Ecology of Freshwater Fish 2004: 13: 8–22
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ECOLOGY OF
FRESHWATER FISH

Habitat use and population structure of four native minnows (family Cyprinidae) in the upper Missouri and lower Yellowstone rivers, North Dakota (USA)

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Welker TL, Scarnecchia DL. Habitat use and population structure of four native minnows (family Cyprinidae) in the upper Missouri and lower Yellowstone rivers, North Dakota (USA).
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Abstract – In 1997 and 1998, sampling was conducted on the Missouri and Yellowstone rivers, North Dakota, to obtain information on the distribution, abundance, and habitat use of the flathead chub (*Platygobio gracilis* Richardson), sicklefin chub (*Macrhybopsis meeki* Jordan & Evermann), sturgeon chub (*Macrhybopsis gelida* Girard), and western silvery minnow (*Hybognathus argyritis* Girard), four declining fish species (family Cyprinidae) native to the Missouri River basin, USA. The study area consisted of four distinct river segments near the confluence of the Missouri and Yellowstone rivers – three moderately altered segments that were influenced by a main-stem dam and one quasi-natural segment. One moderately altered segment was located at the confluence of the two rivers (mixing-zone segment (MZS)). The other two moderately altered segments were in the Missouri River adjacent to the MZS and extended up-river (above-confluence segment (ACS)) and down-river (below-confluence segment (BCS)) from this segment. The quasi-natural segment (Yellowstone River segment (YRS)) extended up-river from the MZS in the Yellowstone River. Catch rates with the trawl for sicklefin chub and sturgeon chub and catch rates with the bag seine for flathead chub and western silvery minnow were highest in the BCS and YRS. Most sicklefin and sturgeon chubs were captured in the deep, high-velocity main channel habitat with the trawl (sicklefin chub, 97%; sturgeon chub, 85%), whereas most flathead chub and western silvery minnow were captured in the shallow, low-velocity channel border habitat with the bag seine (flathead chub, 99%; western silvery minnow, 98%). Best-fit regression models correctly predicted the presence or absence of sicklefin chub, flathead chub, and western silvery minnow more than 80% of the time. Sturgeon chub presence and absence were predicted correctly 55% of the time. Best-fit regression models fit to fish number data for flathead chub, sicklefin chub, and sturgeon chub and fish catch-per-unit-effort (CPUE) data for flathead chub also provided good fits, with R^2 values ranging from 0.32 to 0.55 ($P < 0.0001$). The higher density and catch of the four native minnows in the YRS and BCS suggest that these two segments are better habitat than the ACS and MZS.

Key words: flathead chub; sicklefin chub; sturgeon chub; western silvery minnow; Cyprinidae; predictive model

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Accepted for publication February 16, 2003

Un resumen en español se incluye detrás del texto principal de este artículo.

Introduction

The physical and biological characteristics of riverine systems have been shown to shape fish communities (Kuehne 1962; Barila et al. 1981). Alterations of these river characteristics have led to subsequent changes in fish populations (Walker & Thoms 1993; Duque et al. 1998) and fish community structure (Bain et al. 1988; Layher 1994; Schmidt et al. 1998; Penaz et al. 1999). In many large river systems, dams have been responsible for changes in downstream river physical habitat characteristics (e.g., depth, turbidity, and water temperature), resulting in changes in native fish species distribution, abundance, and community structure (Minckley 1991; Ligon et al. 1995; Gehrke et al. 1999).

Historically, most sections of the Missouri and lower Yellowstone rivers possessed very similar physical characteristics, including high sediment loads, meandering channels, and fluctuating hydrographs (Hesse et al. 1989). Today, the hydrological, physical, and biological characteristics of many Missouri River segments have been altered from dam construction, bank stabilization, and other actions. Impacted river segments often exhibit very different environmental characteristics and fish communities from those of unaltered segments (Hesse et al. 1989).

The confluence of the Missouri and Yellowstone rivers (hereafter referred to as the confluence) occurs in north-west North Dakota near the Montana–North Dakota border. Many native species of fish are abundant in the confluence area, but are considered at risk or threatened in other portions of the Missouri River basin (Hesse et al. 1989). The lower Yellowstone River below the Intake Diversion Dam (114.4 river kilometer (rkm)) is still very turbid and productive, with no dams. Conversely, the Missouri River above the confluence has been impacted by Fort Peck Dam; this segment has an altered hydrograph, a reduced sediment load, and a colder temperature regime (Leopold et al. 1964; Young et al. 1998). The Missouri River below the confluence is influenced by both the lower Yellowstone River and the Fort Peck Dam. Additionally, at the confluence of the Yellowstone and Missouri rivers, there is a mixing zone of the two rivers resulting in a habitat with physical attributes unlike the other three confluence river segments. These four segments of river thus exhibit different physical and, perhaps, biological characteristics. The distinctiveness and close proximity of these segments provide an opportunity to examine the relationship between an array of environmental variables and distribution, abundance, and habitat use of various fish species constituting the native fish community.

Several small cyprinid species common to the confluence area have diminished in distribution and abundance in many other segments of the Missouri River and its tributaries (Pflieger & Grace 1987; Hesse 1994). These species include the flathead chub (*Platygobio gracilis* Richardson), sicklefin chub (*Macrhybopsis meeki* Jordan and Evermann), sturgeon chub (*Macrhybopsis gelida* Girard), and western silvery minnow (*Hybognathus argyritis* Girard). Concerns over reduction in range of the sicklefin and sturgeon chubs prompted petitions to the United States Fish and Wildlife Service in 1994 to list both species as endangered. Although the flathead chub and western silvery minnow have not been considered for Federal listing as endangered species, they are listed by most Missouri River basin states (Montana, North Dakota, South Dakota, Iowa, Kansas, and Missouri) as threatened or species of concern (Hesse et al. 1989). Even though numerous researchers have provided information on the microhabitat preferences of these native cyprinid fishes (Pflieger 1975; Reigh & Elsen 1979; Stewart 1981; Werdon 1992; Hesse 1994; Grisak 1996; Gould, unpublished report; Ozanne, unpublished paper), detailed quantitative assessments concerning their habitat use in relation to environmental features of large rivers are absent. For conservation of these species, it is important to understand the habitat characteristics that are most important to them, and how habitat differences in river segments may be manifested in differences in fish abundance or density. Such comparison is best obtained over a restricted geographic range, where problems with confounding factors are fewer.

The objectives of this study were to: (i) examine habitat use of flathead chub, sicklefin chub, sturgeon chub, and western silvery minnow during summer; and (ii) to determine the comparative importance of four distinct large river segments in close proximity to the Yellowstone–Missouri River confluence as habitat for these four native cyprinids.

Study area

The confluence of the Missouri and Yellowstone rivers is located in north-west North Dakota, approximately 8 km from the North Dakota–Montana border (Fig. 1). All four study segments were within the confluence area. Two study segments were in the Missouri River, one segment was in the Yellowstone River, and the fourth segment was the mixing zone of the Missouri

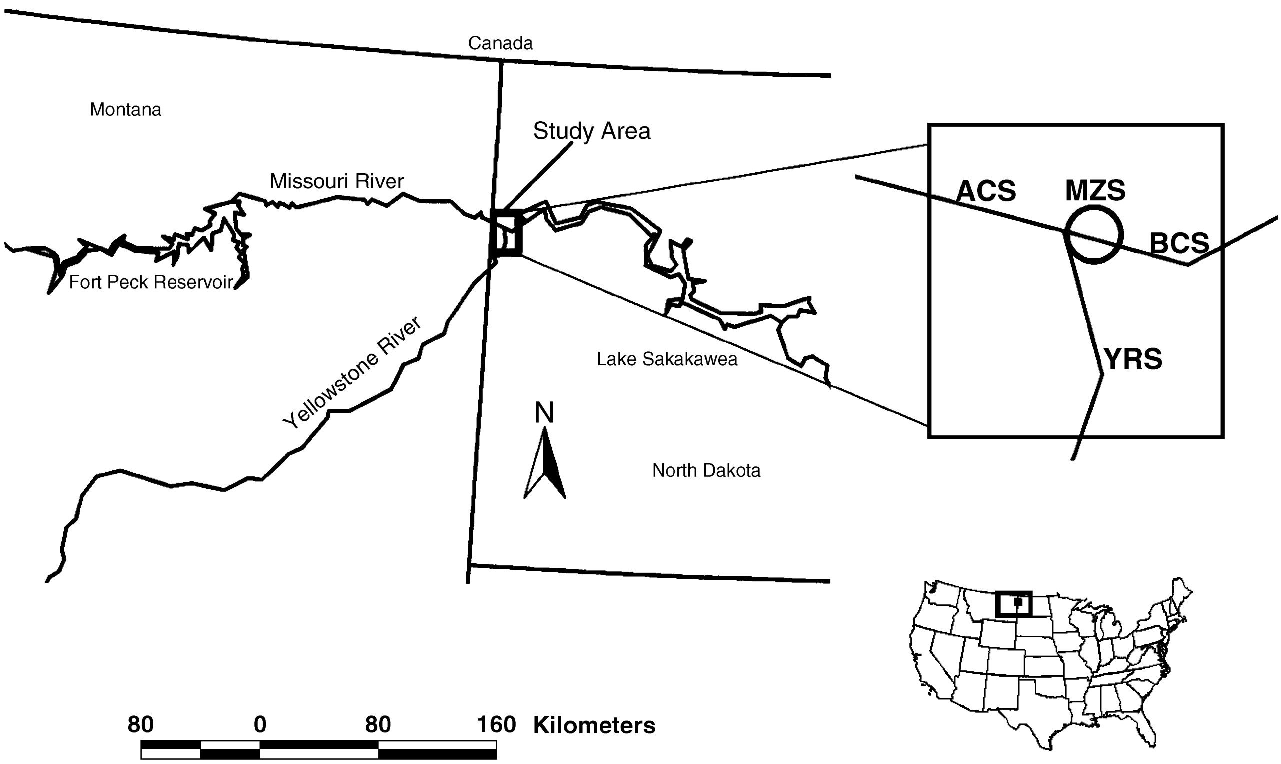

Fig. 1. Map depicting study area location and the four study segments (ACS, above confluence segment; BCS, below confluence segment; MZS, mixing zone segment; YRS, Yellowstone River segment).

and Yellowstone rivers (Fig. 1). The first segment of the Missouri River extended 8 km up-river from the Missouri River and Yellowstone River confluence (Missouri River = 2546 rkm) and is hereafter referred to as the above-confluence segment (ACS; Fig. 1). The second Missouri River segment extended 48.3 km down-river from the confluence to the headwaters of Lake Sakakawea (2470.3 rkm) and is hereafter referred to as the below-confluence segment (BCS; Fig. 1). The Yellowstone River segment (YRS) extended 24.0 km up-river from the confluence and is hereafter referred to as the YRS (Fig. 1). The mixing zone, hereafter referred to as the mixing-zone segment (MZS), extended from the confluence down-river approximately 800 m in the Missouri River.

Materials and methods

Data collection

Two habitat types, main channel and main channel border, were sampled to characterize segment fish communities and to examine the relationships among fish and select physiochemical variables. Main channel habitat paralleled the river shoreline at and immediately adjacent to the thalweg. Channel border habitat was shallower, and extended from the river shoreline toward the thalweg to a maximum depth of 1.5 m. Eight 250-m sample units, each of which contained both habitat types, were selected near the confluence in each of three segments of the river (ACS, BCS, and YRS). A sample unit was defined as a 250-m stretch of the river with its longitudinal boundaries as the shoreline. Sample units were confined within the main-stem river, located between but not within, inside–outside bend complexes. Only two sample units of this length existed in the MZS (the shortest segment), so only these two sample units were used. Data were collected in the period July–September 1997 and 1998. Two sample units were randomly selected, without replacement, in each of the summer months from each study region. Both available sample units in the MZS were sampled once in each of the 3 months. In each month, sample units were sampled within four consecutive days.

Fish collection

Two gears were used to sample fish within sample units. Fish in main channel habitat were sampled with a benthic beam trawl (2 m in width × 0.5 m in height × 5.5 m in length; 0.32 cm inner mesh; 3.81 cm outer chafing mesh; 16.5 cm cod-end opening) and fish in channel border habitat were sampled with a bag seine (10.7 m in length × 1.8 m in height; 1.8 m^3 bag; 5 mm ace mesh).

Three trawl subsamples were taken in main channel habitat in each selected sample unit. For each subsample, the trawl was attached to the bow of the boat and towed downstream (in reverse) beginning at the upstream lateral boundary and proceeding downstream parallel to the shoreline, ending 150 m downstream from the upstream lateral boundary. The first subsample was taken in the thalweg, and a coin toss was used to determine whether the second or third subsample was to the left or right of the first. A buoyed 150-m anchored line marked the upstream and downstream lateral boundaries and the distance to be towed for each subsample.

Two bag seine subsamples were taken in each sample unit. The first was taken on either shoreline at the one-third point upstream of the downstream lateral boundary of the sample unit and the second was taken on the same shoreline at the two-third point upstream from the downstream lateral boundary. The seine was deployed by holding one end stationary and pulling the other end upstream until it was fully extended along the shoreline. The upstream end was then pulled downstream through the water in a 180° arc, keeping the net fully extended or until the water column exceeded a depth of 1.5 m. At the end of the arc, the net was pulled to shore.

The number and type of fish captured were recorded. All flathead chubs, sicklefin chubs, sturgeon chubs, and western silvery minnows were measured for total length (mm). One seine haul or one trawl tow defined one unit of sampling effort. Catch densities of the four minnow species were calculated by segment.

Habitat characterization

Five physiochemical variables (depth, velocity, turbidity, temperature, and substrate) and one biological variable (invertebrate drift density) were measured after each benthic trawl and each bag seine subsample. An additional biological variable, benthic invertebrate density, was measured after each bag seine subsample. These seven variables were a priori believed to be important characteristics of habitats used by the four minnows. In main-channel habitat, preliminary observations indicated a uniformity of the physiochemical and biological variables among 150-m benthic trawl subsamples; it was therefore decided that single-point measurement of these variables, with the exception of depth and velocity, adequately represented the conditions encountered by fish. Depth and velocity were measured at points one-third, one-half, and two-thirds of the tow length upstream from the downstream tow lateral boundary, and were then averaged.

After completing a trawl, the boat was anchored at the center of the trawl path and current velocity was measured with a Marsh–McBirney flow meter. The probe of the flow meter was suspended near the bottom with an A55 metric sounding real and 22.7 kg sounding weight. Current velocity was measured to the nearest $0.1\ m \cdot s^{-1}$.

Water temperature was measured with a YSI 30 temperature/conductivity meter. The meter probe was held 1–2 feet under the water surface, and temperature was measured to the nearest 0.1°C. Water depth was measured with a Lowrance sonar device to the nearest 0.1 m. For turbidity measurements, a sample of water was collected approximately 0.5 m below the water surface and analyzed with a Hach 2100P turbidity meter. Turbidity was measured to the nearest 1.0 Nephalometric turbidity unit (NTU).

A bottom substrate sample was collected with an iron pipe (61.0 cm in length × 10.2 cm in diameter) that had one end closed. The pipe was attached to a rope and dragged upstream with the boat through the path of the trawl tow. The pipe contents were emptied onto the boat and the percentages of silt (particle size ≤0.06 mm), sand (particle size 0.06 and ≤2.0 mm), and gravel (particle size 2.0 mm and ≤16 mm) were estimated visually.

In main-channel habitat, invertebrate drift was collected with a Wisconsin-style plankton net (10.8 cm diameter, 80 μm mesh), fitted with a General Oceanics flow meter. The plankton net was lowered from an anchored boat with the sounding reel and remained suspended near the bottom for 2 min. The quantity of water that passed through the net was used to calculate the invertebrate density, expressed as number of organisms per liter.

In channel border habitat, the five physiochemical variables and benthic invertebrate drift were measured with the same devices at each bag seine subsample. Water column depth and water velocity were measured at 2, 6, and 10 m from the shoreline along a transect perpendicular to the shore at the mid-point of the 180° bag seine arc and were averaged to obtain an estimate of depth and velocity for the subsample. Water temperature, turbidity, and conductivity were measured at the center of the area seined. A substrate sample was collected with the iron pipe by first placing it at the deepest point seined and dragging it towards the shore along the seine midpoint.

Percentages of sand, silt, and gravel were then estimated from the pipe contents.

Benthic drift invertebrates were sampled by attaching the Wisconsin-style plankton net to a wooden pole and towing the net by hand at the site for a period of 3 min. Benthic macroinvertebrates were sampled with a Ponar dredge (22.9 cm × 22.9 cm). Three Ponar grabs were made at the 2, 6, and 10-m points along the transect perpendicular to the midpoint of the seine sample. The three samples were combined and washed in a bucket fitted with a 541 μm sieve screen bottom. The remaining sediment, debris, and macroinvertebrates were placed into a container and preserved with 95% ethanol. In the lab, benthic invertebrates were identified in most cases to family. Invertebrate density was expressed as number of organisms per square meter.

Analyses

Segment and habitat characterization

The degree of physiochemical similarity among the four segments was examined with cluster analysis. Cluster analysis was performed on physiochemical data (depth, current velocity, turbidity, temperature, substrate composition, and discharge) measured in each study segment. In each year and segment, averages of physiochemical variables within each habitat type were weighted by habitat area and then averaged across the habitat types. Yearly means for segments were then converted to standard scores by subtracting the mean and dividing by the standard deviation for each variable (Hair et al. 1995). Finally, standardized scores were averaged across years and a 4×8 (4 segments $\times$ 8 variables) matrix was formed for analysis.

A joining clustering method was employed, with a single linkage amalgamation rule and a Euclidean-type distance measure used to form clusters (Hair et al. 1995). Two of the physiochemical variables, depth and velocity, were highly correlated ($r > 0.90$), so a type of Euclidian distance measure, Mahalanobis distance, was used (Mahalanobis 1936).

Habitat differences among segments were examined with a multivariate technique. Multivariate analysis of variance (MANOVA; Johnson & Wichern 1992) was conducted across segments for each habitat type. Segments and years served as the independent variables and physiochemical categories of water (depth, current velocity, turbidity, temperature, percent silt, and percent sand) served as the dependent variable.

The equal variance–covariance assumption for the MANOVA was checked with the Box test (Box 1949). Residual plots for each dependent variable were constructed to examine homoscedasticity. Multicollinearity between dependent variables was examined by computing the variance inflation factor. An appropriate transformation, such as arc-sine (square root (y)), log ($y + 1$), or square root (y)), was applied to dependent variables that violated any of the assumptions (Hair et al. 1995).

Distribution, abundance, and structure

At the time of data collection, the area (m^2) of each habitat type in a sample unit was measured with a pair of laser range finding binoculars. This information was used to estimate the relative abundance of each fish species in a segment's fish assemblage. In each year, the catch-per-unit-effort (CPUE; number of fish per square meter) for each species from each habitat type in a sample unit was multiplied by the total area estimated for the habitat in a sample unit, and then summed, yielding an estimate of the number of fish in that sample unit. Estimates from the sample units were then summed, yielding the total estimated number of fish in the segment for that year. Relative abundance of each species was computed by dividing the total number of estimated fish for a species by the total number of fish estimated for the segment. The relative abundance computed for each species was then averaged across years to obtain the 2-year average.

Length–frequency histograms were constructed for flathead chub, sicklefin chub, sturgeon chub, and western silvery minnow to examine the population structure and assess year class strength within each study segment.

Habitat use

Habitat use by flathead chub, sicklefin chub, sturgeon chub, and western silvery minnow was characterized by computing the CPUE for each species by habitat type and by determining the number of fish captured and the relative abundance for each species by segment.

Predictive models

Multiple regression models were developed for each species to evaluate fish presence and absence, fish number, or fish density in relation to a variety of environmental variables. Three types of multiple regression models were developed: logistic regression, Poisson regression, and linear regression.

Logistic regression models had fish presence (1) or absence (0) as the dependent variable and environmental variables as predictor variables. The relationship between environmental variables and fish presence or absence was described with the logit form of the logistic regression model.

$$\text{logit pr}\,(Y = 1) = \beta_0 + \in_{j=1} \beta_j X_j$$
$$(j = 1, \cdots, n \text{ environmental variables})$$

where logit is the transformation of the probability pr($Y = 1$), β_0 is the y-intercept, β_j is the slope for each environmental variable, and X_j represents the environmental variables.

Models were developed by combining data from all four segments and used to test the null hypothesis that there was no difference in habitat characteristics where fish were sampled and not sampled. Predictor variable multicollinearity was examined prior to analysis. Depth and velocity were highly correlated ($r > 0.90$; $n = 238$); therefore, principal components analysis was used to derive a new vector for depth and velocity and used in each logistic regression analysis (Dunteman 1989). Akaike's information criterion (AIC; Akaike 1987) was computed for all possible combinations of predictor variables and used to identify the one best-fit model for a species. The hat matrix diagonal was used to detect outlier values, and Pearson residuals were used to identify observations that were not well explained by each best-fit model (Kleinbaum et al. 1998). Final model reliability was examined by using the Chi-square test for covariates ($P < 0.05$ for significance).

Poisson regression models using fish count data were developed for sicklefin chub, sturgeon chub, and western silvery minnow instead of linear regression models using CPUE because of the large number of samples that contained zero fish; this result caused the normality assumption to be violated for the linear regression models. Poisson regression had fish counts as the dependent variable and environmental variables served as predictor variables. The relationship between environmental variables and fish abundance was described with the following form of the Poisson regression model.

$$\log \mathrm{E}\,(Y_i) = \beta_0 + \in_{j=1} \beta_j X_j$$
$$(j = 1, \cdots, n \text{ environmental variables})$$

where E(Y_i) is the expected number of fish, β_0 is the y-intercept, β_j is the slope for each environmental variable, and X_j represents the environmental variables.

Data from all four segments were combined for model development for sicklefin chub, sturgeon chub, and western silvery minnow and used to test the null hypothesis that there was no difference in habitat characteristics based on fish number. Prior to analysis, predictor variable collinearity was examined with a correlation matrix and multicollinearity was examined by computing variance inflation factor. A goodness-of-fit statistic, known as deviance (Kleinbaum et al. 1998), derived from maximum likelihood ratios, was used to identify variables that contributed significantly to fish counts.

Poisson regression models were developed separately by gear type for fish species. Differences in gear selectivity prevented analysis across gear types. The sicklefin chub and sturgeon chub Poisson regression models were developed from fish count data obtained from the benthic trawl in main channel habitat. The western silvery minnow Poisson regression model was developed from fish count data obtained from the bag seine in channel border habitat.

For flathead chub, a linear regression model was developed using CPUE from the bag seine (measured in channel border habitat) as the dependent variable and environmental variables served as predictor variables. The relationship between environmental variables and fish CPUE was described with the following form of the multiple regression model.

$$Y = \beta_0 + \in_{j=1} \beta_j X_j$$
$$(j = 1, \cdots, n \text{ environmental variables})$$

where Y is flathead chub CPUE, β_0 is the y-intercept, β_j is the slope for each environmental variable, and X_j represents the environmental variables.

The model was developed by combining data from all four segments and was used to test the null hypothesis that there was no difference in habitat characteristics based on fish CPUE (number of fish per square meter). Predictor variable collinearity and multicollinearity were examined in the same manner as for Poisson regression models. Influential observations were identified with Cook's distance. Heteroscedasticity was examined with residual plots and normality of the error term distribution was examined with normal probability plots. The dependent variable was square-root transformed to more closely approximate a normal distribution. AIC was used to identify the one best-fit model.

The predictive ability of best-fit logistic regression models and best-fit Poisson regression models was tested against an external data set from the same location in which the data were collected with the same gears in 1997 and 1998 (Galat et al. 2002). However, before logistic regression model testing could begin, each model's optimum decision rule probability for fish presence or absence was determined. For the logistic regression models, 60 observations from the external data set were randomly selected that included 30 observations that were present and 30 that were absent for a species. A fish was determined to be present at an observation when the predicted probability was greater than the optimum decision rule probability. Tables depicting the percent correctly and incorrectly classified were developed to examine how well each model predicted fish presence and absence.

For Poisson regression models, 45 observations, where each species was present, were randomly selected from the external data set and run through each model. Graphs comparing the number of fish predicted by the model to the observed number of fish were generated to examine how well each model predicted fish CPUE. For all regression analyses, the data were analyzed using the Statistical Analysis Systems (SAS 1989) software package.

Results

Distribution, abundance, and structure

Flathead chub

Flathead chub was the most abundant species in each of the four segments (1611 fish) representing from 33 to 65% of the catch in any one segment (Table 1). Most flathead chubs in all study segments ranged from less than 40 to 60 mm in length (Fig. 2). The BCS and YRS had high proportions of flathead chub less than 40 mm in length.

Sicklefin chub

The greatest number of sicklefin chubs was captured in the BCS (Table 1). However, this species had its highest relative abundance in the ACS. Sicklefin chubs ranged from 30 to 120 mm in length (Fig. 2). Most fish ranged from 60 to 90 mm in length with chubs less than 40 mm found in the BCS, MZS, and YRS. No sicklefin chubs less than 60 mm were captured in the ACS.

Sturgeon chub

The highest relative abundance of sturgeon chubs was found in the YRS, where the greatest number of this species was also captured (Table 1). Sturgeon chubs ranged from 20 to 80 mm in length (Fig. 2). Length–frequency distributions were irregular in the ACS, BCS, and MZS. Fish less than 40 mm were captured in all study segments, with the highest proportion in the YRS.

Western silvery minnow

The greatest number of western silvery minnows was captured in the BCS; this segment also had the highest relative abundance of the species (Table 1). Western silvery minnows ranged from 13 to 96 mm in length in the four segments (Fig. 2). Length–frequency distributions were irregular in all study segments. Both the BCS and the YRS had high proportions of fish less than 30 mm.

Habitat use

In the four segments, 99% of the 1611 flathead chubs were captured in the shallow channel border habitat. In this habitat, the highest CPUE for flathead chub was in the BCS and the lowest in the MZS (Table 1). CPUE of flathead chubs was low in main channel habitat in all four segments.

Ninety-seven percent of the 147 sicklefin chubs were captured in the deep, high-velocity main channel habitat. The highest CPUE found for sicklefin chub in this habitat was in the YRS and the lowest in the ACS and MZS (Table 1). Sicklefin chubs were not captured in the shallow channel border habitat except for four fish (3%) in the BCS.

Table 1. Catch-per-unit-effort (CPUE) with the benthic trawl in main channel habitat (MC) and the bag seine in channel border habitat (CB) and catch (no. of fish) and percent relative abundance (%Rel. abun.) for the four minnows in the four study regions (CPUE expressed as number per 100 m^2 in MC and number per m^2 in CB).

	ACS				BCS				MZS				YRS			
	CPUE				CPUE				CPUE				CPUE			
Species	CB	MC	Catch	%Rel. abun.	CB	MC	Catch	%Rel. abun.	CB	MC	Catch	%Rel. abun.	CB	MC	Catch	%Rel. abun.
Flathead chub (*Platygobio gracilis*)	4.4	<0.1	138	54.8	20.4	<0.1	725	65.1	4.1	<0.1	125	32.7	18.0	<0.1	623	46.4
Sicklefin chub (*Macrhybopsis meeki*)	0.0	0.2	23	9.1	0.1	0.3	49	8.6	0.0	0.2	28	7.4	0.0	0.4	47	5.8
Sturgeon chub (*Macrhybopsis gelida*)	0.1	0.1	27	9.7	0.2	0.2	27	1.9	0.1	<0.1	9	2.2	0.3	0.7	92	12.1
Western silvery minnow (*Hybognathus argyritis*)	0.6	0.0	18	2.3	4.4	<0.1	169	9.8	1.1	<0.1	31	5.9	1.1	<0.1	42	2.2

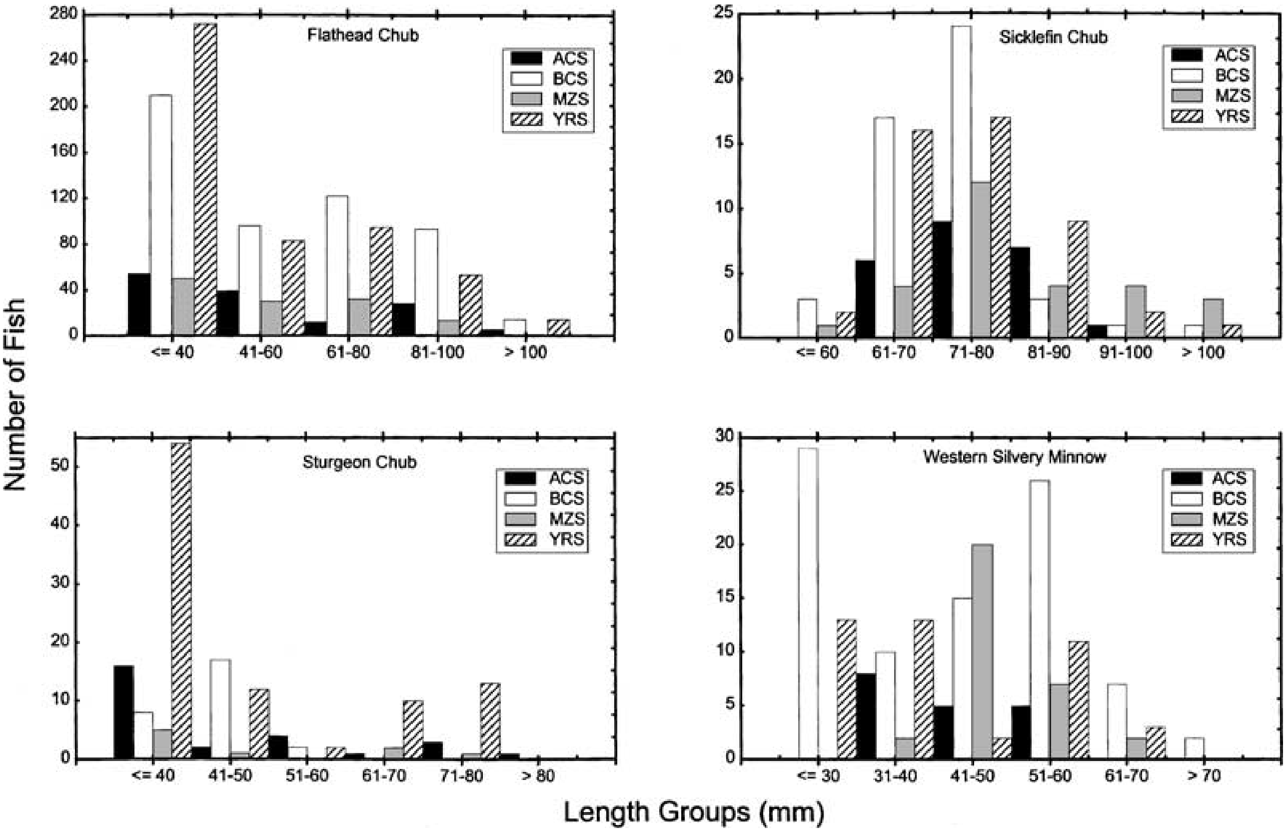

Fig. 2. Length frequency distributions for flathead chub, sicklefin chub, sturgeon chub, and western silvery minnow by river segment (ACS, above confluence segment; BCS, below confluence segment; MZS, mixing zone segment; YRS, Yellowstone River segment).

Most of the 155 sturgeon chubs were captured in main channel habitat. In this habitat, the highest CPUE for sturgeon chub was found in the YRS and the lowest in the MZS (Table 1). CPUE was low for sturgeon chub in channel border habitat in all four segments, but was highest in the YRS.

Most western silvery minnows were captured in channel border habitat. In channel borders, the BCS had the highest CPUE for western silvery minnow and the ACS had the lowest (Table 1). Few western silvery minnows were captured in the main channel.

Overall, the highest catch rates for sicklefin chub, sturgeon chub, western silvery minnow, and flathead chub were found in the BCS and YRS. Catch rates for these species were similar in the ACS and MZS (Table 1).

Nearly all fish collection samples taken at sites less than 1 m in depth (93%) and $0.25\,\mathrm{m \cdot s^{-1}}$ in velocity (94%) contained flathead chubs. More than 99% of flathead chubs were captured in depths less than 1 m and 90% were captured in current velocity less than $0.25\,\mathrm{m \cdot s^{-1}}$. Sixty-six percent of flathead chubs were captured in turbidities less than 250 NTU. Sixty-two percent of flathead chubs were captured in temperatures between 18 and 22°C.

Few samples taken at depths less than 2 m or velocities less than $0.5\,\mathrm{m \cdot s^{-1}}$ contained sicklefin chubs. Approximately 86 and 64% of sicklefin chubs were captured in depths from 2 to 5 m and in current velocity from 0.5 to $1.0\,\mathrm{m \cdot s^{-1}}$, respectively. Most sicklefin chubs were captured in turbidities less than 500 NTU (87%) and in temperatures between 20 and 24°C (83%).

Sturgeon chubs were found using a wide range of depths and velocities. The highest proportion of samples containing fish was from 2 to 4 m in depth and exhibited $0.5–1\,\mathrm{m \cdot s^{-1}}$ current velocities. Approximately 88 and 81% of sturgeon chub were captured in depths from 2 to 5 m and in current velocities from 0.5 to $1\,\mathrm{m \cdot s^{-1}}$. Few samples with turbidities greater than 500 NTU or with temperatures less than 18°C or greater than 24°C contained sturgeon chub. Most sturgeon chubs were captured in turbidities less than 250 NTU (78%) and in temperatures between 18 and 22°C (80%).

Ninety-eight percent of western silvery minnows were captured in depths less than 1 m and in current velocity less than $0.5\,\mathrm{m \cdot s^{-1}}$. Most western silvery minnows were captured in turbidities less than 250 NTU (85%) and in temperatures between 18 and 22°C (64%).

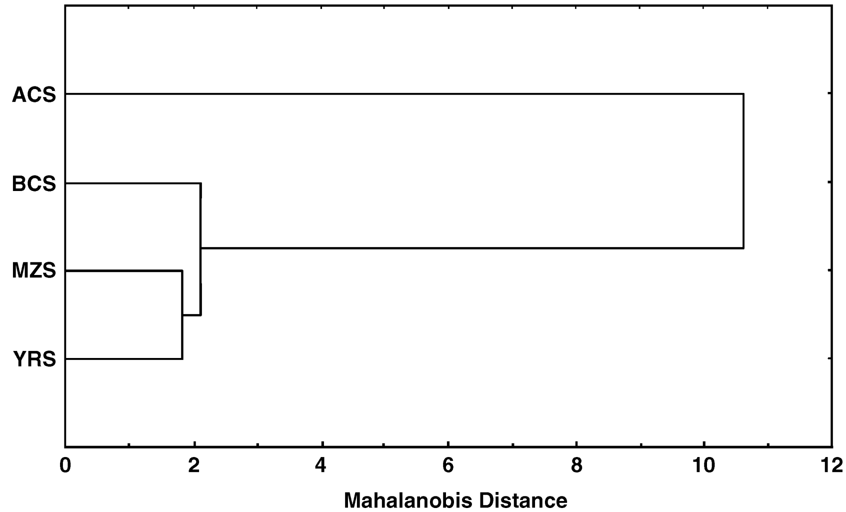

Fig. 3. Cluster analysis of physiochemical data collected from the four study segments (ACS, above confluence segment; BCS, below confluence segment; MZS, mixing zone segment; YRS, Yellowstone River segment).

Segment and habitat characterization

The two segments that were most physiochemically similar were the YRS and MZS, with the ACS being the most dissimilar (Fig. 3). Among the segments, channel border habitat was similar in depth, current velocity, and turbidity (Table 2). The mean water temperature was nearly 2°C cooler in the ACS and both the ACS and the MZS contained two times the mean percent composition of silt as compared to the other two study segments. Current velocity and substrate composition were similar among the four study segments in the main channel habitat (Table 2). Mean depth (5.4 m) and turbidity (239.4 NTU) were greater in the MZS than the other three study segments. Mean water temperature was lowest in the ACS (19.0°C) and highest in the YRS (21.6°C).

Significant differences in physiochemical characteristics were found among segments in both habitat types (main channel, MANOVA, Wilk's lambda = 0.5641, $P < 0.0001$; channel border, MANOVA, Wilk's lambda = 0.6324, $P < 0.001$), but not years (main channel, MANOVA, Wilk's lambda = 0.2142, $P = 0.71$; channel border, MANOVA, Wilk's lambda = 0.2334, $P = 0.11$). No significant interaction was found between study segments and years for either main channel habitat (MANOVA, Wilk's lambda = 0. 1764, $P = 0.22$) or channel border habitat (MANOVA, Wilk's lambda = 0.2875, $P = 0.09$).

Predictive models

For flathead chub, sicklefin chub, sturgeon chub, and western silvery minnow, we rejected the null hypothesis that there was no difference in habitat characteristics where fish were sampled and not

Table 2. Summer physiochemical characterization (mean, range, SD) of main channel and channel border habitat.

	Main channel habitat				Channel border habitat			
Physiochemical variable	ACS	BCS	MZS	YRS	ACS	BCS	MZS	YRS
Depth (m)	3.7	3.9	5.4	4.0	0.4	0.3	0.5	0.5
Range	1.2–6.2	0.9–7.2	2.3–8.5	2.1–6.2	0.2–0.7	0.1–0.8	0.2–0.8	0.2–0.9
SD	1.2	1.5	1.6	1.2	0.2	0.2	0.2	0.2
Current velocity ($m \cdot s^{-1}$)	1.0	1.1	1.1	0.9	0.2	0.1	0.2	0.1
Range	0.6–1.7	0.5–1.5	0.4–1.7	0.5–1.2	0.0–0.4	0.0–0.4	0.0–0.4	0.0–0.5
SD	0.2	0.2	0.3	0.2	0.1	0.1	0.1	0.1
Turbidity (NTU)	122.0	188.9	239.4	224.1	144.3	179.4	183.5	167.0
Range	46.0–423.0	41.0–522.0	24.0–969.0	21.0–605.0	57.0–306.0	38.0–326.0	21.0–423.3	30.0–673.0
SD	93.4	113.0	266.9	200.9	77.8	93.0	126.9	150.4
Temperature (celsius)	19.0	20.9	21.0	21.6	20.2	21.4	22.0	21.7
Range	13.9–21.5	16.3–25.4	15.1–27.6	18.1–24.5	18.4–23.0	16.3–25.4	18.1–25.5	17.8–24.5
SD	2.0	2.1	2.9	1.8	1.5	2.5	2.4	1.8
Substrate composition (%)								
Silt	6.6	<0.1	5.3	2.7	66.8	37.3	68.7	38.3
Sand	91.4	97.2	91.0	90.9	33.2	62.4	31.2	61.7
Gravel	1.9	2.5	3.7	6.4	0.0	0.3	0.1	0.0

ACS, above-confluence segment; BCS, below-confluence segment; MZS, mixing-zone segment; YRS, Yellowstone River segment.

Table 3. Model equations for characterizing summer habitat where flathead chub, sicklefin chub, sturgeon chub, and western silvery minnow were present (1, number or CPUE) or absent (0; pc, principal component).

Species	Model equation	R^2	P-value
Logistic regression			
Flathead chub	Log odds of fish presence: − 1.6079 − 2.0391 (depth and velocity pc)	–	<0.0001
Sicklefin chub	Log odds of fish presence: − 1.3714 + 0.5901 (temperature) + 0.4063 (% sand) − 0.9228 (discharge) + 0.6121 (depth and velocity pc)	–	<0.0001
Sturgeon chub	Log odds of fish presence: − 1.2986 + 0.3113 (% sand) − 1.0122 (discharge)	–	<0.0001
Western silvery minnow	Log odds of fish presence: − 2.5772 − 1.3660 (depth and velocity pc) + 0.0392 (% sand)	–	<0.0001
Poisson regression			
Sicklefin chub	Log number of fish: − 0.8321 −2.3174 (current velocity) + 0.1404 (temperature)	0.32	<0.0001
Sturgeon chub	Log number of fish: 2.4702 − 0.0001 (discharge) + 0.0228 (% gravel) − 0.0021 (turbidity) − 0.8707 (current velocity)	0.55	<0.0001
Western silvery minnow	Log number of fish: − 5.1597 + 0.0321 (effort) − 6.3980 (current velocity) + 0.0293 (%sand)+0.0053 (benthic invertebrate density)	0.43	<0.0001
Linear least-square regression			
Flathead chub	Fish catch-per-unit-effort: 0.1370 − 0.3350 (current velocity) + 0.0003 (turbidity) + 0.0021 (% sand) + 0.000982 (benthic invertebrate density)	0.47	<0.0001

sampled. For each logistic regression model, the environmental variables retained were significantly ($P < 0.0001$) related to fish presence or absence (Table 3).

For logistic regression model testing, optimum decision rule probabilities ranged from 0.50 for sicklefin chub to 0.65 for flathead chub (sturgeon chub = 0.52, western silvery minnow = 0.50). The flathead chub logistic model worked best, predicting flathead chub presence correctly at a rate of 90% and predicting both flathead chub presence and absence at a rate of 95% (Table 4). The logistic models developed for western silvery minnow and sicklefin chub also performed well. Western silvery minnow presence and combined presence and absence were predicted correctly at rates of 97 and 80%, respectively (Table 4). Sicklefin chub presence was predicted correctly at a rate of 70%, whereas combined presence and absence was predicted correctly 80% of the time. The logistic model developed for sturgeon chub performed poorest. It correctly predicted chub

Table 4. Predictive success of logistic models developed for flathead chub (a), sicklefin chub (b), sturgeon chub (c), and western silvery minnow (d).

(a) Flathead Chub

Observed	Predicted: Present	Predicted: Absent
Present	27 (90%)	3 (10%)
Absent	0 (0%)	30 (100%)
Percent classified correctly		95%

(b) Sicklefin Chub

Observed	Predicted: Present	Predicted: Absent
Present	21 (70%)	9 (30.0%)
Absent	3 (10%)	27 (90%)
Percent classified correctly		80%

(c) Sturgeon Chub

Observed	Predicted: Present	Predicted: Absent
Present	17 (57%)	13 (43%)
Absent	14 (47%)	16 (53%)
Percent classified correctly		55%

(d) Western Silvery Minnow

Observed	Predicted: Present	Predicted: Absent
Present	29 (97%)	1 (3%)
Absent	11 (37%)	19 (63%)
Percent classified correctly		80%

presence and combined presence and absence only 57 and 55% of the time, respectively (Table 4). For the four fish species, we rejected the null hypotheses that there was no difference in habitat characteristics based on fish number (sicklefin chub, sturgeon chub, western silvery minnow) or CPUE (flathead chub). The environmental variables retained by each Poisson regression model and the linear regression model were significantly ($P < 0.0001$) related to fish number and CPUE, respectively (Table 3).

The sicklefin chub and sturgeon chub Poisson models showed close agreement between the number of fish observed and the number of fish predicted by both models (sicklefin chub, $r = 0.45$; $P < 0.05$; sturgeon chub, $r = 0.52$; $P < 0.05$). The predictive ability of the Poisson regression model for western silvery minnow and the linear regression model for flathead chub were not tested because one of the environmental variables retained by these models (benthic invertebrate density) was not measured for the external data set. However, the R^2 value for each model indicates that they are good predictors of the dependent variable (Table 3).

Discussion

Segment and habitat characterization

The physiochemical differences among the study segments indicated the presence of distinctly different habitat conditions for fishes among study segments, especially between the ACS and the other segments. For example, the YRS was characterized by high turbidity, high summer water temperatures (in the main channel), and high discharge. In comparison, the ACS of river exhibited lower main channel turbidity, lower water temperature, and lower discharge than the other study segments. Many of the differences are a result of the strong influence of the Yellowstone River on downstream segments and the influence of Fort Peck Dam on the ACS. Fort Peck Dam acts as a sediment sink, trapping in-flowing suspended sediment, and limiting downstream movement of the river's suspended load (Leopold et al. 1964). As a result, turbidity is reduced in the ACS. Hypolimnetic withdrawals from Fort Peck Dam also reduced the summer water temperatures in the ACS. Peak water temperatures in the ACS were from 4.9 to 6.1°C cooler than the other segments (Table 2). The influence of the Missouri River above the confluence on the physiochemical characteristics of the MZS and BCS was dampened by the higher discharge exhibited by the Yellowstone River for most of the study period (July–September), in both 1997 and 1998, causing the ACS to be greatly different from the other segments.

Habitat use

Flathead chub and western silvery minnow used similar depths, velocities, turbidities, temperatures, and substrates. We found that in samples containing western silvery minnows, flathead chubs were also present 83% of the time and in samples containing flathead chubs, western silvery minnows were present approximately 40% of the time. Gould (1985) also frequently captured these two species together in the Musselshell River, Montana. In this study, both species commonly used depths less than 1 m and current velocities less than $0.25\,\mathrm{m \cdot s^{-1}}$, with few individuals of either species captured in the deeper, swifter main channel. Habitat models for both species also included depth and velocity as significant variables in predicting fish presence or abundance, with decreasing depth and velocity resulting in increasing fish number or presence probability.

Pflieger & Grace (1987) documented the precipitous decline in both flathead chub and western silvery minnow in the lower Missouri River over a 40-year period. They hypothesized that the decline in flathead chub was related to reduced turbidity and competition with other fish species and the reduction in western silvery minnow was because of reduced sediment transport and loss of silty backwater habitat. Results of this study indicate that shallow, low-velocity habitat is important for flathead chub. The near absence of this habitat in the lower Missouri River resulting from dredging and channelization and revetment structures (Hesse & Sheets 1993) may also be a contributing factor responsible for the decline of both species.

Sicklefin chub, in contrast, were more associated with the main channel. They commonly used sand substrate and depths greater than 3 m and current velocities greater than $0.5\,\mathrm{m \cdot s^{-1}}$. Grisak (1996) found that sample sites containing this species averaged $0.58\,\mathrm{m \cdot s^{-1}}$ current velocity, 3.4 m depth, and 70% sand substrate. In this study, the mean depth occupied was similar (3.7 m) as in his study. Sites where chubs were found in the present study contained 1.3 times more sand (90.8%) and exhibited an average current velocity ($0.9\,\mathrm{m \cdot s^{-1}}$) that was 1.6 times swifter than sites in Grisak's (1996) study. Habitat models predicting either presence or abundance for this species included percent sand, current velocity, and discharge as significant variables, with an increase in percent sand and current velocity and a decrease in discharge, positively influencing fish presence or abundance. Similar results were obtained by Everett (1999) for sicklefin chub in the confluence area in 1995. The influence of discharge on fish presence or abundance must be its effect on trawl CPUE. For sicklefin chub, discharge and CPUE are negatively correlated ($r = -0.30$). Perhaps at high discharge, a greater amount of suitable habitat is available, thereby reducing fish density and negatively affecting CPUE.

Sturgeon chub commonly used sand substrate and depths ranging from <1–4 m and current velocities ranging from 0 to $1.0\,\mathrm{m \cdot s^{-1}}$. Habitat models for this species included percent gravel, current velocity, and discharge as significant variables in predicting fish abundance, with an increase in percent gravel and a decrease in current velocity and discharge positively influencing fish number. Everett (1999) also found that a decrease in current velocity positively influenced the presence of sturgeon chub. Other researchers found that gravel was the primary substrate used by sturgeon chub (Davis & Miller 1967; Baxter & Simon 1970; Elser et al. 1980; Burr & Warren 1986; Gelwicks et al. 1996; Gould, unpublished report). We found that the primary substrate used by sturgeon chub was sand. However, increasing percent gravel at sample sites positively influenced sturgeon chub density. The negative influence of discharge on CPUE ($r = -0.34$) is similar to that observed for sicklefin chub.

Distribution, abundance, density, and structure

The higher density and catch for flathead chub, western silvery minnow, sicklefin chub, and sturgeon chub in the YRS and BCS, in addition to length-frequency distributions for three of the species (flathead chub, western silvery minnow, and sturgeon chub) that contained a broader range of fish sizes when compared to the other two segments, indicate that these two segments are better habitat for these species of fish than the ACS and MZS. Most individuals of flathead chub and western silvery minnow were captured in channel border habitat in all four study segments. This habitat exhibited lower current velocities and a greater percentage of sand substrate in the YRS and BCS than in the ACS and MZS. Habitat models predicting fish abundance and density included both these variables, with abundance of both species increasing as velocity decreased and percent sand increased.

In the four segments, main channel habitat yielded the highest densities and catches of sicklefin chubs. A habitat model using sicklefin chub abundance data from this habitat included current velocity and temperature, with abundance of sicklefin chubs increasing as velocity increased and temperature increased. Approximately 72% of sicklefin chub were captured in current velocities between 0.75 and $1.25\,\mathrm{m \cdot s^{-1}}$. High proportions of trawl subsamples in both the YRS (86%) and BCS (77%) fell within this velocity category; lower proportions of trawl subsamples in the ACS (62%) and MZS (56%) were within this range of current velocity. Similarly, water temperatures were highest in main channel habitat in the YRS, where this species achieved its highest CPUE.

Most sturgeon chub samples were collected in August and September of 1998 in main channel habitat within the YRS. At this time, the river discharge was lower in the YRS than in the other three segments, which explains the inclusion of this variable in both sturgeon chub models. Coarser substrates (more sand and gravel) were found in both habitat types in YRS and BCS than in the other two segments. The habitat models predicting fish presence and fish number included both these variables, with the presence of sturgeon chub increasing with decreasing discharge and increasing coarseness of substrate.

As of 2003, the status of flathead chub, sicklefin chub, sturgeon chub, and western silvery minnow is a subject of debate. In the lower Missouri River, the abundance of these four species has declined precipitously since the onset of dam construction and channelization (Pflieger & Grace 1987) and each has received considerable support for listing as endangered under the United States Endangered Species Act (Werdon 1993a,b; Hesse 1994). However, studies conducted in the upper Missouri and lower Yellowstone rivers (Grisak 1996; Young et al. 1997; Everett 1999; Gould, unpublished report) suggest that the status of these species may be a cause of less concern in Montana and North Dakota, based on their widespread distribution and abundance. In this study, these four species made up over 65% of the catch, indicating that their status is better in the confluence area than in many portions of the middle and lower Missouri rivers. Further, even in the confluence area, the density and catch of flathead chub, sicklefin chub, and sturgeon chub in the quasi-natural YRS and the BCS were higher than in the ACS which was the segment most impacted by Fort Peck Dam.

For sustainable populations of flathead chub, sicklefin chub, sturgeon chub, and western silvery minnow in the upper Missouri and lower Yellowstone rivers, natural river characteristics, such as a naturally fluctuating hydrograph and a high sediment load, that produce a diversity of habitats and habitat conditions should be preserved and, if possible, improved in altered river segments. Channel modifications, such as bank stabilization and additional irrigation withdrawals, that would alter natural river habitat should be discouraged.

Summary

In 1997 and 1998, sampling was conducted on the Missouri and Yellowstone rivers, North Dakota to obtain information on the distribution, abundance, and habitat use of the flathead chub (*P. gracilis* Richardson), sicklefin chub (*M. meeki* Jordan and Evermann), sturgeon chub (*M.* Girard), and western silvery minnow (*H. argyritis* Girard), four declining fish species (family Cyprinidae) native to the Missouri River basin. The study area consisted of four distinct river segments near the confluence of the Missouri and Yellowstone rivers – three moderately altered segments and one quasi-natural segment.

Catch rates with the trawl for sicklefin chub and sturgeon chub and catch rates with the bag seine for flathead chub and western silvery minnow were highest in the two least altered segments (the quasi-natural segment and one least altered segment). Most sicklefin chubs and sturgeon chubs were captured in the deep, high-velocity main channel habitat with the trawl (sicklefin chub = 97%, sturgeon chub = 85%), whereas most flathead chub and western silvery minnow were captured in the shallow, low-velocity channel border habitat with the bag seine (flathead chub = 99%, western silvery minnow = 98%).

Best-fit regression models predicted sicklefin chub, flathead chub, and western silvery minnow presence and absence correctly greater than 80% of the time. Sturgeon chub presence and absence was predicted correctly 55% of the time. Best-fit regression models fit to fish number data for flathead chub, sicklefin chub, and sturgeon chub and fish CPUE data for flathead chub also provided good fits with R^2 values ranging from 0.32 to 0.55. The presence and density of sicklefin chub and sturgeon chub at collection sites was significantly ($P < 0.0001$) related to current velocity, substrate, and river discharge. For flathead chub and western silvery minnow, fish presence was significantly ($P < 0.0001$) related to depth and velocity.

In this study, these four cyprinids made up over 65% of the catch, indicating that their status is better in the confluence area than in many portions of the middle and lower Missouri Rivers. Further, even in the confluence area, the density and catch of flathead chub, sicklefin chub, and sturgeon chub in the quasi-natural YRS and the BCS were higher than in the ACS, which was the segment most impacted by Fort Peck Dam. For sustainable populations of flathead chub, sicklefin chub, sturgeon chub, and western silvery minnow in the upper Missouri and lower Yellowstone rivers, natural river characteristics, such as a naturally fluctuating hydrograph and a high sediment load, that produce a diversity of habitats and habitat conditions should be preserved and, if possible, improved in altered river segments. Channel modifications, such as bank stabilization and additional irrigation withdrawals, that would alter natural river habitat should be discouraged.

Resumen

1. Durante los años 1997 and 1998, llevamos a cabo muestreos en los Rios Missouri y Yellowstone (Dakota del Norte, USA) para obtener información sobre la distribución, abundancia y uso del habitat de cuatro cypínidos en declive, nativos de la cuenca del Missouri (USA): *P. gracilis* Richarson, *M. meeki* Jordan and Evermann, *M. gelida* Girard e *Hybognathus arguritis* Girard.
2. El area de estudio consistió en cuatro segmentos distintos cerca de la confluencia de los rios Missouri y Yellowstone. Un segmento quasi-natural y tres moderadamente alterados, influenciados por un embalse. Uno de los segmentos alterados estaba localizado en la confluencia de los dos rios (segmento de zona mezclada, MZS). Los otros dos segmentos moderadamente alterados estaban en el rio Missuri cerca de MZS, uno aguas arriba (segmento sobre la confluencia, ACS) y otro aguas abajo (segmento por debajo de la confluencia, BCS). El segmento quasi-natural estaba aguas arriba de MZS en el rio Yellowstone (segmento del rio Yellowstone, YSR).
3. Las tasas de captura con redes de arrastre para *M. meeki* y *M. gelida* y las tasas de captura con redes de bolsa para *P. gracilis* y *H. argyritis* fueron mayores en BCS y YRS. La mayor parte de los *M. meeki* y *M. gelida* fueron capturados en el habitat profundo y de alta velocidad de agua del canal principal con redes de arrastre (*M. meeki* = 97% y *M. gelida* = 85%) mientras que la mayor parte de *P. gracilis* y *H. argyritis* fueron capturados en el habitat de los bordes del canal, de menor velocidad y aguas someras (*P. gracilis* = 99%, *M. gelida* = 98%).
4. La presencia o ausencia de *M. meeki*, *P. gracilis* y *H. argyritis* fue correctamente predicha por modelos modelos de regresión en mas del 80% de las veces y la presencia o ausencia de *M. gelida*, en el 55% de las veces. Modelos de regresión ajustados a la abundancia de *P. gracilis*, *M. meeki* y *M. gelida* tambien produjeron buenos ajustes con valores de R^2 en el rango 0.32–0.55 ($P < 0.0001$). La alta densidad y captura de estos cuatro ciprínidos en YRS y BCS sugirió que estos segmentos son mejores habitats que ACS y MZS.

Acknowledgements

This research was part of the Missouri River Benthic Fishes Project, 'Population structure and habitat use of benthic fishes along the Missouri and lower Yellowstone Rivers', funded by the U.S. Army Corps of Engineers, Omaha, Nebraska Office. Additional funding and support for this study were provided by the U.S. Environmental Protection Agency, Denver, Colorado Office, the North Dakota Game and Fish Department, Bismarck, North Dakota, and the U.S. Geological Survey, University of Idaho, Moscow, Idaho.

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