Prepared in cooperation with the Bureau of Land Management, U.S. Department of the Interior, Wyoming Department of Environmental Quality, Wyoming Game and Fish Department, U.S. Environmental Protection Agency, Montana Department of Environmental Quality, and Montana Department of Fish, Wildlife, and Parks

Ecological Assessment of Streams in the Powder River Structural Basin, Wyoming and Montana, 2005–06

Scientific Investigations Report 2009–5023

U.S. Department of the Interior
U.S. Geological Survey

Front cover photographs:

Hanging Woman Creek below Horse Creek, Wyo. (site T11), June 22, 2005. Photograph by Seth Davidson, U.S. Geological Survey.

Cheyenne River near Spencer, Wyo. (site C6), June 22, 2005. Photograph by Kendra Remley, U.S. Geological Survey.

Youngs Creek near Crow Indian Reservation boundary, Mont. (site T3), June 14, 2005. Photograph by Peter Wright, U.S. Geological Survey.

Cheyenne River near Dull Center, Wyo., (site C3), June 19, 2006. Photograph by Greg Boughton, U.S. Geological Survey.

Ecological Assessment of Streams in the Powder River Structural Basin, Wyoming and Montana, 2005–06

By David A. Peterson, Peter R. Wright, Gordon P. Edwards, Jr., Eric G. Hargett, David L. Feldman, Jeremy R. Zumberge, and Paul Dey

Prepared in cooperation with the Bureau of Land Management, U.S. Department of the Interior, Wyoming Department of Environmental Quality, Wyoming Game and Fish Department, U.S. Environmental Protection Agency, Montana Department of Environmental Quality, and Montana Department of Fish, Wildlife, and Parks

Scientific Investigations Report 2009–5023

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2009

This and other USGS information products are available at *http://store.usgs.gov/*
U.S. Geological Survey
Box 25286, Denver Federal Center
Denver, CO 80225

To learn about the USGS and its information products visit *http://www.usgs.gov/*
1-888-ASK-USGS

Suggested citation:
Peterson, D.A., Wright P.R., Edwards, G.P., Jr., Hargett, E.G., Feldman, D.L., Zumberge, J.R., and Dey, Paul, 2009, Ecological assessment of streams in the Powder River Structural Basin, Wyoming and Montana, 2005–06: U.S. Geological Survey Scientific Investigations Report 2009–5023, 139 p.

Preface

The work described in this report was performed under the direction of a multiagency Aquatic Task Group (ATG) formed to address issues related to development of coalbed natural gas in northeastern Wyoming and southeastern Montana. In addition to the multiagency participation in design and sampling, the multiple aspects of aquatic ecology led to a collaborative multi-agency effort on this report. The sampling was conducted by the U.S. Geological Survey (USGS), with the exception of sampling on the main stem of the Powder River in Wyoming that was coordinated with personnel from the Wyoming Game and Fish Department (WGFD). Personnel from the WGFD collected fish samples and conducted much of the habitat work at eight sampling sites on the Powder River in Wyoming. Gordon Edwards, Jr., of the WGFD is the author of the report sections describing the Powder River fish community and Powder River habitat. Peter Wright of the USGS is the author of the habitat section that encompasses all of the streams, including some habitat data collected by the USGS from the Powder River. Peter Wright and Dave Peterson condensed and rewrote habitat mapping information from a WGFD administrative report by Paul Dey after Mr. Dey took a different job assignment within WGFD. Dave Peterson of the USGS authored the fish section on other streams of the study area, as well as the sections on algae and macroinvertebrate communities with the exception of the sections on macroinvertebrate models and indices. Eric Hargett and Jeremy Zumberge of the Wyoming Department of Environmental Quality and David Feldman of the Montana Department of Environmental Quality authored the report sections on macroinvertebrate models and indices. Other members of the ATG helped to improve the report through comments during the review process. Thank you to everyone for their collaboration and cooperative spirit.

Contents

Figures

Tables

Conversion Factors and Datums

Multiply	By	To obtain
centimeter (cm)	0.3937	inch (in.)
micron (µm)	0.00003937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
square centimeter (cm^2)	0.1550	square inch (in^2)
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
meter per second (m/s)	3.281	foot per second (ft/sec)
milligram (mg)	0.00003527	ounce, avoirdupois (oz)
milligram per square meter (mg/m^2)	0.0003795	ounce per square foot (oz/ft^2)
gram (g)	0.03527	ounce, avoirdupois (oz)
gram per square meter (g/m^2)	0.3795	ounce per square foot (oz/ft^2)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.3048	cubic meter per second (m^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32.$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Elevation, as used in this report, refers to distance above the vertical datum.

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

The water year begins October 1 and ends September 30, and is designated by the year in which it ends. For example, water year 2005 begins October 1, 2004, and ends September 30, 2005.

Abbreviations and Acronyms

$<$	less than
$>$	greater than
$\leq$	less than or equal to
g/m^2	gram per square meter
mg/m^2	milligram per square meter
ρ	Spearman’s rho
AFDM	ash-free dry mass
ANOVA	analysis of variance
ATG	Aquatic Task Group
BLM	Bureau of Land Management
CBNG	coalbed natural gas
DTH	depositional-targeted habitat
EMAP	Environmental Monitoring and Assessment Program
EPT	Ephemeroptera, Plecoptera, and Trichoptera
GIS	geographic information system
GPS	global positioning system

IBI	Index of Biotic Integrity
IWG	Interagency Working Group
MDEQ	Montana Department of Environmental Quality
MFWP	Montana Department of Fish, Wildlife, and Parks
MMI	multimetric index
n	number of measurements/samples
NAWQA	National Water-Quality Assessment Program
NMDS	Nonmetric multidimensional scaling
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
O/E	observed/expected
P	probability level
PCA	principal components analysis
PRB	Powder River Structural Basin
QMH	qualitative multihabitat
r	correlation coefficient
R^2	coefficient of determination
RTH	richest-targeted habitat
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
W/D	width/depth ratio (bankfull width/bankfull depth)
WDEQ	Wyoming Department of Environmental Quality
WGFD	Wyoming Game and Fish Department
WSA	Warm-water Stream Assessment
WSII	Wyoming Stream Integrity Index
WWSC	Wyoming Water Science Center

Ecological Assessment of Streams in the Powder River Structural Basin, Wyoming and Montana, 2005–06

By David A. Peterson[1], Peter R. Wright[1], Gordon P. Edwards, Jr.[2], Eric G. Hargett[3], David L. Feldman[4], Jeremy R. Zumberge[3], and Paul Dey[2]

Abstract

Energy and mineral development, particularly coalbed natural gas development, is proceeding at a rapid pace in the Powder River Structural Basin (PRB) in northeastern Wyoming. Concerns about the potential effects of development led to formation of an interagency working group of primarily Federal and State agencies to address these issues in the PRB in Wyoming and in Montana where similar types of resources exist but are largely undeveloped. Under the direction of the interagency working group, an ecological assessment of streams in the PRB was initiated to determine the current status (2005–06) and to establish a baseline for future monitoring.

The ecological assessment components include assessment of stream habitat and riparian zones as well as assessments of macroinvertebrate, algal, and fish communities. All of the components were sampled at 47 sites in the PRB during 2005. A reduced set of components, consisting primarily of macroinvertebrate and fish community assessments, was sampled in 2006. Related ecological data, such as habitat and fish community data collected from selected sites in 2004, also are included in this report.

The stream habitat assessment included measurement of channel features, substrate size and embeddedness, riparian vegetation, and reachwide characteristics. The width-to-depth ratio (bankfull width/bankfull depth) tended to be higher at sites on the main-stem Powder River than at sites on the main-stem Tongue River and at sites on tributary streams. The streambed substrate particle size was largest at sites on the main-stem Tongue River and smallest at sites on small tributary streams such as Squirrel Creek and Otter Creek. Total vegetative cover at the ground level, understory, and canopy layers ranged from less than 40 percent at a few sites to more than 90 percent at many of the sites. A bank-stability index indicated that sites in the Tongue River drainage were less at risk of bank failure than sites on the main-stem Powder River.

Macroinvertebrate communities showed similarity at the river-drainage scale. Macroinvertebrate communities at sites with mountainous headwaters and snowmelt-driven hydrology, such as Clear Creek, Crazy Woman Creek, and Goose Creek, showed similarity with communities from the main-stem Tongue River. The data also indicated similarity among sites on the main-stem Powder River and among small tributaries of the Tongue River. Data analyses using macroinvertebrate observed/expected models and multimetric indices developed by the States of Wyoming and Montana indicated a tendency toward declining biological condition in the downstream direction along the Tongue River. Biological condition for the main-stem Powder River generally improved downstream, from below Salt Creek to near the Wyoming/Montana border, followed by a general decline downstream from the border to the confluence with the Yellowstone River. The biological condition generally was not significantly different between 2005 and 2006, although streamflow was less in 2006 because of drought.

Algal communities showed similarity at the river-drainage scale with slight differences from the pattern observed in the macroinvertebrate communities. Although the algal communities from Clear Creek and Goose Creek were similar to those from the main-stem Tongue River, as was true of the macroinvertebrate communities, the algal communities from Crazy Woman Creek had more similarity to those of main-stem Powder River sites than to the Tongue River sites, contrary to the macroinvertebrates. Ordination of algal communities, as well as diatom metrics including salinity and dominant taxa, indicated substantial variation at two sites along the main stem of the Powder River.

Fish communities of the PRB were most diverse in the Tongue River drainage. In part due to the effects of Tongue River Reservoir, 15 species of fish were found in the Tongue River drainage that were not found in the Cheyenne, Belle Fourche, or Little Powder River drainages. The number of introduced species and relative abundance of introduced species of fish were higher in the Tongue River and other drainages than at sites on the main-stem Powder River. Although non-native species were identified in the Powder

---

[1] U.S. Geological Survey.

[2] Wyoming Game and Fish Department.

[3] Wyoming Department of Environmental Quality.

[4] Montana Department of Environmental Quality.

River, the native fish community is largely intact. Western silvery minnow and sturgeon chub—species of special concern—were identified only at sites on the main-stem Powder River and were most common in the Montana segment of the main stem. Fish and habitat sampling on the main-stem Powder River indicated affinity of some species for certain habitats such as pools, runs, riffles, backwaters, or shoals.

Introduction

Development of energy and mineral resources in the Powder River Structural Basin (PRB) in northeastern Wyoming and southeastern Montana (fig. 1) currently (2008) includes rapid expansion of coalbed natural gas (CBNG) development in Wyoming. Conventional oil and gas development and coal mining also occur in the PRB. A common theme of CBNG development is discharge of ground water that (1) often is saline or otherwise is unsuitable to use for crop irrigation and (2) has unknown effects on the aquatic communities inhabiting streams that receive the water (*http://www.wy.blm.gov/prbgroup/*).

A total of 41,096 CBNG wells have been permitted in the Wyoming part of the PRB as of October 2006; about one-half (21,018) of those wells have produced water (fig. 2; Wyoming Oil and Conservation Commission, 2008). CBNG development is concentrated along a north-south trending belt associated with the coal fields in the Cheyenne, Belle Fourche, and Powder River drainages but also occurs in the Tongue River drainage. Substantial CBNG resources also exist in the Montana part of the PRB but are largely undeveloped compared to Wyoming. Permit data from the Montana Department of Environmental Quality (MDEQ) indicate cumulative CBNG water production as of October 2006 was about 11,100 acre-feet (acre-ft) from 150 or more wells in the Tongue River drainage in Montana. At maximum development in the PRB, CBNG wells are expected to number 60,000 in Wyoming and more than 10,000 in Montana (Stricker and others, 2006).

To address concerns about the potential effects of CBNG development on cultural and natural resources, the Bureau of Land Management (BLM), U.S. Department of the Interior, formed an Interagency Working Group (IWG) of Federal, State, and tribal agencies. The charter of the IWG states that it "…was established as the forum for government agencies to address, discuss, and find solutions to issues of common concern to all parties involved in permitting and monitoring of CBNG development" (Powder River Natural Gas Interagency Working Group, 2004). The IWG charter also provides for establishment of working groups to address technical issues as envisioned by the April 2003 Record of Decision and Environmental Impact Statement. One working group, the Aquatic Task Group (ATG), was tasked with assessing potential effects on aquatic ecological resources.

The ATG developed a monitoring plan to meet two main objectives: (1) establish current conditions for aquatic biota and their habitat and (2) determine existing and potential effects of CBNG-produced water on aquatic life (Wright and others, 2006). The sample collection conducted during 2005–06 and described in this report was conducted under the direction of the ATG to help meet objective 1 of their monitoring plan. Results from sampling by the Wyoming Game and Fish Department (WGFD) during 2004 and by the U.S. Geological Survey (USGS) during 1980–2007 also are described in this report to help meet objective 1.

At the time the ATG was formed, CBNG development was occurring at a rapid pace in Wyoming, precluding the possibility of designing a regional monitoring plan useful for establishing a baseline of predevelopment conditions. Although it is too late to establish a true baseline, the data collected as part of this ecological assessment can be used to identify the current ecological status of streams in the PRB. The ecological assessment of streams in the PRB in Wyoming and Montana was performed by the USGS in cooperation with the BLM, Wyoming Department of Environmental Quality (WDEQ), WGFD, U.S. Environmental Protection Agency (USEPA), MDEQ, and the Montana Department of Fish, Wildlife, and Parks (MFWP). In light of CBNG activity planned for future years, this "current condition" (2005–06) information will provide scientists and decisionmakers in the public and private sectors data to make scientifically sound decisions related to ATG objective 2. Other work under the direction of the ATG, related to objective 2, includes ongoing studies of potential effects of CBNG water on fish communities in the PRB (Davis and others, 2006a; Skaar and others, 2006), and a literature review of the effects of CBNG activities on fish communities (Davis and others, 2006b). Additional information about CBNG development and monitoring is available from the BLM at *http://www.wy.blm.gov/prbgroup/*; the WDEQ at *http://deq.state.wy.us/wqd/WYPDES_Permitting/WYPDES_cbm/cbm.asp*; and the USGS at *http://wy.water.usgs.gov/*.

Purpose and Scope

The primary purpose of this report is to describe the ecological assessment of streams in the PRB in northeastern Wyoming and southeastern Montana. Characteristics of the habitat and biological communities (macroinvertebrates, algae, and fish) are based on samples collected at 47 sites during 2005–06. Fish and habitat data collected from sites on the main stem of the Powder River in Wyoming and at one miscellaneous site on the South Fork of the Powder River during 2004 also are presented as well as macroinvertebrate and algal data from 1980–2007.

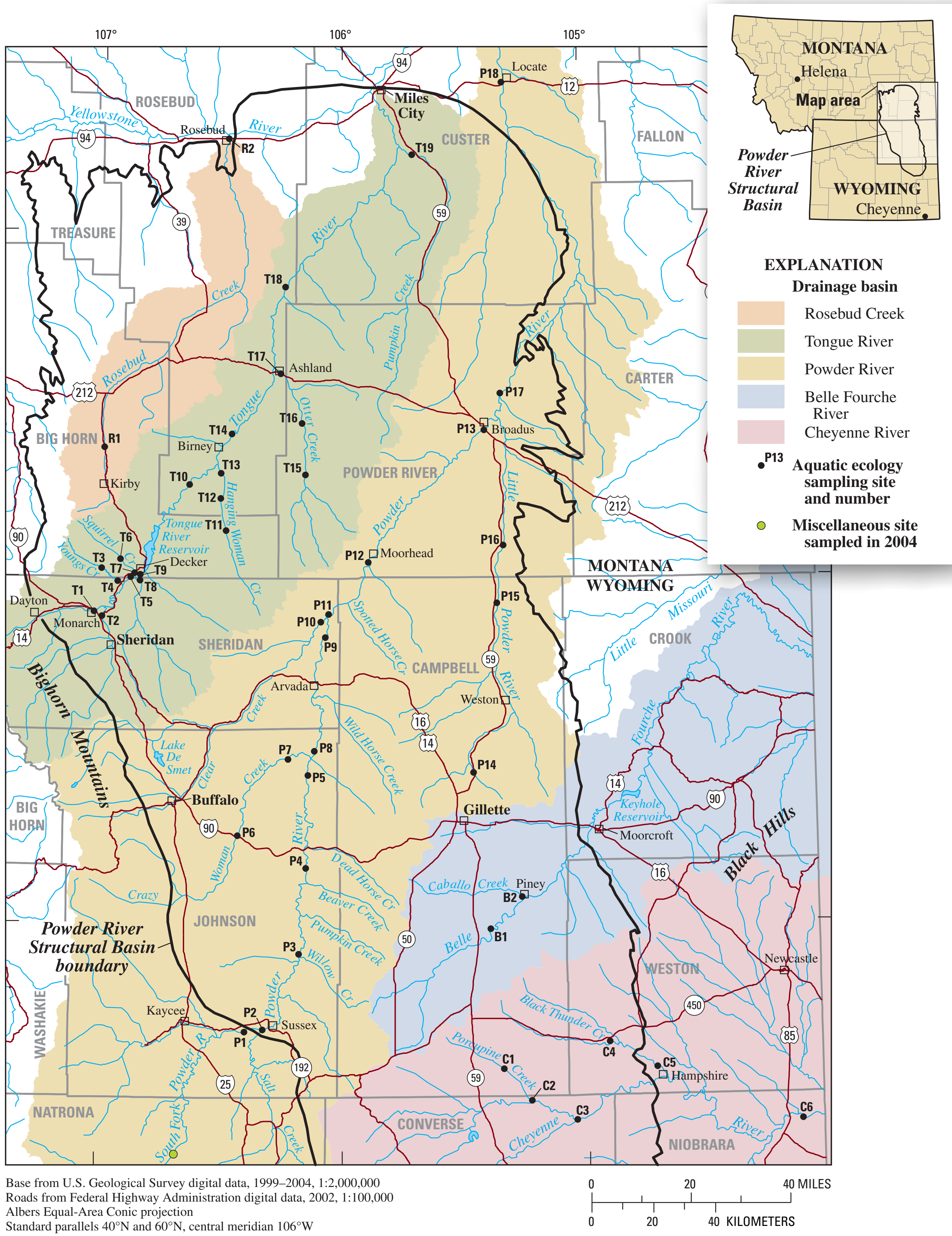

Figure 1. Location of aquatic ecology sampling sites in the Powder River Structural Basin, Wyoming and Montana, 2005–06.

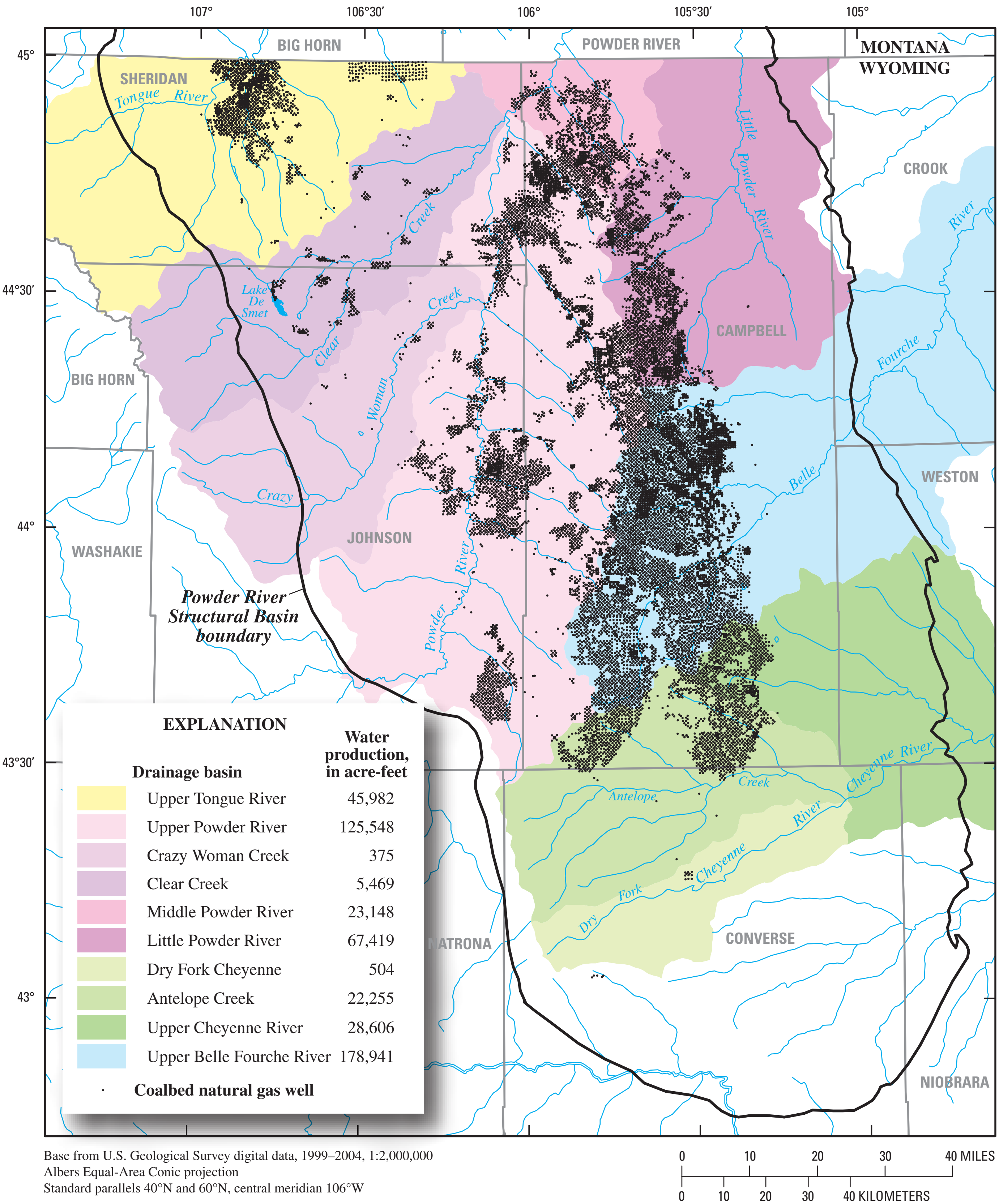

Figure 2. Cumulative water production as of October 2006 from coalbed natural gas wells in the Powder River Structural Basin, Wyoming. (Data from Wyoming Oil and Gas Commission, 2008.)

Description of the Study Area

The PRB includes the namesake Powder River drainage as well as the Tongue River and Rosebud Creek drainages and upstream parts of the Cheyenne and Belle Fourche River drainages (fig. 1). This section of the report describes the geographic setting, climate and hydrology, land and water use, and water quality of the PRB.

Geographic Setting

Elevations in the study area range from about 727 meters (m) above the National Geodetic Vertical Datum of 1929 (NGVD 29) at the Powder River near the confluence with the Yellowstone River in Montana to more than 3,990 m in the Bighorn Mountains in Wyoming. The study area lies within the Northwestern Great Plains ecoregion, although some of the streams originate in the Middle Rockies ecoregion or the Wyoming Basin ecoregion (Woods and others, 2002; Chapman and others, 2003). Stream origins are listed in table 1 as either mountain (Middle Rockies ecoregion) or plains (Northwestern Great Plains and Wyoming Basin ecoregions). The predominant vegetation in the study area is short and mixed grass prairie that includes shrubs (sagebrush and rabbit brush) and scattered trees (Knight, 1994; Bailey, 1995). The landscape is characterized by undulating to highly dissected plains, sheer-sided buttes, and rugged badlands along some river valleys (Bailey, 1995; McNab and others, 2005).

Headwater streams in the western parts of the Tongue and Powder River drainages flow across igneous and metamorphic rocks of Precambrian age (Lindner-Lunsford and others, 1992; Zelt and others, 1999; Clark and Mason, 2007). As these streams continue downslope across the foothills to the plains, they flow across uplifted Paleozoic-era marine sandstone and limestone deposits, Mesozoic era sandstone and shale, and then Tertiary-age sedimentary rocks of the Wasatch and Fort Union Formations (Hembree and others, 1952; Lindner-Lunsford and others, 1992).

Climate and Hydrology

The study area is semiarid (McNab and others, 2005). Precipitation is quite variable and comes in the form of rain and snow, with most precipitation falling as rain during the spring and summer months. Average annual precipitation generally is less than 500 millimeters (mm; Western Region Climate Center, 2009). Temperatures vary widely with extremely cold winters and hot summers. For example, climatic records from Broadus, Mont., show a recorded low temperature of -44 degrees Celsius (°C), a high of 42°C, and a mean annual temperature of 7.5°C during 1948–2007 (Western Regional Climate Center, 2007).

Flow in plains streams is quite variable throughout the study area because of the high variability of precipitation. Some of the plains streams sampled as part of this assessment had intermittent streamflow, meaning they had flow during part of the year. Intermittent streams often have perennial pools that are sustained by ground water but may not have flow between the pools during part of the year. In contrast, some plains streams with mountain headwaters have perennial flow and rarely go dry, even during periods of drought, with streamflow sustained by snowmelt and ground-water discharge (Lindner-Lunsford and others, 1992).

Many of the streams in the study area have diversion dams that are used for irrigation withdrawals, and numerous small impoundments have been built on small tributary streams. The largest reservoir in the study area is Tongue River Reservoir, located between sampling sites T9 and T10 on the main-stem Tongue River (fig. 1). The storage capacity of Tongue River Reservoir is about 68,040 acre-ft (Zelt and others, 1999). The main-stem Powder River is free flowing (no dams) as are the Cheyenne and the Belle Fourche Rivers within the study area.

Data described in this report generally were collected during the summer months (June through September) of 2005 and 2006. By the summer of 2005, the States of Wyoming and Montana were in the 6th year of drought (National Oceanic Atmospheric Administration Satellite and Information Service, 2005). As a result of this drought, with the exception of short-term storms, mean daily flows during both 2005 and 2006 were substantially less than the long-term mean. Streamflow data from three sampling sites are shown in figure 3 to illustrate the severity of the drought and the annual variability of streamflow conditions in the study area. In general, streamflow during the 2006 was considerably less than during the 2005 as shown by the hydrographs for the Powder River at Moorhead (site P12, fig. 3*A*), Cheyenne River near Spencer (site C6, fig. 3*B*), and Tongue River at State line (site T9, fig. 3*C*). The Powder River between Sussex, Wyo. (site P2, fig. 1), and Moorhead, Mont. (site P12, fig. 1), is a losing reach (river loses more water to aquifer and evaporation than it gains), and although the Powder River is considered perennial, it historically has periods when it does not flow (Ringen and Daddow, 1990). During 2006, however, some of the reaches on the Powder River, like many of the small streams (fig. 4), had no flow, which left isolated pools to sample.

In spite of the ongoing 6-year long drought, streamflow in 2005 in the Tongue River at State line (site T9, fig. 3*C*) was closer to the long-term mean streamflow than were many of the streams in the study area. The 2005 streamflow in the Tongue River was affected by intense rainfall; for example, the monthly total precipitation for Dayton, Wyo. (near Monarch, fig. 1) in May 2005 was 160 mm, more than twice the long-term monthly average of 77 mm (Western Region Climate Center, 2009). The above-average precipitation in 2005 helped sustain streamflow later in the year, but the streamflow in 2006 was considerably less than the long-term mean streamflow and more similar to other drought-affected streams in the study area (fig. 3*C*).

Table 1. Aquatic ecology sampling sites and selected characteristics, Powder River Structural Basin, Wyoming and Montana, 2005–06.

[Shaded cells indicate main-stem sampling sites on the Tongue or Powder River. DMS, degrees, minutes, seconds; km^2, square kilometers; m, meters; M, mountains; P, plains]

Site number (fig. 1)	U.S. Geological Survey site identification number	Site name	Abbreviated site name	Latitude (DMS)	Longitude (DMS)	Drainage area (km^2)	Elevation (m)	Stream origin	Reach length (m)
R1	06295113	Rosebud Creek at Reservation Boundary, near Kirby, MT	upper Rosebud Creek	45 21 40	106 59 23	319	1,152	P	200
R2	06296003	Rosebud Creek at mouth, near Rosebud, MT	Rosebud Creek at mouth	46 15 53	106 28 30	3,372	756	P	200
T1	06299980	Tongue River at Monarch, WY	Tongue River at Monarch	44 54 01	107 01 13	1,238	1,103	M	970
T2	06305700	Goose Creek near Acme, WY	Goose Creek	44 53 11	106 59 18	1,070	1,103	M	640
T3	450137106595101	Youngs Creek near Reservation Boundary, near Decker, MT	upper Youngs Creek	45 01 37	106 59 15	56	1,155	P	200
T4	445832106551401	Youngs Creek above mouth, near Decker, MT	Youngs Creek at mouth	44 58 32	106 55 14	161	1,088	P	200
T5	445957106524701	Tongue River below Youngs Creek, near Decker, MT	Tongue River below Youngs Creek	44 59 57	106 52 47	3,711	1,058	M	1,000
T6	06306100	Squirrel Creek near Decker, MT	upper Squirrel Creek	45 03 02	106 55 24	87	1,122	P	200
T7	450047106514201	Squirrel Creek above mouth at Decker, MT	Squirrel Creek at mouth	45 00 47	106 51 42	112	972	P	200
T8	06306250	Prairie Dog Creek near Acme, WY	Prairie Dog Creek	44 59 02	106 50 21	927	1,052	P	170
T9	06306300	Tongue River at State line, near Decker, MT	Tongue River at State line	45 00 32	106 50 08	3,763	1,045	M	1,000
T10	451607106372801	Tongue River at Prairie Dog Creek, near Decker, MT	Tongue River above Hanging Woman Creek	45 16 07	106 37 28	5,208	890	M	1,000
T11	06307570	Hanging Woman Creek below Horse Creek, near Birney, MT	upper Hanging Woman Creek	45 08 04	106 29 04	831	954	P	200
T12	451340106295501	Hanging Woman Creek below Hay Gulch, near Birney, MT	middle Hanging Woman Creek	45 13 44	106 29 57	958	997	P	200
T13	06307600	Hanging Woman Creek near Birney, MT	Hanging Woman Creek at mouth	45 17 57	106 30 28	1,217	960	P	200
T14	06307616	Tongue River at Birney Day School Bridge, near Birney, MT	Tongue River at Birney Day School	45 24 42	106 27 26	6,788	933	M	1,000
T15	451732106085001	Otter Creek below Taylor Creek, near Otter, MT	upper Otter Creek	45 17 32	106 08 53	803	991	P	200

Table 1. Aquatic ecology sampling sites and selected characteristics, Powder River Structural Basin, Wyoming and Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sampling sites on the Tongue or Powder River. DMS, degrees, minutes, seconds; km^2, square kilometers; m, meters; M, mountains; P, plains]

Site number (fig. 1)	U.S. Geological Survey site identification number	Site name	Abbreviated site name	Latitude (DMS)	Longitude (DMS)	Drainage area (km^2)	Elevation (m)	Stream origin	Reach length (m)
T16	452642106091201	Otter Creek below Tenmile Creek, near Ashland, MT	middle Otter Creek	45 26 42	106 09 12	1,331	945	P	200
T17	06307740	Otter Creek at Ashland, MT	Otter Creek at mouth	45 35 18	106 15 17	1,831	889	P	200
T18	06307830	Tongue River below Brandenberg Bridge, near Ashland, MT	Tongue River below Brandenberg Bridge	45 50 23	106 13 09	10,225	841	M	1,000
T19	06308400	Pumpkin Creek near Miles City, MT	Pumpkin Creek	46 13 42	105 41 24	1,805	759	P	200
P1	434056106244101	Powder River above Lone Tree Draw, near Sussex, WY	Powder River above Salt Creek	43 40 56	106 24 41	5,828	1,350	P	[1]3,218
P2	434124106192401	Powder River below Salt Creek, near Sussex, WY	Powder River below Salt Creek	43 41 24	106 19 24	7,980	1,338	P	[1]3,218
P3	435453106104701	Powder River below Willow Creek, near Sussex, WY	Powder River above Pumpkin Creek	43 54 53	106 10 47	9,808	1,311	P	[1]3,218
P4	440919106091401	Powder River above Van Houghton Draw, near Buffalo, WY	Powder River below Burger Draw	44 09 19	106 09 14	11,111	1,216	P	[1]3,218
P5	442538106082001	Powder River below Mitchell Draw, near Arvada, WY	Powder River above Crazy Woman Creek	44 25 38	106 08 20	12,564	1,152	P	[1]3,218
P6	441532106251301	Crazy Woman Creek below I-90, near Buffalo, WY	Crazy Woman Creek below I-90	44 15 32	106 25 13	1,769	1,280	M	340
P7	442817106133001	Crazy Woman Creek near Upper Station, near Arvada, WY	Crazy Woman Creek near mouth	44 28 17	106 13 30	2,385	1,167	M	490
P8	443025106061601	Powder River below Crazy Woman Creek, near Arvada, WY	Powder River below Crazy Woman Creek	44 30 25	106 06 16	15,286	1,134	P	[1]3,218
P9	444857106030401	Powder River above Ivy Creek, near Arvada, WY	Powder River above Clear Creek	44 48 57	106 03 04	17,050	1,062	P	[1]3,218
P10	06324000	Clear Creek near Arvada, WY	Clear Creek	44 52 18	106 04 56	2,875	1,069	M	750
P11	445339106032501	Powder River below Clear Creek, near Arvada, WY	Powder River below Clear Creek	44 53 39	106 03 25	20,106	1,059	P	[1]3,218
P12	06324500	Powder River at Moorhead, MT	Powder River at Moorhead	45 03 28	105 52 39	20,943	1,021	P	[1]3,218
P13	06324710	Powder River at Broadus, MT	Powder River at Broadus	45 25 37	105 24 05	22,657	919	P	[1]3,218
P14	06324790	Little Powder River at State Hwy 59, near Gillette, WY	Little Powder River at Highway 59	44 26 09	105 27 17	110	1,250	P	200

Table 1. Aquatic ecology sampling sites and selected characteristics, Powder River Structural Basin, Wyoming and Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sampling sites on the Tongue or Powder River. DMS, degrees, minutes, seconds; km^2, square kilometers; m, meters; M, mountains; P, plains]

Site number (fig. 1)	U.S. Geological Survey site identification number	Site name	Abbreviated site name	Latitude (DMS)	Longitude (DMS)	Drainage area (km^2)	Elevation (m)	Stream origin	Reach length (m)
P15	06324970	Little Powder River above Dry Creek, near Weston, WY	Little Powder River above Dry Creek	44 55 37	105 21 10	3,204	1,039	P	240
P16	06325000	Little Powder River at Biddle, MT	Little Powder River at Biddle	45 06 17	105 19 51	3,991	991	P	200
P17	453209105201201	Powder River below Little Powder River, near Broadus, MT	Powder River below Little Powder River	45 32 09	105 20 12	29,503	908	P	[1]3,218
P18	06326500	Powder River near Locate, MT	Powder River near Locate	46 25 48	105 18 34	33,846	727	P	[1]3,218
C1	06364300	Porcupine Creek near Teckla, WY	Porcupine Creek	43 34 41	105 20 19	204	1,428	P	200
C2	06364700	Antelope Creek near Teckla, WY	Antelope Creek	43 29 08	105 13 39	2,484	1,366	P	280
C3	06365900	Cheyenne River near Dull Center, WY	Cheyenne River near Dull Center	43 25 45	105 02 43	3,955	1,314	P	320
C4	06375600	Little Thunder Creek near Hampshire, WY	Little Thunder Creek	43 39 20	104 54 20	606	1,341	P	200
C5	06376300	Black Thunder Creek near Hampshire, WY	Black Thunder Creek	43 34 54	104 43 11	1,386	1,244	P	200
C6	06386500	Cheyenne River near Spencer, WY	Cheyenne River near Spencer	43 25 20	104 07 36	13,649	1,105	P	220
B1	06425720	Belle Fourche River below Rattlesnake Creek, near Piney, WY	Belle Fourche River	43 59 04	105 23 16	1,282	1,384	P	200
B2	06425900	Caballo Creek at mouth, near Piney, WY	Caballo Creek	44 04 48	105 15 59	673	1,335	P	200

[1]Established reach length of 3,218 m is maximum reach length; the actual reach length varied each time site was visited depending on location of random starting point and availability of expected habitat types.

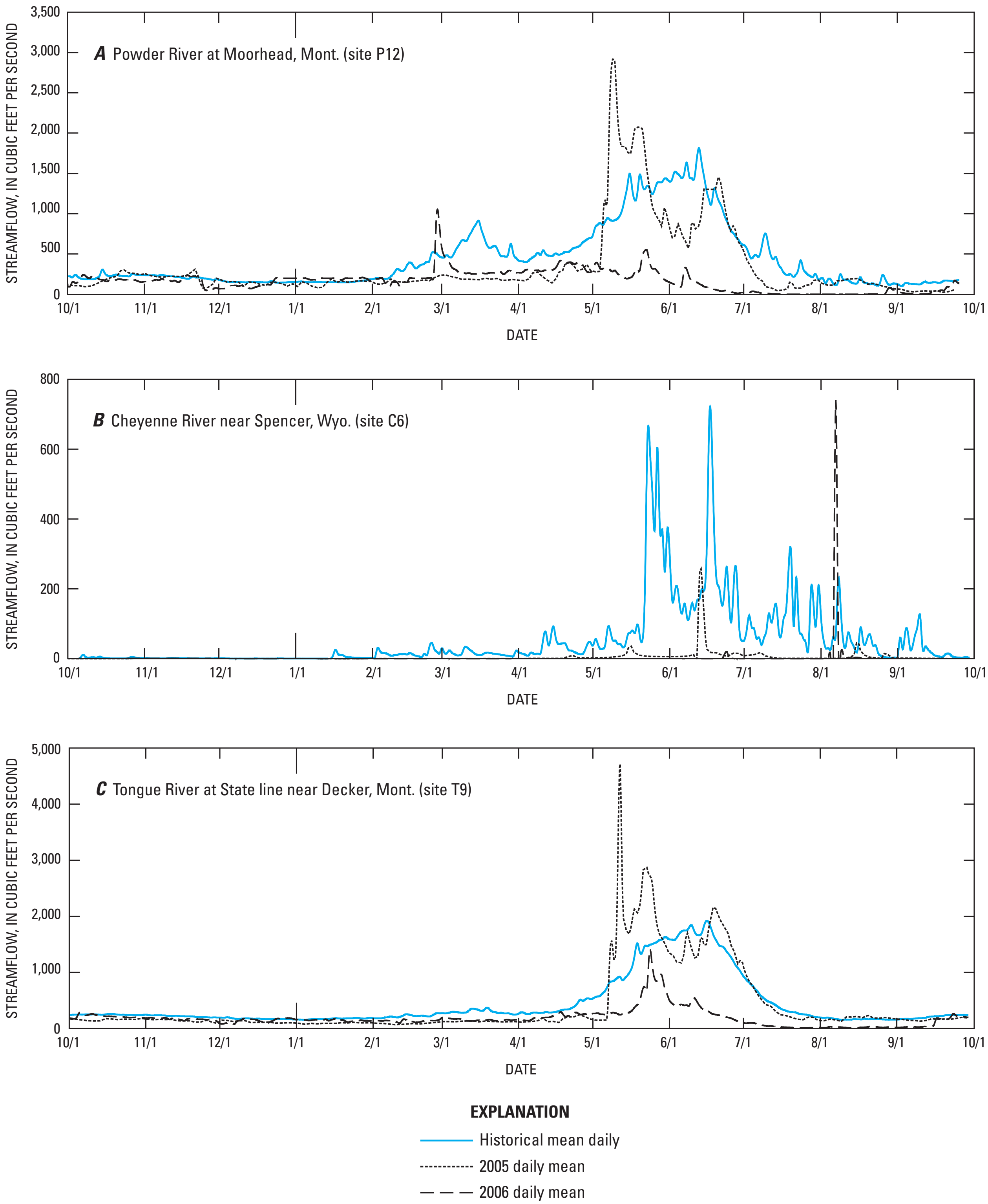

Figure 3. Streamflow hydrographs showing historical mean daily flow and daily mean flow for water years 2005 and 2006 for *A*, Powder River at Moorhead, Mont. (site P12); *B*, Cheyenne River near Spencer, Wyo. (site C6); and *C*, Tongue River at State line near Decker, Mont. (site T9).

Photograph by Stacy M. Kinsey, U.S. Geological Survey.

Photograph by Michael J. Sweat, U.S. Geological Survey.

Figure 4. Photographs of sample reach on Hanging Woman Creek near Birney, Mont. (site T13), showing the difference in water levels for sampling dates in 2005 and 2006.

Land and Water Use

Although few small communities are in the PRB, the predominant land uses are agricultural and mineral related. As of 2000, the largest city in the study area is Gillette, Wyo., with an estimated population of 19,646 (U.S. Census Bureau, 2007). The primary agricultural uses in the study area are livestock production and irrigated and dryland crop production (Zelt and others, 1999). CBNG production followed by coal mining and conventional oil and gas are the dominant mineral-related land uses. Although limited, some timber production occurs in the Bighorn Mountains and in forested areas of the downstream Tongue and Powder River drainages (Zelt and others, 1999).

The following brief summary of water use in the Tongue and Powder River drainages in Wyoming is drawn from HKM Engineering, Inc. and others (2002). Irrigated crop production, primarily associated with production of livestock forage, uses the largest percentage of surface water in the Tongue and Powder River drainages in Wyoming. About 194,000 acre-ft of water, or approximately 87 percent of all surface-water use, is for irrigation. The remaining 13 percent of surface-water use is for municipal supply. Industries with the largest water demands in the Tongue and Powder River drainages in Wyoming include conventional oil and gas production and CBNG development. Together these industries use approximately 68,000 acre-ft of ground water per year. Industry accounts for about 93 percent of the ground-water use in the area, followed by domestic use (6 percent), municipal use (<1 percent), and agricultural use (<1 percent).

Wastewater effluent from municipal treatment plants enters some of the streams in the study area, primarily in Sheridan County in the Tongue River drainage (fig. 1). The town of Sheridan, for example, discharges effluent to Goose Creek, and smaller towns such as Dayton and Ranchester discharge effluent to the Tongue River (Wyoming Department of Environmental Quality, 2009). The total population of Sheridan County in 2007 was estimated to be 27,207 (U.S. Census Bureau, 2009). Other towns include Buffalo, that discharges effluent to Clear Creek approximately 80 kilometers upstream from the nearest sampling site, and Gillette, that discharges to a tributary of the Belle Fourche River downstream from the nearest sampling site.

Water Quality

Water-quality information in this section is drawn from Clark and Mason (2007) unless otherwise specified. Chemical characteristics of surface water are dependent upon many variables, including the sources of the water (snowmelt, rainfall, or ground-water discharge), stream hydrology, and the characteristics of the geologic formations the water traverses. Because of the wide range of environmental settings (chemical, ecological, hydrological, and physical characteristics) in the study area, water-quality characteristics throughout the area are quite variable. Water types in the PRB ranged from magnesium calcium bicarbonate type water for some sites in the Tongue River drainage to sodium sulfate type water at many sites in the Powder, Cheyenne, and Belle Fourche River drainages (Lee and others, 1981; Ringen and Daddow, 1990; Clark and Mason, 2007). Generally, streams with headwaters in the mountains have smaller major ion and dissolved-solids concentrations than streams with headwaters in the plains (Lindner-Lunsford and others, 1992), and concentrations of dissolved constituents become larger as water flows downstream. Two exceptions to this are worth noting and occur in the Powder River between Arvada, Wyo., and Moorhead, Mont., and in the Belle Fourche River. In the Powder River between Arvada and Moorhead, the decrease in dissolved-solids concentrations can be attributed to inflows from Clear Creek that have smaller dissolved-solids concentrations (Hembree and others, 1952; Ringen and Daddow, 1990; Clark and Mason, 2007). Smaller downstream concentrations in the Belle Fourche River likely are because of differences in geology and changes in water quality of tributaries as the Belle Fourche River approaches the Black Hills and Keyhole Reservoir (fig. 1).

Water quality of the Powder River has been affected by discharges from conventional oil and gas production in the Salt Creek drainage. Salt Creek has large concentrations of dissolved solids, chloride, and sodium due to discharges from conventional oil and gas production (Clark and Mason, 2007). Concentrations of chloride frequently were larger than the State of Wyoming chronic criterion for aquatic life of 230 milligrams per liter (Wyoming Department of Environmental Quality, 2001) in the Powder River below Salt Creek (site P2), Powder River below Burger Draw (near site P4), and Powder River at Arvada (downstream from sites P5 and P8), and to a lesser extent, in the Little Powder River above Dry Creek (site P15; Clark and Mason, 2007). The reach of the Powder River from Salt Creek to Clear Creek has been listed by the WDEQ as chloride impaired, and the reach of the Powder River from Salt Creek to Crazy Woman Creek has been listed as selenium impaired (Wyoming Department of Environmental Quality, 2006).

Acknowledgments

Greg Boughton, Kendra Remley, Stacy Kinsey, Tom Cleasby, Billy Justus, Jodi Norris, Pete McCarthy, Fred Bailey, Laura Hallberg, Seth Davidson, Mike Sweat, Ty Blacklock, John Tertuliani, Rick Hubbell, Jon Mason, and others with the USGS and Travis Cundy, Dave Zafft, Bud Stewart, and others with the WGFD assisted with data collection. Travis Cundy also participated in the habitat data analysis from sites on the main-stem Powder River in Wyoming. Many private landowners, as well as the Anadarko Corporation (The Woodlands, Texas), allowed access to sampling sites.

Colleague reviews by Stephen Porter (Texas State University), Jim Petersen (USGS), and Robert Bramblett (Montana State University) improved the quality of the manuscript. Other members of the ATG, including David Zafft (WGFD), and Joe Platz (BLM), also provided helpful comments. Merry Gamper (USGS) helped compile the ancillary macroinvertebrate and algal data. Sue Roberts (USGS) created the illustrations and performed layout work. Laura Hallberg (USGS) performed the geographic information system (GIS) analysis.

Methods of Sample Collection and Analysis

A total of 47 sampling sites (fig. 1; table 1) were chosen for sampling by the ATG on the basis of prioritization with respect to existing and potential CBNG development and availability of existing data and using professional judgment to identify and fill in data gaps. All of the sites were sampled in 2005, the first year of the ATG study. The number of sampling sites was reduced to 39 sites during 2006, and the scope of sampling at each site was smaller in 2006 than 2005 (table 2) partially because of drought and partially because of study constraints.

Sampling and measurement techniques described in this section are drawn primarily from the USGS National Water-Quality Assessment Program (NAWQA) protocols for algae and macroinvertebrates and the USEPA Environmental Monitoring and Assessment Program (EMAP) protocols for habitat and fish community. Protocols used by the WGFD for habitat and fish community assessment on the main-stem Powder River also are described in this section.

Habitat

The description of habitat assessment methods is divided into two parts because of differences in methodology. The first section, “Basinwide Habitat Assessment,” describes habitat assessment methods used by the USGS to collect data for all 47 sampling sites, which includes sites on the main-stem Powder River. The second section, “Main-Stem Powder River Habitat Assessment,” describes habitat assessment methods used by the WGFD to collect data at eight sites on the main-stem Powder River in Wyoming.

Basinwide Habitat Assessment

Habitat assessments were conducted by USGS personnel in 2005 using the EMAP transect-based survey technique (Peck and others, 2003) at each of the 47 sites sampled for aquatic biota. The standard sampling reach length was defined as 40 wetted channel widths and ranged from a minimum of 200 m to a maximum of 1,000 m with the exception of reaches on the main-stem Powder River that were 3,218 m (table 1). At each site, 11 equally spaced transects were established for measurements, and at each transect, five points including the edge of water were measured for features such as depth, substrate, and embeddedness. Reachwide mean values were

Table 2. Types of aquatic ecology measurements and samples by site, Powder River Structural Basin, Wyoming and Montana, 2005–06.

[Data collected by U.S. Geological Survey except as indicated by footnotes. Shaded cells indicate main-stem sites on the Tongue or Powder River. GPS, global positioning system; X, data were collected; A, attempted to collect sample, but reach was dry or did not have enough wetted area to sample; --, data were not collected]

Site number (fig. 1)	Abbreviated site name	Habitat transects and cross sections	Longitudinal-survey profiles	GPS mapping	Algae	Macroinvertebrate community		Fish community		Major ion samples	
		2005				2005	2006	2005	2006	2005	2006
R1	upper Rosebud Creek	X	--	--	--	X	X	X	X	--	--
R2	Rosebud Creek at mouth	X	--	--	--	X	--	X	--	--	--
T1	Tongue River at Monarch	X	X	--	X	X	X	X	X	--	--
T2	Goose Creek	X	X	--	X	X	X	X	X	--	--
T3	upper Youngs Creek	X	--	--	--	X	X	X	X	X	X
T4	Youngs Creek at mouth	X	--	--	--	X	X	X	X	X	X
T5	Tongue River below Youngs Creek	X	--	--	--	X	X	X	X	X	X
T6	upper Squirrel Creek	X	--	--	--	X	X	X	X	X	X
T7	Squirrel Creek at mouth	X	--	--	--	X	A	X	A	X	A
T8	Prairie Dog Creek	X	X	--	X	X	X	X	X	--	--
T9	Tongue River at State line	X	X	--	X	X	X	X	X	--	--
T10	Tongue River above Hanging Woman Creek	X	--	--	--	X	X	X	X	X	X
T11	upper Hanging Woman Creek	X	--	--	--	X	X	X	X	X	X
T12	middle Hanging Woman Creek	X	--	--	--	X	X	X	X	X	X
T13	Hanging Woman Creek at mouth	X	--	--	--	X	X	X	X	--	--
T14	Tongue River at Birney Day School	X	--	--	--	X	X	X	X	--	--
T15	upper Otter Creek	X	--	--	--	X	X	X	X	X	X
T16	middle Otter Creek	X	--	--	--	X	A	X	A	X	A
T17	Otter Creek at mouth	X	--	--	--	X	X	X	X	--	--
T18	Tongue River below Brandenberg Bridge	X	--	--	--	X	X	X	X	--	--
T19	Pumpkin Creek	X	--	--	--	X	--	X	--	--	--
P1	Powder River above Salt Creek	X	--	X	X	X	X	X[1]	X[1]	X	X
P2	Powder River below Salt Creek	X	--	X	X	X	X	X[1]	X[1]	X	X
P3	Powder River above Pumpkin Creek	X	--	X	X	X	X	X[1]	X[1]	X	X

Table 2. Types of aquatic ecology measurements and samples by site, Powder River Structural Basin, Wyoming and Montana, 2005–06.—Continued

[Data collected by U.S. Geological Survey except as indicated by footnotes. Shaded cells indicate main-stem sites on the Tongue or Powder River. GPS, global positioning system; X, data were collected; A, attempted to collect sample, but reach was dry or did not have enough wetted area to sample; --, data were not collected]

Site number (fig. 1)	Abbreviated site name	Habitat transects and cross sections	Longitudinal-survey profiles	GPS mapping	Algae	Macroinvertebrate community		Fish community		Major ion samples	
			2005			2005	2006	2005	2006	2005	2006
P4	Powder River below Burger Draw	X	--	X	X	X	X	X[1]	X[1]	X	X
P5	Powder River above Crazy Woman Creek	X	--	X	X	X	X	X[1]	X[1]	X	X
P6	Crazy Woman Woman Creek below I-90	X	X	X	X	X	X	X	X	X	X
P7	Crazy Woman Creek near mouth	X	X	X	X	X	X	X	X	X	X
P8	Powder River below Crazy Woman Creek	X	--	X	X	X	X	X[1]	X[1]	X	X
P9	Powder River above Clear Creek	X	--	X	X	X	X	X[1]	X[1]	X	X
P10	Clear Creek	X	X	--	X	X	X	X	X	--	--
P11	Powder River below Clear Creek	X	--	X	X	X	X	X[1]	X[1]	X	X
P12	Powder River at Moorhead	X	--	X	X	X	X	X	X	--	--
P13	Powder River at Broadus	X	--	--		X	X	X	X	X	X
P14	Little Powder River at Highway 59	X	X	--	X	X	X	X	X	X	X
P15	Little Powder River above Dry Creek	X	X	--	X	X	X	X	X	--	--
P16	Little Powder River at Biddle	X	--	--	--	X	--	X	--	X	--
P17	Powder River below Little Powder River	X	--	--	--	X	X	X	X	X	X
P18	Powder River near Locate	X	--	--	--	X	--	X		--	--
C1	Porcupine Creek	X	X	--	X	X	X	X	X	--	--
C2	Antelope Creek	X[2]	X[2]	--	X	X	X	X	X	--	--
C3	Cheyenne River near Dull Center	X[2]	X[2]	--	X	X	X	X	X	--	--
C4	Little Thunder Creek	X	X	--	X	X	X	X	X	--	--
C5	Black Thunder Creek	X[2]	X[2]	--	X	X	A	X	A	--	--
C6	Cheyenne River near Spencer	X[2]	X[2]	--	X	X	X	X	X	--	--
B1	Belle Fourche River	X	X	--	X	X	X	X	X	--	--
B2	Caballo Creek	X	X	--	X	X	A	X	A	--	--

[1]Data were collected by the Wyoming Game and Fish Department.

[2]Data were collected by the Wyoming Department of Environmental Quality.

calculated from the transect values, including depths of zero at the edge of water if the banks were less than vertical.

Channel dimensions, bank characteristics, and in-stream fish cover were evaluated at each of the cross-section transects. Bankfull depth measurements described in this report are the height of bankfull stage as measured from the bottom of the thalweg (the line connecting the lowest or deepest points along a streambed). When thalweg data were collected in conjunction with transect measurements, the thalweg depth measured at each transect was added to its corresponding bankfull height above water surface to determine bankfull depth. When thalweg data were collected independently from transect measurements, a reach mean was determined for bankfull height above water surface and thalweg depth, and then these reach means were added to produce the bankfull depths from thalweg. The width/depth ratio (W/D; Rosgen, 1996) was calculated as the mean bankfull width divided by the mean bankfull depth. Incised height was measured as the distance from the water surface to the level of the first terrace. Stream incision values given in this report represent the incised height above the bottom of the thalweg, calculated by adding the incised height above the water surface to the reach mean thalweg depth. Fish cover was recorded as a semiquantitative observation of filamentous algae, aquatic macrophytes, large woody debris, brush, live trees or roots, overhanging vegetation, undercut banks, and boulders. Areal coverage of each fish-cover type was estimated for a 10-m segment of the stream at each cross-section transect by estimating cover classes ranging from “0” (absent) to “4” (>75 percent; Peck and others, 2003). Fish-cover estimates can exceed 100 percent when all categories are added together because of the ranges used for observations. At each site, a sketch of the reach was drawn, and photographic points were established to assist in documenting channel, bank, and riparian conditions and as a reference for possible long-term comparisons.

Substrate size and embeddedness were measured along the transects at all sites; additionally, the substrate size was estimated for an additional 50 particles along the thalweg profile at sites in Montana. Substrate measurements were recorded as a code that represented a substrate size range or class. Substrate statistics presented in this report were calculated according to methods described by Kaufmann and others (1999) by assigning a numeric value to each class, representing the logarithm of the midpoint diameter of each size class (table 3). Bedrock is operationally defined in this report as rock, concrete, or hardpan greater than 4,000 mm in diameter. Embeddedness of particles was estimated to the nearest 10 percent at the transects (55 points per site).

In addition to the reachwide substrate characteristics collected as part of the EMAP procedures, pebble counts were collected following procedures outlined in Wolman (1954). Wolman pebble counts were collected at one riffle and one pool, if present, at all Wyoming sites and sites T9 (Tongue River at State line) and P12 (Powder River at Moorhead). At each riffle or pool, at least 100 particles were measured at evenly spaced intervals across the stream starting at bankfull. Particle size was measured using a U.S. SAH-97 Hand Held Particle Size Analyzer (gravelometer) and tallied by standard ½ phi Wentworth size classes (Potyondy and Bunte, 2002). Cumulative distribution curves for the pebble count data were generated using a spreadsheet developed by J.P. Potyondy (U.S. Department of Agriculture, Forest Service) and K. Bunte (Colorado State University, written commun., 2007).

Several measures of riparian vegetation were collected at each cross-section transect. Canopy density, the area of the sky bracketed by vegetation (Peck and others, 2003), was measured in six locations (four directions mid-stream and at each bank). Reachwide mean values of canopy density were calculated separately for mid-stream and bank densiometer measurements and reported as a percentage of possible density, as much as 100 percent (Kaufmann and others, 1999). Riparian vegetation type and cover were visually estimated for three vegetative layers—ground cover (<0.5 m high), understory (0.5 to 5 m high), and canopy (>5 m high)—using classes of 0 percent (absent), less than 10 percent (sparse), 10 to 40 percent (moderate), 40 to 75 percent (dense), and more than 75 percent (very dense). Reachwide vegetative cover was calculated by averaging the midpoint values (0, 5, 25, 57.5, and 87.5 percent) of the classes observed while onsite. One “legacy” tree, generally the largest tree in or near the riparian zone, was chosen for each transect. Information recorded for each tree included type, the taxonomic group (if possible), estimated height, diameter at breast height, and distance from the wetted edge of the stream. Study personnel also noted the presence, if any, of eight specific invasive plant species, also referred to as target species—Canada thistle (*Cirsium arvense*), leafy spurge (*Euphorbia esula*), musk thistle (*Carduus nutans*), English ivy (*Hedera helix*), Russian olive (*Elaeagnus angustifolia*), salt cedar (*Tamarix* spp.), cheatgrass (*Bromus tectorum*), and common burdock (*Arctium minus*).

Table 3. Substrate codes, numbers, and size classes.

[mm, millimeter; <, less than; >, greater than]

Substrate	Substrate code	Substrate number	Substrate size (mm)
Fines	FN	1	<0.06
Sand	SA	2	0.06 to 2
Gravel (fine)	GF	2.5	>2 to 16
Gravel (coarse)	GC	3.5	>16 to 64
Cobble	CB	4	>64 to 250
Boulder (small)	SB	5	>250 to 4,000
Boulder (large)	XB	5	>250 to 4,000
Bedrock (rough)	RR	6	>4,000
Bedrock (smooth)	RS	6	>4,000
Concrete	RC	6	>4,000
Hardpan	HP	6	>4,000

Reach characteristics that were documented included bank stability and riparian disturbance. Bank-stability scores were calculated from bank angle, vegetative cover, bank height, and bank substrate (Fitzpatrick and others, 1998). Site scores for each category (table 4) were summed to determine the bank-stability index with a possible range of 4 to 22. Bank-stability scores that range from 4 to 7 are considered stable, 8 to 10 are at risk, 11 to 15 are unstable, and 16 to 22 are very unstable (Fitzpatrick and others, 1998). Eleven human land-use activities (wall or dam; building; pavement; road; intake or outlet pipe; trash or landfill; park or lawn; row crops; pasture, range, or hayfield; logging operations; and mining activity) were recorded at each transect along with the proximity of each to the riparian zone. Proximity weighted disturbance indices were calculated by weighting the total number of observances of each land-use activity as follows: observations in the channel or on the bank were weighted 1.5; observations within the 10- by 10-m riparian sample plot were weighted 1.0; and observations behind or adjacent to the riparian sample plot were weighted 0.667 (Kaufmann and others, 1999).

Additional survey data were collected at many of the 47 sites. In both Wyoming and Montana, at least two cross sections, one through a riffle and one through a pool, in each reach were identified with rebar when possible and surveyed using a transit or total station. In Wyoming, longitudinal profiles were conducted at many sites (table 2) profiling the streambed, water surface, bankfull stage and low terraces, if any, as described by Harrelson and others (1994). Longitudinal profiles were conducted using either surveying equipment or a high-resolution global positioning system (GPS). Collection of additional data varied between States due to study scope.

Statistical tests of the data, such as the Wilcoxon rank sum test (Helsel and Hirsch, 2002), were calculated in S-Plus, version 7.0 (Insightful Corp., 2005). The probability level (P) used to determine significance was 0.05 unless specified otherwise.

Table 4. Components of bank-stability index (from Fitzpatrick and others, 1998).

[>, greater than; ≤, less than or equal to; <, less than]

Bank characteristics (unit of measurement)	Measurement	Score
Angle (degrees)	0–30	1
	31–60	2
	>60	3
Vegetative cover (percent)	>80	1
	50–80	2
	20≤50	3
	<20	4
Height (meters)	0–1	1
	1.1–2	2
	2.1–3	3
	3.1–4	4
	>4	5
Substrate (category)	Bedrock, artificial	1
	Boulder, cobble	3
	Silt	5
	Sand	8
	Gravel/sand	10

Main-Stem Powder River Habitat Assessment

Aquatic habitat assessments were conducted by WGFD personnel during 2004–06 at eight sites on the main-stem Powder River in Wyoming (sites P1–P5, P8, P9, and P11; fig. 1). Data collected during 2004 from a miscellaneous site on the South Fork Powder River (Wyoming Game and Fish Department, 2007) also are included in this report.

Three approaches to habitat assessment were used during 2004–06 to better describe the homogenous, shifting sand habitats of the Powder River. The quantity of various habitat types, fish species presence, and relative abundance of fish inhabiting each habitat type were considered important variables to help assess potential changes in habitat availability as a result of possible changes in streamflow from CBNG activities.

The first and primary approach applied during 2004–06 was adapted from the Warm-water Stream Assessment (WSA) methodology developed by the Wyoming Cooperative Fish and Wildlife Research Unit in Laramie, Wyoming (Quist and others, 2004). The WSA provides standardized methods to describe baseline aquatic habitat conditions within specific habitat types at a local level. Two additional aquatic habitat assessment approaches were used in 2005 and 2006, in conjunction with modified WSA methods, to quantify the availability of each habitat type within study reaches. Aquatic habitat types were mapped with high-precision GPS units in 2005. A transect-based survey technique was adapted from EMAP methods and implemented in 2006 to increase efficiency, objectivity, and repeatability (Peck and others, 2003).

The primary aquatic habitat types were defined as pool, riffle, run, backwater, and shoal (table 5). One other habitat type, isolated pool, was recorded where it occurred but was not considered a primary habitat type. To encompass all available habitat types, the reach length at each site was set to 3,218 m (the typical distance of two meander lengths as estimated from aerial photographs) instead of using the reach-length criteria provided in the WSA. Sampling of the entire 3,218 m at each site was not feasible, however, because of time and personnel constraints, and therefore, the reach was divided into eight starting points, evenly spaced downstream (402 m apart) from the upstream end of each reach. One of the eight starting points was chosen at random, and sampling progressed downstream until two units of each primary habitat type (pool, riffle, run, backwater, and shoal) were sampled

(2 units times five habitat types equals ten units total per reach if all habitat types were present in the reach). If the bottom of the reach was encountered before two units of each available habitat type were sampled, sampling resumed at the upstream end of the same reach.

The length, mean width, and geographical coordinates of the approximate center of each sampled habitat unit were recorded. Runs longer than about 100 m were recorded as such rather than measured. Wetted stream width was recorded on a line bisecting each habitat unit, perpendicular to streamflow. Velocity was measured using dye or a floating object in pools, riffles, runs, and shoals.

The aerial coverage (percentage of total area) of substrate and cover types was visually estimated within about 5-percent accuracy for each habitat unit (Quist and others, 2004). The minimum size of a patch of substrate or cover required to record its presence was 0.21 square meters (m^2). A "trace" of substrate or cover was recorded where it was present but visually estimated to be less than 5 percent of the total area of a habitat type. Substrate types were roughly defined as silt, sand, gravel, cobble, boulder, or bedrock. Cover types were classified as aquatic vegetation, woody debris, undercut banks, and overhead cover according to Quist and others (2004).

Habitat types were sampled on a monthly basis from May through October in 2004 to capture seasonal variation. After sampling was completed in 2004, it was noted that major changes in aquatic habitat were affected by three major streamflow periods. In 2005, sites were sampled three times—during pre-high flows, post-high flows, and low flows. Sampling was reduced further to a single sampling at each site in 2006 during the low-flow period. The low-flow period was considered the most valuable for assessing the effects of flow augmentation from CBNG development on aquatic habitat and the fish community.

During the spring and summer of 2005, high-resolution GPS mapping was added to the modified WSA habitat sampling and was used to estimate the distribution of habitat types and total area of each habitat type throughout a range of streamflow. Working cooperatively, USGS and WGFD personnel used high-resolution GPS units to map pools, riffles, runs, shoals, backwater, isolated pools, and islands at each reach during three different flow conditions in May, July, and August. Two to three individuals mapped habitat features at each site over the course of a single day. Mapping involved walking the edge of water on both banks and the perimeter of identified habitat types within the channel and recording coordinates as needed to delineate each habitat unit. Habitat units estimated to be smaller than 10 m^2 were not mapped. Streamflow was measured at each survey reach during or immediately after completion of mapping so that relations between streamflow and relative amounts of available habitat types (table 5) could be tested. Geographic information system (GIS) programs were used to generate maps of habitat units. Additional information about surveying equipment, methods, and results is available from the Wyoming Game and Fish Department (2007).

Table 5. Habitat types used to classify aquatic habitat in the main-stem Powder River, Wyoming and Montana, 2005–06.

[≥, greater than or equal to]

Habitat type	Description
Pool	Relatively deep, slow-moving water with a predominance of fine substrate. Little to no surface disturbance. Formed by scour (mid-channel scour, scour against a streambank, scour below or adjacent to a log, boulder, or other obstruction) or beaver activity. Usually shorter than the active channel width. Pools required RPD[1] ≥ 0.31 meter.
Riffle	Relatively shallow, fast-moving water with a predominance of coarse substrate (≥25 percent gravel and cobble). Obvious surface turbulence. Gravel and cobble in the Powder River often were ≥25 percent embedded. Cross-sectional profiles were usually broad and uniform.
Run	Uniform depth and flow with little or no surface turbulence and homogenous features. Variable, but predominantly fine substrate. Often longer than the active channel width. Deeper than riffles with few flow obstructions (such as boulders and logs). Scarce structure.
Backwater	Located along a channel margin, island, or within a mid-channel bar. Predominantly fine substrate. Partially connected to the main channel, usually at just one end. Negligible flow. No surface turbulence. Scoured at high flows and remains after flows recede.
Shoal	Very shallow, flowing water, generally less than 10 centimeters deep. Predominantly sand substrate with occasional embedded gravel or cobble. Formed as flow recedes and cuts across mid-channel and stream margin deposits such as point bars.
Isolated pool	Disconnected from streamflow but within the active channel. Isolated pools are usually associated with gravel bars and may be sustained by subsurface flow during late summer. Substrate is highly variable.

[1]The residual pool depth (RPD) is the difference between the maximum pool depth and the pool tail crest (PTC). The PTC is the deepest point at the downstream margin of a pool where the pool transitions into another habitat unit—analogous to the spout on a pitcher. The RPD is similar to the distance from the bottom of a pitcher's spout to the pitcher's base.

In 2006, a transect-based approach modeled after the EMAP protocol (Peck and others, 2003) was added to the modified WSA habitat assessment. At each site, as many as 30 transects were established at even intervals throughout a reach length of about 111 m. At each transect, a GPS location was recorded, and wetted width was measured and divided by four to identify three locations for depth and habitat-type observations. The widths of shoals and islands were excluded from wetted width calculations. The widths of the dry emergent sandbars associated with shoals were included in the point-sample spacing calculations along each transect, which allowed depth measurements to occur on dry shoal areas. The widths of islands were excluded from point-sample spacing calculations to ensure no sample points were on islands. Measurements also were collected at left and right water's edge for a total of five measurement locations per transect. The predominant habitat type was noted for each point along the transect. After transect measurements were completed, the number and location of pools, riffles, and backwater in the study reach were recorded by collecting a GPS point in the center of each habitat while returning upstream through the reach.

Water Chemistry

During 2005 and 2006, onsite water-quality measurements of specific conductance, pH, water temperature, and dissolved oxygen were collected at each site using a multiprobe instrument. Turbidity measurements were made using a portable turbidity meter. Instruments were calibrated and measurements collected following procedures outlined in the USGS National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, variously dated).

Many sites chosen for ecological sampling also were part of a USGS water-chemistry monitoring network. At sites not included in the network, a grab sample was collected and processed in accordance with the USGS National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, variously dated). Water-quality samples were sent to the USGS National Water Quality Laboratory (NWQL) in Denver for analysis of major ions. Two replicate samples were collected and analyzed for major ions. Results of the major ion analyses were published in the annual data reports for Wyoming and Montana and can be retrieved from the Web at *http://pubs.usgs.gov/wdr/*. Water-quality results, including onsite measurements, also are available on the Web at *http://waterdata.usgs.gov/nwis*.

Specific conductance, water temperature, and turbidity were collected by the WGFD in conjunction with fish and habitat assessments performed at the eight main-stem Powder River sites in Wyoming. Additional surface-water temperatures were recorded sporadically during the sample collection in an attempt to approximate daily maximum water temperature. The data for specific conductance, water temperature, and turbidity collected by the WGFD are available upon request to WGFD, Casper, Wyo.

Macroinvertebrates and Algae

Two types of macroinvertebrate samples were collected in 2005–06 that followed NAWQA protocols described by Moulton and others (2002). The first was the richest-targeted habitat (RTH) sample collected at sites where riffles were present (about three-fourths of the sites). RTH samples are intended to represent the habitat with highest taxa richness. Each RTH macroinvertebrate sample was a composite of five 0.25-m^2 samples collected from multiple riffles, where available, with a Slack sampler equipped with 500-micron (µm) mesh. The second type of macroinvertebrate sample was a qualitative multihabitat (QMH) sample collected at all sites and that served as the primary sample at sites where riffles were absent. QMH samples are intended to represent the taxa that are present throughout the sample reach. Each QMH sample was a timed collection (1-hour) from all of the multiple habitats identified in the sample reach, such as woody snags, macrophytes, pool sediment, and riffles.

Macroinvertebrate samples were sent to the Buglab at Utah State University in Logan for taxonomic identification under BLM contract. A reference collection of identified macroinvertebrates is maintained at the Buglab. Identification of Chironomidae was subcontracted to Rhithron Associates, Inc. in Missoula, Mont. Replicate samples were collected at two sites and processed in the same manner as the environmental samples.

Algae samples were collected at 26 sites within Wyoming and near the Wyoming-Montana State line during the summer of 2005 following NAWQA protocols described by Moulton and others (2002; table 2). Similar to the RTH habitat for macroinvertebrates, riffles were designated as RTH habitat for algae and were sampled where present (20 sites). The algae sample from riffles was a composite sample of 25 collections of periphyton scraped from rocks using an SG–92 sampler (cylinder with brush) to delineate a known area. At six of the sampling sites, no riffles were present, and therefore, the algae sample at those sites was collected from depositional-targeted habitat (DTH) in the euphotic zone of pools (Moulton and others, 2002).

Algae samples were homogenized at each site, and aliquots were withdrawn for taxonomic identification and enumeration. At sites with riffles, aliquots also were withdrawn for analysis of chlorophyll-*a* and ash-free dry mass (AFDM). Algal taxonomy samples were sent to Ecoanalysts, Inc., Moscow, Idaho, for identification and enumeration under BLM contract. Chlorophyll-*a* and AFDM samples were preserved on dry ice and sent to the USGS NWQL for analysis. Algae DTH samples from pools were not analyzed for either chlorophyll-*a* or AFDM. Replicate samples of algae were collected at three sites for quality-assurance purposes and analyzed following the same procedures as the environmental samples.

Macroinvertebrate and algal community data were analyzed in PRIMER (Clarke and Gorley, 2006). Macroinvertebrate abundance data were log transformed to approximate normality. Algal abundance data were transformed to relative abundance for analysis of diatoms and soft algae, and to presence/absence data for analysis of combined diatoms and soft algae in each sample, due to lack of density or biovolume data for the algae samples. Bray-Curtis similarity coefficients (Bray and Curtis, 1957) were computed to determine (dis-)similarity among samples. The similarity data then were used in nonmetric multidimensional scaling (NMDS) ordinations to determine relations among sites. Macroinvertebrate and algal metrics were calculated using procedures and attributes described by Cuffney (2003) and Porter (2008).

Macroinvertebrate and algal community data also were tested for relations with environmental variables, including geographic, habitat, and water-quality variables. Geographic variables selected for testing with the biological communities were location (northing and easting), drainage area, elevation, and proximity-weighted human riparian disturbance. The geographic variables used in the PCA overlap with variables used in the Wyoming and Montana observed/expected (O/E) models, such as location (latitude and longitude), elevation, and drainage area (Hargett and others, 2007).

Because the number of habitat and water-quality variables was too large to assess directly against the biological data, the habitat and water-quality data sets were each assessed separately through principal components analysis (PCA; Clarke and Gorley, 2006). Prior to running the PCA, the environmental data were transformed as needed and standardized. Habitat variables were selected from the EMAP reachwide measurements and from microhabitat variables that were measured at the point of the macroinvertebrate sample collections. Variables were tested for collinearity, and those that were highly correlated with the selected variables were removed from the analysis. Streamflow and water-quality variables were analyzed in a manner similar to habitat variables. Water-quality variables included onsite measurements of specific conductance, pH, water temperature, turbidity, and dissolved oxygen that were collected with the biological samples and major ion data. At sites where water samples were collected for analysis of major ions as part of this study, those major ion data were used. At other sites that are part of the USGS monitoring network (about one-half of the ATG sites), the major ion data collected for the network were retrieved from the USGS's National Water Information System (NWIS). The major ion data selected from NWIS generally were from the sample collected most recently in time (within 30 days) before collection of the biological sample. Alkalinity was automatically selected as a variable of interest because of potential toxicity of bicarbonate (Skaar and others, 2006) and use of alkalinity in the Wyoming O/E model (Hargett and others, 2007).

The final set of environmental variables was analyzed using PCA to determine relations among the variables and sites and then tested for correlation with the macroinvertebrate communities using the BEST routine in PRIMER (Clarke and Gorley, 2006). The BEST routine tests multiple iterations of various combinations of the environmental variables to determine which combination of environmental variables is best correlated with the biological data as indicated by maximum values of Spearman's rho (ρ).

The O/E models and multimetric indices (MMIs) developed by the State of Wyoming (Hargett and others, 2005, 2007) and the State of Montana (Montana Department of Environmental Quality, 2006) also were used to evaluate the macroinvertebrate data. Similar to other multivariate predictive models such as RIVPACS (Moss and others, 1987; Wright and others, 1993; Clarke and others, 2003) and its derivatives, the Wyoming and Montana O/E models are statewide macroinvertebrate-based predictive models that provide an assessment of biological condition by comparing the macroinvertebrate taxa observed at a site of unknown biological condition to the indigenous macroinvertebrate taxa expected to occur in the absence of human stress. Predictor variables, such as site latitude and longitude, substrate type, precipitation, air temperature, drainage area, elevation, and geology were used to construct the models. The expected macroinvertebrate taxa were derived from an appropriate set of reference sites that were minimally or least affected by human stress. The deviation of the observed from the expected taxa, known as the O/E score, is a measure of the compositional similarity expressed in units of taxa richness, and thus, is a community-level measure of biological condition. O/E scores near 1 indicate a favorable biological condition similar to expected conditions, whereas O/E scores less than 1 indicate some degree of biological degradation as a result of the absence of expected taxa.

The MMIs developed by the States of Wyoming and Montana are similar in design to other MMIs such as the Index of Biotic Integrity (IBI; Kerans and Karr, 1994) in that both are regionally calibrated macroinvertebrate-based indices designed to evaluate the biological condition of wadeable perennial streams in Wyoming and Montana (Hargett and Zumberge, 2006; Montana Department of Environmental Quality, 2006). The Wyoming Stream Integrity Index (WSII) is an aggregation of seven individual indices developed for seven bioregions delineated within Wyoming. Similarly, three individual MMIs were developed for three bioregions in the State of Montana. The MMIs developed by Wyoming and Montana for their respective "Plains" bioregions were used in the evaluation of macroinvertebrate data collected at ATG sampling sites. Core macroinvertebrate metrics (for example, composition, structure, tolerance, and functional guilds) with moderate to high discrimination efficiencies (degree of separation between metric values of reference and degraded sites) within and across bioregions, a relatively consistent mode of response to human disturbance across bioregions, and no redundancy with other metrics were incorporated into the WSII and MMI.

Biological condition as summarized by the Wyoming Plains WSII is calculated from seven metrics—Ephemeroptera richness, Trichoptera richness, total taxa, percentage of Trichoptera individuals (less Hydropsychidae) within the community, percentage of Ephemeroptera individuals (less Baetidae) within the community, percentage of collector-gatherer individuals, and the Hilsenhoff Biotic Index (Hilsenhoff, 1987). Most members of the families Baetidae and Hydropsychidae are considered tolerant to environmental stressors. Similarly, seven metrics compose the Montana MMI—Ephemeroptera, Trichoptera, and Plecoptera richness; percentage of Tanypodinae individuals within the community; percentage of Orthocladiinae individuals of the total Chironomid population within the community; predator taxa richness; and the percentage of collector/filterers.

The majority of metrics from both indices (WSII and MMI) are expected to decline with increasing perturbation. The exceptions that are expected to increase with increasing perturbation are percentage of collector-gatherers, Hilsenhoff Biotic Index (Hilsenhoff, 1987), percentage of Orthocladiinae of the total Chironomid population within the community, and percentage of collector/filterers. The final index score for both the Wyoming and Montana MMI models is a mean of the individual metric scores where final scores decline with increased perturbation.

Fish Communities

The methods used to collect fish samples varied depending on the site. EMAP methods (Peck and others, 2003) were used at all sites except on the main stem of the Powder River where modified WSA methods (Quist and others, 2004) were used.

Fish community data from all of the sites were assessed using an IBI developed for small plains streams in Montana (Bramblett and others, 2005). The IBI contains 10 metrics that measure various aspects of community structure—species richness and composition, trophic composition, reproductive guilds, and fish abundance and condition. The IBI score assigned to a fish sample can range from 0 (worst) to 100 (best) as determined by summing the scores from each of the 10 individual metrics with scores that can range from 0 to 10. As outlined by Bramblett and others (2005), creek chubs were included with invertivorous cyprinids, and the IBI score was manually set to 10 for any sample with less than 10 fish because the sample might not accurately reflect environmental conditions. Although the IBI was not intended for use in rivers with a drainage area as large as that of the Tongue River or Powder River, the IBI can be used to compare fish community structure among sites and between years within the main-stem Tongue River or Powder River (Bob Bramblett, Montana State University, written commun., May 27, 2008). The IBI scores from the Tongue and Powder Rivers should not, however, be compared to the smaller plains streams for which the IBI was designed.

Basinwide Fish Community Assessment

Near the time of macroinvertebrate and algal sampling, fish communities at 35 sites (excluding those on the main-stem Powder River) were sampled by USGS once per year following EMAP techniques described by Peck and others (2003). Seining was the primary fish-collection method, although electrofishing from a boat or barge was used at sites on the main stem of the Tongue River and some of the larger tributaries. The reach length for fish sampling was defined as 40 times the mean wetted channel width, with a minimum reach length set at 200 m and maximum at 1,000 m. Multiple seine hauls were completed within each reach to determine relative abundance of fish species.

Voucher specimens of fish, particularly Cyprinidae (minnows), were collected as per the fish taxonomy quality-assurance plan (Walsh and Meador, 1998) and sent to Dr. Robert Bramblett at Montana State University in Bozeman for taxonomic confirmation. The Museum of Southwestern Biology at the University of New Mexico in Albuquerque was selected as the long-term repository for the fish-voucher specimens.

Main-Stem Powder River Fish Community Assessment

Fish community samples from 12 sites on the main-stem Powder River were collected following modified WSA protocols. WGFD collected the samples at eight main-stem Powder River sites and one miscellaneous site on the South Fork Powder River in Wyoming, and USGS collected the samples at four main-stem Powder River sites in Montana. Fish sampling at the sites in Wyoming generally occurred on the same schedule as the modified WSA aquatic habitat surveys—six times in sampling conducted by the WGFD in 2004 (Wyoming Game and Fish Department, 2007) and three times in 2005 and once in 2006 for the study described in this report. Exceptions to the general pattern of sampling in Wyoming were that the South Fork of the Powder River was sampled only in 2004 and the site below Burger Draw was sampled in 2005–06 but not in 2004. Fish sampling at the four main-stem Powder River sites in Montana occurred at site P12, twice in 2005 and once in 2006; sites P13 and P17, once each in 2005 and in 2006; and site P18, once in 2005.

The WSA fish sampling methodology documents basic presence and absence information for fish species and was designed as a framework for comparing current fish assemblages with expected unaltered native communities and for interpreting fish community changes (Quist and others, 2004). The seining methods used in this study, however, are best suited to small-bodied fish. Large-bodied fish known to be present in the main-stem Powder River, such as adult sauger

(*Sander canadense),* shovelnose sturgeon (*Scaphirhynchus platorynchus),* and others, were not targeted by seining, and therefore, their abundance in samples might not be reflective of their true relative abundance in the river. The distribution of large-bodied fishes in the main-stem Powder River was addressed separately (Wyoming Game and Fish Department, 2007). Each habitat unit sampled was seined repeatedly until no new species were captured (minimum of two seine hauls).

Data from individual seine hauls were recorded separately. All fish were identified using characteristics determined onsite from dichotomous keys (Brown, 1971; Baxter and Stone, 1995; Pflieger, 1997) and enumerated by species or group. The smallest and largest individuals of each species or group sampled from each habitat unit were measured for total length. Fish vouchers were retained for identification or confirmation from sites in Wyoming and Montana, although the sampling process differed slightly between the States in part because the 6.4-mm mesh-opening size of the seines used by USGS at Montana sites was larger than the 4.8-mm mesh-opening size of the seines used by WGFD at Wyoming sites. At Wyoming sites, groups of juvenile fish (age-0) too small for field identification and groups of the genus *Hybognathus* were retained for laboratory identification. All age-0 fish and subsamples of *Hybognathus* spp. (number of samples (n) ≤20) collected in Wyoming were retained and identified at the Larval Fish Laboratory at Colorado State University, Fort Collins, Colo. Voucher specimens of each species present at Wyoming sites were curated by the Museum of Southwestern Biology in Albuquerque. At the Montana sites, voucher specimens of each species, including *Hybognathus* spp., also were retained, but the vouchers were sent to Montana State University in Bozeman for species verification. Larval fish were treated as part of regular samples at Montana sites. All fish that were retained were fixed in a 10-percent formalin solution.

Rarefaction curves were developed for all sites on the main-stem Powder River to allow consistent and standardized methods for comparison of species richness among sites despite varied sampling effort (Kwak and Peterson, 2007). Effort was roughly equal among surveys, but the number of surveys varied among some sites because of the addition or deletion of sites during study years and minor sample scheduling irregularities within the cumulative data set. For example, site P4 was not sampled in 2004, and site P5 was sampled an additional time in 2004. Therefore, the rarefaction technique was used to evaluate expected species richness among sites using all data, standardized to equal effort. Rarefaction extrapolates species richness from a given sample to lesser sample sizes on the basis of species composition within a given sample.

The overall slope of a rarefaction curve relates a general trend among data for a site that indicates the “thoroughness” of sampling species diversity (Kwak and Peterson, 2007). Steep rarefaction curves indicate relatively high species diversity and (or) that the sampling effort was inadequate to accurately reflect species richness. Flat rarefaction curves indicate relatively low species diversity and (or) that the species assemblage was sampled thoroughly with the effort expended. The results of applying the rarefaction technique also provide a visual representation of sampling efficiency as it relates to identifying species richness at all sites. These data are useful for determining the sampling effort required for adequate monitoring and future research.

Data distributions were tested for normality, using the Shapiro-Wilk normality test (Helsel and Hirsch, 2002), before performing analysis of variance (ANOVA). The equality of the variances in the ANOVA was tested using Bartlett’s test. The analyses were performed in Statistix, version 7 (*http://www.statistix.com/*) at $P < 0.05$ to indicate significance.

Ancillary Investigations

For comparative purposes, emphasis was placed on ancillary samples collected from ATG sites under low-flow, summer conditions using collection and analysis methods as similar as possible to those used for the ATG investigation. Ancillary data were available from three programs—NAWQA, the USGS Wyoming Water Science Center (WWSC) monitoring network (network), and a 1980–81 WWSC project investigation (project; table 6).

Macroinvertebrate and algae samples from the NAWQA Program for 1999-2007 and the WWSC monitoring network for 2002 generally were collected following the same NAWQA protocols used for collection of the ATG samples. The 1999 NAWQA chlorophyll-*a* data were omitted from this report because the laboratory analytical method was different than that used for the remainder of the samples. The ancillary data from the WWSC monitoring network are available from the USGS ATG project Web site (*http://wy.water.usgs.gov/*).

Macroinvertebrate samples from the 1980–81 investigative project were collected with a Surber sampler following methods described by Peterson (1990). The 1980–81 periphyton samples were collected by scraping algae from areas of hard surfaces present in the reach, such as rocks and logs. Ancillary data from the 1980–81 project used in this report, as well as other algae and macroinvertebrate data collected for the 1980–81 project from other sites in the PRB, are available from the ATG project Web site (*http://wy.water.usgs.gov/*).

Table 6. Sampling sites with ancillary data for macroinvertebrates and algae, Powder River Structural Basin, Wyoming and Montana.

[Network, Wyoming Water Science Center monitoring network; Project, Wyoming Water Science Center project; NAWQA, National Water-Quality Assessment Program]

Site number (fig. 1)	Abbreviated stream name	Sampling program	Dates of ancillary data
T9	Tongue River at State line	Network	2002
P10	Clear Creek	Network	2002
P14	Little Powder River at Highway 59	Project	1980–81
P15	Little Powder River above Dry Creek	Project and NAWQA	1980–81, 1999–2007
P18	Powder River near Locate	NAWQA	1999
C3	Cheyenne River near Dull Center	Project	1980–81
[1]C6	Cheyenne River at Riverview	Network	2002
B1	Belle Fourche River	Project	1980–81

[1]Ancillary data site is located at U.S. Geological Survey gaging station 06386400 (*http://waterdata.usgs.gov/nwis*), several kilometers upstream from site C6.

Ecological Assessment

The ecological assessment consists of four main parts: habitat, macroinvertebrates, algae, and fish communities. The "Implications" section that follows the ecological assessment includes comparison among selected biological communities.

Habitat Assessment

Results of habitat measurements collected at all 47 sampling sites in the PRB and including the main-stem Powder River followed the EMAP protocol or a modified version of it and are described in the section "Habitat Characteristics of Streams in the Powder River Structural Basin." Results of habitat measurements collected at eight sites on the main-stem Powder River followed a modified WSA protocol and are presented in the section "Habitat Characteristics of the Main-Stem Powder River in Wyoming."

Habitat Characteristics of Streams in the Powder River Structural Basin

Reach-scale habitat measurements collected at all 47 sampling sites in the PRB are described in this section, but the reader should be aware that methods used at the 12 sites along the main-stem Powder River varied slightly from methods used at the other 35 sites and could affect results for these 12 sites.

Channel Characteristics

The geometry of a stream channel is a function of streamflow (quantity and frequency), streambed and bank materials and composition (vegetative cover), and the character of the sediment transported through the stream section (Leopold and others, 1992). Any changes of these variables can cause modifications to the channel characteristics.

Mean wetted widths in the study area (table 7) ranged from 0.90 m at Squirrel Creek at mouth (site T7) to 52.4 m at Powder River below Little Powder River (site P17). Mean wetted widths on the Cheyenne and Belle Fourche Rivers and including all of the tributaries were less than 10 m except at the two largest tributaries, Goose Creek (site T2, 16.4 m) and Clear Creek (site P10, 19.7 m). Mean wetted width generally increased in the downstream direction along the Tongue and Powder Rivers. The Tongue River had an increase of about 6 m between sites T1 (Tongue River at Monarch, mean wetted width = 19.0 m) and T18 (Tongue River below Brandenberg Bridge, mean wetted width = 25.4 m), and the Powder River had the greatest increase in mean wetted width of about 37 m between sites P1 (Powder River above Salt Creek, mean wetted width = 14.1 m) and P18 (Powder River near Locate, mean wetted width = 51.1 m).

Mean water depths ranged from a minimum of 2.3 centimeter (cm) at Caballo Creek (site B2) to a maximum of 55 cm at Prairie Dog Creek (site T8). Caballo Creek had no flow during sampling, and the reach only had two shallow pools making up less than 50 percent of its length. Prairie Dog Creek had the maximum mean water depth because of nearly vertical bank angles along almost the entire reach in contrast to other sites with sloping banks and water depths of zero at the ends of the transects.

Mean thalweg depths were deepest on the main-stem Tongue River with a mean of 88 cm for depths from six sites. Although several tributary stream sites have shallow mean thalweg depths, the mean thalweg depth for tributary streams was 39 cm, which is 3 cm deeper than the mean thalweg depth of 36 cm on the Powder River. Although all the stream reaches included in this study were considered wadeable, some pools

Table 7. Summary of channel characteristics measured at sampling sites in the Powder River Structural Basin, Wyoming and Montana, 2005.

[m, meter; cm, centimeter; m/km, meters/kilometers; NC, measurements not collected; NA, measurement not available due to missing data; NA1, measurements not collected properly]

Site number (fig. 1)	Mean wetted width (m)	Mean water depth (cm)	Mean thalweg depth (cm)	Maximum measured depth (cm)	Mean bank angle (degrees)	Median bank angle (degrees)	Mean bankfull height above thalweg (m)	Mean bankfull height above water surface (m)	Mean bankfull width (m)	Width-to-depth ratio	Mean incised height above thalweg (m)	Mean incised height (m)	Mid-stream canopy density (percent)	Bank canopy density (percent)	Reach gradient (m/km)
Main-stem Tongue River															
T1	19.0	35	63	177	47	16	0.98	0.35	22.3	22.9	1.58	0.95	17	81	2.50
T5	30.0	35	88	142	30	23	1.42	.54	37.1	26.2	3.04	2.16	.3	8.6	7.51
T9	34.3	35	77	173	30	25	1.36	.59	36.8	27.0	2.12	1.35	.4	59	.73
T10	29.2	39	101	205	35	23	1.64	.64	33.1	20.1	2.34	1.34	.0	7.5	1.44
T14	26.7	37	[1]86	200	46	39	1.56	.70	27.1	17.4	2.87	2.01	3.7	78	1.03
T18	25.4	44	112	210	48	33	1.92	.80	33.2	17.3	3.08	1.95	7.1	63	1.08
Main-stem Powder River															
P1	14.1	7.5	22	91	11	7	1.35	1.13	34.7	25.7	1.77	1.55	0.4	5.2	0.93
P2	15.0	7.5	23	53	11	7	1.49	1.26	42.7	28.6	1.93	1.70	.6	5.7	[2]1.1
P3	26.6	4.3	20	43	19	14	1.38	1.17	42.4	30.8	1.78	1.58	.5	2.7	.30
P4	21.9	6.5	26	53	7	4	1.03	.77	46.2	45.0	1.61	1.35	.4	3.6	1.36
P5	37.7	8.7	32	60	22	10	1.25	.93	40.1	32.2	2.97	2.65	.7	2.9	.33
P8	41.4	17	29	84	34	24	1.13	.84	51.9	45.7	1.59	1.30	.0	3.9	[2].90
P9	29.4	20	41	80	26	27	.92	.51	41.7	45.2	1.38	.97	.4	7.0	[2]1.0
P11	37.5	28	49	200	27	22	1.54	1.05	50.8	33.1	2.24	1.75	.1	5.0	[2]1.0
P12	47.0	18	37	130	11	8	.94	.58	61.4	65.0	1.41	1.04	1.7	37	[2]1.3
P13	30.8	23	60	152	22	15	1.69	1.09	52.4	31.0	2.50	1.90	.0	3.7	[2]1.0
P17	52.4	9.0	50	125	31	33	1.76	1.26	74.5	42.2	2.30	1.80	.0	.3	[2]0.9
P18	51.1	14	40	79	13	11	1.53	1.14	75.7	49.3	2.22	1.83	.0	.2	[2]1.0
Cheyenne and Belle Fourche Rivers, Rosebud Creek, and all tributary streams															
R1	4.40	28	66	113	39	41	1.03	0.37	5.50	5.35	1.90	1.25	56	90	0.40
R2	4.97	13	26	59	32	21	.59	.34	7.23	12.2	1.07	.82	34	78	.87
T2	16.4	28	62	129	37	31	1.27	.65	20.4	16.0	1.72	1.10	5.8	76	7.51
T3	2.20	15	31	50	40	33	.74	.43	4.35	5.89	1.28	.96	14	15	8.45
T4	1.85	19	31	45	22	23	.95	.64	5.94	6.23	1.85	1.54	5.1	6.2	4.81
T6	1.64	14	27	51	20	15	.57	.31	4.12	7.17	.90	.64	3.5	1.6	2.42

Table 7. Summary of channel characteristics measured at sampling sites in the Powder River Structural Basin, Wyoming and Montana, 2005.—Continued

[m, meter; cm, centimeter; m/km, meters/kilometers; NC, measurements not collected; NA, measurement not available due to missing data; NA1, measurements not collected properly]

Site number (fig. 1)	Mean wetted width (m)	Mean water depth (cm)	Mean thalweg depth (cm)	Maximum measured depth (cm)	Mean bank angle (degrees)	Median bank angle (degrees)	Mean bankfull height above thalweg (m)	Mean bankfull height above water surface (m)	Mean bankfull width (m)	Width-to-depth ratio	Mean incised height above thalweg (m)	Mean incised height (m)	Mid-stream canopy density (percent)	Bank canopy density (percent)	Reach gradient (m/km)
Cheyenne and Belle Fourche Rivers, Rosebud Creek, and all tributary streams—Continued															
T7	0.90	11	18	40	63	61	0.48	0.30	2.82	5.86	0.86	0.68	1.1	4.3	7.21
T8	4.34	55	78	117	97	84	1.19	.41	5.03	4.22	1.57	.79	9.1	99	1.91
T11	3.39	17	31	55	65	68	.71	.40	5.97	8.42	.96	.65	23	55	5.15
T12	2.67	17	24	78	47	34	.64	.40	5.37	8.39	1.61	1.37	1.4	6.8	6.15
T13	5.63	19	32	72	70	70	.72	.40	7.15	9.96	1.52	1.20	11	55	1.85
T15	3.37	12	[1]25	45	24	20	.66	.41	6.94	10.5	[3].66	NA1	8.6	13	1.11
T16	5.45	14	[1]34	55	32	32	.71	.36	8.70	12.2	[3].71	NA1	14	15	1.75
T17	5.55	28	58	56	70	90	.62	.05	5.98	9.58	[3].62	NA1	3.1	43	.40
T19	6.19	10	25	93	29	21	.65	.40	11.2	17.3	.82	.57	5.0	18	3.00
C1	4.36	12	22	64	44	38	.82	.60	11.3	13.9	1.17	.95	.1	1.1	4.51
C2	7.53	21	30	75	50	64	.66	.36	16.2	24.5	.66	.36	2.9	5.9	[4]2.1
C3	9.97	14	NC	58	50	43	NA	.72	18.9	NA	NA	1.21	1.5	5.0	[4]1.44
C4	3.40	17	52	101	42	24	1.20	.68	12.0	9.99	1.20	.68	.1	1.5	6.82
C5	3.44	13	NC	50	53	43	NA	.83	3.92	NA	NA	2.60	3.8	8.3	[4]1.18
C6	7.37	11	NC	59	23	18	NA	.39	11.7	NA	NA	.61	.4	1.8	[4]1.37
B1	5.95	14	5.9	64	39	34	.47	.41	11.9	25.5	1.04	.98	.2	3.7	1.42
B2	8.33	2.3	1.1	19	16	8	.63	.62	17.6	28.0	1.49	1.48	4.0	7.2	.83
P6	8.57	13	68	153	75	81	1.72	1.05	12.0	6.97	2.58	1.90	2.4	8.0	1.25
P7	9.01	31	58	110	41	40	1.48	.90	12.2	8.22	2.06	1.47	.2	5.8	3.74
P10	19.7	25	63	155	34	25	1.24	.61	24.6	19.8	2.34	1.71	3.5	53	1.44
P14	2.55	21	31	55	61	68	.82	.51	5.36	6.58	2.19	1.88	5.0	8.1	3.08
P15	6.01	32	52	98	61	60	1.37	.85	9.08	6.64	1.89	1.37	.6	9.4	1.26
P16	5.35	41	61	101	67	90	1.58	.97	7.48	4.74	.87	.26	.8	7.0	.35

[1]Indicates this number was calculated with an incomplete data set because of nonwadeable pools.

[2]Estimate from U.S. Geological Survey 1:24,000-scale topographic maps.

[3]Used the bankfull height, which is the minimum this measurement can be.

[4]Measurements collected by Wyoming Department of Environmental Quality.

were not wadeable, and measurements were not collected. The mean thalweg depths associated with these nonwadeable pools are noted in table 7 and are biased low.

The slope or angle of a streambank is important when determining the ability of a bank to resist erosion. Generally, the steeper the angle of the bank, the more prone it is to erosion and even failure. However, many other variables such as bank-material composition, stratigraphy, bank vegetation, and root density contribute to streambank stability (Rosgen, 1996). Mean bank angles (table 7) ranged from 7 degrees for the Powder River below Burger Draw (site P4) to 97 degrees for Prairie Dog Creek (site T8). Sites on the main-stem Powder River (sites P1-P5, P8, P9, P11-P13, P17, and P18) generally had the shallowest bank angles, whereas tributaries to the Powder River (sites P6, P7, P10, and P14-P16) had the steepest angles (fig. 5). Although the ranges of bank angles varied, the sites on the main-stem Tongue River (sites T1, T5, T9, T10, T14, and T18), Tongue River tributaries (sites T2-T4, T6-8, T11-T13, T15-T17, and T19) and Rosebud Creek and the Cheyenne and Belle Fourche River drainages (sites R1, R2, C1-C6, B1, and B2) all had median bank angles (fig. 5) of approximately 40 degrees.

Mean bankfull height above thalweg ranged from about 0.5 m at several of the tributary sites (table 7) to about 1.92 m at Tongue River below Brandenberg Bridge (site T18). The tributaries to the Tongue River and the category including Rosebud Creek and the Cheyenne and Belle Fourche Rivers had the lowest median bankfull height (near 0.7 m; fig. 5), whereas the Tongue River, Powder River, and Powder River tributaries all had median bankfull heights almost twice as high, near 1.4 m.

Mean bankfull widths (table 7) ranged from 2.82 m at Squirrel Creek at mouth (site T7) to 75.7 m at Powder River near Locate (site P18). Mean bankfull widths at tributary sites were less than 20 m except at Goose Creek (site T2) and Clear Creek (site P10), which had mean bankfull widths of 20.4 and 24.6 m, respectively. The main-stem Powder River had the greatest variability in bankfull width (fig. 5), ranging from 34.7 m at Powder River above Salt Creek (site P1) to 75.7 m at Powder River near Locate (site P18).

The geometry of stream channels can be described using a ratio of mean width to mean depth (W/D) as related to the channel cross section at bankfull stage (Rosgen, 1996). The W/D ratio varies with channel slope, streamflow, channel roughness, erosion resistance of bed and bank material, and degree of entrenchment. Channel geometry is directly affected by changes in streamflow and sediment regimes. Thus, the W/D ratio can be symptomatic of both natural and human-induced changes to the stream's flow and sediment regimes but cannot by itself be used as an indicator of specific stressors. Using reach means for bankfull height above thalweg and bankfull width, W/D ratios ranged from 4.22 at Prairie Dog Creek (site T8) to 65.0 at Powder River at Moorhead (site P12; table 7). W/D ratios generally were lowest at tributary sites and highest on the main-stem Powder River (fig. 6). The main-stem Powder River had large variability in W/D ratios, often having ratio differences of 10 or more between sites (table 7). Variations in the W/D ratio can indicate differences in streamflow and (or) sediment load among stream reaches (Chorley, 1984).

Stream incision, or the vertical distance between the thalweg and the level of the first terrace above the active flood plain, can be a fairly sensitive indicator of changes within a drainage because stream channels naturally incise (downcut) and aggrade (raise streambed by sediment deposition) as weather patterns change and variations occur in annual flows and sediment loads (Peck and others, 2003). The balance that stream systems naturally achieve can be altered by external factors such as human activities that increase or decrease the "natural" sediment supply or the stream's ability to transport sediment (Chorley and others, 1984). Although channel stability may not be evident at the time of sampling, monitoring the incision over time will provide an indication of whether a stream reach is eroding or aggrading. Stream incision heights above thalweg (table 7) ranged from a mean of 0.66 m at Antelope Creek (site C2) to about 3 m at Tongue River below Youngs Creek (site T5) and Tongue River below Brandenberg Bridge (site T18). The main-stem Tongue River (fig. 5) had the highest median incision height (about 2.5 m), whereas Tongue River tributaries had the lowest median incision height (about 1.0 m). Powder River tributaries had a median incised height of about 2.1 m, which is about 0.2 m higher than the median incised height on the main-stem Powder River.

Geomorphic units (riffles, runs, pools) were recorded at 27 sampling sites during habitat data collection and are presented in figure 7 as a percentage of reach. Of the 27 sites where geomorphic units were measured, four sites or 15 percent did not have a riffle present within the reach, two sites did not have a run, and two sites had no pools.

The main-stem Powder River generally had the least total fish cover, whereas fish cover was variable among the tributary streams (table 8). Total fish-cover percentages at sites on the main-stem Powder River ranged from 1.0 percent for the Powder River below Crazy Woman Creek (site P8) to 20.1 percent above Pumpkin Creek (site P3). Among other streams in the study area, the largest percentages of fish cover occurred in Rosebud Creek (sites R1 and R2), two of the three sites on Otter Creek (sites T15 and T16), and the Little Powder River at Highway 59 (site P14). The Little Powder River drainage had the greatest variability in total fish cover with a maximum of 122 percent cover at Little Powder River at Highway 59 (site P14), decreasing to 18 percent at Little Powder River above Dry Creek (site P15) and 10 percent at Biddle (site P16).

Aquatic macrophytes, brushy debris, overhanging vegetation, undercut banks, and boulders were the most common fish cover identified (fig. 8). Manmade structures were the least common fish cover (fig. 8) and were noted at only seven sites, four of which were on the main-stem Tongue River. Filamentous algae were identified at many sites on the Tongue River and its tributaries but were rarely noted at sites in other drainages. Filamentous algae need a stable substrate and flow to

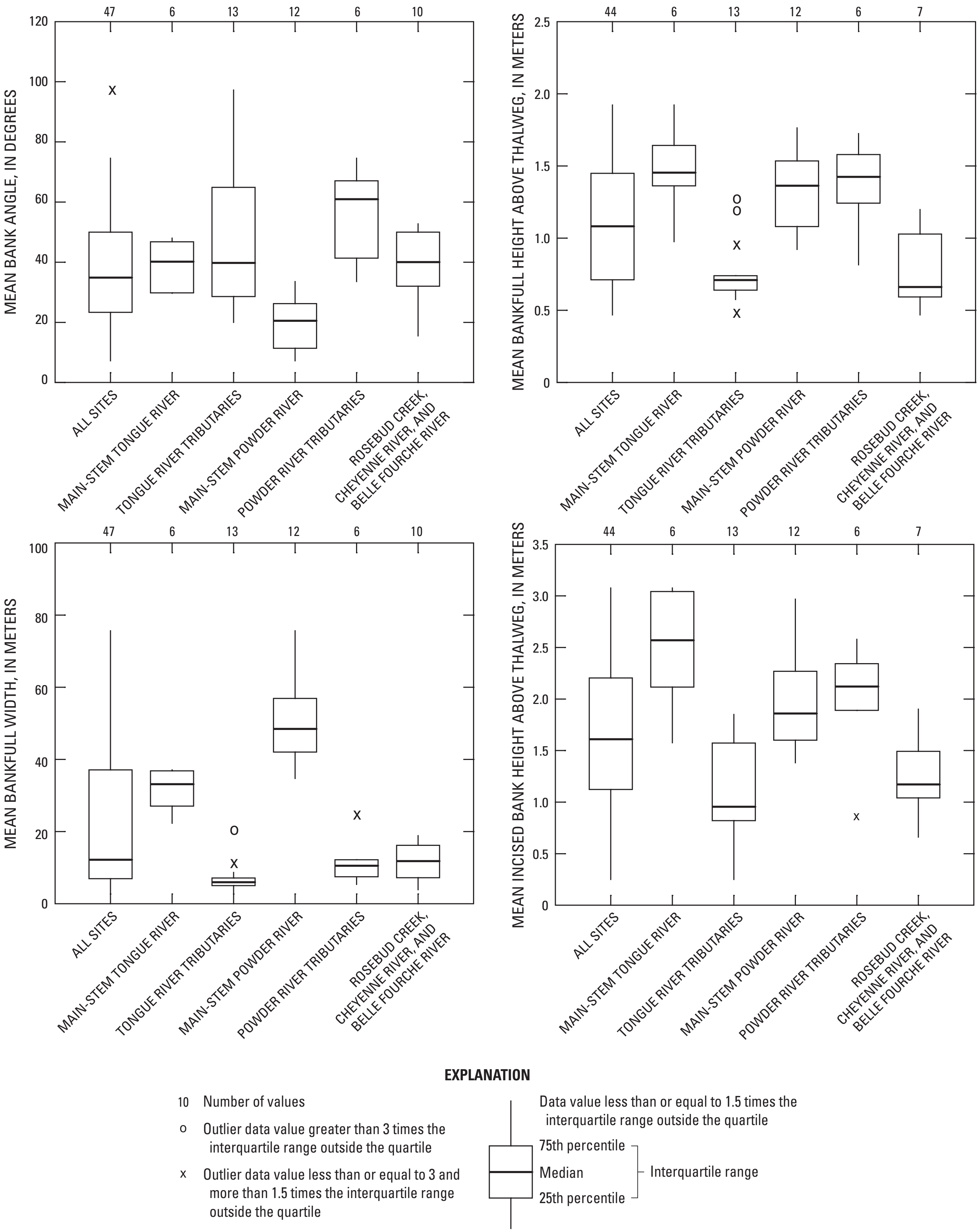

Figure 5. Streambank angle, bankfull height, bankfull width, and incised height by stream drainage, Powder River Structural Basin, 2005.

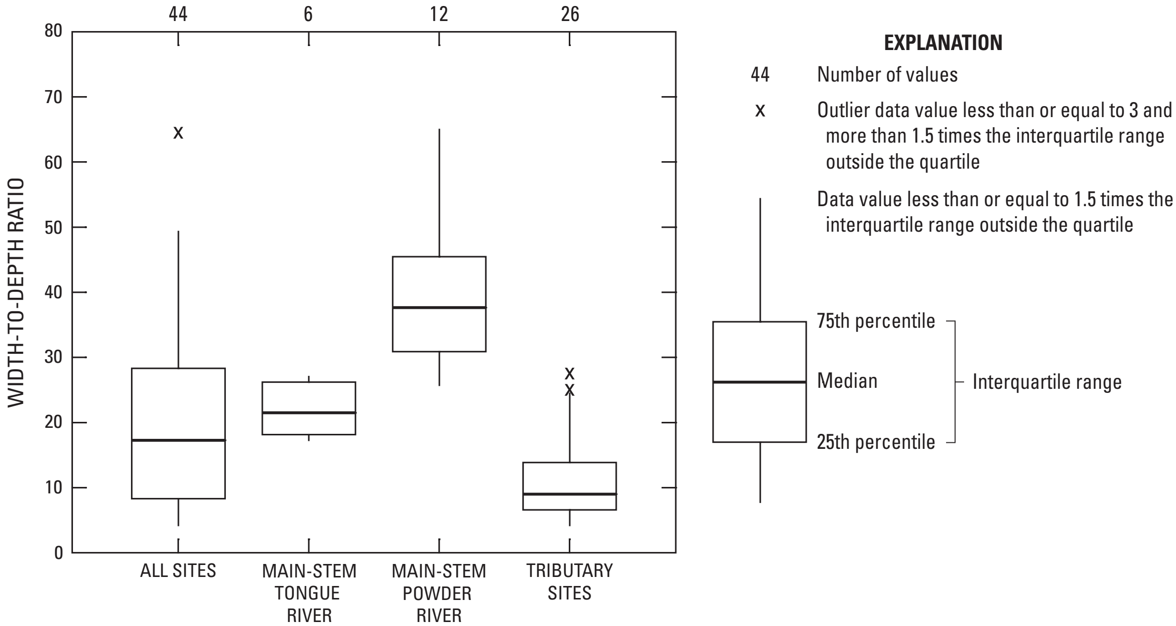

Figure 6. Width-to-depth ratios by stream drainage, Powder River Structural Basin, 2005.

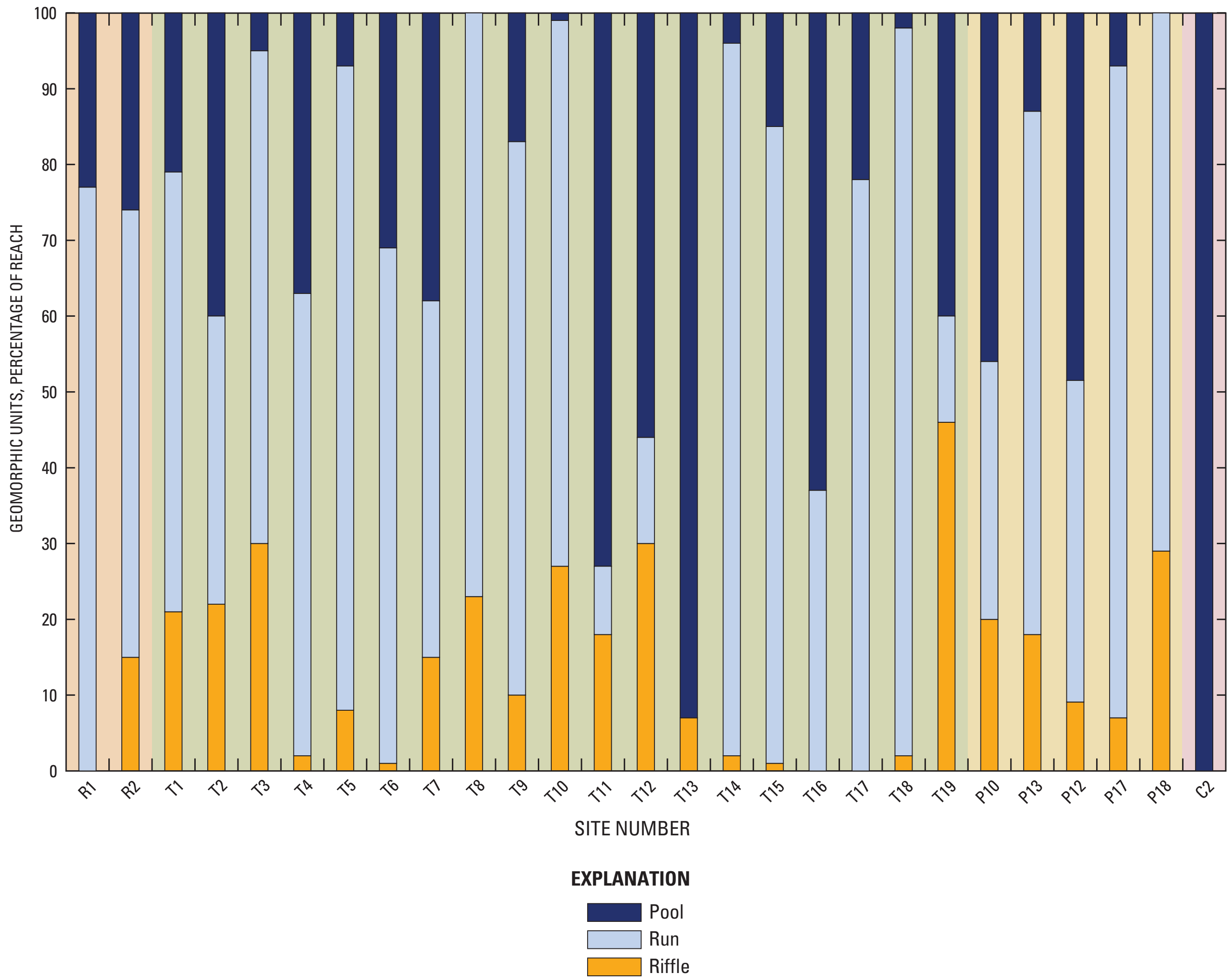

Figure 7. Geomorphic channel units as a percentage of reach at 27 sampling sites, Powder River Structural Basin, 2005.

Table 8. Fish cover identified during habitat sampling, Powder River Structural Basin, Wyoming and Montana, 2005.

[Total fish cover may exceed 100 percent due to use of range categories during sampling]

Site number (fig. 1)	Fish cover, in percent									
	Filamentous algae	Aquatic macrophytes	Woody debris	Brushy debris	Live trees or roots	Overhanging vegetation	Under-cut banks	Boulders	Man-made structures	Total fish cover
Main-stem Tongue River										
T1	0	21.0	4.6	5.8	5.4	7.9	6.3	8.8	5.6	65.4
T5	5.0	5.0	.5	1.4	1.8	3.6	0	0	0	17.3
T9	0	25.0	2.3	0	0	4.5	1.8	8.6	2.7	44.9
T10	13.2	13.6	.0	0	0	4.1	.5	5.0	.9	37.3
T14	2.7	5.0	3.0	3.7	4.3	11.7	2.7	0	0	33.1
T18	5.0	6.8	4.1	5.0	8.6	20.2	3.2	0	.5	53.4
Main-stem Powder River										
P1	0	0.5	0	1.0	1.0	1.0	0.5	9.3	0	13.3
P2	0	0	1.0	8.5	0	2.5	0	0	0	12.0
P3	0	0	8.4	8.9	0	2.3	0	.5	0	20.1
P4	0	8.0	0	.5	0	0	0	.5	0	9.0
P5	0	.5	.5	0	0	.5	.5	0	.5	2.5
P8	0	0	.0	.5	0	0	.5	.0	0	1.0
P9	0	0	2.5	2.5	0	0	0	0	0	5.0
P11	0	0	.5	1.0	0	0	.5	8.0	0	10.0
P12	0	0	0	1.3	0	0	0	9.7	0	11.0
P13	0	.6	1.3	0	0	1.9	0	9.1	0	12.9
P17	0	0	4.4	.6	0	0	0	0	0	5.0
P18	0	.6	0	0	0	0	0	8.1	0	8.7
Cheyenne and Belle Fourche Rivers, Rosebud Creek, and all tributary streams										
R1	6.4	68.0	14.8	29.1	17.7	25.5	0	0	0	161.5
R2	.9	12.3	0	1.4	7.3	43.4	.9	44.5	0	110.7
T2	0	6.8	.5	2.7	2.3	1.4	.5	19.8	0	34.0
T3	4.1	18.2	3.6	10.2	1.8	14.8	.5	.9	0	54.1
T4	0	33.2	0	2.3	0	57.5	.5	0	0	93.5
T6	5.0	82.0	0	.5	0	0	.0	0	0	87.5
T7	0	9.3	0	.9	0	13.6	1.4	0	0	25.2
T8	0	0	0	0	0	6.8	5.0	6.1	0	17.9
T11	.5	41.1	0	.5	5.9	19.5	2.7	2.3	0	72.5
T12	6.4	54.3	0	.5	0	17.0	3.2	0	0	81.4
T13	14.8	36.8	0	1.4	.9	17.0	2.3	0	0	73.2
T15	4.5	29.1	0	62.3	0	64.1	.9	0	8.0	168.9
T16	82.0	13.4	.5	3.6	0	70.7	0	5.5	0	175.7
T17	5.0	20.0	1.4	5.9	.5	12.5	2.7	.9	0	48.9
T19	5.0	5.0	0	0	0	0	0	0	0	10.0
C1	0	50.9	0	0	.5	0	.5	0	0	51.9

Table 8. Fish cover identified during habitat sampling, Powder River Structural Basin, Wyoming and Montana, 2005.—Continued

[Total fish cover may exceed 100 percent due to use of range categories during sampling]

Site number (fig. 1)	Fish cover, in percent									
	Filamentous algae	Aquatic macrophytes	Woody debris	Brushy debris	Live trees or roots	Overhanging vegetation	Under-cut banks	Boulders	Manmade structures	Total fish cover
Cheyenne and Belle Fourche Rivers, Rosebud Creek, and all tributary streams—Continued										
C2	0	87.5	0	2.3	0	0.5	0.5	0	0	90.8
C3	0	28.0	0	2.3	0	0	1.8	.9	0	33.0
C4	0	22.0	0	.9	0	.9	7.3	20.9	0	52.0
C5	0	15.5	0	0	0	0	1.4	.5	0	17.4
C6	0	15.0	.0	1.8	.5	.5	.5	.5	0	18.8
B1	0	77.3	0	0	0	0	3.2	0	0	80.5
B2	0	22.7	2.7	13.9	0	.5	.9	0	0	40.7
P6	0	2.3	.9	2.3	.5	3.2	4.5	2.3	0	16.0
P7	0	8.2	0	0	0	2.7	2.3	4.1	0	17.3
P10	0	5.0	0	0	.9	2.7	1.8	14.8	0	25.2
P14	0	87.5	0	8.4	8.6	17.0	0	.5	0	122.0
P15	0	4.5	0	1.4	3.6	.5	5.5	2.3	.5	18.3
P16	1.8	0	0	.5	0	4.5	2.3	.9	0	10.0

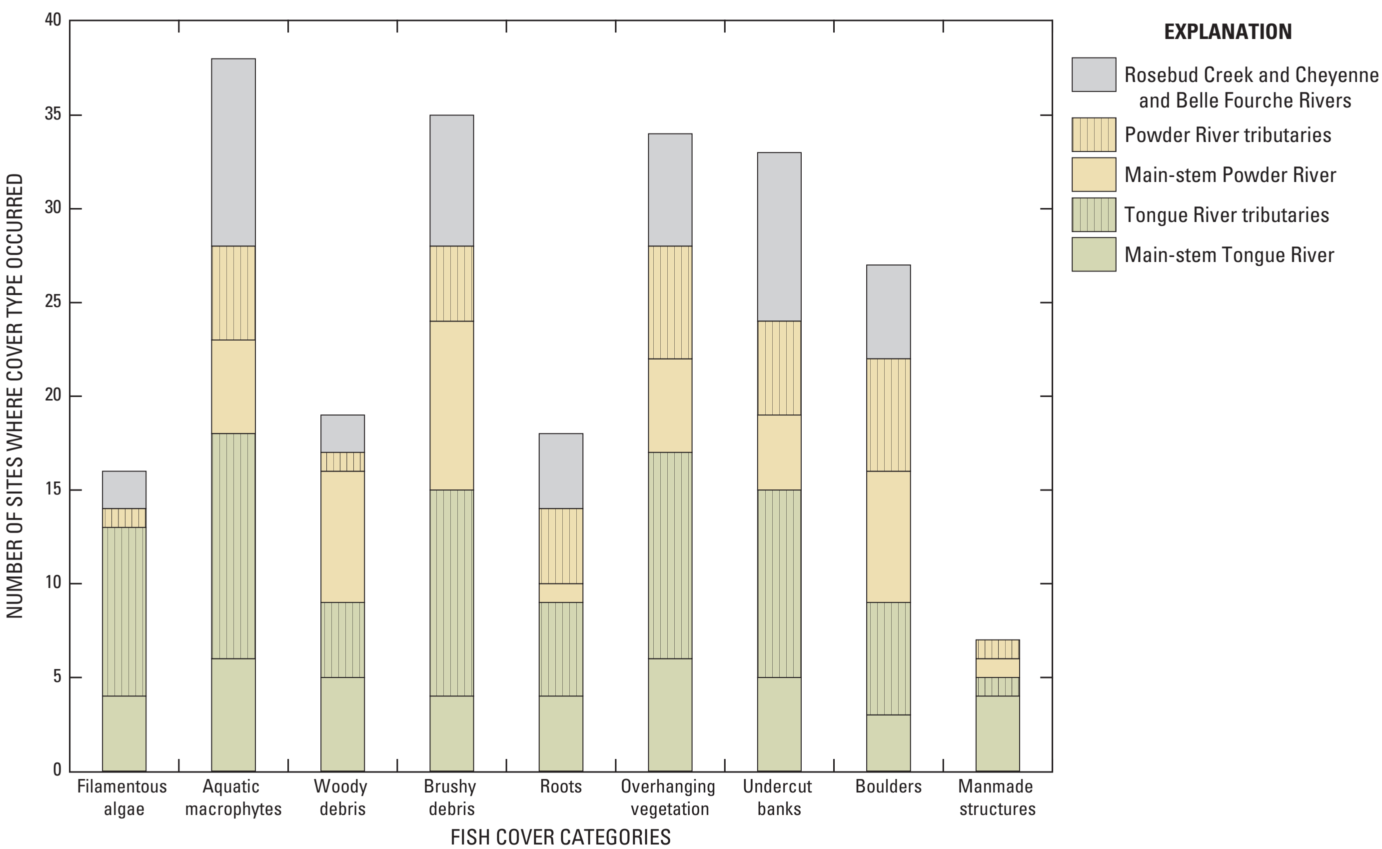

Figure 8. Presence of fish cover identified in the Powder River Structural Basin, 2005.

thrive, so it is not surprising that they are mostly absent in the Powder River where homogenous mobile silt and sand are the dominant substrates and in the Cheyenne and Belle Fourche drainages where flow often is intermittent.

Substrate Characteristics

Streambed substrate is an important variable to consider when evaluating aquatic habitat. Although substrates are relatively sensitive to human effects, they are not affected greatly by small changes in flow as are the other variables determining aquatic habitat (Fitzpatrick and Giddings, 1995). Substrate size and embeddedness should be similar between annual visits unless there has been some major change to the system. This change could be of human origin or could be natural, such as recent major flooding. If sampling occurs before a stream has time to reach equilibrium after flooding, then variability in the data likely will be because of timing of sampling with respect to flooding and not necessarily human-induced change (Fitzpatrick and Giddings, 1995).

The number of substrate size estimates collected under the EMAP protocol generally was either 55 particles from the transect data or 105 particles if both transect particles and intermediate points between transects were measured. To determine the validity of comparing reachwide substrate data from sites with 55 measured particles to those with 105 measured particles, a Wilcoxon rank sum test was conducted using data from each of the 26 sites with complete data sets. All of the P values were greater than 0.05; therefore, the null hypothesis that the two data sets (55 or 105 measurements) were not different from each other was accepted. Therefore, discussion of reachwide substrate data includes all of the available data for each site.

Substrate size varied considerably among sites (table 9). Median streambed substrate size classes were sand at 20 sites, fines at 15 sites, fine gravel at 7 sites, and coarse gravel at 5 sites. Sites with fines as the median substrate size were located on tributaries to the Tongue and Powder Rivers or in the Rosebud, Cheyenne, and Belle Fourche drainages. Coarse gravel was the median substrate class at three sites on the main-stem Tongue River (sites T1, T5, and T10) and at Rosebud Creek at mouth (site R2) and Goose Creek (site T2). Fines were present at nearly all 47 sites (<0.06 mm; table 9), whereas bedrock was noted at only six sites (>4,000 mm; table 9). Little Thunder Creek (site C4) had a relatively large proportion of bedrock, as shown in table 9 by the large numbers for the D75, D84, and Bedrock categories. Substrate data for nine different streams were plotted using box plots and are presented in figure 9. The Tongue River had the coarsest substrates overall, whereas Squirrel and Otter Creeks had the finest substrates. Seventy-five percent of the substrate found at sites on the main-stem Powder River was sand to fine gravel.

Pebble counts indicated riffles measured on streams in the Tongue River drainage (fig. 10*A*) had median particle sizes that ranged from about 20 to 50 mm (coarse gravel, table 3). Median particle size from riffles measured on the main-stem Powder River (fig. 10*B*), and its tributaries (fig. 10*C*) had median values ranging from <4 mm (the minimum particle size measured) to almost 60 mm (coarse gravel). The median substrate values were <4 mm for riffles at all sites on the Cheyenne and Belle Fourche Rivers and tributaries (fig. 10*D*). Although pebble counts were performed at both pools and riffles, the pool substrates tended to be all fine material, <4 mm, and therefore the pool data are not shown.

The degree to which coarse streambed substrates are surrounded by fine sediment and sand is called embeddedness. Most coarse substrates are naturally embedded to some degree dependent on stream characteristics such as gradient, flow regime, and geology. However, as interstitial spaces between coarse substrates fill and substrates become more embedded, the habitat area available to many algae, macroinvertebrates, and fish decreases. Embeddedness alone is not a good measure of stress in streams that naturally have predominantly fine substrates and hence high embeddedness. Mean embeddedness ranged from 50 percent at Tongue River at Monarch (site T1) to 100 percent at upper Squirrel Creek (site T6), Porcupine Creek (site C1), and Caballo Creek (site B2; table 9). Embeddedness on the Tongue River increased in the downstream direction and then decreased below Tongue River Reservoir (located between sites T9 and T10), indicating that the reservoir is acting as a sediment trap.

For this study, soft sediment at each thalweg measurement point was defined as fine gravel and smaller (≤16 mm diameter). The presence of soft sediment was measured at 32 sites (table 9) and ranged from 1 percent at Tongue River at Monarch (site T1) to 100 percent at 17 sites. The mean presence of soft sediment was 84.5 percent. The 1 percent noted at site T1 seems unusually small compared to the rest of the data, but site T1 had a large median substrate (median of about 51 mm in fig. 10*A*) and the lowest mean embeddedness, indicating it had less fine substrates than other sites.

Riparian Characteristics

Along all streambanks is a corridor or transition zone between the aquatic and terrestrial systems. This corridor most often is referred to as the riparian zone. Generally, riparian zones with complex, multi-layered vegetation are considered healthier than zones with simple, single-layered vegetation. When a riparian zone is healthy, it performs many critical functions. Riparian vegetation holds soils along streambanks (thus reducing erosion), intercepts surface flow (thus encouraging ground-water recharge and sustained late-summer flows), and reduces flooding while filtering sediment, excess nutrients, and other potential contaminants. Trees, shrubs, and herbaceous plants provide stream shading, which helps to control stream temperature variations. Riparian vegetation also provides food, in the form of leaf litter, seeds, insects, and deadfall for the aquatic system. This litter and deadfall also can provide additional habitat to the system. For this study, riparian characteristics were assessed through measurements

Table 9. Statistical summary of reachwide substrate data, Powder River Structural Basin, Wyoming and Montana, 2005.

[N, number of substrate measurements used to calculate statistics; soft sediment, percentage presence of sediment less than or equal to (≤) 16 millimeters in diameter; <, less than; mm, millimeters; >, greater than. Bank substrate was calculated using substrate measured at stream margin. Substrate size classes: 1, fines <0.06 mm; 2, sand 0.06–2 mm; 2.5, fine gravel >2 to 16 mm; 3.5, coarse gravel >16 to 64 mm; 4, cobble >64 to 250 mm; 5, boulders >250 to 4,000 mm; 6, bedrock >4,000 mm; NM, not measured]

Site number (fig. 1)	N values	Soft sediment (percentage presence)	Streambed substrate											Bank substrate
			Mean em-beddedness (percent)	Percentile				Fraction						Mean (class)
				25th (class)	50th (median) (class)	75th (class)	84th (class)	<0.06 mm	0.06–2 mm	≤2 mm	≤16 mm	>16 mm	Bedrock	
Main-stem Tongue River														
T1	104	1	50	2.00	3.50	4.00	4.00	0.20	0.03	0.24	0.29	0.71	0	2.25
T5	105	96	69	1.50	3.50	3.50	3.50	.33	.16	.49	.58	.40	0	1.32
T9	105	42	76	1.00	2.00	3.50	3.50	.33	.24	.56	.69	.31	0	1.59
T10	94	90	55	2.00	3.50	3.88	4.00	.17	.11	.28	.31	.69	0	2.61
T14	103	100	71	1.00	2.00	3.50	4.00	.35	.19	.53	.57	.43	0	1.30
T18	100	100	56	2.00	2.50	3.50	3.50	.07	.31	.38	.51	.49	0	2.07
Main-stem Powder River														
P1	50	NM	69	2.00	2.00	2.50	2.50	0.14	0.47	0.56	0.88	0.12	0	2.10
P2	50	100	72	2.00	2.50	3.50	3.50	.04	.38	.42	.68	.32	0	2.50
P3	55	NM	86	2.00	2.00	2.50	3.50	.05	.67	.73	.82	.18	0	2.55
P4	50	100	70	2.00	2.00	3.50	3.50	0	.52	.52	.70	.30	0	3.03
P5	55	NM	92	1.00	2.00	2.00	2.00	.49	.42	.91	.98	.02	0	1.27
P8	50	100	90	1.00	2.00	2.00	2.00	.36	.48	.84	.86	.12	0	1.45
P9	50	NM	98	1.00	2.00	2.00	2.00	.36	.56	.92	.92	.08	0	1.23
P11	50	100	78	2.00	2.00	3.50	3.58	.24	.36	.60	.72	.28	0	1.63
P12	39	100	65	1.00	2.00	4.00	4.00	.30	.20	.50	.58	.38	.03	2.33
P13	75	81.82	71	2.00	2.00	3.50	3.50	.08	.50	.58	.65	.32	.03	2.44
P17	75	76.62	94	2.00	2.00	2.00	2.00	.10	.78	.88	.98	.02	0	1.97
P18	75	100	64	2.00	2.50	3.50	4.00	.03	.42	.45	.55	.45	0	3.19
Cheyenne and Belle Fourche Rivers, Rosebud Creek, and all tributary streams														
R1	104	100	99	1.00	1.00	1.00	1.00	1.00	0	1.00	1.00	0	0	1.00
R2	105	88	62	3.00	3.50	4.00	4.00	.24	0	.24	.29	.71	0	2.57
T2	105	43	58	2.00	3.50	4.00	5.00	.07	.16	.24	.27	.69	.04	2.00
T3	105	100	90	1.00	2.00	2.00	2.50	.40	.42	.82	.95	.04	0	1.41
T4	105	100	99	1.00	1.00	1.00	1.00	.95	.04	.98	1.00	0	0	1.00

Table 9. Statistical summary of reachwide substrate data, Powder River Structural Basin, Wyoming and Montana, 2005.—Continued

[N, number of substrate measurements used to calculate statistics; soft sediment, percentage presence of sediment less than or equal to (≤) 16 millimeters in diameter; <, less than; mm, millimeters; >, greater than. Bank substrate was calculated using substrate measured at stream margin. Substrate size classes: 1, fines <0.06 mm; 2, sand 0.06–2 mm; 2.5, fine gravel >2 to 16 mm; 3.5, coarse gravel >16 to 64 mm; 4, cobble >64 to 250 mm; 5, boulders >250 to 4,000 mm; 6, bedrock >4,000 mm; NM, not measured]

Site number (fig. 1)	N values	Soft sediment (percentage presence)	Streambed substrate											Bank substrate
			Mean em-beddedness (percent)	Percentile				Fraction						Mean (class)
				25th (class)	50th (median) (class)	75th (class)	84th (class)	<0.06 mm	0.06–2 mm	≤2 mm	≤16 mm	>16 mm	Bedrock	
Cheyenne and Belle Fourche Rivers, Rosebud Creek, and all tributary streams—Continued														
T6	105	100	100	1.00	1.00	1.00	1.00	1.00	0	1.00	1.00	0	0	1.00
T7	105	45	91	1.00	1.00	1.38	2.50	.82	0	.82	.91	.07	0	1.00
T8	105	69	73	2.00	2.00	3.50	4.00	.07	.53	.60	.75	.25	0	1.89
T11	105	100	88	1.00	1.00	3.50	3.50	.67	.04	.71	.76	.24	0	1.14
T12	105	100	91	1.00	2.00	2.50	3.50	.38	.33	.71	.78	.18	0	1.64
T13	105	100	95	1.00	1.00	1.00	1.00	.85	.02	.87	.91	.09	0	1.16
T15	105	89	87	1.00	1.00	2.50	3.50	.73	0	.73	.76	.24	0	1.18
T16	105	87	94	1.00	1.00	1.00	1.00	.83	.02	.85	.85	.15	0	1.20
T17	105	100	83	1.00	1.00	2.00	2.00	.62	.13	.75	.82	.18	0	1.50
T19	105	100	65	1.00	2.50	3.50	3.50	.35	.09	.44	.56	.44	0	1.84
P6	55	NM	77	1.00	1.00	2.50	2.86	.51	.15	.65	.84	.16	0	1.30
P7	55	NM	81	1.00	2.00	3.50	4.00	.38	.22	.60	.62	.38	0	1.64
P10	105	39	65	1.00	2.50	4.00	4.00	.29	.20	.49	.56	.40	.04	1.77
P14	54	NM	93	1.00	1.00	2.00	2.00	.62	.22	.84	.89	.09	0	1.27
P15	55	NM	86	1.00	1.00	2.00	2.50	.51	.25	.76	.93	.07	0	1.64
P16	105	96	76	1.00	2.50	3.50	3.50	.35	.02	.37	.55	.45	0	1.77
C1	55	NM	100	1.00	2.00	2.00	2.00	.44	.56	1.00	1.00	0	0	1.68
C2	55	60	99	1.00	1.00	1.00	2.00	.76	.22	.98	1.00.	0	0	1.25
C3	55	NM	90	1.00	2.00	2.00	2.50	.47	.31	.78	.89	.11	0	1.50
C4	55	NM	53	2.00	2.50	5.50	6.00	.20	.18	.38	.53	.22	.25	3.11
C5	55	NM	83	2.00	2.00	2.25	2.50	.13	.62	.75	.95	.05	0	1.75
C6	55	NM	71	2.00	2.00	2.50	2.50	.18	.36	.55	.85	.07	.07	1.86
B1	55	NM	96	1.00	1.00	1.50	2.00	.75	.18	.93	.98	.02	0	1.14
B2	55	NM	100	1.00	1.00	1.00	1.00	1.00	0	1.00	1.00	0	0	1.00

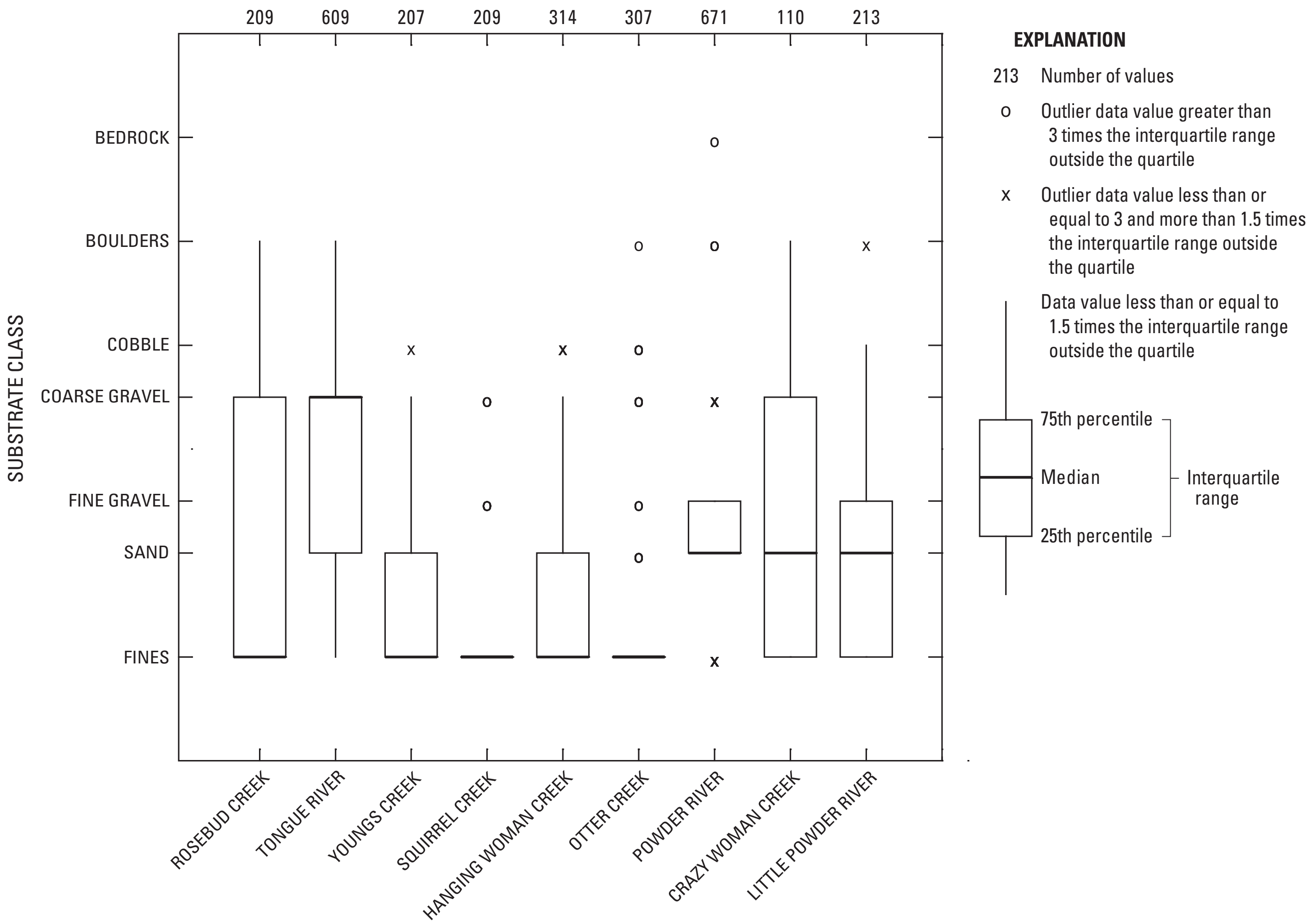

Figure 9. Particle-size distribution of reachwide streambed substrate data, by stream, Powder River Structural Basin, 2005.

of density of vegetative (canopy) cover, vegetation complexity, identification of legacy trees, and presence of invasive species.

Mid-stream canopy density ranged from zero percent cover at sites T10, P8, P13, P17, and P18 to 56 percent cover at upper Rosebud Creek (site R1; table 7). Although measurements of mid-stream canopy density indicated less density at the large river sites on the main-stem Powder River (mean = <1 percent) and Tongue River (mean = 4.8 percent) than at tributary streams (mean = 7.5 percent) as one might expect, 19 of the tributary sites had means of 5 percent or less, and 7 of those sites had means of less than 1 percent. Bank or streamside canopy density measurements ranged from 0.2 percent at Powder River near Locate (site P18) to 99 percent at Prairie Dog Creek (site T8). The main-stem Tongue River had the largest mean bank canopy density (about 49 percent) when compared to the main-stem Powder River (about 6 percent) and tributary sites (about 24 percent).

Woody and non-woody vegetation were observed in the riparian zone at all 47 sampling sites. Non-woody vegetation comprised the largest percentage of vegetative cover at most of the sites (table 10). All of the sites surveyed had some type of ground vegetation, whereas two sites (Little Powder River at Biddle, site P16, and Antelope Creek, site C2) had no woody vegetation observed for either ground cover or the understory. Several sites had less than 10 percent total understory vegetative cover including upper Squirrel Creek (site T6), Little Thunder Creek (site C4), Black Thunder Creek (site C5), Cheyenne River near Spencer (site C6), and Powder River above Pumpkin Creek (site P3). Percentages of mean areal vegetative cover for the canopy were generally small with only eight sites having combined total percentages of 10 percent or more. Four sites, upper Rosebud Creek (site R1), Rosebud Creek at mouth (site R2), Powder River at Broadus (site P13), and upper Youngs Creek (site T3), had canopies with percentages of mean areal vegetative cover larger than 20 percent. Eighteen sites had summed mean areal vegetative cover greater than 100 percent (table 10); eight of these sites had little or no bare ground. Summed mean areal vegetative cover and bare ground or duff were inversely correlated (ρ = –0.76).

Nine different tree types were identified as legacy trees (fig. 11). Cottonwoods composed 65 percent of the legacy trees, and boxelder trees were the second most common.

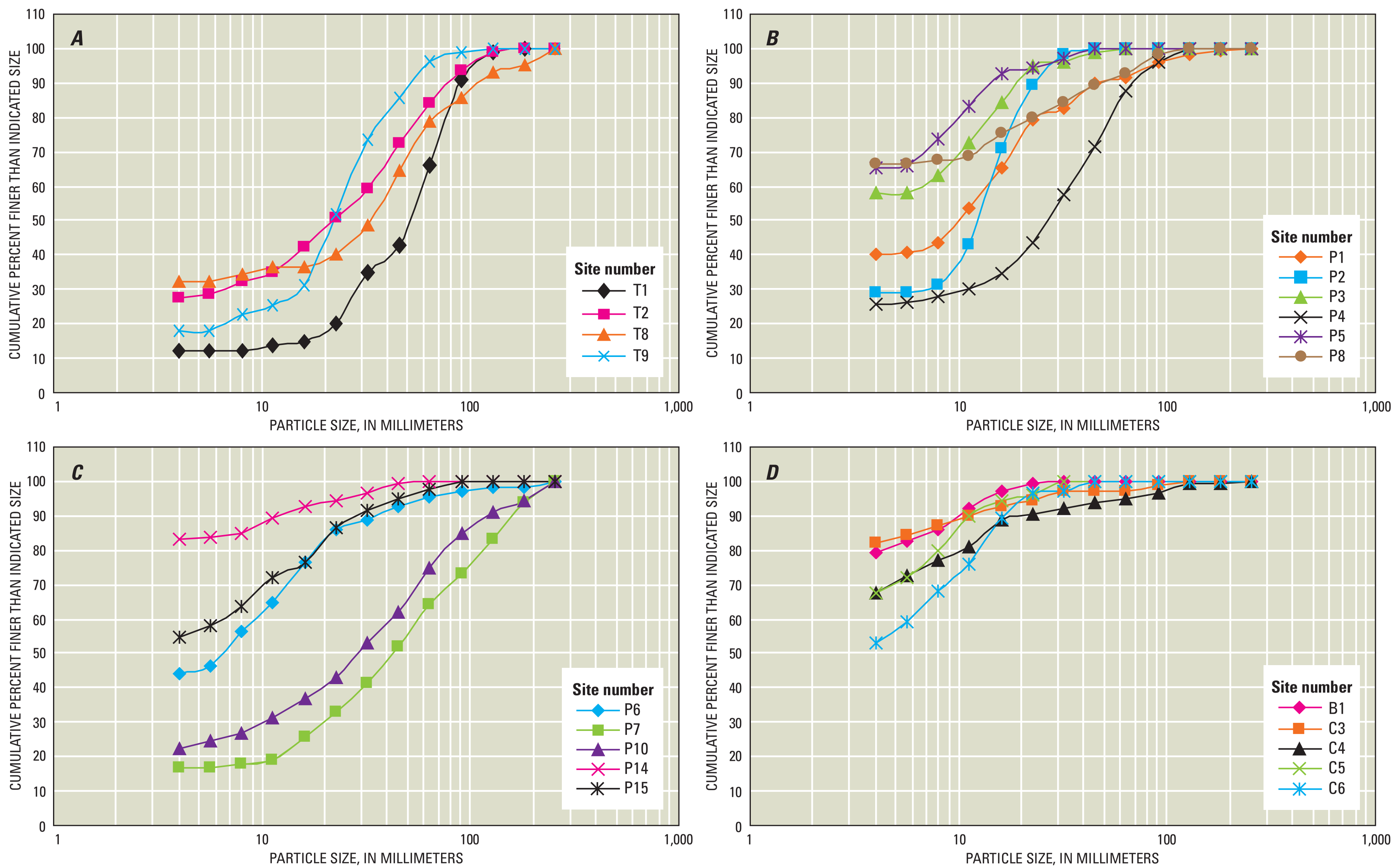

Figure 10. Cumulative particle-size distributions of riffle pebble counts collected at sites on the *A*, Tongue River and tributaries; *B*, main-stem Powder River; *C*, tributaries to the Powder River; and *D*, Cheyenne and Belle Fourche Rivers and tributaries, Powder River Structural Basin, 2005.

Table 10. Riparian vegetative structure and percentages of mean areal vegetative cover identified by semiquantitative visual estimates, Powder River Structural Basin, Wyoming and Montana, 2005.

[Shaded cells indicate main-stem sampling sites on the Tongue or Powder River. <, less than; m, meter; >, greater than; DBH, diameter at breast height. Total vegetative cover may exceed 100 percent due to use of range categories during sampling]

Site number (fig. 1)	Bare/duff (percent)	Mean areal vegetative cover (percent)						Sum of mean areal vegetative cover (percent)	Total vegetative cover (percent)
		Ground cover, <0.5 m		Understory, 0.5–5 m		Canopy, >5 m			
		Non-woody	Woody	Non-woody	Woody	Small trees, <0.3 m DBH	Large trees, >0.3 m DBH		
R1	0	37	12	71	42	24	7	192	100
R2	1	46	27	52	33	36	.5	193	99
T1	11	8	6	19	44	4	1	81	89
T2	14	11	5	22	28	1	0	68	86
T3	14	34	8	50	10	8	14	123	86
T4	.5	88	7	21	6	.5	1	124	100
T5	5	30	6	45	9	2	1	94	95
T6	36	50	1	7	2	0	0	60	64
T7	.5	86	1	23	1	0	0	111	100
T8	0	24	17	40	22	0	.2	104	100
T9	20	15	3	44	6	1	0	68	80
T10	6	47	5	47	5	8	3	116	94
T11	10	60	3	52	7	4	0	126	90
T12	0	58	4	52	7	3	1	125	100
T13	1	58	1	58	3	4	1	124	99
T14	9	45	17	43	22	13	4	144	91
T15	8	80	0	77	9	1	.2	167	92
T16	8	80	0	40	2	0.2	1	123	92
T17	9	53	17	10	12	1	0	93	91
T18	14	35	17	37	23	5	5	122	86
T19	20	25	4	17	3	2	4	54	80
P1	45	8	7	6	23	0.3	0	43	55
P2	40	10	6	6	21	7	3	52	60
P3	43	33	2	1	3	0	1	39	58
P4	43	14	5	14	10	1	1	44	57
P5	61	12	4	8	13	0	.2	36	39
P6	37	28	7	14	8	.5	10	66	63
P7	37	37	3	14	5	0	1	59	63
P8	27	32	11	6	13	2	1	65	73
P9	38	8	5	18	23	0	.3	53	62
P10	32	26	.2	31	2	1	.2	60	68
P11	22	30	6	22	7	.3	.3	66	78
P12	26	12	4	32	8	2	2	59	74
P13	15	38	5	23	20	29	2	116	85
P14	2	32	2	36	6	8	.2	84	98

Table 10. Riparian vegetative structure and percentages of mean areal vegetative cover identified by semiquantitative visual estimates, Powder River Structural Basin, Wyoming and Montana, 2005.—Continued

[Shaded cells indicate main-stem sampling sites on the Tongue or Powder River. <, less than; m, meter; >, greater than; DBH, diameter at breast height. Total vegetative cover may exceed 100 percent due to use of range categories during sampling]

Site number (fig. 1)	Bare/duff (percent)	Mean areal vegetative cover (percent)						Sum of mean areal vegetative cover (percent)	Total vegetative cover (percent)
		Ground cover, <0.5 m		Understory, 0.5–5 m		Canopy, >5 m			
		Non-woody	Woody	Non-woody	Woody	Small trees, <0.3 m DBH	Large trees, >0.3 m DBH		
P15	10	59	1	10	2	0.2	0	71	90
P16	2	88	0	11	0	3	0	101	98
P17	18	51	13	31	13	2	.3	111	83
P18	23	52	7	42	4	0	1	105	78
C1	8	49	1	34	.2	0	0	85	92
C2	6	76	0	.2	0	3	.2	80	94
C3	33	41	4	6	6	1	.5	59	67
C4	6	68	4	1	3	0	0	76	94
C5	55	35	4	0	2	0	0	42	45
C6	64	22	3	1	6	0	0	32	36
B1	39	32	5	18	3	0	0	59	61
B2	18	53	5	11	9	0	0	77	82

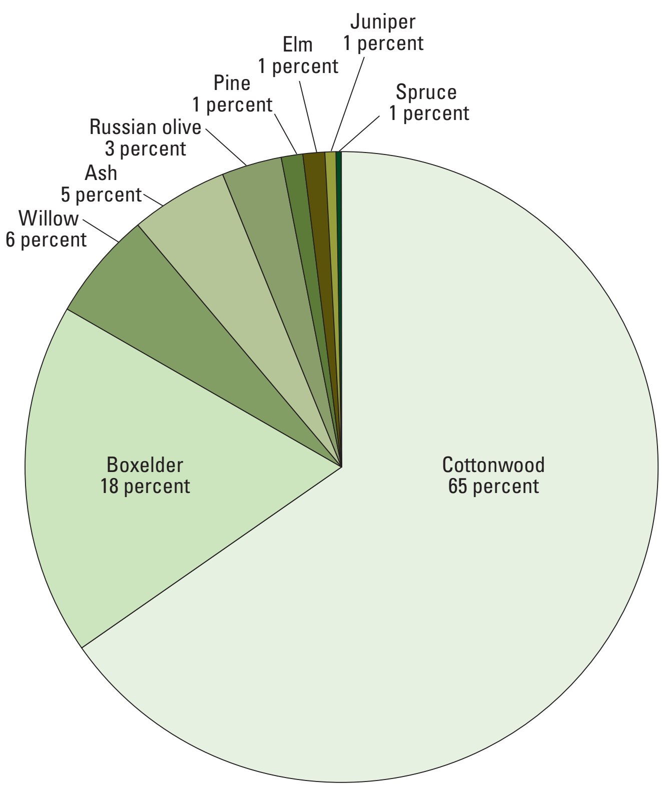

Figure 11. Percentages of legacy tree types identified at study reaches, Powder River Structural Basin, 2005.

Of the eight species that were targeted for this study, cheatgrass and Canada thistle were the most commonly noted invasive plants in the riparian zone at the sampling sites. Cheatgrass and Canada thistle were identified at 35 and 26 percent of the sites, respectively (fig. 12). One target species, English ivy, was not observed by study personnel.

Reach Characteristics

Bank-stability scores, computed according to Fitzpatrick and others (1998), indicated the streambanks tended to be more stable at sites on tributaries in the Tongue River drainage than at sites on tributaries in the Powder River drainage and the main-stem Powder River. Low index scores for bank angle, vegetative cover, bank height, and substrate resulted in relatively small bank-stability scores (more stable) for Tongue River tributary sites (table 11). Bank-stability scores were mixed for sites on the main-stem Tongue River. Streambanks at sites in the Cheyenne and Belle Fourche River drainages were relatively stable (small bank-stability scores) with the exception of Little Thunder Creek (site C4), which was tied with Tongue River above Hanging Woman Creek (site T10) and sites on the Powder River (sites P2-P4 and P18) with maximum scores of 15 (least stable). The narrative ratings of “at risk” (25 sites) or “unstable” (22 sites) in table 11 provide a relative indicator of current bank conditions; however, observations of erosion or bank slumping also should be considered when evaluating bank stability.

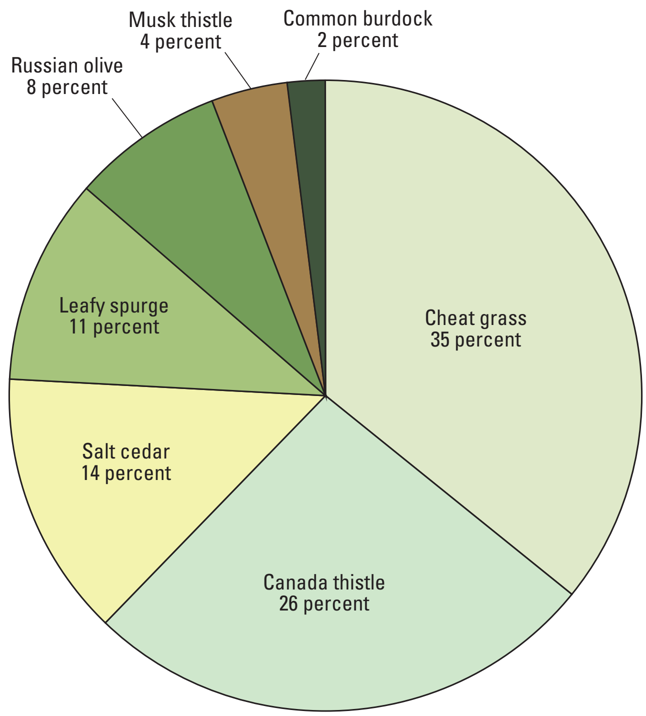

Figure 12. Distribution of invasive plant species identified in study reaches, Powder River Structural Basin, 2005.

Table 11. Bank-stability index and scores for sites sampled in the Powder River Structural Basin, Wyoming and Montana, 2005.

[Shaded cells indicate main-stem sites on the Tongue or Powder River. Bank-stability scores: 4–7 = stable; 8–10 = at risk; 11–15 = unstable; 16–22 = very unstable; from Fitzpatrick and others, 1998]

Site number (fig. 1)	Index scores				Bank-stability score	Bank-stability rating
	Angle	Vegetative cover	Height	Substrate		
R1	2	1	2	5	10	At risk
R2	2	1	1	10	14	Unstable
T1	2	1	1	8	12	Unstable
T2	2	1	2	8	13	Unstable
T3	2	1	1	5	9	At risk
T4	1	1	1	5	8	At risk
T5	1	1	2	5	9	At risk
T6	1	2	1	5	9	At risk
T7	3	1	1	5	10	At risk
T8	3	1	2	5	11	Unstable
T9	1	1	2	5	9	At risk

Table 11. Bank-stability index and scores for sites sampled in the Powder River Structural Basin, Wyoming and Montana, 2005.—Continued

[Shaded cells indicate main-stem sites on the Tongue or Powder River. Bank-stability scores: 4–7 = stable; 8–10 = at risk; 11–15 = unstable; 16–22 = very unstable; from Fitzpatrick and others, 1998]

Site number (fig. 1)	Index scores				Bank-stability score	Bank-stability rating
	Angle	Vegetative cover	Height	Substrate		
T10	2	1	2	10	15	Unstable
T11	3	1	1	5	10	At risk
T12	2	1	1	5	9	At risk
T13	3	1	1	5	10	At risk
T14	2	1	2	5	10	At risk
T15	1	1	1	5	8	At risk
T16	2	1	1	5	9	At risk
T17	3	1	1	5	10	At risk
T18	2	1	2	8	13	Unstable
T19	1	2	1	5	9	At risk
P1	1	2	2	8	13	Unstable
P2	1	2	2	10	15	Unstable
P3	1	2	2	10	15	Unstable
P4	1	2	2	10	15	Unstable
P5	1	3	2	5	11	Unstable
P6	3	2	2	5	12	Unstable
P7	2	2	2	5	11	Unstable
P8	2	2	2	5	11	Unstable
P9	1	2	1	5	9	At risk
P10	2	2	2	5	11	Unstable
P11	1	2	2	5	10	At risk
P12	1	2	1	8	12	Unstable
P13	1	1	2	8	12	Unstable
P14	3	1	1	5	10	At risk
P15	3	1	2	5	11	Unstable
P16	3	1	2	5	11	Unstable
P17	2	1	2	5	10	At risk
P18	1	2	2	10	15	Unstable
C1	2	1	1	5	9	At risk
C2	2	1	1	5	9	At risk
C3	2	2	[1]1	5	10	At risk
C4	2	1	2	10	15	Unstable
C5	2	3	[1]1	5	11	Unstable
C6	1	3	[1]1	5	10	At risk
B1	2	2	1	5	10	At risk
B2	1	1	1	5	8	At risk

[1]Value may be underestimated because bank height was calculated using the mean water depth instead of the mean thalweg depth.

Cross-sectional and longitudinal surveys along with mapping of habitat types were performed at several sites during the summer of 2005. Examples of data collected during a longitudinal survey at Porcupine Creek (site C1) are presented in figure 13 as both longitudinal-profile and plan views. Longitudinal survey data, from sites that are noted in table 2, are available upon request from the USGS WWSC in Cheyenne, Wyo.

Proximity-weighted human disturbance values indicated that the sites with the largest amount of human activities were Tongue River at State line (site T9) and Tongue River at Birney Day School (site T14), each with six human activities present, and Hanging Woman Creek at mouth (site T13) with seven observed activities (table 12). At 32 sites, two or more human activities were observed. The most-common land use, "pasture, range, or hay field," was identified at 45 of 47 sites. The least-common land use, "mining," was identified at Porcupine Creek (site C1) and Caballo Creek (site B2).

Three summary categories were added to table 12—"agricultural" (the sum of "row crops" and "pasture, range, or hay field"), "nonagricultural" (the sum of all other categories), and "all types" (the sum of all categories). In the PRB, agricultural land-use activities were twice as likely to disturb sampled stream reaches as nonagricultural land-use activities (table 12). Powder River below Salt Creek (site P2) had the least riparian disturbance with an overall proximity-weighted disturbance value of 0.14, whereas Hanging Woman Creek at mouth (site T13) showed the greatest disturbance with a value of 3.32 (table 12).

Habitat Characteristics of the Main-Stem Powder River in Wyoming

A total of 690 habitat units were surveyed during 72 periods of sample collection at eight sites on the main-stem Powder River during 2004–06. Periods of sample collections numbered 40 in 2004, 24 in 2005, and 8 in 2006.

The median wetted stream width of the main-stem Powder River in Wyoming increased from 12.0 m above Salt Creek (site P1) to 32.6 m below Clear Creek (site P11, table 13). A wide range of wetted stream widths was observed at each site (table 13) and depended on the streamflow conditions at the time of sampling.

The mean and maximum depths observed from 2004 through 2006 varied little among sites (table 14). The mean of mean depths at each site ranged from 0.15 to 0.27 m. The mean of maximum depths observed ranged from 0.34 to 0.49 m across all sites. The deepest maximum depths observed at all sites ranged from 1.10 to 2.13 m. Onsite observations indicate that the deepest habitats were pools scoured near in-stream obstructions such as large woody debris or boulders. Residual pool depths had a mean of 0.55 m and ranged from 0.30 to 1.71 m (table 14).

Sand was the most common substrate in the main-stem Powder River. Mean percentages of gravel were larger at the sites farthest upstream (sites P1 and P2) than downstream (fig. 14), but sand predominated at all sites other than site P1, which had similar proportions of gravel (41.4 percent) and sand (35.8 percent). The largest percentages of cobble were observed at sites P11 (11.7 percent) and P4 (9.4 percent). Bedrock generally was rare but was observed most commonly at sites P3-P5 and P9. Substrate categorized as bedrock was primarily sandstone that was scoured by the river where the channel was controlled by bluffs.

Substrate varied substantially among habitat units. The substrate of pools, runs, and shoals in the main-stem Powder River was predominantly sand (mean of 67 to 74 percent, fig. 15). Riffles had the largest mean percentage of gravel (56.5 percent) and cobble (22.3 percent). Backwater had a consistently large percentage of silt (mean 58.3 percent) and sand (mean 31.2 percent). Isolated pools were dominated by a variable combination of silt (mean 67.5 percent) and sand (mean 32.5 percent). The mean water velocity in riffles (0.54 meters per second, m/s) was substantially greater than in pools (0.31 m/s) and shoals (0.20 m/s) but was similar to that observed in runs (0.44 m/s; fig. 16).

Fish cover, such as vegetation and woody debris, was observed more frequently at upstream Powder River sites than at downstream sites (fig. 17). Although fish cover often was not abundant enough to be quantified, the presence of discernable cover was observed in 30 percent of surveys of habitat units ($n = 204$). Overall, the mean percentages of fish cover containing aquatic vegetation (1.4 percent), woody debris (1.6 percent), undercut bank (0.2 percent), and overhead cover (0.7 percent) were considerably smaller than the perceived margin of error for visual coverage estimates (about 5 percent). However, the presence of cover was denoted as a trace for many habitat units where the percentage of coverage was smaller than could be estimated precisely.

Zero-flow conditions were encountered during sampling at two sites (P8 and P9) in August 2006. Six isolated pools were surveyed at each site. Surface-water temperatures of the isolated pools during late morning ranged from 17.5 to 27.5ºC (four measurements). In a single pool at site P9, transparency was 40 cm, and specific conductance was 6,400 µS/cm, which was the maximum observation during the study. The mean of mean depths measured in the isolated pools was 0.18 m, and the mean of maximum depths was 0.34 m (range of 0.12–0.70 m). The overall substrate composition of the isolated pools differed slightly from that of other pools but was dominated by sand (88.7 percent). Cobble (5.0 percent), gravel (3.8 percent), bedrock (1.3 percent), and silt (0.8 percent) were less common in isolated pools than sand. Cover types such as woody debris, undercut bank, and overhead cover were observed in 33 percent of the isolated pools. Aquatic vegetation was not observed in any of the isolated pools surveyed.

The aquatic habitat of isolated pools surveyed under intermittent conditions was fairly homogeneous and harsh, which concurs with the description of "isolated streambed pools" in other warm-water stream studies (Ostrand and Wilde, 2004). Most isolated pools were small and temporary,

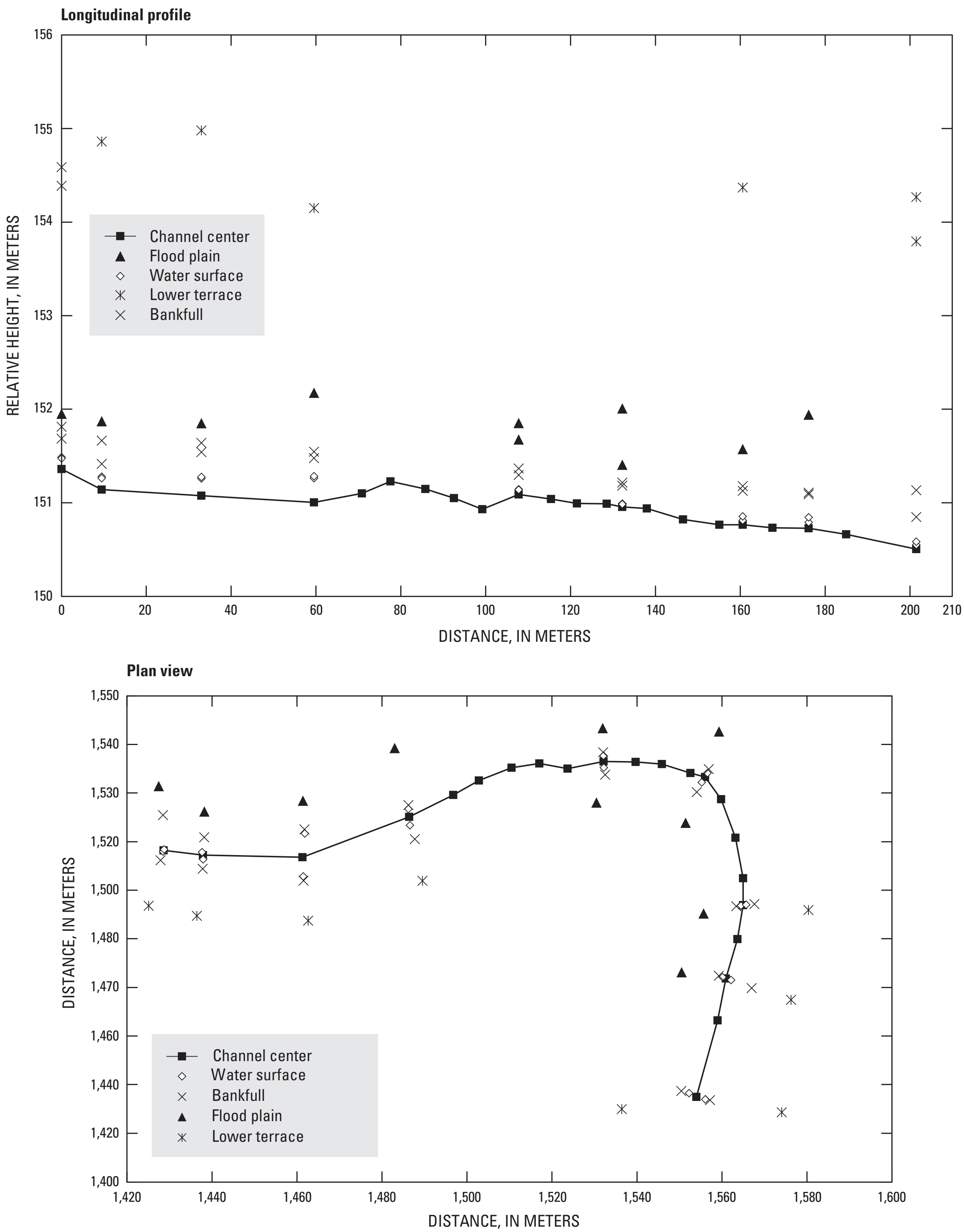

Figure 13. Examples of longitudinal survey data, Porcupine Creek near Teckla, Wyo. (site C1), 2005.

Table 12. Proximity-weighted human riparian disturbance values, Powder River Structural Basin, Wyoming and Montana, 2005.

[Shaded cells indicate main-stem sites on the Tongue or Powder River. Disturbance values are weighted number of observations]

Site number (fig. 1)	Human activities											Summed activities		
	Wall or dam	Building	Pavement	Road	Intake or outlet pipe	Trash or landfill	Park or lawn	Row crops	Pasture, range, or hay field	Logging operations	Mining activity	Agricultural	Non-agricultural	All types
R1	0	0.30	0	0.30	0	1.34	0.30	0	0.61	0	0	0.61	2.25	2.85
R2	0	0	0	.67	0	0	0	0	.67	0	0	.67	.67	1.33
T1	.17	.11	0	.23	0	0	0	0	.17	0	0	.17	.50	.67
T2	0	0	0	.33	0	0	0	0	.98	0	0	.98	.33	1.31
T3	0	.09	0	.33	0	0	0	0	1.50	0	0	1.50	.43	1.93
T4	0	0	0	.48	0	0	0	0	0	0	0	0	.49	.49
T5	0	.07	0	.52	.58	0	0	.64	.64	0	0	1.27	1.17	2.44
T6	0	.21	0	.33	0	0	0	0	1.00	0	0	1.00	.55	1.55
T7	0	0	0	.33	0	.03	0	0	0	0	0	0	.37	.37
T8	0	0	0	0	0	0	0	0	.67	0	0	.67	0	.67
T9	.06	.07	0	.06	.14	0	0	.03	.30	0	0	.33	.33	.66
T10	.10	0	0	.67	.21	0	0	0	.67	0	0	.67	.98	1.65
T11	0	.33	.0	.67	0	0	.03	0	.45	.64	0	.45	1.67	2.12
T12	0	0	0	.67	0	0	0	0	.67	.64	0	.67	1.33	2.00
T13	.67	.33	0	.67	0	0	.21	.11	.67	.67	0	.78	2.55	3.32
T14	0	.38	0	.69	0	.62	.02	.09	.67	.00	0	.75	1.72	2.47
T15	0	0	0	0	0	0	0	0	1.50	0	0	1.50	0	1.50
T16	.07	0	0	.06	.20	.07	0	0	1.50	0	0	1.50	.41	1.91
T17	0	.03	0	.03	0	.16	.03	0	1.50	0	0	1.50	.26	1.76
T18	0	0	0	.67	0	.03	0	0	.67	0	0	.67	.70	1.37
T19	0	0	0	.67	0	.03	0	0	.89	0	0	.89	.70	1.59
P1	0	0	0	0	0	0	0	0	1.18	0	0	1.18	0	1.18
P2	.08	0	0	0	0	0	0	0	.07	0	0	.07	.08	.14
P3	0	0	0	0	0	0	0	0	1.14	0	0	1.13	0	1.13
P4	0	0	0	0	0	0	0	0	.93	0	0	.93	0	.93
P5	0	0	0	0	0	0	0	0	.94	0	0	.93	0	.93

Table 12. Proximity-weighted human riparian disturbance values, Powder River Structural Basin, Wyoming and Montana, 2005.—Continued

[Shaded cells indicate main-stem sites on the Tongue or Powder River. Disturbance values are weighted number of observations]

Site number (fig. 1)	Human activities											Summed activities		
	Wall or dam	Building	Pavement	Road	Intake or outlet pipe	Trash or landfill	Park or lawn	Row crops	Pasture, range, or hay field	Logging operations	Mining activity	Agricul-tural	Non-agricul-tural	All types
P6	0	0	0	0	0	0	0	0	0.80	0	0	0.80	0	0.80
P7	0	0	0	0	0	0	0	0	1.41	0	0	1.41	0	1.41
P8	0	0	0	0	0	0	0	0	1.43	0	0	1.43	0	1.43
P9	0	0	0	0	0	0	0	0	.71	0.03	0	.71	.03	.74
P10	0	0	0	.12	0	0	0	0	1.03	0	0	1.02	.12	1.15
P11	0	0	0	0	0	0	0	0	.33	0	0	.33	0	.33
P12	0	0	0	0	0	0	0	0	.67	0	0	.67	0	.67
P13	0	.25	.21	.33	0	0	0	0	.54	0	0	.54	.79	1.33
P14	0	0	0	.33	0	0	0	0	1.08	0	0	1.07	.33	1.41
P15	.62	0	0	.15	0	.12	0	0	1.02	0	0	1.03	.89	1.93
P16	0	0	0	0	0	0	0	0	1.50	0	0	1.50	0	1.50
P17	0	.08	.08	.21	0	0	0	0	1.50	0	0	1.50	.37	1.87
P18	.10	.13	0	.63	0	0	0	0	1.40	0	0	1.41	.87	2.25
C1	.67	0	0	.12	0	0	0	0	1.43	0	.67	1.43	1.45	2.88
C2	0	0	0	0	0	0	0	0	1.50	0	0	1.50	0	1.50
C3	0	0	0	0	0	0	0	0	1.32	0	0	1.33	0	1.33
C4	.06	0	0	0	0	0	0	0	1.41	0	0	1.41	6	1.47
C5	0	0	0	0	0	0	0	0	1.09	0	0	1.09	0	1.09
C6	0	.05	0	0	0	0	0	0	1.48	0	0	1.48	.05	1.52
B1	.06	0	0	.06	0	0	0	0	1.41	0	0	1.41	.12	1.53
B2	0	0	0	0	0	0	0	0	1.25	.14	.03	1.25	.17	1.42

Table 13. Wetted stream widths observed at sites on the main-stem Powder River, Wyoming, 2004–06.

[Median stream widths that do not share the same letter under homogeneous groups are statistically different (Dunn's test, P < 0.05)]

Site number and location on Powder River (fig. 1)	Wetted stream width		Homogeneous groups for median stream widths				
	Median (meters)	Range (meters)					
P1, above Salt Creek	12.0	1.7–39.3	A				
P2, below Salt Creek	14.0	6.2–42.7	A	B			
P3, above Pumpkin Creek	18.0	1.2–38.8		B	C		
P4, below Burger Draw	20.1	4.3–52.0			C	D	
P5, above Crazy Woman Creek	21.6	2.1–49.4			C	D	
P8, below Crazy Woman Creek	26.4	1.8–52. 4				D	E
P9, above Clear Creek	23.2	3.2–50.0				D	
P11, below Clear Creek	32.6	6.4–59.5					E

Table 14. Mean, maximum, and residual pool depths observed at sites on the main-stem Powder River, Wyoming, 2004–06.

Site number and location on Powder River (fig. 1)	Depth (meters)		Maximum depth (meters)		Residual pool depth (meters)	
	Mean	Range	Mean	Range	Mean	Range
P1, above Salt Creek	0.21	0.03–0.67	0.46	0.03–1.22	0.55	0.34–1.01
P2, below Salt Creek	.18	0.03–0.55	.46	0.03–1.16	.46	0.30–0.70
P3, above Pumpkin Creek	.18	0.03–0.49	.49	0.06–1.83	.73	0.30–1.71
P4, below Burger Draw	.21	0.03–0.67	.34	0.03–1.13	.52	0.34–0.73
P5, above Crazy Woman Creek	.15	0.03–0.58	.40	0.03–2.13	.46	0.34–0.79
P8, below Crazy Woman Creek	.27	0.03–1.16	.43	0.06–1.52	.55	0.30–1.13
P9, above Clear Creek	.24	0.03–1.07	.40	0.06–1.10	.52	0.37–0.76
P11, below Clear Creek	.27	0.03–0.91	.40	0.06–1.52	.52	0.52–1.01

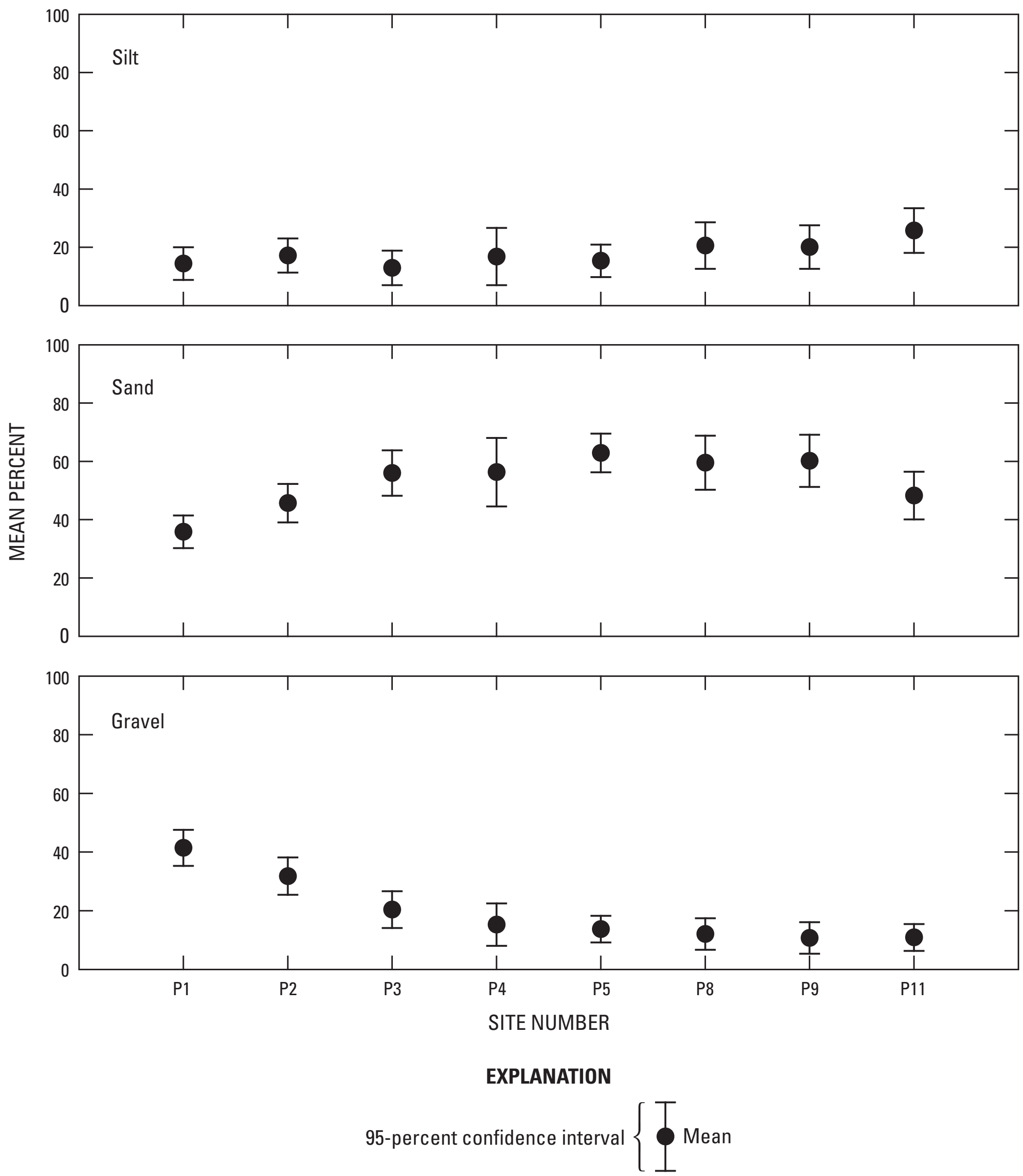

Figure 14. Mean percentages of silt, sand, and gravel observed at sites sampled during flow in the main-stem Powder River, Wyoming, 2004–06.

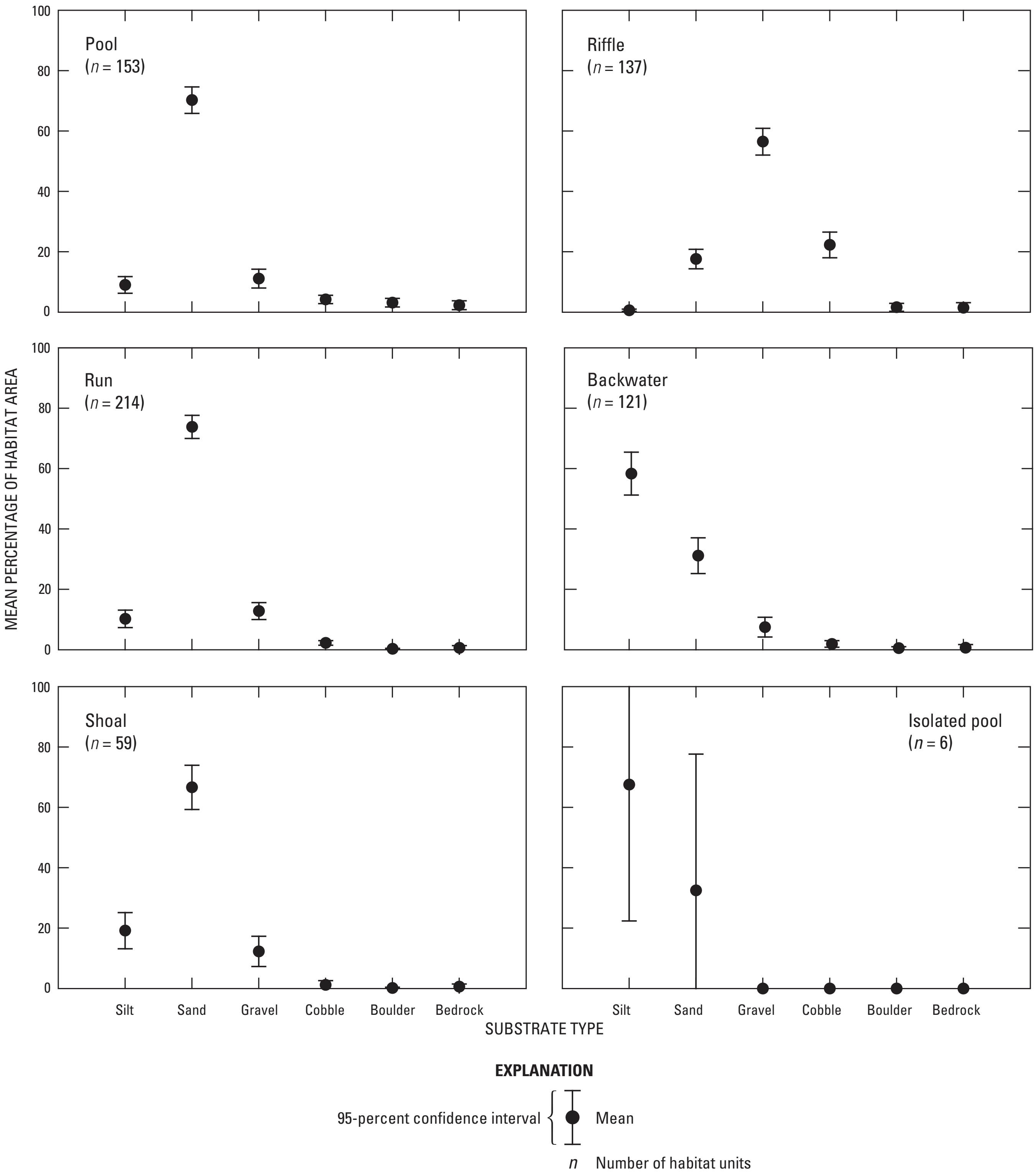

Figure 15. Mean percentage of substrate size by habitat type surveyed during flow in the main-stem Powder River, Wyoming, 2004–06.

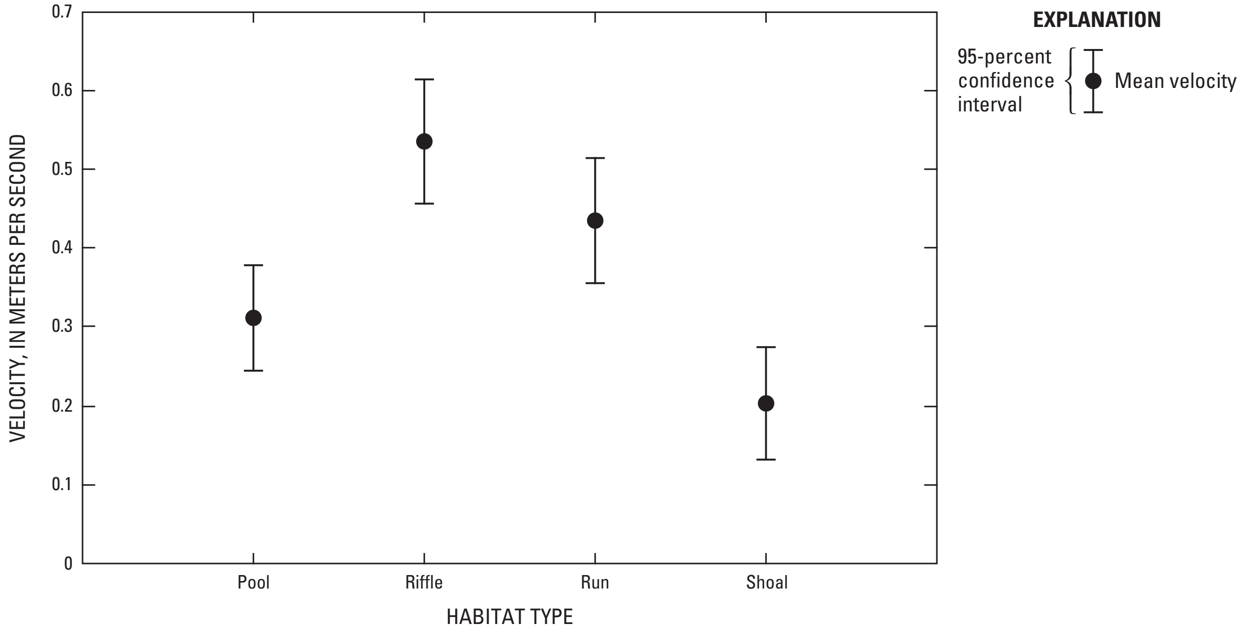

Figure 16. Mean stream velocity of habitat units categorized as pool, riffle, run, or shoal during periods of sample collection on the main-stem Powder River, Wyoming, 2004–06.

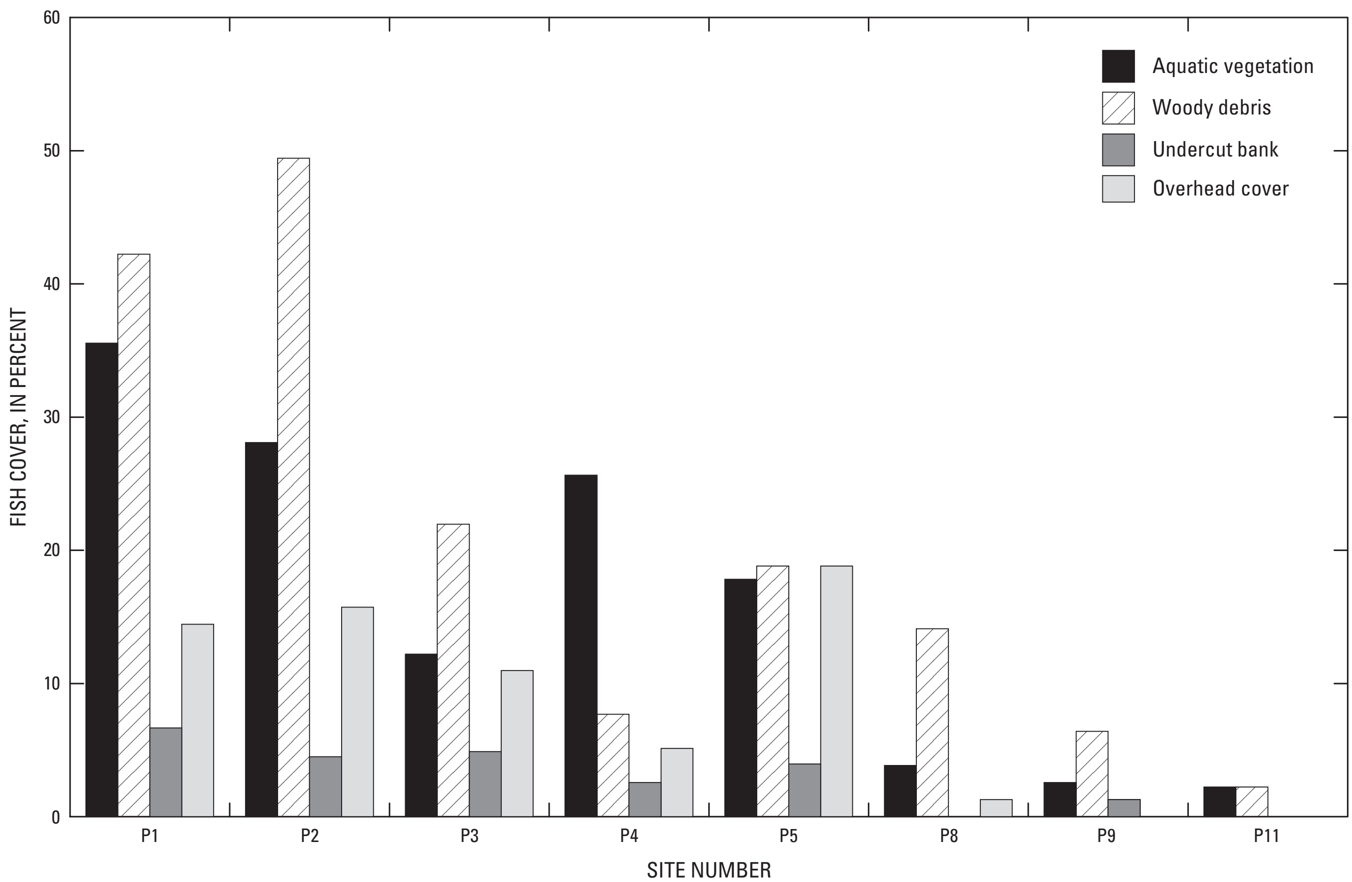

Figure 17. Fish cover at sampling sites on the main-stem Powder River, Wyoming, 2004–06.

probably lasting less than a week. However, some isolated pools, such as one at the end of the stream reach at site P5, were fairly large and recurred from one year to the next.

High-resolution GPS units were used to map stream habitat types at main-stem Powder River sites in Wyoming during three different flow periods in 2005 (May, July, and August that generally corresponded with high, middle, and low flows, respectively), with the exception of Powder River above Pumpkin Creek (site P3) where streamflow was similar in July and August. Percentages of habitat types were calculated for each site and flow period. These values then were averaged for each site to identify general differences or tendencies among the study sites. Runs were the most extensive habitat feature at all the main-stem sites (fig. 18), accounting for more than 80 percent of the habitat at all of the sites except below Burger Draw (site P4). The Powder River below Clear Creek (site P11) had the largest percentage of pool habitat among the main-stem sites. Riffle habitat tended to be greater at the upstream Powder River sites (fig. 18) and was largest at the Powder River below Burger Draw (site P4). Shoal habitat was greatest at Powder River above Crazy Woman Creek (site P5) and smallest at Powder River above Salt Creek (site P1) and Powder River below Clear Creek (site P11). Additional information regarding the methodology and results of the GPS mapping and transect-based estimates of habitat can be found in Wyoming Game and Fish Department (2007).

Analysis of habitat types mapped during the high-, middle-, and low-flow periods in 2005 indicated some changes between time periods, but none were consistent among all sites (Wyoming Game and Fish Department, 2007). Riffle percentages, for example, appeared to increase at some sites, decrease at others, and remain relatively unchanged at still other sites as flow declined. Shoals were more common at lower flows, except at the uppermost and lowermost sites where they were uncommon habitat types at all flows. With the exception of the site on the Powder River above Clear Creek (site P9) where pools were always a very small percentage of total wetted area, pools accounted for their smallest relative percentage of total habitat during the high-flow visit. Percentages of backwater habitats generally were larger during the middle- or low-flow visit, except for the sites on the Powder River below Crazy Woman Creek (site P8), Powder River above Clear Creek (site P9), and Powder River below Clear Creek (site P11, fig. 19) where overall percentages of backwater were consistently small.

In 2006, all of the Powder River sites in Wyoming were revisited; however, each site was sampled only once. Flow during sampling in 2006 was extremely low during the last week of July, and zero flow occurred during the first week of August. Data for the USGS gage at Moorhead, Mont. (fig. 3*A*), show mean daily flows were less than 1 cubic foot per second (ft^3/s) during the 2006 sampling activities, including 1 day of no flow on August 1.

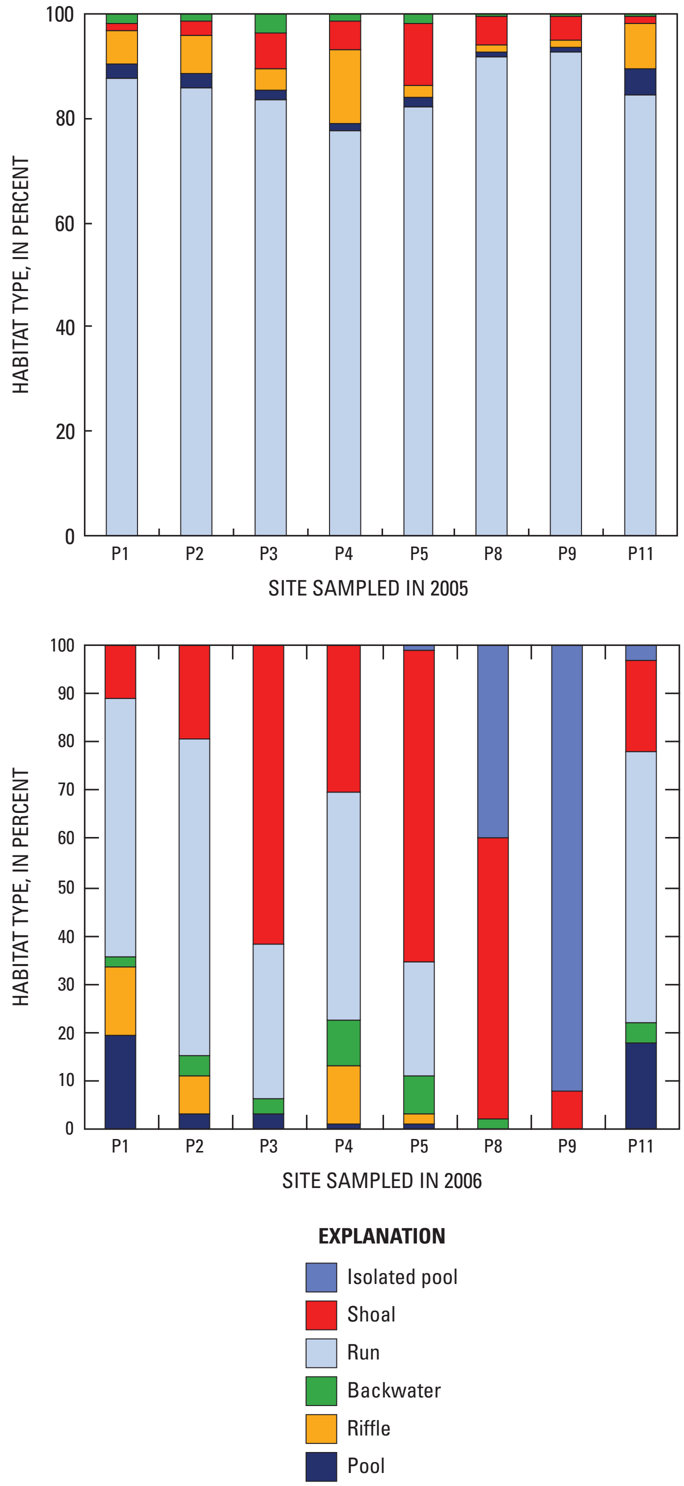

Figure 18. Habitat types determined from global positioning system mapping in 2005 and from transects in 2006 at eight sampling sites on the main-stem Powder River, Wyoming.

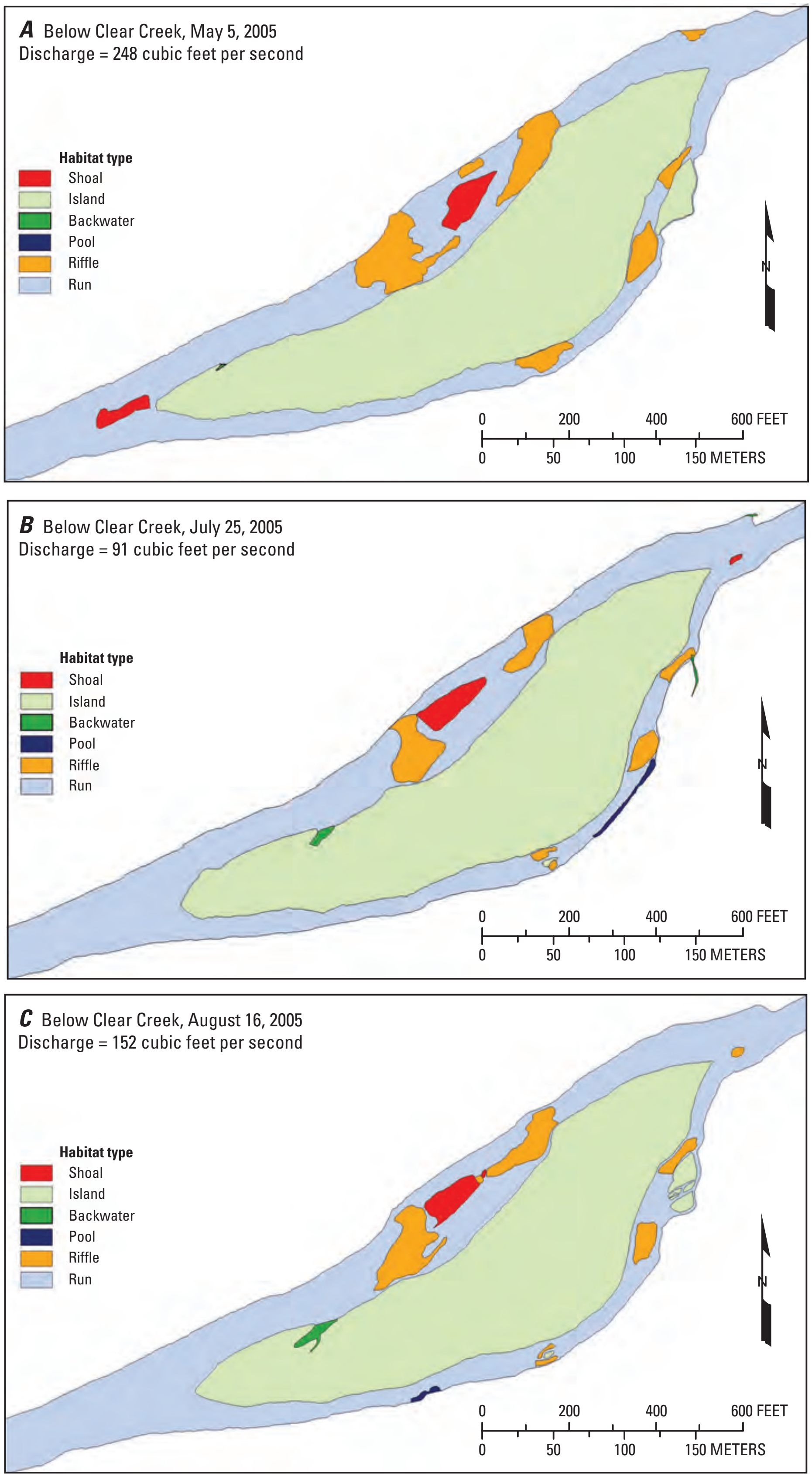

Figure 19. Habitat composition at varying flows in *A*, May; *B*, July; and *C*, August 2005 for a segment of the Powder River below Clear Creek, Wyoming (site P11).

Percentages of habitats identified during transect-based sampling during 2006 are presented in figure 18. Site P1 (Powder River above Salt Creek) had larger percentages of pool and riffle habitat than other sites. The site on the Powder below Salt Creek (site P2) had the largest relative run percentage, and the Powder River above Pumpkin Creek (site P3) is notable for its large percentage of shoal habitat. The Powder River below Burger Draw (site P4) had a small percentage of pool habitat, the second largest riffle percentage, and the largest percentage of backwater habitat (fig. 18). Site P5 is notable for large percentages of backwater and shoals. Sites P8 (Powder River below Crazy Woman Creek) and P9 (Powder River above Clear Creek) did not have streamflow, and most habitat types were not present (Wyoming Game and Fish Department, 2007).

Macroinvertebrate Community Assessment

Macroinvertebrate samples were collected from riffles when present in the sample reach (RTH samples) and from multiple habitats (qualitative, QMH samples) at each site regardless of whether riffles were present. These samples were collected during 2005–06.

Community Characteristics at Sites with Riffles

Macroinvertebrate samples were collected from riffles at 37 sites in 2005 and at 20 sites in 2006. Fewer sites were sampled in 2006 than in 2005 because of the drier conditions (fewer sites with flowing water) and study constraints in 2006.

Community Composition

The number of macroinvertebrate taxa per sample (taxa richness) in the 2005–06 PRB data varied considerably from 5 taxa identified in Pumpkin Creek (site T19) in 2005 to 47 taxa identified in upper Hanging Woman Creek (site T11), also in 2005 (table 15). A mean of 28 macroinvertebrate taxa per sample was identified after removal of ambiguous taxa. The Chironomidae (midges, Diptera) were the most common group, comprising a mean of 35 percent of the taxa identified per sample. The Ephemeroptera (mayflies) comprised a mean of about 18 percent of the taxa, and the Trichoptera (caddisflies) comprised a mean of about 13 percent of the taxa identified per sample. The remainder of the taxa included Plecoptera (stoneflies, 1 percent), noninsects (such as snails and worms, 8 percent), and other organisms such as Coleoptera (beetles) and Odonata (dragonflies and damselflies). In general, the proportion of Ephemeroptera, Plecoptera, and Trichoptera (EPT), both as number of taxa and relative abundance of organisms, is expected to be greater with good water-quality conditions, and the proportion of Chironomids and noninsects is expected to be greater in response to increasing perturbation (disturbance or decline in water quality; Barbour and others, 1999). These are general patterns, however, and the harsh environmental conditions (for example, large specific conductance values and flooding; Wangsness and Peterson, 1980) in streams of the PRB affect macroinvertebrate community composition regardless of anthropogenic effects.

Ephemeroptera accounted for a mean of about 24 percent of the relative abundance of individuals in the macroinvertebrate community. Mean values for other taxonomic groups in the samples were 22 percent for Trichoptera, 35 percent for Diptera (of which more than one-half were Chironomidae), 9 percent for Coleoptera, 8 percent for noninsects, and 0.4 percent for Odonata. The density of macroinvertebrates ranged from 144 to 19,592 individuals per square meter (individuals/m^2), with a mean of 4,100 individuals/m^2. The proportion of the single-most common taxon in each sample ranged from 13 to 98 percent with a mean of 43 percent. The proportion of the single-most dominant, or of the five most dominant taxa (table 15), can be used as an indicator of water quality because dominance is expected to increase in response to increasing perturbation (Barbour and others, 1999). Samples with the largest percentages of single dominant taxa were Pumpkin Creek (site T19, 98 percent), Cheyenne River near Spencer (site C6, 94 percent), Little Powder River above Dry Creek (site P15, 94 percent), and Little Thunder Creek (site C4, 94 percent); those four samples all were collected in 2005 and were dominated by blackfly larvae *Simulium*. Other taxa that dominated samples, but at smaller percentages, included *Baetis*, *Traverella albertana*, and *Tricorythodes* (Ephemeroptera), and *Cheumatopsyche* (Trichoptera).

The primary functional groups of the macroinvertebrate communities were gatherer-collectors (mean abundance of 40 percent) and filter-collectors (mean abundance of 43 percent). Gatherer-collectors are organisms that feed by moving to food patches, in contrast to filterer-collectors that generally are stationary and obtain food by filtering particles from flowing water (Merritt and Cummins, 1996). The expected response of the percentage of gather-collectors and filter-collectors to perturbation is variable (Barbour and others, 1999), but a shift in percentages can be an indicator of environmental changes. Other functional groups that were present in the samples, generally in small percentages, included predators, scrapers, and shredders.

Macroinvertebrate communities showed some similarities within river drainages on the basis of Bray-Curtis similarity coefficients (fig. 20). Four groups of relatively similar sites were identified; Tongue River main-stem and mountainous tributaries; Powder River main-stem; Tongue River plains tributaries; and the Cheyenne and Belle Fourche Rivers. Replicate macroinvertebrate samples collected for quality-control purposes plotted near to the parent samples indicating considerable similarity among parent and replicate samples (samples T1 and T1R; sites P6 and P6R; fig. 20).

The Tongue River group of samples in the lower-right corner of figure 20 includes all of the samples collected in 2005 from the main stem of the Tongue River as well as from tributaries with mountainous headwaters—Goose Creek, Clear Creek, and Crazy Woman Creek. Although two of

Table 15. Macroinvertebrate metrics for samples collected from riffles, Powder River Structural Basin, Wyoming and Montana, 2005–06.

[Shaded cells indicate main-stem sites on the Tongue or Powder River. m², square meter]

Site number (fig. 1)	Sample date	Taxa richness						Density (number/m²)	Taxa percentage abundance							Functional group richness					Functional group percentage abundance				
		Total	Ephemeroptera	Plecoptera	Trichoptera	Chironomidae	Noninsect taxa		Ephemeroptera	Plecoptera	Trichoptera	Chironomidae	Noninsects	Dominant taxon	Dominant five taxa	Predator taxa	Gatherer-collector taxa	Filterer-collector taxa	Scraper taxa	Shredder taxa	Predator	Gatherer-collector	Filterer-collector	Scraper	Shredder
R2	9/15/2005	28	4	0	2	5	3	237	2	0	19	10	14	26	70	11	10	2	3	1	18	23	19	39	0
T1	8/15/2005	35	8	0	8	5	5	2,274	76	0	14	2	3	33	81	6	15	4	5	2	3	79	12	4	2
T1	8/23/2006	34	7	0	7	9	4	14,808	32	0	33	9	3	25	72	4	13	6	5	2	3	51	12	26	1
T2	8/17/2005	26	8	0	4	5	4	4,394	57	0	16	1	10	27	72	5	12	4	2	1	7	72	15	5	0
T2	8/22/2006	29	6	0	4	8	4	8,984	42	0	7	7	1	32	86	5	12	4	3	2	2	75	6	12	1
T3	6/15/2005	35	1	0	6	11	5	3,871	34	0	3	3	11	42	86	7	12	8	3	1	2	44	50	3	0
T3	6/28/2006	37	2	1	5	13	5	4,198	37	0	33	7	5	37	78	7	14	8	3	2	3	58	34	5	1
T4	6/14/2005	39	2	0	2	19	6	1,537	12	0	7	19	41	24	59	5	21	4	4	1	6	57	19	10	0
T4	6/27/2006	35	2	0	3	17	5	5,647	6	0	15	11	45	36	74	10	13	5	2	3	3	52	30	11	2
T5	8/15/2005	30	7	0	4	7	1	8,452	44	0	30	3	2	26	77	6	9	6	4	1	1	62	31	4	1
T5	8/22/2006	32	7	0	6	8	5	1,323	25	0	17	6	12	32	75	6	12	5	5	1	5	61	15	18	0
T7	6/13/2005	39	2	0	1	16	4	2,571	1	0	1	49	15	25	70	15	18	1	1	2	10	59	25	4	1
T8	8/25/2006	28	2	0	5	11	1	3,830	20	0	32	10	0	27	81	5	11	6	4	0	3	48	35	13	0
T9	9/14/2005	31	5	1	7	12	0	7,763	69	0	14	9	0	55	76	6	13	6	3	2	3	74	17	3	1
T9	8/24/2006	33	6	0	5	7	8	6,791	39	0	13	3	9	28	78	9	11	6	3	1	10	71	11	7	0
T10	8/16/2005	31	6	0	5	8	7	1,340	26	0	19	17	12	20	66	5	12	6	5	1	8	56	15	19	1
T10	8/28/2006	24	4	0	4	4	4	2,338	7	0	10	1	9	68	88	5	9	4	4	0	1	77	12	10	0
T11	6/22/2005	47	1	0	0	27	2	654	0	0	0	61	24	27	71	19	21	2	1	3	17	58	4	19	2
T12	6/21/2005	44	2	0	2	18	5	1,907	4	0	4	31	48	28	68	15	16	4	3	2	21	40	7	29	1
T13	6/23/2005	40	3	0	0	18	3	1,934	2	0	0	23	56	29	72	15	14	2	3	4	17	38	12	31	1
T14	9/12/2005	24	7	0	6	4	0	7,760	67	0	26	1	0	45	79	3	10	5	4	0	1	66	26	7	0
T14	8/28/2006	30	9	1	6	6	2	1,248	46	1	36	2	0	24	73	6	11	6	4	1	2	48	37	12	0
T17	6/30/2005	31	1	0	3	15	4	2,806	1	0	51	13	3	46	84	6	13	6	3	0	4	9	79	3	0

Table 15. Macroinvertebrate metrics for samples collected from riffles, Powder River Structural Basin, Wyoming and Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sites on the Tongue or Powder River. m², square meter]

Site number (fig. 1)	Sample date	Taxa richness						Density (number/m²)	Taxa percentage abundance							Functional group richness					Functional group percentage abundance				
		Total	Ephemeroptera	Plecoptera	Trichoptera	Chironomidae	Noninsect taxa		Ephemeroptera	Plecoptera	Trichoptera	Chironomidae	Noninsects	Dominant taxon	Dominant five taxa	Predator taxa	Gatherer-collector taxa	Filterer-collector taxa	Scraper taxa	Shredder taxa	Predator	Gatherer-collector	Filterer-collector	Scraper	Shredder
T17	6/28/2006	26	2	0	4	11	4	19,592	0	0	23	7	7	57	89	3	12	6	1	1	1	7	90	1	0
T18	9/13/2005	30	7	1	5	10	0	1,285	39	1	37	15	0	27	75	6	10	7	3	1	3	40	38	7	1
T18	8/31/2006	38	10	2	8	10	1	1,109	55	1	23	3	0	29	65	9	14	5	9	1	3	58	20	18	0
T19	6/23/2005	5	0	0	1	3	0	8,423	0	0	0	1	0	98	100	2	1	2	0	0	1	0	99	0	0
P1	7/20/2005	38	7	0	3	22	2	3,035	18	0	28	43	4	13	52	7	21	5	3	0	13	46	33	6	0
P1	7/24/2006	34	7	0	3	16	1	2,422	32	0	26	34	1	21	66	9	13	5	4	1	9	50	37	1	3
P2	7/21/2005	20	4	0	3	10	0	3,864	9	0	5	86	0	57	84	6	5	4	2	1	7	13	59	3	7
P2	7/25/2006	33	4	0	3	17	1	6,891	6	0	10	77	0	23	69	8	13	6	1	1	6	57	29	0	3
P3	7/19/2005	21	5	0	1	8	1	1,480	16	0	10	7	0	65	93	7	6	4	1	1	4	12	76	7	1
P3	7/26/2006	28	4	1	4	10	1	2,869	14	0	57	19	1	53	89	7	10	5	4	1	7	18	73	1	1
P4	7/22/2005	17	4	1	2	7	0	348	9	0	46	15	0	41	82	4	6	4	1	1	12	12	71	0	2
P4	7/27/2006	24	1	1	4	12	1	3,826	1	0	36	52	5	41	83	6	8	4	3	1	11	5	78	5	1
P5	7/13/2005	16	5	0	2	5	1	1,346	12	0	18	2	1	66	97	2	7	4	0	1	1	13	85	0	0
P5	7/28/2006	21	5	1	4	6	0	275	8	0	59	15	0	37	81	5	7	5	2	2	16	17	64	1	2
P6	7/11/2005	34	8	0	4	10	3	2,035	53	0	23	6	5	29	68	6	14	5	4	1	2	59	32	4	1
P7	7/12/2005	17	6	0	3	2	1	5,655	5	0	6	0	0	85	95	3	6	4	1	1	2	6	92	0	0
P8	7/23/2005	34	4	0	2	18	1	290	6	0	20	55	3	25	61	9	14	5	1	2	17	24	51	0	6
P9	7/24/2005	32	6	0	1	17	2	144	11	0	4	45	2	21	58	8	15	3	2	2	30	21	31	1	15
P10	9/13/2005	17	6	0	4	3	1	5,069	74	0	20	0	0	62	92	2	7	4	3	0	0	79	20	1	0
P10	8/21/2006	34	5	0	6	10	5	16,800	18	0	42	9	4	30	74	10	12	5	4	1	3	45	42	9	2
P11	7/25/2005	26	12	0	3	4	1	3,673	49	0	32	1	0	16	67	3	12	5	4	1	1	40	49	10	0
P11	8/3/2006	24	3	1	4	8	2	2,729	5	0	67	11	3	45	86	8	7	3	4	1	2	23	69	3	3
P12	7/26/2005	29	7	0	5	9	1	925	34	0	32	12	3	19	79	6	9	4	7	1	2	37	49	3	9

Table 15. Macroinvertebrate metrics for samples collected from riffles, Powder River Structural Basin, Wyoming and Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sites on the Tongue or Powder River. m^2, square meter]

Site number (fig. 1)	Sample date	Taxa richness						Density (number/m^2)	Taxa percentage abundance							Functional group richness					Functional group percentage abundance				
		Total	Ephemeroptera	Plecoptera	Trichoptera	Chironomidae	Noninsect taxa		Ephemeroptera	Plecoptera	Trichoptera	Chironomidae	Noninsects	Dominant taxon	Dominant five taxa	Predator taxa	Gatherer-collector taxa	Filterer-collector taxa	Scraper taxa	Shredder taxa	Predator	Gatherer-collector	Filterer-collector	Scraper	Shredder
P13	7/19/2005	10	5	1	1	1	0	2,646	66	0	1	0	0	65	99	3	5	2	0	0	1	66	34	0	0
P13	8/2/2006	28	4	1	6	10	2	1,872	15	0	55	18	2	47	80	7	10	4	4	1	11	24	54	6	5
P15	6/13/2005	12	2	0	2	5	1	10,181	1	0	2	1	0	94	99	2	5	3	1	0	0	2	96	0	0
P15	6/23/2006	29	2	0	4	11	2	4,427	1	0	91	4	1	77	94	7	11	4	2	1	4	3	91	1	0
P16	6/27/2005	37	2	0	3	19	3	502	3	0	47	24	2	38	66	8	17	4	3	1	9	13	58	8	0
P17	7/21/2005	20	6	1	3	6	1	506	59	0	18	13	0	41	82	5	8	3	1	2	3	69	26	1	2
P18	7/22/2005	9	4	1	2	1	0	8,825	74	0	7	0	0	74	100	1	5	3	0	0	0	74	25	0	0
C3	6/27/2005	28	2	0	2	16	3	2,136	3	0	0	28	51	38	84	7	14	3	1	0	4	35	18	42	0
C4	6/9/2005	16	1	0	0	7	2	4,275	1	0	0	2	1	94	98	5	5	3	1	0	1	3	95	0	0
C6	6/6/2005	18	1	0	1	10	1	2,708	0	0	0	4	1	94	98	5	8	2	1	1	3	2	94	1	0
B1	6/29/2005	17	1	0	1	7	2	3,740	0	0	1	2	19	76	98	6	7	1	0	0	2	20	77	0	0

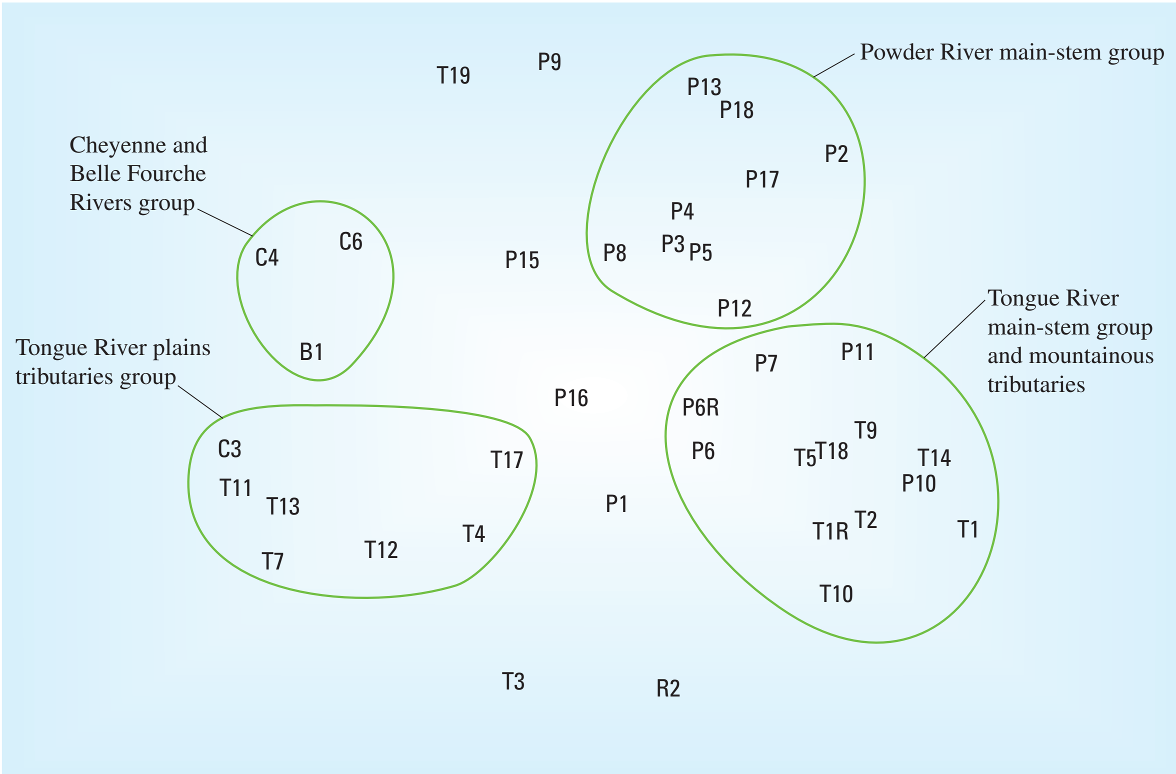

Figure 20. Similarities of macroinvertebrate communities within stream drainages depicted by nonmetric multidimensional scaling ordination, Powder River Structural Basin, 2005.

the three tributaries drain to the Powder River, the common variable among the three tributaries and the main stem of the Tongue River is their origin in the Bighorn Mountains. The inclusion of site P11, Powder River below Clear Creek, in the Tongue River group might be a reflection of the effect of Clear Creek on the main stem of the Powder River. The Tongue River group generally is characterized by relatively large Ephemeroptera taxa richness and relative abundance, and smaller percentages of Chironomidae and noninsects than the mean of the 2005–06 riffle samples (PRB mean). The Tongue River group also has a relatively large percentage of the gatherer-collector functional group with a mean abundance of 60 percent. Dominant taxa in the Tongue River group include Ephemeroptera such as *Baetis*, *Tricorythodes*, and *Fallceon quilleri*, although caddisfly larvae such as *Hydropsyche* and *Cheumatopsyche*, riffle beetles *Microcylloepus pusillus*, and blackfly larvae *Simulium* also occur in the dominant five taxa.

Macroinvertebrate communities from the main stem of the Powder River during 2005 form a group in the upper right corner of figure 20. The Powder River main-stem group is characterized by slightly fewer taxa (mean of 20 taxa per sample), with greater relative abundance of Ephemeroptera and Chironomidae, and less relative abundance of Trichoptera and noninsects, than the PRB mean. Filterer-collectors, such as *Simulium* and *Cheumatopsyche*, had a mean abundance of 53 percent, which is larger than the PRB mean of 43 percent. Chironomidae, including *Tanytarsus* and *Cricotopus*, were among the dominant five taxa at some of the sites in the upstream part of the main-stem Powder River. The mayfly *Traverella albertana* dominated the 2005 samples from the downstream part of the Powder River (sites P13, P17, and P18).

Macroinvertebrate communities from the Tongue River tributaries with plains origins, including Hanging Woman Creek, Squirrel Creek, and Youngs Creek, are somewhat similar to each other and form a group in the lower left of figure 20. The Tongue River plains tributaries group contained a mean of 40 taxa per sample, which is relatively large; noninsects and Chironomidae had a mean abundance of 74 percent. Dominant taxa in the Tongue River plains tributaries group included snails, *Physa* and *Lymnaea*, the scud (Crustacea) *Hyallela azteca*, and the Chironomid *Micropsectra*.

Some of the 2005 samples from the Cheyenne and Belle Fourche River drainages had macroinvertebrate communities that were somewhat similar to each other (fig. 20, left center). A few samples, such as from Rosebud Creek, Pumpkin Creek, and the Little Powder River, were either loosely or not associated with communities at other sites.

Clustering and ordination of the 2006 macroinvertebrate data indicated persistence of two of the main groups observed from the 2005 data. The groups in the 2006 macroinvertebrate communities are the Tongue River and mountainous tributaries and the main stem of the Powder River (fig. 21). Macroinvertebrate communities in the Tongue River group contained a

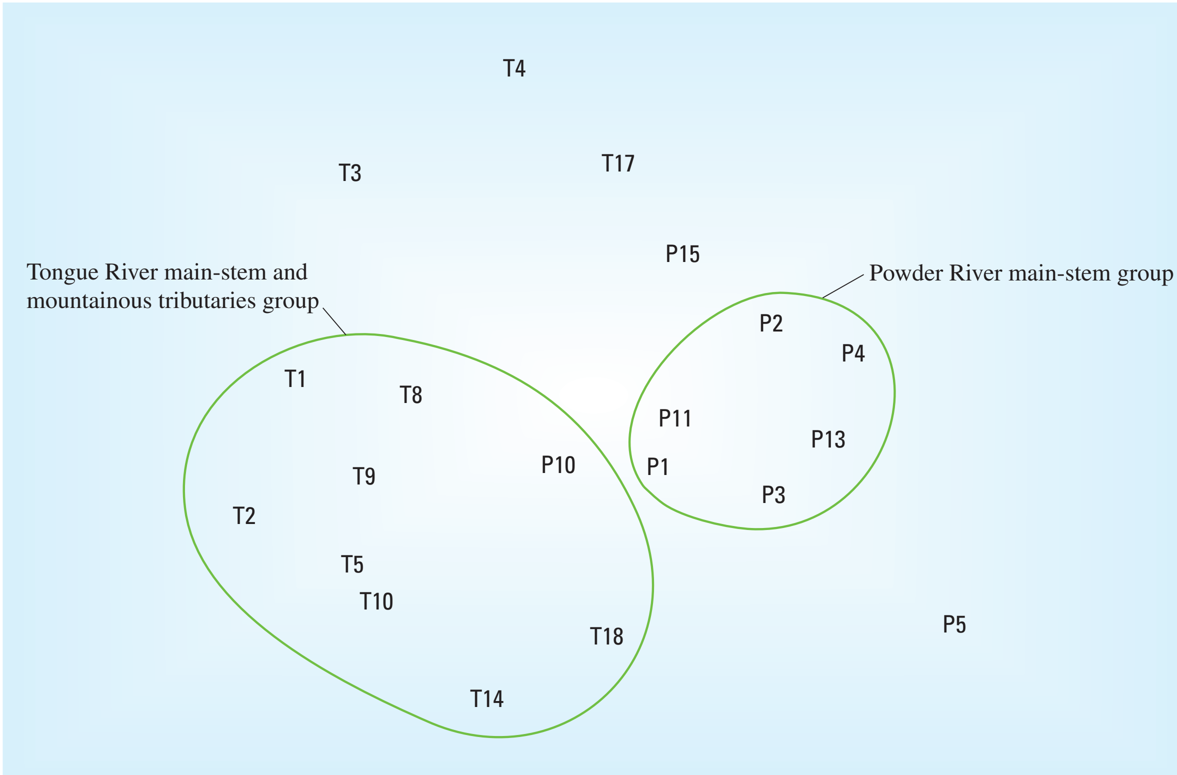

Figure 21. Similarities of macroinvertebrate communities within stream drainages depicted by nonmetric multidimensional scaling ordination, Powder River Structural Basin, 2006.

smaller mean percentage of Ephemeroptera relative abundance in 2006 (32 percent) than in 2005 (54 percent) but were still slightly larger than the PRB mean (25 percent). The mean relative abundances of Chironomidae and noninsects in 2006 were similar to those in 2005 and were less than the PRB mean. Dominant taxa in the Tongue River group for 2006 included *Tricorythodes*, *Microcylloepus pusillus*, *Chimarra* (Trichoptera: Philopotamidae), *Fallceon quilleri*, and *Hydropsyche*. As in 2005, the 2006 samples from the Tongue River group contained larger mean percentages of collector-gatherers and smaller percentages of filterer-collectors than the PRB mean.

Macroinvertebrate communities from sites on the main stem of the Powder River generally were grouped together (fig. 21), but the group contained fewer sites in 2006 than 2005 because some of the sites on the main stem had no flow (pools present but not riffles) in 2006. Taxa richness in the Powder River group was greater in 2006 (mean of 28 taxa per sample) than in 2005 (mean of 20 taxa per sample), and the community composition was somewhat different. The communities consisted of a larger mean relative abundance of Trichoptera and Chironomidae and smaller mean relative abundance of Ephemeroptera in 2006 than in 2005. Dominant taxa in 2006 included *Cheumatopsyche* and *Tanytarsus*, similar to 2005, but *Simulium* was not among the dominant five taxa in 2006 as it was in 2005. The difference in community composition between years could be a reflection of different environmental conditions, the different number of sites sampled, or some combination of those factors. The predominant functional group of the macroinvertebrate communities of the main-stem Powder River sites in 2006 was the filter-collector group (mean abundance of 57 percent), similar to 2005. The sample from site P5, Powder River above Crazy Woman Creek, was an outlier from the main-stem Powder River group in 2006, perhaps due to smaller taxa richness and smaller percentage of Chironomids at site P5 compared to other sites on the main stem.

Effect of Environmental Variables on Macroinvertebrate Communities

Environmental variables that were assessed for effect on macroinvertebrate communities fell into three main categories—geographic, habitat, and water-quality variables. Geographic variables included location (northing and easting), drainage area, elevation, and the reachwide estimate of riparian disturbance. Habitat variables were selected from the reachwide measurements presented previously in this report in the “Habitat Characteristics of Streams in the Powder River Structural Basin” section and microhabitat variables that were measured at the point of the macroinvertebrate sample collections (table 27 in Appendix 1). The PCA of the habitat data indicated seven habitat variables were best suited to carry forward in further analyses. These variables were mean reachwide embeddedness, percentage of gravel or larger substrate, mean wetted width, mean bankfull height above water surface, microhabitat velocity, fish cover, and thalweg depth (table 16). Water-quality variables included major ions and onsite measurements of specific conductance, pH, water temperature, dissolved oxygen, and turbidity that were collected with the macroinvertebrate samples (table 28 in Appendix 1); streamflow was included with the water-quality variables because of the relation between water chemistry and streamflow (Clark and Mason, 2007). Variables selected on the basis of the PCA in the water-quality data set were streamflow, specific conductance, water temperature, calcium, magnesium, and turbidity; alkalinity also was carried forward because of potential toxicity of bicarbonate (Skaar and others, 2006) and use of alkalinity in the Wyoming O/E model (Hargett and others, 2007).

The PCA analysis of the final environmental variables indicated the linear combinations of the variables that best explained the variation in the data (table 17). Streamflow and wetted width were strongly and positively correlated with PCA axis 1 as indicated by the relatively large values of the eigenvectors (a measure of association) for those variables in table 17. Specific conductance, magnesium, and alkalinity were negatively correlated with PCA axis 1. The variables associated with PCA axis 1 cumulatively explain 29 percent of the variability in the environmental data. The variables most strongly correlated with PCA axis 2 were calcium (positive) and fish cover (negative: table 17). The variables associated with PCA axis 2 explain 22 percent of the variability in the environmental data. Together, PCA axes 1 and 2 explain 51 percent of the variability in the environmental data. Eigenvectors listed in table 17 also are shown in figure 22, where the length and direction of the vector in the figure corresponds to the positive or negative values in the table. Eigenvectors were computed for additional axes 3 to 5, but the data are not shown because they explained only a small amount of the variability.

The PCA ordination also can be used to show relations among sampling sites on the basis of differences in the environmental variables. Main-stem sites on the Tongue and Powder Rivers plotted to the right (positive values) on PCA axis 1 (fig. 22) because of their higher streamflow and greater widths, whereas smaller streams with large specific conductance values and larger magnesium concentrations, such as Squirrel Creek (site T7) and Hanging Woman Creek (sites T11 and T12), plotted to the left (negative values) on axis 1. Sites with large calcium concentrations, such as sites C3 and C6 on the Cheyenne River, plotted near the top of figure 22, whereas sites with large values for fish cover tended to plot near the bottom (for example, site R2 on Rosebud Creek, site T4 on Youngs Creek, and site T12 on Hanging Woman Creek).

Some of the environmental variables that were important in describing variability among sites also were correlated with the macroinvertebrate communities. The environmental variables listed in table 16 were tested against the Bray-Curtis similarity indices of the macroinvertebrate communities, using the BEST routine (Clarke and Gorley, 2006). Two combinations of five environmental variables were identified that produced the best correlation (largest values of Spearman's rho, ρ) between environmental variables and the macroinvertebrate communities. Streamflow and magnesium, which were correlated with PCA axis 1, were in the first combination along with drainage area, easting, and embeddedness ($\rho = 0.66$). A second combination, also using streamflow, drainage area, easting, and embeddedness but using specific conductance in place of magnesium, also indicated $\rho = 0.66$. Successive iterations from the BEST routine indicated substrate, thalweg depth, and alkalinity also were useful explanatory variables associated with slightly smaller correlation coefficients.

The correlations of the environmental variables with the macroinvertebrate communities determined from the BEST routine also are evident to some degree from the PCA and NMDS ordinations. Streamflow, for example, was identified as an important variable from the BEST and PCA routines. Sites with high streamflow, such as sites T10, T14, and T18 on the main stem of the Tongue River, were grouped together in the NMDS ordination (fig. 20) and plotted along the upper end of PCA axis 1 (fig. 22). Specific conductance, magnesium, and alkalinity were identified from the BEST and PCA routines. Sites in the Tongue River plains tributaries group of the NMDS ordination, such as Squirrel Creek and Hanging Woman Creek, generally had relatively large concentrations of magnesium and alkalinity but large specific conductance values were not confined to that group.

The relations between macroinvertebrate communities and environmental variables described in this section should be considered tentative in part because they are based on only 1 year (2005) of data. This analysis is constrained to the 2005 data for consistency and because fewer data were collected during 2006 by design and because of drought. Additional sampling and data analysis would be required to confirm the patterns described and to better determine which variables have the most effect on the macroinvertebrate communities of the PRB.

Table 16. Environmental variables tested for correlation with macroinvertebrate communities, Powder River Structural Basin, Wyoming and Montana, 2005.

[Shaded cells indicate main-stem sampling sites on the Tongue or Powder River. UTM, Universal Transverse Mercator; km², square kilometers; NGVD 29; National Geodetic Vertical Datum of 1929; Riparian disturbance index, proximity-weighted disturbance value from table 12; °C, degrees Celsius; ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; NTU, nephelometric turbidity units; embed, embeddedness; m, meters; m/s; meters per second; cm, centimeters]

Site number (fig. 1)	Northing (UTM)	Easting (UTM)	Drainage area (km²)	Elevation (meters above NGVD 29)	Riparian disturbance index	Streamflow (ft³/s)	Specific conductance (µS/cm)	Water temperature (°C)
R2	5124517.888	386333.771	3,372	756	1.33	0.01	4,300	12.5
T1	4973858.036	340495.082	1,238	1,104	.67	123	426	14.8
T2	4972252.878	342979.36	1,070	1,104	1.31	69	653	20.5
T3	4987865.115	343428.017	56	1,155	1.93	2.3	675	19
T4	4982029.167	348566.429	161	1,088	.49	0.99	1,690	12
T5	4984576.562	351846.947	3,711	1,058	2.44	171	544	19
T7	4986086.578	353305.488	112	972	.37	0.17	5,940	13
T9	4985576.746	355352.485	3,763	1,045	.66	162	655	13.6
T10	5014073.901	372568.691	5,208	890	1.65	408	363	20
T11	4998957.461	383277.047	831	954	2.12	.03	5,000	22.5
T12	5009470.727	382314.206	958	997	2.00	.04	3,870	24.5
T13	5017290.634	381784.208	1,217	960	3.32	.11	2,090	20.3
T14	5029715.78	385974.163	6,788	933	2.47	308	466	18.5
T17	5049075.745	402126.116	1,831	889	1.76	1.6	2,700	18
T18	5076962.445	405325.098	10,225	841	1.37	330	503	14.5
T19	5119648.757	446791.955	1,805	759	1.59	1.1	1,140	29.4
P1	4837546.759	386240.398	5,828	1,351	1.18	2.7	2,100	21.8
P2	4838293.577	393351.624	7,980	1,338	.14	13	4,990	23
P3	4863077.684	405281.187	9,808	1,311	1.13	9.3	4,810	24.3
P4	4889766.716	407729.405	11,111	1,216	.93	7.9	4,600	20.7
P5	4919955.969	409348.212	12,564	1,152	.93	25	3,500	26.1
P6	4901608.494	386626.475	1,769	1,280	.80	37	777	20.8
P7	4924960.865	402567.494	2,385	1,168	1.41	40	894	22.7
P8	4928773.725	412209.471	15,286	1,134	1.43	99	2,050	21.4
P9	4963029.492	416891.369	17,050	1,063	.74	149	2,280	24
P10	4969263.986	414514.112	2,875	1,069	1.15	35	1,200	13.6
P11	4971737.101	416543.372	20,106	1,059	.33	92	1,940	21.2
P12	4989743.314	430909.122	20,943	1,022	.67	76	1,930	18.2
P13	5030458.647	468600.245	22,657	920	1.33	111	1,690	22.5
P15	4974895.432	472160.404	3,204	1,040	1.93	3.8	3,480	13.6
P16	4994637.05	473972.815	3,991	991	1.50	7.6	2,720	17.5
P17	5042532.613	473714.003	29,503	909	1.87	85	1,820	28.5
P18	5141871.762	476225.295	33,846	727	2.25	90	1,970	21.3
C3	4808475.814	496335.272	39,55	1,314	1.32	0	3,070	21.3
C4	4833621.645	507615.667	606	1,341	1.47	.02	1,950	14.3
C6	4808073.951	570694.767	13,649	1,105	1.52	6.4	3,910	20.4
B1	4870218.204	468902.131	1,282	1,384	1.53	1	3,360	16.6

Table 16. Environmental variables tested for correlation with macroinvertebrate communities, Powder River Structural Basin, Wyoming and Montana, 2005.—Continued

[Shaded cells indicate main-stem sampling sites on the Tongue or Powder River. UTM, Universal Transmercator; km^2, square kilometers; NGVD 29; National Geodetic Vertical Datum of 1929; Riparian disturbance index, proximity-weighted disturbance value from table 12; °C, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; NTU, nephelometric turbidity units; embed, embeddedness; m, meters; m/s; meters per second; cm, centimeters]

Site number (fig. 1)	Calcium (mg/L)	Magnesium (mg/L)	Alkalinity (mg/L)	Turbidity (NTU)	Mean reach-wide embeddedness (percent)	Percentage of gravel or larger substrate	Mean wetted width (m)	Mean bankfull height (m above water surface)	Microhabitat velocity (m/s)	Reach-wide fish cover (percent)	Thalweg depth (cm)
R2	73.8	183	450	9.1	62	71	5.0	0.34	0.16	111	26
T1	44.2	19.6	167	30	50	71	19.0	.35	.42	65	63
T2	54.1	34.5	194	9	58	69	16.4	.65	.55	34	62
T3	55.1	38.2	293	62	90	4	2.2	.43	.81	54	31
T4	108	149	422	33	99	0	1.8	.64	.41	94	31
T5	56.9	31.9	210	48	69	40	30.0	.54	.94	17	88
T7	153	463	590	6.8	91	7	.9	.30	.24	25	18
T9	54.2	35.7	208	12	76	31	34.3	.59	.49	45	77
T10	37.2	17	130	13	55	69	29.2	.64	.59	37	101
T11	140	249	492	10	88	24	3.4	.40	.00	73	31
T12	81.8	200	414	9	91	16	2.7	.40	.19	81	24
T13	77.4	113	572	7	95	9	5.6	.40	.15	73	32
T14	44.9	22.3	160	10	71	43	26.7	.70	.58	33	79
T17	87.3	180	592	97	83	18	5.5	.05	.44	49	58
T18	45	23.6	156	16	56	49	25.4	.80	.83	53	112
T19	32	14.5	214	158	65	44	6.2	.40	.21	10	25
P1	175	74.7	177	4.7	69	12	14.1	1.13	.36	13	22
P2	113	75.4	288	16	72	32	15.0	1.26	.35	12	23
P3	183	111	187	2.9	86	18	26.6	1.17	.19	20	20
P4	115	100	318	4.1	70	30	21.9	.77	.21	9	26
P5	122	72.6	233	28	92	2	37.7	.93	.34	3	32
P6	79.9	40.5	122	58	77	16	8.6	1.05	.38	16	68
P7	82.5	40.7	145	120	81	38	9.0	.90	.66	17	58
P8	232	46.3	92	960	90	12	41.4	.84	.53	1	29
P9	287	77.5	101	1,000	98	8	29.4	.51	.41	5	41
P10	109	46.9	154	4.3	65	40	19.7	.61	.45	25	63
P11	206	59.8	132	420	78	28	37.5	1.05	.41	10	49
P12	79.9	36.1	153	619	65	29	47.0	.58	.31	11	37
P13	130	59.3	198	18	71	25	30.8	1.09	.63	13	60
P15	189	145	344	120	86	7	6.0	.85	.60	18	52
P16	152	84.8	246	810	76	45	5.3	.97	.67	10	61
P17	136	62.6	201	22	94	3	52.4	1.26	.30	5	50
P18	122	62	212	22	64	45	51.1	1.14	.40	9	40
C3	252	155	284	4.8	90	11	10.0	.72	.10	33	30
C4	82.5	61.9	225	41	53	22	3.4	.68	.05	52	52
C6	323	139	239	163	71	7	7.4	.39	.20	19	25
B1	112	151	90	3.8	96	2	6.0	.41	.17	81	6

Table 17. Eigenvectors from principal components analysis of environmental variables, Powder River Structural Basin, Wyoming and Montana, 2005.

Variable	Axis 1	Axis 2	Variable	Axis 1	Axis 2
Northing	0.121	–0.291	Alkalinity	–0.308	–0.177
Easting	–.009	.271	Turbidity	.149	.122
Drainage area	.251	.272	Embeddedness	–.216	.193
Elevation	–.106	.241	Substrate size	.208	–.281
Riparian disturbance	.023	–.124	Wetted width	.304	.171
Water temperature	.076	.255	Bankfull height	.188	.278
Streamflow	.374	.049	Microhabitat velocity	.275	–.135
Specific conductance	–.307	.185	Fish cover	–.192	–.352
Calcium	–.098	.379	Thalweg depth	.296	–.195
Magnesium	–.356	–.012			

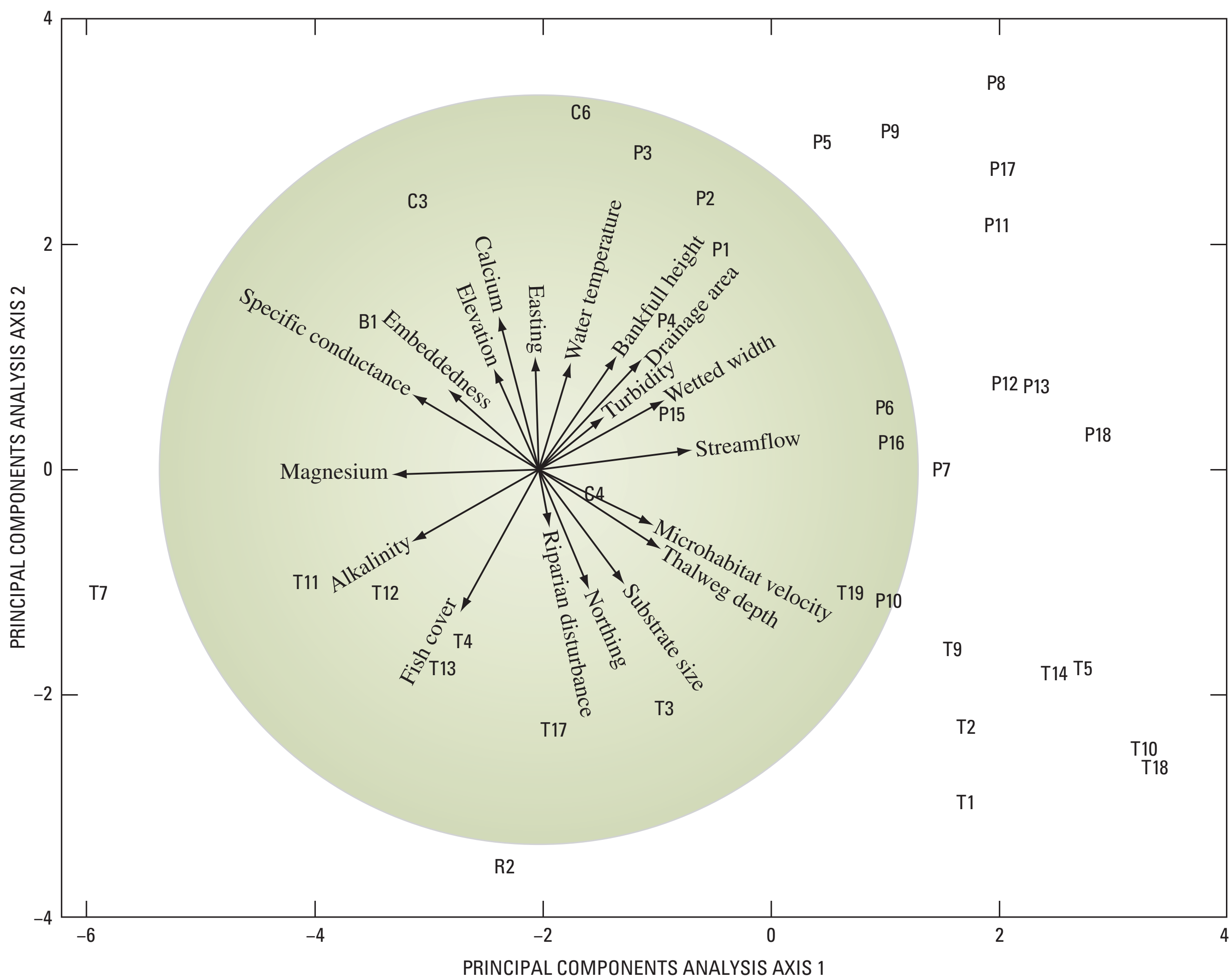

Figure 22. Principal components analysis showing relations among sampling sites based on selected environmental variables, Powder River Structural Basin, 2005. Environmental variables are listed in table 16.

Modeling and Metric Indices

The following sections present analyses of ATG macroinvertebrate data from riffle samples. Analyses included O/E models and MMIs developed by the States of Wyoming and Montana.

Wyoming Observed/Expected Index Biological Condition

Overall, the Wyoming O/E scores indicated biological condition was about the same in 2005 (mean = 0.54) as in 2006 (mean = 0.56) at sites where both years of data were collected; the difference between years was not significant (P > 0.05). During 2005–06, Wyoming O/E scores ranged from 0 at Powder River below Salt Creek (site P2) to 0.95 at Crazy Woman Creek below I-90 (site P6; table 18). The wide variety of biologic conditions in streams sampled for this study is reflected in the wide range of O/E scores (fig. 23).

Despite the variability in O/E scores, some general broad-scale patterns were identified. ATG sampling sites located on streams with mountain origins had higher O/E scores compared to sites on streams with plains origins. This is not surprising because water from mountain streams generally is of high quality as a result of persistent flows, cool water temperatures, small concentrations of dissolved constituents, and low turbidity. The PCA of environmental variables and macroinvertebrate communities by site validated this spatial pattern (fig. 22). Conversely, plains-origin streams in the region, such as the Powder River, are characterized by large dissolved concentrations and turbidity attributed to the erodible soils and geology in their drainages. Flow regimes of plains-origin streams are dependent on springs and intense precipitation. For both years, O/E scores generally were highest in the Tongue River drainage, followed by the Powder, Belle Fourche, and Cheyenne River drainages, respectively. Higher O/E scores in the Tongue River drainage are related to the dominance of higher quality snowmelt-driven streams with mountainous headwaters compared to the other drainages. An evaluation of the spatial and temporal patterns at the drainage scale is described in the following sections.

Tongue River Drainage

Among samples collected from three sites on the main stem of the Tongue River (sites T1, T5, and T9), the O/E score decreased slightly from 2005 (mean = 0.78) to 2006 (mean = 0.71), although the difference was not significant (P > 0.05; fig. 23). Overall, O/E scores were higher at site T1 than at site T9 in both 2005 and 2006 (fig. 23), partially due to absence of expected mayfly (*Ephemerella*), caddisfly (*Helicopsyche* and *Nectopsyche*), and riffle beetle (*Zaitzevia*) taxa, which have low to moderate stressor tolerances.

O/E scores also were computed for sites on tributaries to the Tongue River. Both sites on Youngs Creek (sites T3 and T4) had improved biological conditions on the basis of O/E scores from 2005 (combined mean = 0.71) to 2006 (combined mean = 0.81), although the improvements were not significant (P > 0.05; fig. 23). Similar to Youngs Creek, Prairie Dog Creek (site T8) had a relatively high O/E score of 0.74 in 2006 (no riffle sample was collected from site T8 in 2005). The biological condition of Goose Creek (site T2) was similar in both years (O/E scores of 0.22 in 2005 and 0.21 in 2006), although this site had markedly lower O/E scores relative to sites on the Tongue River, Youngs Creek, and Prairie Dog Creek. At site T2, only three taxa were collected in each year out of 13 expected taxa in 2005 and 14 expected taxa in 2006. Because of Goose Creek's flow regime and site T2's location close to its mountain source, several less tolerant stonefly (Chloroperlidae and *Pteronarcella*), mayfly (*Drunella, Ephemerella,* and *Rhithrogena*), and caddisfly (*Brachycentrus*) taxa were expected to occur at site T2. The assemblage at site T2 was represented by a large percentage of taxa with moderate to high tolerances that include midges *Microcylloepus* and *Rheocricotopus* and the mayfly *Tricorythodes*. The PCA of environmental variables did not show site T2 separate from the rest of the Tongue River drainage sites (fig. 22), which indicates that one or more variables not represented by the PCA could be contributing to the low biological condition at site T2 on Goose Creek.

Powder River Drainage

Among sites on the main-stem Powder River, O/E scores were similar in 2005 (mean = 0.44) and 2006 (mean = 0.44). In 2005, biological conditions appeared to improve with distance downstream (fig. 23), which might reflect the cumulative effects of tributary (particularly streams coming off the Bighorn Mountains) and spring inputs and perhaps increased habitat complexity. In 2006, fewer data points were available for the main-stem Powder River, and a downstream trend was not as obvious as in 2005, although the lowest O/E scores in 2006 were for sites P1 and P2.

Exceptions to the general pattern of improving biological condition with downstream direction on the main-stem Powder River include a substantial decrease in O/E scores in both years for the Powder River from above Salt Creek (site P1) to below Salt Creek (site P2). An appreciable absence of expected mayfly, caddisfly, beetle, and midge taxa, among other groups, contributed to the decrease in O/E scores for the Powder River below Salt Creek (site P2). Instead of the expected taxa, the macroinvertebrate community at site P2 was dominated by tolerant midges such as *Polypedilum* and *Tanytarsus*. A large increase in specific conductance from site P1 to site P2 might partially explain the decline in biological condition (table 16). Analysis of the 2005 data also showed a decline in biological condition of the Powder River from below Crazy Woman Creek (site P8) to above Clear Creek (site P9), followed by an increase in O/E score below Clear Creek (site P11). Natural intermittency between sites P8 and P9 may have contributed to the decline in biological condition in this reach (Armentrout and Wilson, 1987). In 2006, the

Table 18. Scores from the Wyoming observed/expected model and the Wyoming Stream Integrity Index metrics for macroinvertebrate samples collected at riffles in streams in Wyoming and adjacent areas of Montana, 2005–06.

[Shaded cells indicate main-stem sampling sites on the Tongue or Powder River]

Site number (fig. 1)	Sampling date	Observed/expected score	Ephemeroptera taxa	Ephemeroptera taxa score	Trichoptera taxa	Trichoptera taxa score	Total taxa	Total taxa score	Trichoptera percentage (less Hydropsychidae)	Trichoptera percentage (less Hydropsychidae) score	Ephemeroptera percentage (less Baetidae)	Ephemeroptera percentage (less Baetidae) score	Collector-gatherer (percent)	Collector-gatherer (percent) score	Hilsenhoff Biotic Index	Hilsenhoff Biotic Index score	Wyoming Stream Integrity Index Score
R2	09/15/2005	0.67	4	50	2	22	27	64	0	0	2	4	28	82	3.64	100	46
T1	08/15/2005	.78	7	88	8	89	32	76	3	15	31	57	78	24	3.56	100	64
	08/23/2006	.78	7	88	7	78	33	79	27	100	27	49	38	70	3.79	100	80
T2	08/17/2005	.22	8	100	4	44	25	60	3	13	19	35	63	41	3.61	100	56
	08/22/2006	.21	6	75	4	44	29	69	6	31	32	58	53	53	4.06	100	62
T3	06/15/2005	.66	1	13	6	67	33	79	3	14	0	0	41	67	4.40	100	49
	06/28/2006	.79	2	25	5	56	35	83	6	28	0	1	46	61	4.02	100	50
T4	06/14/2005	.76	2	25	2	22	34	81	3	15	1	3	56	49	4.80	100	42
	06/27/2006	.82	2	25	3	33	30	71	4	19	1	2	56	49	5.66	83	40
T5	08/15/2005	.89	7	88	4	44	29	69	5	25	11	20	43	64	3.90	100	58
	08/22/2006	.67	7	88	6	67	31	74	16	75	7	14	44	63	3.43	100	69
T7	06/13/2005	.45	2	25	1	11	36	86	1	6	0	1	62	43	5.68	83	36
T8	08/25/2006	.74	2	25	5	56	26	62	2	7	16	30	30	80	4.15	100	51
T9	09/14/2005	.67	5	63	7	78	31	74	7	31	59	100	73	30	4.13	100	68
	08/24/2006	.67	6	75	6	67	33	79	12	56	9	17	44	64	3.64	100	65
T10	08/16/2005	.67	6	75	5	56	30	71	15	71	4	6	36	72	3.62	100	65
	08/28/2006	.78	4	50	4	44	22	52	7	35	0	0	11	100	3.64	100	55
T11	06/22/2005	.32	1	13	0	0	46	100	0	0	0	0	72	30	4.36	100	35
T12	06/21/2005	.63	2	25	2	22	42	100	1	5	4	7	67	37	4.19	100	42
T13	06/23/2005	.33	3	38	0	0	40	95	0	0	0	1	67	37	4.11	100	39
T14	09/12/2005	.67	7	88	6	67	24	57	2	11	55	100	55	50	3.06	100	68
	08/28/2006	.67	9	100	6	67	29	69	25	100	17	32	44	63	3.57	100	76

Table 18. Scores from the Wyoming observed/expected model and the Wyoming Stream Integrity Index metrics for macroinvertebrate samples collected at riffles in streams in Wyoming and adjacent areas of Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sampling sites on the Tongue or Powder River]

Site number (fig. 1)	Sampling date	Observed/expected score	Ephemeroptera taxa	Ephemeroptera taxa score	Trichoptera taxa	Trichoptera taxa score	Total taxa	Total taxa score	Trichoptera percentage (less Hydropsychidae)	Trichoptera percentage (less Hydropsychidae) score	Ephemeroptera percentage (less Baetidae)	Ephemeroptera percentage (less Baetidae) score	Collector-gatherer (percent)	Collector-gatherer (percent) score	Hilsenhoff Biotic Index	Hilsenhoff Biotic Index score	Wyoming Stream Integrity Index Score
T17	06/30/2005	.56	1	13	3	33	28	67	2	10	1	2	13	100	4.58	100	46
	06/28/2006	.67	2	25	4	44	22	52	0	2	0	1	8	100	5.10	96	46
T18	09/13/2005	.89	7	88	5	56	30	71	1	3	26	48	49	57	3.81	100	60
	08/31/2006	.78	10	100	8	89	35	83	3	17	22	40	55	51	3.81	100	69
T19	06/23/2005	.22	0	0	1	11	5	12	0	0	0	0	0	100	5.97	76	28
P1	07/20/2005	.20	7	88	3	33	35	83	5	23	7	13	45	62	4.69	100	57
	07/24/2006	.27	7	88	3	33	30	71	0	1	25	46	47	60	4.24	100	57
P2	07/21/2005	0	4	50	3	33	20	48	2	12	9	17	21	90	5.66	83	48
	07/25/2006	.13	4	50	3	33	28	67	6	29	5	10	59	46	5.58	85	46
P3	07/19/2005	.44	5	63	1	11	20	48	0	0	8	15	13	100	5.43	88	46
	07/26/2006	.67	4	50	4	44	25	60	0	2	14	26	18	94	4.20	100	54
P4	07/22/2005	.56	4	50	2	22	17	40	0	0	2	4	13	99	4.85	100	45
	07/27/2006	.45	1	13	4	44	21	50	3	13	1	2	5	100	4.92	100	46
P5	07/13/2005	.67	5	63	2	22	15	36	0	0	12	22	13	99	5.67	83	46
	07/28/2006	.56	5	63	4	44	20	48	1	4	6	11	16	96	4.11	100	52
P6	07/11/2005	.95	9	100	4	44	33	79	2	8	41	76	56	49	4.08	100	65
P7	07/12/2005	.84	6	75	3	33	16	38	0	1	2	4	5	100	5.62	84	48
P8	07/23/2005	.67	4	50	2	22	30	71	0	0	5	9	18	94	3.78	100	50
P9	07/24/2005	.44	6	75	1	11	31	74	0	0	11	19	21	90	4.98	98	53
P10	09/13/2005	.44	6	75	4	44	17	40	8	39	64	100	74	29	2.67	100	61
	08/21/2006	.67	5	63	6	67	30	71	32	100	17	32	27	84	3.40	100	74
P11	07/25/2005	.78	12	100	3	33	26	62	0	1	30	56	33	77	3.94	100	61

Table 18. Scores from the Wyoming observed/expected model and the Wyoming Stream Integrity Index metrics for macroinvertebrate samples collected at riffles in streams in Wyoming and adjacent areas of Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sampling sites on the Tongue or Powder River]

Site number (fig. 1)	Sampling date	Observed/expected score	Ephemeroptera taxa	Ephemeroptera taxa score	Trichoptera taxa	Trichoptera taxa score	Total taxa	Total taxa score	Trichoptera percentage (less Hydropsychidae)	Trichoptera percentage (less Hydropsychidae) score	Ephemeroptera percentage (less Baetidae)	Ephemeroptera percentage (less Baetidae) score	Collector-gatherer (percent)	Collector-gatherer (percent) score	Hilsenhoff Biotic Index	Hilsenhoff Biotic Index score	Wyoming Stream Integrity Index Score
	08/03/2006	.56	3	38	4	44	20	48	1	5	3	5	11	100	4.10	100	49
P12	07/26/2005	.67	7	88	5	56	27	64	2	9	33	60	22	88	4.19	100	67
P13	07/19/2005	.22	5	63	1	11	10	24	0	0	65	100	1	100	3.36	100	57
	08/02/2006	.56	4	50	6	67	25	60	5	24	14	27	23	88	4.24	100	59
P15	06/13/2005	.44	2	25	2	22	12	29	0	0	1	2	2	100	5.93	77	36
	06/23/2006	.67	2	25	4	44	26	62	1	4	0	0	2	100	4.00	100	48
P16	06/27/2005	.78	2	25	3	33	34	81	2	11	2	4	20	92	4.66	100	49
P17	07/21/2005	.56	6	75	3	33	19	45	0	1	56	100	28	83	3.77	100	62
P18	07/22/2005	.22	4	50	2	22	9	21	0	0	74	100	1	100	2.91	100	56
C3	06/27/2005	.11	2	25	2	22	28	67	0	1	2	3	75	27	3.04	100	35
C4	06/09/2005	.11	1	13	0	0	15	36	0	0	1	2	3	100	6.01	75	32
C6	06/06/2005	.11	1	13	1	11	18	43	0	0	0	0	2	100	5.92	77	35
B1	06/29/2005	.42	1	13	1	11	16	38	1	5	0	0	20	91	6.29	69	32

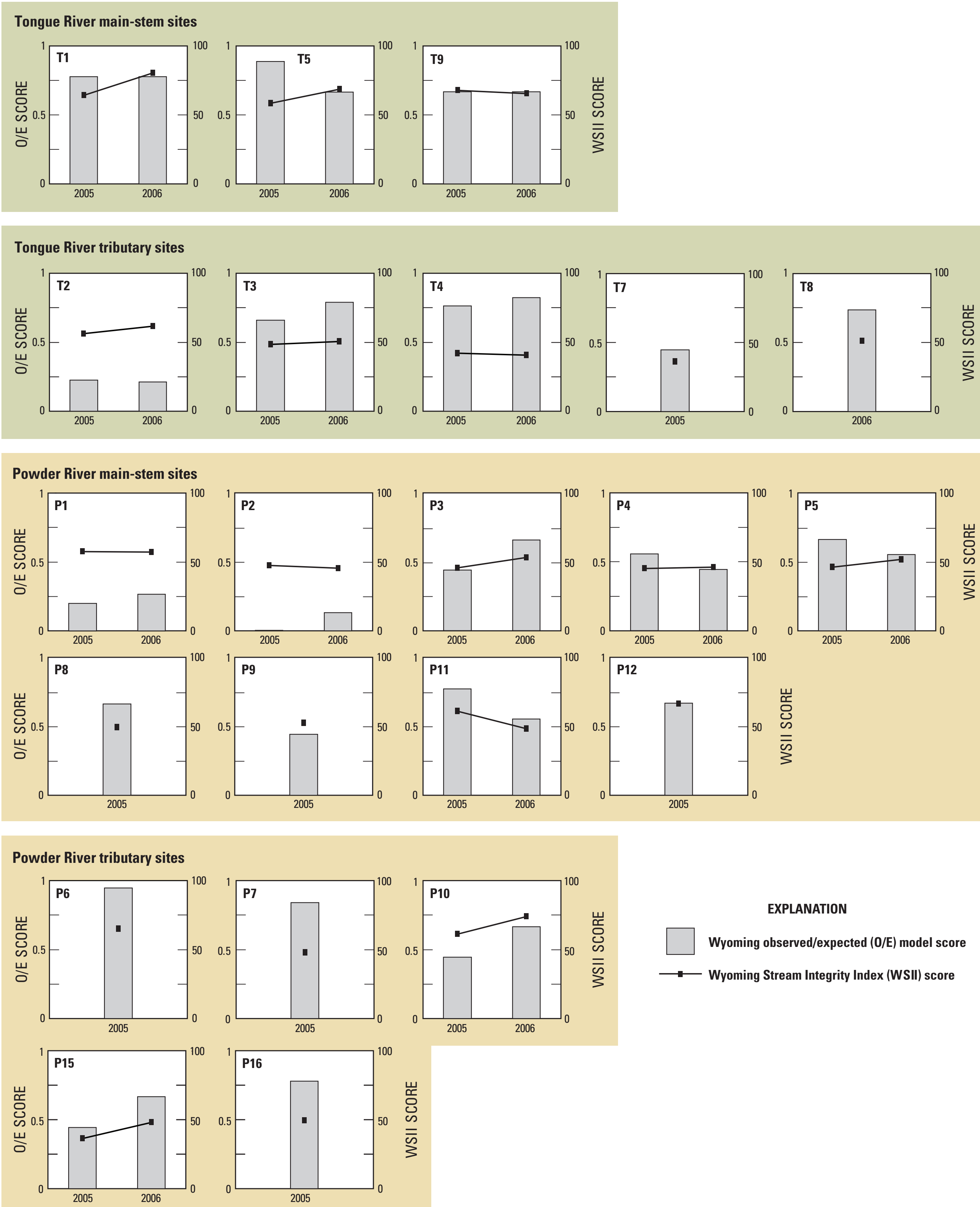

Figure 23. Wyoming observed/expected model and Wyoming Stream Integrity Index scores for macroinvertebrate samples collected in Wyoming and adjacent areas of Montana, 2005–06.

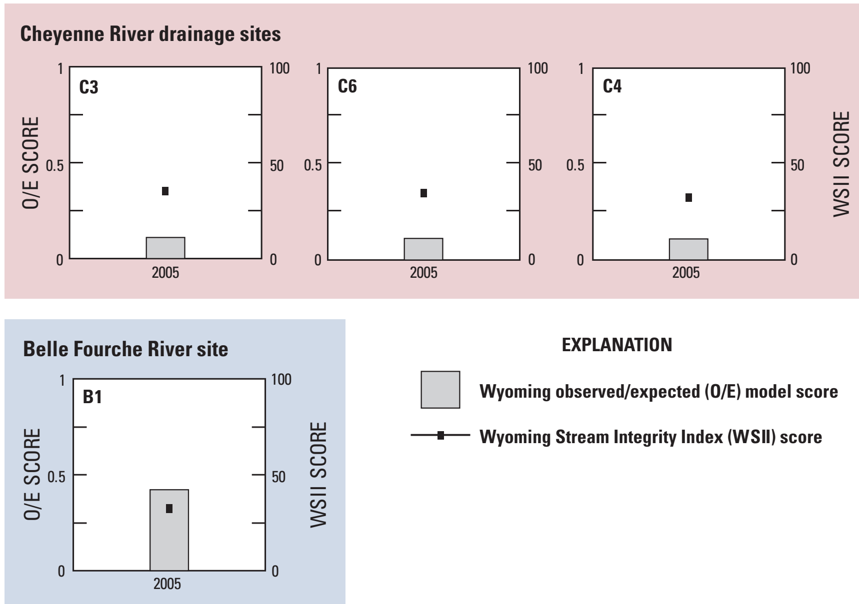

Figure 23. Wyoming observed/expected model and Wyoming Stream Integrity Index scores for macroinvertebrate samples collected in Wyoming and adjacent areas of Montana, 2005–06.—Continued

O/E score in the Powder River decreased from above Pumpkin Creek (site P3) to below Burger Draw (site P4), then increased above Crazy Woman Creek (site P5). Absence of less tolerant mayflies (*Fallceon quilleri*, Leptophlebiidae, and *Tricorythodes*) played a large role in the decline in biological condition between sites P3 and P4. Many of these and other mayfly taxa were present at site P5, which contributed to the increase in the 2005 and 2006 O/E scores.

Tributaries to the Powder River that were sampled were Crazy Woman Creek and Clear Creek, which have mountainous headwaters, and the Little Powder River, which has plains headwaters. O/E scores for Crazy Woman Creek decreased slightly with distance downstream from site P6 (0.94) to site P7 (0.84), although they were some of the highest scores in the study area (fig. 23). This was expected considering this stream's mountain origins and mountainous headwaters (snowmelt-driven flow regime). However, Clear Creek (site P10) had a less favorable biological condition (0.45) than Crazy Woman Creek (sites P6 and P7) in 2005. Because of their common origins and flow regimes, the biological condition between Crazy Woman and Clear Creeks would be expected to be similar. The less favorable biological condition at site P10 was attributed to absence of both tolerant and potentially sensitive expected taxa such as the midge *Orthocladius*, Simuliidae (black flies), and the riffle beetle *Dubiraphia*. The biological-condition score at site P10 increased to 0.67 in 2006, although many members of the community remained a mixture of adaptive taxa with generally varying tolerances to pollution.

Biological conditions in the Little Powder River were similar to biological conditions in the Powder River with an increase in O/E scores at Little Powder River above Dry Creek (site P15) from 2005 (0.44) to 2006 (0.67; fig. 23). The similarity in biological conditions between the Little Powder and Powder Rivers is expected considering their plains-dominated origins and largely spring-fed flow regimes supplemented by intense precipitation. Biological conditions became more favorable with distance downstream in 2005 in the Little Powder River from an O/E score of 0.44 above Dry Creek (site P15) to an O/E score of 0.78 at Biddle (site P16, fig. 23). Similar to the Powder River, cumulative tributary and spring inputs may partially explain the increase in O/E scores from site P15 to site P16. Collector-filterer midges and other fly larvae were common taxa collected at both of these Little Powder River sites.

Belle Fourche and Cheyenne River Drainages

The O/E score of 0.42 for the macroinvertebrate community of the Belle Fourche River (site B1) in 2005 was similar to O/E scores for the Powder and Little Powder Rivers, likely due to similar drainage characteristics. In contrast, communities for sites C3, C4, and C6 in the Cheyenne River drainage had appreciably low O/E scores (0.11 for all three sites; fig. 23). These scores may be artificially low, however, and inaccurately represent the biological condition of the drainage. The low scores may be because of limitations of the model in accurately representing reference conditions in streams of the Cheyenne River drainage, which have a greater propensity for intermittent/ephemeral flow regimes relative to the Powder and Tongue River drainages. Despite model limitations, the macroinvertebrate assemblages among ATG sites in the Cheyenne River drainage were similar to one another and comparable to expected conditions derived from the literature for intermittent and ephemeral systems. Common macroinvertebrate fauna of intermittent and ephemeral streams consist of widespread opportunistic species that are tolerant of the naturally “harsh” environmental conditions and include small crustaceans, beetles, tolerant caddisflies and mayflies, and a large assemblage component of midges and other fly larvae (Zale and others, 1989; Peterson, 1990; Graham, 2002).

Wyoming Stream Integrity Index Biological Condition

Although the relation between WSII and Wyoming O/E scores was poor (coefficient of determination $R^2 = 0.16$, $P < 0.05$), the general spatiotemporal patterns of biological condition among ATG sites assigned by both indicators were similar. The relation between both indicators improved when data from only the 2005 sampling season were considered ($R^2 = 0.25$, $P < 0.05$). No relation between indicator scores was found for the 2006 season ($R^2 = 0.03$, $P > 0.05$), which probably is the result of a smaller data set and perhaps more variable environmental conditions. The range of WSII scores was smaller than the range of Wyoming O/E scores. During 2005–06, WSII scores ranged from 32 at Little Thunder Creek (site C4) and the Belle Fourche River (site B1) to 80 at Tongue River at Monarch (site T1; table 18).

WSII scores increased from 2005 (mean = 53) to 2006 (mean = 56) at sites sampled in both years, although similar to the O/E scores, the increase was not significant ($P > 0.05$). The broad-scale pattern in WSII scores largely mimicked what was revealed with the Wyoming O/E scores—higher WSII scores for sites on mountain-origin streams compared to plains-origin streams and improved biological condition for the Tongue River drainage, followed by the Powder, Cheyenne, and Belle Fourche River drainages, respectively.

Tongue River Drainage

Of the seven metrics included in the Plains WSII, the percentages of Trichoptera (less Hydropsychidae) ($R^2 = 0.59$), Ephemeroptera taxa richness ($R^2 = 0.57$), Hilsenhoff Biotic Index ($R^2 = 0.54$), and Trichoptera taxa richness ($R^2 = 0.52$) were the most important in affecting the WSII scores for the Tongue River drainage (fig. 24*A–D*). The WSII scores among the three sites on the main-stem Tongue River (sites T1, T5, and T9) increased slightly from 2005 (mean = 63) to 2006 (mean = 71), although the difference was not significant ($P > 0.05$; fig. 23). Similar to the Wyoming O/E scores, WSII scores generally decreased from upstream to downstream for sampling sites on the Tongue River in 2006. Decreases in the percentages of Trichoptera less Hydropsychidae and Ephemeroptera less Baetidae strongly affected the downstream decrease in WSII scores in 2006. In 2005, increases in the percentages of both aforementioned metrics resulted in an increase in WSII scores from site T5 to site T9.

Patterns derived from the WSII for Tongue River tributaries were similar to those obtained from the Wyoming O/E model. When considered together, biological conditions at Youngs Creek (sites T3 and T4) were similar between 2005 (mean = 46) and 2006 (mean = 45). The WSII score at Prairie Dog Creek (site T8) was 51, which was slightly higher than scores from Youngs Creek. The WSII score at Goose Creek (site T2) was similar in both years (56 in 2005 and 62 in 2006) and slightly higher compared to scores from Youngs and Prairie Dog Creeks. However, complementing the Wyoming O/E scores, Goose Creek had a lower WSII score relative to sites on the Tongue River because of small values for Trichopteran taxa score and percentage of Trichoptera less Hydropsychidae (table 18).

Powder River Drainage

Metrics that were most important in discriminating between high and low WSII scores for the Powder River drainage were the Hilsenhoff Biotic Index ($R^2 = 0.50$) and the percentage of Ephemeroptera less Baetidae ($R^2 = 0.47$), both of which exhibited a linear relation with WSII scores (fig. 24*E–F*). WSII scores among sites on the main-stem Powder River were similar in 2005 and 2006 (mean = 50, $P > 0.05$). The 2005 WSII scores tended to increase downstream from site P4 to site P12 as seen with the Wyoming O/E model (fig. 23). Corroborating results from the Wyoming O/E index, WSII scores showed the same decline in biological condition of the Powder River from sites P1 to P2 in both years. The decreases in WSII scores from sites P1 to P2 were attributed to an appreciable loss of total taxa, including Ephemeroptera (mayflies) and Trichoptera (caddisflies). Specific to 2006, a substantial decrease in the percentage of Ephemeroptera less Baetidae was another contributor to the decreased WSII scores from sites P1 to site P2.

Mimicking the Wyoming O/E scores, WSII scores in 2006 for the main-stem Powder River showed an improvement in biological condition from sites P2 to P3, a decline from sites P3 to P4, followed by an improvement at site P5 (fig. 23). Decreases in total taxa, percentage of Ephemeroptera less Baetidae, and number of Ephemeroptera taxa were the primary metrics causing the decrease in the WSII score from site P3 to site P4. These declines are corroborated by the absence of expected mayfly taxa detected by the Wyoming O/E index. Too few data points for 2006 are available downstream from site P5 in 2006 to identify a linear pattern.

Contrary to the Wyoming O/E scores, the WSII scores did not decrease between Powder River sites P8 and P9 in 2005. In fact, the 2005 WSII metrics show a consistent downstream improvement in biological condition of the Powder River beginning below Burger Draw at site P4. Only Trichoptera taxa scores showed a decrease from site P8 to site P9. All other metrics used in the Plains WSII had increasing values between the two sites. The increase in metric scores might indicate that several expected indigenous taxa were intolerant to stressors acting upon the system (hence, their absence according to the Wyoming O/E model) and were replaced by more tolerant (supported by the increased Hilsenhoff Biotic Index score) congener taxa that received higher metric scores under the existing conditions.

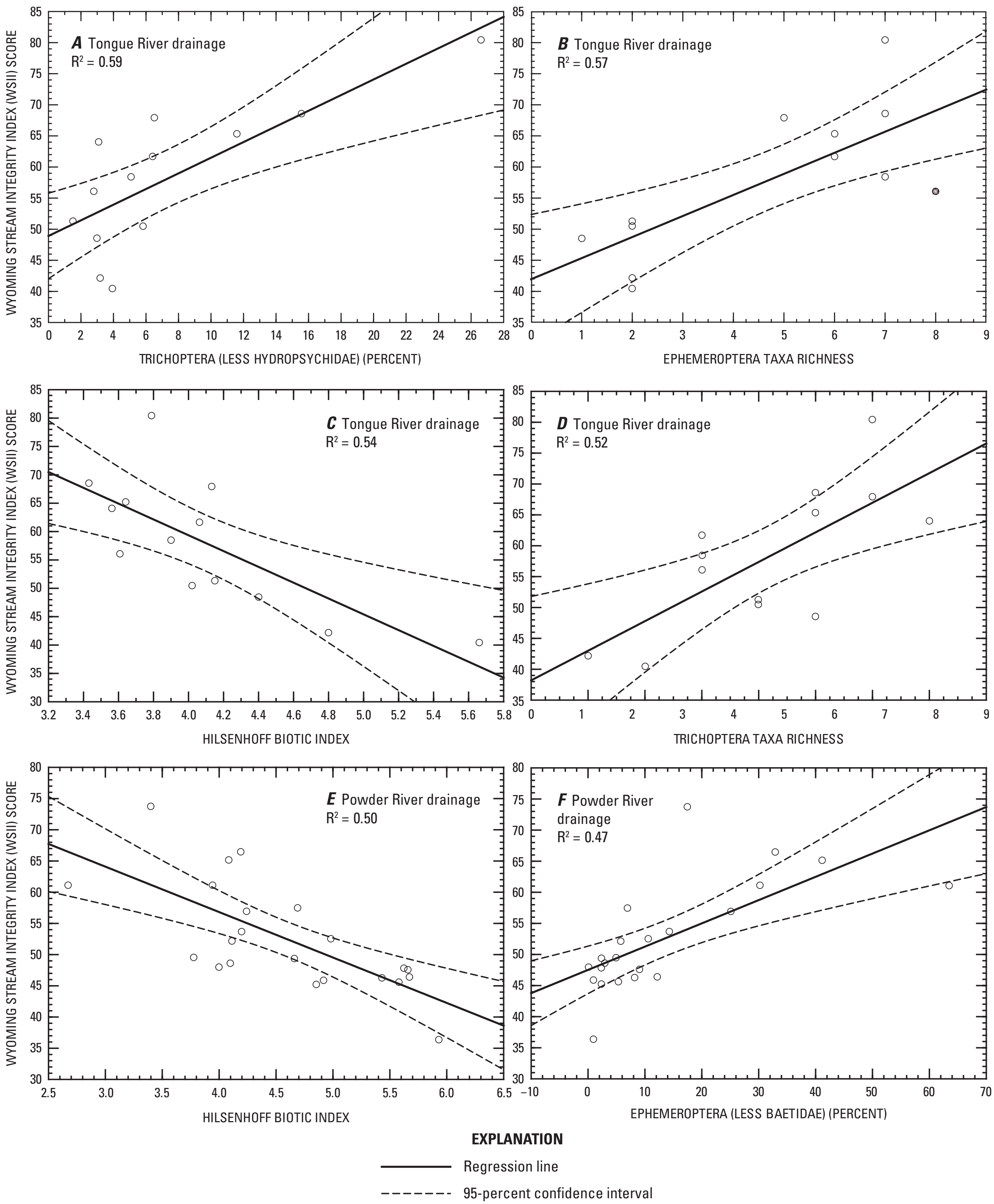

Figure 24. Regression of selected macroinvertebrate metrics using scores of the Wyoming Stream Integrity Index for sites in the Tongue and Powder River drainages in Wyoming and adjacent areas of Montana, 2005–06.

Among the tributaries to the Powder River, the downstream difference in biological condition according to the WSII scores for Crazy Woman Creek sites P6 (65) to P7 (48) in 2005 was greater than was detected with the Wyoming O/E model (fig. 23). The decrease in WSII score was caused by decreases in the percentages of collector-gatherers, Ephemeroptera less Baetidae, and numbers of Ephemeroptera and total taxa. The WSII and O/E scores for Crazy Woman Creek might indicate that stressors were present to alter community attributes, although perhaps near the extremes of tolerance ranges for the majority of indigenous taxa still present. Unlike the Wyoming O/E score, the WSII score of 61 for Clear Creek (site P10) in 2005 was similar to or greater than WSII scores for samples from Crazy Woman Creek. Although several expected taxa were absent at site P10, large percentages of non-Baetid mayflies (*Acentrella*, *Fallceon quilleri*, Leptophlebiidae, and Heptageniidae) with low pollution tolerances were present. An increased percentage of Ephemeroptera less Baetidae was found in place of the expected taxa, decreasing the Hilsenhoff Biotic Index value, and resulting in an elevated WSII score comparable to Crazy Woman Creek.

Complementing scores from the Wyoming O/E model, WSII scores for the Little Powder River showed that biological conditions were similar to conditions in the upstream and middle sections of the Powder River in Wyoming, with an increase in WSII scores from site P15 (36) downstream to site P16 (49) in 2005. In addition, the WSII scores increased temporally from 36 in 2005 to 48 in 2006 at site P15 (table 18).

Belle Fourche and Cheyenne River Drainages

In general, the patterns of WSII scores for the Belle Fourche and Cheyenne River drainages relative to scores for the Powder and Tongue River drainages were similar to patterns from the Wyoming O/E model. The Belle Fourche River (site B1) WSII score of 32 was similar to WSII scores for the Cheyenne River drainage (site C3 = 35, site C4 = 32, site C6 = 35; table 18). However, as with the Wyoming O/E model, the biological condition of the Cheyenne River drainage assigned by the WSII scores may be underestimated due to limitations of this index in effectively evaluating intermittent water in this drainage.

Montana Observed/Expected Biological Condition

Data from sites in Montana, as well as sites in Wyoming near the Montana border, are described in the following sections. The O/E and MMI scores are listed in table 19 along with scores from the individual metrics that compose the MMI.

Tongue River Drainage

Overall, samples collected from sites on the main-stem Tongue River had lower scores than the samples from tributary sites in the Tongue River drainage as measured by the Montana O/E model (fig. 25). The tributary sites had less streamflow and smaller wetted widths than main-stem sites (fig. 22; table 7; table 16). The physical properties of the tributaries more closely matched the physical properties of those streams identified as reference streams by MDEQ that were used to calibrate the O/E model than did the physical properties of the main-stem sites (Suplee and others, 2005).

Within the Tongue River drainage (fig. 25), the mean O/E score was 0.81 in both 2005 and 2006. The Montana O/E model was sensitive to the mountainous headwater, snowmelt-driven stream settings found in the upstream part of the Tongue River drainage (upstream from Tongue River Reservoir) and scored those sites slightly higher both years; O/E scores ranged from 0.75 to 1.28 in 2005 and from 0.90 to 1.41 in 2006 (table 19). The samples collected from the Youngs Creek sites (T3 and T4) had the highest O/E scores both years. Site T3 scored 1.28 in 2005 and 1.41 in 2006. Site T4 scored 1.26 in 2005 and 1.12 in 2006. Scores exceeding 1.0 indicate that more taxa were observed than were expected on the basis of Great Plains reference sites in Montana. Scores from samples collected at site T5 on the main-stem Tongue River below Youngs Creek (0.44 in 2005 and 0.88 in 2006) were lower than those measured for the Tongue River at Monarch (site T1) and at the State line (site T9). The samples from the upstream part of the Tongue River drainage contained both tolerant taxa (for example, scuds, *Hyalella azteca*; black flies, *Simulium*; and snails, *Physa*) and potentially sensitive taxa (for example, riffle beetles, *Dubiraphia*; and caddisflies, *Hydroptila*). Different percentages of these taxa affected the O/E scores for the Tongue River sites.

The O/E scores from samples collected from the main-stem Tongue River downstream from Tongue River Reservoir decreased from site T10 (above Hanging Woman Creek) to site T14 (at Birney Day School) and increased from site T14 to site T18 (below Brandenberg Bridge) in both 2005 and 2006. The O/E scores for samples from sites T10, T14, and T18 tended to be higher in 2005 than in 2006 (table 19). The mean score for these three sites was 0.55 in 2005 and 0.46. The O/E model scores were correlated with predator taxa richness (for example, midges, Chironomidae; and creeping water bugs, Naucoridae; $R^2 = 0.44$; fig. 26*A*).

Powder River Drainage

The macroinvertebrate data collected from the eight sampling sites in the downstream part of the Powder and Little Powder River drainages showed no significant difference ($P > 0.05$) in O/E scores between 2005 and 2006. Data for six sites on the main-stem Powder River, starting from site P9 above Clear Creek in Wyoming and continuing downstream to site P18 near the mouth, and for two sites on the Little Powder River are shown in figure 25.

In 2005, the highest O/E score for sites on the main-stem Powder River was at site P9 (0.50). The 2005 O/E scores tended to decrease downstream from site P9, reach-

Table 19. Scores from the Montana observed/expected model and the Montana multimetric index (MMI) for macroinvertebrate samples collected at riffles in streams in Montana and adjacent areas of Wyoming, 2005–06.

[Shaded cells indicate main-stem sampling sites on the Tongue or Powder River; EPT, Ephemeroptera, Plecoptera, and Trichoptera]

Site number (fig. 1)	Sample date	Observed/ expected score	MMI score	EPT taxa (percent)	EPT taxa score	Tany-podinae (percent)	Tany-podinae score	Orthocladiinae to Chironomidae (percent)	Orthocladiinae to Chironomidae score	Predator taxa (percent)	Predator taxa score	Filter-collector (percent)	Filter-collector score
R2	09/15/2005	1.00	55	6.0	42.9	1.4	13.5	10.3	89.7	10.0	100.0	80.4	30.1
T1	08/15/2005	1.05	42	12.6	90.3	.1	1.3	46.2	53.8	5.0	55.6	94.0	9.2
	08/23/2006	1.05	43	12.4	88.9	1.4	13.6	75.4	24.6	4.4	48.8	73.3	41.0
T2	08/17/2005	.75	44	10.2	72.7	.4	4.3	22.2	77.8	5.0	55.6	93.4	10.2
	08/22/2006	.90	30	7.9	56.5	.8	8.4	74.5	25.5	4.7	52.2	95.4	7.1
T3	06/15/2005	1.28	34	5.7	40.4	.2	1.6	60.0	40.0	6.3	69.7	89.6	16.0
	06/28/2006	1.41	35	6.8	48.4	1.0	10.1	64.6	35.4	6.0	67.0	89.6	16.1
T4	06/14/2005	1.26	35	4.0	28.5	1.1	10.9	56.6	43.4	6.2	68.4	84.1	24.5
	06/27/2006	1.12	40	4.7	33.4	1.8	17.6	21.1	78.9	5.2	57.2	92.7	11.3
T5	08/15/2005	.44	36	9.7	69.3	.2	1.5	37.1	62.9	3.3	36.1	93.2	10.4
	08/22/2006	.88	56	11.0	78.6	3.8	37.8	14.3	85.7	5.3	59.1	89.1	16.7
T7	06/13/2005	.98	35	2.6	18.2	.2	2.4	34.9	65.1	7.0	78.1	91.7	12.7
T9	09/14/2005	.57	39	10.8	76.9	1.7	17.2	58.2	41.8	4.3	48.3	93.9	9.4
	08/24/2006	1.00	52	9.8	70.2	1.9	19.3	19.2	80.8	6.5	72.8	90.6	14.5
T10	08/16/2005	.77	51	9.8	69.9	2.0	20.0	36.5	63.5	4.9	54.7	69.7	46.6
	08/28/2006	.64	40	6.8	48.3	.2	1.6	12.5	87.5	4.8	53.5	93.1	10.6
T11	06/22/2005	.87	55	.5	3.5	5.0	50.5	7.0	93.0	9.4	100	82.9	26.3
T12	06/21/2005	1.25	68	3.4	24.5	12.0	100	10.3	89.7	8.2	91.4	78.5	33.1
T13	06/23/2005	.94	53	2.0	13.9	6.7	66.7	18.6	81.4	6.9	76.6	83.3	25.6
T14	09/12/2005	.38	36	10.8	77.3	.0	.0	37.5	62.5	2.4	26.8	92.5	11.5
	08/28/2006	.25	48	13.6	97.1	.6	6.3	13.3	86.7	3.7	41.4	93.8	9.5
T17	06/30/2005	.89	24	4.0	28.4	.1	1.4	67.1	32.9	4.5	50.1	94.2	9.0
	06/28/2006	.38	22	4.0	28.4	.0	.0	54.4	45.6	3.1	34.7	98.8	1.9
T18	09/13/2005	.50	32	10.2	72.6	.6	6.5	85.4	14.6	5.3	58.4	93.4	10.2
	08/31/2006	.50	56	17.1	100	.9	8.5	13.0	87.0	6.4	71.5	91.7	12.7
T19	06/23/2005	.25	23	.6	4.5	.9	9.1	12.5	87.5	1.0	10.8	98.7	2.0
P9	07/24/2005	.50	63	7.0	50.0	6.7	66.7	18.5	81.5	7.0	77.8	73.9	40.2

Table 19. Scores from the Montana observed/expected model and the Montana multimetric index (MMI) for macroinvertebrate samples collected at riffles in streams in Montana and adjacent areas of Wyoming, 2005–06.—Continued

[Shaded cells indicate main-stem sampling sites on the Tongue or Powder River; EPT, Ephemeroptera, Plecoptera, and Trichoptera]

Site number (fig. 1)	Sample date	Observed/ expected score	MMI score	EPT taxa (percent)	EPT taxa score	Tany-podinae (percent)	Tany-podinae score	Orthocladiinae to Chironomidae (percent)	Orthocladiinae to Chironomidae score	Predator taxa (percent)	Predator taxa score	Filter-collector (percent)	Filter-collector score
P11	07/25/2005	.38	46	14.1	100	.2	1.7	16.7	83.3	2.5	27.5	89.3	16.5
	08/03/2006	.50	46	7.0	49.7	1.0	10.3	5.3	94.7	6.0	66.7	94.2	9.0
P12	07/26/2005	.37	44	8.8	62.9	.3	3.2	5.6	94.4	4.5	50.2	93.3	10.3
P13	07/19/2005	.12	31	4.4	31.1	.2	2.4	.0	100	1.9	21.1	98.9	1.6
	08/02/2006	.50	52	8.7	62.3	1.6	16.0	7.5	92.5	5.6	62.0	81.0	29.3
P15	06/13/2005	.62	22	3.1	22.2	.1	1.2	28.6	71.4	1.2	13.6	99.9	.2
	06/23/2006	.87	40	4.6	33.0	1.9	18.7	20.0	80.0	5.5	60.6	94.0	9.3
P16	06/27/2005	.87	43	4.9	34.7	5.1	51.0	59.5	40.5	6.4	70.6	89.2	16.7
P17	07/21/2005	.25	44	8.6	61.4	.3	3.2	1.2	98.8	4.8	53.4	96.5	5.3
P18	07/22/2005	.12	27	4.1	29.1	0	0	0	100	.7	8.2	99.9	.2

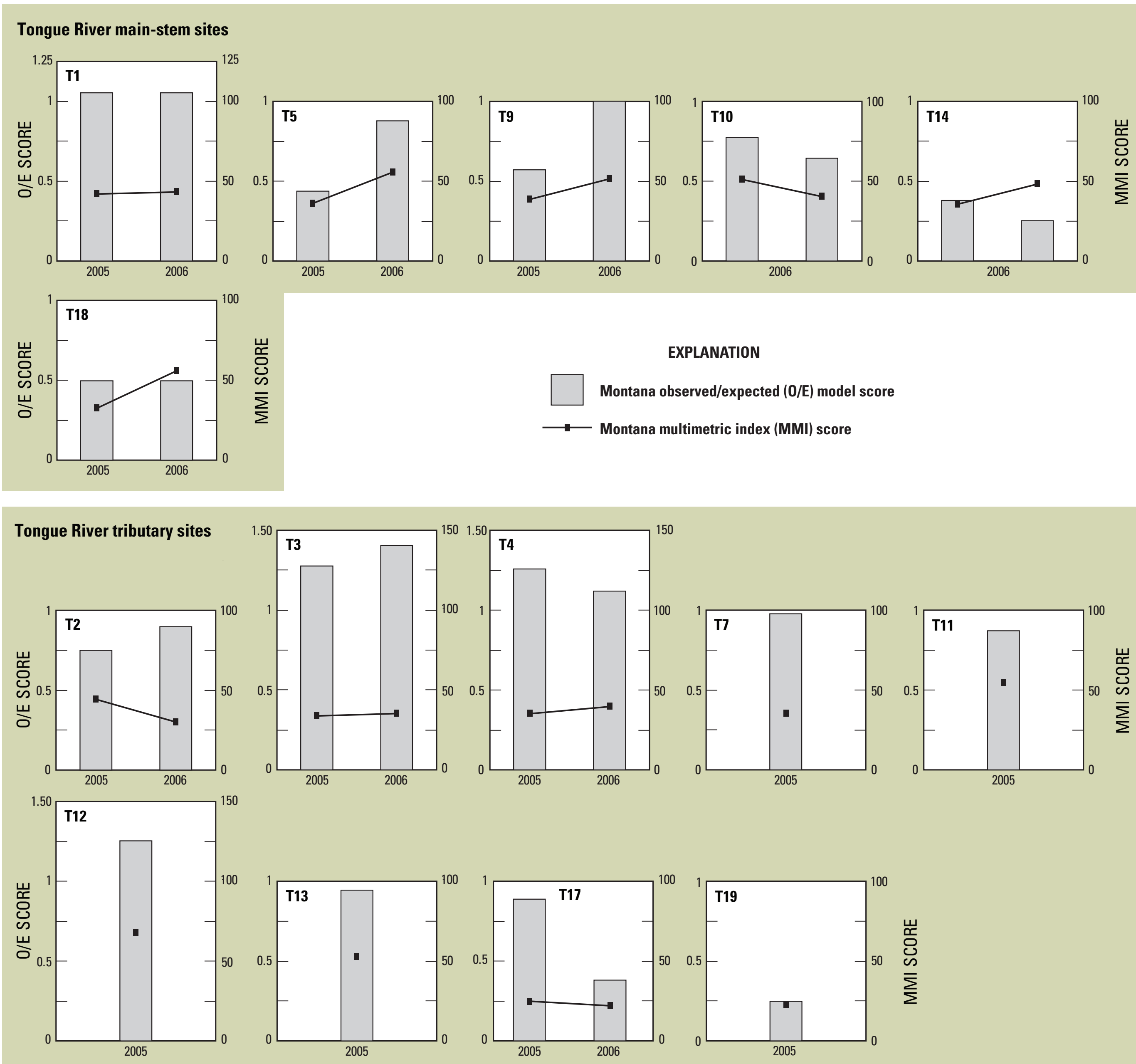

Figure 25. Montana observed/expected model and Montana multimetric index scores for macroinvertebrate samples collected in Montana and adjacent areas of Wyoming, 2005–06.

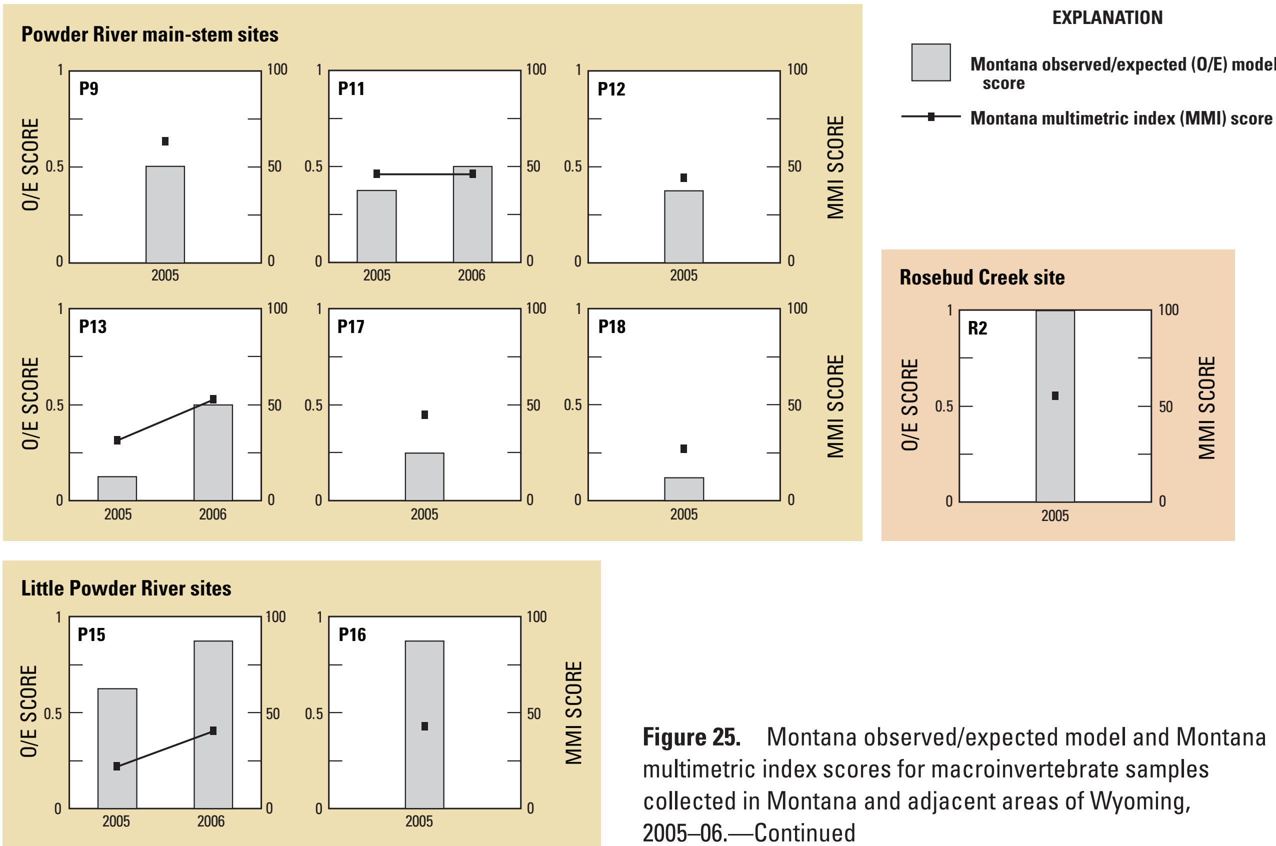

Figure 25. Montana observed/expected model and Montana multimetric index scores for macroinvertebrate samples collected in Montana and adjacent areas of Wyoming, 2005–06.—Continued

ing a minimum of 0.12 at site P13 at Broadus and site P18 near Locate. The O/E scores were related to the percentage of Orthocladiinae midges among the total Chironomidae in the samples ($R^2 = 0.63$; fig. 26*B*). This diverse group of midges was sampled in different proportions to the total Chironomid numbers in the upstream part of the Powder drainage (site P9 = 18.5 percent; site P11 = 16.7 percent) and trended downward into the downstream part of the Powder River drainage (site P12 = 5.6 percent, site P13 = 0 percent, site P17 = 1.2 percent, site P18 = 0 percent). This is another line of evidence that demonstrates how the O/E model is potentially sensitive to cold-water effects in plains streams. Overall, the Powder River naturally maintains less abundant and diverse macroinvertebrate populations than other drainages in the plains (Stagliano, 2006). The O/E scores for samples collected from the main-stem Powder River therefore, might be artificially low compared to samples from other drainages in the plains.

Samples from both sites in the Little Powder River drainage (sites P15 and P16) scored relatively high using the O/E model in 2005 (site P15 = 0.62, site P16 = 0.87; table 19). Site P15 was sampled again in 2006, and the O/E score (0.87) was higher than in 2005. The O/E scores calculated from the samples collected at these sites were affected by a diverse macroinvertebrate community dominated by filter/collector taxa (for example, mayflies, *Traverella*; black flies, Simuliidae; and caddisflies, *Hydropsyche* and *Cheumatopsyche*).

Rosebud Creek

Macroinvertebrate riffle data were collected at one site (R2) within the Rosebud Creek drainage in 2005. The 2005 O/E score was 1.00 at site R2 (table 19), indicating that the macroinvertebrate community at site R2 was very similar to communities at regional reference sites in Montana (Suplee and others, 2005).

Montana Multimetric Index Biological Condition

Tongue River Drainage

Mean MMI scores at sites in the Tongue River drainage were higher in 2006 (mean = 42) than in 2005 (mean = 40), but the difference was not statistically significant ($P > 0.05$). The Tongue River MMI scores did not follow the same general pattern as the scores from the O/E model. The MMI scores at the six main-stem Tongue River sites did not show a consistent pattern in the downstream direction, whereas the O/E scores were highest for the main-stem sites farthest upstream (fig. 25). MMI scores for sites on the Tongue River tributaries generally were either near or lower than scores from the main-stem Tongue River sites, whereas the maximum O/E scores occurred at the tributary sites. The maximum MMI score of 68 for Tongue River sites (table 19) occurred at site T12 (middle Hanging Woman Creek) in 2005.

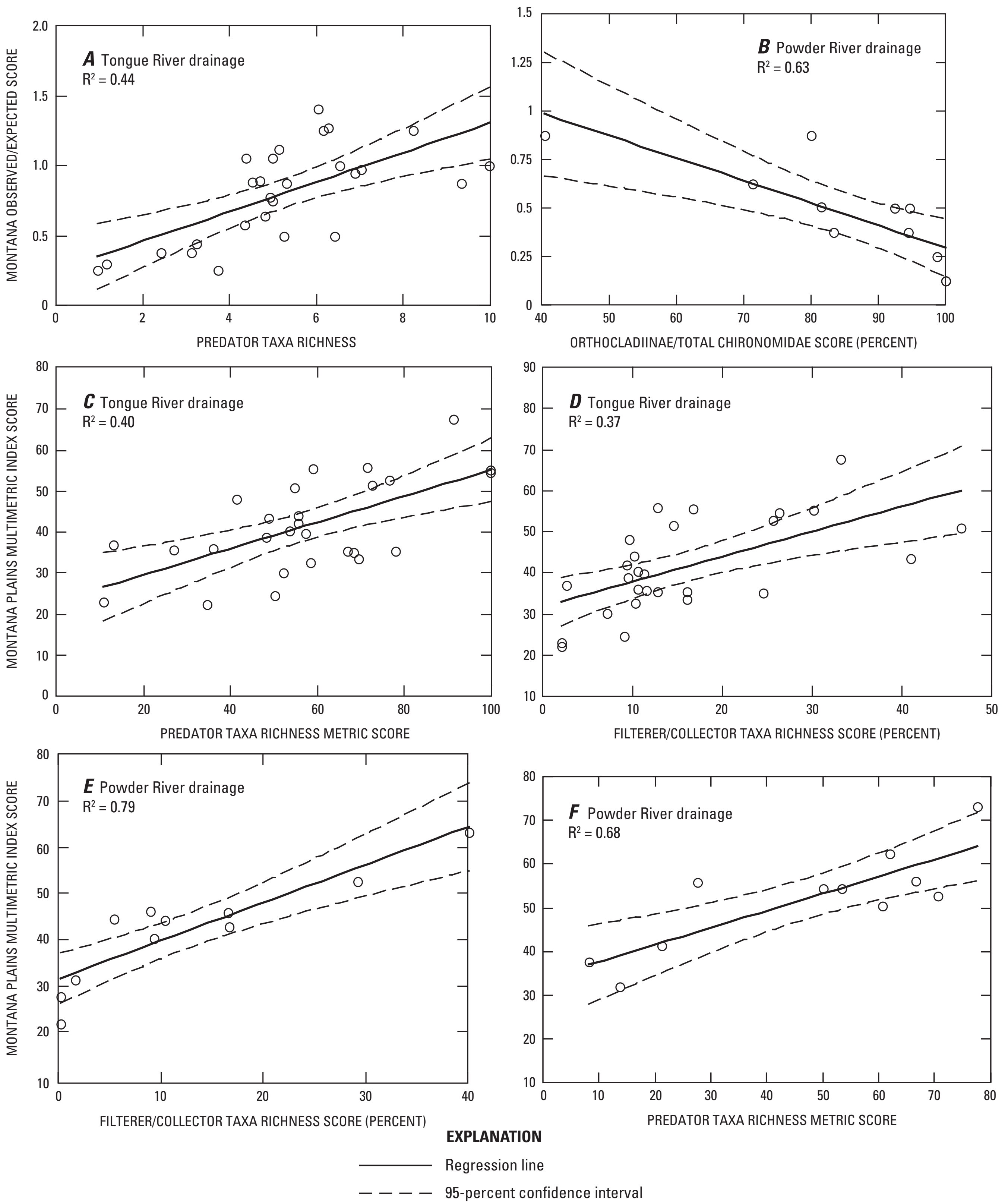

Figure 26. Regression of selected macroinvertebrate metrics compared to Montana observed/expected model scores and Montana multimetric index scores for sampling sites in the Tongue and Powder River drainages in Montana and adjacent areas of Wyoming, 2005–06.

The MMI model was sensitive to some of the same aspects of the macroinvertebrate community as the O/E model. The MMI scores were most correlated to the predator taxa richness score ($R^2 = 0.40$; fig. 26*C*) and the percentage filterer/collector taxa richness score ($R^2 = 0.37$; fig. 26*D*). The metrics of Tanypodinae (midge; table 19) and filterer/collector percentages (table 19) represent generally hardy and tolerant taxa that increase in the sample population with increased environmental perturbation (Kerans and Karr, 1994; Montana Department of Environmental Quality, 2006). Decreases in the percentages of these taxa within the samples caused the higher overall MMI scores at sites T11–T13.

Powder River Drainage

The mean of the MMI scores from samples collected in the Powder River drainage in Montana and adjacent areas of Wyoming were higher in 2006 (mean = 46) than in 2005 (mean = 42), but the difference was not significant ($P > 0.05$). The maximum MMI score of 63 occurred at site P9 (above Clear Creek) on the main-stem Powder River (table 19; fig. 25). MMI scores for the Little Powder River samples appeared to be similar to those for the main-stem Powder River samples. The MMI score for the Little Powder River above Dry Creek (site P15) was higher in 2006 (40) than in 2005 (22) due to smaller percentages of Tanypodinae and larger numbers of predator taxa in 2006. For the Powder River drainage, the MMI was more sensitive to different aspects of the macroinvertebrate community than those affecting the O/E model. Although the O/E was sensitive to the presence of potentially cold stenotherm Orthocladiinae (midge) taxa, the MMI responded to the percentage of filterers/collectors taxa richness ($R^2 = 0.79$) and predator taxa richness ($R^2 = 0.68$) metrics in the samples (fig. 26*E–F*).

Rosebud Creek

Macroinvertebrate riffle data were collected at one site (R2) in the Rosebud Creek drainage in 2005. The sample collected in 2005 had an MMI score of 55, which was relatively high compared to scores for other sites in Montana and adjacent areas of Wyoming (table 19).

Comparison of Model and Multimetric Results

Analysis of the entire ATG data set with both the Wyoming and Montana O/E and MMI indicators was considered initially in this study. However, preliminary investigations revealed appreciable differences in indicator scores between the Wyoming and Montana indicators for the same sites. These differences were attributed predominantly to fundamental differences in the development and expectations of each State's respective indicators in addition to application in areas outside the regions for which they were intended. For these reasons, ATG sites within Wyoming and Montana were evaluated with the respective indicators developed for that State. Selected sites on either side of the Wyoming/Montana State line that were reasonably within the geographic applicability of each indicator also were included in each State's respective analysis to provide additional resolution when identifying spatial patterns in biological condition. Spatial and temporal patterns in biological condition obtained from the initial 2 years of this study provide baseline information to augment future data collections of biological data.

The general similarity in patterns of biological condition in the study area and at drainage scales derived from the indicators are encouraging in that these indicators, in conjunction with other data types and tools, can serve as suitable indicators of water-quality change in the ATG study area. The overall degree of differences in O/E scores among ATG sites generally was greater than differences in the multimetric scores for both the Wyoming and Montana indicators. Furthermore, the O/E scores sometimes showed more substantial changes in biological condition between sites relative to the multimetric indicators. This may indicate that the O/E indicators are more sensitive in detecting environmental change than the multimetric indicators for the ATG study area. On the other hand, evaluation of the multimetric scores and associated metric values were valuable for identifying why particular similarities or differences existed between the two indicator outputs.

The disagreements in biological condition as assessed by the Wyoming and Montana indicators primarily were at the drainage scale and associated with differences in the indicators' responses to environmental gradients and sensitivity to the magnitude and duration of stressors. Better spatial and temporal patterns are more likely to emerge with additional data collections. These additional data collections may increase the probability of developing causal relations between anthropogenic stressors and changes in biological condition. Furthermore, it will be important to differentiate the effects of human activities from naturally occurring perturbations (such as variations in flows and drought).

Macroinvertebrate Community Composition in Multiple Habitats

At sites where riffles were absent, the QMH macroinvertebrate samples are the only type of macroinvertebrate data available (table 20). Fewer sites had riffles in 2006 than in 2005 because of drier conditions in 2006, and therefore, some sites appear in table 20 with only a QMH sample for 1 year. As an aid to interpreting data for QMH-only sites, RTH and QMH data were compared at sites that had both types of macroinvertebrate samples. A total of 57 sample-collection periods in 2005–06 were used for the RTH–QMH comparison.

Total taxa richness was greater in the QMH samples than in the RTH samples collected at the same sites (fig. 27) as would be expected given that riffles and additional habitats such as macrophytes and pool sediment were sampled for the QMH sample. Pair-wise comparison of the QMH and RTH samples indicated total taxa richness as well as taxa richness of Ephemeroptera, Chironomidae, and noninsects were

Table 20. Macroinvertebrate community metrics for sampling sites where qualitative multihabitat (QMH) samples were the primary macroinvertebrate sample type, Powder River Structural Basin, Wyoming and Montana, 2005–06.

[Shaded cells indicate main-stem sampling sites on the Powder River]

Site number (fig. 1)	Abbreviated site name	Sample date	Taxa richness	Ephemer-optera richness	Plecoptera richness	Trichoptera richness	Chironomi-dae richness	Noninsect taxa richness	Predator taxa richness	Gatherer-collector taxa richness	Filterer-collector taxa richness	Taxa tolerance
R1	upper Rosebud Creek	06/20/2005	23	2	0	1	8	2	12	7	1	6.6
R1	upper Rosebud Creek	07/12/2006	49	3	0	4	23	6	13	23	4	6.2
T6	upper Squirrel Creek	06/16/2005	46	2	0	3	27	6	12	22	4	5.8
T6	upper Squirrel Creek	06/29/2006	44	2	0	1	19	6	15	15	3	6.3
T8	Prairie Dog Creek	08/16/2005	27	8	0	3	2	2	7	8	3	4.5
T11	upper Hanging Woman Creek	06/27/2006	43	4	0	0	20	4	14	18	2	6.8
T12	middle Hanging Woman Creek	06/26/2006	53	4	0	4	22	5	18	22	6	6.0
T13	Hanging Woman Creek at mouth	06/26/2006	48	2	0	0	19	4	22	17	3	6.4
T15	upper Otter Creek	06/29/2005	31	1	0	1	14	2	15	11	3	6.1
T15	upper Otter Creek	07/12/2006	45	3	0	1	16	6	16	20	4	5.9
T16	middle Otter Creek	06/28/2005	46	2	0	1	23	3	19	18	3	6.8
P6	Crazy Woman Creek below I-90	07/31/2006	49	2	0	2	23	3	22	16	2	6.1
P7	Crazy Woman Creek near mouth	08/01/2006	42	2	0	2	15	3	20	11	3	6.5
P8	Powder River below Crazy Woman Creek	08/02/2006	40	4	1	2	19	1	16	16	2	5.6
P9	Powder River above Clear Creek	08/04/2006	37	2	0	3	16	1	14	14	3	5.9
P12	Powder River at Moor-head	08/02/2006	41	5	1	5	19	2	14	16	3	5.6
P14	Little Powder River at Highway 59	06/14/2005	41	1	0	4	22	0	15	16	4	5.3
P14	Little Powder River at Highway 59	06/22/2006	49	2	0	2	24	4	19	19	5	6.1
P17	Powder River below Little Powder River	08/03/2006	52	9	1	4	17	3	17	19	4	5.6

Table 20. Macroinvertebrate community metrics for sampling sites where qualitative multihabitat (QMH) samples were the primary macroinvertebrate sample type, Powder River Structural Basin, Wyoming and Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sampling sites on the Powder River]

Site number (fig. 1)	Abbreviated site name	Sample date	Taxa richness	Ephemer-optera richness	Plecoptera richness	Trichoptera richness	Chironomi-dae richness	Noninsect taxa richness	Predator taxa richness	Gatherer-collector taxa richness	Filterer-collector taxa richness	Taxa tolerance
C1	Porcupine Creek	06/15/2005	36	0	0	0	18	3	14	16	1	6.6
C1	Porcupine Creek	06/22/2006	36	2	0	0	18	4	14	16	0	7.1
C2	Antelope Creek	06/08/2005	39	1	0	0	21	7	11	19	4	6.6
C2	Antelope Creek	06/20/2006	42	3	0	0	27	5	13	22	2	6.7
C3	Cheyenne River near Dull Center	06/19/2006	36	2	0	0	13	4	21	12	0	7.2
C4	Little Thunder Creek	06/21/2006	44	3	0	0	24	4	15	21	1	6.7
C5	Black Thunder Creek	06/07/2005	45	2	0	0	24	2	19	19	1	6.8
C6	Cheyenne River near Spencer	06/20/2006	46	2	0	1	23	4	18	19	1	6.6
B1	Belle Fourche River	06/21/2006	18	2	0	0	5	4	8	7	0	7.1
B2	Caballo Creek	06/28/2005	11	0	0	0	3	3	7	2	0	8.3

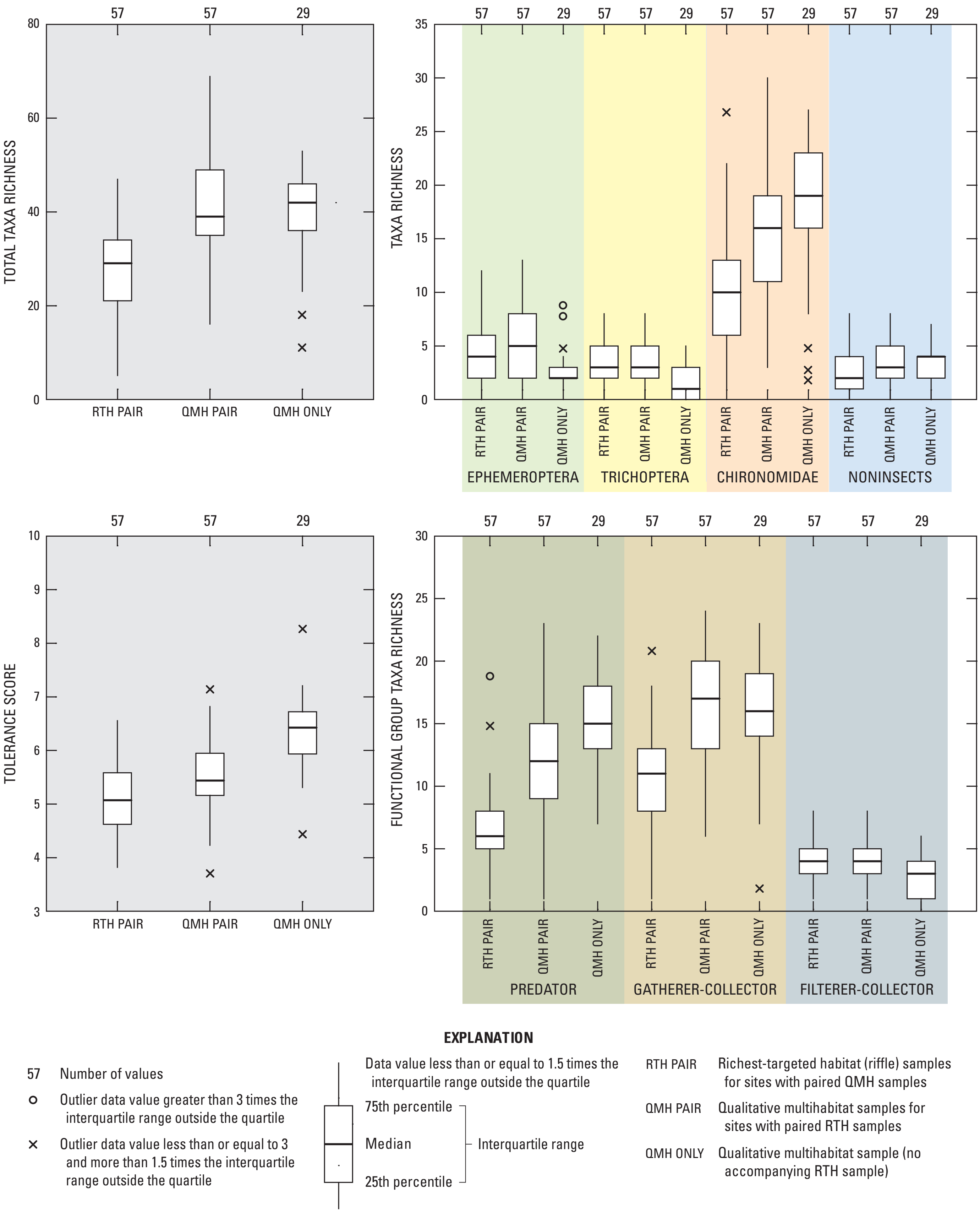

Figure 27. Macroinvertebrate taxa richness, functional groups, and tolerance for sampling sites with both richest-targeted habitat and qualitative multihabitat samples, and for sites with only qualitative multihabitat samples, Powder River Structural Basin, 2005–06.

significantly ($P < 0.05$) different between the QMH and RTH samples. The macroinvertebrate communities in the QMH samples also differed somewhat by functional groups from the RTH samples. The QMH samples contained significantly larger numbers of predator taxa and gatherer-collector taxa ($P < 0.05$) but about the same number of filterer-collector taxa ($P > 0.05$). The tolerance scores of taxa in the QMH samples were significantly ($P < 0.05$) higher than scores in the RTH samples (fig. 27), indicating that more organisms in the QMH samples were tolerant of poor water quality.

Total taxa richness for sites with QMH-only samples was similar to total taxa richness for paired QMH samples (fig. 27). The general composition of the macroinvertebrate community for QMH-only samples, however, was considerably different from the composition of paired QMH samples. The QMH-only samples generally contained larger percentages of Chironomidae taxa and noninsect taxa, and smaller percentages of Ephemeroptera and Trichoptera taxa than the paired QMH samples. Because Ephemeroptera and Trichoptera generally are associated with higher water-quality and lower tolerance scores, the taxa-tolerance scores for the QMH-only samples were higher than scores for the paired QMH samples (fig. 27). The QMH-only samples also contained more predator taxa than the paired QMH samples and fewer filter-collector taxa as might be expected when sampling includes habitats with little or no flowing water needed to provide a food source for the filterer-collectors.

Common taxa of Chironomids in the QMH-only samples included *Procladius*, *Dicrotendipes*, *Tanytarsus*, and *Micropsectra*. Common taxa of noninsects included the pond snail *Physa,* the scud or side swimmer *Hyallela azteca*, and mites (Trombidiformes). The most common genus of Ephemeroptera was *Callibaetis*. The predator functional group was well represented in the QMH-only samples, including damselfly nymphs (Coenagrionidae), water striders (Corixidae), and predaceous diving beetles (Dytiscidae). Plant piercers (herbivores) such as *Haliplus* and *Berosus* (beetles, Coleoptera) also were common in the QMH-only samples.

Ancillary Macroinvertebrate Data

Data collected at ATG sites for other USGS studies were evaluated as ancillary data. This included ancillary macroinvertebrate data from the NAWQA Program, the WWSC water-quality monitoring network, and a WWSC project investigation (table 6).

Taxa richness of macroinvertebrate samples from the Little Powder River (site P15) ranged from 15 to 36 taxa per sample in riffle samples collected during 1999–2007 under the NAWQA Program. Chironomidae generally had greater taxa richness than Ephemeroptera or Trichoptera, but Coleoptera and noninsects also were well represented (fig. 28). Dominant taxa in terms of relative abundance included caddisfly larvae *Cheumatopsyche*, mayflies *Caenis* and *Choroterpes*, blackfly larvae *Simulium*, riffle beetles *Stenelmis* and *Dubiraphia*, and Chironomids such as *Ablabesmyia*. The predominant functional groups were the gatherer-collectors and filter-collectors; a mean of about 35 to 40 percent of the macroinvertebrate individuals fell into each of those two functional groups.

Macroinvertebrate samples also were collected from the Little Powder River at sites P15 and P14 as part of a WWSC project investigation during 1980–81 (Peterson, 1990). Project samples collected at site P15 on six dates between April 1980 and March 1981 indicated the dominant macroinvertebrates during 1980–81 often were the same species that predominated in the ATG and NAWQA samples from site P15. Predominant species at site P15 during 1980–81 included *Simulium*, *Caenis*, *Cheumatopsyche*, and *Choroterpes* (Peterson, 1990). Macroinvertebrate samples also were collected in 1980–81 from riffles, runs, pools, and drift (timed collections of macroinvertebrates suspended in the water column) in the Little Powder River at Highway 59 (site P14). The ATG samples from site P14 were QMH samples because no riffles were present at the time of sampling. Some species, such as *Hyallela azteca* and *Tanytarsus*, were identified in both the ATG and project samples, whereas others, such as *Caenis* and *Choroterpes*, were present in the project samples but not the ATG samples from site P14.

Macroinvertebrate samples were collected during 1980–81 from the Cheyenne River near Dull Center (site C3) and the Belle Fourche River (site B1). The predominant species in the 1980–81 samples from runs in the Cheyenne River at site C3 was the Chironomid *Stictochironomus*, whereas the predominant species in the 2005 sample from riffles at site C3 were the snails *Physa* and *Lymnaea*, and the Chironomids *Micropsectra* and *Pseudochironomus*. The 1980–81 samples from the Belle Fourche River were collected primarily from the pools and were dominated by the mayfly *Caenis* and the Chironomids *Limnochironomus* (now taxonomically revised to *Dicrotendipes*) and *Tanytarsus* (Peterson, 1990, p. 28). One or more of the 2005–06 samples from the Belle Fourche River contained the mayfly family Caenidae as well as *Dicrotendipes* and *Tanytarsus*.

Ancillary data also are available from three ATG sites that were sampled using the NAWQA protocol for riffles; the Tongue River at State line (site T9) and Clear Creek (site P10) were sampled during 2002 as part of monitoring network activities, and the Powder River near Locate (site P18) was sampled during 1999 as part of the Yellowstone River Basin NAWQA study (Peterson and others, 2004). The macroinvertebrate community in the Tongue River at site T9, identified on the basis of the 2002 riffle sample, was a diverse assemblage dominated by *Microcylloepus*, *Stenelmis, Simulium*, and *Fallceon quilleri*. Those same taxa were present and sometimes dominant in the 2005 and 2006 riffle samples from site T9. The 2002 riffle sample from Clear Creek was dominated by *Microcylloepus*, *Fallceon quilleri*, and *Simulium*. The 2005–06 riffle samples from Clear Creek at site P10 contained *Microcylloepus* and *Fallceon quilleri*, but not *Simulium*. No *Simulium* or any other members of Simuliidae were identified in either the riffle or qualitative samples collected from Clear

Creek in 2005–06. The cause is not known for the absence of *Simulium* in the 2005–06 samples given that *Simulium* is a widely distributed, common genus of blackflies. The 1999 riffle sample from the Powder River near Locate (site P18) was dominated by *Simulium*, *Cheumatopsyche*, and three genera of Chironomids—*Saetheria*, *Cricotopus/Orthocladius*, and *Cardiocladius*. The Perlid stonefly *Acroneuria abnormis* was a subdominant in the 1999 Powder River sample and was common underneath the largest boulders in the riffles. The 2005 riffle sample from the Powder River near Locate contained some of the same species as the 1999 sample, including *Simulium*, *Cheumatopsyche*, *Saetheria,* and *Acroneuria abnormis*.

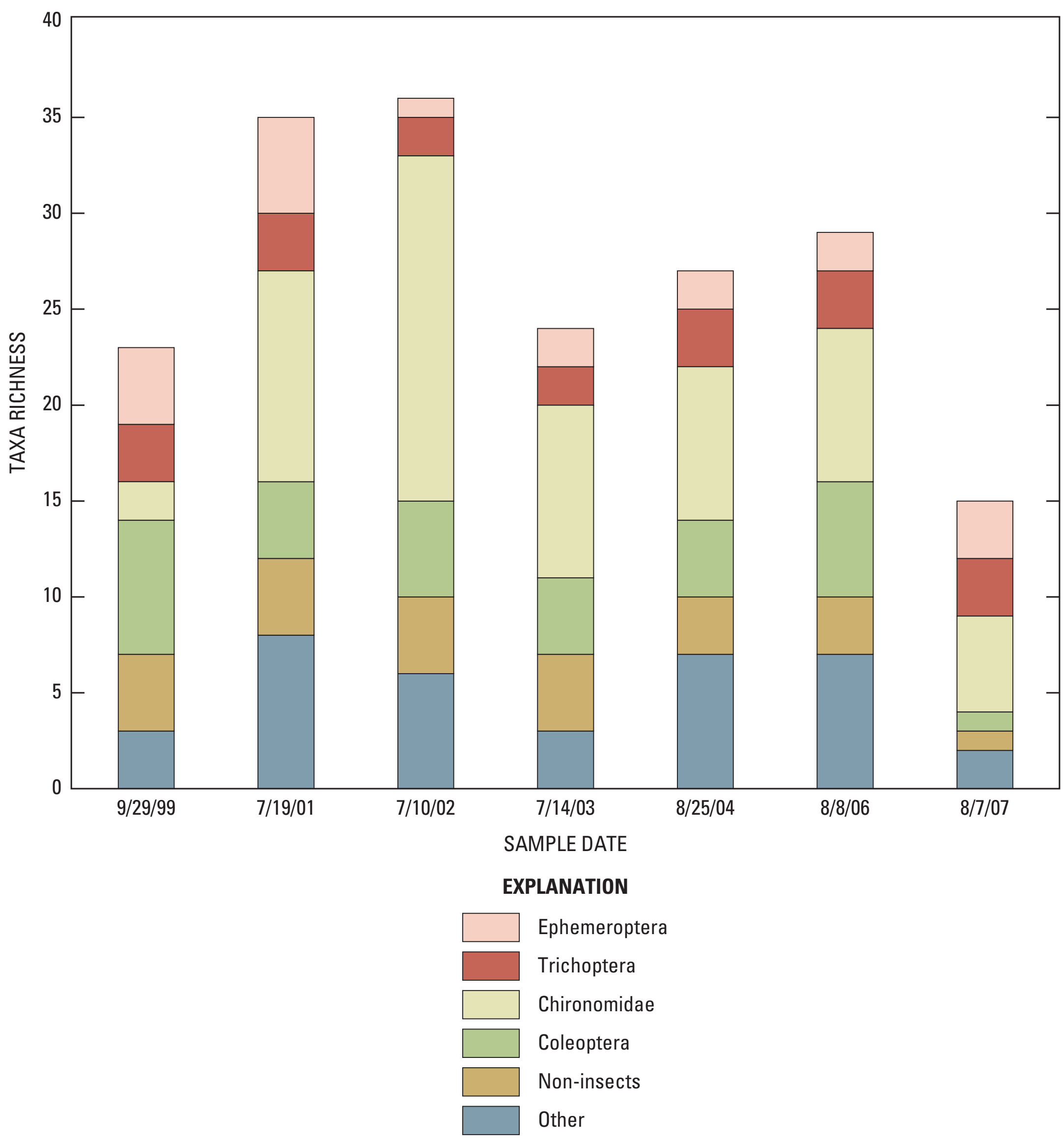

Figure 28. Macroinvertebrate community composition in National Water-Quality Assessment samples from the Little Powder River above Dry Creek (site P15), 1999–2007.

Algal Community Assessment

Previous analysis of NAWQA data (Potapova and Charles, 2005) has shown that differences in substrate (habitat) can affect algal diversity, biovolume, and abundance of specific taxa, however, algal relations with their physical and chemical environment (autecology) were not significantly affected by differences in substrate. Results described in this section of the report follow the recommendations of Potapova and Charles (2005) for presentation of RTH data separate from DTH data where appropriate.

Standing Crop

Concentrations of chlorophyll-*a* and AFDM generally were small, indicating a relatively small amount of algal biomass in riffles. Chlorophyll-*a* concentrations ranged from 0.6 to 71.3 milligrams per square meter (mg/m^2; fig. 29), with relatively large values observed at downstream sites on the main-stem Powder River below Clear Creek and at Moorhead (sites P11 and P12) and the main-stem Tongue River at the state line (site T9). Values for AFDM ranged from 3.5 to 61.6 grams per square meter (g/m^2), with relatively large values observed at sites P12 and T9. Median concentrations of chlorophyll-*a* and AFDM were 4.2 mg/m^2 and 12.7 g/m^2, respectively; chlorophyll-*a* and AFDM concentrations were positively correlated ($R^2 = 0.67$, $P < 0.05$). For comparison, all chlorophyll-*a* values were less than the 100-mg/m^2 seasonal mean target concentration to avoid nuisance algal conditions in the Clark Fork River in western Montana (Watson and others, 2000).

Community Composition

Taxa richness, the number of algal species in a sample, ranged from 25 in the Little Powder River above Dry Creek (site P15) to 115 in Crazy Woman Creek below I-90 (site P6; table 21). Although diatoms (Chrysophyta, Bacillariophyceae) contributed most to overall taxa richness, blue-green algae (Cyanophyta, cyanobacteria) and green algae (Chlorophyta) accounted for a substantial amount of periphyton standing crop at many sites, shown as relative (percentage) abundance in figure 30 and table 21. The abundance of blue-green algae ranged from 25 to 98 percent, whereas the abundance of diatoms and green algae varied from one percent to about 50 percent among sites. The abundance of green algae and diatoms generally was larger in pools than riffles; however, several riffle sites along the main stem of the Powder and Tongue Rivers (table 21, sites T9, P2, and P4) were characterized by more than 50 percent abundance of diatoms and green algae, that are considered a more desirable food source for macroinvertebrates (and certain fish) than blue-green algae. Taxa richness and relative abundance of euglenoid (Euglenophyta) and yellow-green (Chrysophyta, Chrysophyceae) algae generally were low-to-absent at sites in the study area (table 21).

Periphyton communities also can be classified, functionally, by the abundance of periphyton (attached or benthic) taxa compared with the abundance of suspended (phytoplankton or sestonic) taxa (table 21) for diatoms and "soft" algae (algae exclusive of diatoms). For example, within the blue-green algal division, common benthic taxa included *Oscillatoria*, *Lyngbya*, *Nostoc*, and *Calothrix* spp., whereas common sestonic taxa included *Microcystis*, *Aphanothece*, *Anabaena*, and *Gleocapsa* spp. Similarly, within the green algal division, common benthic taxa included *Cladophora*, *Rhizoclonium*, *Microspora*, and *Ulothrix* spp., whereas common sestonic taxa included *Oocystis*, *Sphaerocystis*, *Botryococcus*, and *Scenedesmus* spp.

Most sites in the study were dominated (more than 75 percent abundance) by sestonic soft algae, regardless of whether riffles or pools were sampled (table 21). The exceptions, sites with more than 25 percent abundance of benthic soft algae, included primarily main-stem sites along the Powder River (sites P1-P3, P8, P11, and P12), Little Powder River at Highway 59 (site P14), and Cheyenne River near Dull Center (site C3). In contrast to the soft algae, diatoms were more than 90 percent benthic forms at all of the sites, with the exception of sites P5 and P8 on the main-stem Powder River (table 21). The presence of sestonic algae in the samples might be affected by phytoplankton (free-floating) algae originating in pools or slow-flowing reaches upstream from the sample collection points.

Similarity of algal communities within river drainages and within specific habitats (riffles and pools) was indicated by NMDS ordination of Bray-Curtis similarity coefficients calculated from presence and absence data for diatoms and soft algae (fig. 31). Five groups of sites were identified that correspond with riffles in three river drainages (Tongue, Powder, and Cheyenne River groups), pools representing all river drainages in the study, and a small group containing only two riffle sites (sites P2 and P4). Site P15 (Little Powder River above Dry Creek) was an outlier in the ordination (fig. 31).

The Tongue River group (fig. 31) included the main-stem Tongue River (sites T1 and T9), Goose Creek (site T2), and Clear Creek (site P10). A replicate sample from site T1, indicated as T1R in figure 31, also plotted within the Tongue River group, indicating high similarity with the parent sample. As was found with the macroinvertebrate data, the presence of Clear Creek in the Tongue River group likely reflects the commonality of mountainous headwaters and snowmelt-driven hydrology. In contrast to the macroinvertebrate data, however, algal-community structure in Crazy Woman Creek (sites P6 and P7) was more similar to other sites in the Powder River drainage than to those in the Tongue River drainage. *Microcystis*, *Aphanothece*, and *Oscillatoria* were common blue-green algal taxa whereas *Oocystis* and *Sphaerocystis* were common green algal taxa in the Tongue River group. Diatom communities were dominated by *Cocconeis pediculus* and

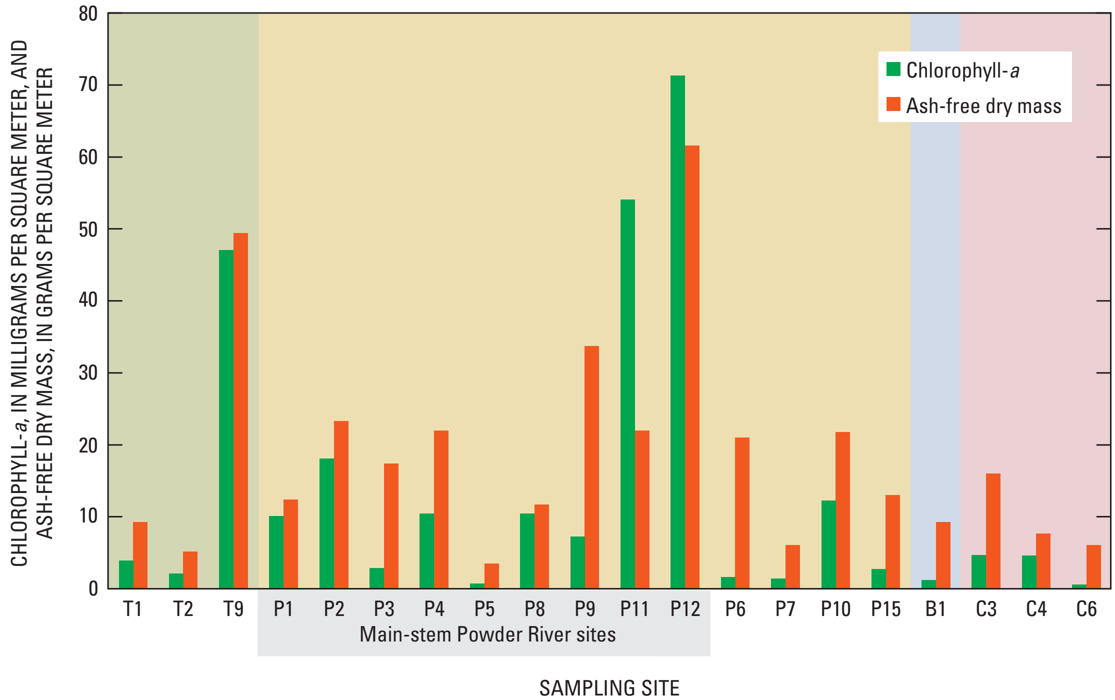

Figure 29. Chlorophyll-*a* and ash-free dry mass concentrations in algae samples, Powder River Structural Basin, 2005.

Cocconeis placentula var. *lineata. Cocconeis* is a eutrophic taxon found commonly as an epiphyte (attached to plants) on filamentous algae or aquatic macrophytes (Prescott, 1978), which were relatively abundant in the Tongue River drainage (table 8). Predominant diatoms in Clear Creek (site P10) included *Fragilaria construens* var. *venter* (32 percent), *Fragilaria brevistrata* var. *inflata* (19 percent), that are halophilic species (tolerant to dissolved salts) that might be responding to slightly larger specific conductance values at site P10 (1,200 µS/cm) compared with other sites in the Tongue River group (426–655 µS/cm; table 16).

The Powder River group (fig. 31) included most of the sites on the main-stem Powder River, both sites on Crazy Woman Creek (sites P6 and P7, and the replicate sample P7R) and site B1 on the Belle Fourche River. The replicate sample (P7R) plotted close to the parent sample (P7) in the Powder River group, indicating high similarity between those two samples. Predominant soft algae were the blue-green algae *Microcystis*, *Aphanothece*, *Lyngbya*, and *Oscillatoria* and the green algae *Oocystis*, *Sphaerocystis*, *Rhizoclonium*, and *Ulothrix*. The most common diatom taxa at main-stem Powder River sites were *Nitzchia, Caloneis,* and *Fragilaria*, which are generally found in eutrophic waters with large concentrations of dissolved ions. Specific conductance values at sites in the Powder River group ranged from less than 1,000 µS/cm in Crazy Woman Creek to over 3,000 µS/cm at sites P3, P5, and B1. Common diatoms in Crazy Woman Creek and the Belle Fourche River (sites P6, P7, and B1) included species of *Cocconeis* and *Fragilaria*. The occurrence of nitrogen-fixing algae (for example, *Anabaena*, *Calothrix*, *Nostoc*, and diatoms in the family Rhopalodiaceae (listed as "nitrogen fixers" diatom metric in table 21)) at many sites in the PRB possibly indicates nitrogen limitation. Nitrogen-fixing algae are capable of using atmospheric nitrogen gas as a source of nitrogen, and they are found commonly in aquatic systems with low concentrations of dissolved nitrogen or low ratios of nitrogen:phosphorus (Porter and others, 2008).

The Cheyenne River group of algal samples (fig. 31) contained four of the six sites in the Cheyenne River basin (sites C3–C6). All sites were dominated by sestonic blue-green (*Microcystis*, *Aphanothece*, and *Anabaena*) and green (*Oocystis*) soft algal taxa. *Rhizoclonium* and *Stigeoclonium* (benthic, filamentous green algae) accounted for 12 and 9 percent of algal abundance, respectively, in the Cheyenne River near Dull Center (site C3). Common diatoms at sites in the Cheyenne River group included *Fragilaria* spp., *Gomphonema* spp., *Epithemia* spp. (nitrogen fixing diatoms), and *Mastogloia smithii* (associated with highly saline, brackish waters; Porter, 2008). Nitrogen-fixing algae accounted for 21 percent of the diatom community at site C6, probably indicative of low dissolved nitrogen concentrations (or low ratios of nitrogen:phosphorus) at that site. The presence of halophilic diatoms in the Cheyenne River group is consistent with elevated specific conductance values (1,410 to 3,610 µS/cm) at those sites. Overall, algal community structure is similar between sites in the Cheyenne River group and those in the Powder River group.

Table 21. Algal taxa richness and diatom metrics from periphyton samples, Powder River Structural Basin, Wyoming and Montana, 2005.

[Shaded cells indicate main-stem sites on the Tongue or Powder River; %, percent; <, less than; >, greater than]

Site number (fig. 1)	Habitat	Sample date	Taxa richness and relative abundance										
			Sample taxa richness	Diatom taxa richness	Diatom abundance (%)	Blue-green algae richness	Blue-green algae abundance (%)	Green algae richness	Green algae abundance (%)	Euglenoid algae richness	Euglenoid algae abundance (%)	Yellow-green algae richness	Yellow-green algae abundance (%)
T1	Riffle	8/15/2005	43	34	2	4	64	5	34	0	0	0	0
T2	Riffle	8/17/2005	49	39	6	5	51	5	42	1	1	0	0
T8	Pool	8/16/2005	95	82	8	5	58	6	31	2	3	0	0
T9	Riffle	9/14/2005	73	58	44	5	37	9	19	1	<1	0	0
P1	Riffle	7/20/2005	69	59	3	5	77	5	20	0	0	0	0
P2	Riffle	7/21/2005	42	34	29	4	41	3	30	1	1	0	0
P3	Riffle	7/19/2005	63	53	3	4	77	6	20	0	0	0	0
P4	Riffle	7/22/2005	56	47	26	3	25	6	49	0	0	0	0
P5	Riffle	7/13/2005	92	81	1	3	65	6	33	1	<1	1	1
P6	Riffle	7/11/2005	115	106	11	4	54	4	34	1	1	0	0
P7	Riffle	7/12/2005	78	72	<1	3	92	3	8	0	0	0	0
P8	Riffle	7/23/2005	68	57	1	6	81	5	18	0	0	0	0
P9	Riffle	7/24/2005	96	82	9	5	58	8	32	1	1	0	0
P10	Riffle	9/13/2005	56	47	22	3	47	5	26	1	5	0	0
P11	Riffle	7/25/2005	58	50	1	4	81	4	18	0	0	0	0
P12	Riffle	7/26/2005	79	69	3	5	73	4	23	1	<1	0	0
P14	Pool	6/14/2005	56	51	56	3	34	2	10	0	0	0	0
P15	Riffle	6/13/2005	25	20	<1	3	90	2	8	0	0	0	0
C1	Pool	6/15/2005	80	74	25	3	49	3	26	0	0	0	0
C2	Pool	6/8/2005	60	47	26	3	30	8	43	2	1	0	0
C3	Riffle	6/27/2005	56	48	9	3	60	5	31	0	0	0	0
C4	Riffle	6/22/2005	66	61	1	4	98	1	1	0	0	0	0
C5	Pool	6/7/2005	74	59	11	4	40	9	48	2	2	0	0
C6	Riffle	6/21/2005	74	67	17	3	50	2	32	2	1	0	0
B1	Riffle	6/29/2005	69	64	9	3	78	2	13	0	0	0	0
B2	Pool	6/28/2005	86	77	33	4	44	5	23	0	0	0	0

Table 21. Algal taxa richness and diatom metrics from periphyton samples, Powder River Structural Basin, Wyoming and Montana, 2005.—Continued

[Shaded cells indicate main-stem sites on the Tongue or Powder River; %, percent; <, less than; >, greater than]

Site number (fig. 1)	Soft Algae metrics		Diatom metrics											
	Benthic soft algae (%)	Sestonic soft algae (%)	Benthic diatoms (%)	Sestonic diatoms (%)	*Achnanthes minutissima* (%)	Prefer low salinity (%)	Prefer high salinity (halophilic) (%)	Prefer pH near 7 (%)	Prefer pH >7 (alkaliphilous) (%)	Indifferent to pH (%)	Eutrophic (%)	Nitrogen heterotrophs (%)	Nitrogen fixers (%)	Motile (%)
T1	15	85	100	0	1	56	44	3	95	1	92	0	19	3
T2	14	86	100	0	1	80	20	7	92	1	88	1	6	3
T8	24	76	100	0	1	81	19	19	75	6	77	14	1	33
T9	24	76	98	2	1	79	21	5	93	2	82	3	8	5
P1	65	35	100	0	0	83	17	13	86	1	63	4	33	42
P2	28	72	97	3	40	57	43	2	56	42	21	8	0	11
P3	53	47	93	7	0	87	13	23	68	8	47	8	7	46
P4	9	91	96	4	60	97	3	7	28	65	25	15	0	4
P5	7	93	85	15	1	85	15	30	65	5	46	10	1	41
P6	8	92	96	4	0	82	18	17	80	3	70	14	8	24
P7	0	100	100	0	1	84	16	32	67	2	61	4	5	14
P8	61	39	65	35	0	71	29	34	57	9	49	18	1	28
P9	17	83	98	2	0	81	19	23	62	15	52	12	1	40
P10	17	83	100	0	1	87	13	3	95	1	65	1	1	5
P11	82	18	100	0	0	94	6	16	82	1	44	3	3	11
P12	50	50	97	3	1	93	7	8	90	2	48	3	4	19
P14	39	61	96	4	2	77	23	10	88	2	82	13	1	20
P15	2	98	100	0	26	86	14	7	67	26	69	6	8	3
C1	11	89	94	6	0	71	29	8	84	7	86	17	2	32
C2	19	81	100	0	1	86	14	11	84	5	44	12	2	16
C3	32	68	100	0	0	78	22	3	94	3	40	5	6	16
C4	8	92	99	1	1	78	22	32	62	6	45	17	9	27
C5	12	88	100	0	12	76	24	14	63	23	51	2	8	39
C6	0	100	100	0	1	82	18	12	86	2	48	3	21	21
B1	5	95	99	1	0	89	11	7	88	5	73	4	0	7
B2	14	86	100	0	0	68	32	21	60	19	70	14	1	55

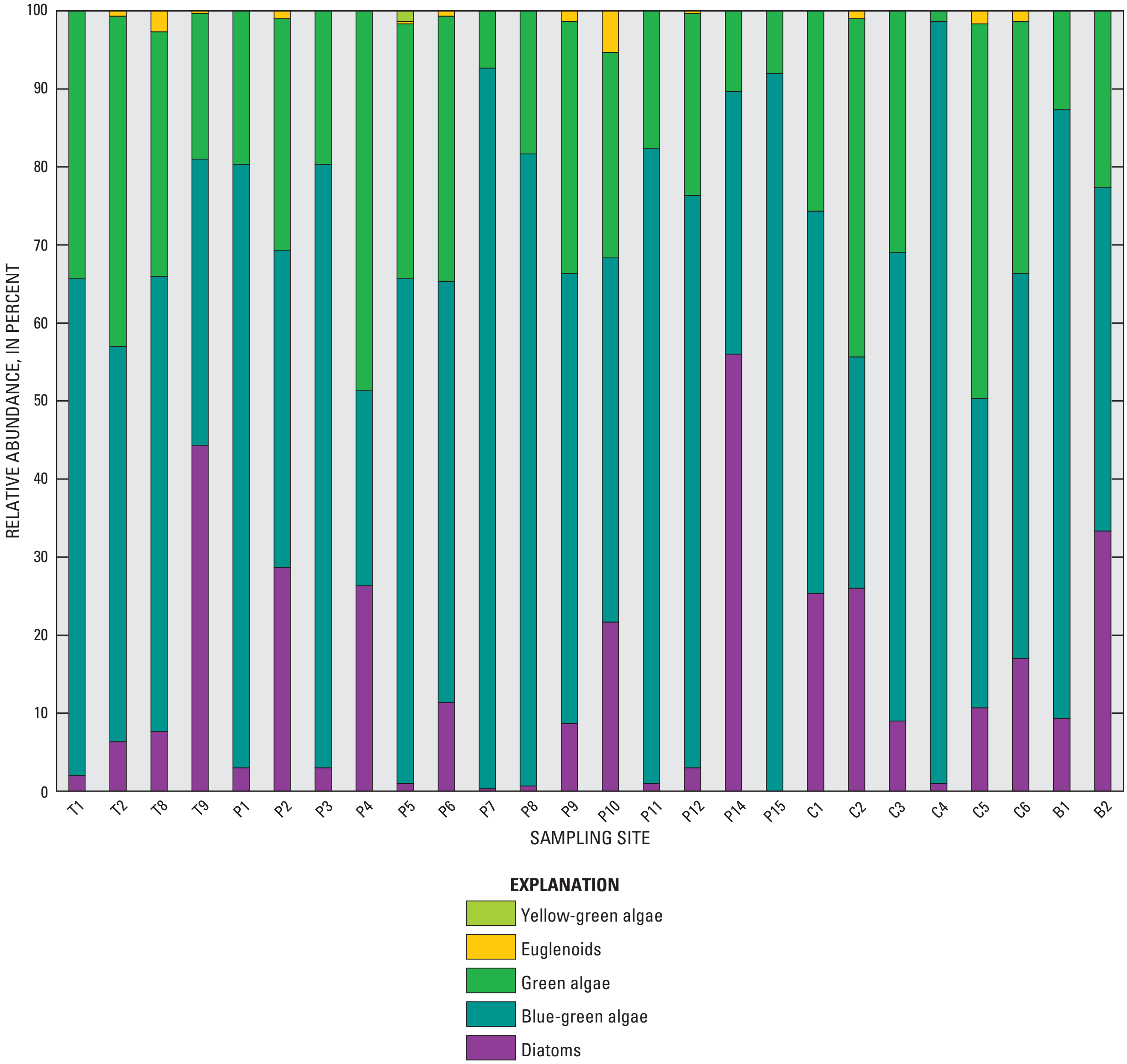

Figure 30. Relative abundance of algal divisions by site, Powder River Structural Basin, 2005.

The fourth NMDS group in figure 31 consists of five sites from all major river basins in the study (T8, P14, C1, C2, and B2); the common variable among these sites is that algae samples were collected from pools rather than riffles. Consistent with the other three major-river basin groups, algal communities were dominated by sestonic soft algae; however, the abundance of green algae (10–48 percent) and diatoms (8–56 percent) was considerably larger than found in other groups, and similarly, the percentage of blue-green algae (30–58 percent) was relatively smaller. The replicate sample from Caballo Creek (B2R) plotted close to the parent sample (B2) indicating high similarity between those two samples (fig. 31). The distribution of common sestonic and benthic diatom taxa, as well as the percentage of halophilic diatoms was similar to the other three major-river basin groups; however, the percentage of nitrogen-fixing diatoms was small (less than or equal to 2 percent). Percentages of halophilic diatoms (table 21) were similar to the other three major-river basin groups, and specific conductance values in the pool group ranged from 775–4,240 µS/cm. The relative abundance of motile diatoms (16–55 percent) was relatively larger in the pool group than the other three major-river basin groups. These taxa are capable of moving through streambed sediments and avoiding burial by sedimentation. This finding is consistent with embeddedness values listed in table 9 that ranged from 73 percent at site T8, to 99 percent at site C2,

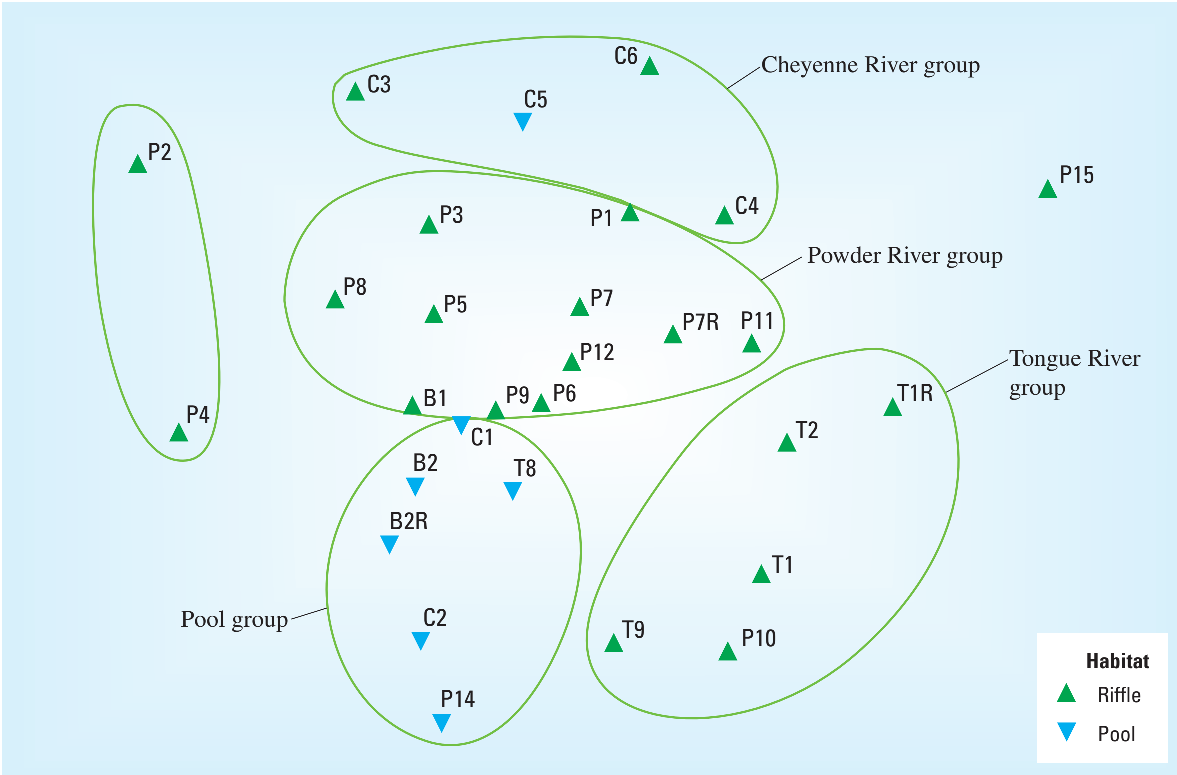

Figure 31. Algal communities depicted by nonmetric multidimensional scaling ordination, Powder River Structural Basin, 2005.

and 100 percent at sites C1and B2, among the largest reported values in the NMDS algal groups. Curiously, the remaining pool site in the study (C5) grouped with its major river basin (Cheyenne).

Algal communities in the Powder River below Salt Creek (site P2) and below Burger Draw (site P4) were similar relative to one another but highly dissimilar to other site groups in the study (fig. 31). A similar case can be made for site P15 (Little Powder River above Dry Creek), which is an outlier to all NMDS groups. Considering the P2-P4 group, both sites were dominated by sestonic soft algae; however, the abundance of diatoms (26 to 29 percent) was larger than other Powder River sites as was the abundance of green algae (30 to 49 percent; table 21). No nitrogen-fixing algae were identified in the P2–P4 group. Although the percentage of halophilic diatoms at site P2 (43 percent; table 21) was among the largest in the study, the percentage of halophils at site P4 (3 percent) was among the smallest in the study. The relative abundance of *Mastogloia smithii* in the diatom community at site P2 was 28 percent, indicative of elevated salinity. Specific conductance values at P2 (4,990 µS/cm) and P4 (4,600 µS/cm) were among the largest observed in the study (with site P3; 4,800 µS/cm).

Although community structure generally was disparate between the P2-P4 group and site P15 outlier, one common element was a relatively large percentage of *Achnanthes minutissima*. The relative abundance of *A. minutissima* was 60 percent of the diatom community at site P4, 40 percent at site P2, 26 percent at site P15, and 12 percent at site C5 (table 21); percentages at other sites in the study were very small. The percentage of *A. minutissima* frequently has been used as an indicator of disturbance (Barbour and others, 1999; Bahls and others, 1984), in part because the taxon is a pioneer species (with high rates of immigration on to clean substrates) whose abundance “has been found to be directly proportional to the time that has elapsed since the last scouring flow or episode of toxic pollution” (Barbour and others, 1999, p. 6–16). Conversely, *A. minutissima* is known to exhibit a broad range of ecological tolerance (Bahls and others, 1984; Porter, 2008), so its use as disturbance indicator may be questionable.

Diatom species are excellent indicators of salinity or specific conductance values (for example, van Dam and others, 1994). Diatom communities with the largest percentages of halobiontic (salt-loving; relatively high salinity) species occurred in the Powder River below Salt Creek (site P2), Tongue River at Monarch, WY (site T1), and Caballo Creek (site B2; table 21). Percentages of halobiontic diatoms ranged from 3 percent in the Powder River below Burger Draw (site P4) to 43 and 44 percent at sites P2 and T1. The salinity metric presented by van Dam and others (1994) is reflective of a European data set from freshwater, estuarine, and marine habitats, representing a wider gradient of salinity concentrations than found in most continental studies. Sources of constituents contributing to elevated specific-conductance values include anthropogenic sources and natural geochemical and soil properties in the PRB.

Diatom species also are good indicators of pH and water hardness. Species occurring in the Powder River structural basin generally reflect pH values greater than 7 (alkaliphilous). The abundance of alkaliphilous diatoms ranged from 28 percent at site P4 to 95 percent at sites T1 and P10 (table 21). This corresponds with pH values ranging from 6.8 to 8.8 (median = 8.0) measured during the time of biological sampling. Caution should be used in interpretation of single measurements of pH (and dissolved oxygen) at eutrophic sites because of considerable variability in these constituents over a 24-hr cycle as a result of primary productivity (for example, Peterson and others, 2001).

The nutrient status, as indicated by diatom communities, varied among river drainages. The relative abundance of eutrophic, or nutrient-rich, species was generally greater in samples from the Tongue River, Little Powder, and Belle Fourche River drainages than from the Powder and Cheyenne River drainages (table 21). The percentage of eutrophic diatoms ranged from 21 percent of the diatom community in the Powder River below Salt Creek (site P2) to 88–92 percent of the community at sites that receive wastewater-effluent discharges from small towns in the study area (for example, sites T1 and T2; table 21). Another diatom indicator of nutrient status is the percentage of nitrogen heterotrophs, species with requirements for organic forms of nitrogen (van Dam and others, 1994; Porter and others, 2008). The percentage of nitrogen heterotrophs in samples ranged from zero (site T1) to 18 percent (site P8) with relatively little differences among sites in major-river basins. Sources of organic nitrogen enrichment include wastewater-effluent discharges and localized uses of streams by livestock or wildlife. As previously described, many of the algal communities contained both diatom and soft algae nitrogen fixers, associated with either small concentrations of nitrogen or low ratios of nitrogen:phosphorus. This might indicate nitrogen is a limiting nutrient to algal growth in streams of the PRB, similar to indications from a study of the Yellowstone River in Montana (Peterson and Porter, 2002).

The relative abundance of motile diatoms in samples from riffles was greatest at sites on the main-stem Powder River. The percentage of motile diatoms is based on the sum of diatoms that are thought to be capable of movement to avoid sedimentation (Porter, 2008). Forty percent or more of the diatoms at the Powder River above Salt Creek (site P1), above Pumpkin Creek (site P3), above Crazy Woman Creek (site P5), and above Clear Creek (site P9) were motile species (table 21). Algae samples collected from pools, such as Caballo Creek (site B2), Black Thunder Creek (site C5), and Prairie Dog Creek (site P8) also contained large percentages of motile diatoms as might be expected given the depositional nature of the habitat.

Effect of Environmental Variables on Algal Communities

The environmental variables previously selected as indicators of geographic variables, habitat, and water quality (table 16) were tested for relation to the algal communities in the RTH (riffle) samples using the BEST routine (Clarke and Gorley, 2006). The five environmental variables chosen by the routine as best correlated with the Bray-Curtis similarity coefficients for the algal communities were northing, riparian disturbance, specific conductance, water temperature, and alkalinity ($\rho = 0.58$). Three of the five environmental variables best correlated with the algal riffle communities were related to water quality, and the other two were geographic variables; none were habitat related. A greater degree of correlation might have been achieved by including other variables. For example, nutrient concentrations are known to affect algal communities (Porter and others, 2008), but nutrient data were not collected because they were beyond the scope of this study. Comparison of results from the BEST routine for algal communities to the BEST results described previously for macroinvertebrate communities in the section "Effect of Environmental Variables on Macroinvertebrate Communities" indicates that specific conductance and alkalinity were explanatory variables common to both algal and macroinvertebrate communities.

Ancillary Algal Data

Concentrations of chlorophyll-*a* in algae samples collected from the Little Powder River (site P15) for the NAWQA Program ranged from 3.0 to 48.5 mg/m^2 during 2001–04 and 2006–07 (fig. 32). The ATG chlorophyll data from 2005 are included in figure 32 for comparison. The median chlorophyll-*a* concentration was 5.5 mg/m^2 at site P15 during 2001–07. Chlorophyll-*a* concentrations in samples collected for the WWSC water-quality monitoring network in 2002 were 7 mg/m^2 at sampling site T9 on the Tongue River at State line and 28.6 mg/m^2 at site P10 on Clear Creek. Algae samples were not analyzed for chlorophyll-*a* during the WWSC project in 1980–81.

Diatoms dominated the algal taxa identified in the NAWQA samples from the Little Powder River at site P15, constituting a mean of 91 percent of the taxa during 1999–2006. The most common species of diatom in the NAWQA samples were *Nitzchia inconspicua* and *Achnanthidium minutissimum*. The dominance of *Nitzchia inconspicua*, a halophil, is consistent with the relatively high specific conductance values observed at this site. Blue-green algae sometimes dominated the NAWQA samples in terms of density and biovolume; the most common taxa of blue-green algae were *Calothrix* spp. (nitrogen fixers) and *Homoeothrix* spp. The predominant species of diatoms and blue-green algae differed

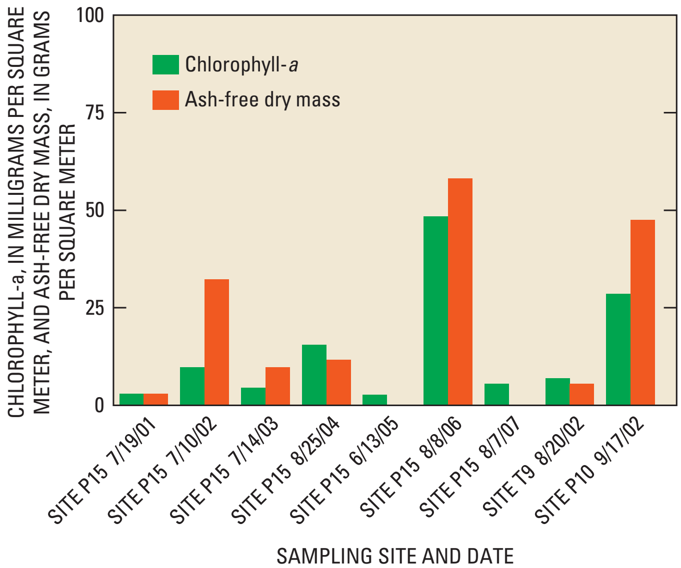

Figure 32. Chlorophyll-*a* and ash-free dry mass concentrations in ancillary algae samples, Powder River Structural Basin, 2001–07.

between the NAWQA and ATG samples, but some were from the same families in both data sets. In contrast, blue-green algae were not identified in three algae samples collected during 1980 from periphyton at site P15 for a WWSC project. The lack of blue-green algae in 1980 might be because the samples were collected earlier in the season (April, May, and June) than the NAWQA samples (July through September).

The mean number of taxa identified and the number of samples (n) from the Little Powder River at site P15 were ATG, 25 taxa (n = 1); WWSC project, 25 taxa (n = 3); and NAWQA, 40 taxa (n = 6). One of the predominant algae species in the WWSC project samples and the ATG sample from site P15 was the diatom *Achnanthes minutissima*, which also was common in the NAWQA samples under the newer synonym *Achnanthidium minutissimum*. Diatom species in the NAWQA samples generally were alkaliphilous, with optima greater than pH 7. Salinity optima for the diatoms were in the fresh-brackish category (dissolved-solids concentrations less than 500 mg/L) and to a lesser extent, the brackish-fresh category (dissolved-solids concentrations of 500 to 1,000 mg/L). Nutrient optima indicated most diatoms in the NAWQA samples from site P15 were either tolerant of or moderately dependent on large concentrations of organic nitrogen.

NAWQA protocols were used to collect algae samples in 2002 as part of the WWSC monitoring network at the Tongue River at State line (site T9), Clear Creek (site P10), and Cheyenne River at Riverview (USGS gaging station 06386400, several kilometers upstream from site C6). The dominant algae in terms of relative abundance in the riffle sample from the Tongue River were the blue-green algae *Phormidium* and the diatom *Cocconeis pediculus*. Nitrogen optima indicated about 76 percent of the diatoms in the Tongue River sample were nitrogen autotrophs that are tolerant of, but not necessarily dependent on, large concentrations of organic nitrogen. The 2002 riffle sample from Clear Creek was dominated by blue-green algae, mainly *Phormidium* and *Oscillatoria*; the most common diatoms were *Achnanthidium minutissimum* and *Encyonopsis subminuta.* The diatom community from Clear Creek contained mostly nitrogen autotrophs, with low to moderate tolerance of organic nitrogen. Blue-green algae (*Oscillatoria*) also dominated the algae sample from the Cheyenne River, which was collected from pools due to lack of riffles at the site. About 64 percent of the diatoms from the Cheyenne River sample fell into the fresh-brackish salinity category.

Algae samples were collected from the Little Powder River at Highway 59 (site P14), Cheyenne River near Dull Center (site C3), and the Belle Fourche River (site B1) during a WWSC project investigation in 1980. Algae samples from the Little Powder River were dominated by the diatoms *Nitzchia dissipata* and *Gomphonema* spp. during April and May, the diatom *Amphora perpusilla* in June, and the blue-green algae *Anabaena* during August. Motile species of diatoms dominated in the algae samples from the Cheyenne River, including *Surirella ovata* in April, *Nitzchia constricta* and *Nitzchia palea* in May, and *Nitzchia acicularis* in June. Algal communities sampled in the Belle Fourche River were dominated by the halophilic diatom *Fragilaria construens venter* in April and August and by *Navicula gregaria* in June. The periphyton algae samples from the WWSC project sites typically each contained 20 to 30 species of algae.

Fish Community Assessment

The results of the fish community assessment are organized by river drainage because of differences in sampling methods. For convenience, the term “tributaries” is used to encompass all streams not specifically named in the section title.

Fish Communities of the Tongue, Cheyenne, and Belle Fourche Rivers and Tributaries

Fish communities were sampled at 35 sites during 2005; 28 of the same sites were sampled during 2006. The number of sites sampled in 2006 was smaller than in 2005 because of dry sample reaches (sites T7, T16, C5, and B2) and study limitations at other sites (sites R2, T19, and P16).

Spatial and Temporal Distribution of Fish

A total of 36 species of fish were identified in samples collected during 2005 and 2006 (table 22). Ecological characteristics of those 36 fish species, as well as of 2 fish species identified only in the main-stem Powder River, are listed in table 23. About one-half of the species (17) identified in the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries were native, including eight minnows (Cyprinidae) and all five suckers (Catostomidae). Introduced fish species included eight sunfishes (Centrarchidae), two topminnows (Cyprinodontidae), northern pike (Esocidae), and yellow perch (Percidae). Other fish identified included goldeye (Hiodontidae, native) and catfishes (Ictaluridae, two native species and two introduced species), and sauger (Percidae, native). The fishes sampled generally were warm-water species, although trout (Salmonidae) were captured in the Tongue River at Monarch (site T1). Site T1 is located at the boundary between the cold-water and warm-water fishery as defined by WGFD and might be considered a transition zone on the basis of the presence of both cold- and warm-water species.

Fathead minnows were the most common fish in the collective samples during 2005–06 and comprised 16 percent of the relative abundance of fish captured (fig. 33). Smallmouth bass and sand shiner each comprised more than 10 percent of the fish, whereas rock bass, white sucker, common carp, green sunfish, and shorthead redhorse each comprised 5 percent or more of the fish. The other 27 species comprised 24 percent of the fish captured.

Fish species richness was greatest at sampling sites on the Tongue River. Samples from the Tongue River at State line (site T9) contained 18 species in 2005 and 17 species in 2006 (table 22), whereas other sites on the Tongue River (sites T1, T5, T10, T14, and T18) contained 10 to 16 species. The Tongue River Reservoir on the main stem between sites T9 and T10 appears to affect the fish communities of the river. Open-water species, such as spottail shiner and yellow perch (Baxter and Stone, 1995), were identified only at sites upstream from the reservoir—sites T5 and T9 on the Tongue River and site T8 on Prairie Dog Creek. Black crappie and white crappie, also known as open-water species, were found in small numbers in the Tongue River upstream and downstream from Tongue River Reservoir. Farther downstream from the reservoir, in the Tongue River below Brandenberg Bridge (site T18), the fish community shifted toward a warm-water community adapted to turbid water and large rivers, as indicated by larger numbers of flathead chub, channel catfish, and river carpsucker (Baxter and Stone, 1995).

A total of 15 species of fish were identified in the main stem of the Tongue River and its tributaries that were not identified in the Cheyenne and Belle Fourche Rivers and their tributaries, nor in Rosebud Creek or the Little Powder River. Additionally, of those 15 species, only one—the mountain sucker—was identified in samples from the main-stem Powder River. Several of the 15 species were open-water species as noted previously. Some native species, such as the brassy minnow and lake chub, were found only in the Tongue River drainage, as were introduced species such as the yellow bullhead and golden shiner. Of the 31 species of fish identified in samples from the Tongue River drainage in 2005–06, 16 species were introduced. Introduced fish comprised 51 percent of the total abundance of fish in samples from the Tongue River drainage and included smallmouth bass, rock bass, common carp, and green sunfish.

Tributary streams with relatively large numbers of fish species in both 2005 and 2006 were Goose Creek (site T2), Prairie Dog Creek (site T8), Clear Creek (site P10), and Little Powder River above Dry Creek (site P15). Fourteen species of fish were collected in both 2005 and 2006 from Clear Creek, including sauger in both years. Sauger, which is a species of concern, were not collected at any of the other 34 sampling sites. The number of species per sample was smallest in small intermittent streams such as Rosebud Creek (site R1), Porcupine Creek (site C1), and the Belle Fourche River (site B1). The fish community at site R1 was atypical because northern pike (an efficient carnivore) was the only species captured there in 2005, and no fish were captured during the 2006 sampling. Site R1 also was the only site where northern pike were observed. Only one species of fish (fathead minnow) was collected at Porcupine Creek in 2005–06, and two and three species of fish were captured from the Belle Fourche River in 2005 and 2006, respectively.

Fish communities sampled in 2006 appeared to be similar to those in 2005 on the basis of taxa richness and abundance. Although 2006 was a drier year and fish habitat appeared to be reduced (figs. 3 and 4), the mean number of species collected was similar between the years. Using data from sites sampled in both years, a mean of 6.9 species per site was sampled in 2005, and a mean of 7.1 species per site was sampled in 2006. The total abundance of fish collected from those sites was 7,132 fish in 2005 and 11,638 fish in 2006. The largest increases in fish abundance from 2005 to 2006 were for sand shiner, fathead minnow, and common carp, but the differences in abundance between years might be related to normal year-to-year variation or perhaps due to more efficient capture related to reduction in the available habitat associated with smaller flows.

Fish Community Structure

The structure and integrity of the fish community were assessed using the Index of Biotic Integrity (IBI) developed for prairie streams in Montana (Bramblett and others, 2005). As noted in the methods section of this report, IBI scores for the main-stem Tongue River are presented for comparative purposes among the main-stem sites and between years, and should not be compared directly to the scores from the small plains streams.

Of the small plains streams that were sampled, the fish communities from Youngs Creek (sites T3 and T4) and Squirrel Creek (sites T6 and T7) had some of the highest IBI scores in this study (table 24). The highest observed IBI score of 87 occurred at site T3 on upper Youngs Creek in both 2005 and 2006 (table 24). IBI scores from sites on lower Youngs Creek (site T4) and Squirrel Creek (sites T6 and T7) also were relatively high and ranged from 66 to 81. Other sites with IBI scores greater than 60 in both years were Crazy Woman Creek near mouth (site P7), Clear Creek (site P10), and the Little Powder River at Highway 59 (site P14).

Table 22. Fish abundance in samples from the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries, Wyoming and Montana, 2005–06.

[Shaded cells indicate main-stem sampling sites on the Tongue River. Numbers indicate the number of individuals]

Site number (fig. 1)	Abbreviated site name	Sample date	Black bullhead	Black crappie	Bluegill	Brassy minnow	Brown trout	Channel catfish	Common carp	Creek chub	Fathead minnow	Flathead chub	Golden shiner	Goldeye	Green sunfish	Lake chub	Largemouth bass	Longnose dace
R1	upper Rosebud Creek	06/20/05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		08/22/06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R2	Rosebud Creek at mouth	09/14/05	1	0	0	0	0	1	2	0	21	2	0	0	6	0	0	0
T1	Tongue River at Monarch	08/23/05	2	0	0	0	3	0	26	0	1	0	0	0	22	0	0	0
		08/23/06	1	0	0	0	1	0	20	0	0	0	0	0	15	0	0	2
T2	Goose Creek	08/22/05	3	0	0	0	0	0	18	0	1	0	0	0	3	0	6	3
		08/22/06	15	0	0	0	0	0	30	0	0	0	0	0	3	0	0	8
T3	upper Youngs Creek	06/15/05	0	0	0	0	0	0	0	6	2	0	0	0	0	0	0	69
		06/28/06	0	0	0	0	0	0	0	62	15	0	0	0	0	0	0	32
T4	Youngs Creek at mouth	06/14/05	0	0	0	1	0	0	0	0	22	0	0	0	0	0	0	6
		06/27/06	0	0	0	54	0	0	0	9	104	0	0	0	0	4	0	7
T5	Tongue River below Youngs Creek	08/29/05	108	3	0	0	0	0	43	0	17	0	0	0	42	0	0	6
		08/24/06	10	0	0	0	0	0	129	0	0	4	0	0	5	0	0	31
T6	upper Squirrel Creek	06/16/05	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	10
		06/29/06	0	0	0	1	0	0	0	10	83	0	0	0	0	0	0	0
T7	Squirrel Creek at mouth	06/13/05	1	0	0	0	0	0	0	8	3	0	0	0	0	1	0	0
T8	Prairie Dog Creek	08/26/05	13	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		08/25/06	0	0	0	0	0	0	8	168	0	0	0	0	1	0	0	5

Table 22. Fish abundance in samples from the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries, Wyoming and Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sampling sites on the Tongue River. Numbers indicate the number of individuals]

Site number (fig. 1)	Abbreviated site name	Sample date	Black bullhead	Black crappie	Bluegill	Brassy minnow	Brown trout	Channel catfish	Common carp	Creek chub	Fathead minnow	Flathead chub	Golden shiner	Goldeye	Green sunfish	Lake chub	Largemouth bass	Longnose dace
T9	Tongue River at State line	08/25/05	30	25	4	1	0	6	89	9	0	2	0	0	1	0	0	5
		08/28/06	13	3	0	0	0	9	99	51	0	3	0	0	6	0	0	13
T10	Tongue River above Hang-ing Woman Creek	08/30/05	0	9	0	0	0	10	21	0	0	0	0	0	1	0	0	0
		08/29/06	0	0	0	0	0	7	24	0	0	0	0	0	0	0	0	1
T11	upper Hanging Woman Creek	06/22/05	0	0	0	3	0	0	0	0	0	0	0	0	52	0	0	0
		06/27/06	0	0	0	8	0	0	4	0	6	0	0	0	24	0	0	0
T12	middle Hanging Woman Creek	06/21/05	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0
		06/26/06	0	0	0	0	0	0	0	0	7	0	0	0	18	0	0	0
T13	Hanging Woman Creek at mouth	06/23/05	0	0	0	0	0	0	0	0	85	0	0	0	17	0	0	0
		06/26/06	0	0	0	0	0	0	0	0	266	0	0	0	0	0	0	0
T14	Tongue River at Birney Day School	08/31/05	0	0	0	0	0	18	35	0	0	0	0	0	0	0	0	2
T14	Tongue River at Birney Day School	08/30/06	2	0	0	0	0	63	35	0	0	0	2	0	17	0	0	19
T15	upper Otter Creek	06/29/05	0	0	0	12	0	0	0	0	0	0	0	0	0	12	0	0
		07/12006	0	0	0	1	0	0	0	0	0	0	0	0	0	4	0	0
T16	middle Otter Creek	06/28/05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 22. Fish abundance in samples from the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries, Wyoming and Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sampling sites on the Tongue River. Numbers indicate the number of individuals]

Site number (fig. 1)	Abbreviated site name	Sample date	Black bullhead	Black crappie	Bluegill	Brassy minnow	Brown trout	Channel catfish	Common carp	Creek chub	Fathead minnow	Flathead chub	Golden shiner	Goldeye	Green sunfish	Lake chub	Largemouth bass	Longnose dace
T17	Otter Creek at mouth	06/30/05	0	0	1	114	0	0	31	0	360	0	0	0	0	0	0	0
		06/28/06	1	0	0	0	0	0	122	0	931	0	0	0	6	0	0	0
T18	Tongue River below Brandenberg Bridge	09/01/05	0	1	0	0	0	19	18	0	5	237	0	0	54	0	0	19
		08/31/06	0	0	0	0	0	55	81	0	11	136	0	0	4	0	0	9
T19	Pumpkin Creek	06/24/05	0	0	0	0	0	1	0	0	36	4	0	2	0	0	0	0
P6	Crazy Woman Creek below I-90	07/14/05	0	0	0	0	0	0	0	0	0	5	0	2	0	0	0	0
		07/31/06	0	0	0	0	0	6	330	0	2	0	0	7	0	0	0	4
P7	Crazy Woman Creek near mouth	07/14/05	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	3
		08/01/06	0	0	0	0	0	9	6	0	16	15	0	0	4	0	0	67
P10	Clear Creek	08/24/05	0	0	0	0	0	9	29	0	22	8	0	15	2	0	0	0
		08/21/06	0	0	0	0	0	4	14	5	0	128	0	6	2	0	0	1
P14	Little Powder River at Highway 59	06/23/05	0	0	0	0	0	0	0	0	27	0	0	0	0	0	0	0
		06/22/06	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	18
P15	Little Powder River above Dry Creek	06/23/05	12	0	0	0	0	2	5	3	56	3	0	0	27	0	0	0
		06/23/06	3	0	0	0	0	4	3	0	8	1	0	0	18	0	0	19
P16	Little Powder River at Biddle	06/27/05	2	0	0	0	0	2	2	2	50	0	0	0	4	0	0	0

Table 22. Fish abundance in samples from the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries, Wyoming and Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sampling sites on the Tongue River. Numbers indicate the number of individuals]

Site number (fig. 1)	Abbreviated site name	Sample date	Black bullhead	Black crappie	Bluegill	Brassy minnow	Brown trout	Channel catfish	Common carp	Creek chub	Fathead minnow	Flathead chub	Golden shiner	Goldeye	Green sunfish	Lake chub	Largemouth bass	Longnose dace
C1	Porcupine Creek	06/20/05	0	0	0	0	0	0	0	0	373	0	0	0	0	0	0	0
		06/22/06	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0
C2	Antelope Creek	06/20/05	0	0	0	0	0	0	1	0	69	0	0	0	356	0	0	0
		06/20/06	3	0	0	0	0	0	0	0	0	0	0	0	335	0	0	0
C3	Cheyenne River near Dull Center	06/22/05	1	0	0	0	0	0	3	0	2	0	0	0	40	0	0	0
		06/19/06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C4	Little Thunder Creek	06/2205	16	0	0	0	0	0	1	0	36	0	0	0	14	0	0	0
		06/21/06	15	0	0	0	0	0	3	0	200	0	0	0	13	0	0	0
C5	Black Thunder Creek	06/21/05	1	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0
C6	Cheyenne River near Spencer	06/21/05	1	0	0	0	0	0	4	0	20	0	0	0	33	0	0	0
		06/20/06	0	0	0	0	0	0	0	0	8	0	0	0	1	0	0	0
B1	Belle Fourche River	06/24/05	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0
		06/21/06	0	0	0	0	0	0	22	0	58	0	0	0	0	0	0	0
B2	Caballo Creek	06/23/05	0	0	0	0	0	0	3	0	13	0	0	0	0	0	0	0

Table 22. Fish abundance in samples from the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries, Wyoming and Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sampling sites on the Tongue River. Numbers indicate the number of individuals]

Site num-ber (fig. 1)	Sample date	Longnose sucker	Mountain sucker	Northern pike	Northern plains killifish	Plains minnow	Plains topminnow	Pumpkinseed	Rainbow trout	River carpsucker	Rock bass	Sand shiner	Sauger	Shorthead red-horse	Smallmouth bass	Spottail shiner	Stonecat	White crappie	White sucker	Yellow bullhead	Yellow perch	Total number of species
R1	6/20/2005	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	8/22/2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R2	9/14/2005	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	4	0	0	8
T1	8/23/2005	11	0	0	0	0	0	0	1	0	240	0	0	57	93	0	13	0	46	0	0	12
	8/23/2006	20	0	0	0	0	0	0	0	0	369	0	0	67	559	0	53	0	68	0	0	11
T2	8/22/2005	0	0	0	0	0	0	0	0	0	314	0	0	31	288	0	69	0	37	0	0	11
	8/22/2006	0	0	0	0	0	0	0	0	0	203	0	0	0	186	0	65	0	51	0	0	8
T3	6/15/2005	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
	6/28/2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	4
T4	6/14/2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
	6/27/2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	6
T5	8/29/2005	4	0	0	0	0	0	0	0	0	93	0	0	56	412	77	2	0	125	0	0	13
	8/24/2006	4	0	0	0	0	0	4	0	0	116	0	0	58	217	148	11	0	57	178	0	14
T6	6/16/2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
	6/29/2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4
T7	6/13/2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	5
T8	8/26/2005	3	0	0	0	0	0	0	0	0	10	0	0	0	2	1	56	0	9	4	0	9
	8/25/2006	4	0	0	0	0	0	0	0	0	5	0	0	13	26	0	1	0	56	0	0	10
T9	8/25/2005	0	0	0	0	0	0	0	0	0	34	0	0	42	264	40	10	1	102	0	1	18
	8/28/2006	1	0	0	0	0	0	34	0	0	55	0	0	95	234	150	46	0	119	301	0	17
T10	8/30/2005	0	0	0	0	0	0	0	0	6	41	0	0	21	39	0	12	0	18	21	0	11
	8/29/2006	0	0	0	0	0	0	0	0	1	52	0	0	42	60	0	23	0	57	24	0	10
T11	6/22/2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	3
	6/27/2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
T12	6/21/2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	6/26/2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	3

Table 22. Fish abundance in samples from the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries, Wyoming and Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sampling sites on the Tongue River. Numbers indicate the number of individuals]

Site num-ber (fig. 1)	Sample date	Longnose sucker	Mountain sucker	Northern pike	Northern plains killifish	Plains minnow	Plains topminnow	Pumpkinseed	Rainbow trout	River carpsucker	Rock bass	Sand shiner	Sauger	Shorthead red-horse	Smallmouth bass	Spottail shiner	Stonecat	White crappie	White sucker	Yellow bullhead	Yellow perch	Total number of species
T13	6/23/2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	6	0	0	4
T13	6/26/2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
T14	8/31/2005	0	0	0	0	0	0	0	0	19	61	0	0	37	21	0	16	8	62	38	0	11
	8/30/2006	4	0	0	0	0	0	0	0	9	69	0	0	39	138	0	46	0	111	39	0	14
T15	6/29/2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	3
	7/12/2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
T16	6/28/2005	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	2
T17	6/30/2005	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	6	0	0	6
	6/28/2006	0	0	0	0	0	0	0	0	0	0	43	0	0	0	0	0	0	0	0	0	5
T18	9/1/2005	4	0	0	0	0	0	3	0	51	1	0	0	81	8	0	7	0	95	9	0	16
	8/31/2006	1	0	0	0	0	0	0	0	155	1	1	0	354	24	0	4	0	214	2	0	15
T19	6/24/2005	0	0	0	0	0	0	0	0	1	0	162	0	0	0	0	0	0	0	0	0	6
P6	7/14/2005	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	3
	7/31/2006	0	0	0	0	0	0	0	0	4	0	160	0	10	30	0	9	0	156	0	0	11
P7	7/14/2005	0	0	0	0	0	0	0	0	0	0	33	0	0	0	0	1	0	8	0	0	5
	8/1/2006	0	0	0	0	0	0	0	0	0	0	402	0	0	0	0	9	0	227	0	0	9
P10	8/24/2005	0	0	0	0	0	0	0	0	13	91	71	2	40	22	0	32	0	19	0	0	14
	8/21/2006	0	0	0	0	0	0	0	0	0	76	192	1	12	33	0	45	0	13	0	0	14
P14	6/23/2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	6/22/2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	3
P15	6/23/2005	0	0	0	0	0	0	0	0	0	0	95	0	0	0	0	0	0	13	0	0	9
	6/23/2006	0	0	0	0	2	0	0	0	5	0	453	0	0	0	0	0	0	4	0	0	11
P16	6/27/2005	0	0	0	0	0	0	0	0	0	0	226	0	1	0	0	1	0	11	0	0	10
C1	6/20/2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	6/22/2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
C2	6/20/2005	0	0	0	0	0	160	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4

Table 22. Fish abundance in samples from the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries, Wyoming and Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sampling sites on the Tongue River. Numbers indicate the number of individuals]

Site num-ber (fig. 1)	Sample date	Longnose sucker	Mountain sucker	Northern pike	Northern plains killifish	Plains minnow	Plains topminnow	Pumpkinseed	Rainbow trout	River carpsucker	Rock bass	Sand shiner	Sauger	Shorthead red-horse	Smallmouth bass	Spottail shiner	Stonecat	White crappie	White sucker	Yellow bullhead	Yellow perch	Total number of species
	6/20/2006	0	0	0	0	0	192	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4
C3	6/22/2005	0	0	0	14	0	7	0	0	0	0	8	0	0	0	0	0	0	24	0	0	8
	6/19/2006	0	0	0	18	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
C4	6/22/2005	0	0	0	3	0	0	0	0	0	0	12	0	0	0	0	0	0	6	0	0	7
	6/21/2006	0	0	0	21	0	0	0	0	0	0	69	0	0	0	0	0	0	5	0	0	7
C5	6/21/2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
C6	6/21/2005	0	0	0	37	2	6	0	0	1	0	34	0	0	0	0	0	0	2	0	0	10
C6	6/20/2006	0	0	0	66	1	0	0	0	0	0	14	0	0	0	0	0	0	1	0	0	6
B1	6/24/2005	0	0	0	0	0	0	0	0	0	0	74	0	0	0	0	0	0	0	0	0	2
	6/21/2006	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3
B2	6/23/2005	0	0	0	0	0	0	0	0	0	0	78	0	0	0	0	0	0	0	0	0	3

Table 23. Ecological characteristics of fish species sampled in the Powder River Structural Basin, Wyoming and Montana, 2005–06.

[Modified from Bramblett and others, 2005. Trophic category: IN, invertivore; HB, herbivore; OM, omnivore; IC, invertivore-carnivore; CA, carnivore. Feeding habitat: WC, water column; BE, benthic; GE, generalist. Reproductive class: LO, litho-obligate; TR, tolerant reproductive strategists; --, not determined or not available; General tolerance: INT, intolerant; MOD, moderate; TOL, tolerant. Origin: N, native; I, introduced. mm, millimeters; NA, not applicable because species generally lives less than 3 years]

Family	Common name	Scientific name	Trophic category	Feeding habitat	Repro-ductive class	General toler-ance	Origin	Length at 3 years (mm)
Hiodontidae	Goldeye	*Hiodon alosoides*	IN	WC	LO	INT	N	259
Cyprinidae	Lake chub	*Couesius plumbeus*	IN	WC	--	MOD	N	140
	Common carp	*Cyprinus carpio*	OM	BE	--	TOL	I	381
	Western silvery minnow[1]	*Hybognathus argyritis*	HB	BE	--	MOD	N	94
	Brassy minnow	*Hybognathus hankinsoni*	HB	BE	--	MOD	N	81
	Plains minnow	*Hybognathus placitus*	HB	BE	--	MOD	N	94
	Sturgeon chub[1]	*Macrhybopsis gelida*	IN	BE	LO	INT	N	50
	Golden shiner	*Notemigonus crysoleucas*	OM	WC	--	MOD	I	102
	Spottail shiner	*Notropis hudsonius*	IN	WC	LO	MOD	I	85
	Sand shiner	*Notropis stramineus*	OM	GE	LO	MOD	N	61
	Fathead minnow	*Pimephales promelas*	OM	GE	TR	TOL	N	76
	Flathead chub	*Platygobio gracilis*	IN	GE	--	MOD	N	140
	Longnose dace	*Rhinicthys cataractae*	IN	BE	LO	INT	N	71
	Creek chub	*Semotilus atromaculatus*	IC	GE	LO	MOD	N	114
Catostomidae	River carpsucker	*Carpiodes carpio*	OM	BE	LO	MOD	N	229
	Longnose sucker	*Catostomus catostomus*	IN	BE	LO	MOD	N	216
	White sucker	*Catostomus commersonii*	OM	BE	LO	TOL	N	229
	Mountain sucker	*Catostomus platyrhynchus*	HB	BE	LO	MOD	N	102
	Shorthead red-horse	*Moxostoma macrolepidotum*	IN	BE	LO	MOD	N	254
Ictaluridae	Black bullhead	*Ameiurus melas*	IC	BE	TR	TOL	I	152
	yellow bullhead	*Ameiurus natalis*	IC	BE	TR	MOD	I	254
	channel catfish	*Ictalurus punctatus*	IC	BE	TR	MOD	N	254
	stonecat	*Noturus flavus*	IC	BE	LO	INT	N	140
Esocidae	northern pike	*Esox lucius*	CA	WC	--	MOD	I	457
Salmonidae	rainbow trout	*Oncorhynchus mykiss*	IC	WC	LO	INT	I	279
	brown trout	*Salmo trutta*	IC	WC	LO	INT	I	305

Table 23. Ecological characteristics of fish species sampled in the Powder River Structural Basin, Wyoming and Montana, 2005–06.—Continued

[Modified from Bramblett and others, 2005. Trophic category: IN, invertivore; HB, herbivore; OM, omnivore; IC, invertivore-carnivore; CA, carnivore. Feeding habitat: WC, water column; BE, benthic; GE, generalist. Reproductive class: LO, litho-obligate; TR, tolerant reproductive strategists; --, not determined or not available; General tolerance: INT, intolerant; MOD, moderate; TOL, tolerant. Origin: N, native; I, introduced. mm, millimeters; NA, not applicable because species generally lives less than 3 years]

Family	Common name	Scientific name	Trophic category	Feeding habitat	Reproductive class	General tolerance	Origin	Length at 3 years (mm)
Cyprinodontidae	Northern plains killifish	*Fundulus kansae*	OM	GE	--	TOL	I	81
	Plains topminnow	*Fundulus sciadicus*	IN	GE	--	MOD	I	NA
Centrarchidae	Rock bass	*Ambloplites rupestris*	IC	GE	TR	MOD	I	89
	Green sunfish	*Lepomis cyanellus*	IC	GE	--	TOL	I	102
	Pumpkinseed	*Lepomis gibbosus*	IC	GE	LO	MOD	I	89
	Bluegill	*Lepomis macrochirus*	IC	GE	LO	MOD	I	102
	Smallmouth bass	*Micropterus dolomieu*	IC	GE	TR	MOD	I	154
	Largemouth bass	*Micropterus salmoides*	IC	GE	TR	MOD	I	140
	White crappie	*Pomoxis annularis*	IC	WC	TR	MOD	I	152
	Black crappie	*Pomoxis nigromaculatus*	IC	WC	TR	MOD	I	203
Percidae	Yellow perch	*Perca flavescens*	IC	WC	--	MOD	I	140
	Sauger	*Sander canadensis*	IC	GE	LO	MOD	N	279

[1]Identified only in the main-stem Powder River.

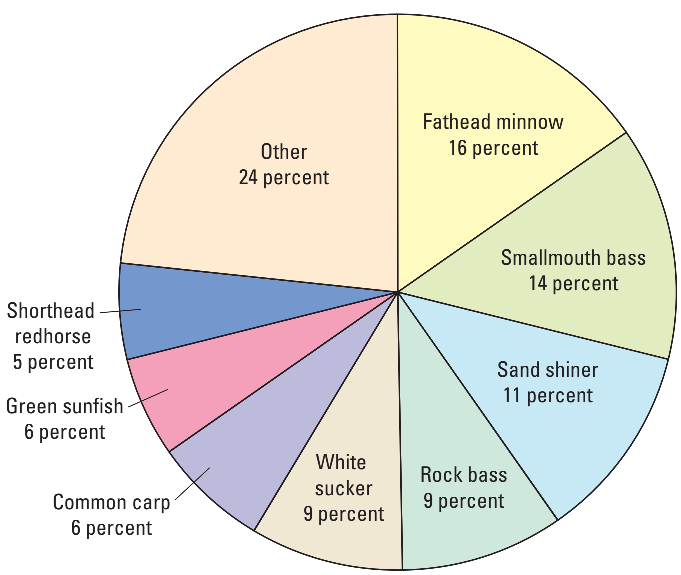

Figure 33. Relative abundance of fish by species in samples from the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries, 2005–06.

Fish communities in other small plains streams included Hanging Woman Creek (sites T11–T13) that received IBI scores ranging from 10 to 46, with a mean score of 31. Scores for Otter Creek (sites T15–T17) ranged from 10 to 60, with a mean of 32. Scores for the Cheyenne River drainage (sites C1–C6) ranged from 10 to 53, with a mean of 30. All of the fish samples from sites in the Cheyenne and Belle Fourche River drainages received metric scores of 0 for the percentage of invertivorous cyprinids (table 24). Most of the sites in the Cheyenne River drainage did, however, support plains topminnow and northern plains killifish that might occupy a similar ecological niche as the invertivorous cyprinids, but because these species are introduced, their presence lowers IBI scores.

Fish communities of the main-stem Tongue River sites received IBI scores ranging from 49 to 63. The lowest scores from sites on the main-stem Tongue River in 2005 and again in 2006 were at site T10, downstream from Tongue River Reservoir. Scores increased in the downstream direction from the reservoir, from site T10 to site T18, in both years. The highest IBI scores for the main-stem Tongue River fish communities were from site T1 at Monarch. The IBI scores for site T1 might be affected by the presence of cold-water species for which the IBI was not designed (Bob Bramblett, Montana State University, oral commun., Dec. 2007).

Fish Communities of the Main-Stem Powder River

In total, 134,938 fish were collected during 80 surveys by the WGFD and the USGS on the main-stem Powder River in Wyoming and Montana, representing a total of six families and 21 species (table 25). Of the 21 fish species identified, 15 were native, and 6 were introduced. Native fish species included 8 minnows (Cyprinidae), 4 suckers (Catostomidae), 3 catfish (Ictaluridae), and 1 goldeye (Hiodontidae). Introduced species included 3 sunfishes (Centrarchidae), 1 killifish (Cyprinidontidae), 1 catfish, and 1 minnow. Sand shiners (61 percent), flathead chub (21 percent), *Hybognathus* spp. (8 percent), northern plains killifish (4 percent), and longnose dace (2 percent) dominated the total catch when data from all sampling periods were combined (fig. 34; tables 29 and 30 in Appendix 2). Northern plains killifish was the most abundant and widespread introduced species and was present at nearly all of the sites. All other introduced species (common carp, green sunfish, smallmouth bass, rock bass, and black bullhead) were uncommon and collectively comprised less than 1 percent of the total catch.

Spatial Distribution of Fish

Fish species richness per sample ranged from a minimum of 4 species, collected in the Powder River below Crazy Woman Creek (site P8) on August 31, 2004, to a maximum of 13 species, collected in the Powder River above Salt Creek (site P1) on July 20, 2005, and the Powder River above Pumpkin Creek (P3) on September 7, 2004 (table 25). The mean number of fish species ranged from 6.0 species per sample at the South Fork Powder River (miscellaneous site) to 10.1 species per sample at the Powder River at Moorhead (site P12; table 25).

When considering the total number of species identified at each site during all of the sampling periods, the Powder River above Crazy Woman Creek (site P5) had the greatest richness of 17 species. At least 15 species in total were observed at five (sites P1, P5, P8, P9, and P11) of the eight sites in Wyoming. The largest total species count among sites in Montana was observed at Moorhead (site P12, 14 species). The total species counts by site might be affected by differences in sampling frequency given that sites in Wyoming generally were sampled nine times each, whereas sites in Montana were sampled one to three times each. Patton (1997) showed that increased sampling effort can increase species counts, but recommended that the target level of species richness be set to 90 percent or some value less than 100 percent of all species present because of diminishing returns at increased levels of effort. Rarefaction curves described in the following paragraph were calculated to help explain the relation between sampling effort and species abundance for this study.

Rarefaction curves plotted for the main-stem Powder River sampling sites indicated that the site with the maximum overall species richness, site P5, had a relatively flat curve, indicating that the fish community is reasonably represented in the overall sample (fig. 35). The least expected species richness for the main-stem sites occurred at Broadus (site P13), and the maximum expected species richness occurred at Moorhead (site P12). The rarefaction curves were steepest for the Powder River above Salt Creek (site P1), below Clear Creek (site P11), at Moorhead (site P12), and below Little Powder River (site P17), which indicates that either the species diversity of the fish community is underrepresented in the samples or that the greatest species diversity was present at those sites regardless of sampling effort. Similar to the species richness counts, interpretation of the rarefaction curves might be affected by differences in sampling frequency at sites.

Native fish predominated in the main-stem Powder River, both in terms of number of species and abundance (tables 23 and 25). The native fish community at all main-stem sites included flathead chub, sand shiner, and channel catfish. Minnows in the genus *Hybognathus* also were found at nearly every site. Other native fish species identified in small numbers included shorthead redhorse, river carpsucker, white sucker, and goldeye. This core community of fish species identified in the main-stem Powder River is well adapted to life in turbid water, shifting substrates, and wide variations in streamflow (Hubert, 1993).

The distribution of fish species appeared to shift longitudinally along the main-stem Powder River in Wyoming. White sucker, mountain sucker, northern plains killifish, and longnose dace were more common at the upstream sites (sites P1–P3) than downstream sites (sites P8–P11; fig. 36); mountain sucker were not collected downstream from site P3. Other fish species, such as channel catfish and stonecat, were more common at the downstream sites (particularly sites P9 and P11) than the upstream sites. River carpsucker and goldeye, which are large-bodied species, tended to be more common at the downstream sites than upstream sites. The longitudinal distribution might be related to changes in habitat, water quality, and streamflow in the downstream direction or by migration from the Yellowstone River (Hubert, 1993).

Introduced species of fish generally were rare in the main-stem Powder River. Northern plains killifish were the most common introduced fish species and were observed in small numbers at all sites except near Locate (site P18) where the number of sampling periods (1) was fewest. Green sunfish (n = 17) were found at three sites in Wyoming and two sites in Montana. Common carp (n = 39) were found at six sites in Wyoming and two sites in Montana. Smallmouth bass (n = 3) and rock bass (n = 1) were identified only in the Powder River below Clear Creek (site P11) where common carp and northern plains killifish also were noted.

Table 24. Fish community metric scores and Index of Biotic Integrity (IBI) scores for the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries, Wyoming and Montana, 2005–06.

[Metric definitions from Bramblett and others (2005). Shaded cells indicate main-stem sampling sites on the Tongue River; indv., individuals]

Site number (fig. 1)	Abbreviated site name	Sample date	Species richness and composition scores				Trophic composition scores		Reproductive guild composition scores		Fish abundance and composition scores		IBI score
			Number of native species	Number of native families	Number of native catostomid and ictalurid species	Percentage of tolerant indv.	Percentage of invertivorous cyprinid indv.	Number of benthic invertivorous species	Percentage of litho-obligate reproductive guild indv.	Percentage of tolerant reproducetive guild indv.	Percentage of native indv.	Number of native species with long-lived indv.	
R1	upper Rosebud Creek	06/20/2005	0	0	0	10.0	0	0	0	10.0	0	0	20
R2	Rosebud Creek at mouth	09/14/2005	4.6	6.7	4.4	2.8	.5	2.7	4.1	5.2	8.2	3.5	43
T1	Tongue River at Monarch	08/23/2005	5.9	7.5	8.1	8.0	0	8.0	3.1	7.4	2.5	8.3	59
		08/23/2006	5.9	7.5	8.1	9.1	0	9.7	2.2	9.0	1.8	9.4	63
T2	Goose Creek	08/22/2005	6.1	7.6	7.2	9.2	.1	8.2	2.2	9.0	1.8	7.6	59
		08/22/2006	5.0	7.6	6.2	8.1	.2	6.5	2.7	8.2	2.2	7.6	54
T3	upper Youngs Creek	06/15/2005	9.4	8.1	9.6	9.7	10.0	10.0	10.0	.3	10.0	10.0	87
		06/28/2006	9.4	8.1	9.6	7.9	10.0	10.0	10.0	1.5	10.0	10.0	87
T4	Youngs Creek at mouth	06/14/2005	7.5	5.4	6.9	2.0	2.8	10.0	2.5	8.6	10.0	9.9	66
		06/27/2006	9.1	7.2	8.0	3.6	1.5	10.0	1.7	6.3	10.0	9.9	67
T5	Tongue River below Youngs Creek	08/29/2005	5.0	6.6	6.4	6.4	1.2	7.6	3.3	7.3	2.1	6.4	52
		08/24/2006	5.0	6.6	6.4	7.8	2.6	7.6	3.9	6.1	1.7	6.4	54
T6	upper Squirrel Creek	06/16/2005	7.7	5.9	7.9	10.0	10.0	10.0	10.0	.0	10.0	9.9	81
		06/29/2006	8.8	7.7	9.0	.6	1.4	9.5	1.4	9.9	10.0	8.9	67
T7	Squirrel Creek at mouth	06/13/2005	8.5	7.5	8.6	6.2	8.8	9.0	7.8	3.3	9.3	9.5	78
T8	Prairie Dog Creek	08/26/2005	5.2	5.9	7.5	7.5	.1	6.8	8.4	3.3	6.9	7.8	59
		08/25/2006	6.8	7.7	8.6	7.6	8.3	10.0	10.0	1.2	8.6	8.9	78
T9	Tongue River at State line	08/25/2005	6.1	6.6	6.4	6.5	1.2	5.9	3.8	6.1	2.7	6.4	52
		08/28/2006	6.1	6.6	7.5	8.0	2.4	7.6	5.0	5.7	2.7	5.4	57

Table 24. Fish community metric scores and Index of Biotic Integrity (IBI) scores for the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries, Wyoming and Montana, 2005–06.—Continued

[Metric definitions from Bramblett and others (2005). Shaded cells indicate main-stem sampling sites on the Tongue River; indv., individuals]

Site number (fig. 1)	Abbreviated site name	Sample date	Species richness and composition scores				Trophic composition scores		Reproductive guild composition scores		Fish abundance and composition scores		IBI score
			Number of native species	Number of native families	Number of native catostomid and ictalurid species	Percentage of tolerant indv.	Percentage of invertivorous cyprinid indv.	Number of benthic invertivorous species	Percentage of litho-obligate reproductive guild indv.	Percentage of tolerant reproducetive guild indv.	Percentage of native indv.	Number of native species with long-lived indv.	
T10	Tongue River above Hanging Woman Creek	08/30/2005	4.0	6.3	7.0	7.9	0	3.6	3.5	6.9	3.4	6.9	49
		08/29/2006	4.5	6.3	7.0	7.1	0	5.3	5.1	5.6	4.5	7.9	53
T11	upper Hanging Woman Creek	06/22/2005	4.7	5.9	5.5	0	0	5.3	.4	.0	.9	6.0	29
		06/27/2006	4.7	4.1	4.4	1.4	0	5.3	0	1.6	3.3	4.9	30
T12	middle Hanging Woman Creek	06/21/2005	3.4	2.1	4.2	0	0	5.0	0	0	0	4.7	[1]10
		06/26/2006	4.6	5.8	5.2	0	0	5.0	.9	2.9	3.3	4.7	33
T13	Hanging Woman Creek at mouth	06/23/2005	4.8	7.5	6.0	0	0	4.6	.8	8.9	8.4	5.3	46
		06/26/2006	3.7	3.8	3.8	0	0	4.6	0	10.0	10.0	4.3	40
T14	Tongue River at Birney Day School	08/31/2005	4.2	6.1	6.6	6.8	.1	4.8	5.2	5.2	4.9	6.4	50
		08/30/2006	4.8	6.1	7.6	7.1	.4	6.5	4.6	6.0	4.9	8.5	56
T15	upper Otter Creek	06/29/2005	6.6	6.7	7.0	7.4	5.2	7.1	3.0	0	10.0	6.7	60
		07/12/2006	6.0	4.9	5.9	10.0	10.0	7.1	0	0	10.0	6.7	[1]10
T16	middle Otter Creek	06/28/2005	5.4	6.3	6.2	7.4	0	6.2	10.0	0	10.0	5.8	[1]10
T17	Otter Creek at mouth	06/30/2005	4.8	5.3	4.2	2.0	0	3.8	.4	7.8	9.4	3.6	41
		06/28/2006	3.7	3.5	3.2	0	0	3.8	.5	9.6	8.8	4.6	38
T18	Tongue River below Brandenberg Bridge	09/01/2005	5.3	5.8	7.0	7.0	5.7	5.7	5.1	.8	8.5	6.7	58
		08/31/2006	5.9	5.8	7.0	6.9	1.9	5.7	8.5	1.0	8.9	7.7	59

Table 24. Fish community metric scores and Index of Biotic Integrity (IBI) scores for the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries, Wyoming and Montana, 2005–06.—Continued

[Metric definitions from Bramblett and others (2005). Shaded cells indicate main-stem sampling sites on the Tongue River; indv., individuals]

Site number (fig. 1)	Abbreviated site name	Sample date	Species richness and composition scores				Trophic composition scores		Reproductive guild composition scores		Fish abundance and composition scores		IBI score
			Number of native species	Number of native families	Number of native catostomid and ictalurid species	Percentage of tolerant indv.	Percentage of invertivorous cyprinid indv.	Number of benthic invertivorous species	Percentage of litho-obligate reproductive guild indv.	Percentage of tolerant reproducetive guild indv.	Percentage of native indv.	Number of native species with long-lived indv.	
T19	Pumpkin Creek	06/24/2005	5.9	9.0	5.3	8.2	0.3	3.8	9.7	2.0	10.0	7.7	62
P6	Crazy Woman Creek below I-90	07/14/2005	4.3	5.3	3.2	10.0	2.5	3.9	9.8	0	10.0	6.7	56
		07/31/2006	7.6	9.0	8.6	2.8	.1	7.3	5.9	.6	5.0	8.7	56
P7	Crazy Woman Creek near mouth	07/14/2005	5.0	7.0	4.9	8.5	3.2	5.0	9.9	0	10.0	7.2	61
		08/01/2006	6.1	7.0	6.0	6.5	1.5	5.0	10.0	.4	9.9	8.2	61
P10	Clear Creek	08/24/2005	7.6	10.0	7.9	8.0	.3	4.7	6.2	4.4	6.2	10.0	65
		08/21/2006	7.6	10.0	6.8	9.4	3.5	6.4	6.2	2.4	7.7	10.0	70
P14	Little Powder River at Highway 59	06/23/2005	8.1	6.5	9.0	0	0	10.0	0	10.0	10.0	10.0	64
		06/22/2006	8.7	8.3	10.0	6.7	9.5	10.0	9.3	0	7.7	10.0	80
P15	Little Powder River above Dry Creek	06/23/2005	5.2	6.7	4.5	4.5	.4	2.8	6.2	3.7	8.0	3.6	45
		06/23/2006	6.3	6.7	5.5	9.3	.5	4.5	10.0	.3	9.5	6.7	59
P16	Little Powder River at Biddle	06/27/2005	5.5	6.5	6.3	7.6	.1	4.1	9.7	2.0	9.7	5.3	57
C1	Porcupine Creek	06/20/2005	6.0	5.2	6.6	0	0	7.9	0	10.0	10.0	7.4	53
		06/22/2006	6.0	5.2	6.6	0	0	7.9	0	10.0	10.0	7.4	53
C2	Antelope Creek	06/20/2005	2.7	3.2	2.7	2.3	0	3.2	0	1.3	1.2	3.0	20
		06/20/2006	2.7	3.2	3.8	3.2	0	3.2	0	.1	0	3.0	19
C3	Cheyenne River near Dull Center	06/22/2005	3.2	4.7	4.1	1.0	0	2.4	3.9	.3	3.4	3.2	26
		06/19/2006	1.6	1.0	2.0	4.0	0	2.4	0	0	0	2.2	13

Table 24. Fish community metric scores and Index of Biotic Integrity (IBI) scores for the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries, Wyoming and Montana, 2005–06.—Continued

[Metric definitions from Bramblett and others (2005). Shaded cells indicate main-stem sampling sites on the Tongue River; indv., individuals]

Site number (fig. 1)	Abbreviated site name	Sample date	Species richness and composition scores				Trophic composition scores		Reproductive guild composition scores		Fish abundance and composition scores		IBI score
			Number of native species	Number of native families	Number of native catostomid and ictalurid species	Percentage of tolerant indv.	Percentage of invertivorous cyprinid indv.	Number of benthic invertivorous species	Percentage of litho-obligate reproductive guild indv.	Percentage of tolerant reproducetive guild indv.	Percentage of native indv.	Number of native species with long-lived indv.	
C4	Little Thunder Creek	06/22/2005	5.7	6.2	5.9	0.9	0	5.9	2.5	6.7	6.1	7.5	47
		06/21/2006	5.7	6.2	5.9	1.7	0	5.9	2.7	7.5	8.4	6.5	51
C5	Black Thunder Creek	06/21/2005	3.5	3.7	3.6	0	0	4.3	0	8.5	5.0	4.1	[1]10
C6	Cheyenne River at Spencer	06/21/2005	2.7	3.7	2.2	2.7	0	.1	3.2	1.7	4.2	2.1	23
		06/20/2006	2.2	3.7	1.1	1.2	0	.1	2.0	1.0	2.6	1.1	15
B1	Belle Fourche River	06/24/2005	4.2	3.7	3.7	7.3	0	4.5	9.0	2.9	10.0	4.2	50
		06/21/2006	4.2	3.7	3.7	0	0	4.5	.1	8.1	7.3	5.2	37
B2	Caballo Creek	06/23/2005	5.0	4.3	4.7	8.2	0	5.7	10.0	1.6	9.7	6.3	55

[1]An IBI score of 10 was assigned because less than 10 fish were present in sample.

Table 25. Fish abundance in samples from the main-stem Powder River, Wyoming and Montana, 2004–06.

[L, species that were only identified in larval fish samples; the total number of species includes laboratory identification of larval fish and *Hybognathus* spp.]

Site number (fig. 1)	Abbreviated site name	Sample date	Number of fish								
			Black bullhead	Channel catfish	Common carp	Creek chub	Fathead minnow	Flathead chub	Goldeye	Green sunfish	*Hybognathus* spp.[1]
P1	Powder River above Salt Creek	06/07/04	0	0	0	1	14	717	0	0	38
		07/08/04	0	0	0	1	3	466	0	0	48
		08/10/04	0	0	0	0	0	460	0	0	22
		09/09/04	0	0	0	0	13	403	0	0	18
		10/13/04	0	0	0	0	7	214	0	0	4
		05/07/05	0	0	0	0	21	72	0	0	2
		07/20/05	0	3	0	20	2	402	1	0	0
		08/12/05	1	1	0	0	0	139	0	0	7
		07/24/06	0	0	0	0	47	427	0	0	0
P2	Powder River below Salt Creek	06/08/04	0	0	0	0	1	452	0	0	330
		07/09/04	0	1	0	0	1	107	0	0	57
		08/11/04	0	1	2	0	3	553	1	0	55
		09/08/04	0	2	0	0	5	459	1	0	28
		10/14/04	0	0	0	0	0	140	1	0	2
		05/09/05	0	0	0	0	L	133	0	0	41
		07/21/05	0	0	0	0	9	810	0	0	246
		08/11/05	0	8	0	0	7	363	0	0	119
		07/25/06	0	0	0	0	35	2,641	0	2	132
P3	Powder River above Pumpkin Creek	07/07/04	0	1	0	0	7	396	1	0	287
		08/09/04	0	14	1	0	33	223	1	0	24
		09/07/04	0	5	3	0	2	466	0	0	34
		10/12/04	0	5	0	0	20	359	0	0	74
		05/08/05	0	0	0	0	0	51	0	0	23
		07/19/05	0	1	3	0	2	631	1	0	506
		08/10/05	0	9	0	0	2	703	0	0	26
		07/26/06	0	9	0	0	1	161	0	0	8
P4	Powder River below Burger Draw	05/03/05	0	3	1	0	0	135	0	0	49
		07/22/05	0	73	4	0	5	172	0	0	838
		08/19/05	0	46	1	0	2	272	3	0	174
		07/27/06	0	10	0	0	13	1,079	1	0	259

Table 25. Fish abundance in samples from the main-stem Powder River, Wyoming and Montana, 2004–06.—Continued

[L, species that were only identified in larval fish samples; the total number of species includes laboratory identification of larval fish and *Hybognathus* spp.]

Site number (fig. 1)	Abbreviated site name	Sample date	Number of fish								
			Black bullhead	Channel catfish	Common carp	Creek chub	Fathead minnow	Flathead chub	Goldeye	Green sunfish	*Hybognathus* spp.[1]
P5	Powder River above Crazy Woman Creek	05/20/04	0	8	0	0	30	272	4	0	80
		06/02/04	0	4	0	0	0	456	2	0	94
		07/13/04	0	20	0	0	1	587	0	0	328
		08/02/04	0	12	L	0	2	584	0	0	258
		09/08/04	0	12	0	0	1	1,101	0	0	183
		10/12/04	0	0	0	1	L	684	0	0	185
		04/26/05	0	4	0	0	231	165	0	0	427
		07/13/05	0	16	0	0	3	470	3	2	245
P5	Powder River above Crazy Woman Creek	08/24/05	0	12	0	0	2	412	0	0	207
		07/28/06	0	61	0	0	3	2,384	0	0	96
P8	Powder River below Crazy Woman Creek	06/07/04	0	12	0	0	0	302	7	0	882
		07/06/04	0	7	0	0	3	232	0	0	89
		08/04/04	0	40	0	1	0	343	0	0	173
		08/31/04	0	1	0	0	0	144	0	0	5
		10/05/04	0	35	0	0	1	387	0	0	447
		05/02/05	0	8	0	0	0	93	0	0	60
		07/23/05	0	4	0	0	0	54	0	0	227
		08/18/05	0	27	0	0	2	335	0	0	76
		08/02/06	0	41	7	2	1	118	2	0	51
P9	Powder River above Clear Creek	06/09/04	0	5	1	0	0	156	3	0	91
		07/07/04	0	12	0	0	0	108	0	0	4
		08/05/04	0	24	0	L	0	78	0	0	8
		08/31/04	0	28	0	4	3	355	0	1	10
		10/04/04	0	12	0	0	5	100	0	0	467
		05/04/05	0	10	0	0	0	209	0	0	0
		07/24/05	0	131	0	0	9	21	0	0	9
		08/17/05	0	191	0	0	8	67	0	0	6
		08/04/06	0	166	4	0	2	324	1	1	80

Table 25. Fish abundance in samples from the main-stem Powder River, Wyoming and Montana, 2004–06.—Continued

[L, species that were only identified in larval fish samples; the total number of species includes laboratory identification of larval fish and *Hybognathus* spp.]

Site number (fig. 1)	Abbreviated site name	Sample date	Number of fish								
			Black bullhead	Channel catfish	Common carp	Creek chub	Fathead minnow	Flathead chub	Goldeye	Green sunfish	*Hybognathus* spp.[1]
P11	Powder River below Clear Creek	06/10/04	0	16	0	0	0	188	4	0	387
		07/08/04	0	35	2	0	0	207	3	0	253
		08/06/04	0	31	0	0	L	157	1	0	17
		09/01/04	0	4	0	0	0	178	3	0	32
		10/06/04	0	3	2	0	1	88	1	0	699
		05/05/05	0	35	0	0	0	248	0	0	2
		07/25/05	0	228	1	0	8	43	0	0	0
		08/16/05	0	90	0	0	10	8	1	0	72
		08/03/06	0	2	0	0	0	112	0	0	0
P12	Powder River at Moorhead	05/06/05	0	34	0	0	0	167	0	0	8
		07/18/05	0	0	0	0	0	36	2	0	2
		08/02/06	0	105	1	0	0	218	12	0	0
P13	Powder River at Broadus	07/19/05	0	2	0	0	0	13	0	0	4
		08/02/06	0	8	0	0	0	416	0	4	0
P17	Powder River below Little Powder River	07/20/05	0	2	0	0	0	3	0	0	98
		08/03/06	0	12	6	0	2	62	1	7	63
P18	Powder River near Locate	07/21/05	0	3	0	0	1	47	5	0	0
([2])	South Fork Powder River	05/26/04	0	0	0	0	0	224	0	0	455
		06/29/04	0	0	0	4	0	431	0	0	214
		08/03/04	0	0	0	2	0	210	0	0	35
		09/01/04	0	0	0	3	0	342	0	0	22
		09/29/04	0	0	0	1	0	303	0	0	72

Table 25. Fish abundance in samples from the main-stem Powder River, Wyoming and Montana, 2004–06.—Continued

[L, species that were only identified in larval fish samples; the total number of species includes laboratory identification of larval fish and *Hybognathus* spp.]

Site number (fig. 1)	Sample date	Number of fish													
		Plains minnow[1]	Western silvery minnow[1]	Longnose dace	Mountain sucker	Northern plains killifish	River carpsucker	Rock bass	Sand shiner	Shorthead redhorse	Smallmouth bass	Stonecat	Sturgeon chub	White sucker	Species richness
P1	06/07/2004	38	0	0	L	85	0	0	378	0	0	0	0	4	8
	07/08/2004	48	0	4	1	26	0	0	186	0	0	0	0	0	8
	08/10/2004	22	0	141	103	116	0	0	235	1	0	0	0	1	8
	09/09/2004	18	0	31	341	207	0	0	469	0	0	0	0	0	7
	10/13/2004	4	0	29	33	125	0	0	315	0	0	0	0	0	7
	05/07/2005	2	0	15	12	36	0	0	391	0	0	0	0	0	7
	07/20/2005	0	0	15	L	20	106	0	1,216	0	0	1	0	L	13
	08/12/2005	7	0	225	20	624	7	0	838	0	0	6	0	3	11
	07/24/2006	0	0	628	14	142	4	0	5,078	0	0	3	0	5	9
	Mean														**8.7**
P2	06/08/2004	0	0	0	0	70	0	0	552	0	0	0	0	3	6
	07/09/2004	57	0	1	L	9	2	0	254	0	0	0	0	0	9
	08/11/2004	0	0	104	80	139	3	0	1,065	0	0	0	0	1	11
	09/08/2004	28	0	78	25	217	10	0	1,832	0	0	0	0	7	11
	10/14/2004	2	0	24	11	38	0	0	141	0	0	0	0	1	8
	05/09/2005	41	0	86	32	12	0	0	353	0	0	0	0	1	8
	07/21/2005	246	0	142	16	23	7	0	1,612	0	0	0	0	3	9
	08/11/2005	119	0	135	8	810	38	0	1,354	0	0	0	0	4	10
	07/25/2006	0	0	472	13	123	10	0	5,020	0	0	0	0	2	10
	Mean														**9.1**
P3	07/07/2004	287	0	5	2	21	2	0	827	0	0	0	0	0	10
	08/09/2004	24	0	28	1	27	8	0	487	0	0	1	0	0	12
	09/07/2004	30	4	42	1	238	2	0	433	0	0	1	0	1	13
	10/12/2004	74	0	11	1	671	15	0	2,513	0	0	1	0	0	10
	05/08/2005	23	0	36	0	3	0	0	82	0	0	0	0	0	5
	07/19/2005	497	9	22	3	12	9	0	589	0	0	0	0	0	12
	08/10/2005	26	0	17	0	80	70	0	847	0	0	1	0	1	10
	07/26/2006	0	0	24	0	164	50	0	4,486	0	0	4	0	0	9
	Mean														**10.1**
P4	05/03/2005	49	0	54	0	7	1	0	505	0	0	0	0	0	8
	07/22/2005	0	0	102	0	83	31	0	1,471	0	0	0	0	0	9
	08/19/2005	166	8	52	0	197	68	0	685	0	0	0	0	0	11
	07/27/2006	0	0	70	0	43	46	0	3,789	0	0	2	0	0	10
	Mean														**9.5**

Table 25. Fish abundance in samples from the main-stem Powder River, Wyoming and Montana, 2004–06.—Continued

[L, species that were only identified in larval fish samples; the total number of species includes laboratory identification of larval fish and *Hybognathus* spp.]

Site number (fig. 1)	Sample date	Number of fish													
		Plains minnow[1]	Western silvery minnow[1]	Longnose dace	Mountain sucker	Northern plains killifish	River carpsucker	Rock bass	Sand shiner	Shorthead redhorse	Smallmouth bass	Stonecat	Sturgeon chub	White sucker	Species richness
P5	05/20/2004	0	0	0	0	3	1	0	252	0	0	0	0	1	8
	06/02/2004	0	0	3	0	4	2	0	1,019	1	0	0	0	0	9
	07/13/2004	319	9	15	0	8	6	0	1,294	0	0	1	0	0	10
	08/02/2004	258	0	16	0	35	14	0	1,381	0	0	3	0	0	10
	09/08/2004	181	2	6	0	36	3	0	4,677	0	0	0	0	0	9
	10/12/2004	185	0	7	0	96	5	0	2,638	0	0	0	0	0	8
	04/26/2005	0	0	13	0	4	102	0	1,398	0	0	0	0	0	8
	07/13/2005	245	0	2	0	4	136	0	1,668	1	0	0	0	0	11
	08/24/2005	207	0	22	0	54	3	0	968	0	0	4	0	0	9
	07/28/2006	0	0	17	0	20	75	0	3,104	0	0	0	2	0	9
	Mean														**9.1**
P8	06/07/2004	662	221	1	0	4	21	0	1,361	0	0	0	0	0	10
	07/06/2004	89	0	19	0	6	18	0	1,026	0	0	0	0	0	8
	08/04/2004	173	0	33	0	0	2	0	933	1	0	12	0	0	9
	08/31/2004	5	0	0	0	0	0	0	467	0	0	0	0	0	4
	10/05/2004	447	0	28	0	16	5	0	2,596	0	0	4	0	0	9
	05/02/2005	56	4	3	0	1	1	0	298	0	0	0	0	0	8
	07/23/2005	0	0	7	0	0	11	0	498	0	0	3	1	0	8
	08/18/2005	0	0	29	0	15	4	0	875	0	0	0	0	0	8
	08/02/2006	0	0	14	0	3	182	0	1,903	3	0	0	0	0	12
	Mean														**8.4**
P9	06/09/2004	90	1	0	0	0	5	0	587	0	0	0	0	0	8
	07/07/2004	4	0	2	0	0	5	0	760	0	0	1	0	0	7
	08/05/2004	8	0	1	0	1	2	0	446	0	0	2	0	0	9
	08/31/2004	8	2	3	0	0	13	0	1,181	2	0	0	0	2	12
	10/04/2004	467	0	1	0	23	0	0	1,497	0	0	0	0	0	7
	05/04/2005	0	0	2	0	0	1	0	330	0	0	0	0	0	5
	07/24/2005	0	0	0	0	0	4	0	370	0	0	0	0	0	6
	08/17/2005	6	0	2	0	0	44	0	475	0	0	0	0	0	7
	08/04/2006	0	0	0	0	0	25	0	794	0	0	0	0	0	9
	Mean														**7.8**

Table 25. Fish abundance in samples from the main-stem Powder River, Wyoming and Montana, 2004–06.—Continued

[L, species that were only identified in larval fish samples; the total number of species includes laboratory identification of larval fish and *Hybognathus* spp.]

Site number (fig. 1)	Sample date	Number of fish													
		Plains minnow[1]	Western silvery minnow[1]	Longnose dace	Mountain sucker	Northern plains killifish	River carpsucker	Rock bass	Sand shiner	Shorthead redhorse	Smallmouth bass	Stonecat	Sturgeon chub	White sucker	Species richness
P11	06/10/2004	387	0	0	0	0	29	0	317	19	0	6	0	0	8
	07/08/2004	253	0	0	0	0	7	0	687	0	0	33	0	0	8
	08/06/2004	17	0	2	0	0	3	0	687	0	1	7	0	0	10
	09/01/2004	32	0	0	0	6	1	0	1,465	0	0	1	0	0	8
	10/06/2004	698	1	4	0	7	2	0	2,222	0	0	1	0	0	12
	05/05/2005	0	0	3	0	2	5	0	472	0	0	17	0	0	8
	07/25/2005	0	0	0	0	0	25	0	404	0	1	17	0	L	10
	08/16/2005	0	0	0	0	L	257	1	311	0	1	1	0	0	11
	08/03/2006	0	0	4	0	0	3	0	289	0	0	3	0	0	6
	Mean														**9.0**
P12	05/06/2005	8	0	3	0	1	6	0	18	0	0	9	0	0	8
	07/18/2005	1	1	11	0	0	0	0	14	0	0	0	0	0	6
	08/02/2006	0	0	6	0	0	116	0	283	2	0	1	4	0	10
	Mean														**8.0**
P13	07/19/2005	4	0	246	0	6	0	0	39	0	0	0	1	0	7
	08/02/2006	0	0	55	0	28	43	0	559	0	0	0	0	0	7
	Mean														**7.0**
P17	07/20/2005	0	98	0	0	2	4	0	170	0	0	0	2	0	7
	08/03/2006	0	63	0	0	55	369	0	477	0	0	0	18	0	11
	Mean														9.0
P18	07/21/2005	0	0	0	0	0	1	0	8	0	0	0	3	0	7
	Mean														7.0
([2])	05/26/2004	0	0	13	0	3	0	0	35	0	0	0	0	0	5
	06/29/2004	0	0	10	0	52	0	0	67	0	0	0	0	1	7
	08/03/2004	0	0	17	0	214	0	0	115	0	0	0	0	0	6
	09/01/2004	0	0	14	0	501	0	0	199	0	0	0	0	1	7
	09/29/2004	0	0	3	0	413	0	0	86	0	0	0	0	0	6
	Mean														**6.2**

[1]*Hybognathus* spp. represents genus-level onsite identifications. Subsamples of *Hybognathus* spp. were retained from selected samples for laboratory identification and are subdivided by species, either plains minnow or western silvery minnow.

[2]Miscellaneous site sampled by Wyoming Game and Fish Department (2004).

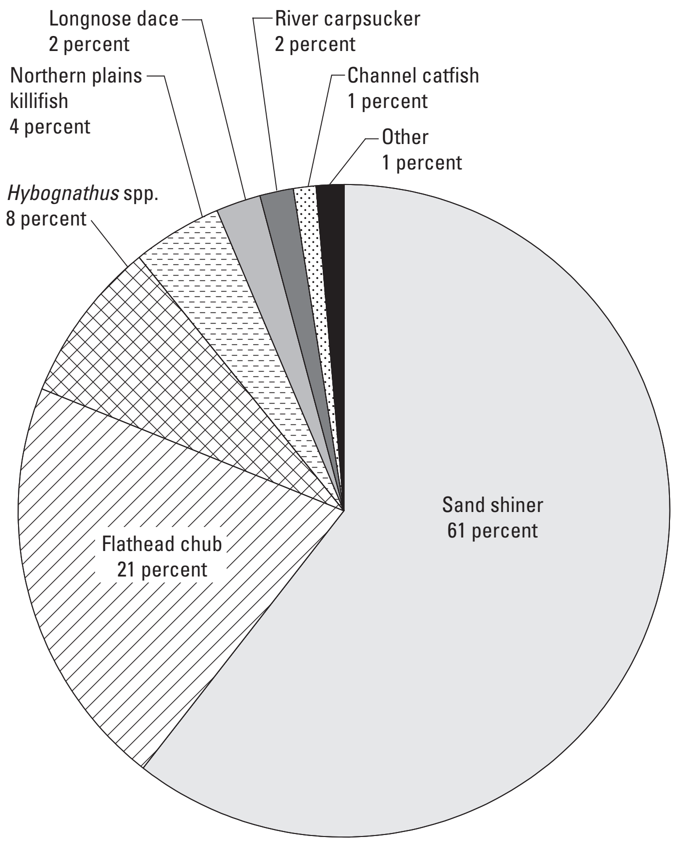

Figure 34. Relative abundance of fish taxa in samples from the main-stem Powder River, Wyoming and Montana, 2004–06.

Laboratory identification of adult *Hybognathus* spp. samples from main-stem sites in Wyoming indicated 98.8 percent were plains minnow (n = 1,457), 1.2 percent were western silvery minnow (n = 17), and a single *Hybognathus* spp. specimen collected at site P5 was identified meristically (by relating body parts) as a plains minnow X western silvery minnow hybrid. No *Hybognathus* spp. specimens collected in the main-stem Powder River in Wyoming were identified as brassy minnow. Plains minnow were common at all Wyoming sites, but western silvery minnow were not collected at the two sites farthest upstream, sites P1 and P2. Occurrences of western silvery minnow were sporadic among the other six Wyoming sites (sites P3–P11). Counts of western silvery minnow from Wyoming sites were less than 10 fish per sample, except for 221 western silvery minnow collected in June 2004 from site P8 below Crazy Woman Creek (table 25). Occurrences of western silvery minnow were unique to the main-stem Powder River; the species was not identified at any of the sites on the Tongue, Cheyenne, Belle Fourche Rivers or tributaries.

Laboratory identification of *Hybognathus* spp. (n = 175) from main-stem Powder River sites in Montana indicated 43 percent plains minnow and 57 percent western silvery minnow. Occurrences of both species were relatively infrequent at the four Montana sites but were most common at the Powder River below Little Powder River (site P17; table 25).

Sturgeon chub were collected infrequently from the main-stem Powder River but were most common in Montana. Sturgeon chub were collected in one sample each from two sites in Wyoming, sites P5 and P8. The largest numbers of sturgeon chub were observed in the Powder River below Little Powder River (site P17), but sturgeon chub also were identified from sites P12, P13, and P18 on the main-stem Powder River in Montana. Similar to the distribution of the western silvery minnow, sturgeon chub were collected only from the main-stem Powder River and not from other drainages in the PRB.

Identification of larval fish (n = 6,846) at the Larval Fish Laboratory, Fort Collins, Colo., showed that age-0 fish in the main-stem Powder River were primarily sand shiner (60 percent), plains minnow (17 percent), and flathead chub (17 percent). The remainder of species collectively accounted for 6 percent of the larval fish identified and less than 2 percent individually. Identification of larval fish at the laboratory also included four relatively uncommon species (mountain sucker, white sucker, fathead minnow, and creek chub) and one dominant species (northern plains killifish) during nine sampling periods (table 31 in Appendix 2). However, these occurrences did not add to the overall list of species observed at those sites at older age classes. Only in the case of common carp at the P5 site and white sucker at the P11 site did the identification of larval fish detect additional species that were not identified onsite at the time of sampling.

Temporal Distribution of Fish

Changes in species composition were notable among data collected monthly from May through October 2004 at sites on the main-stem Powder River in Wyoming (fig. 37). It was notable that the total sample size was substantially smaller in May (n = 1,381) than in all other months (n = 9,833–17,678) although sampling effort was approximately equal among months. The percentage of sand shiner in the total monthly catch increased from 21 percent in May to 70 percent in October. Conversely, the percentages of flathead chub and *Hybognathus* spp. decreased from 36 and 39 percent, respectively, in May to 12 and 11 percent, respectively, in October. These trends may be explained in part by the growth of age-0 sand shiner to a size large enough to be captured by seining in late summer and early fall. The largest percentage of fathead minnow (2.2 percent) was observed in May, and fathead minnow were observed less frequently during all other months. Northern plains killifish were a smaller percentage of the total catch during May through June (0.4–2.3 percent) than during August through September (4.4–11 percent). The largest percentages of longnose dace were observed during August (2.9 percent) and September (1.2 percent). Mountain suckers were not observed during May and June but were a noteworthy percentage of the September sample (2.4 percent). The largest percentage of channel catfish was observed

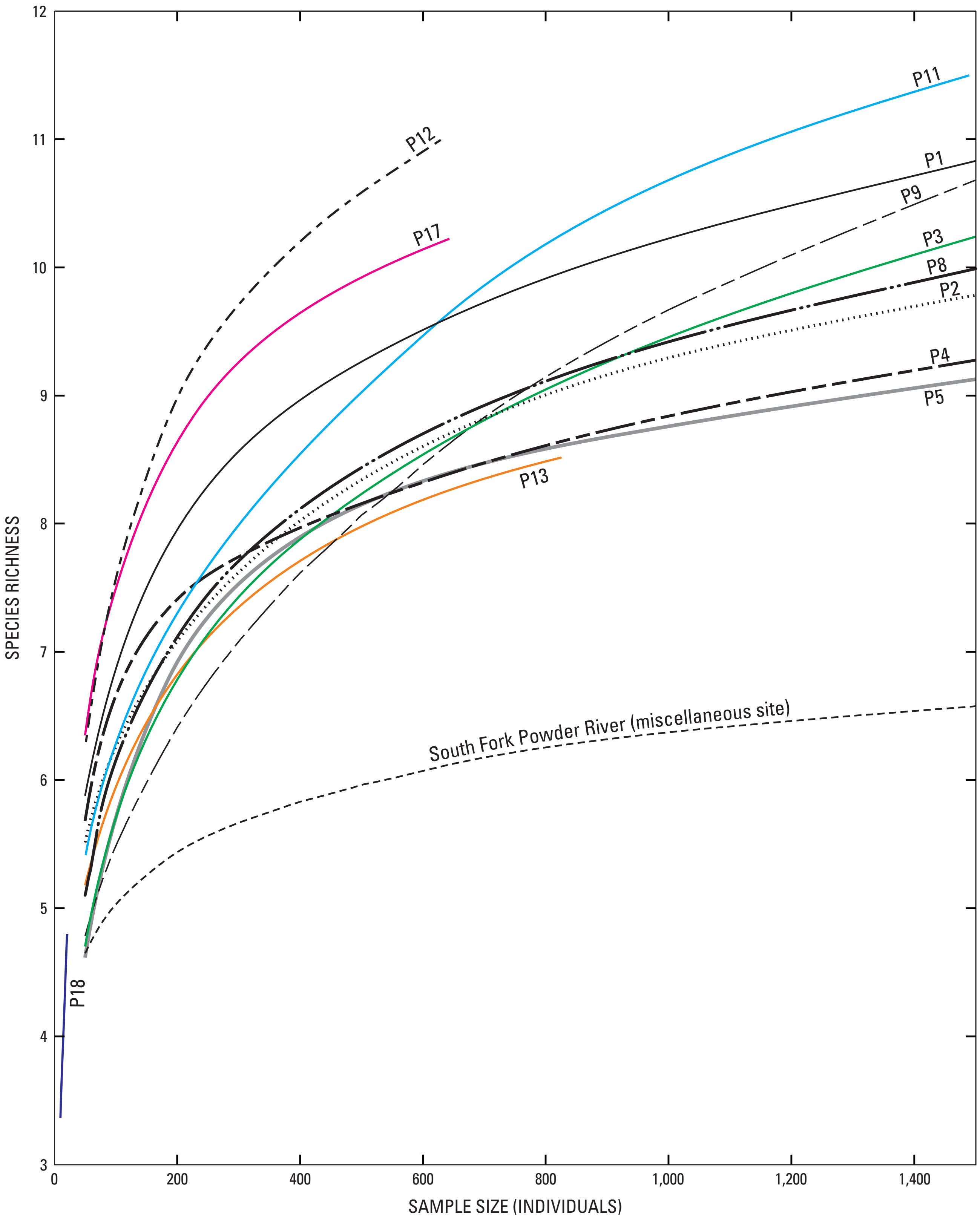

Figure 35. Rarefaction curves relating species richness to fish community samples for sampling sites on the main-stem Powder River, Wyoming and Montana, and the South Fork of the Powder River, Wyoming, 2004–06.

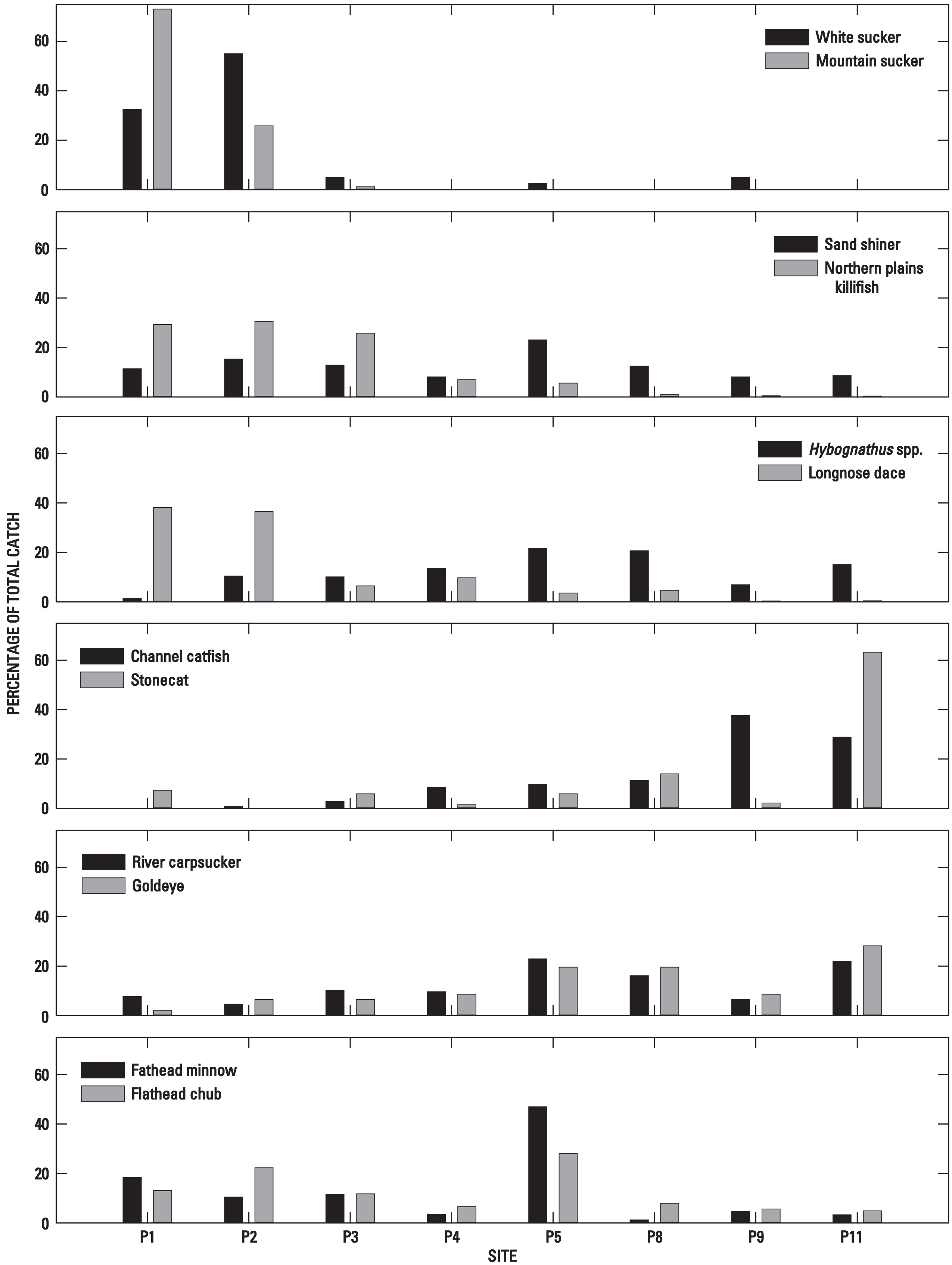

Figure 36. Longitudinal distribution of selected fish species in the main-stem Powder River, Wyoming, 2004–06.

in August (1.3 percent). Species such as river carpsucker, stonecat, goldeye, shorthead redhorse, white sucker, creek chub, common carp, green sunfish, and smallmouth bass were collected but never accounted for more than 1 percent of a total monthly sample.

Temporal changes in species composition during pre-high (May), post-high (June/July), and low streamflow conditions (August/September) in 2005 also were examined using data from all sites in Wyoming and one site in Montana (site P12). It was notable that the total sample size during pre-high streamflow (n = 6,547) was substantially less than the samples sizes during post-high (n = 14,563) and low-flow conditions (n = 51,410), although the sampling effort was approximately equal during the three sampling periods. Sand shiners consistently dominated samples and accounted for 55–64 percent of the total catch (fig. 38). The percentage of flathead chub in the total catch also was consistently large among three flow conditions (19–20 percent). Northern plains killifish accounted for a slightly smaller percentage of the total catch during pre-high (1.0 percent) and post-high flow (1.0 percent) than during low-flow conditions (4.7 percent). The percentages of longnose dace (3.3–3.8 percent) and river carpsucker (1.8–2.8 percent) were similar among different flow conditions. Substantially larger percentages of *Hybognathus* spp. were collected during pre-high (9.3 percent) and post-high (15 percent) flow than during low-flow (2.6 percent) conditions. Fathead minnows accounted for a notable percentage of the catch (3.8 percent) only during pre-high streamflow sampling. The largest percentage of channel catfish (3.2 percent) was collected during post-high streamflow. Species such as mountain sucker, stonecat, goldeye, sturgeon chub, common carp, creek chub, white sucker, green sunfish, and shorthead redhorse also were observed less frequently than the aforementioned species during all flow periods with percentages of species composition less than 1 percent. Mountain sucker and stonecat were present during all flow periods; however, goldeye, sturgeon chub, creek chub, green sunfish, and shorthead redhorse only were collected during the post-high and low-flow periods.

Fish Distribution by Habitat Type

Associations among fish species and habitat types were explored by plotting the mean number of observations (occurrences) per habitat type for each species during individual surveys (fig. 39). This facilitated the calculation of confidence intervals needed to infer potential differences in distribution of fishes among available habitat types that were sampled. Data points from all sampling periods were aggregated. The percentages of channel catfish and goldeye observations from pools were larger than all other habitat types. Goldeye (n = 63) were never sampled from riffles, backwater, or shoals. Stonecats and mountain sucker were collected in larger percentages in pools, runs, and riffles than in backwater and shoals. River carpsucker occurred more often in pool, run, and backwater habitats than in either riffle or shoal habitats. Although the overall abundance of white sucker was relatively low (n = 41), the percentages of white sucker found in pools and runs were larger than in riffles, backwater, and shoals. The percentages of *Hybognathus* spp. observed in pools and runs were significantly larger than that observed for other habitat types. The percentage of longnose dace observations was larger in riffles than in other habitats, but a substantial percentage of longnose dace also occurred in pools and runs. Flathead chub, sand shiner, and fathead minnow were most commonly observed in pools and runs, whereas northern plains killifish preferred runs and backwater.

Fish Community Structure

The Index of Biotic Integrity (IBI) developed for small plains streams of eastern Montana by Bramblett and others (2005) was applied to the fish community data from the main-stem Powder River, using the same metrics and caveats applied to data from the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries. IBI scores for fish communities in the main-stem Powder River ranged from 38 to 64 (table 26). The mean IBI score for all of the sampling sites and dates during 2004–06 was 50. Individual mean IBI scores by site (table 26) were lowest below the Little Powder River (site P17, mean = 43) and highest above Pumpkin Creek (site P3, mean = 53). The IBI scores at site P17 and other sites on the main-stem of the Powder River in Montana might be biased (low) because the drainage area adjustment built into some of the metrics by Bramblett and others (2005) has not been thoroughly tested for drainage areas as large as the lower Powder River.

The IBI scores for main-stem sites in Wyoming during 2005–06 were tested for differences between years and between sites. The 2005-06 data were selected as an appropriate subset because of consistency in sampling methods and to facilitate comparisons among a variety of data types, although three fish surveys were conducted at each site in 2005 compared to just one survey per site in 2006. The IBI subset appeared normally distributed, which was verified by the Shapiro-Wilk normality test ($P > 0.05$). An ANOVA with IBI value as the dependent variable, the site as the independent variable, and year as a covariate was applied to the subset of IBI values. Year was not significant as a covariate ($P > 0.05$) and was removed. A second ANOVA revealed no statistical differences ($P > 0.05$) in IBI values among Wyoming sites during 2005–06. Bartlett's test showed that variances were equal ($P > 0.05$) for the second test.

The drainage areas for the seven sites on the main-stem Powder River below Crazy Woman Creek (including and downstream from site P8) exceeded the largest drainage areas used by Bramblett and others (2005) in the development of the IBI. Mean IBI scores for those seven downstream sites were less than or equal to 50, whereas mean scores from the five upstream most sites (P1–P5) were slightly higher than 50 (table 26). The IBI values for the main-stem Powder River reported herein should be interpreted cautiously within the context of drainage-size effects on species richness that may

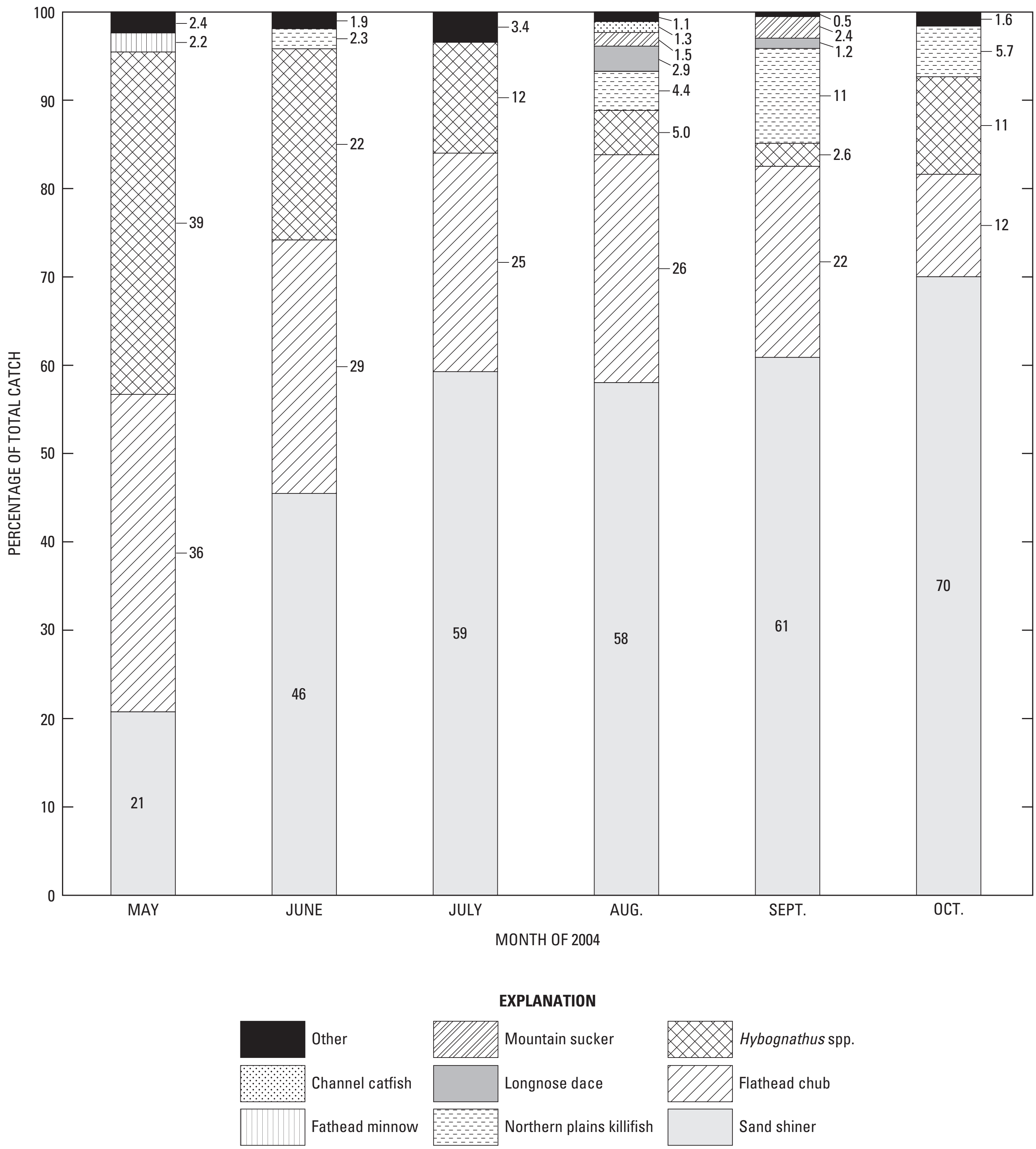

Figure 37. Fish species composition in monthly (May–October) samples at eight sampling sites on the main-stem Powder River, Wyoming, 2004.

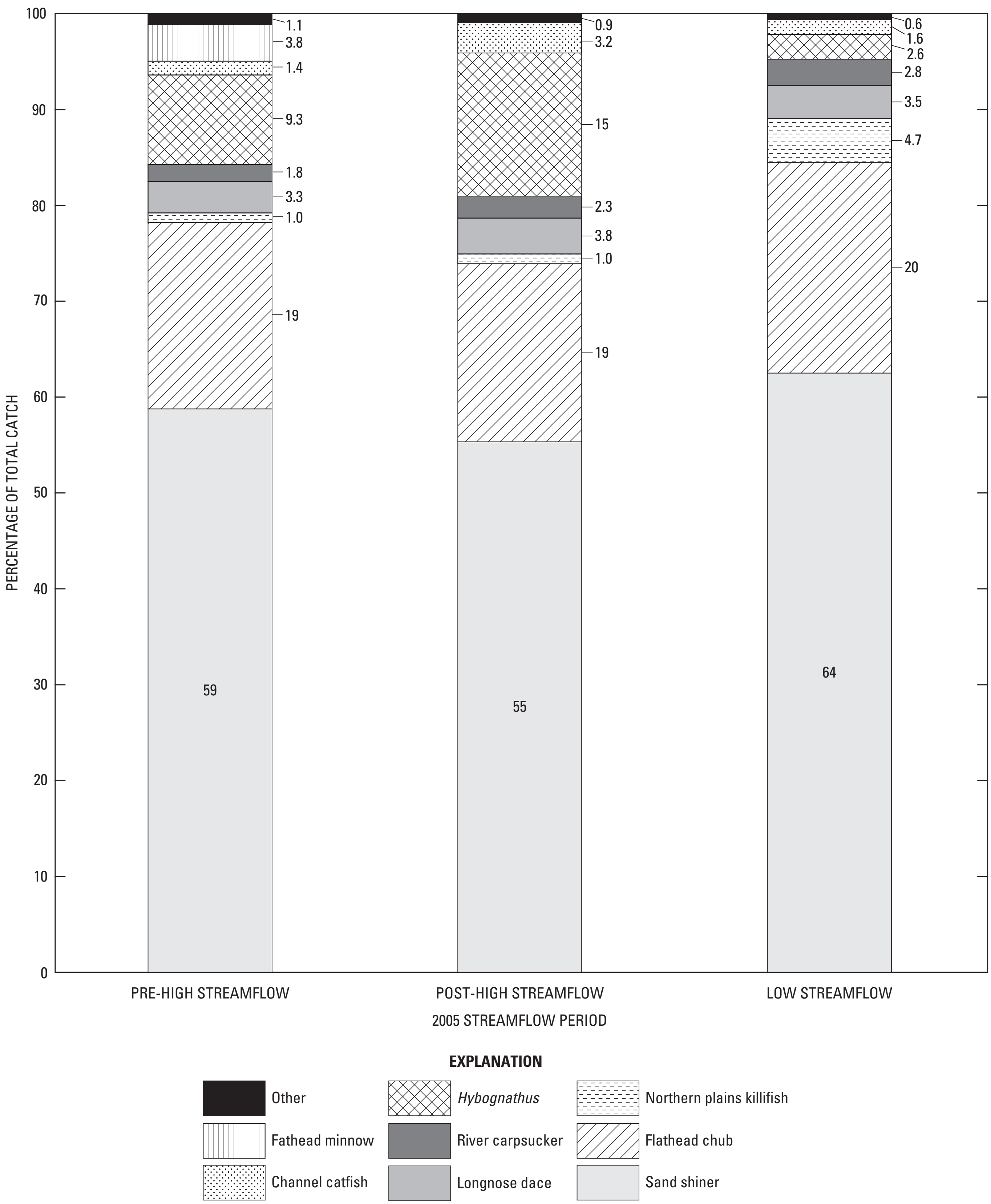

Figure 38. Species composition of fish community during pre-high flow, post-high flow, and low-flow conditions for eight sampling sites on the main-stem Powder River in Wyoming and one sampling site in Montana, 2005.

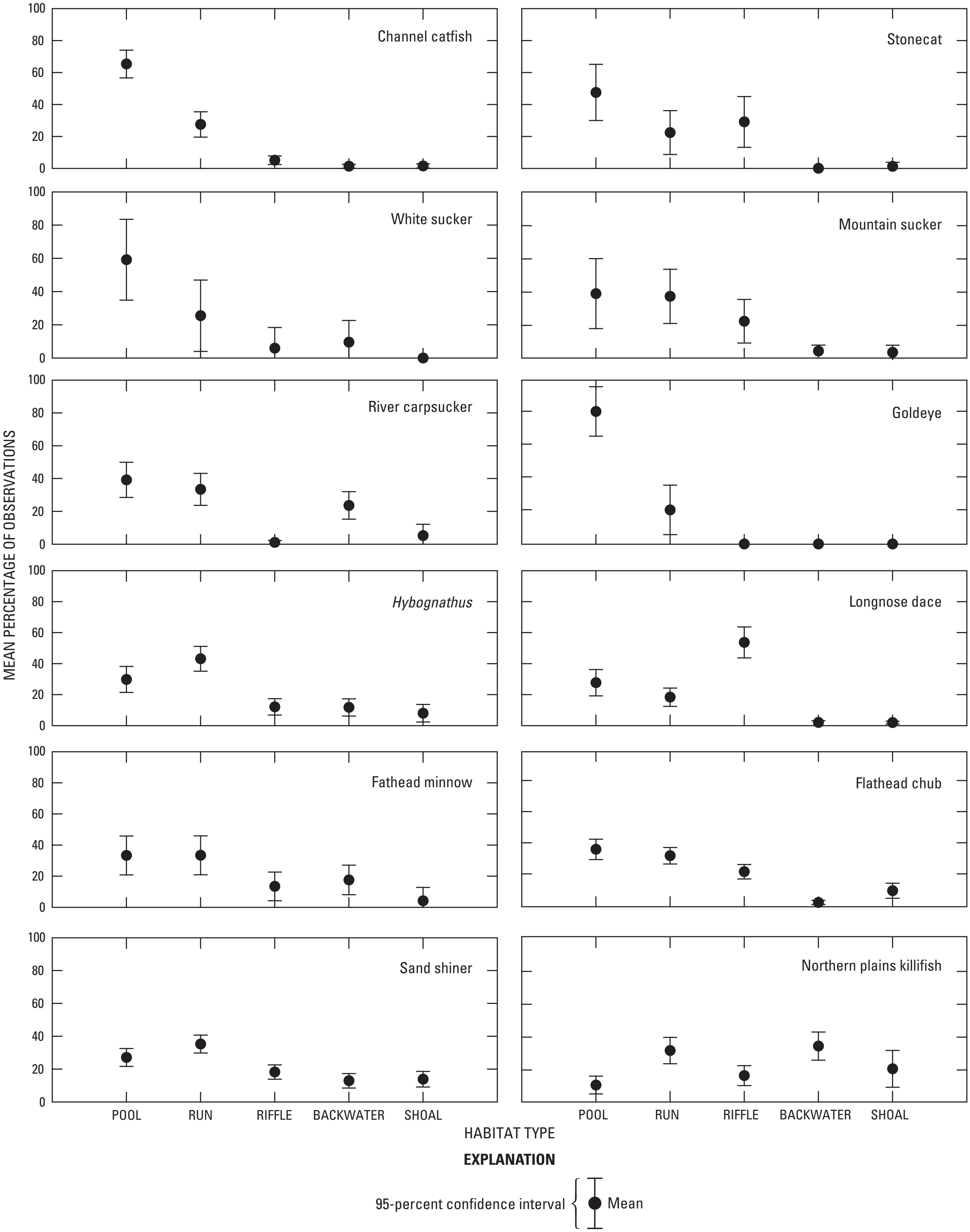

Figure 39. Mean percentage of fish observations per sampling period within connected aquatic habitat types for eight sampling sites on the main-stem Powder River in Wyoming and one sampling site in Montana, 2004–06.

Table 26. Fish community metric scores and Index of Biotic Integrity (IBI) scores for the main-stem Powder River, Wyoming and Montana, 2005–06.

[Metric definitions from Bramblett and others (2005). SD, standard deviation; indv., individuals; NA, not applicable]

Site number (fig. 1)	Abbreviated site name	Sample date	Species richness and composition scores				Trophic composition scores		Reproductive guild composition scores		Fish abundance and composition scores		IBI score	Mean IBI score for site (SD)
			Number of native species	Number of native families	Number of native catostomid and ictalurid species	Percentage of tolerant indv.	Percentage of invertivorous cyprinid indv.	Number of benthic invertivorous species	Percentage of litho-obligate reproductive guild indv.	Percentage of tolerant reproductive guild indv.	Percentage of native indv.	Number of native species with long-lived indv.		
P1	Powder River above Salt Creek	06/07/2004	5.0	4.4	3.5	9.1	8.0	1.7	3.7	0.1	9.3	2.6	47	
		07/08/2004	5.0	4.4	2.4	9.6	8.8	3.4	3.1	0	9.7	5.6	52	
		08/10/2004	5.0	4.4	4.6	8.9	7.7	5.1	4.2	0	8.9	7.7	56	
		09/09/2004	4.4	4.4	2.4	8.4	4.0	3.4	4.1	.1	8.6	2.6	42	
		10/13/2004	4.4	4.4	2.4	8.1	4.6	3.4	5.7	.1	8.3	4.6	46	
		05/07/2005	4.4	4.4	2.4	8.9	2.2	3.4	8.9	.4	9.3	1.5	46	
		07/20/2005	7.7	8.1	6.8	9.9	3.4	3.4	9.2	0	9.9	5.6	64	
		08/12/2005	6.1	6.2	6.8	6.4	2.7	3.4	7.0	0	6.7	6.7	52	
		07/24/2006	5.5	6.2	5.7	9.7	2.3	3.4	10.0	.1	9.8	5.6	58	52 (7.0)
P2	Powder River below Salt Creek	06/08/2004	2.9	4.1	2.0	9.4	4.4	1.1	4.8	0	9.5	2.0	40	
		07/09/2004	5.1	6.0	4.1	9.8	3.4	2.8	7.2	.1	9.8	4.1	52	
		08/11/2004	6.2	7.8	5.2	9.2	4.5	2.8	7.1	0	9.3	9.2	61	
		09/08/2004	6.2	7.8	5.2	9.1	2.8	2.8	8.7	0	9.2	9.2	61	
		10/14/2004	4.5	6.0	3.0	8.8	6.3	2.8	5.6	0	8.9	4.1	50	
		05/09/2005	4.5	4.1	3.0	9.8	4.6	2.8	8.1	0	9.8	4.1	51	
		07/21/2005	5.1	4.1	4.1	9.9	4.6	2.8	7.4	0	9.9	6.1	54	
		08/11/2005	5.7	6.0	5.2	6.9	2.4	2.8	6.5	.1	7.2	5.1	48	
		07/25/2006	4.5	4.1	4.1	9.8	5.1	2.8	7.9	0	9.9	6.1	54	52 (6.5)

Table 26. Fish community metric scores and Index of Biotic Integrity (IBI) scores for the main-stem Powder River, Wyoming and Montana, 2005–06.—Continued

[Metric definitions from Bramblett and others (2005). SD, standard deviation; indv., individuals; NA, not applicable]

Site number (fig. 1)	Abbreviated site name	Sample date	Species richness and composition scores				Trophic composition scores		Reproductive guild composition scores		Fish abundance and composition scores		IBI score	Mean IBI score for site (SD)
			Number of native species	Number of native families	Number of native catostomid and ictalurid species	Percentage of tolerant indv.	Percentage of invertivorous cyprinid indv.	Number of benthic invertivorous species	Percentage of litho-obligate reproductive guild indv.	Percentage of tolerant reproductive guild indv.	Percentage of native indv.	Number of native species with long-lived indv.		
P3	Powder River above Pumpkin Creek	07/07/2004	5.4	7.7	3.8	9.8	3.6	2.4	6.5	.1	9.9	2.7	52	
		08/09/2004	6.5	7.7	4.9	9.2	4.1	2.4	7.5	.6	9.7	4.7	57	
		09/07/2004	7.0	5.8	6.0	7.9	5.7	2.4	4.7	.1	8.0	5.8	53	
		10/12/2004	5.4	5.8	4.9	8.0	1.4	2.4	8.3	.1	8.2	4.7	49	
		05/08/2005	2.6	5.8	.6	9.8	6.1	2.4	7.3	0	9.9	2.7	47	
		07/19/2005	6.5	7.7	3.8	9.9	5.0	2.4	4.2	0	9.9	7.8	57	
		08/10/2005	5.4	5.8	4.9	9.5	5.6	2.4	6.4	.1	9.5	4.7	54	
		07/26/2006	4.3	5.8	3.8	9.6	.5	2.4	10.0	.0	9.7	5.8	52	53 (3.6)
P4	Powder River below Burger Draw	05/03/2005	4.1	5.7	2.5	9.9	3.4	2.2	8.9	.0	9.9	3.5	50	
		07/22/2005	4.1	5.7	2.5	9.6	1.4	2.2	7.0	.3	9.7	4.5	47	
		08/19/2005	5.8	7.6	2.5	8.6	3.0	2.2	6.5	.4	8.7	6.6	52	
		07/27/2006	4.7	7.6	3.6	9.9	3.0	2.2	8.9	.0	9.9	7.6	57	52 (4.3)

Table 26. Fish community metric scores and Index of Biotic Integrity (IBI) scores for the main-stem Powder River, Wyoming and Montana, 2005–06.—Continued

[Metric definitions from Bramblett and others (2005). SD, standard deviation; indv., individuals; NA, not applicable]

Site number (fig. 1)	Abbreviated site name	Sample date	Species richness and composition scores				Trophic composition scores		Reproductive guild composition scores		Fish abundance and composition scores		IBI score	Mean IBI score for site (SD)
			Number of native species	Number of native families	Number of native catostomid and ictalurid species	Percentage of tolerant indv.	Percentage of invertivorous cyprinid indv.	Number of benthic invertivorous species	Percentage of litho-obligate reproductive guild indv.	Percentage of tolerant reproductive guild indv.	Percentage of native indv.	Number of native species with long-lived indv.		
P5	Powder River above Crazy Woman Creek	05/20/2004	3.9	7.5	3.4	9.4	5.7	.2	4.8	.7	10.0	3.3	49	
		06/02/2004	3.9	7.5	3.4	10.0	4.0	3.6	7.8	0	10.0	5.3	56	
		07/13/2004	5.1	5.6	3.4	10.0	3.7	1.9	7.0	.1	10.0	3.3	50	
		08/02/2004	5.1	5.6	3.4	9.8	3.6	1.9	7.4	.1	9.9	4.3	51	
		09/08/2004	4.5	5.6	2.3	9.9	2.5	1.9	9.4	0	9.9	4.3	51	
		10/12/2004	3.9	5.6	1.3	9.7	2.6	1.9	8.8	0	9.7	5.3	49	
		04/26/2005	3.4	5.6	2.3	8.9	1.0	1.9	7.8	1.1	10.0	5.3	48	
		07/13/2005	5.1	7.5	3.4	10.0	2.5	3.6	8.6	.1	10.0	5.3	56	
		08/24/2005	4.5	5.6	3.4	9.6	3.5	1.9	7.1	.1	9.7	5.3	51	
		07/28/2006	3.9	5.6	2.3	10.0	5.7	3.6	6.7	.1	10.0	5.3	53	51 (2.8)
P8	Powder River below Crazy Woman Creek	06/07/2004	4.2	7.3	2.0	10.0	1.6	1.6	6.5	.1	10.0	1.9	45	
		07/06/2004	3.7	5.5	2.0	9.9	2.5	1.6	9.2	.1	10.0	0	44	
		08/04/2004	4.8	5.5	4.2	10.0	3.4	3.3	7.7	.3	10.0	6.0	55	
		08/31/2004	2.0	3.6	1.0	10.0	3.2	0	9.1	0	10.0	0	39	
		10/05/2004	4.2	5.5	3.1	9.9	1.6	1.6	9.0	.1	10.0	0	45	
		05/02/2005	3.7	5.5	2.0	10.0	2.8	1.6	7.9	.2	10.0	.9	44	
		07/23/2005	3.7	5.5	3.1	10.0	1.1	3.3	7.8	.1	10.0	5.0	49	
		08/18/2005	3.7	5.5	2.0	9.9	3.7	1.6	8.0	.2	9.9	4.0	48	
		08/02/2006	5.4	7.3	3.1	9.9	.8	3.3	10.0	.2	10.0	5.0	55	47 (5.3)

Table 26. Fish community metric scores and Index of Biotic Integrity (IBI) scores for the main-stem Powder River, Wyoming and Montana, 2005–06.—Continued

[Metric definitions from Bramblett and others (2005). SD, standard deviation; indv., individuals; NA, not applicable]

Site number (fig. 1)	Abbreviated site name	Sample date	Species richness and composition scores				Trophic composition scores		Reproductive guild composition scores		Fish abundance and composition scores		IBI score	Mean IBI score for site (SD)
			Number of native species	Number of native families	Number of native catostomid and ictalurid species	Percentage of tolerant indv.	Percentage of invertivorous cyprinid indv.	Number of benthic invertivorous species	Percentage of litho-obligate reproductive guild indv.	Percentage of tolerant reproductive guild indv.	Percentage of native indv.	Number of native species with long-lived indv.		
P9	Powder River above Clear Creek	06/09/2004	4.1	7.2	1.9	10.0	2.5	.0	8.5	.1	10.0	4.8	49	
		07/07/2004	3.5	5.4	3.0	10.0	1.7	1.3	10.0	.2	10.0	2.7	48	
		08/05/2004	4.1	5.4	3.0	10.0	1.9	1.3	9.7	.5	10.0	4.8	51	
		08/31/2004	5.8	5.4	4.0	10.0	3.1	3.1	9.1	.2	10.0	3.8	54	
		10/04/2004	3.0	5.4	.8	9.9	.7	1.3	8.6	.1	9.9	0	40	
		05/04/2005	2.4	5.4	1.9	10.0	5.3	1.3	7.3	.2	10.0	1.7	46	
		07/24/2005	3.0	5.4	1.9	9.8	.5	.0	8.3	2.9	10.0	1.7	44	
		08/17/2005	3.5	5.4	1.9	9.9	1.2	1.3	7.9	2.9	10.0	.7	45	
		08/04/2006	3.5	7.2	1.9	9.9	3.2	.0	7.1	1.4	10.0	5.8	50	47 (4.4)
P11	Powder River below Clear Creek	06/10/2004	3.9	7.1	3.8	10.0	2.7	1.0	4.7	.2	10.0	4.5	48	
		07/08/2004	3.9	7.1	2.7	10.0	2.3	.0	7.2	.3	10.0	4.5	48	
		08/06/2004	4.4	7.1	2.7	10.0	2.4	1.0	9.3	.4	10.0	5.5	53	
		09/01/2004	3.3	7.1	2.7	10.0	1.4	.0	10.0	0	10.0	2.5	47	
		10/06/2004	5.5	7.1	2.7	10.0	.4	1.0	8.9	0	10.0	3.5	49	
		05/05/2005	3.3	5.3	2.7	10.0	4.4	1.0	7.6	.5	10.0	3.5	48	
		07/25/2005	4.4	5.3	3.8	9.9	.8	0	7.4	3.7	10.0	4.5	50	
		08/16/2005	3.9	7.1	2.7	9.9	.1	0	9.1	1.5	10.0	1.4	46	
		08/03/2006	2.8	5.3	2.7	10.0	3.9	1.0	8.7	.1	10.0	1.4	46	48 (2.2)

Table 26. Fish community metric scores and Index of Biotic Integrity (IBI) scores for the main-stem Powder River, Wyoming and Montana, 2005–06.—Continued

[Metric definitions from Bramblett and others (2005). SD, standard deviation; indv., individuals; NA, not applicable]

Site number (fig. 1)	Abbreviated site name	Sample date	Species richness and composition scores				Trophic composition scores		Reproductive guild composition scores		Fish abundance and composition scores		IBI score	Mean IBI score for site (SD)
			Number of native species	Number of native families	Number of native catostomid and ictalurid species	Percentage of tolerant indv.	Percentage of invertivorous cyprinid indv.	Number of benthic invertivorous species	Percentage of litho-obligate reproductive guild indv.	Percentage of tolerant reproductive guild indv.	Percentage of native indv.	Number of native species with long-lived indv.		
P12	Powder River at Moorhead	05/06/2005	3.3	5.2	2.6	10.0	9.5	1.0	1.8	1.6	10.0	4.4	49	
		07/18/2005	2.7	3.4	0	10.0	9.9	1.0	5.0	0	10.0	.3	42	
		08/02/2006	5.5	7.1	3.7	9.9	4.1	4.4	6.8	1.6	10.0	6.5	59	50 (8.5)
P13	Powder River at Broadus	07/19/2005	2.6	3.3	.3	9.8	10.0	2.5	10.0	.1	9.8	1.2	50	
P13		08/02/2006	2.1	5.2	1.4	9.7	5.8	.8	7.1	.1	9.7	.2	42	46 (5.4)
P17	Powder River below Little Powder River	07/20/2005	2.3	5.0	1.0	9.9	.2	.3	7.6	.1	9.9	1.8	38	
P17	Powder River below Little Powder River	08/03/2006	3.9	6.8	1.0	9.6	7.6	.3	5.0	.1	9.7	2.8	45	41 (4.5)
P18	Powder River near Locate	07/21/2005	2.6	6.7	.8	9.8	10.0	.1	3.0	.7	10.0	0	44	44 (NA)
([1])	South Fork Powder River	05/26/2004	4.2	3.4	3.1	10.0	4.5	5.5	.8	0	10.0	6.6	48	
		06/29/2004	5.3	5.3	4.2	9.3	7.8	5.5	1.3	0	9.3	6.6	55	
		08/03/2004	4.8	3.4	3.1	6.2	5.3	5.5	2.7	0	6.4	4.6	42	
		09/01/2004	5.3	5.3	4.2	5.1	4.6	5.5	2.4	0	5.4	6.6	44	
		09/29/2004	4.8	3.4	3.1	5.0	4.8	5.5	1.2	0	5.3	5.6	39	46 (6.1)

[1]Miscellaneous site sampled by Wyoming Game and Fish Department (2004).

not be adequately accommodated by the metric normalizations for drainage area. Stagliano (2006) reported a mean IBI score of 60 for sites on the middle Powder River in Montana and noted that the input metrics with the lowest score included adjustments for drainage area. Further work and testing of an IBI for large plains streams would be beneficial to the assessment of fish communities of the Powder and Tongue Rivers.

Implications

Ongoing development of CBNG and other resources has the potential to affect biological communities in streams of the PRB, but predevelopment data on biological condition have not been available at the basin scale. Although this report provides a snapshot of current conditions (2005–06), this section of the report describes patterns in the data that bear further scrutiny. Most sampling sites were located in the Tongue and Powder River drainages (fig. 1), areas of current and anticipated CBNG development (fig. 2); therefore, the following implications apply only to those rivers and areas of development.

Macroinvertebrate and fish communities of the main-stem Tongue River are affected by many environmental variables including the mountainous origins of the river and, therefore, the water in Tongue River Reservoir. Scores from the Wyoming macroinvertebrate O/E model and the multimetric WSII indicated the biological condition of the Tongue River was slightly better at Monarch (site T1, nearest to the mountains) than at site T9 at the State line in both 2005 and 2006; the biological condition at site T5 below Youngs Creek tended to be intermediate to the condition at sites T1 and T9 (fig. 23). For comparison, the Montana macroinvertebrate O/E model scores also indicated the biological condition of the Tongue River was slightly better at site T1 than at site T9 during 2005–06, but Montana O/E scores were lower for site T5 than for either site T1 or site T9 (fig. 25). The Montana MMI (multimetric index) indicated relatively stable biological conditions from site T1 to site T9 in 2005 and a slight improvement from site T1 to site T9 in 2006. Scores of the Montana O/E model and MMI for the Tongue River sites downstream from Tongue River Reservoir (sites T10, T14, and T18) were in about the same range as scores for sites upstream from the reservoir.

Fish communities of the main-stem Tongue River were dominated by warm-water species, but trout were collected at Monarch (site T1; table 22). Open-water fish species, such as black crappie, were captured at sites T5, T9, and T10 and probably are associated with the Tongue River Reservoir. Scores from the Index of Biotic Integrity (IBI) for fish indicated a slight decrease from site T1 to site T9 in both 2005 and 2006. The variety of water-quality effects in the upstream Tongue River drainage, including natural change in water quality with distance from the mountains as well as municipal, urban, agricultural, and industrial development, makes it difficult to determine from the current data whether CBNG development has any role in the apparent decline in biological condition.

Biological data available for the main-stem Powder River include algae, macroinvertebrates, and fish communities at eight sites in Wyoming and four sites in Montana. The algae data collected in 2005 indicated two sites were distinctly different from other sites on the Powder River. Algae samples from the main stem of the Powder River below Salt Creek (site P2) and below Burger Draw (site P4) were outliers to the main-stem sample group in an NMDS ordination (fig. 31) and with regard to some of the algal metrics (table 21). For example, diatom communities at sites P2 and P4 were dominated by a single taxon, *Achnanthes minutissima*, whereas diatom communities at sites P1 and P3, upstream from sites P2 and P4, respectively, contained much smaller percentages of *A. minutissima*. The diatom community at site P2 had the largest percentages of halobiontic (salt loving) species of any of the sites in this study, whereas the sample from site P4 indicated relatively low salinity (salt) conditions.

Some differences among macroinvertebrate communities at sites on the main-stem Powder River were noted, although the NMDS ordination indicated sites P2 and P4 were similar to other sites on the main-stem Powder River in both 2005 (fig. 20) and 2006 (fig. 21). The Wyoming O/E macroinvertebrate model indicated a general improvement in biological condition from upstream to downstream on the Powder River in 2005, but declines in condition were noted from site P1 to site P2 in 2005 and 2006, from site P8 (below Crazy Woman Creek) to site P9 (above Clear Creek) in 2005, and from site P11 (below Clear Creek) to site P12 (Moorhead) in 2005 (fig. 23). The Wyoming WSII showed a decline in biological condition from site P1 to site P2 in 2005 and 2006, similar to the results from the O/E model.

Fish communities in the Powder River changed longitudinally from larger percentages of mountain sucker, white sucker, northern plains killifish, and longnose dace at sites farthest upstream to larger percentages of channel catfish, stonecat, river carpsucker, and goldeye at the sites farthest downstream in Wyoming (fig. 36). An ANOVA of fish IBI scores (table 26) indicated no significant differences among Wyoming sites.

Differences in patterns observed from the algal, macroinvertebrate, and fish data from the Powder River might be a reflection of different time scales for response to environmental effects. For example, life cycles can be measured in days for algae, and therefore algal communities would respond to environmental effects more quickly than macroinvertebrates with life cycles measured in months, which in turn might respond more quickly than species of fish with life cycles measured in years. Differences among the biota in ability to respond to environmental perturbations might also play a role in explaining patterns observed in the Powder River. The Powder River below Salt Creek is on the WDEQ 303d list for impaired water because of large chloride concentrations associated with discharges from conventional oil and gas development in the Salt Creek Basin (Wyoming Department of Environmental Quality, 2006); the WDEQ report also describes the need for additional monitoring of the main-stem Powder River downstream from Pumpkin Creek, which enters the Powder River between sites P3 and P4, due to CBNG development.

Summary

Development of energy and mineral resources in the Powder River Structural Basin (PRB) of northeastern Wyoming and southeastern Montana includes rapid expansion of coalbed natural gas (CBNG) development in Wyoming. Concerns about the potential effects of development on cultural and natural resources led to the formation of the Aquatic Task Group (ATG), which is an interagency working group of primarily Federal and State agencies formed to address these issues in the PRB in Wyoming and Montana, where similar types of resources exist but are largely undeveloped. Under the direction of the ATG, an ecological assessment of streams in the PRB was performed by the U.S. Geological Survey in cooperation with the Bureau of Land Management (BLM), Wyoming Department of Environmental Quality (WDEQ), Wyoming Game and Fish Department (WGFD), U.S. Environmental Protection Agency (USEPA), Montana Department of Environmental Quality (MDEQ), and Montana Department of Fish, Wildlife, and Parks (MFWP) to determine current (2005–06) status and to establish a baseline for future monitoring.

The primary purpose of this report is to describe the ecological assessment of streams in the PRB in northeastern Wyoming and southeastern Montana. Habitat characteristics and condition of macroinvertebrate, algal, and fish communities are based on samples collected at 47 sites during 2005–06. The results of habitat and fish sampling at eight sites on the main-stem Powder River in Wyoming and at one miscellaneous site on the South Fork Powder River during 2004 also are presented. Macroinvertebrate and algae data collected at ATG sites from various investigations during 1980–2007 also are presented for comparison with the ATG data.

Habitat measurements, including characterization of stream channels, substrate, riparian features, and reach-scale features, were made by the U.S. Geological Survey (USGS) following Environmental Monitoring and Assessment Program (EMAP) protocols at all 47 sites during 2005. Channel characteristics measured included features such as wetted width, bankfull width, thalweg depth, and bankfull height. The bankfull width/depth ratios generally were smallest at tributary sites and largest at main-stem Powder River sites. Sites on the main-stem Tongue River tended to have the highest median incision height, whereas Tongue River tributaries had the lowest median incision height. Rosebud Creek, as well as some of the sites on Otter Creek, had the largest percentages of fish cover. The Powder River had small percentages of fish cover compared to other streams.

Reachwide substrate data indicated the Tongue River had the coarsest substrates, whereas Squirrel and Otter Creeks had the finest substrates. Reachwide substrate embeddedness ranged from 50 percent in the Tongue River at Monarch to 100 percent at sites on upper Squirrel Creek, Porcupine Creek, and Caballo Creek. Streamside (bank) canopy density measurements indicated the main-stem Tongue River sites had greater mean canopy density than main-stem Powder River and tributary sites. Scores of the bank-stability index indicated streambanks at sites on the main-stem Tongue River in Montana and tributaries to the Tongue River were more stable than streambanks at sites on the main-stem Powder River and tributaries. Sites with the largest proximity-weighted human riparian disturbance scores included Hanging Woman Creek, Porcupine Creek, Rosebud Creek, and the Tongue River. The most commonly noted riparian disturbance was pasture, range, or hay fields that were noted at 45 of 47 sites.

Habitat characteristics of eight sites on the main-stem Powder River in Wyoming also were surveyed by the WGFD, using three approaches to provide data that might be useful in assessing the availability of habitat types and their respective fish communities with regard to changes in streamflow such as from CBNG activities. Modified Warm-water Stream Assessment (WSA) protocols were used to quantify habitat types, starting in 2004. In addition, ground-based, high-resolution global positioning system (GPS) mapping of habitat types was used in 2005, and EMAP-style transects were used in 2006. Habitat types that were measured at each site included riffle, run, pool, shoal, and backwater. Characteristics such as area, depth, substrate, and velocity were recorded for each habitat unit. The predominant aquatic habitat in the main-stem Powder River was shallow runs with low stream velocity, sand substrate, and little fish cover. Riffles and shoals were subdominant habitat types, depending on the site and the streamflow.

Macroinvertebrate communities were sampled following National Water-Quality Assessment (NAWQA) protocols. Riffles were the preferred sampling habitat and were sampled at 37 sites in 2005 and at 20 sites in 2006. Nonmetric multidimensional scaling (NMDS) ordinations indicated similarity of macroinvertebrate communities within river drainages. One group of similar sites included sites on the main-stem Tongue River as well as sites on other streams with mountainous headwaters—Goose Creek, Clear Creek, and Crazy Woman Creek. Macroinvertebrate communities of the Tongue River group were characterized by relatively large percentages of Ephemeroptera taxa richness and relative abundance and smaller percentages of Chironomidae and noninsects compared to other sampling sites in the PRB. Sites on the main-stem Powder River in Wyoming and Montana formed a second group of similar sites characterized by slightly fewer taxa, greater relative abundance of Ephemeroptera and Chironomidae, and less relative abundance of Trichoptera and noninsects than other sampling sites. A third group of

similar sites in the ordination was Tongue River tributary sites representing streams with plains origins, including Hanging Woman Creek, Squirrel Creek, and Youngs Creek. The Tongue River tributaries group was characterized by a relatively large number of taxa with large percentages of Chironomids and noninsects. Geographic, habitat, and water-quality variables were selected by principal components analysis (PCA) to test for correlation with the macroinvertebrate communities. The BEST routine indicated macroinvertebrate communities were best correlated with easting, drainage area, streamflow, specific conductance, magnesium concentration, percentage embeddedness, and alkalinity.

The macroinvertebrate data from the 2005–06 riffle samples also were analyzed using modeling and metric indices developed independently by the State of Wyoming and the State of Montana. The Wyoming observed/expected (O/E) model and Wyoming Stream Integrity Index (WSII) indicated that samples from sites on streams originating in the mountains had higher scores than those originating in the plains. For both 2005 and 2006, the O/E and WSII scores generally were highest in the Tongue River drainage followed by the Powder River drainage and then the Belle Fourche and Cheyenne River drainages. A general gradual downstream decline in biological condition was noted on the main-stem Tongue River upstream of Tongue River Reservoir. Among main-stem Powder River sites in Wyoming and near the State line, the O/E and WSII scores indicated a general increase in biological condition in the downstream direction, with the exception of declines in biological condition from upstream to downstream at Salt Creek and between Crazy Woman Creek and Clear Creek. Low scores were assigned to samples from the Cheyenne and Belle Fourche River drainages. Low O/E and WSII scores in the Cheyenne drainage may be because of limitations of the models in accurately representing reference conditions for streams in this drainage that have a greater tendency towards intermittent/ephemeral flow regimes compared to the Powder and Tongue River drainages. The Wyoming O/E and WSII scores were not significantly different between years.

Similar to the Wyoming O/E model, the Montana O/E model indicated higher scores for sites on streams with mountainous origins than those with plains origins. The Montana O/E scores for samples from the main-stem Tongue River were lower than scores for samples from tributaries of the Tongue River. This might be, in part, because the tributaries more closely matched the physical properties of those streams identified by MDEQ as reference streams used to calibrate the O/E model. The Montana O/E scores trended downward in the downstream direction along the main-stem Tongue River as opposed to the Montana Multimetric Index (MMI) scores that did not show a distinct trend downstream. The Montana O/E and MMI scores from the Tongue River and Powder River drainages generally were higher in 2006 than in 2005, but the differences were not statistically significant. The Powder River MMI scores were most affected by the presence of filterer-collectors and predator taxa, whereas the O/E scores were sensitive to the presence of potentially cold stenotherm Orthocladiinae (Chironomidae) taxa.

Analysis of the ATG macroinvertebrate data set with both the Wyoming and Montana O/E models and MMIs indicated appreciable differences in model scores between the Wyoming and Montana models for the same sites. The differences in scores were attributed to fundamental differences in the way the States designed their tools, including selection of relevant metrics and choice of reference sites, that resulted in differences in the models' responses to environmental gradients and sensitivity to the magnitude and duration of stressors. In spite of those differences, the O/E models and MMIs generally showed similar patterns in biological condition at the study-area and drainage-basin scales. The results indicate that O/E indicators might be more sensitive in detecting environmental change than the MMIs, but the MMIs were valuable for identifying particular similarities or differences between the macroinvertebrate communities. Additional data collection and analysis are needed to confirm and further define these patterns for both Wyoming and Montana. Given the regional scale of the drainage basins and development issues, development of biological indicators at a regional scale might provide additional insights and understanding of the processes affecting biological communities.

Qualitative multihabitat (QMH) samples of the macroinvertebrates were collected at all of the ATG sites, including sites where no riffles were present. The QMH samples exhibited significantly larger values than richest targeted habitat (RTH), or riffle, samples in terms of taxa tolerance scores, total taxa richness, and taxa richness of Ephemeroptera, Chironomidae, and noninsects. Ancillary data from other USGS studies also were evaluated. For example, comparison of macroinvertebrate samples collected a site on the Little Powder River during a 1980–81 Wyoming Water Science Center (WWSC) project investigation, NAWQA samples collected during 1999–2007, and ATG samples collected during 2005–06 indicated the same macroinvertebrate taxa often dominated the samples collected at the site during all three studies.

Algal samples were collected from sites in Wyoming and near the Wyoming-Montana State line during 2005. An NMDS ordination of the algal data indicated similarity of algal communities within the Tongue River drainage, the main-stem Powder River, and the Cheyenne River drainage. The groups of sites determined to be most similar for the algal communities generally were similar to the groups determined for the macroinvertebrate communities, with some exceptions. Algal samples from Crazy Woman Creek were more similar to those from the main-stem Powder River, whereas macroinvertebrate samples from Crazy Woman Creek were more similar to those in the Tongue River group. Samples from sites on the main-stem Powder River below Salt Creek (site P2) and below Burger Draw (site P4) were outliers to the main-stem group in the ordination and with regard to some of the diatom metrics related to *Achnanthes minutissima* and salinity. Diatom communities at sites P2 and P4 were dominated by a single taxon, *Achnanthes minutissima*, which is sometimes used as an indicator of disturbance. The diatom community at site P2 had the largest relative abundance of halobiontic (salt loving) species of any of the sites, which may reflect tributary inflows from Salt Creek.

Algal data were tested for correlation with environmental variables using the BEST routine, similar to the analysis of the macroinvertebrate communities. The algal communities were best correlated with northing, riparian disturbance, specific conductance, water temperature, and alkalinity. The environmental variables correlated with both the algal and macroinvertebrate communities were specific conductance and alkalinity. Although nutrients were beyond the scope of this study, collection of nutrient data in conjunction with any future sampling of algae might help define environmental variables affecting the algal communities.

Algal data from other programs also were evaluated where available for ATG sites. For example, NAWQA samples were collected at the Little Powder River above Dry Creek during 1999–2006. Diatoms generally dominated in those samples, although blue-green algae also were common. Algal data also were available from the WWSC water-quality monitoring network during 2002 and from a WWSC project investigation during 1980 for some of the ATG sites. For example, diatoms in the genus *Cocconeis* dominated in the 2002 and the 2005 samples from the Tongue River at the State line.

Fish community samples were collected by the USGS following EMAP protocols at 35 sites in the Tongue, Cheyenne, and Belle Fourche River drainages as well as tributaries to the Powder River during 2005–06. Fish community samples were collected following modified WSA protocols by the WGFD at eight sites on the main-stem Powder River in Wyoming during 2004–06 and by the USGS at four sites on the main-stem Powder River in Montana during 2005–06. A total of 36 fish species were identified in the samples from the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries, of which about one-half were native species including eight species of minnows (Cyprinidae) and five species of suckers (Catostomidae). A total of 16 native and 5 introduced species were identified in samples from the main-stem Powder River in Wyoming and Montana.

Fourteen species of fish were collected in samples from the Tongue River drainage that were not collected in samples from any of the other drainages, including the main-stem Powder River. Many of the fish species unique to the Tongue River drainage appeared to be associated with Tongue River Reservoir as indicated by the presence of open-water species such as spottail shiner, yellow perch, black crappie, and white crappie. Other species captured only in the Tongue River drainage included brassy minnow, lake chub, golden shiner, and yellow bullhead. Native species, such as fathead minnow, sand shiner, white sucker, and shorthead redhorse were the most abundant fish in the Tongue, Cheyenne, and Belle Fourche Rivers and tributaries, but introduced species, such as smallmouth bass, rock bass, common carp, and green sunfish, also were common in the Tongue River drainage and some tributaries. Tributary streams with relatively large numbers of fish species in 2005–06 were Clear Creek, Little Powder River, Prairie Dog Creek, and Goose Creek. The number of species per sample was smallest in small, intermittent streams such as Rosebud Creek, Porcupine Creek, and the Belle Fourche River. Fish species sampled in 2006 appeared to be similar to those sampled in 2005 in spite of notably drier conditions during 2006.

Fish abundance in the main-stem Powder River was dominated by native species such as sand shiner, flathead chub, and plains minnow. Although northern plains killifish were common, other introduced fish were relatively rare in the main-stem Powder River. Two species of fish, the sturgeon chub and western silvery minnow, were identified in samples from the main-stem Powder River that were not found in samples from any of the other sites in this study. The sturgeon chub and western silvery minnow are species of special concern to the States of Wyoming and Montana. Sturgeon chub were documented more often at the Montana sampling sites than the Wyoming sites, potentially indicating more favorable conditions in the Montana part of the Powder River than in Wyoming. Laboratory confirmation of *Hybognathus* spp. from the Powder River sites in Wyoming indicated that 99 percent of the voucher specimens were plains minnow (*H. placitus*) and 1 percent were western silvery minnow (*H. argyritis*), whereas laboratory confirmation of *Hybognathus* spp. from Montana sites indicated 43 percent were plains minnow and 57 percent were western silvery minnow. Both sturgeon chub and western silvery minnow generally were rare in the samples.

Monthly sampling from May through October 2004 at main-stem Powder River sites in Wyoming indicated the percentage of sand shiner in the overall catch increased substantially from May through October in concert with a substantial decrease in the percentage of flathead chub and *Hybognathus* spp. These trends may be explained in part by the recruitment of age-0 sand shiner to the sampling equipment by late summer and early fall. This shift in species composition was not repeated in 2005 when samples were collected pre-high flow, post-high flow, and during low flow. Samples collected early in the year contained noticeably fewer fish than samples collected later in the year despite equal sampling effort in both 2004 and 2005.

Comparison of fish species by habitat indicated some associations in the main-stem Powder River. Channel catfish and goldeye, for example, were found significantly more often in pools than in riffles, backwater, or shoals. The percentages of *Hybognathus* spp. were significantly larger in runs and pools than in riffles, backwaters, or shoals. Flathead chubs were found more often in pools and runs than in other habitats. Data for other species also are available.

The structure and integrity of the fish communities was assessed using an Index of Biotic Integrity (IBI) developed for small plains streams in Montana. The highest IBI scores, associated with best condition, among the small plains streams were from Youngs Creek, Squirrel Creek, Clear Creek, Little

Powder River, and Crazy Woman Creek. The lowest IBI scores among the small plains streams, using mean values, occurred in the Hanging Woman Creek, Otter Creek, Cheyenne River, and Belle Fourche River drainages. Small intermittent streams such as those in the Cheyenne River drainage have naturally small numbers of fish species, and therefore, the IBI scores might be biased toward lower values. Of the six sites on the main-stem Tongue River, the lowest IBI scores in both 2005 and 2006 were at the site downstream from the Tongue River Reservoir, but these data should be used with caution because the IBI was not designed for larger rivers such as the Tongue River and Powder River. An analysis of variance of the IBI scores from main-stem Powder River sites in Wyoming indicated no significant difference between sites or between years (2005–06).

The data collected for habitat, algae, macroinvertebrates, and fish from streams of the PRB indicate substantial variation in habitat characteristics and biological communities from one river drainage to another and in the downstream direction within river drainages. Differences in the algal communities at sampling sites on the Powder River below Salt Creek and below Burger Draw from other sampling sites as determined from the ordination and various diatom metrics were supported in part by the macroinvertebrate data. Wyoming O/E and WSII scores were quite low at sites in the Powder River below Salt Creek. The macroinvertebrate ordination, however, showed the macroinvertebrate communities below Salt Creek and Burger Draw were generally similar to other sites on the main-stem Powder River. The ANOVA of fish community IBI scores from the main-stem Powder River in Wyoming did not indicate significant differences among the sites. In combination, these data might indicate that the algal communities respond to different environmental variables, or at a different time scale, than the macroinvertebrate or fish communities.

These data provide a snapshot of conditions in streams of the PRB during 2005–06 and can be used in conjunction with future monitoring to assess the effects of coalbed natural gas and other development. Additional data analysis tools, such as development of regional macroinvertebrate O/E and MMI models, and calibration of a fish IBI for large plains rivers also may warrant further investigation.

References Cited

Armentrout, G.W., Jr., and Wilson, J.F., Jr., 1987, An assessment of low flows in streams in northeastern Wyoming: U.S. Geological Survey Water-Resources Investigations Report 85–4246, 30 p.

Bahls, L.L., Weber, E.E., and Jarvie, J.O., 1984, Ecology and distribution of major diatom ecotypes in the southern Fort Union coal region of Montana: U.S. Geological Survey Professional Paper 1289, 151 p.

Bailey, R.G., 1995, Description of the ecoregions of the United States (2d ed.): U.S. Department of Agriculture, Forest Service Miscellaneous Publication No. 1391 (rev.), 108 p., 1 pl. in pocket.

Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B., 1999, Rapid bioassessment protocols for use in streams and wadeable rivers—Periphyton, benthic macroinvertebrates, and fish (2nd ed.): U.S. Environmental Protection Agency, Office of Water, EPA 841–B–99–002, variable pagination.

Baxter, G.T., and Stone, M.D., 1995, Fishes of Wyoming: Cheyenne, Wyo.: Wyoming Game and Fish Department Bulletin Number 4, 290 p.

Bramblett, R.G., Johnson, T.R., Zale, A.V., and Heggem, D.G., 2005, Development and evaluation of a fish assemblage index of biotic integrity for northwestern Great Plains streams: Transactions of the American Fisheries Society, v. 134, p. 624–640.

Bray, J.R., and Curtis, J.T., 1957, An ordination of the upland forest communities of southern Wisconsin: Ecological Monographs, v. 27, p. 325–349.

Brown, C.J.D., 1971, Fishes of Montana: Bozeman, Mont., Big Sky Books, Montana State University, 207 p.

Chapman, S.S., Bryce, S.A., Omernik, J.M., Despain, D.G., Zumberge, J., and Conrad, M., 2003, Ecoregions of Wyoming (color poster with map, descriptive text, summary tables, and photographs): Reston, Va., U.S. Geological Survey, scale 1:1,400,000, accessed October 2, 2007, at *http://www.epa.gov/wed/pages/ecoregions/wy_eco.htm*

Chorley, R.J., Schumm, S.A., and Sugden, D.E., 1984, Geomorphology: New York, Methuen & Co., 605 p.

Clark, M.L., and Mason, J.P., 2007, Water-quality characteristics for sites in the Tongue, Powder, Cheyenne, and Belle Fourche River drainage basins, Wyoming and Montana, water years 2001–05, with temporal patterns of selected long-term water-quality data: U.S. Geological Survey Scientific Investigations Report 2007–5146, 65 p.

Clarke, K.R., and Gorley, R.N., 2006, PRIMER v6: Plymouth, United Kingdom, Plymouth Marine Laboratory, PRIMER-E Ltd., 190 p.

Clarke, R.T., Wright, J.F., and Furse, M.T., 2003, RIVPACS models for predicting the expected macroinvertebrate fauna and assessing the ecological quality of rivers: Ecological Modeling, v. 160, p. 219–233.

Cuffney, T.C., 2003, User's manual for the National Water-Quality Assessment Program invertebrate data analysis system (IDAS) software—version 3: U.S. Geological Survey Open-File Report 03–172, 103 p.

Davis, W.N., Bramblett, R.G., and Zale, A.V., 2006a, Effects of coalbed natural gas development on fish assemblages in the Powder River Basin, 2005: Bozeman, Montana Cooperative Fishery Research Unit, 3 p.

Davis, W.N., Bramblett, R.G., and Zale, A.V., 2006b, The effects of coalbed natural gas activities on fish assemblages—a review of the literature: Bozeman, Montana Cooperative Fishery Research Unit, 47 p.

Fitzpatrick, F.A., and Giddings, E.M., 1995, Stream habitat characteristics of fixed sites in the Western Lake Michigan drainages, Wisconsin and Michigan, 1993–95: U.S. Geological Survey Water-Resources Investigations Report 95–4211–B, 58 p.

Fitzpatrick, F.A., Waite, I.R., D'Arconte, P.J., Meador, M.R., and Gurtz, M.E., 1998, Revised methods for characterizing stream habitat in the National Water-Quality Assessment Program: U.S. Geological Survey Water-Resources Investigations Report 98–4052, 67 p.

Graham, T.B., 2002, Climate change and ephemeral pool ecosystems—potholes and vernal pools as potential indicator systems: U.S. Geological Survey Biological Resources Division, accessed December 19, 2007, at *http://geochange.er.usgs.gov/sw/impacts/biology/vernal/.*

Hargett, E.G., and Zumberge, J.R., 2006, Redevelopment of the Wyoming Stream Integrity Index (WSII) for assessing the biological condition of wadeable streams of Wyoming: Wyoming Department of Environmental Quality, Water Quality Division Report, 70 p.

Hargett, E.G., Zumberge, J.R., and Hawkins, C.P., 2005, Development of a RIVPACS model for wadeable streams of Wyoming: Wyoming Department of Environmental Quality, Water Quality Division Report, 64 p.

Hargett, E.G., Zumberge, J.R., Hawkins, C.P., and Olson, J.R., 2007, Development of a RIVPACS-type predictive model for bioassessment of wadeable streams in Wyoming: Ecological Indicators, v. 7, p. 807–826.

Harrelson, C.C., Rawlins, C.L., and Potyondy, J.P., 1994, Stream channel reference sites—an illustrated guide to field technique: Fort Collins, Colo., U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experimentation Station, General Technical Report RM–245, 61 p.

Helsel, D.R., and Hirsch, R.M. 2002, Statistical methods in water resources: U.S. Geological Survey techniques of water resources investigations, book 4, chap. A3, 522 p.

Hembree, C.H., Colby, B.R., Swensen, H.A., and Davis, J.R., 1952, Sedimentation and chemical quality of water in the Powder River drainage basin, Wyoming and Montana: U.S. Geological Survey Circular 170, 99 p.

Hilsenhoff, W.L., 1987, An improved index of organic stream pollution: Great Lakes Entomologist, v. 20, p. 31–39.

HKM Engineering, Inc., Lord Consulting, and Watts and Associates, 2002, Powder/Tongue River Basin Plan—executive summary: Available on the Web, accessed March 16, 2008, at *http://censtats.census.gov/data/WY/1605631855.pdf*

Hubert, W.A., 1993, The Powder River—a relatively pristine stream on the Great Plains, *in* Hesse, L.W., Stalnaker, C.B., Benson, N.G., and J. R. Zuboy, J.R., eds., Restoration planning for the rivers of the Mississippi River ecosystem: Washington, D.C., National Biological Survey, Biological Report 19, p. 387–395.

Insightful Corp., 2005, S-Plus 7.0 for Windows—professional developer: Palo Alto, California, TIBCO Software, Inc.

Kaufmann, P.R., Levine, P., Robison, E.G., Seeliger, C., and Peck, D.V., 1999, Quantifying physical habitat in wadeable streams: U.S. Environmental Protection Agency, EPA/620/R–99/003, 102 p.

Kerans, B.L., and Karr, J.R., 1994, A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley: Ecological Applications, v. 4, p. 768–785.

Knight, D.H., 1994, Mountains and plains—the ecology of Wyoming landscapes: New Haven and London, Yale University Press, 338 p.

Kwak, T.J., and Peterson, J.T., 2007, Community indices, parameters, and comparisons, *in* Guy, C.S., and Brown, M.L., eds., Analysis and interpretation of freshwater fisheries data: Bethesda, Md., American Fisheries Society, p. 677–763.

Lee, R.W., Slagle, S.E., and Stimson, J.R., 1981, Magnitude and chemical quality of base flow of Otter Creek, Tongue River, and Rosebud Creek, southeastern Montana, October 26–November 5, 1977: U.S. Geological Survey Water-Resources Investigations, Open-File Report 80–1298, 25 p.

Leopold, L.B., Wolman, M.G., and Miller, J.P., 1992, Fluvial processes in geomorphology: Mineola, N.Y., Dover Publications, Inc., 522 p.

Lindner-Lunsford, J.B., Parrett, Charles, Wilson, J.F., Jr., and Eddy-Miller, C.A., 1992, Chemical quality of surface water and mathematical simulation of the surface-water system, Powder River drainage basin, northeastern Wyoming and southeastern Montana: U.S. Geological Survey Water-Resources Investigations Report 91–4199, 85 p.

Lowe, R.L., 1974, Environmental requirements and pollution tolerance of freshwater diatoms: U.S. Environmental Protection Agency, EPA–670/4–74–005, 333 p.

McNab, W.H., Cleland, D.T., Freeouf, J.A., Keys, J.E., Jr., Nowacki, G.J., and Carpenter, C.A., compilers, 2005, Description of ecological subregions—sections of the conterminous United States: Washington, D.C., U.S. Department of Agriculture, Forest Service, 80 p., [CD-ROM].

Merritt, R.W., and Cummins, K.W., 1996, An introduction to the aquatic insects of North America (3d ed.): Dubuque, Iowa, Kendall/Hunt Publishing Co., 862 p.

Montana Department of Environmental Quality, 2006, Sample collection, sorting and taxonomic identification of benthic macroinvertebrates: Water Quality Planning Bureau, Standard Operating Procedure (WQPBWQM-009), 32 p.

Moss, D., Furse, M.T., Wright, J.F., and Armitage, P.D., 1987, The prediction of the macroinvertebrate fauna of unpolluted running water sites in Great Britain using environmental data: Freshwater Biology, v. 17, p. 41–52.

Moulton, S. R., II, Kennen, J.G., Goldstein, R.M., and Hambrook, J.A., 2002, Revised protocols for sampling algal, invertebrate, and fish communities as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 02–150, 75 p.

National Oceanic Atmospheric Administration, Satellite and Information Service, 2005, Climate of 2005—June, Wyoming Division 4 Drought, Regional Overview/ Paleo Perspective, accessed October 26, 2007, at *http://www.ncdc.noaa.gov/oa/climate/research/2005/jun/st048dv04pcp200506.html*

Ostrand, K.G., and Wilde, G.R., 2004, Changes in prairie stream fish assemblages restricted to isolated streambed pools: Transactions of the American Fisheries Society, v. 133, p. 1329–1338.

Patton, T.M., 1997, Distribution and status of fishes in the Missouri River drainage in Wyoming—implications for identifying conservation areas: Laramie, University of Wyoming, doctoral dissertation, 173 p.

Peck, D.V., Lazorchak, J.M., and Klemm, D.J., eds., 2003, Environmental Monitoring and Assessment Program—surface waters—Western Pilot Study field operations manual for wadeable streams: Washington, D.C., U.S. Environmental Protection Agency, 258 p.

Peterson, D.A., 1990, Invertebrate communities of small streams in northeastern Wyoming: U.S. Geological Survey Water-Resources Investigation Report 85–4287, 45 p.

Peterson, D.A., Miller, K.A., Bartos, T.T., Clark, M.L., Porter, S.D., and Quinn, T.L., 2004, Water quality in the Yellowstone River Basin, Wyoming, Montana, and North Dakota, 1999–2001: U.S. Geological Survey Circular 1234, 34 p., available on the Web at *http://pubs.usgs.gov/circ/2004/1234/*.

Pflieger, W.L., 1997, The fishes of Missouri, revised edition: Jefferson City, Missouri Department of Conservation, 371 p.

Porter, S.D., 2008, Algal attributes—An autecological classification of algal taxa collected by the National Water-Quality Assessment Program: U.S. Geological Survey Data Series 329, available on the Web at *http://pubs.usgs.gov/ds/ds329*

Porter, S.D., Mueller, D.K., Spahr, N.E., Munn. M.D., and Dubrovsky, N.M,, 2008, Efficacy of algal metrics for assessing nutrient and organic enrichment in flowing waters: Freshwater Biology, v. 53, p. 1036-1054.

Potapova, M., and Charles, D.F., 2005, Choice of substrate in algae-based water-quality assessment: Journal of the North American Benthological Society, v. 24, no. 2, p. 415–427.

Potyondy, J.P., and Bunte, K., 2002, Sampling with the US SAH–97 Hand-held Particle Size Analyzer: Federal Interagency Sedimentation Project, 6 p., available on the Web at *http://fisp.wes.army.mil/Instructions %20US_SAH-97_040412.pdf*

Powder River Natural Gas Interagency Working Group, 2004, Charter: Buffalo, Wyo., Bureau of Land Management, 15 p., accessed April 1, 2008, at *http://www.wy.blm.gov/prbgroup/pdfs/charter061504.pdf*

Prescott, G.W., 1978, How to know the freshwater algae: Dubuque, Iowa, Wm. C. Brown Co., 293 p.

Quist, M.C., Hubert, W.A., and Rahel, F.J., 2004, Warmwater stream assessment manual: Cheyenne, Wyoming Game and Fish Department, 190 p.

Rice, C.A., Ellis, M.S., and Bullock, J.H., Jr., 2000, Water co-produced with coalbed methane in the Powder River Basin, Wyoming—preliminary compositional data: U.S. Geological Survey Open-File Report 00–372, 22 p.

Ringen, B.H., and Daddow, P.B., 1990, Hydrology of the Powder River alluvium between Sussex, Wyoming, and Moorhead, Montana: U.S. Geological Survey Water-Resources Investigations Report 89–4002, 48 p.

Rosgen, D.L., 1996, Applied river morphology: Pagosa Springs, Colo., Wildland Hydrology, 342 p.

Skaar, D., Farag, A., and Harper, D., 2006, Toxicity of sodium bicarbonate to fish from coal-bed natural gas production in the Tongue and Powder River drainages, Montana and Wyoming: U.S. Geological Survey Fact Sheet 2006–3092, 4 p.

Stagliano, D., 2006, Aquatic surveys and assessment within the Middle Powder River watershed: U.S. Bureau of Land Management Report (ESA010009), 37 p., accessed Dec.13, 2007, at *http://mtnhp.org/Reports/Mid_Powd_Riv_Water_Assess.pdf*

Stoner, D.L., 1993, Microbial transformation of organic nitrogen and sulfur in low rank coals, *in* Crawford, D.L. ed., Microbial transformations of low rank coals: Ann Arbor, Mich., CRC Press, 223 p.

Stricker, G.D., Flores, R.M., McGarry, D.E., Stillwell, D.P., Hoppe, D.J., Stillwell, C.R., Ochs, A.M., Ellis, M.S., Osvald, K.S., Taylor, S.L., Thorvaldson, M.C., Trippi, M.H., Grose, S.D., Crockett, F.J., and Shariff, A.J., 2006, Gas desorption and adsorption isotherm studies of coals in the Powder River Basin, Wyoming and adjacent basins in Wyoming and North Dakota: U.S. Geological Survey Open-File Report 2006–1174, 21 p., available on the Web at *http://pubs.usgs.gov/of/2006/1174/.*

Suplee, M., Sada de Suplee, R., Feldman, D., and Laidlaw, T., 2005, Identification and assessment of Montana reference streams—a follow-up and expansion of the 1992 Benchmark Biology Study: Helena, Montana Department of Environmental Quality, Planning Prevention and Assistance Division, Water Quality Planning Bureau, Water Quality Standards Section, 41 p.

U.S. Census Bureau, 2007, 2000 Census: digital data available on the Web, accessed March, 16, 2007, at *http://censtats.census.gov/data/WY/1605631855.pdf*

U.S. Census Bureau, 2009, American fact finder: digital data available on web, accessed January 28, 2009 at *http://factfinder.census.gov/home/saff/main.html?_lang=en*

U.S. Geological Survey, 2008, NAWQA data warehouse home: Information available on the Web, accessed June 6, 2008, at *http://water.usgs.gov/nawqa/data*

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1–A9, available on the Web, accessed March 10, 2008 at *http://pubs.water.usgs.gov/twri9A*

Van Dam, H., Mertens, A., and Sinkeldam, J., 1994, A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands: Netherlands Journal of Aquatic Ecology, v. 28, no. 1, p. 117–133.

Walsh, S.J., and Meador, M.R., 1998, Guidelines for quality assurance and quality control of fish taxonomic data collected as part of the National Water-Quality Assessment Program: U.S. Geological Survey Water-Resources Investigations Report 98–4239, 33 p.

Wangsness, D.J., and Peterson, D.A., 1980, Behavioral and catastrophic drift of invertebrates in two streams in northeastern Wyoming: U.S. Geological Survey Open-File Report 80–1101, 13 p.

Watson, V.J., Ingman, G., and Anderson, B., 2000, Appendix A. Case studies, *in* U.S. Environmental Protection Agency, Nutrient criteria technical guidance manual—rivers and streams: EPA–B22–B–00–002, p. A–19 to A–23.

Western Regional Climate Center, 2007, Broadus, Montana: digital data available on the Web, accessed October, 26, 2007, at *http://www.wrcc.dri.edu/cgi-bin/cliGCStT.pl?mt1127*

Western Regional Climate Center, 2009, Digital data available on the Web, accessed January 28, 2009, at *http://www.wrcc.dri.edu/.*

Wolman, M.G., 1954, A method for sampling coarse riverbed material: Transactions of the American Geophysical Union, v. 35, p. 951–956.

Woods, A.J., Omernik, J.M., Nesser, J.A., Shelden, J., Comstock, J.A., and Azevedo, S.H., 2002, Ecoregions of Montana (2d ed.) (color poster with map, descriptive text, summary tables, and photographs): U.S. Environmental Protection Agency, map scale 1:1,500,000, accessed October 17, 2007, at *http://www.epa.gov/wed/pages/ecoregions/mt_eco.htm#Ecoregions%20denote*

Wright, J.F., Furse, M.T., and Armitage, P.D., 1993, RIVPACS—a technique for evaluating the biological quality of rivers in the U.K.: European Water Pollution Control, v. 3, p. 15–25.

Wright, P.R., Peterson, D.A., and Hallberg. L.L., 2006, Data collection for the assessment of aquatic communities in northeastern Wyoming and southeastern Montana, 2005: U.S. Geological Survey Fact Sheet 2006–3047, 6 p.

Wyoming Department of Environmental Quality, 2001, Water quality rules and regulations—Chapter 1, Wyoming Surface Water Quality Standards: Cheyenne, 23 p. plus appendixes.

Wyoming Department of Environmental Quality, 2006, Wyoming's 2006 305(b) State water quality assessment report and 2006 303(d) list of waters requiring TMDLs: Cheyenne, Water Quality Division, 107 p., accessed August 3, 2008, at *http://deq.state.wy.us/wqd/watershed/Downloads/305b/2006/2006_305b_.pdf*

Wyoming Department of Environmental Quality, 2009, National Pollutant Discharge Elimination System (NPDES) Program; digital data accessed January 28, 2009 at *http://deq.state.wy.us/wqd/npdes/.*

Wyoming Game and Fish Department, 2007, Annual fisheries progress report on the 2006 work schedule: Cheyenne, Wyoming Game and Fish Department, 451p.

Wyoming Oil and Gas Conservation Commission, 2008, Coal bed methane wells: digital data accessed July 21, 2008 at: *http://wogcc.state.wy.us/crms.cfm*

Zale, A.V., Leslie, D.M., Jr., Fisher, W.L., and Merrifield, S.G., 1989, The physicochemistry, flora, and fauna of intermittent prairie streams—a review of the literature: U.S. Fish and Wildlife Service, Biological Report 89(5), 44 p.

Zelt, R.B., Boughton, G.K., Miller, K.A., Mason, J.P., and Gianakos, L.M., 1999, Environmental setting of the Yellowstone River basin, Montana, North Dakota, and Wyoming: U.S. Geological Survey Water-Resources Investigations Report 98–4269, 112 p., available on the Web at *http://pubs.usgs.gov/wri/wri984269/*.

Appendixes

Appendix 1. Supporting Data for Macroinvertebrates

Table 27. Mean values of microhabitat measurements collected at macroinvertebrate sampling sites in riffles, Powder River Structural Basin, Wyoming and Montana, 2005–06.

[Shaded cells indicate main-stem sampling sites on the Tongue or Powder River; m/s, meters per second; E, estimate]

Site number (fig. 1)	Abbreviated site name	Sample date	Mean depth (meters)	Mean embeddedness (percent)	Mean velocity (m/s)	Gravel or larger substrate (percent)
R2	Rosebud Creek at mouth	09/15/2005	0.02	54	0.16	100
T1	Tongue River at Monarch	08/15/2005	.09	36	.42	100
		08/23/2006	.10	34	.43	100
T2	Goose Creek	08/17/2005	.13	24	.55	70
		08/22/2006	.17	48	.60	80
T3	upper Youngs Creek	06/15/2005	.10	0	.81	100
		06/28/2006	.05	38	.34	80
T4	Youngs Creek at mouth	06/14/2005	.19	54	.41	100
		06/27/2006	.16	50	.35	50
T5	Tongue River below Youngs Creek	08/15/2005	.11	24	.94	100
		08/22/2006	.11	28	.62	80
T7	Squirrel Creek at mouth	06/13/2005	.08	10	.24	100
T8	Prairie Dog Creek	08/25/2006	.09	44	.32	78
T9	Tongue River at State line	09/14/2005	.11	24	.49	80
		08/24/2006	.12	22	.45	100
T10	Tongue River above Hanging Woman Creek	08/16/2005	.15	48	.59	100
		08/28/2006	.16	48	.70	100
T11	upper Hanging Woman Creek	06/22/2005	.05	68	0	56
T12	middle Hanging Woman Creek	06/21/2005	.10	2	.19	50
T13	Hanging Woman Creek near Birney, MT	06/23/2005	.08	20	.15	90
T14	Tongue River at Birney Day School	09/12/2005	.20	46	.58	100
		08/28/2006	.17	36	.63	100
T17	Otter Creek at mouth	06/30/2005	.12	34	.44	100
		06/28/2006	.06	68	.22	100
T18	Tongue River below Bran-denberg Bridge	09/13/2005	.23	40	.83	100
		08/31/2006	.21	26	.74	100
T19	Pumpkin Creek	06/23/2005	.07	14	.21	100
P1	Powder River above Salt Creek	07/20/2905	.06	36	.36	80
		07/24/2006	.07	38	.30	50

Table 27. Mean values of microhabitat measurements collected at macroinvertebrate sampling sites in riffles, Powder River Structural Basin, Wyoming and Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sampling sites on the Tongue or Powder River; m/s, meters per second; E, estimate]

Site number (fig. 1)	Abbreviated site name	Sample date	Mean depth (meters)	Mean embeddedness (percent)	Mean velocity (m/s)	Gravel or larger substrate (percent)
P2	Powder River below Salt Creek	07/21/2005	0.09	48	0.35	70
		07/25/2006	.11	22	.50	50
P3	Powder River above Pump-kin Creek	07/19/2005	.05	28	.19	100
		07/26/2006	.05	26	.17	50
P4	Powder River below Burger Draw	07/22/2005	.08	36	.21	100
		07/27/2006	.07	22	.41	90
P5	Powder River above Crazy Woman Creek	07/13/2005	.07	60	.34	50
		07/28/2006	.07	14	.31	50
P6	Crazy Woman Creek below I-90	07/11/2005	.08	14	.38	50
P7	Crazy Woman Creek near mouth	07/12/2005	.24	15	.66	50
P8	Powder River below Crazy Woman Creek	07/23/2005	.17	64	.53	100
P9	Powder River above Clear Creek	07/24/2005	.12	74	.41	100
P10	Clear Creek	09/13/2005	.10	34	.45	90
		08/21/2006	.08	22	.51	80
P11	Powder River below Clear Creek	07/25/2005	.11	24	.41	E50
		08/03/2006	.04	42	.25	50
P12	Powder River at Moorhead	07/26/2005	.11	46	.31	100
P13	Powder River at Broadus	07/19/2005	.17	2	.63	90
		08/02/2006	.07	69	.38	100
P15	Little Powder River above Dry Creek	06/13/2005	.11	30	.60	100
		06/23/2006	.09	14	.45	100
P16	Little Powder River at Biddle	06/27/2005	.21	18	.67	100
P17	Powder River below Little Powder River	07/21/2005	.10	34	.30	70
P18	Powder River near Locate	07/22/2005	.12	44	.40	80
C3	Cheyenne River near Dull Center	06/27/2005	.05	34	.10	70
C4	Little Thunder Creek	06/09/2005	.02	32	.05	100
C6	Cheyenne River near Spencer	06/06/2005	.04	40	.20	100
B1	Belle Fourche River	06/29/2005	.07	40	.17	50

Table 28. Onsite measurements of physical and chemical characteristics collected in conjunction with biological samples, Powder River Structural Basin, Wyoming and Montana, 2005–06.

[Shaded cells indicate main-stem sites on the Tongue or Powder River; µS/cm, microsiemens per centimeter at 25°C; NC, not collected or missing]

Site number (fig. 1)	Sample date	Streamflow (cubic feet per second)	Specific conductance (µS/cm)	pH (standard units)	Water temperature (degrees Celsius)	Dissolved oxygen (milligrams per liter)	Turbidity (nephelometric turbidity units)
R1	06/20/2005	5.6	1,079	7.7	21.2	NC	3.0
	07/12/2006	.37	985	7.2	20.0	6.8	.9
R2	09/15/2005	.01	4,300	8.6	12.5	9.3	9.1
T1	08/15/2005	123	426	7.5	14.8	7.5	30
	08/23/2006	27	535	8.2	19.6	7.7	14
T2	08/17/2005	69	653	8.3	20.5	8.3	9.0
	08/22/2006	22	735	8.2	19.7	7.3	4.5
T3	06/14/2005	2.3	675	8.3	19.0	7.6	62
	06/28/2006	.36	704	8.4	22.0	7.2	85
T4	06/14/2005	.99	1,690	8.4	12.0	8.1	33
	06/27/2006	.58	1,000	8.3	19.5	9.2	18
T5	08/15/2005	171	544	7.8	19.0	8.2	48
	08/24/2006	23	695	7.9	19.0	7.3	12
T6	06/16/2005	.12	1,570	7.8	14.0	7.7	2.1
	06/29/2006	.12	1,480	8.0	13.5	7.8	3
T7	06/13/2005	.17	5,940	8.3	13.0	9.7	6.8
T8	08/16/2005	45	775	8.1	18.8	7.2	120
	08/25/2006	1.2	2,270	8.1	15.3	9.1	10
T9	09/14/2005	162	655	7.6	13.6	8.4	12
	08/24/2006	11	1,060	8.4	24.1	10.8	4.4
T10	08/16/2005	408	363	8.0	20.0	8.0	13
	08/29/2006	153	540	8.2	18.5	7.5	.6
T11	06/22/2005	.03	5,000	7.9	22.5	NC	10
	06/27/2006	0	4,500	9.3	18.5	10.0	3.9
T12	06/21/2005	.04	3,870	8.1	24.5	NC	9.0
	06/26/2006	.06	3,970	9.3	26.0	14.8	3.1
T13	06/23/2005	.11	2,090	7.8	20.3	NC	7.0
	06/26/2006	0	3,890	8.1	14.5	1.5	140
T14	09/12/2005	308	466	8.1	18.5	8.3	10
	08/28/2006	139	572	8.0	23.5	10.5	NC
T15	06/29/2005	.75	3,470	7.7	19.0	7.8	5.5
	07/12/2006	.1	3,510	8.6	26.5	12.1	3.2
T16	06/28/2005	.26	3,600	8.8	21.5	6.4	4.4
T17	06/30/2005	1.6	2,700	8.2	18.0	5.3	97
	06/28/2006	.82	2,890	8.4	22.2	5.0	79
T18	09/14/2005	330	503	8.3	14.5	9.3	16
	08/03/2006	81.8	684	8.4	17.8	8.6	NC

Table 28. Onsite measurements of physical and chemical characteristics collected in conjunction with biological samples, Powder River Structural Basin, Wyoming and Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sites on the Tongue or Powder River; µS/cm, microsiemens per centimeter at 25°C; NC, not collected or missing]

Site number (fig. 1)	Sample date	Streamflow (cubic feet per second)	Specific conductance (µS/cm)	pH (standard units)	Water temperature (degrees Celsius)	Dissolved oxygen (milligrams per liter)	Turbidity (nephelometric turbidity units)
T19	06/23/2005	1.1	1,140	8.4	29.4	NC	158
P1	07/20/2005	2.7	2,100	7.6	21.8	7.4	4.7
P1	07/24/2006	1.2	2,210	7.9	28.5	6.8	19
P2	07/21/2005	13	4,990	7.9	23.0	7.7	16
	07/25/2006	5.1	5,650	8.3	32.7	7.3	12
P3	07/19/2005	9.3	4,810	8.1	24.3	7.2	2.9
	07/26/2006	0.22	4,650	7.8	27.1	11.4	18
P4	07/22/2005	7.9	4,600	7.9	20.7	8.0	4.1
	07/27/2006	2.2	3,210	8.7	24.7	13.9	84
P5	07/13/2005	25	3,500	8.8	26.1	6.6	28
	07/28/2006	1.7	2,960	8.1	21.7	8.7	5.8
P6	07/11/2005	37	777	7.9	20.8	7.0	58
	07/31/2006	0	3,500	8.1	19.7	8.8	28
P7	07/12/2005	40	894	7.7	22.7	7.0	120
	08/01/2006	0	3,410	7.0	17.6	6.8	97
P8	07/23/2005	99	2,050	8.1	21.4	5.9	960
	08/02/2006	0	3,990	7.3	22.6	6.1	15
P9	07/24/2005	149	2,280	7.7	24.0	5.6	1000
	08/04/2006	0	2,360	7.7	21.6	5.2	20
P10	09/13/2005	35	1,200	8.0	13.6	8.0	4.3
	08/21/2006	1.7	1,840	8.0	20.4	8.2	12
P11	07/25/2005	92	1,940	8.2	21.2	7.4	420
	08/03/2006	0.2	2,260	8.1	21.1	7.2	7.6
P12	07/26/2005	76	1,930	8.4	18.2	8.0	619
	08/02/2006	0	4,300	8.3	16.0	6.2	41
P13	07/19/2005	111	1,690	8.3	22.5	8.2	18
	08/02/2006	1.1	4,750	8.1	27.0	9.5	3.3
P14	06/14/2005	0.73	2,080	8.1	11.2	9.5	7.3
	06/22/2006	0.27	2,060	8.5	22.8	10.0	1.5
P15	06/13/2005	3.8	3,480	6.8	13.6	7.5	120
	06/23/2006	0.23	3,380	8.1	19.5	8.8	96
P16	06/27/2005	7.6	2,720	7.9	17.5	6.4	810
P17	07/20/2005	85	1,820	8.4	28.5	5.8	22
	08/03/2006	.01	3,010	8.1	25.0	8.3	4.2
P18	07/22/2005	90	1,970	8.3	21.3	7.3	NC
C1	06/15/2005	.33	3,110	8.1	19.4	7.8	5.0
	06/22/2006	.12	3,690	9.8	17.9	10.6	1.8

Table 28. Onsite measurements of physical and chemical characteristics collected in conjunction with biological samples, Powder River Structural Basin, Wyoming and Montana, 2005–06.—Continued

[Shaded cells indicate main-stem sites on the Tongue or Powder River; µS/cm, microsiemens per centimeter at 25°C; NC, not collected or missing]

Site number (fig. 1)	Sample date	Streamflow (cubic feet per second)	Specific conductance (µS/cm)	pH (standard units)	Water temperature (degrees Celsius)	Dissolved oxygen (milligrams per liter)	Turbidity (nephelometric turbidity units)
C2	06/08/2005	0.09	3,050	7.8	14.1	7.2	9.3
	06/20/2006	0	2,840	7.8	29.1	5.1	4.2
C3	06/27/2005	0	3,070	8.1	21.3	5.3	4.8
	06/19/2006	0	6,560	8.1	30.6	6.4	49.4
C4	06/22/2005	.02	1,950	7.7	14.3	8.1	41
	06/21/2006	0	6,370	8.9	15.6	5.6	19
C5	06/07/2005	0	1,410	8.1	20.2	6.5	48
C6	06/06/2005	6.4	3,910	8.0	20.4	7.2	163
	06/20/2006	0	7,100	8.0	20.6	6.5	3.4
B1	06/29/2005	1	3,360	8.8	16.6	8.1	3.8
	06/21/2006	.5	4,960	7.8	29.8	8.1	5.7
B2	06/28/2005	0	4,240	8.0	21.7	10.0	160

Appendix 2. Supporting Data for Fish

Table 29. Total numbers of fish by sampling site collected by the Wyoming Game and Fish Department at sites on the main-stem Powder River, Wyoming, 2004–06.

[Location of sampling sites shown in figure 1. SFP, South Fork Powder River; n, number of sampling periods]

Species	Total numbers of fish at sampling sites (percent of total catch[1])									
	Site SFP[2] (n=5)	Site P1 (n=9)	Site P2 (n=9)	Site P3 (n=8)	Site P4 (n=4)	Site P5 (n=10)	Site P8 (n=9)	Site P9 (n=9)	Site P11 (n=9)	Overall
Sand shiner	502 (12.4)	9,106 (57.6)	12,183 (56.2)	10,264 (64.4)	6,450 (62.3)	18,399 (63.9)	9,957 (68.1)	6,440 (69.3)	6,854 (65.3)	80,155 (61.2)
Flathead chub	1,510 (37.2)	3,300 (20.9)	5,658 (26.1)	2,990 (18.8)	1,658 (16.0)	7,115 (24.7)	2,008 (13.7)	1,418 (15.3)	1,229 (11.7)	26,886 (20.5)
Hybognathus spp.	798 (19.6)	139 (0.9)	1,010 (4.7)	982 (6.2)	1,320 (12.8)	2,103 (7.3)	2,010 (13.7)	675 (7.3)	1,462 (13.9)	10,499 (8.0)
Northern plains killifish	1,183 (29.1)	1,381 (8.7)	1,441 (6.6)	1,216 (7.6)	330 (3.2)	264 (0.9)	45 (0.3)	24 (0.3)	15 (0.1)	5,899 (4.5)
Longnose dace	57 (1.4)	1,088 (6.9)	1,042 (4.8)	185 (1.2)	278 (2.7)	101 (0.4)	134 (0.9)	11 (0.1)	13 (0.1)	2,909 (2.2)
River carpsucker	0	117 (0.7)	70 (0.3)	156 (1.0)	146 (1.4)	347 (1.2)	244 (1.7)	99 (1.1)	332 (3.2)	1,511 (1.2)
Channel catfish	0	4	12 (0.1)	44 (0.3)	132 (1.3)	149 (0.5)	175 (1.2)	579 (6.2)	444 (4.2)	1,539 (1.2)
Mountain sucker	0	524 (3.3)	185 (0.9)	8 (0.1)	0	0	0	0	0	717 (0.5)
Fathead minnow	0	107 (0.7)	61 (0.3)	67 (0.4)	20 (0.2)	273 (0.9)	7	27 (0.3)	19 (0.2)	581 (0.4)
Stonecat	0	10 (0.1)	0	8 (0.1)	2	8	19 (0.1)	3	86 (0.8)	136 (0.1)
Goldeye	0	1	3	3	4	9	9 (0.1)	4	13 (0.1)	46
White sucker	2	13 (0.1)	22 (0.1)	2	0	1	0	2	0	42
Creek chub	10 (0.2)	22 (0.1)	0	0	0	1	3	4	0	40
Common carp	0	0	2	7	6 (0.1)		7	5 (0.1)	5	32
Sturgeon chub	0	0	0	0	0	2	1	0	0	3
Northern redhorse	0	1	0	0	0	2	4	2	19 (0.2)	28
Green sunfish	0	0	2	0	0	2	0	2	0	6
Smallmouth bass	0	0	0	0	0	0	0	0	3	3
Black bullhead	0	1	0	0	0	0	0	0	0	1
Rock bass	0	0	0	0	0	0	0	0	1	1
Total	**4,062**	**15,814**	**21,691**	**15,932**	**10,346**	**28,776**	**14,623**	**9,295**	**10,495**	**131,034**

[1]Percentage of total catch not listed if less than 0.1 percent.

[2]Miscellanous site location.

Table 30. Total numbers of fish by sampling site collected by the U.S. Geological Survey at sites on the main-stem Powder River, Montana, 2005–06.

[Location of sampling sites shown in figure 1. n, number of sampling periods]

Species	Total numbers of fish									
	Site P12 (n=3)		Site P13 (n=2)		Site P17 (n=2)		Site P18 (n=1)		Overall	Percentage of total
	Count	Percentage of total	Count	Percentage of total	Count	Percentage of total	Count	Percentage of total		
Sand shiner	315	29.7	598	42.0	647	47.8	8	11.8	1,568	40.2
Flathead chub	421	39.8	429	30.1	65	4.8	47	69.1	962	24.6
River carpsucker	122	11.5	43	3.0	373	27.6	1	1.5	539	13.8
Longnose dace	20	1.9	301	21.1	0	0	0	0	321	8.2
Channel catfish	139	13.1	10	.7	14	1.0	3	4.4	166	4.3
Western silvery minnow	1	.1	0	.0	98	7.2	0	0	99	2.5
Northern plains killifish	1	.1	34	2.4	57	4.2	0	0	92	2.4
Plains minnow	9	.8	4	.3	63	4.7	0	0	76	1.9
Sturgeon chub	4	.4	1	.1	20	1.5	3	4.4	28	.7
Goldeye	14	1.3	0	.0	1	.1	5	7.4	20	.5
Green sunfish	0	.0	4	.3	7	.5	0	0	11	.3
Stonecat	10	.9	0	0	0	0	0	0	10	.3
Common carp	1	.1	0	0	6	.4	0	0	7	.2
Fathead minnow	0	.0	0	0	2	.1	1	1.5	3	.1
Shorthead redhorse	2	.2	0	0	0	0	0	0	2	.1
Total	**1,059**	**99.9**[1]	**1,424**	**100.0**	**1,353**	**99.9**	**68**	**100.1**	**3,904**	**100.1**

[1]Total percentage not equal to 100.0 due to rounding

Table 31. Larval fish collected by the Wyoming Game and Fish Department from eight sampling sites on the main-stem Powder River, Wyoming, 2004–05.

[CKC, creek chub; CRP, common carp; FHC, flathead chub; PMN, plains minnow; LND, longnose dace; SDS, sand shiner; MTS, mountain sucker; RCS, river carpsucker; SHR, shorthead redhorse; WHS, white sucker; CCF, channel catfish; STC, stonecat; PKF, northern plains killifish]

Site number (fig. 1)	Sample date	Number of fish collected														Total
		CKC	CRP	FHC	FHM	PMN	LND	SDS	MTS	RCS	SHR	WHS	CCF	STC	PKF	
P1	06/07/2004	1	0	2	1	0	0	1	1	0	0	0	0	0	2	8
	07/08/2004	0	0	7	0	0	0	52	0	0	0	0	0	0	0	59
	08/10/2004	0	0	0	0	1	0	3	0	0	0	0	0	0	0	4
	09/09/2004	0	0	0	0	0	0	10	0	0	0	0	0	0	0	10
	10/13/2004	0	0	0	0	0	0	11	0	0	0	0	0	0	0	11
	07/20/2005	0	0	376	1	1	35	940	3	32	0	2	0	0	17	1,407
	08/12/2005	0	0	0	0	0	0	65	0	0	0	0	0	0	4	69
	Total	**1**	**0**	**385**	**2**	**2**	**35**	**1,082**	**4**	**32**	**0**	**2**	**0**	**0**	**23**	**1,568**
P2	07/09/2004	0	0	258	0	0	13	505	34	0	0	3	0	0	1	814
	09/08/2004	0	0	1	0	0	0	7	0	0	0	0	0	0	0	8
	10/14/2004	0	0	0	0	0	0	1	0	0	0	0	0	0	1	2
	05/09/2005	0	0	1	1	0	0	2	0	0	0	0	0	0	0	4
	07/21/2005	0	0	25	0	0	1	36	22	5	0	0	0	0	5	94
	08/10/2005	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
	08/11/2005	0	0	7	0	0	0	408	0	1	0	0	0	0	63	479
	Total	**0**	**0**	**292**	**1**	**0**	**14**	**960**	**56**	**6**	**0**	**3**	**0**	**0**	**70**	**1,402**
P3	07/07/2004	0	0	1	2	0	0	6	0	0	0	0	0	0	0	9
	08/09/2004	0	0	0	0	0	0	15	0	0	0	0	0	0	0	15
	10/12/2004	0	0	1	3	0	0	15	0	0	0	0	0	0	0	19
	07/19/2005	0	0	1	0	0	1	16	0	2	0	0	0	0	3	23
	08/10/2005	0	0	9	0	0	0	240	0	0	0	0	0	0	6	255
	Total	**0**	**0**	**12**	**5**	**0**	**1**	**292**	**0**	**2**	**0**	**0**	**0**	**0**	**9**	**321**

Table 31. Larval fish collected by the Wyoming Game and Fish Department from eight sampling sites on the main-stem Powder River, Wyoming, 2004–05.—Continued

[CKC, creek chub; CRP, common carp; FHC, flathead chub; PMN, plains minnow; LND, longnose dace; SDS, sand shiner; MTS, mountain sucker; RCS, river carpsucker; SHR, shorthead redhorse; WHS, white sucker; CCF, channel catfish; STC, stonecat; PKF, northern plains killifish]

Site number (fig. 1)	Sample date	Number of fish collected														Total
		CKC	CRP	FHC	FHM	PMN	LND	SDS	MTS	RCS	SHR	WHS	CCF	STC	PKF	
P4	07/13/2004	0	0	0	6	0	2	18	0	0	0	0	0	0	0	26
	05/03/2005	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
	08/19/2005	0	0	6	0	0	0	227	0	0	0	0	0	0	3	236
	Total	**0**	**0**	**7**	**6**	**0**	**2**	**245**	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**263**
P5	07/13/2004	0	0	1	0	0	0	16	0	0	0	0	0	0	3	20
	07/23/2004	0	0	36	0	21	0	17	0	0	0	0	0	0	0	74
	08/02/2004	0	2	4	17	0	0	282	0	14	0	0	0	0	3	322
	09/08/2004	0	0	10	1	94	0	66	0	0	0	0	0	0	0	171
	09/09/2004	0	0	10	1	250	0	62	0	0	0	0	0	0	0	323
	10/11/2004	1	0	2	2	0	4	111	0	0	0	0	0	0	2	122
	07/13/2005	0	0	71	6	0	1	5	0	2	0	0	0	0	0	85
	07/23/2005	0	0	53		11	5	2	0	11	0	0	0	0	0	82
	08/24/2005	0	0	0	1	1	0	55	0	0	0	0	0	0	0	57
	Total	**1**	**2**	**187**	**28**	**377**	**10**	**616**	**0**	**27**	**0**	**0**	**0**	**0**	**8**	**1,256**
P8	06/04/2004	0	0	0	0	31	0	44	0	0	0	0	0	0	0	75
	06/08/2004	0	0	0	0	1	0	66	0	0	0	0	0	0	0	67
	07/06/2004	0	0	0	3	0	0	0	0	0	0	0	0	0	0	3
	08/04/2004	0	0	2	0	3	0	19	0	0	0	0	0	0	0	24
	08/31/2004	0	0	0	0	44	0	9	0	0	0	0	0	0	0	53
	10/05/2004	0	0	2	2	25	0	105	0	0	0	0	0	0	0	134
	05/02/2005	0	0	0	0	10	0	2	0	0	0	0	0	0	0	12
	08/18/2005	0	0	99	1	33	17	21	0	0	0	0	0	0	0	172
	Total	**0**	**0**	**103**	**6**	**147**	**17**	**266**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**540**

Table 31. Larval fish collected by the Wyoming Game and Fish Department from eight sampling sites on the main-stem Powder River, Wyoming, 2004–05.—Continued

[CKC, creek chub; CRP, common carp; FHC, flathead chub; PMN, plains minnow; LND, longnose dace; SDS, sand shiner; MTS, mountain sucker; RCS, river carpsucker; SHR, shorthead redhorse; WHS, white sucker; CCF, channel catfish; STC, stonecat; PKF, northern plains killifish]

Site number (fig. 1)	Sample date	Number of fish collected													Total
		CKC	CRP	FHC	FHM	PMN	LND	SDS	MTS	RCS	SHR	WHS	CCF	STC	PKF	
P9	06/09/2004	0	0	1	0	0	0	21	0	0	0	0	0	0	0	22
	07/07/2004	0	0	0	0	0	0	15	0	0	0	0	0	0	0	15
	08/05/2004	1		9	0	51	0	80	0	0	0	0	1	0	0	142
	08/08/2004	0	0	0	0	52	0	50	0	0	0	0	0	0	0	102
	08/31/2004	0	0	0	0	88	0	20	0	0	1	0	0	0	0	109
	10/04/2004	0	0	3	1	114	0	86	0	0	0	0	0	0	1	205
	07/24/2005	0	0	17	9	37	0	51	0	6	0	0	2	0	0	122
	08/17/2005	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
	Total	**1**	**0**	**30**	**10**	**342**	**0**	**324**	**0**	**6**	**1**	**0**	**3**	**0**	**1**	**718**
P11	06/10/2004	0	0	0	0	22	0	13	0	0	0	0	0	0	0	35
	07/08/2004	0	0	26	0	1	0	34	0	0	0	0	0	0	0	61
	08/06/2004	0	0	52	1	65	0	168	0	0	0	0	0	1	0	287
	09/01/2004	0	0	0	0	96	0	24	0	0	0	0	0	0	0	120
	10/01/2004	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
	10/06/2004	0	0	1	0	92	0	13	0	0	0	0	0	0	0	106
	05/05/2005	0	0	0	0	3	0	0	0	0	0	0	0	0	0	3
	07/25/2005	0	0	25	6	14	0	12	0	5	0	3	0	0	0	65
	08/16/2005	0	0	39	2	5	0	33	0	20	0	0	0	0	1	100
	Total	**0**	**0**	**143**	**9**	**299**	**0**	**297**	**0**	**25**	**0**	**3**	**0**	**1**	**1**	**778**
	Overall	**3**	**2**	**1,159**	**67**	**1,167**	**79**	**4,082**	**60**	**99**	**1**	**8**	**3**	**1**	**115**	**6,846**

Publishing support provided by:
Helena Publishing Service Center

For more information concerning this publication, contact:
Director, Wyoming Water Science Center
U.S. Geological Survey
2617 East Lincolnway Avenue, Suite B
Cheyenne, Wyoming 82001
(307) 778-2931

Or visit the Wyoming Water Science Center Web site at:
http://wy.water.usgs.gov

Back cover photographs:

Little Powder River above Dry Creek, Wyo. (site P15), June 23, 2006. Photograph by Greg Boughton, U.S. Geological Survey.

Powder River below Mitchell Draw, Wyo. (site P5), July 28, 2006. Photograph by Greg Boughton, U.S. Geological Survey.

Hanging Woman Creek below Horse Creek, Wyo. (site T11), June 22, 2005. Photograph by Seth Davidson, U.S. Geological Survey.

Otter Creek Creek at Ashland, Mont. (site T17), June 30, 2005. Photograph by John Tertuliani, U.S. Geological Survey.

Peterson and others—**Ecological Assessment of Streams in the Powder River Structural Basin, Wyo. and Mont., 2005–06**—SIR 2009–5023

ISBN 978-1-4113-2346-9

Printed on recycled paper