with a benthic trawl, throughout 94% of the range sampled in the Williston and Yellowstone segments. Sicklefin and sturgeon chubs were the second and third most abundant cyprinids, respectively, collected from the Williston and Yellowstone segments. Best-fit regression models indicated that the presence of sturgeon chubs increased with decreasing depth, increasing velocity and decreasing water clarity, and that the presence of sicklefin chubs increased with increasing depth, decreasing velocity and decreasing water clarity. In contrast, no chubs of either species were collected in trawls from the Bismarck segment. This segment had significantly deeper, faster, and clearer water than both the Williston and Yellowstone segments.

Introduction

The sturgeon chub (*Macrhybopsis gelida*) and sicklefin chub (*M. meeki*) are two small minnows (Family Cyprinidae) native to the Missouri River, lower Mississippi River, and some major tributaries. Both species historically inhabited turbid, free-flowing, unchannelized river segments often characterized by sloughs and sandbars, and containing considerable woody debris (snags) in the channel (Hesse, 1994).

As part of their adaptation to turbid habitats, both sturgeon chubs and sicklefin chubs have evolved specialized characteristics such as reduced eye size and reduced optic lobes (Davis & Miller, 1967). Both chubs have numerous cutaneous sensory papillae ventrally, within their buccal cavities, and on their heads and fins (Davis & Miller, 1967; Pflieger, 1975; Werdon, 1993a).

In the last half-century, the distribution and abundance of both species have decreased greatly following the construction of six mainstem Missouri River dams. These structures, as well as agricultural and urban development, have resulted in several significant habitat changes along most of the Missouri River's 3768 km length. These habitat changes include alterations of the natural hydrograph (Hesse & Mestl, 1993), altered river temperatures and decreases in the river's turbidity. Many riverine segments of the Missouri River now consist of a single, narrow, deep channel with swiftly flowing water (Hesse et al., 1989a, b; Hesse & Sheets, 1993). Moreover, each reservoir serves as a sediment sink, limiting the downstream movement of the river's suspended load, thus reducing turbidity in river reaches below the impoundments (Hesse, 1987; Hesse & Mestl, 1993). Currently, the sturgeon chub inhabits isolated portions of the Missouri River, the Yellowstone River, the Platte River, and the Powder River (Werdon, 1993a). The sicklefin chub has been located in isolated portions of the Missouri River, and the Mississippi River (Werdon, 1993b). Because both species are sometimes captured in the same sampling effort, in the same portion of the Missouri and Yellowstone rivers, information is needed on how habitat use of the two species differs.

The Missouri and the Yellowstone rivers in northwestern North Dakota and eastern Montana contain some of the most natural remaining habitat in the Missouri River drainage (Hesse et al., 1989a; Power et al., 1994). The objectives of this paper were to compare the distribution, relative abundance and habitat use of sturgeon and sicklefin chubs in three portions of the Yellowstone River and Missouri River of North Dakota.

Three main hypotheses were tested. The first hypothesis was that any habitat differences within the study area would result in differences in abundance and distribution within a species for both sturgeon chubs and sicklefin chubs. The second was that the specific habitat occupied by the two species would differ. The third was that different age-classes of both species would occupy different habitats.

Materials and methods

The study area included two segments of the Missouri River and one segment of the Yellowstone River, all entirely within the state of North Dakota (Fig. 1). The three segments are characterized by different flow regimes and habitat characteristics. The first segment of the Missouri River (hereafter called the Williston segment; 58 km long) is upstream of Lake Sakakawea and is free-flowing with a seminatural hydrograph, a result of the merging of the relatively free-flowing Yellowstone River and the highly regulated Missouri River. The second segment (hereafter called the Yellowstone segment; 28 km long) is in the Yellowstone River and is relatively free-flowing

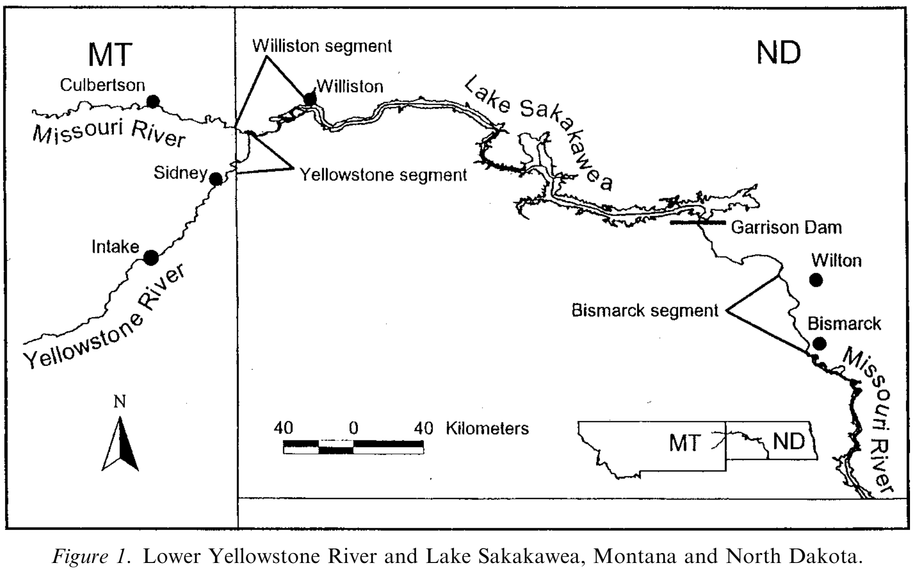

Figure 1. Lower Yellowstone River and Lake Sakakawea, Montana and North Dakota.

with a near natural hydrograph. Both segments are characterized by high main channel turbidity, no major shoreline development, and few revetment banks (rip-rap). The third segment (hereafter called the Bismarck segment; 53 km long) is in a portion of the Missouri River downstream of Lake Sakakawea (i.e., below Garrison Dam) and upstream of Lake Oahe. This segment extends into the northern Bismarck/Mandan urban area and is characterized by lower main channel turbidity, numerous revetments, and a much higher degree of shoreline development and bank stabilization (i.e., 25–40%) than the other two segments. In all, the three segments total approximately 139 river kilometers.

Distribution and abundance

The three river segments were stratified according to six macrohabitat types: main channel, border channel, side channel, sandbar, revetment and backwater. Starting from an initial random sampling unit, sampling sites were selected systematically along each macrohabitat type. Three samples were taken from within each site. This sampling design resulted in each macrohabitat type in each segment being sampled in proportion to its abundance in that segment (Table 1).

Sampling for chubs occurred from 10 July to 30 August, 1995 using two gear types, a benthic trawl and bag seines. The trawl has proven effective in recent studies for capturing benthic minnows and chubs (Grisak, 1996; Herzog, 1997). It consisted of a 3 m cross bar and two triangular 0.5 m high steel sleds. These supported two nets, an inner sampling net (mesh size 0.6 cm) and an outer protective net (mesh size 3 cm). The trawl collected fish by scraping the substrate of main channel, border channel, deep (>4 m) side channel, and revetment habitats. Trawl tows occurred on pre-marked 100 m transects parallel to the channel and near the thalwag. The trawl was suspended from the bow of a boat, and trawling proceeded downstream. The trawl sampled an area approximately 300 m^2.

Table 1. Distribution of sampling effort (number of each macrohabitat sampled) among segments

	Williston (56 km)	Yellowstone (28 km)	Bismarck (55 km)
Main channel	18	10	12
Border channel	6	3	4
Side channel	3	1	3
Sandbar	10	5	0
Backwater	2	2	0
Revetment	0	0	3

Historically, seines were more commonly used to sample benthic fishes in the Missouri River Basin, but more recently have been shown to be effective at capturing both sturgeon chubs and sicklefin chubs (Werdon, 1993a, b; Hesse, 1994). The bag seines used for this study were 10 m long with a mesh size of 0.6 cm. Sandbars, backwaters, and shallow side channels were sampled using bag seines. Seine hauls were 30 m long (area 300 m^2) and proceeded downstream.

Catch per unit effort (CPUE) of both chub species was calculated by segment. One trawl tow or one seine haul defined one unit of sampling effort. All sturgeon chubs and sicklefin chubs were measured to the nearest mm for total length (TL), weighed to the nearest gram, and had a scale sample removed for age determination. Scales were taken from the left side, above the lateral line, below and just posterior to the dorsal fin.

Habitat use

Each sampling site was characterized according to water depth, velocity, conductivity, temperature, clarity and substrate. Depth was measured using a Lowrance brand depth finder in deep waters and a calibrated pole in shallow waters. At trawl sites, depth was measured at the beginning, middle, and end of each trawl. At seine sites, depth was measured at the middle of the seine (generally 5 m from shore), at the beginning, middle and end of each seine haul. The reported depth is the mean of these three measurements.

Velocity was measured just above the substrate using a Marsh–McBirney Model 2000 flow meter. Measurements were taken at the beginning and end of each trawl and seine site. The reported velocity is the mean of these two measurements.

Temperature (°C) and conductivity (μmhos) were measured using an Orion brand electronic probe from just below the surface at each sampling site.

Water clarity was measured at each trawl and seine site using a 30 cm Secchi disk. The disk was lowered until it disappeared, and the length from the surface to the disk was measured. Then the disk was lowered well below this depth and slowly raised until it reappeared, and the length was measured again. The reported Secchi depth is the mean of these two measurements (Orth, 1989).

Substrate was sampled using an Ekman dredge at sites where trawling was conducted. At seining sites, the substrate was observed directly or a scoop was brought to the surface for identification. Samples were taken at the beginning and at the end of each sampling site. Sampling sites were classified based on the dominant substrate observed. Using the Wentworth Scale (Allen, 1995), inorganic substrate was categorized into three groups: mud/silt (particle size: ≤0.06 mm), sand (particle size: 0.06 mm ≤ 2 mm) and gravel (particle size: 2 mm ≤ 16 mm). Organic substrate (particle size: 1 mm ≤ 20 mm) was categorized as course organic matter (COM).

Because of the wide variation of discharge observed during the study, the effect of discharge on CPUE for both the trawl and seines was examined. Daily discharge data from the U.S. Geological Survey's Sidney, Montana gauging station were used for the Yellowstone segment, and from the Bismarck, North Dakota gauging station for the Bismarck segment. Daily discharge for the Williston segment was calculated by adding the previous day's discharge at both the Sidney gauging station and the Culbertson, Montana gauging station (Bramblett, 1996). Spearman's rank correlation coefficient (r_s) was used to test the significance of the relationship between daily discharge and CPUE for each segment and gear type.

Multiple logistic regression models were developed for each species to test the null hypothesis that there was no difference in habitat characteristics at sites where chubs were collected and not collected. Chub CPUE resulted in low numbers per sampling site and actual counts were converted to a simple measure of presence or absence. Logistic regression was selected because predictor variables need not be normally distributed and can be either continuous or categorical. The models had chub presence (1) or absence (0) as the dependent variable and depth, velocity, conductivity, temperature, water clarity, substrate and river macrohabitat as independent variables. First, a multiple logistic regression model was fitted with all variables. Categorical variables (substrate and macrohabitat) with α-values less than 0.05 were forced into the model (Johnson, 1998). Secondly, variable selection continued using a backward elimination procedure. The outcome was one best-fit model from available data for each species.

In order to estimate the relative contribution each macrohabitat variable made toward the presence of each chub species, the odds ratio between each macrohabitat variable was examined (Johnson, 1998). Each macrohabitat variable's estimated odds of being associated with the chubs' presence was calculated. The ratio of these probabilities is the odds ratio.

Model reliability was examined by calculating two indices. First, the χ^2 test for covariates was calculated to test whether the variables were statistically significant predictors of fish presence ($\alpha < 0.05$ for significance). Secondly, a summary classification matrix was created to identify the model's ability to accurately classify habitats as either containing or not containing chubs.

Species-specific habitat use

ANOVA procedures were used to test the null hypothesis that there was no difference in habitat occupied by sturgeon chubs and sicklefin chubs during the summer. The chub catch variable was presence (1), or absence (0). If the F-test for treatments was significant, then pairwise comparisons were made using Tukey's pairwise test. Differences in substrate composition between successful and unsuccessful chub sampling sites were evaluated using a χ^2 test (Ott, 1993).

Age-specific habitat use

All fish scales were analyzed in the laboratory at the University of Idaho. Scales were cleaned, placed in a microscope slidewell filled with glycerin and aged with the aid of Biosonic's Optical Pattern Recognition System (OPRS). ANOVA procedures were used to test the null hypothesis that there was no difference in habitat characteristics among areas occupied by different age-classes of sturgeon chubs and sicklefin chubs during the summer. If the F-test for treatments was significant, then pairwise comparisons were made using Tukey's pairwise test. Differences in substrate composition between age-classes at sampling sites were evaluated using a χ^2 test (Ott, 1993).

Results

Distribution and abundance

A total of 2726 fishes of 27 species was collected from the three segments: 1417 fishes from the Williston segment (376 trawl, 1041 seine), 1305 fishes from the Yellowstone segment (347 trawl, 958 seine) and four fishes from the Bismarck segment (four trawl). Thirty-one sturgeon chubs (ranked 15th in species abundance) and 63 sicklefin chubs (ranked 12th in species abundance) were collected. Both the trawl and seine strongly selected for fish below 150 mm in length. Ninety-three percent of all fishes in the trawl catch were less than 150 mm and 92% in the seine catch were less than 150 mm (Fig. 2).

The sturgeon chub and sicklefin chub were captured throughout 94% of the area sampled in the Williston and the Yellowstone segments. Both chub species were collected from the Williston segment between river kilometer (Rkm) 2553 and Rkm 2500. In the Yellowstone segment both the sturgeon chub and sicklefin chub were collected from 94% of the segment's 28 km length. The sturgeon chubs were collected between Rkm 28 and Rkm 2, and the sicklefin chubs were collected between Rkm 27 and Rkm 1. In contrast, no chubs of either species were collected from the Bismarck segment (length 53 km).

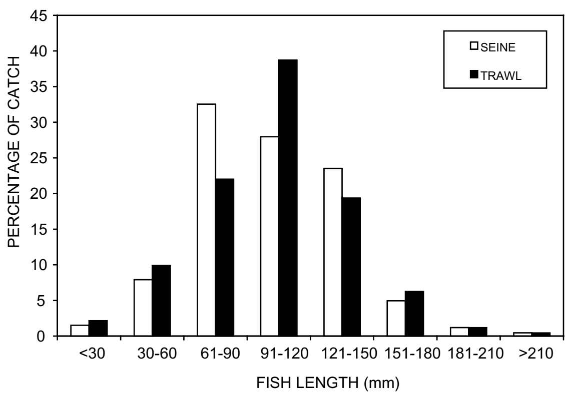

Figure 2. Length frequency distribution of the seine and trawl catch for all species.

In the Williston segment, 15 sturgeon chubs and 34 sicklefin chubs were captured, constituting less than 11% of the trawl catch and less than 2% of the seine catch. The overall relative species composition in the Williston segment consisted of 1.1% sturgeon chubs and 2.5% sicklefin chubs. The CPUE was 0.13 for sturgeon chubs and 0.30 for sicklefin chubs.

In the Yellowstone segment, 16 sturgeon chubs and 29 sicklefin chubs were captured, constituting less than 12% of the trawl catch and less than 0.5% of the seine catch. The overall relative species composition in the Yellowstone segment consisted of 1.2% sturgeon chubs and 2.2% sicklefin chubs. The CPUE was 0.25 for sturgeon chubs and 0.46 for sicklefin chubs.

Habitat use

At observed discharges, no significant differences in habitat use were found between the Williston and Yellowstone segments at sampling sites. In both the Williston and Yellowstone segments, there was no significant relationship between discharge and CPUE (Spearman's rank correlation; $p > 0.05$). However, depth, velocity and Secchi depths were significantly different (ANOVA, $p < 0.05$; Tukey's pairwise test, $p < 0.05$) between the Bismarck segment and both the Williston and Yellowstone segments. The Bismarck segment was significantly faster, deeper and had clearer water than the other two segments (Table 2, Figs. 3 and 4A).

Of the 15 sturgeon chubs from the Williston segment, most were collected from main channels (53.3%), followed by sandbars (40.0%), and border channels (6.7%). No sturgeon chubs were found in side channel, backwater or revetment habitats. In the Yellowstone segment, similar to the Williston segment, most of the 16 sturgeon chubs were collected from main channels (68.8%), followed by sandbars (12.5%), border channels (12.5%), and side channels (6.3%). No sturgeon chubs were found in backwater or revetment habitats.

Of the 35 sicklefin chubs from the Williston segment, most were collected from main channels (62.9%), followed by sandbars (14.3%), border

Table 2. Habitat characteristics of sites sampled for sturgeon chubs and sicklefin chubs

	Williston (n = 117)	Yellowstone (n = 63)	Bismarck (n = 66)
Mean depth (m)	4.8^a (3.0 SD)	4.1^a (2.5 SD)	8.7^b (2.2 SD)
Range	0.3–13.7	0.3–12.4	3.9–15.2
Mean bottom velocity (m/s)	0.7^a (0.3 SD)	0.5^a (0.3 SD)	1.5^b (0.3 SD)
Range	0.1–1.4	0.1–1.2	1.0–1.9
Mean Secchi depth (cm)	21.0^a (3.2 SD)	20.0^a (3.7 SD)	104.0^b (9.8 SD)
Range	17.0–30.0	15.0–32.0	57.0–175.0
Mean conductivity (μmhos)	597^a (45.2 SD)	594^a (55.8 SD)	637^a (51.2 SD)
Range	535–735	521–701	576–779
Mean temperature (°C)	22.7^a (1.3 SD)	21.6^a (1.4 SD)	19.4^a (1.6 SD)
Range	16.7–24.4	18.0–23.5	15.4–22.6
Substrate composition (%)			
Sand	42.7	42.9	9.1
COM	23.9	25.4	48.5
Woody debris	14.5	12.7	30.3
Mud/silt	11.1	11.1	7.6
Gravel	7.7	7.9	4.5

Means with differing superscripts indicate significant difference ($p < 0.05$).

channels (17.1%), and side channels (5.7%). No sicklefin chubs were found in backwater or revetment habitats. In the Yellowstone segment most of the 29 sicklefin chubs were collected from main channels (62.1%), followed by border channels (27.6%), sandbars (6.9%), and side channels (3.4%). No sicklefin chubs were found in backwater or revetment habitats.

One model for each species was developed to relate chub presence and habitat characteristics

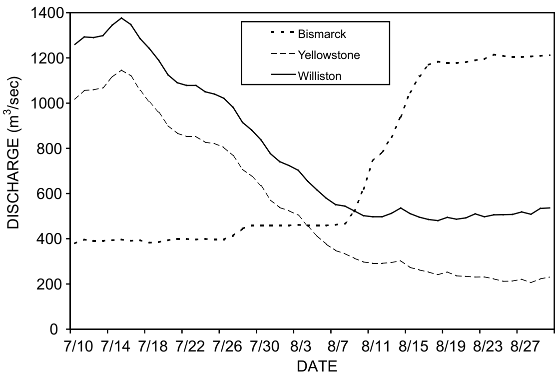

Figure 3. Daily discharge for the Williston, Yellowstone, and Bismarck segments from July 10 to August 30, 1995 (U.S.G.S., 1998).

(Table 3). No model was developed for the Bismarck segment because of the lack of catch. Because there were few differences in habitat characteristics at sampling sites between the Williston and Yellowstone segments, the models were developed by combining data from these two segments. Three variables, velocity, depth and turbidity were significantly ($p < 0.05$) related to sturgeon chub presence. For the sicklefin chub, four variables, velocity, depth, turbidity and substrate were significantly ($p < 0.05$) related to chub presence. Therefore, we rejected the null hypothesis that there was no difference in habitat characteristics where sturgeon and sicklefin chubs were captured and not captured.

Variables that entered both models were good predictors of chub presence (χ^2 test of covariates; $p < 0.05$). The sturgeon chub model accurately predicted sturgeon chub presence at 72.2%. The model indicated that sturgeon chub presence increased significantly as depth decreased, velocity increased and water clarity decreased.

The sicklefin chub model accurately predicted presence at 85.5%. The model indicated that sicklefin chub presence increased as depth increased, velocity decreased, water clarity decreased and sand became the dominant substrate.

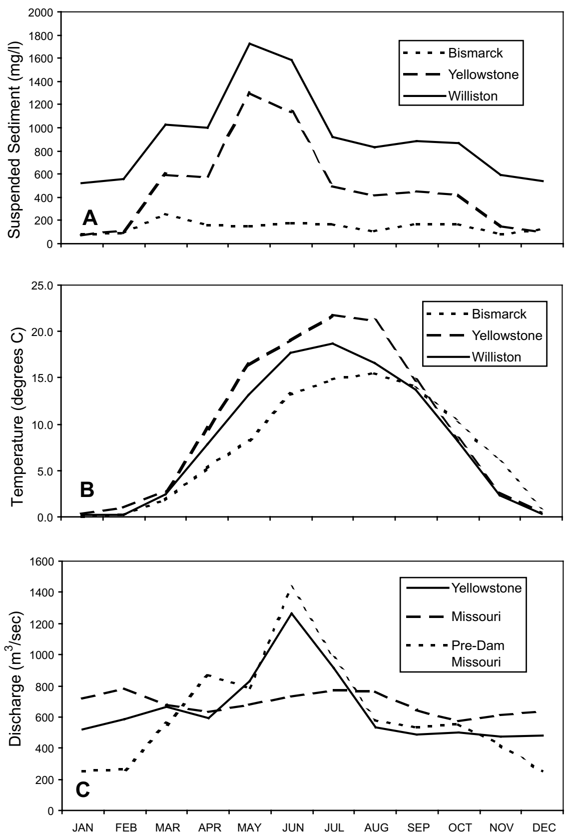

Figure 4. (A) Mean monthly suspended sediment loads for the Bismarck, Yellowstone and Williston segments from 1971 to 1996 (U.S.G.S., 1998). (B) Mean monthly water temperature for the Bismarck, Yellowstone and Williston segments from 1971 to 1996 (U.S.G.S., 1998). (C) Mean monthly discharge for the Yellowstone River at Sidney, MT, Missouri River at Bismarck, ND from 1971 to 1996, and Missouri River at Bismarck from 1928 to 1953 (U.S.G.S., 1998).

Species-specific habitat use

Significant differences were found between the habitat characteristics of sturgeon chub and sicklefin chub capture sites in the Williston and Yellowstone segments (ANOVA; $p < 0.05$). Therefore, we rejected the null hypothesis that there was no difference in habitat characteristics where either sturgeon chubs or sicklefin chubs were captured. Depth, velocity and substrate significantly differed between sturgeon chub and sicklefin chub capture sites (Tukey's pairwise test; $p < 0.05$). Sturgeon chubs used shallow habitats (mean depth = 2.5 m), with higher water velocities (mean velocity = 0.89 m/s) and gravel substrate (particle size: 2 mm ≤ 16 mm). In contrast, sicklefin chubs used deeper habitats (mean depth = 6.8 m) with lower water velocities (mean velocity = 0.47 m/s) and sand substrate (particle size: 0.06 mm ≤ 2 mm). Furthermore, both chubs were present together in only 13.2% of the successful chub sampling sites, which further suggests dissimilarity in the specific habitat selection of the two chubs.

Age-specific habitat use

The most common age of both sicklefin chubs and sturgeon chubs was age-2 (Table 4). Overall, 6% of the sturgeon chubs collected were age-1, 68% were age-2, and 26% were age-3. The sicklefin chub age structure was 6% age-1 fish, 70% age-2 fish, 22% age-3 fish and 2% age-4 fish.

Both sturgeon chubs and sicklefin chubs of different ages showed no significant differences in habitat use (ANOVA; $p > 0.05$). Therefore, we failed to reject the null hypothesis that there was no difference in depth, velocity, water clarity, temperature, conductivity, substrate and river habitat type among areas occupied by different age-classes of sturgeon chubs and sicklefin chubs during the summer. However, age-1 sturgeon chubs were only captured in the main channel, and age-1 sicklefin chubs were only captured in main channel and border channel habitats.

Table 3. Final model equations for characterizing habitat where sturgeon chubs and sicklefin chubs were presence or absent

Model equation	*p*-Value
Log odds of sturgeon chub presence = 12.9947 − 0.4328 (depth) + 5.2058 (water velocity) − 0.8798 (water clarity)	<0.001
Log odds of sicklefin chub presence = 12.3535 + 0.2913 (depth) − 2.7027 (water velocity) − 0.8056 (water clarity) + 2.1990 (sand) − 2.5728 (gravel) − 4.6161 (mud)	<0.01

Table 4. Length range and mean length at age for sturgeon chubs and sicklefin chubs in the middle Missouri and lower Yellowstone rivers, North Dakota

Age (year)	Mean length (mm)		Length range (mm)		Number of fish	
	Sturgeon	Sicklefin	Sturgeon	Sicklefin	Sturgeon	Sicklefin
1	42.5	46.0	35–50	39–53	2	4
2	65.4	75.3	51–75	53–85	21	45
3	82.8	93.1	73–86	86–99	8	14
4	–	107	–	107	0	1

Discussion

Significant differences in habitat use between sturgeon chubs and sicklefin chubs are consistent with results reported elsewhere. For example, we found that sturgeon chubs used shallower water than sicklefin chubs. W.R. Gould (Montana State University, Bozeman, Pers. Comm.) collected sturgeon chubs in the Powder River in depths of 0.6 m or less, and Grisak (1996) collected sicklefin chubs in the Missouri River in depths of 1.5 m or greater. Other studies demonstrated differences in habitat depth (Burr & Warren, 1986; Cross & Moss, 1987). The biological significance of depth is unclear. Chubs may be seeking specific depths, or they may be seeking combinations of velocity, substrates or other factors associated with these depths.

Water velocities of habitat used by chubs differed. Sturgeon chubs inhabited areas with higher water velocities than sicklefin chubs. Hesse (1994) reported sturgeon chubs use a habitat with strong current (not measured) and Grisak (1996) found sicklefin chubs used habitats with a mean water velocity of only 0.58 m/s. The sturgeon chub's uniquely keeled scales may improve its hydrodynamics, allowing it to hold its position in high water velocities (Pflieger, 1975). Furthermore, Davis & Miller (1967) found the sturgeon chub's cerebellum to be more highly developed than that of the sicklefin chub. A larger cerebellum has been associated with inhabiting fast water (Davis & Miller, 1967).

Substrate use also differed between the two chub species. Although gravel was the least common substrate observed over all sampling sites, it was the second most common substrate observed at sites where sturgeon chubs were found. The primary substrate reportedly used by the sturgeon chub elsewhere was gravel (Davis & Miller, 1967; Baxter & Simon, 1970; Gelwicks et al., 1996). Sicklefin chubs were found predominately over sand substrate, as has been found elsewhere (Davis & Miller, 1967; Klutho, 1983; Gelwicks et al., 1996). As an adaptation to these types of substrate, both chub species have fleshy coverings over their eyes, which are thought to serve to reduce abrasion by sand and fine gravel (Davis & Miller, 1967; Werdon 1993a, b). In addition, Davis & Miller (1967) suggested that the difference in substrate use between the two chubs is due to a difference in feeding mechanisms. Davis & Miller (1967) hypothesized that the sturgeon chub is more selective and detects food more readily because it has a higher density of cutaneous taste buds than the sicklefin chub. This would allow it to feed more effectively over coarser substrates, such as gravel, which requires a good external sorting mechanism for food to avoid ingestion of the larger inert particles. In contrast, the sicklefin chub has a higher density of pharyngeal taste buds and is capable of ingesting large quantities of detritus and then use its more efficient internal sorting mechanism to separate food particles from inedible matter (Davis & Miller, 1967). This would allow it to feed effectively over smaller substrates, such as sand, which can be readily picked up and sorted by the chub.

The lack of significant differences in habitat use by fish of different ages of both sturgeon chubs and sicklefin chubs suggest younger fish do not require different habitat from mature fish. Fish in this study were collected during the reported summer spawning period.

The inability to seine the Bismarck segment made it impossible to accurately compare fish total abundance between the Bismarck segment and the other two segments. However, comparisons among catches were possible among the three segments for the trawl, which has been found to be the most successful gear for sampling both species in this portion of the Missouri River (Welker, 2000). In this study, trawls were also the more successful gear of the two used for both chubs (sicklefin chub: 57 trawl versus 7 seine; sturgeon chub: 23 trawl versus 8 seine), and sampled more than 20 other species (Everett, 1999). Total catch of all fishes in the trawl samples (4 fish) in the Bismarck segment was much lower than in the other two segments (376 fish and 347 fish). These results were similar to those later reported by Welker (2000), who found both species to be common in the Yellowstone and Missouri (below Fort Peck Dam), but absent in the Bismarck segment.

The lack of chubs (as well as near absence of other fishes) in the Bismarck segment corresponded to major differences in habitat between that segment and the other two. The sampling sites in the Bismarck segment were deeper, faster flowing and clearer than both the Williston and Yellowstone segments. Both habitat models from the Yellowstone and Williston segments included these three variables (depth, velocity and water clarity) as significantly correlated with the variation in the presence of both chub species. Evidently, these three variables are habitat characteristics that influence the chubs' distribution and abundance.

Temperature differences between the segments also exist. Although no significant differences were found in water temperature between the Bismarck, Williston and Yellowstone segments during our brief, late summer sampling period, monthly mean temperatures over the 25-year period 1971–1996 were much lower in the Bismarck segment than in both the Williston and Yellowstone segments (Fig. 4B). In addition, water temperatures at Bismarck depicted in Figure 4B are often several degrees higher than water 130 km upriver at Garrison Dam, especially in mid to late summer.

The significant differences observed in depth, velocity, water clarity and temperature between the Bismarck segment and both the Williston and Yellowstone segments are associated with habitat changes resulting from Garrison Dam. The deepened channel below Garrison Dam is the result of high discharges scouring the streambed. After the closure of Garrison Dam in December 1953, mean monthly discharge has increased from its historical level as much as 514 m^3/s in February and decreased as much as 697 m^3/s in June (Fig. 4C). The resulting flow regulation and channel morphology has reduced the range of depths and velocities, thereby reducing the diversity of ecological niches the river once provided (Hesse & Sheets, 1993).

Garrison Dam has also increased water clarity in the river. Inflowing suspended sediments settle out behind the dam under reduced current velocities. The habitat models indicate that both chub species inhabit areas with low water clarity, such as in the Yellowstone and Williston segments, as opposed to the clearer waters of the Bismarck segment. More investigations are needed on the exact mechanism resulting in the absence of both chub species in the clearer water. Predation by sight-feeding fishes is one possible cause worth investigating. Regardless of the exact cause, the absence of chubs in all habitats in the Bismarck segment indicates that turbidity is one factor associated with the presence or absence of these species.

Hypolimnetic withdrawals from Garrison Dam have also reduced water temperature in the Bismarck segment. Such temperature alterations have been shown to have substantial effects on fish communities. Several studies have shown fish growth to be temperature dependent (Ricker, 1979; Jobling, 1981). Altered temperatures also alter the prey composition. Both chub species feed on benthic invertebrates (Reigh & Elsen, 1979; Stewart, 1981). Vannote & Sweeney (1980) demonstrated that decreased temperatures reduced the adult body size of several invertebrates, which in turn resulted in decreased fecundity. Moreover, many fish species need a natural temperature cycle for proper egg development. The consistently cool temperatures caused by dams have in some states resulted in spawning event failure (Allen, 1995). More research is needed on the effects of temperature on the two chub species.

The status of both the sturgeon chub and sicklefin chub is currently a subject of debate. Some studies show depressed populations that indicate a threatened or endangered status of both species (Werdon, 1993a, b; Hesse, 1994). In contrast, W.R. Gould (Montana State University, pers. comm.) sampled for sturgeon chubs in

Montana in the 1990s and found them to exhibit a more widespread distribution and higher catch rates than found elsewhere in its range. Similarly, Grisak (1996) reported high relative abundance of sicklefin chubs from trawl catches in Montana, as well as high catch rates of different aged fish, indicating a healthy population. These two species were captured in greater numbers in the two uppermost segments of our study area than any other cyprinids except the flathead chub (*Platygobio gracilis*) and common carp (*Cyprinus carpio*).

The sturgeon and sicklefin chubs' widespread distribution, high relative abundance, and diversity of ages in the Williston and Yellowstone segments indicate that their status in these segments is better than at most locations throughout their range. Therefore, maintaining a near natural hydrograph, a natural thermal regime, natural habitat diversity, and natural levels of turbidity should be considered vital to the survival of these two native Missouri River chubs.

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References

Allen, J. D., 1995. Stream Ecology: Structure and Function of Running Waters. Chapman and Hall, New York, 388 pp.

Baxter, G. T. & J. R. Simon, 1970. Wyoming Fishes. Wyoming Game and Fish Department Bulletin 4. Cheyenne: 168 pp.

Bramblett, R. G., 1996. Habitats and movements of pallid and shovelnose sturgeon in the Yellowstone and Missouri rivers, Montana and North Dakota. Doctoral Dissertation. Montana State University, Bozeman: 210 pp.

Burr, B. M. & M. L. Warren. Jr., 1986. A Distributional Atlas of Kentucky Fishes. Kentucky Nature Preserve Commission. Scientific and Technical Series No. 4, Frankfort: 398 pp.

Cross, F. B. & R. E. Moss, 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. In Matthews, W. J. & D. C. Heins (eds), Community and Evolutionary Ecology of North American Stream Fishes. University of Oklahoma Press, Norman: 155–165.

Davis, B. J. & R. J. Miller, 1967. Brain patterns in minnows of the genus Hybopsis in relation to feeding habits and habitat. Copeia 1967: 1–39.

Everett, S. R., 1999. Life history and ecology of three native benthic fishes in the Missouri and Yellowstone rivers. Master's Thesis, University of Idaho, Moscow: 69 pp.

Gelwicks, G. T., K. Graham, D. Galat & G. D. Novinger, 1996. Status survey for sicklefin chub, sturgeon chub, and flathead chub in the Missouri River, Missouri. Final Report. Missouri Department of Conservation, Columbia: 22 pp.

Grisak, G. G., 1996. The status and distribution of the sicklefin chub in the middle Missouri River, Montana. Master's Thesis. Montana State University, Bozeman: 77 pp.

Herzog, D. P., 1997. Long term resource monitoring program (LTRMP) fisheries. In Gutreuter, S., E. W. Burkhardt, M. Stopyro, A. Bartels, E. Kramer, M. C. Bowler, F. A. Cronin, D. W. Soergel, M. D. Petersen, D. P. Herzog, K. S. Irons, T. M. O'Hara, K. D. Blodgett & P. T. Raibley (eds), 1995 Annual Status Report: A Summary of Fish Data in Six Reaches of the Upper Mississippi River System. U.S. Geological Survey, Environmental Management Technical Center, LTRMP 97-P009. Onalaska, Wisconsin: 178–216.

Hesse, L. W., 1987. Taming the wild Missouri River: what has it cost? Fisheries 12: 2–9.

Hesse, L. W., 1994. The status of Nebraska fishes in the Missouri River, 5. Selected chubs and minnows (Cyprindae): sicklefin chub (*Macrhybopsis meeki*), sturgeon chub (*M. gelida*), silver chub (*M. aestivalis*), flathead chub (*Platygobio gracilis*), plains minnow (*Hybognathus placitus*), and western silvery minnow (*H. argyritis*). Transactions of the Nebraska Academy of Science 21: 99–108.

Hesse, L. W. & G. E. Mestl, 1993. An alternative hydrograph for the Missouri River based on the precontrol condition. North American Journal of Fisheries Management 13: 360–366.

Hesse, L. W. & W. Sheets, 1993. The Missouri River hydrosystem. Fisheries 18: 5–14.

Hesse, L. W., G. R. Chaffin & J. Brabander, 1989a. Missouri River mitigation: a system approach. Fisheries 14: 11–15.

Hesse, L. W., J. C. Schmulbach, J. M. Carr, K. D. Keenlyne, D. G. Unkenholz, J. W. Robinson & G. E. Mestl, 1989b. Missouri River fishery resources in relation to past, present, and future stresses. In Dodge D. P. (ed.), Proceedings of the International Large River Symposium. Canadian Special Publication of Fisheries and Aquatic Sciences 106, Ottawa, Ontario, Canada: 352–371.

Jobling, M., 1981. Temperature tolerance and the final preferendum: rapid methods for the assessment of optimum growth temperatures. Journal of Fish Biology 19: 439-455.

Johnson, D. E., 1998. Applied Multivariate Methods for Data Analysis. Duxbury Press, Pacific Grove, California: 642 pp.

Klutho, M. A., 1983. Seasonal, daily, and spatial variation of shoreline fishes in the Mississippi River at Grand Tower, Illinois. Master's Thesis. Southern Illinois University, Carbondale: 84 pp.

Orth, D. J., 1989. Aquatic habitat measurements. In Neilsen, L. A. & D. L. Johnson (eds), Fisheries Techniques. American Fisheries Society, Bethesda, Maryland: 61–94.

Ott, R. L., 1993. An Introduction to Statistical Methods and Data Analysis. 4th edn. Duxbury Press, Cincinnati, Ohio: 1051 pp.

Pflieger, W. L., 1975. The Fishes of Missouri. Missouri Department of Conservation, Jefferson City: 343 pp.

Power, G. J., J. C. Henderickson, J. D. Lee & F. Ryckman, 1994. Missouri River system fishery reference and operational management document. North Dakota Game and Fish Department Division Report 10, Bismarck: 72 pp.

Reigh, R. C. & D. S. Elsen, 1979. Status of the sturgeon chub (*Hybopsis gelida*) and sicklefin chub (*Hybopsis meeki*) in North Dakota. Prairie Naturalist 11: 49–52.

Ricker, W. E., 1979. Growth rates and models. In Hoar, W. S., D. J. Randall & J. R. Brett (eds), Fish Physiology. Academic Press, New York: 677–743.

Stewart, D. D., 1981. The biology of the sturgeon chub (*Hybopsis gelida* Girard) in Wyoming. Master of Science Thesis, University of Wyoming, Laramie: 54 pp.

U.S.G.S. (United States Geological Survey), 1998. http://water.usgs.gov/data.html.

Vannote, R. L. & B. W. Sweeney, 1980. Geographic analysis of thermal equilibria: A conceptual model for evaluating the effect of natural and modified thermal regimes on aquatic insect communities. American Naturalist 115: 667–695.

Welker, T. L., 2000. Ecology and Structure of Fish Communities in the Missouri and Lower Yellowstone Rivers. Doctoral Dissertation, University of Idaho, Moscow: 232 pp.

Werdon, S. J., 1993a. Status report on sicklefin chub (*Macrhybopsis meeki*), a candidate endangered species. Report of the U.S. Fish and Wildlife Service, Bismarck, North Dakota: 41 pp.

Werdon, S. J., 1993b. Status report on sturgeon chub (*Macrhybopsis gelida*), a candidate endangered species. Report of the U.S. Fish and Wildlife Service, Bismarck, North Dakota: 58 pp.