CHARACTERISTICS OF FISH ASSEMBLAGES AND RELATED ENVIRONMENTAL VARIABLES FOR STREAMS OF THE UPPER SNAKE RIVER BASIN, IDAHO AND WESTERN WYOMING, 1993–95

By Terry R. Maret

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 97–4087

Boise, Idaho
1997

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Gordon P. Eaton, Director

For additional information write to:

District Chief
U.S. Geological Survey
230 Collins Road
Boise, ID 83702-4520

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Box 25286
Federal Center
Denver, CO 80225

Information regarding the National Water-Quality Assessment (NAWQA) Program is available on the Internet via the World Wide Web. You may connect to the NAWQA home pages using the universal resource locator (URL) at:

http://wwwrvares.er.usgs.gov/nawqa/nawqa_home.html

or

http://wwwidaho.wr.usgs.gov/nawqa/usnk_home.html

FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequence of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

•Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.

•Describe how water quality is changing over time.

•Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

To convert °C (degrees Celsius) to °F (degrees Fahrenheit), use the following equation:

$$°F = (1.8)(°C) + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units:

mL	milliliter
µS/cm	microsiemens per centimeter at 25°C

CHARACTERISTICS OF FISH ASSEMBLAGES AND RELATED ENVIRONMENTAL VARIABLES FOR STREAMS OF THE UPPER SNAKE RIVER BASIN, IDAHO AND WESTERN WYOMING, 1993–95

By Terry R. Maret

Abstract

Fish assemblages and environmental variables were evaluated for 30 first- through seventh-order streams in the upper Snake River Basin, Idaho and western Wyoming. Data were collected as part of the National Water-Quality Assessment Program to characterize aquatic biota and associated habitats in surface water. Sampling sites represented major stream types in the basin—large river, agricultural, and least-disturbed reference streams and springs in forested and (or) rangeland watersheds.

Twenty-four environmental variables representing various spatial scales, from watershed characteristics to instream habitat and physicochemical measures, were used to examine relations with fish assemblages. Twenty-six fish species in the families Catostomidae, Centrarchidae, Cottidae, Cyprinidae, Ictaluridae, Percidae, and Salmonidae were collected. Detrended correspondence analysis and canonical correspondence analysis differentiated fish assemblages on the basis of site type and showed that fish assemblages were most strongly correlated with percent agricultural and forest land uses, stream width, watershed size, and elevation. Fish assemblages did not correspond to the four major ecoregions in the basin. Comparisons between multiple-year and multiple-reach collections using Jaccard's coefficient of community similarity index generally indicated little difference in fish assemblages. Percent substrate fines, percent embeddedness, and specific conductance typically were higher for streams influenced by agricultural land use than for reference streams in forested and (or) rangeland watersheds. The number of native species, percent introduced species, percent omnivores, percent common carp, percent salmonids, and percent coldwater-adapted species varied according to site type. Percent omnivores and percent common carp were higher for large river and agricultural sites than for reference stream and spring sites. The introduction of intolerant salmonid species throughout the basin confounds the use of introduced species as a measure of environmental disturbance.

Analysis of fish metrics identified some large river and agricultural sites in the lower part of the basin that did not support viable coldwater fish assemblages. These sites characteristically were dominated by tolerant, warmwater-adapted species. The findings of this study support the water-quality-limited designation for the middle reach of the Snake River between Milner Dam and King Hill and provide a framework for developing indices of biotic integrity by using fish assemblages to evaluate water quality of streams in the upper Snake River Basin.

INTRODUCTION

The upper Snake River Basin (USNK) in eastern Idaho and western Wyoming was 1 of 20 National

Water-Quality Assessment (NAWQA) study units to begin full implementation in 1991 (Leahy and others, 1990). The surface-water component of the NAWQA Program included the collection of biological information to aid in the interpretation and assessment of changes in stream quality (Gurtz, 1994). This biological information consisted of ecological surveys that characterized fish, macroinvertebrates, algae, and associated riparian and instream habitats. One important aspect of this program addresses the relation of physical and chemical characteristics of streams and associated fish assemblages. The analyses of these relations in this report are part of the multiple lines of evidence the NAWQA Program uses to assess stream quality in the USNK.

Human activities can alter physical, chemical, or biological conditions of surface water. Many rivers and streams in the conterminous United States have been degraded as a result of nonpoint source pollutants, fragmentation by dams and diversions, habitat alteration, and introduction of non-native fish species (Moyle, 1986; Heede and Rinne, 1990; Allan and Flecker, 1993; Doppelt and others, 1993; Dynesius and Nilsson, 1994). Human alterations of physical, chemical, or biological conditions in lotic systems usually result in changes in the distribution and structure of fish assemblages. In fact, many endemic fish species of the Western United States are endangered, threatened, or of special concern as a result of human activities (Warren and Burr, 1994).

Fish assemblages, which are groups of species that co-occur in the same area, are structured by local, regional, and historical processes operating at various spatial and temporal scales (Tonn, 1990). The habitat structure of a stream is determined by climate, geology, vegetation, and other features of the surrounding watershed (Frissell and others, 1986), and stream classification schemes have been developed that are based on measures of stream morphology (Rosgen, 1994). Fish assemblages are most directly influenced by local physical and chemical characteristics of the stream habitat. The depauperate fish faunas of the Western United States have been attributed, in part, to natural geological barriers like waterfalls and mountain ranges (Smith, 1981). Thus, comparisons in fish assemblages in different ecoregions having similar land surface form, potential natural vegetation, land use, and soils (Omernik and Gallant, 1986) within a geographic region can enhance understanding of the relative importance of environmental factors influencing the distribution of stream fish (Jackson and Harvey, 1989). Comparisons of historical and recent fish distributions also can provide information on whether changes in occurrence patterns of various species are the result of human activities or natural processes.

Many ecologists have used multivariate analyses to identify and interpret patterns in assemblage structure as they relate to environmental conditions (Gauch, 1982). These multivariate analyses summarize patterns of association within a species-by-sample data matrix for purposes of classification. Ordination frequently is used to summarize patterns within this matrix by defining a series of axes that express the major environmental gradients in assemblage structure. Multivariate analyses are effective for identifying similarities among sites with respect to various physical, chemical, and biological characteristics and for depicting relations between assemblage patterns and environmental gradients. Hypotheses can be formulated from these exploratory analyses about relations between fish assemblages and environmental variables.

Documenting spatial and temporal changes in fish assemblages among streams can provide important information on stream quality and the biotic integrity of freshwater ecosystems. Karr and Dudley (1981) defined biotic integrity as the ability to support and maintain "a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region." Because aquatic assemblages integrate the characteristics of their environment, they provide useful measures for evaluating the effects of human activities in a river basin (Karr, 1991). However, before the effects of human alterations to streams can be evaluated, biological criteria are required for least-disturbed, or "reference," streams or are formulated from historical data (Hughes and others, 1986).

Information about the kinds of species and their relative abundances provides a direct measure of beneficial uses of surface water for coldwater aquatic life and salmonid spawning, helps detect problems that other monitoring methods may miss or underestimate, and provides the basis for systematically measuring the progress of pollution abatement programs (U.S. Environmental Protection Agency, 1990). One approach to evaluating biotic integrity is the index of biotic integrity (IBI), which is a multimetric rating based on structure, composition, and functional attributes of a fish assemblage (Karr and others, 1986). This index is dependent on regional reference information to score individual fish metrics, and different assemblages associated with specific regions may require different metrics for evaluating biotic integrity (Miller and others, 1988). The IBI has been modified successfully for use in many different types of streams throughout North America (Simon and Lyons, 1995). However, more data are needed on the response of entire fish assemblages in coldwater streams to environmental change (Lyons and others, 1996).

A number of independent studies have documented correlations between biological and environmental variables and ecoregions (Hughes and Larsen, 1988; Hughes and others, 1994). Consequently, many State-level monitoring programs have been relatively successful in using an IBI and ecoregion approach to implement aquatic biological assessment programs (Fausch and others, 1984; Gallant and others, 1989). Specific instream biological monitoring protocols for fish have been developed for wadable streams of the Pacific Northwest (Hayslip, 1993). Fisher (1989) developed a modified fish IBI for small headwater streams of northern Idaho and found index scores significantly correlated with timber harvest, road density, and cobble embeddedness.

Few studies have examined relations between entire fish assemblages and measured environmental factors for the major environmental settings of the USNK. Distribution and abundance information also is needed on endemic fish species in spring habitats because most of the large springs in the basin have been altered for aquaculture or irrigation purposes. Information is lacking on nongame species distributions throughout the basin. This study provides data with which to characterize fish assemblages in medium to large rivers (third- through seventh-order streams) and springs in the basin, describes relations between fish assemblages and environmental variables, and identifies attributes of the fish assemblages. Results of this study will provide information needed to develop indices to evaluate biotic integrity using fish assemblages. Ultimately, water resource managers can use these indices as tools to evaluate the status of the beneficial uses of water for aquatic life.

Purpose and Scope

Purposes of this report are to (1) describe fish assemblages and their spatial patterns within the USNK; (2) identify and characterize some of the predominant environmental variables that affect fish assemblages; and (3) identify attributes, or metrics, of fish assemblages, which will be useful in evaluating the biotic integrity of the basin. This report will provide a framework for using fish assemblages to develop an IBI for streams in the USNK.

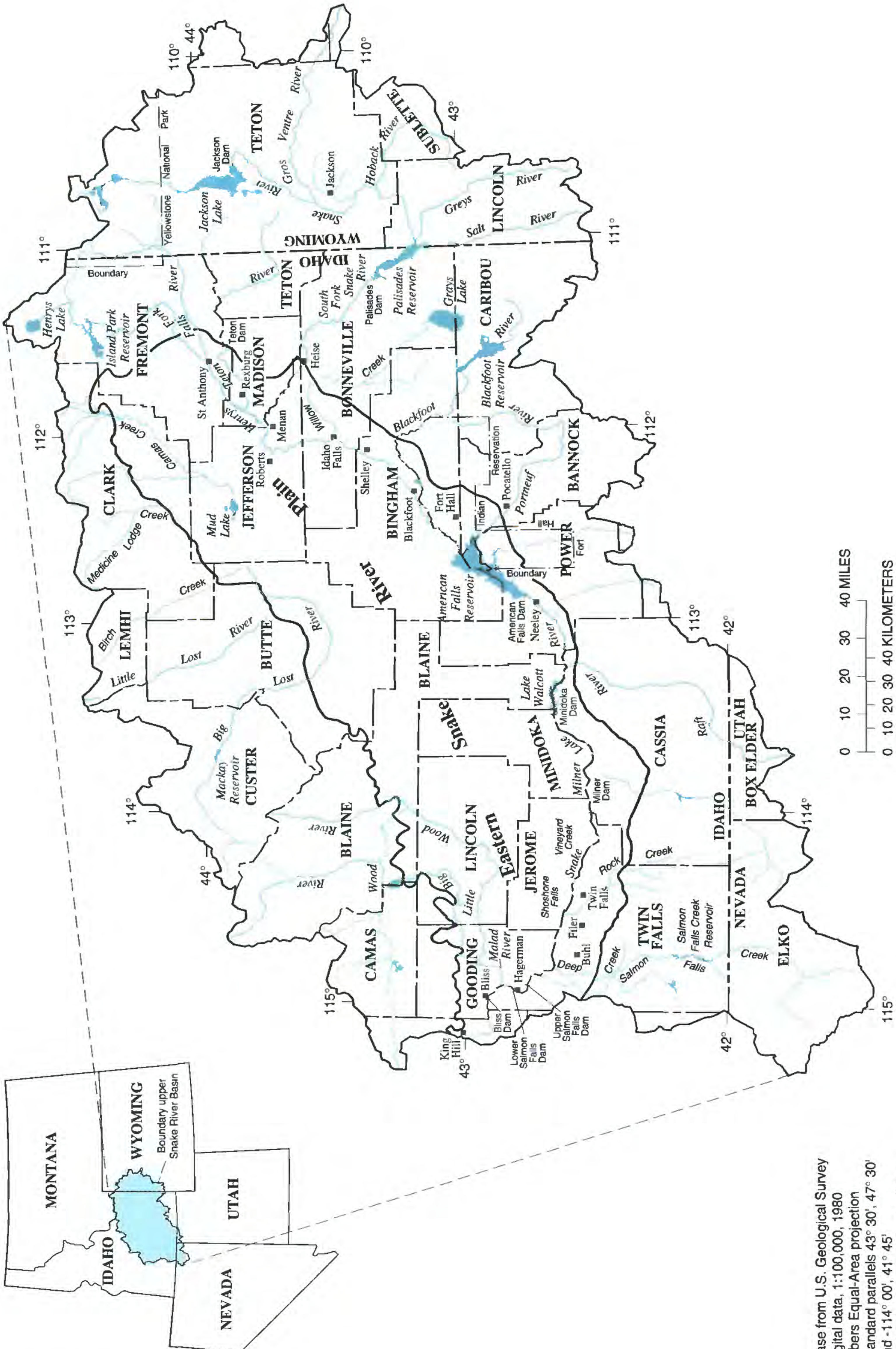
This report summarizes the results of fish collections and measures of associated stream habitats in major environmental settings in the USNK during 1993–95. Major site types sampled included medium to large rivers, streams in agricultural watersheds, and reference streams and springs. Selected sites and reaches were sampled multiple times to characterize temporal and spatial variability of fish assemblages within a stream segment.

Previous Studies

Fish assemblages in the Snake River have been investigated since the late 1800's. Gilbert and Evermann (1895) and Evermann (1896) described fish distribution in the middle reach of the Snake River (between Milner Dam and King Hill, fig. 1) and tributaries before hydroelectric-power development. Anadromous chinook salmon (*Oncorhynchus tshawytscha*) and Pacific lamprey (*Lampetra tridentata*) have been eliminated from the basin downstream from Shoshone Falls since the construction of hydroelectric-power facilities on the main-stem Snake River.

The Wyoming Game and Fish Department (WGFD) and Idaho Department of Fish and Game (IDFG) have done most of the fishery studies to assess sportfishery populations and associated habitats. Simpson and Wallace (1982) and Thurow and others (1988) described fish species distributions in the USNK. Maret (1995) summarized in detail the fish species in the basin and land uses affecting their habitat.

Fish species in the USNK are adapted for predominantly coldwater habitats and are represented by the families Salmonidae (trout), Cottidae (sculpins), Cyprinidae (minnows), and Catostomidae (suckers). Currently (1995), the fish fauna in this basin are represented by 26 native species belonging to 5 families and an additional 13 species introduced primarily to enhance the sportfishery (Maret, 1995). The Idaho Division of Environmental Quality (IDEQ; formerly the Idaho Department of Health and Welfare, Division of Environmental Quality) has published protocols for the use of fish information to assess Idaho streams



Base from U.S. Geological Survey digital data, 1:100,000, 1980
Albers Equal-Area projection
Standard parallels 43° 30', 47° 30' and -114° 00', 41° 45'
No false easting or false northing

Figure 1. Location of the upper Snake River Basin.

(Chandler and others, 1993). Their report also summarizes species origin, tolerance to pollution, and trophic group.

Fish assemblages in headwater first- and second-order streams in the basin typically comprise few species and low abundances (Robinson and Minshall, 1994; Maret and others, 1997). Trout and (or) sculpins typically make up entire collections from many of the streams sampled. These investigators also noted a shift from an intolerant assemblage composed predominantly of coldwater species such as trout to a more tolerant warmwater assemblage in streams affected by human disturbances.

Maret (1995) grouped five discrete drainages on the basis of cluster analysis of fish species presence or absence: (1) The upper Snake River and South Fork Snake River upstream from Shoshone Falls contained a high-quality cutthroat trout fishery; (2) Henrys Fork, Teton River, Salt River, Portneuf River, Blackfoot River, and Willow Creek upstream from Shoshone Falls contained a cutthroat trout fishery with introduced species; (3) Snake River tributaries downstream from Shoshone Falls, including Rock Creek and Big Wood River, contained a trout fishery dominated by introduced trout species consisting primarily of brown and rainbow trout; (4) Big Lost and Little Lost Rivers contained a trout fishery with few native species; and (5) part of a large river fishery in the Snake River between Shoshone Falls and King Hill contained a large number of species, many of which were introduced and adapted to warmwater habitats.

Six native fish species currently are listed as Species of Special Concern by IDFG: the white sturgeon (*Acipenser transmontanus*), Shoshone sculpin (*Cottus greenei*), Wood River sculpin (*Cottus leiopomus*), bull trout (*Salvelinus confluentus*), cutthroat trout (*Oncorhynchus clarki* sp.), and leatherside chub (*Gila copei*). These species and the redband trout (*Oncorhynchus mykiss gibbsi*) are candidates for threatened and endangered listing by the U.S. Fish and Wildlife Service (Idaho Conservation Data Center, 1994). The WGFD has listed four species as Species of Special Concern in the Wyoming part of the basin: cutthroat trout, leatherside chub, bluehead sucker (*Catostomus discobolus*), and hornyhead chub (*Nocomis biguttatus*) (Robin Jones, Wyoming Natural Diversity Database, written commun., 1992). A more complete discussion of the distribution and habitat needs of these Species of Special Concern is given in a report by Maret (1995).

Acknowledgments

Numerous individuals assisted in collecting and processing data during the course of the study, including Michael A. Beckwith, Gregory M. Clark, Steven L. Goodbred, Stephanie J. Eisenbarth, William H. Mullins, Douglas S. Ott, Michael G. Rupert, Terry M. Short, Kenneth D. Skinner, Marc A. Sylvester, Ian R. Waite, and Catherine A. Wolf, all from the U.S. Geological Survey (USGS). Molly A. Maupin (USGS) provided valuable assistance with summarizing the geographic information system (GIS) data. John C. Kingston and Harry V. Leland (USGS) provided useful insights on multivariate analyses and interpretation. Carl E. Bond, Oregon State University, was helpful in verifying sculpin species. Marc S. Gamblin, Fred E. Partridge, Richard Scully, and Charles D. Warren (IDFG), provided valuable advice and field assistance. John W. Kiefling (WGFD) also provided valuable assistance with the collection of field data. Colleague reviews by Robert M. Goldstein, Walton H. Low, Terry M. Short, and Joseph M. Spinazola (USGS) greatly improved the quality of the manuscript.

ENVIRONMENTAL SETTING

The 35,800-mi^2 USNK extends about 450 river miles from its headwaters in southern Yellowstone National Park to King Hill in south-central Idaho (fig. 1). Land surface elevation above sea level ranges from 13,770 ft for mountain peaks in the headwaters of the Snake River to 2,500 ft at King Hill. Most streams in the basin originate in foothill or montane regions (6,000 to 10,000 ft in elevation). Maupin (1995) provided a detailed discussion of the geology, climate, hydrology, and land use in the basin.

The geology of the basin is characterized largely by basalt flows in the lowlands of the central and southern parts and by intrusive volcanic, sedimentary, and metamorphic rocks in the uplands and mountains to the north, south, and east (Maupin, 1995). Basalt flows in the northern part of the basin prevent northern streams such as the Big Lost and Little Lost Rivers and Medicine Lodge Creek from reaching the Snake River.

Climate in most of the basin is semiarid and annual precipitation ranges from 10 to 20 inches. At higher elevations in the eastern part of the basin, annual precipitation can average more than 20 inches. Precipitation occurs primarily as snow, and peak flows in streams result from spring snowmelt.

The basin contains about 8,460 mi of streams (Maret, 1995). Streamflow in the Snake River and its major tributaries is highly regulated by dams and diversions, primarily for agricultural use and hydroelectric-power generation. Irrigation projects have resulted in about 5,700 mi of canals and about 1,300 mi of drains in the basin (U.S. Water and Power Resources Service, 1981), and water transfer from one river basin to irrigate crops in another is common practice. Ecological consequences of interbasin transfer of water include changes in streamflow, introduction of exotic species, and alteration of habitat (Meador, 1992).

Clark (1994) described in detail the characteristics of surface-water quality and hydrology of the basin. Thurow and others (1988) reported that surface water is generally high in alkalinity (greater than 150 mg/L as $CaCO_3$), contains large concentrations of various ions, and generally supports productive aquatic assemblages. Upland streams in forested watersheds and lowland streams in rangeland watersheds are typified by coarse substrates (gravel and cobbles), high gradients (greater than 1.0 percent), well-defined riffle-pool habitats, and sparse macrophyte growth. Springs are typified by a wide variety of substrates (sand to large basalt boulders), low gradients (1.0 percent or less), and abundant macrophyte growth. Large rivers and streams in agricultural watersheds are typified by fine-grained substrates, low gradients, and abundant macrophyte growth.

Water years 1988–92 were extremely dry years in the USNK, and streamflows were smaller than historical averages throughout the basin. Streamflows were variable during water years 1993–95 and continued to be smaller than historical averages in many parts of the USNK; however, some streamflows actually exceeded historical averages during water years 1993 and 1995. Streamflows at most gaging stations on the main stem of the Snake River were smaller than average during the sampling period, 1993–95 (G.M. Clark, U.S. Geological Survey, written commun., 1996).

Springs along the Snake River between Milner Dam and King Hill provide more than 50 percent of the discharge measured at King Hill on the Snake River. Many of the springs along the Snake River between Twin Falls and Hagerman are used for commercial trout production. More than 80 percent of the Nation's trout supply is produced in this area (Brockway and Robinson, 1992).

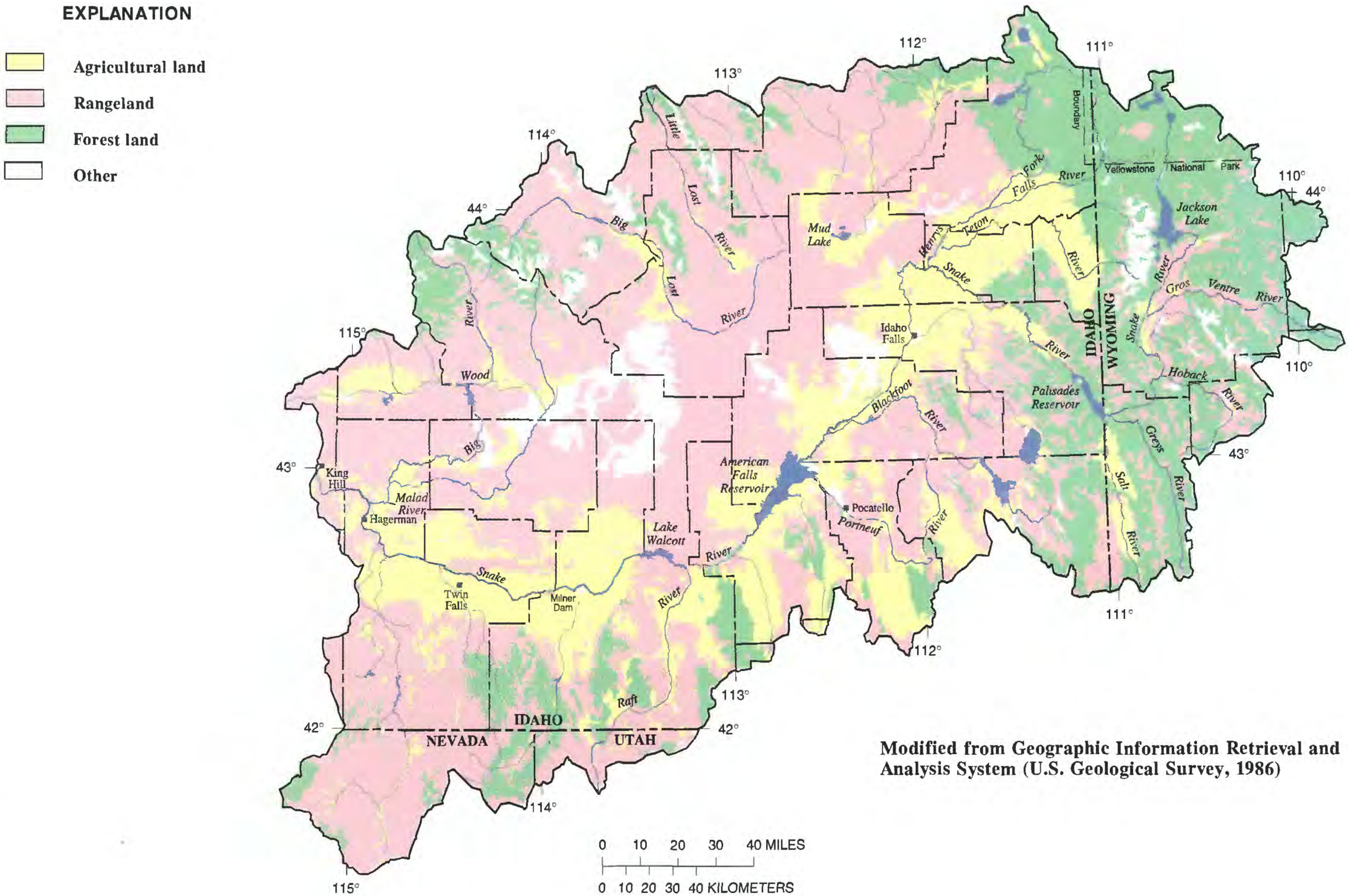
Shoshone Falls, a large waterfall on the Snake River near the city of Twin Falls, prevents migration of fish upstream. Native species living only in the Snake River and its tributaries downstream from the falls include the bridgelip sucker (*Catostomus columbianus*), largescale sucker (*Catostomus macrocheilus*), chiselmouth (*Acrocheilus alutaceus*), leopard dace (*Rhinichthys falcatus*), northern squawfish (*Ptychocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), white sturgeon, Wood River sculpin, and Shoshone sculpin (Maret, 1995).

Designated beneficial uses of streams in the basin are agriculture, industry, public water supply, recreation, and propagation of fish and wildlife, and criteria have been developed in State water-quality standards to protect these beneficial uses from impairment (Idaho Department of Health and Welfare, 1989). In addition, coldwater aquatic life is a designated use for most streams in the basin, and these streams are suitable for protection and maintenance of viable assemblages of aquatic organisms whose optimal growing temperature is below 18°C (Idaho Department of Health and Welfare, 1990).

Nonpoint source pollution and water diversions are the predominant influences on surface-water quality in the basin. Pollutants of greatest concern that have been associated with habitat degradation of streams include nutrients, sediment, bacteria, organic waste, and elevated water temperature (Idaho Department of Health and Welfare, 1989). Beneficial uses of streams most impaired by pollutants include sustaining coldwater biota, salmonid spawning, and water-contact recreation (Maret, 1995).

Water quality of the middle reach of the Snake River is affected by irrigation drainage, fish-farm effluent, municipal effluent, hydrologic modification, and dams (Brockway and Robinson, 1992). As a result of these activities, segments of this river were listed as "water-quality limited" in 1990 because nuisance weed growth had exceeded water-quality criteria and standards established for protection of coldwater biota and salmonid spawning (Idaho Department of Health and Welfare, 1995).

Land use in the basin (fig. 2) comprises 50 percent rangeland, 23 percent forest land, and 21 percent agricultural land; the remaining area, classified in this study as "other," comprises barren soil or rock with little vegetation, urban areas, water bodies, wetlands, and tundra (Maupin, 1995). Most agricultural lands are adjacent to the Snake River because of irrigation needs.



Modified from Geographic Information Retrieval and Analysis System (U.S. Geological Survey, 1986)

Figure 2. Major land uses in the upper Snake River Basin.

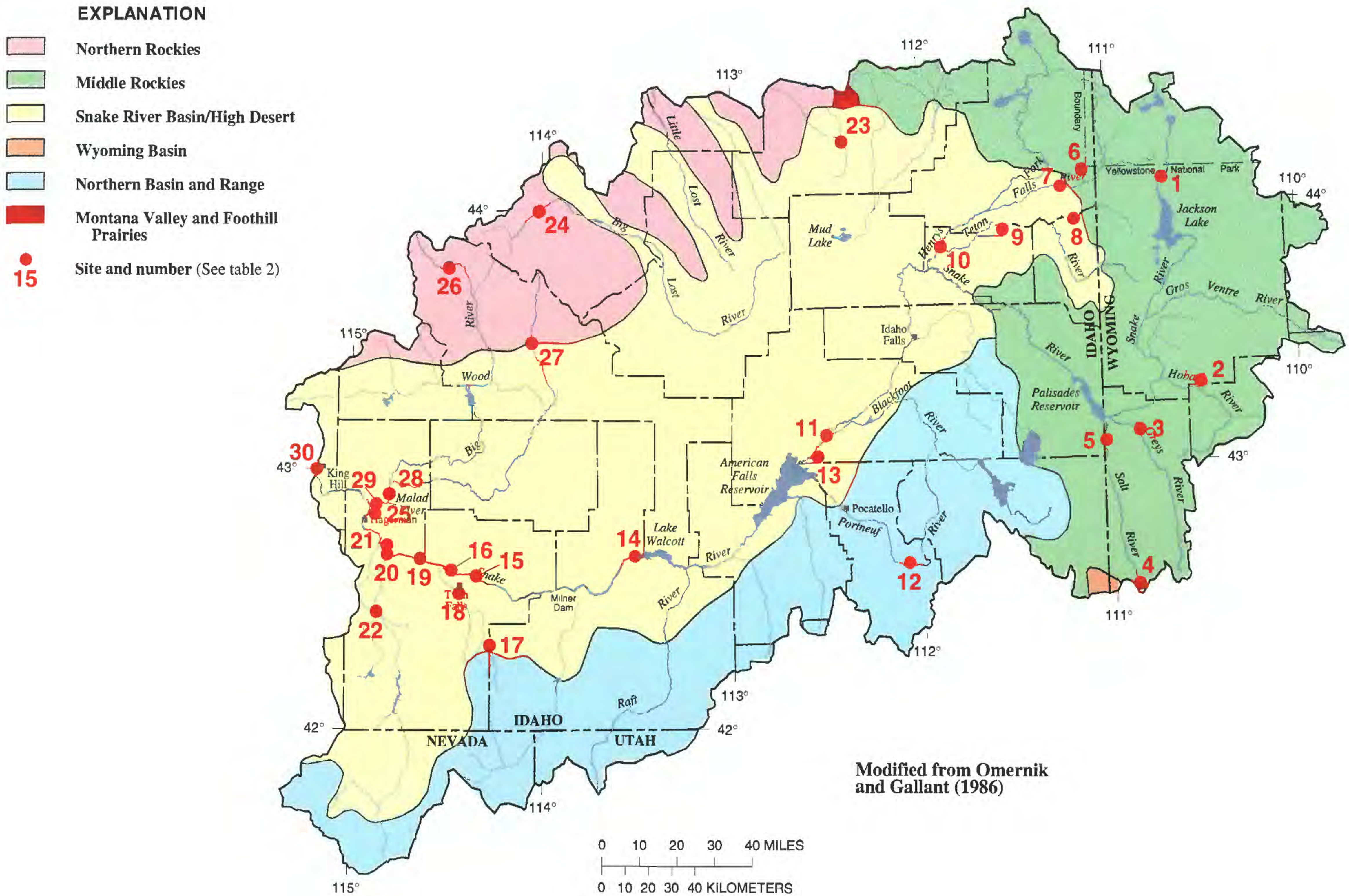


Figure 3. Ecoregions and site locations in the upper Snake River Basin.

Livestock grazing is common throughout the basin. Logging, mining, and recreation also are predominant land uses. Population in the basin is 435,000. The largest cities are Idaho Falls, Pocatello, and Twin Falls.

Four ecoregions compose more than 99 percent of the land area in the basin: Snake River Basin/High Desert, 50 percent; Middle Rockies, 23 percent; Northern Basin and Range, 18 percent; and Northern Rockies, 9 percent (fig. 3). The Wyoming Basin and Montana Valley and Foothill Prairies ecoregions compose less than 1 percent of the land area in the basin. Landscape characteristics of the major ecoregions are listed in table 1. Vegetation in the upper elevations consists of coniferous forests, whereas sagebrush (*Artemisia* sp.) communities dominate the lowlands. Typical woody vegetation in riparian areas consists of river birch (*Betula occidentalis*), alder (*Alnus* sp.), dogwood (*Cornus stolinifera*), willow (*Salix* sp.), and poplar (*Populus* sp.).

DATA COLLECTION METHODS

Thirty stream sites were selected for sampling (fig. 3, table 2) by spatially stratifying the basin by ecoregion, land use, and site type. Five sites represented large rivers and included nonwadable tributaries of the Snake River (large river site type); 5 sites represented streams characterized by a direct association with irrigated agriculture, row crop production, and livestock grazing (agricultural site type); and 20 sites represented reference streams and springs. Fourteen of these 20 sites were streams located primarily in forested and (or) rangeland watersheds (reference stream site type), and 6 were springs located in rangeland watersheds (reference spring site type). Photographs (figs. A–H) showing each of these site types are included at the back of this report. All the large river and agricultural sites had some form of water regulation (diversions or dams) upstream. Only 4 of the 20 reference sites had any form of water regulation upstream.

Fish sampling and habitat surveys were conducted during base-flow conditions in summer and autumn 1993 through 1995. All springs were sampled during spring and early summer of 1994. Selected streams were third- through seventh-order and springs were considered first order (Strahler, 1957).

Six sites were selected to evaluate year-to-year variability in fish assemblages for various site types and environmental settings. These included Snake River at Flagg Ranch (site 1), Salt River near Etna (site 5), Portneuf River at Topaz (site 12), Rock Creek at Twin Falls (site 18), Big Lost River near Chilly (site 24), and Snake River at King Hill (site 30) (table A, back of report). Multiple reaches also were sampled at Rock Creek at

Table 1. Characteristics of major ecoregions in the upper Snake River Basin

[Modified from Omernik and Gallant (1986)]

Ecoregion	Percentage of surface area	Land surface form	Potential natural vegetation	Land use	Soils
Snake River Basin/ High Desert	50	Tablelands with moderate to high relief; plains with hills or low mountains.	Sagebrush steppe (sagebrush, wheatgrass, saltbush, and greasewood).	Desert shrubland grazed; some irrigated. agriculture.	Aridisols, aridic Mollisols
Middle Rockies	23	High mountains.	Douglas-fir, western spruce and fir, alpine meadows (bentgrass, sedge, fescue, and bluegrass).	Grazed and ungrazed forest and woodland.	Alfisols.
Northern Basin and Range	18	Plains with low to high mountains; open high mountains.	Great Basin sagebrush, saltbush, and greasewood.	Desert shrubland grazed.	Aridisols.
Northern Rockies	9	High mountains.	Cedar, hemlock, pine, western spruce, fir, grand fir, and Douglas-fir.	Forest and woodland mostly ungrazed.	Inceptisols; Eastern interior mountain soils with acidic rock types.

Table 2. Watershed and site characteristics, upper Snake River Basin

[Site No., locations shown in figure 3. No., number; latitude and longitude, in degrees, minutes, and seconds. Site type: R, reference; A, agricultural; S, spring; LR, large river. Regulated, structures such as dams and diversions upstream from gaging station that alter natural river discharge and (or) obstruct fish movement. Ecoregions: MR, Middle Rockies; SRB, Snake River Basin/High Desert; NBR, Northern Basin and Range; NR, Northern Rockies. <, less than]

Site No.	Gaging-station name	Gaging-station No.	Latitude	Longitude	Site type	Regulated (yes or no)	Stream order	Ecoregion(s)	Elevation (feet)	Watershed size (square miles)	Percentage of watershed: Agricultural land	Percentage of watershed: Rangeland	Percentage of watershed: Forest land	Percentage of watershed: Other	Sinuosity	Stream gradient (percent)
1	Snake River at Flagg Ranch	13010065	440521	1104138	R	N	4	MR	6,802	511		4	89	7	1.27	0.16
2	Little Granite Creek near Bondurant	13019438	431756	1103133	R	N	3	MR	6,390	23		34	62	4	1.24	6.70
3	Greys River near Alpine	13022970	430708	1105124	R	N	4	MR	6,092	344		17	82	1	1.09	.51
4	Salt River near Smoot	13023700	423132	1105258	R	N	3	MR	7,040	20		30	70		1.40	8.30
5	Salt River near Etna	13027500	430447	1110212	A	Y	5	MR	5,676	852	18	29	52	1	1.59	.21
6	Robinson Creek near Warm River	13044550	440741	1111025	R	N	3	MR	5,955	41			100		1.49	1.97
7	Falls River near Squirrel	13047500	440407	1111425	R	N	4	MR	5,590	309		6	92	2	1.13	1.58
8	Bitch Creek near Lamont	13054300	435623	1111024	R	N	3	MR	5,820	83	7	6	81	6	1.19	1.04
9	Teton River near St. Anthony	13055000	435538	1113655	A	Y	5	SRB/MR	4,972	886	42	12	40	6	1.32	.15
10	Henrys Fork near Rexburg	13056500	434934	1115415	LR	Y	6	SRB/MR	4,807	3,218	27	17	52	4	1.90	.02
11	Snake River near Blackfoot	13069500	430731	1123106	LR	Y	7	SRB	4,401	12,184	20	28	47	5	1.44	.07
12	Portneuf River at Topaz	13073000	423730	1120520	A	Y	5	NBR	4,918	588	35	54	10	1	1.62	.35
13	Spring Creek near Fort Hall	13075983	430236	1123315	R	N	3	SRB	4,377	4	14	86			1.26	.09
14	Snake River near Minidoka	13081500	424023	1132958	LR	Y	7	SRB	4,132	18,853	23	38	34	5	1.26	.01
15	Devils Washbowl Spring near Kimberly	13089500	423523	1142046	S	N	1	SRB	3,666	<1		100			1.00	.10

Table 2. Watershed and site characteristics, upper Snake River Basin—Continued

Site No.	Gaging-station name	Gaging-station No.	Latitude	Longitude	Site type	Regulated (yes or no)	Stream order	Ecoregion(s)	Elevation (feet)	Watershed size (square miles)	Percentage of watershed: Agricultural land	Rangeland	Forest land	Other	Sinuosity	Stream gradient (percent)
16	Blue Lakes Spring near Twin Falls	13091000	423653	1142806	S	Y	1	SRB	3,300	<1		100			1.00	0.10
17	Rock Creek near Rock Creek	13091995	421929	1141620	R	N	4	NBR	4,700	52		27	73		1.48	1.87
18	Rock Creek at Twin Falls	13092747	423347	1142942	A	Y	5	SRB/NBR	3,625	241	24	52	24		1.36	.92
19	Snake River near Buhl	13094000	423958	1144241	LR	Y	7	SRB	2,952	29,384	22	46	26	6	1.08	.07
20	Briggs Spring near Buhl	13095175	424026	1144830	S	N	1	SRB	3,005	<1		100			1.00	.10
21	Box Canyon Springs near Wendell	13095500	424229	1144835	S	Y	1	SRB	3,020	<1		100			1.00	.50
22	Salmon Falls Creek at Lily Grade Crossing	13107200	422709	1145144	R	Y	6	SRB	3,232	1,855	4	86	10		1.20	.55
23	Medicine Lodge Creek near Small	13116500	441522	1122412	R	N	4	SRB/NR	5,440	263	1	83	14	2	1.16	.94
24	Big Lost River near Chilly	13120500	435954	1140112	R	N	5	NR	6,622	440		53	29	18	1.25	.57
25	Florence Spring near Hagerman	13134700	424948	1145227	S	Y	1	SRB	3,108	<1		100			1.00	.10
26	Big Wood River below Boulder Creek	13135350	434647	1142943	R	N	4	NR	6,540	125		13	72	15	1.34	.86
27	Little Wood River above High Five Creek	13147900	432930	1140330	R	N	5	NR	5,320	249	3	72	18	7	1.13	.63
28	Malad River near Gooding	13152500	425312	1144808	A	Y	5	SRB/NR	3,345	3,323	15	66	12	7	1.35	1.64
29	Cove Creek Spring at outlet	13152900	425201	1145206	S	N	1	SRB	3,038	<1		100			1.00	.1
30	Snake River at King Hill	13154500	430008	1151206	LR	Y	7	SRB	2,492	35,884	21	51	23	5	1.26	.11

Twin Falls and Big Lost River near Chilly to evaluate reach variability in fish assemblages.

Reference streams and springs were selected using criteria established by Hughes and others (1986). Some of the surveyed streams were identified as candidates for aquatic research natural areas (Rabe and Savage, 1977). Federal and State agency personnel provided guidance in the selection of additional sites. The 14 reference stream sites showed little evidence of human disturbance such as obvious point source pollution, mining, large clearcut areas, adjacent cropland, or excessive livestock grazing.

Representative reaches were selected on the basis of criteria outlined by Meador (1993b). Reach length usually depended on the presence of at least two repeating geomorphic channel units (riffle, run, pool) per site. Reach length at all sites ranged from 187 ft for Blue Lakes Spring near Twin Falls (site 16) to 4,216 ft for the Snake River near Buhl (site 19) (table A, back of report).

Fish Collections

Fish sampling procedures followed methods outlined by Meador and others (1993a). Fish from small wadable streams were collected using backpack electrofishing equipment (Smith-Root model 12 or Coffelt model BP–6). A 10-ft jon boat carrying a Smith-Root model VI–A and a 5,000-watt, 240-volt generator with multiple electrodes was used in larger wadable streams (more than 30 ft in width). For large nonwadable streams, the electrofishing equipment included a drift boat or 16-ft or larger jon boat equipped with bow-mounted electrodes and motor. Electrofishing was completed in an upstream direction, and all habitats were sampled to ensure that a representative sample was collected from each reach. A crew of four to six people generally was used in each collection effort. On occasion, both boat and backpack electrofishing gear were used, and (or) multiple passes were made through the reach to sample all habitats more effectively. Actual electrofishing time was recorded for each site. All collections made at each site were combined into a single total for the site. The collected fish were identified to species level, measured for total length and weight, examined for anomalies, and returned to the stream. Blackspot disease, caused by a parasitic trematode (*Neascus* sp.), was identified on fish at some reference sites and therefore was not included as an anomaly among site comparisons. The occurrence of this fish parasite may be related more to the suitability of a stream for snails, the intermediate host of this parasite, than to habitat degradation (Leonard and Orth, 1986). Hybrids were uncommon; a few rainbow trout (*Oncorhynchus mykiss*) crossed with cutthroat trout (*Oncorhynchus clarki*) were collected only at Spring Creek near Fort Hall (site 13).

State collection permits were obtained from IDFG and WGFD, and species data were provided to these agencies as provisions of these annual permits. Field identifications were made by Terry R. Maret, USGS, Boise, Idaho. Specimens of selected species were retained for reference and verification of field identifications. Taxonomic verifications of sculpins were conducted by Carl E. Bond, Oregon State University, Corvallis. A voucher collection is located in the Orma J. Smith Museum of Natural History, Albertson College, Caldwell, Idaho. Electronic copies of data files containing site-specific data on fish species, abundances, and body measurements can be retrieved from the Internet (see back of inside cover for the World Wide Web address).

Environmental Variables

Twenty-four environmental variables consisting of watershed, hydrologic, and habitat characteristics were evaluated for each site (table 2; table A, back of report). Several sources were used to construct geographic data layers for some characteristics. Watershed size, stream order, and land use were determined using Arc/Info, a GIS. Watershed boundaries were delineated using the hydrography and hydrologic unit boundary data layers (U.S. Geological Survey, 1975) and 1:24,000-scale topographic maps. The hydrography data layer was modified from 1:100,000-scale digital line graph files (U.S. Geological Survey, 1989). Stream segments were defined on the basis of major tributary junctions and (or) major landform features (Meador and others, 1993b) and ranged from about 1 to 7 mi in length. Stream sinuosity and gradient were determined for each stream segment in which a site was located. Stream sinuosity, gradient, and elevation were derived from 1:24,000-scale topographic maps. Land use was modified from 1:250,000-scale digital data (U.S. Geological Survey, 1986) consisting of Anderson levels I and II land use classifications at a 40-acre mapping resolution (Anderson and others, 1976). Land use consisted of agricultural (including pasture land), rangeland, conifer forest, and other. Field observations were used to estimate watershed size, gradient, and land use for all spring sites, due to the small size of their watersheds.

The following physical, hydrologic, and physicochemical habitat characteristics were determined at three to six transects within each stream reach sampled (table A, back of report): reach length, width, depth, width/depth ratio, velocity, discharge, discharge as percent coefficient of variation (CV), specific conductance, water temperature, pH, dissolved oxygen, percent dissolved oxygen saturation, substrate size, percent embeddedness, percent substrate fines, percent cover, and percent open canopy (Platts and others, 1983; Meador and others, 1993b). Width was recorded for the wetted stream width, and depth was measured at the thalweg and two intermediate locations for each transect. Water velocity also was determined at these same transect locations at 0.6 of the depth using a Marsh-McBirney meter.

Instantaneous discharge was measured or taken from USGS gaging-station records for the time of collection. Monthly mean discharge values (discharge CV) were calculated and expressed as a percentage of discharge taken from gaging-station records for periods of record greater than 5 years (Kjelstrom and others, 1995, 1996). In a few instances where continuous discharge data were not available, discharge CV was estimated using the continuous record of discharge from a gaging station in a nearby drainage basin. In the case of springs, a mean of discharge from nearby gaged springs was used. Discharge CV is widely used in fishery studies as an index of hydrologic stability (Osborne and Wiley, 1992; Poff and Allan, 1995).

Specific conductance and water temperature were measured using a calibrated conductivity meter (Orion model 122). A calibrated Orion model 250A pH meter was used to measure pH. Dissolved oxygen and percent dissolved oxygen saturation were measured with a calibrated Orion model 260 dissolved oxygen meter. Substrate size was determined at each transect using methods described by Wolman (1954). Substrate particles were randomly selected from the stream bottom at each step across the transect and their intermediate axis measured. Percent embeddedness at each transect was estimated visually in increments of 25 (0, 25, 50, 75, or 100). Percent substrate fines was defined as those particles less than 0.1 in. in diameter. Cover providing shelter for fish was measured and consisted of natural habitat features such as boulders, woody debris, undercut banks, and aquatic macrophytes, and constructed features such as rip-rap. These habitat features had to be in at least 8 in. of water to be counted as cover. Percent cover was estimated visually within a 6-ft zone on either side of each transect. Percent open canopy for left and right banks at each transect was estimated using a clinometer. A mean value was calculated to represent the multiple measurements made for each habitat characteristic within a reach. Photographs were taken of all reaches and at selected transects across the stream where habitat characteristics were measured.

ANALYTICAL METHODS

General Approach

A variety of analytical methods were used to describe and evaluate fish assemblages and environmental variables. Initially, the characteristics of the fish species collected were described and spatially displayed to evaluate patterns in the data. Fish collected at selected sites during multiple years or among multiple reaches were compared to determine spatial and temporal variability. Patterns were evaluated on the basis of the two *a priori* classification schemes, ecoregions and site types. Multivariate and multimetric analyses then were used to evaluate the fish and environmental data. Multivariate analyses are based on statistical algorithms, whereas multimetric analyses incorporate more descriptive ecological information. As a result of multivariate analyses, selected fish metrics and environmental variables were examined further using regression analysis and boxplots, and medians were statistically tested among site types. These latter analyses helped evaluate specific relations between fish metrics and environmental variables and provided a visual description of variability among site types. Finally, selected fish metrics for the main-stem Snake River and its major tributaries were compared to identify longitudinal changes (from upstream to downstream) in fish assemblages.

Fish Species and Spatial Patterns

The frequency of occurrence of each species was calculated for each of the four site types to compare species assemblages. The range of abundances and number of species were spatially displayed for all sample sites in the basin.

Major faunal shifts in many streams in the Western United States are the result of introduced fish species. Often, introduced fish species are better adapted than native species to thrive in altered habitats (Moyle, 1994). The status of biotic integrity is related to the extent of habitat disturbance and the occurrence of native versus introduced species. The zoogeographic integrity coefficient (ZIC), an index derived from the ratio of the number of native species to the total number of species, was used to evaluate the degree of habitat disturbance, whereby a value of 1 indicated an undisturbed environment and a value of 0 indicated a highly disturbed environment (Elvira, 1995). The range of ZIC values was spatially displayed for each sample site.

Multivariate Analyses

Multivariate analyses are an effective way to examine the distribution patterns of species and assemblages in relation to environmental variables (Gauch, 1982). These analyses were done initially to generate hypotheses about relations between fish assemblages and environmental variables. The use of several types of multivariate analyses was essential to reduce the number of environmental variables and to provide supportive evidence for the initial hypotheses.

Normal probability plots and univariate statistics were obtained using SYSTAT (Wilkinson, 1992) for all environmental variables to evaluate frequency distributions and skewness. Log or square-root transformations of the variables watershed size, gradient, discharge, and percent dissolved oxygen saturation were required to meet the assumption of normality prior to multivariate analyses.

Initially, cluster analysis was used on species presence data to group sites with common species compositions and to identify similarities among sites that may correspond to ecoregions, site type, or other environmental factors. Principal components analysis (PCA) and correlation matrices then were used to identify the environmental variables that distinguished the types of streams and to reduce the environmental variables used in subsequent analyses. Fish assemblage data were evaluated using detrended correspondence analysis (DCA), where the ordination is not constrained by the environmental variables. The final DCA axes 1 and 2 scores and the PCA results were regressed to select a subset of ecologically relevant environmental variables to evaluate with the fish assemblage data using canonical correspondence analysis (CCA). This final multivariate analysis provided a picture of the principal relations between fish assemblages and environmental variables.

The eight environmental variables selected for CCA along with the fish assemblage data were watershed size, percent forest land, elevation, percent agricultural land, percent substrate fines, specific conductance, discharge CV, and velocity. Even though the variability explained by the principal component where discharge CV and velocity were located was low (8 and 12 percent, respectively), both variables can be important in characterizing differences in hydrologic preferences of fish species (Poff and Allan, 1995). Even though PCA identified dissolved oxygen concentration and percent saturation as relevant components, these were dropped from further analysis because saturation was at or near 100 percent in all measurements. Although percent substrate fines and specific conductance were strongly correlated with percent agricultural land, these variables were retained to emphasize the effects of agricultural land use in the basin and to evaluate their direct influence on fish assemblages.

Contrary to Gauch's recommendation (1982), rare species (typically representing less than 5 percent of the samples) were retained in all multivariate analyses. The presence of rare fish species at a particular site often indicated specific habitat conditions and, therefore, provided critical information regarding ecological conditions. For instance, the relatively rare Shoshone sculpin was collected only at spring sites.

Preliminary DCA and CCA analyses were done on fish species presence or absence and absolute, relative, and natural logarithms of fish abundance data. Rahel (1990) suggested examining different levels of numerical resolution when searching for patterns in biological data. Results presented in this report were obtained from the natural logarithms of the abundance data. This transformation provided an intermediate range of abundance values from 0 to 10. According to Gauch (1982), this range allows expression of quantitative and qualitative information with neither dominating the other. All variables used in multivariate analyses were standardized to zero mean and unit variance.

Multiple-year and multiple-reach sites were included as separate samples in the multivariate analyses to illustrate temporal and spatial variability among site types. All pairwise combinations of multiple sites also were summarized using a similarity index and coefficient of variation of species and abundances to describe variability. The Teton River at St. Anthony site was excluded from multivariate analyses of environmental variables because of missing data. A detailed description of each multivariate analysis is presented in the following sections.

CLUSTER ANALYSIS

Cluster analysis was used to assess spatial relations among fish assemblages on the basis of similarities in assemblage composition (Jongman and others, 1995). A cluster analysis was performed using the software program Numerical Taxonomy and Multivariate Analysis System (NTSYS-pc, Rohlf, 1990). First, Jaccard's coefficient of community similarity (JC) index was calculated for each site pair as the proportion of species out of the total list of species common to both sites: $JC = C/(A + B + C)$, where C is the number of species common to both sites, and A and B are the number of species unique to each site. A dendrogram then was constructed from the matrix of JC index values for all site pairs by using the average linkage procedure.

PRINCIPAL COMPONENTS ANALYSIS

PCA was performed using SYSTAT to group and summarize subsets of environmental variables (Wilkinson, 1992). PCA is appropriate for analyzing data that have an underlying linear structure and summarizes the variance-covariance or correlation structure of a data set by identifying major axes or components for variation within the data set. This analysis was used to shorten an otherwise long list of variables containing redundant information. Ruhl (1995) used PCA to describe relations between water-quality variables and fish community structure for basins in Illinois, whereby one or more variables were selected to represent an entire group or component in analyses of relations between fish assemblages and environmental variables.

The degree of association between a variable and a principal component was expressed by a measure called loading. If a group of variables all loaded heavily on a particular principal component, then the variables all expressed similar information about that component. Principal components with eigenvalues greater than 1.0 were retained and rotated by use of the Varimax procedure. Eigenvalues equal the maximum dispersion of the variable scores on the ordination axis and are a measure of importance of the ordination axis (Jongman and others, 1995).

DETRENDED CORRESPONDENCE ANALYSIS

Ordination by DCA arranged sites with similar taxonomic composition in clusters and produced site scores independent of environmental variables. These site scores then were related to each environmental variable by calculating correlation coefficients. DCA was performed using the computer program CANOCO (Ter Braak, 1988).

From the DCA ordination plots, site groups were identified solely on the basis of associated fish species composition. Relations between DCA axes 1 and 2 scores and individual environmental variables were determined using linear regression analyses. These regression results identified which environmental variables were most strongly related to the species assemblage data.

CANONICAL CORRESPONDENCE ANALYSIS

Fish assemblages were related to multiple environmental variables using CCA (Ter Braak, 1986). This analytical technique was used to perform direct gradient analysis, whereby ordination axes were chosen on the basis of fish species and environmental data. CCA was designed to detect patterns of variation in the fish species data that were explained best by the observed environmental variables (Jongman and others, 1995). CCA, which was applied using the computer program CANOCO (Ter Braak, 1988), depicts fish species and sites in an ordination diagram by assuming that fish species exhibited Gaussian-type responses to environmental gradients. In other words, fish species were depicted at various locations along an environmental gradient and exhibited a peak in occurrence at some optimum value along that gradient. In the ordination diagram, environmental gradients were displayed as vectors. Vector direction and length indicated the relative magnitude and influence of a particular variable on fish assemblages. Sites with the most species in common were clustered in the ordination diagram.

CANOCO also provided several diagnostics during an interactive session. One diagnostic was the examination of variable inflation factors that illustrated the degree to which an environmental variable independently contributed to explaining variance in fish species data. Variable inflation factors were examined to determine whether they contributed unique information in the analysis. Inflation factors greater than 20 suggested that a variable was highly correlated with other variables and did not contribute unique information in the regression (Ter Braak, 1988). The eight environmental variables had inflation factors less than 20 and were retained for further analysis. Canonical coefficients, which are analogous to regression coefficients, were examined for significance against the first two axes using a nonparametric t-test. According to Ter Braak (1988), absolute t-values greater than 2.1 generally were considered significant at the 0.05 probability level.

Because previous multivariate analyses helped in the variable selection process, the forward selection process available in CCA was not used. This process has been overused and, often, too many variables are selected to be significant (H.J.B. Birks, University of Bergen, Norway, written commun., 1996).

Environmental Variables and Fish Metrics

Fore and Karr (1996) suggested using simple bivariate graphical displays of variables and sample sites to evaluate response to increasing human disturbance. Accordingly, boxplots were examined initially to evaluate and display differences in environmental variables and fish metrics among large river, agricultural, and reference stream and spring site types. A Kruskal-Wallis test was calculated using SYSTAT (Wilkinson, 1992) to test statistical differences in all variables among site types. This test computed ranks on all data values pooled from all the site types being compared. The ranks were summed for individual populations, and an overall test statistic was computed and compared with tabulated values to determine significant differences among the site types. The level of confidence in each test was determined by selection of an alpha value. Two-sided tests with an alpha value of 0.05 were used for all the comparative tests in this report. If a significant difference was found, then a Tukey's multiple-comparison test was calculated on ranked data to determine significant differences among site types.

Fish metrics were used to compare taxonomically dissimilar communities over large spatial scales (Poff and Allan, 1995) and to provide direct measures of biotic integrity and aquatic life beneficial uses (Karr, 1991). Fourteen fish metrics were determined: number of fish collected, number of fish per minute of electrofishing, number of species, number of native species, percent anomalies, percent introduced species, percent common carp, percent cottids, percent salmonids, percent juvenile salmonids (less than 4 in. in length), percent adult salmonids (greater than 8 in. in length), number of intolerant species, percent omnivores, and percent coldwater adapted (table B, back of report). These fish metrics are based on ecological principles; many have predictable responses to human activities (Karr, 1994). Each species was categorized according to geographic origin (native or introduced); trophic group; and tolerance to sediment, warmwater, and organic pollution (table 3) by using protocols developed by Chandler and others (1993). Water temperature preferences (cold- or warmwater adapted) were assigned using data compiled by IDEQ (Don Zaroban, written commun., 1995).

RESULTS OF FISH SPECIES COLLECTED AND GEOGRAPHIC PATTERNS

A total of 5,295 fish were collected during this study. The number of fish collected from any one site ranged from 11 to 666, and the mean for all sites was 115 (table B, back of report). Twenty-six fish species were collected in the families Catostomidae, Centrarchidae, Cottidae, Cyprinidae, Ictaluridae, Percidae, and Salmonidae (table 3). About 73 percent of the species collected from all sites were native species. The number of species collected from any one site ranged from 2 to 11, and the mean for all sites was 6 (table B, back of report).

The total number of individuals and number of native species collected from all sites are geographically summarized in figure 4. Most collections contained fewer than 200 individuals and comprised fewer than 8 native species. Fewer than 100 individuals and fewer than 5 native species typically were collected from reference stream sites at high elevations in the drainage basins. Maret and others (1997) reported similar findings for small first- to second-order reference streams throughout the USNK. The greatest number of individuals and native species was collected from the Snake River at Flagg Ranch and Snake River at King Hill sites. Although 10 species were collected at King Hill (site 30), this is only about one-half the number of

Table 3. Geographic origin; trophic group; water temperature preference; and tolerance to sediment, warmwater, and organic pollution for fish species collected in the upper Snake River Basin, 1993–95

[Sources of information for origin, trophic group, and tolerance to pollution were reports by Scott and Crossman (1973); Simpson and Wallace (1982); Sigler and Sigler (1987); Chandler and others (1993); and Don Zaroban (Idaho Division of Environmental Quality, written commun., 1995). Common and scientific names were standardized using a report by Robins and others (1991). Gaging-station name and number shown in table 2; locations shown in figure 3]

Family / Common name	Species	Geographic origin	Trophic group of adults	Temperature preference	Tolerance to pollution	Occurrence (site No.)
Catostomidae (suckers)						
Bridgelip sucker	*Catostomus columbianus*	Native	Herbivore	Cold	Tolerant	18, 30
Largescale sucker	*Catostomus macrocheilus*	Native	Omnivore	Warm	Tolerant	18, 19, 21, 28, 30
Mountain sucker	*Catostomus platyrhynchus*	Native	Herbivore	Cold	Intermediate	1, 12, 17, 22
Utah sucker	*Catostomus ardens*	Native	Omnivore	Warm	Tolerant	1, 5, 10, 11, 12, 13, 14, 15
Centrarchidae (sunfishes)						
Smallmouth bass	*Micropterus dolomieui*	Introduced	Piscivore	Warm	Intermediate	28, 30
Cottidae (sculpins)						
Mottled sculpin	*Cottus bairdi*	Native	Invertivore	Cold	Intermediate	1, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 16, 18, 20, 21, 22, 29, 30
Paiute sculpin	*Cottus beldingi*	Native	Invertivore	Cold	Intolerant	1, 2, 3, 4, 5, 6, 7, 8, 9, 22, 24, 29
Shorthead sculpin	*Cottus confusus*	Native	Invertivore	Cold	Intolerant	23
Shoshone sculpin	*Cottus greenei*	Native	Invertivore	Cold	Intolerant	20, 21, 25
Wood River sculpin	*Cottus leiopomus*	Native	Invertivore	Cold	Intolerant	26, 27
Cyprinidae (carps and minnows)						
Chiselmouth	*Acrocheilus alutaceus*	Native	Herbivore	Cold	Tolerant	18, 19, 22, 30
Common carp	*Cyprinus carpio*	Introduced	Omnivore	Warm	Tolerant	11, 12, 14, 19, 28, 30
Fathead minnow	*Pimephales promelas*	Introduced	Omnivore	Warm	Tolerant	10
Longnose dace	*Rhinichthys cataractae*	Native	Invertivore	Cold	Tolerant	1, 5, 7, 11, 12, 18
Northern squawfish	*Ptychocheilus oregonensis*	Native	Piscivore	Cold	Tolerant	18,19, 22, 30
Peamouth	*Mylocheilus caurinus*	Native	Invertivore	Warm	Intermediate	19, 30
Redside shiner	*Richardsonius balteatus*	Native	Invertivore	Warm	Tolerant	1, 9, 10, 11, 12, 14, 16, 17, 18, 19, 22, 28, 30
Speckled dace	*Rhinichthys osculus*	Native	Invertivore	Cold	Tolerant	1, 5, 7, 9, 10, 11, 12, 14, 16, 17, 18, 22, 27, 29, 30
Utah chub	*Gila atraria*	Native	Omnivore	Warm	Tolerant	5, 10, 14, 18
Ictaluridae (bullhead catfishes)						
Black bullhead	*Ameiurus melas*	Introduced	Omnivore	Warm	Tolerant	28
Percidae (perches)						
Yellow perch	*Perca flavescens*	Introduced	Invertivore	Warm	Intermediate	14, 30
Salmonidae (trouts)						
Brook trout	*Salvelinus fontinalis*	Introduced	Invertivore	Cold	Intolerant	1, 6, 26, 27
Brown trout	*Salmo trutta*	Introduced	Invertivore	Cold	Intolerant	1, 5, 6, 10, 12, 18
Cutthroat trout	*Oncorhynchus clarki* sp.	Native	Invertivore	Cold	Intolerant	1, 2, 3, 4, 5, 8, 9, 10, 13
Mountain whitefish	*Prosopium williamsoni*	Native	Invertivore	Cold	Intolerant	1, 5, 8, 10, 11, 13, 24, 27, 30
Rainbow trout	*Oncorhynchus mykiss* sp.[1]	Native	Invertivore	Cold	Intolerant	1, 5, 6, 7, 8, 10, 11, 13, 15, 16, 17, 18, 20, 21, 22, 23, 24, 25, 26, 27, 29, 30

[1]Native in Snake River and tributaries downstream from Shoshone Falls.

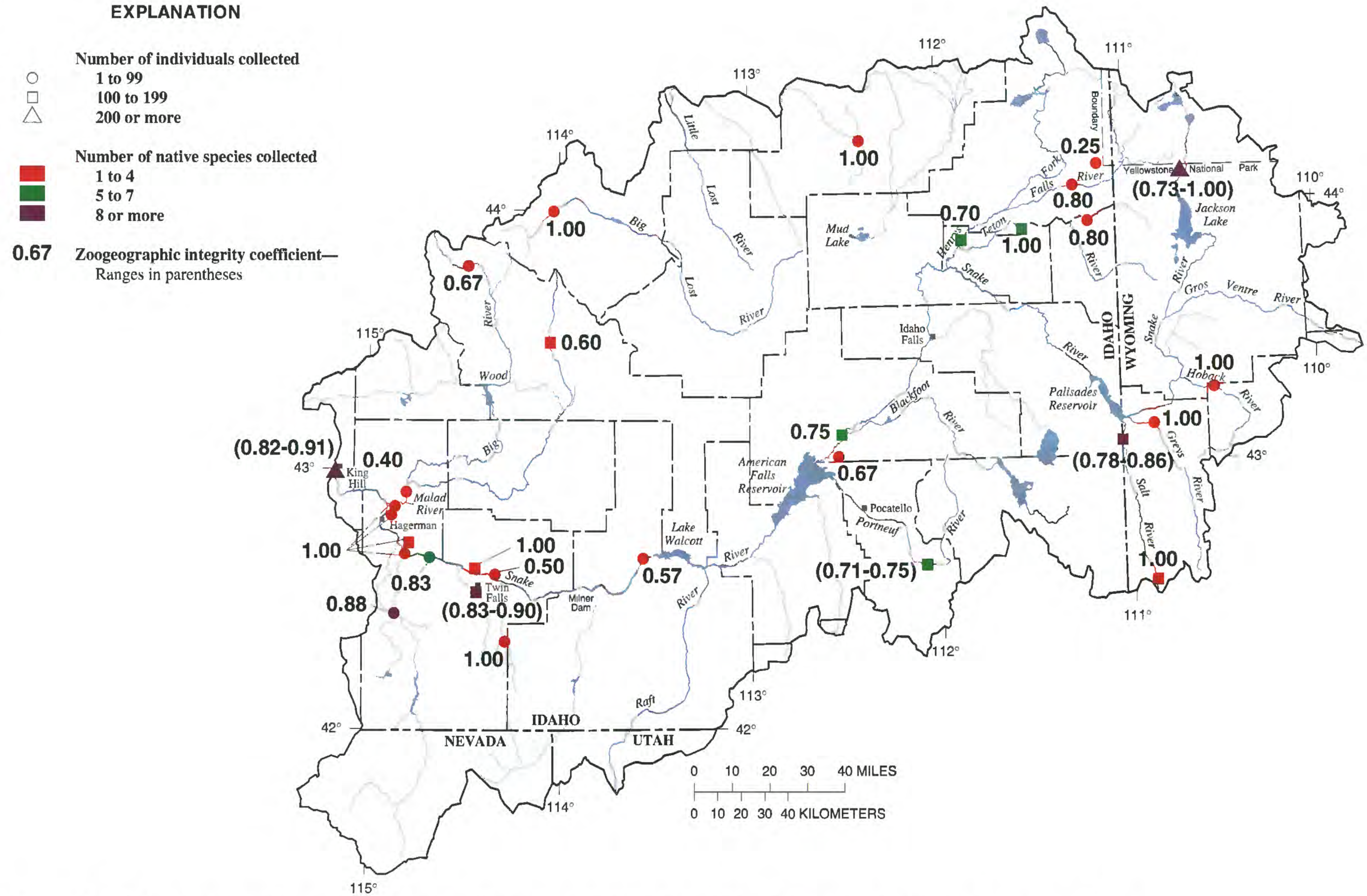


Figure 4. Fish abundances, native species, and range of zoogeographic integrity coefficient index values for all sites in the upper Snake River Basin, 1993–95. (Maximum values were used for abundances and native species for sites with multiple-reach collections. Site locations and numbers are shown in figure 3)

native species that historically have been collected from this large river downstream from Shoshone Falls (Maret, 1995). The loss of the anadromous species from the basin accounts for some of this difference.

The greatest number of species (19) was collected from large rivers and the fewest (8) was collected from springs (fig. 5). Species common to all site types included the mottled sculpin, rainbow trout, redside shiner, speckled dace, and Utah sucker. Rainbow trout, mottled sculpin, and speckled dace were the most frequently collected species at 73, 60, and 50 percent of the sites, respectively. Shorthead sculpin, fathead minnow, and black bullhead were collected from only one site. Shoshone sculpin were also rare, collected only from a few spring sites near Hagerman. Species collected only from reference stream sites were brook trout, shorthead sculpin, and Wood River sculpin. The relatively rare bluehead sucker was collected from the lower Portneuf River during fish tissue sampling (not listed in table 3 or fig. 5). Two adult specimens, each measuring about 16 in. in length, were collected approximately 3 mi downstream from Pocatello on August 11, 1994.

Comparison of Fish Assemblages Among Multiple-Year and Multiple-Reach Sites

The JC index was used to compare fish assemblages at multiple-year and multiple-reach sites. Values for this index range from 0 (no species in common) to 1 (species composition is identical). Gauch (1982) suggested that, because biological community samples can be highly variable, replicate samples from a community often have a JC of less than 1 and typically range from 0.60 to 0.90.

The ranges of JC values for multiple-year sites (table 4) showed little temporal variability in fish assemblages, with the exception of Snake River at King Hill, a large river site. Although a low JC value of 0.46 was recorded for the King Hill site, a wider range of variability was expected for this site because a lower capture efficiency normally occurs when sampling a large river. Also, the highest coefficient of variation for the number of individual fish collected (73.1 percent) was recorded for this site, owing primarily to the unusu-

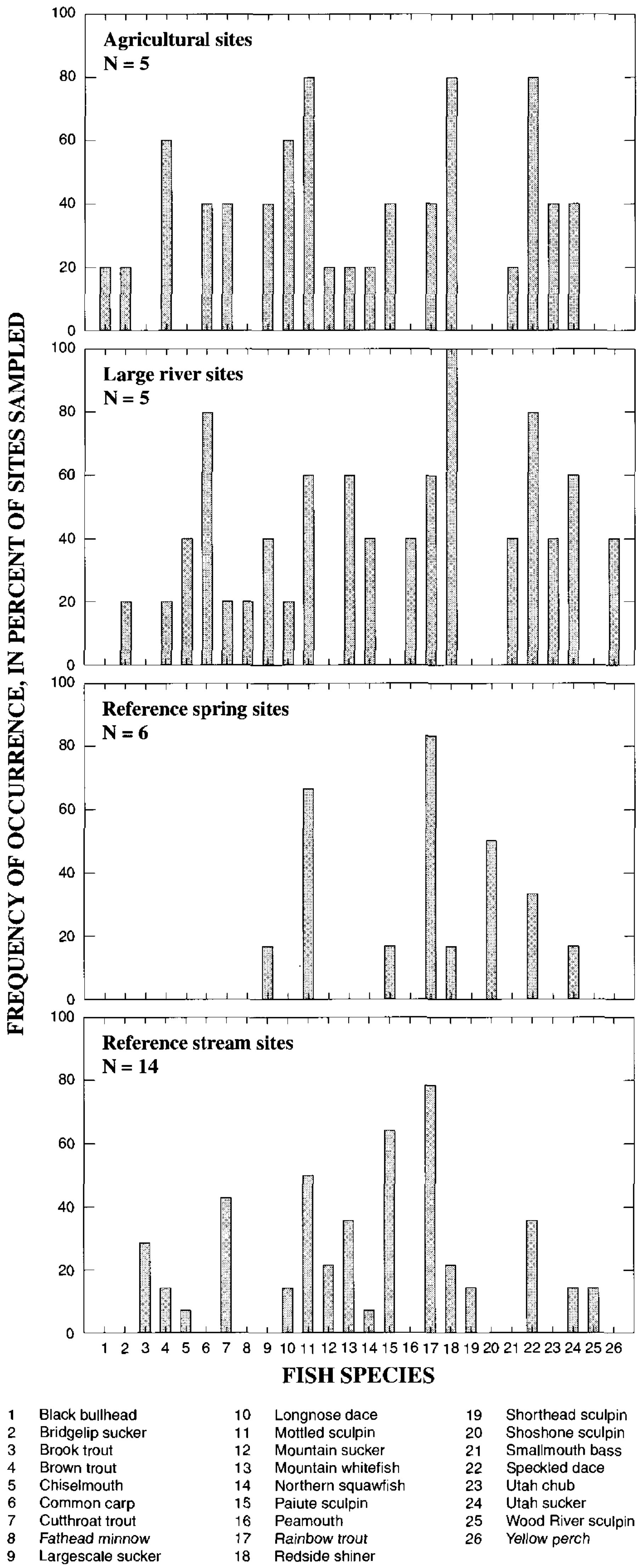


Figure 5. Frequency of occurrence of fish species by site types, upper Snake River Basin.

Table 4. Jaccard's coefficients for all fish species and percent coefficient of variation for number of species and total number of individuals collected from the six multiple-year and two multiple-reach sites, upper Snake River Basin

[Jaccard's coefficients are the range of similarity values between all pairwise combinations for each site. The six multiple-year sites consisted of three consecutive years (1993–95), and the two multiple-reach sites consisted of three reaches each. Locations of sites shown in figure 3. MY, multiple year; MR, multiple reach]

Site No.	Gaging-station name	Site type	Jaccard's coefficient	Coefficient of variation: No. of species	Coefficient of variation: No. of individuals collected
1	Snake River at Flagg Ranch	MY	0.67–0.73	16.4	55.8
5	Salt River near Etna	MY	0.60–0.86	20.9	37.4
12	Portneuf River at Topaz	MY	0.88–1.0	7.9	27.2
18	Rock Creek at Twin Falls	MY	0.60–0.75	25.0	33.5
		MR	0.80–0.88	18.4	55.3
24	Big Lost River near Chilly	MY	0.67–1.0	21.5	25.1
		MR	0.67–1.0	0	48.5
30	Snake River at King Hill	MY	0.46–0.73	17.3	73.1

ally large number of largescale suckers (555) collected in 1993. According to Rahel (1990), most fish assemblages appear to be more unstable and fluctuate in terms of species abundances than in terms of species presence or absence. The JC value for the Portneuf River at Topaz and the Big Lost River near Chilly sites was 1.0, indicating that the same species were collected in two of the three years that samples were collected.

JC values ranged from 0.67 to 1.0 for both multiple-reach sites, indicating that fish species were taxonomically similar. The similarity of the coefficient of variation for the two multiple-reach sites indicates little spatial variability in fish assemblages among the reaches sampled. This suggests that fish collected from a representative reach are representative of local stream conditions. The coefficient of variation for the number of fish species collected ranged from 0 to 18.4 percent, and the coefficient of variation for the number of individual fish collected ranged from 48.5 to 55.3 percent.

RESULTS OF MULTIVARIATE ANALYSES

Cluster Analysis

Cluster analysis of species occurrence data did not reveal any distinct pattern of taxonomic groupings corresponding to the four ecoregions (fig. 6). Maret and others (1997) reported similar results from cluster analysis of species data for small to medium reference streams in the basin. The lack of correspondence between fish assemblage pattern and ecoregions may be due in part to the fact that many of the sampling sites were located near the boundary of adjacent ecoregions and, hence, may represent conditions characteristic of one or both ecoregions. Introduced fish species such as rainbow trout, and barriers such as waterfalls and historical lava flows are other possible explanations for this lack of correspondence.

Principal Components Analysis

Principal components analysis of 24 environmental variables identified 5 principal components with eigenvalues greater than 1 (table 5). These 5 principal components explained 77 percent of the variance in the data set. Loadings with an absolute value greater than 0.5 for each principal component (table 5, in bold) indicated groups of closely associated variables, including stream size, elevation, percent agricultural land, and percent dissolved oxygen on principal components 1, 2, 3, and 4, respectively. Principal component 5 included discharge CV and pH. Velocity did not associate closely with any other variable.

Mean substrate size was inversely related to percent agricultural land, percent embeddedness, percent substrate fines, sinuosity, and specific conductance (PCA component 3). Richards and Host (1994) noted similar relations between agricultural land and substrate characteristics. Specific conductance increased with increased irrigation-return flows for streams in the basin (Clark, 1994). Eight variables that represented the major components identified with PCA and that were biologically relevant were selected (table 5, in bold) to examine relations between land uses and instream habitat variables.

Detrended Correspondence Analysis

Two DCA ordinations are shown for all sites (fig. 7A) and species (fig. 7B). These ordinations are unconstrained by the environmental variables used in the DCA. Fish assemblages were similar for sites that plotted nearest one another. The number of fish species

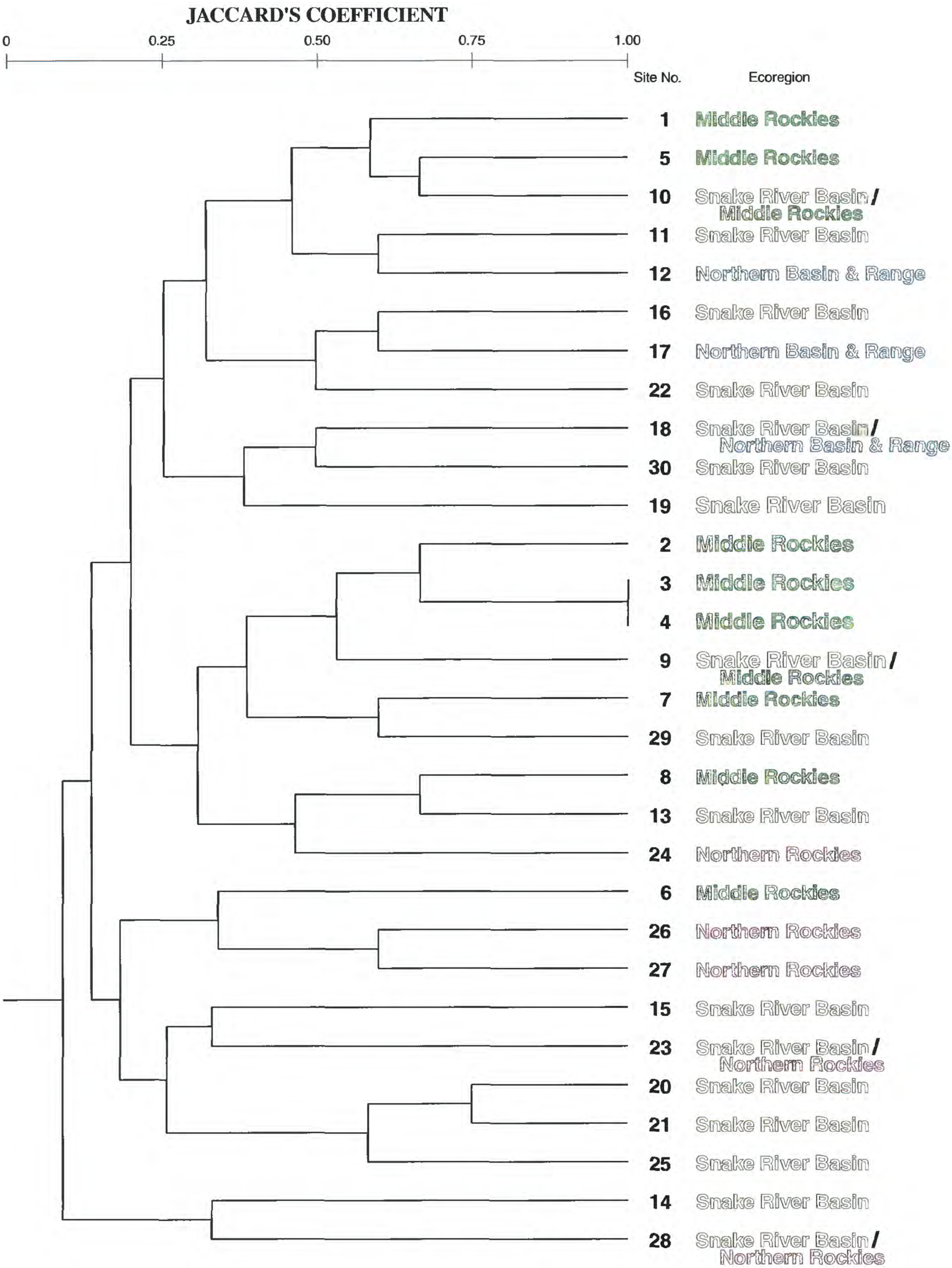


Figure 6. Relative similarities in fish species for all sites in the upper Snake River Basin. (Locations of sites are shown in figure 3)

Table 5. Principal components analysis of environmental variables on the first five principal components, upper Snake River Basin

[Groups of closely associated variables with absolute values of loadings >0.5 and variables selected for canonical correspondence analysis shown in bold]

Environmental variable	Principal component				
	1	2	3	4	5
Width	**0.924**	0.057	0.076	0.040	0.224
Discharge	**.895**	.153	.188	–.008	.264
Depth	**.835**	–.205	.156	.050	.266
Gradient	**–.684**	.242	–.068	.228	.327
Watershed size	**.629**	.228	.297	–.138	.616
Percent open canopy	**.560**	.296	.436	.168	–.011
Stream order	**.515**	.175	.387	–.166	.666
Percent forest land	–.021	**.903**	–.173	.031	.071
Percent rangeland	–.127	**–.901**	–.108	.027	–.205
Elevation	–.350	**.792**	–.088	.025	.060
Percent cover	–.139	**–.651**	–.331	.219	–.450
Width/depth	.352	**.644**	–.077	.056	–.218
Water temperature	.372	**–.643**	.480	–.035	.137
Percent embeddedness	.116	–.174	**.884**	–.102	.059
Percent agricultural land	.340	–.163	**.857**	–.088	.132
Percent substrate fines	.220	–.310	**.758**	.004	–.081
Sinuosity	–.008	.435	**.755**	–.078	.147
Specific conductance	.058	–.475	**.650**	.045	–.227
Substrate size	–.052	–.374	**–.573**	.169	–.245
Percent dissolved oxygen saturation	.028	–.026	.046	**.939**	.150
Dissolved oxygen	–.060	.034	–.235	**.903**	.016
Discharge CV	.100	.185	.094	.070	**.765**
pH	.088	–.181	–.097	.314	**.715**
Velocity	.210	.466	–.211	.001	.421
Percent of variance explained	19	20	18	8	12

for each site also is displayed on the figure to show relative differences among sites. The position of each species represents the average for all sites where that particular species was collected and is useful for interpreting the predominant species that represent the individual or various groups of sites.

The relative magnitude of eigenvalues for each DCA axis is an expression of the relative importance of each axis, and eigenvalues greater than or near 0.5 indicate good separation of the species on both axes (Jongman and others, 1995). DCA axis 1 (eigenvalue = 0.63) and axis 2 (eigenvalue = 0.46) indicate a good separation, whereas eigenvalues for DCA axes 3 and 4 (not shown) were only 0.21 and 0.13, respectively.

DCA of fish assemblages among sites did not show any correspondence to ecoregions. In contrast, Whittier and others (1988) reported good correspondence between ecoregions and fish assemblages in Oregon streams. The lack of correspondence between fish assemblages and ecoregions in the USNK could be an effect of introduced species. For example, rainbow trout have been introduced throughout the basin and were collected from more than half the sites upstream from Shoshone Falls. These introductions effectively homogenize the fish assemblage in such species-depauperate basins.

Although the DCA ordination shows three general groupings of site types—springs, reference streams, and agricultural/large river (fig. 7A)—there was a high overlap in the kind of species collected among the site types. Species such as mottled sculpin, redside shiner, longnose dace, speckled dace, Utah sucker, and brown trout that plot in the central region of the species ordination (fig. 7B) represent the species most commonly collected from the three site types.

The species ordination (fig. 7B) showed that the highest scores on DCA axis 1 were associated with introduced warmwater species that are more tolerant of habitat degradation than native salmonids are. The introduced species include black bullhead, smallmouth bass, yellow perch, and common carp. In addition, the native peamouth, chiselmouth, and northern squawfish were considered relatively tolerant and were collected primarily from sites with high scores (fig. 7A) that represented many of the large river and agricultural site types (sites 12, 14, 19, 28, and 30). The fish assemblage collected from the agricultural site Malad River near Gooding (site 28) was particularly poor in relation to fish assemblages from other agricultural sites—only 5 species and 30 fish were collected (table B, back of report). Most species collected from this site were warmwater adapted and pollution tolerant. Discharge CV at this site was 100 percent (table A, back of report), the highest for all sites sampled. Zero discharges recorded for extended times during the late autumn and winter preceding the summer sampling at this site in 1993 (Brennan and others, 1995) would, in part, explain the lack of a coldwater fishery.

Springs exhibited high site scores on DCA axis 2 (fig. 7A), and sites 15, 20, 21, and 25 grouped together. These sites supported six or fewer species that usually included rainbow trout and Shoshone sculpin, an endemic species collected only from spring habitats along the Snake River between Twin Falls and Hagerman (Simpson and Wallace, 1982). Medicine Lodge Creek (site 23) plotted as an outlier with the lowest score on DCA axis 1 and the highest score on DCA axis 2. The two species collected at this site, rainbow trout and shorthead sculpin, reflect isolated conditions for streams like Medicine Lodge Creek that do not reach the Snake River. Sites 26 and 27, which exhibited the lowest scores on both DCA axes, are in the Wood River drainage. Only five or fewer species—rainbow trout,

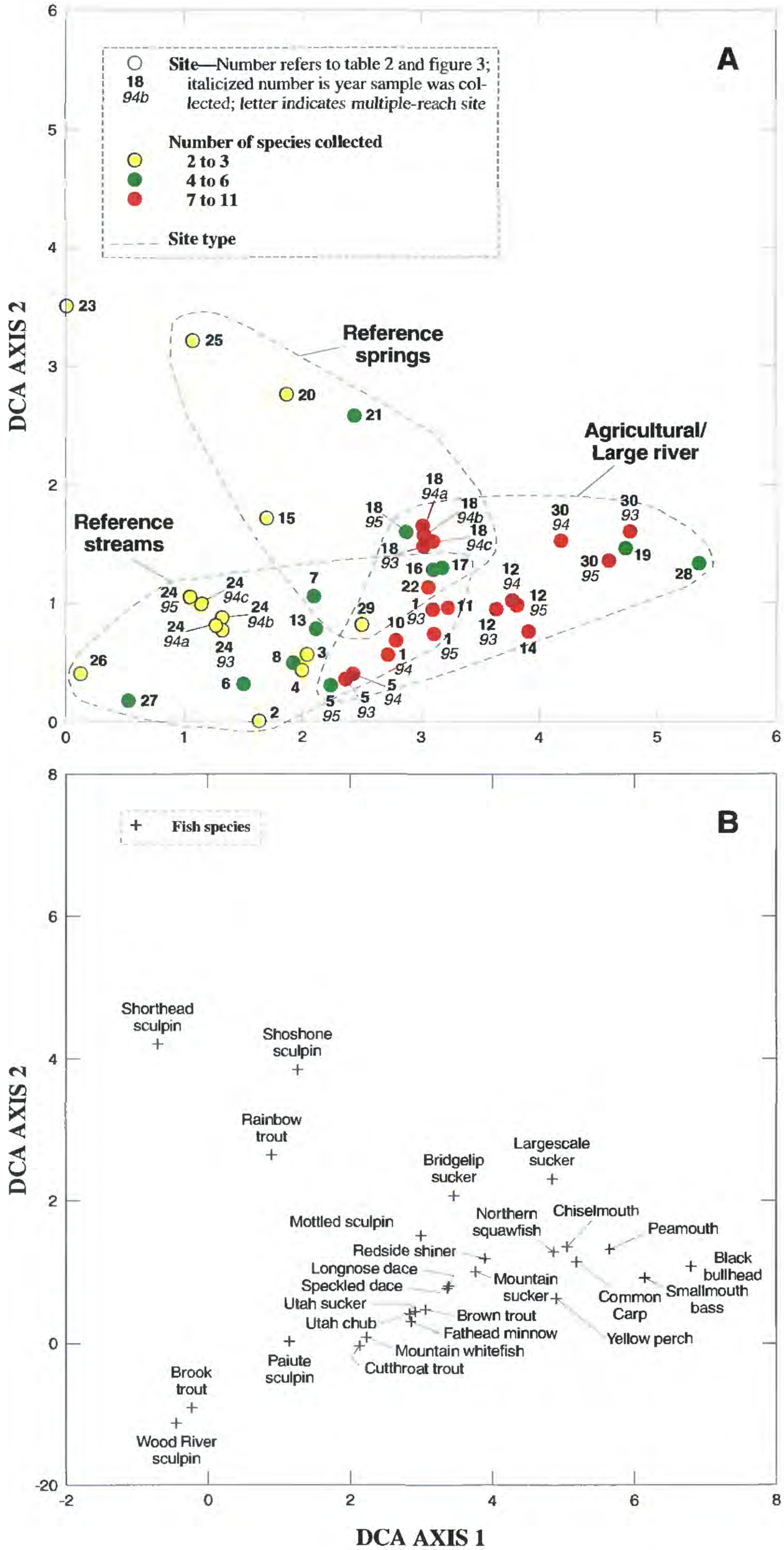


Figure 7. Detrended correspondence analyses (DCA) ordination plots of (A) site scores and number of species collected and (B) species scores, upper Snake River Basin. (Site names and locations shown in table 2 and figure 3. Site 9 was excluded because of missing information)

brook trout, mountain whitefish, speckled dace, and the endemic Wood River sculpin—were collected at each of these sites. The occurrence of rare species such as the shorthead sculpin, Shoshone sculpin, and Wood River sculpin appears to influence the DCA ordination greatly. However, eliminating rare species prior to DCA, as suggested by Gauch (1982), was not justified in species-depauperate systems or where endemic species were indicative of a particular aquatic habitat or drainage basin. As would be expected, the multiple-year and multiple-reach sites were in close proximity in the ordination, which suggests that the spatial and temporal variability was relatively small for these sites.

Regression of DCA axes 1 and 2 scores for all 24 environmental variables (13 for axis 1 and 11 for axis 2) indicated significant relations at the $p<0.05$ probability level (table 6). Thus, DCA axis 1 separated sites primarily on the basis of percent agricultural land, depth, water temperature, width, and discharge. Each variable accounted for 30 percent or more of the variance in DCA axis 1 scores with a correlation coefficient greater than 0.30 at the $p<0.05$ probability level. All these variables were associated with land use and (or) measures of stream size. DCA axis 2 scores separated sites primarily on the basis of percent rangeland, elevation, and percent forest land, and each variable again accounted for 30 percent or more of the variance in DCA axis 2 scores. Axis 2 also showed the importance of land use and elevation in the separation of sites. Elevations at reference stream sites sampled in this study were higher (median of more than 6,000 ft) than at other sites. Similarly, Whittier and others (1988) reported that, for Oregon streams, differences in biotic assemblages and physicochemical measurements were greatest between montane and desert regions. Rahel and Hubert (1991) also identified elevation as an important environmental variable shaping fish assemblages in Wyoming streams.

Table 6. Environmental variables having significant regression ($p<0.05$) with detrended correspondence analysis (DCA) axis 1 and 2 scores, upper Snake River Basin

[r^2, coefficient of determination; CV, coefficient of variation]

Environmental variable	r^2
DCA axis 1	
Percent agricultural land	0.41
Depth	.38
Water temperature	.35
Width	.33
Discharge	.30
Elevation	.29
Watershed size	.27
Specific conductance	.22
Percent embeddedness	.21
Stream order	.21
Percent open canopy	.16
Percent substrate fines	.15
Discharge CV	.11
DCA axis 2	
Percent rangeland	0.37
Elevation	.31
Percent forest land	.30
Water temperature	.17
Sinuosity	.17
Percent cover	.13
Width/depth	.13
Discharge CV	.11
Percent open canopy	.10
Specific conductance	.10
Velocity	.10

Canonical Correspondence Analysis

Two CCA ordinations are shown for all sites, excluding site 9 (fig. 8A), and for all species (fig. 8B). This analysis was designed to detect patterns of variation in the species assemblages that can best be explained by the measured environmental variables. Environmental variables with long vectors were more strongly correlated with the ordination axes than were those with short vectors. In other words, long vectors depict greater influence of that environmental variable in structuring the fish assemblage. These ordination analyses were constrained by the environmental variables shown in the figures and directly relate the gradients of the environmental variables to the fish assemblages. The position of each species (fig. 8B) represents the average for all sites where that particular species was collected.

Sites did not appear to correspond to ecoregions. CCA axis 1 (fig. 8A) appeared to separate sites in a manner similar to that of the DCA ordination. Large river and agricultural site types generally were spread along axis 1 (lower right), whereas the reference stream and spring site types were spread along axis 2 (upper left). Similar to the DCA ordination of sites, there was

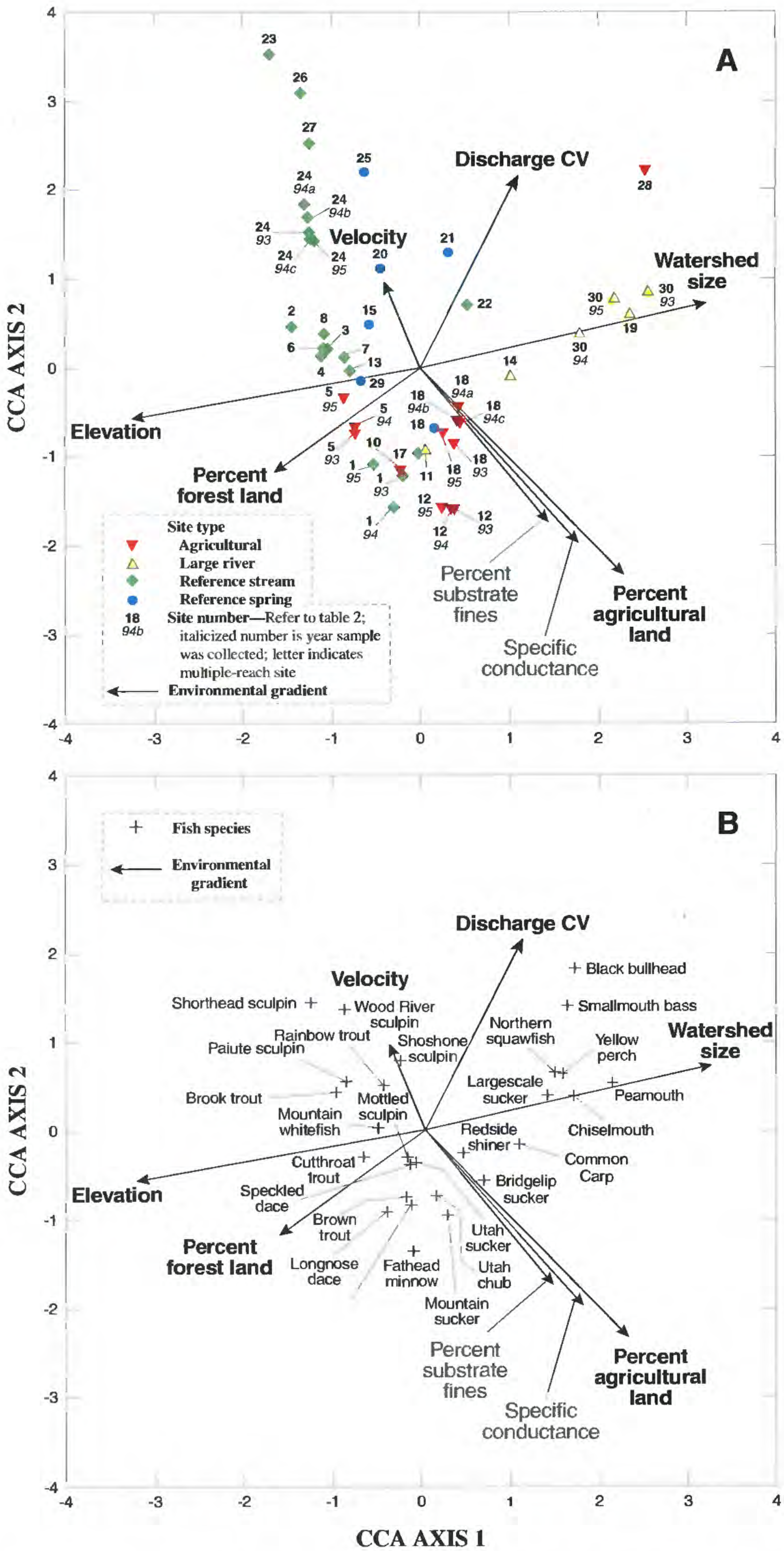


Figure 8. Canonical correspondence analyses (CCA) ordination plots of (A) site scores by site type and (B) species scores with selected environmental variables, upper Snake River Basin. (Environmental variables in bold letters were significant ($p<0.05$) on one or both axes; see table 7. Site names and locations shown in table 2 and figure 3. Site 9 was excluded because of missing information)

a high overlap in the kind of species among site types in the CCA ordination.

Multiple-year and multiple-reach sites (1, 5, 12, 18, 24, and 30) generally grouped near each other (fig. 8A), indicating that fish assemblages and environmental variables for these sites were similar. This similarity supports the premise that fish assemblages from a representative reach were indicative of local conditions.

As with DCA, the relative magnitude of eigenvalues for each CCA axis also expressed the relative importance of each axis. CCA axes 1 and 2 accounted for 51 and 29 percent, respectively, of the explained joint variance in the fish assemblages and environmental variables.

Most of the variability was accounted for by elevation, watershed size, percent agricultural land, and discharge CV, with eigenvalues of 0.40, 0.38, 0.28, and 0.24, respectively (table 7). Six of the eight variables were statistically significant in the ordination for one or both axes, indicating that these six variables were correlated with the ordination axes. These six variables were elevation, watershed size, percent agricultural land, discharge CV, percent forest land, and velocity. Greater absolute values of canonical coefficients indicated stronger correlation between a variable and the axis tested. The variables with the strongest correlations along each axis had the greatest influence on the species composition of the samples. Most sites were correlated along axis 1 by elevation and watershed size with canonical coefficients of -0.61 and 0.39, respectively. Percent forest land, percent agricultural land, and discharge CV, with canonical coefficients of - 0.93, -0.61, and 0.39, respectively, were strongly correlated along

Table 7. Summary of correspondence analysis including eigenvalues, canonical coefficients, and t-values of canonical coefficients for environmental variables, upper Snake River Basin

[CV, coefficient of variation; probability values <0.05 shown in bold]

Environmental variable	Eigen-value	Canonical coefficient Axis 1	Canonical coefficient Axis 2	Canonical coefficient t-values Axis 1	Canonical coefficient t-values Axis 2
Elevation	0.40	−0.61	0.17	**−5.34**	0.85
Watershed size	.38	.39	.17	**4.34**	1.09
Percent agricultural land	.28	.31	−.61	**2.17**	**−2.52**
Discharge CV	.24	.34	.39	**4.07**	**2.80**
Specific conductance	.22	.01	−.25	.10	−1.21
Percent forest land	.19	.26	−.93	**2.39**	**−5.04**
Percent substrate fines	.19	.07	.02	.53	.11
Velocity	.11	−.21	.34	**−2.51**	**−2.45**

axis 2 (table 7). Even though specific conductance and percent substrate fines were not significant in the ordination for either axis, the strong correlation with percent agricultural land was evident with the alignment of the environmental vectors (figs. 8A and 8B). Land use can be an important, large-scale factor affecting composition and structure of fish assemblages. Studies have shown the effects of siltation on salmonid fisheries (Chapman, 1988) and relations of fish assemblages to specific conductance (Matthews and others, 1992).

According to Jongman and others (1995), sites that differ by a score of 4 standard deviations of CCA axis units tend to have few, if any, species in common. Sites approached this amount of separation on axis 1 and exceeded this amount of separation on axis 2. For example, the amount of separation between sites 12 and 23 of more than 5 for axis 2 suggests that these sites have no species in common. These two sites are quite different. Medicine Lodge Creek (site 23) is a reference stream in a rangeland watershed and is a disjunct drainage where only two intolerant species were collected (rainbow trout and shorthead sculpin). The Portneuf River at Topaz (site 12) is severely affected by agricultural land use, as indicated by excessive siltation (83 to 92 percent substrate fines and 88 to 99 percent embeddedness) and the presence of relatively large numbers of common carp.

The CCA analysis indicates that most sites are separated by stream size, which was inversely correlated with elevation. The development of an IBI using fish assemblages will need to account for this in deriving scoring criteria. Land use is another important factor to consider in development of an IBI. Streams in agricultural areas of the basin generally have fish assemblages different from those of other stream types sampled; therefore, metrics selection should account for this difference. CCA analysis also suggests that percentage of agricultural land use can be used as an indicator of human disturbance when validating and testing an IBI.

Results of the CCA were similar to those of DCA. This similarity would be expected because the eight environmental variables selected for CCA were also significant in the regression analysis of DCA axes 1 and 2 scores. The results of this study indicate that GIS and multivariate analyses can be useful tools in characterizing fish assemblages and patterns relating to environmental variables at various landscape scales. Once similar patterns in fish assemblages are identified using these tools, a multimetric analysis, with indices such as the IBI, can be developed for various geographic regions and (or) site types.

ANALYSES OF SELECTED ENVIRONMENTAL VARIABLES

Kruskal-Wallis test results indicated that all environmental variables except dissolved oxygen, dissolved oxygen saturation, pH, and width/depth were significantly different among site types. Eight environmental variables—elevation, stream width, velocity, percent open canopy, percent cover, specific conductance, percent substrate fines, and percent embeddedness were selected to best illustrate differences among site types (fig. 9, A–H). These eight variables were selected on the basis of PCA and DCA results. In addition, these environmental variables reflect site-specific measures of reach conditions that could directly influence fish species.

Median elevation was significantly higher for reference stream sites than for other site types (fig. 9A). Spring sites had a narrow range of elevation because of their similar geographic location in the basin and proximity to the main-stem Snake River. Median stream widths for large river site types were significantly greater than for other site types (fig. 9B).

Median velocity among all site types was lowest (0.76 ft/s) for springs and was significantly lower than for large river and reference stream sites (fig. 9C). Median velocities for agricultural sites were significantly lower than for large river sites. Median open canopy among all site types was lowest (55 percent) for springs (fig. 9D), due primarily to the shading from rocky canyons and the presence of thick riparian vegetation. Agricultural and large river site types characteristically had open canopies, and median values for canopy opening were significantly higher for these sites than for reference stream sites (figs. A–H, back of report).

Median percent cover for springs was significantly higher (85 percent) than for the other three site types (fig. 9E), due primarily to the predominance of large boulders and abundance of aquatic macrophytes.

Results from boxplot comparisons of environmental variables and previous PCA analyses showed that specific conductance, percent substrate fines, and percent embeddedness for agricultural sites were typically higher than for reference stream sites (figs. 9F, 9G, and 9H). Median specific conductance for reference stream sites was significantly lower (212 μS/cm) than for the other site types (fig. 9F). Median specific conductance for agricultural sites was significantly higher (709 μS/cm) than for large river and reference stream sites. Interestingly, median specific conductance for springs (432 μS/cm) was not significantly different from that for agricultural or large river sites, and specific conductance for at least one spring was 647 μS/cm. The similarity of specific conductance for springs and agricultural sites indicates influence of land use on the local ground-water quality. Background specific conductance of water in the Snake River Plain aquifer is slightly greater than 300 μS/cm (M.G. Rupert, U.S. Geological Survey, oral commun., 1996).

Percent substrate fines and percent embeddedness (figs. 9G and 9H) showed similar patterns for all site types. Median percent substrate fines (10) and percent embeddedness (34) for reference stream sites, for example, were significantly lower than for agricultural and large river sites. Median percent embeddedness (32) for springs was significantly lower than for agricultural and large river sites.

ANALYSES OF SELECTED FISH METRICS

Fourteen fish metrics were summarized for all site types (table B, back of report). Eight of the metrics that demonstrated significant differences (p-values <0.05) on the basis of a Kruskal-Wallis test were selected to best illustrate the relations among fish metrics and site types (fig. 10, A–H). The remaining six metrics were redundant, were dependent on stream size and sample effectiveness (such as total number collected), or exhibited low or no values (such as percent anomalies).

In general, native fish species are most abundant and diverse in relatively undisturbed environments (Moyle, 1986). Therefore, the occurrence of native fish species in relation to non-native species can indicate the extent of habitat degradation, which may include physical and (or) chemical changes detrimental to native fish species. Number of species and number of native species for agricultural and large river site types were significantly greater than for reference stream and spring site types (figs. 10A and 10B). Fewer introduced species were collected from many of the reference stream and spring sites than from agricultural sites (fig. 10E).

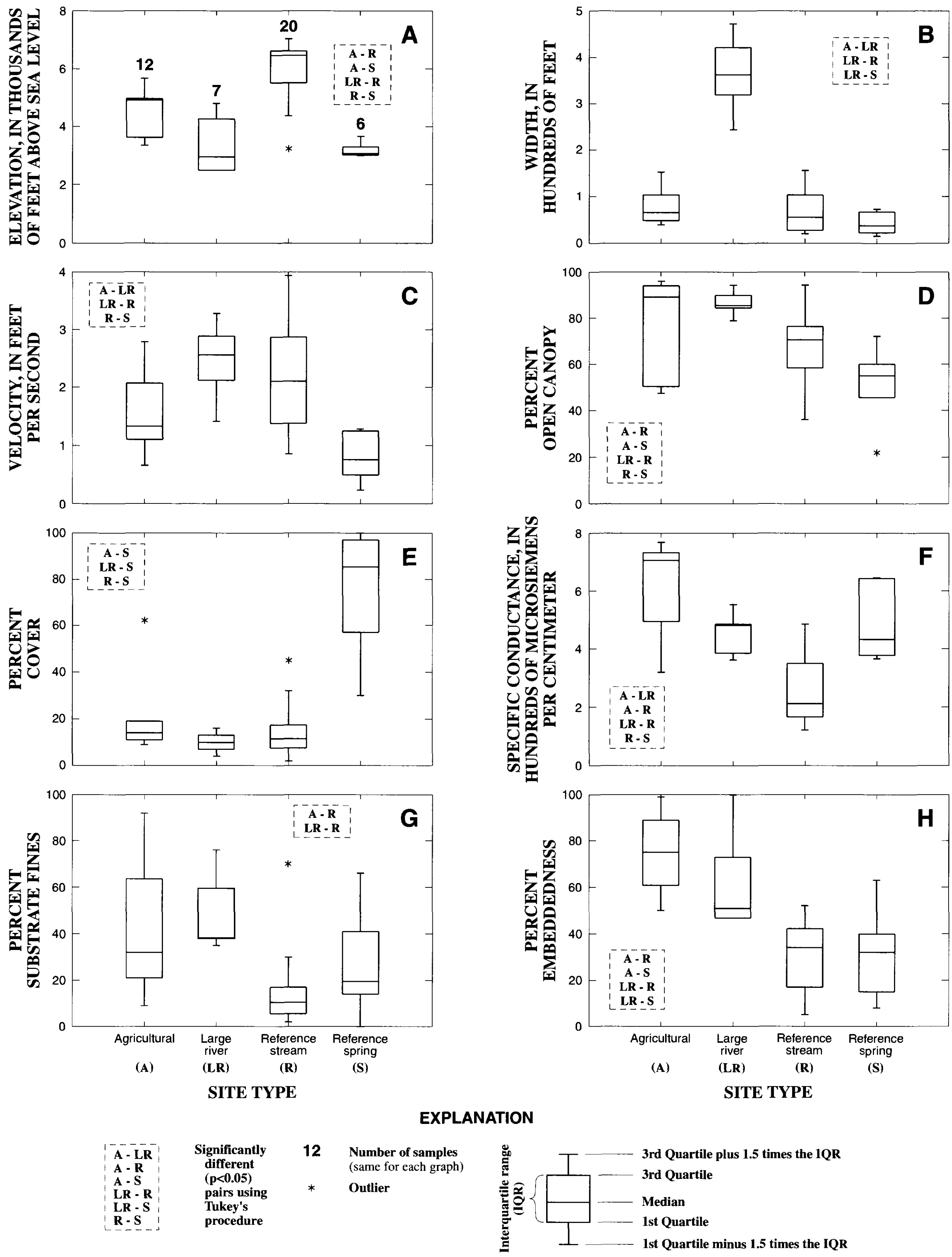


Figure 9. Selected environmental variables for all site types sampled in the upper Snake River Basin. (All plots include multiple-reach and multiple-year measurements. Site 9 was excluded because of missing information)

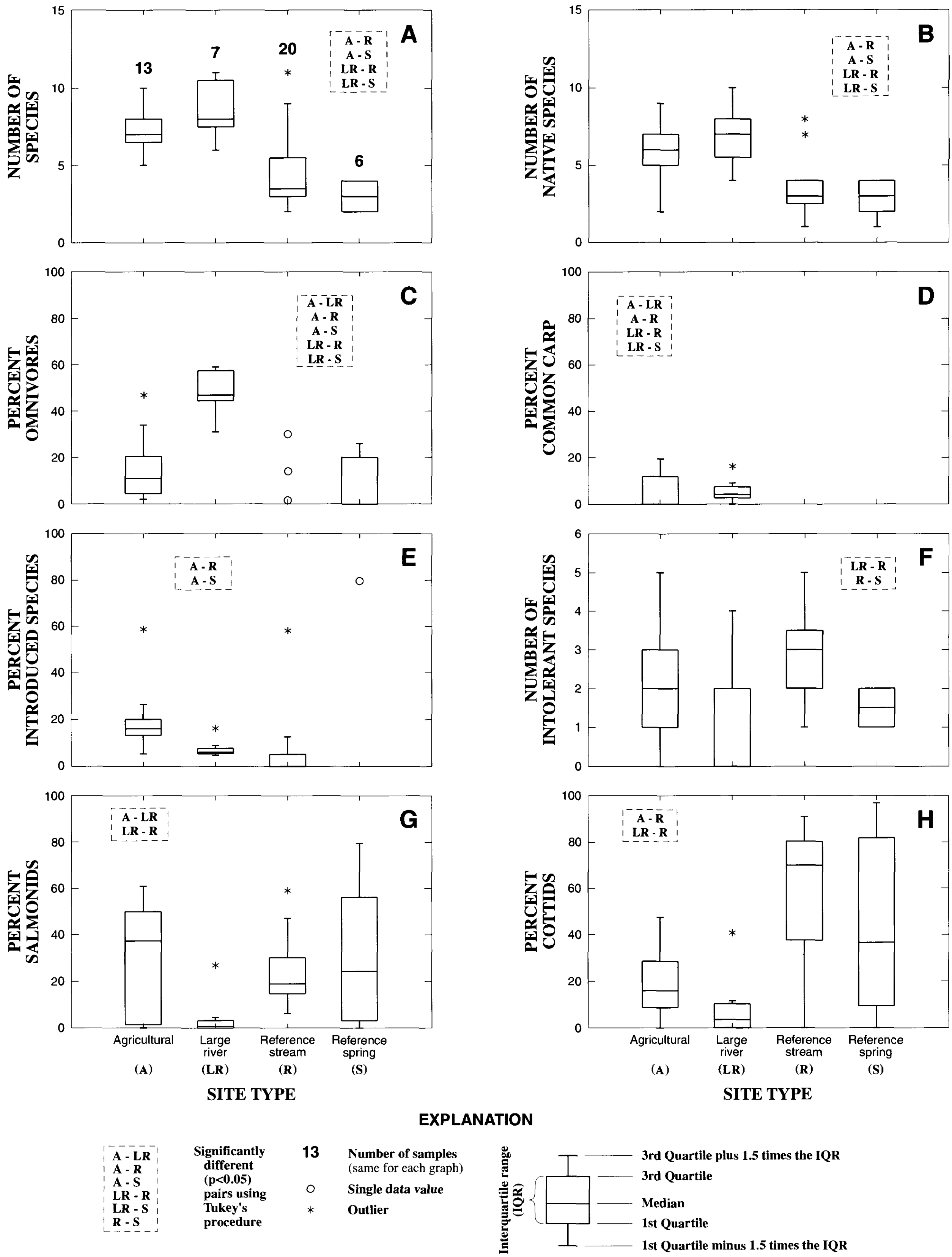


Figure 10. Selected fish metrics for all site types sampled in the upper Snake River Basin. (All plots include multiple-reach and multiple-year collections)

Springs typically contained only native species, with the exception of Devils Washbowl (site 15) upstream from Shoshone Falls, where rainbow trout were collected. Reference stream and spring sites also were generally smaller than agricultural and large river sites, which typically contain more fish species than do smaller streams (Fausch and others, 1984).

The basinwide introduction of intolerant salmonid species, including brook, brown, and rainbow trout, confounds the use of introduced species as a metric for measuring habitat degradation. Introduced species were collected from a number of the reference streams during this study (fig. 4, table 3). Kruskal-Wallis test results indicated no significant differences among site types for the ZIC index. The lowest ZIC index value of 0.25 was for the reference stream site, Robinson Creek at Warm River (site 6), where three of the four species collected were introduced salmonids. The native cutthroat trout was not collected from this site. Therefore, the ZIC index may not be a useful indicator of environmental disturbance where intolerant fish species such as salmonids commonly have been introduced and have become part of the resident fishery.

Percent omnivores and percent common carp are metrics that typically increase with increasing habitat degradation or other environmental disturbance. Percent omnivores was higher for agricultural and large river sites than for reference stream and spring sites, and common carp were collected only from the agricultural and large river sites (figs. 10C and 10D).

The number of intolerant species (fig. 10F) varied greatly for all site types except springs. The median was highest for reference stream sites and was significantly different from that for large river and spring sites.

Percent salmonids and percent cottids metric values also varied greatly; values ranged from 0 to more than 80 percent for some site types (figs. 6G and 6H). The median percent salmonids was highest for agricultural sites, primarily because of large percentages of salmonids collected from Salt River (site 5) and Rock Creek (site 18). According to IDFG, Rock Creek is heavily stocked with rainbow and brown trout upstream and downstream from site 18 (Fred Partridge, Idaho Department of Fish and Game, written commun., 1993), which would likely inflate the median percent salmonids. The large river site type typically had few salmonids, and median values were significantly lower than those for agricultural and reference stream site types. The percent cottids was highest for reference stream and spring sites. Median percent cottids for agricultural and large river sites was significantly lower than for reference stream sites.

ANALYSES OF RELATIONS BETWEEN ENVIRONMENTAL VARIABLES AND FISH METRICS

An increase in the number of fish species with an increase in stream size, which has been described by measures of stream width, discharge, stream order, and watershed size, has been documented for other basins (Kuehne, 1962; Goldstein, 1981; Fausch and others, 1984; Paller, 1994), but not for the USNK. This particular relation is important because fish metrics used to evaluate biotic integrity may need to be adjusted to account for these differences. Data collected and analyzed for the USNK indicated a direct relation between the number of species and changes in stream size. The number of native fish species was significantly correlated at the $p < 0.01$ probability level with watershed size (fig. 11A) and stream width (fig. 11B) with coefficients of determination of 0.28 and 0.29, respectively. Including additional data representing small first- and second-order streams that were not sampled in this study would likely increase the strength of both relations because most headwater streams in the basin contain only one or two species (Maret and others, 1997). The number of fish species also increased in relation to increased stream size. The correlation between elevation and number of native species for all sites was not significant at the <0.05 probability level.

Angermeier and Schlosser (1989) suggested three potential factors to explain the direct relation between numbers of fish species and stream size. An increase in stream size (1) results in an increase in diversity of habitat types, (2) provides a larger area that can support more individuals and that enables the pool of available species to be sampled more completely, and (3) results in different rates of immigration and extinction. Accordingly, headwater tributaries or springs are not expected to contain as many species as do larger streams or drainage areas at low elevations in the basin.

Even though spring sites were considered tributaries to the main-stem Snake River and were at lower elevations in the basin relative to other similar small streams, they characteristically contained only two to four species. Contrary to this, Osborne and Wiley (1992) reported that in Illinois, fish assemblages in trib-

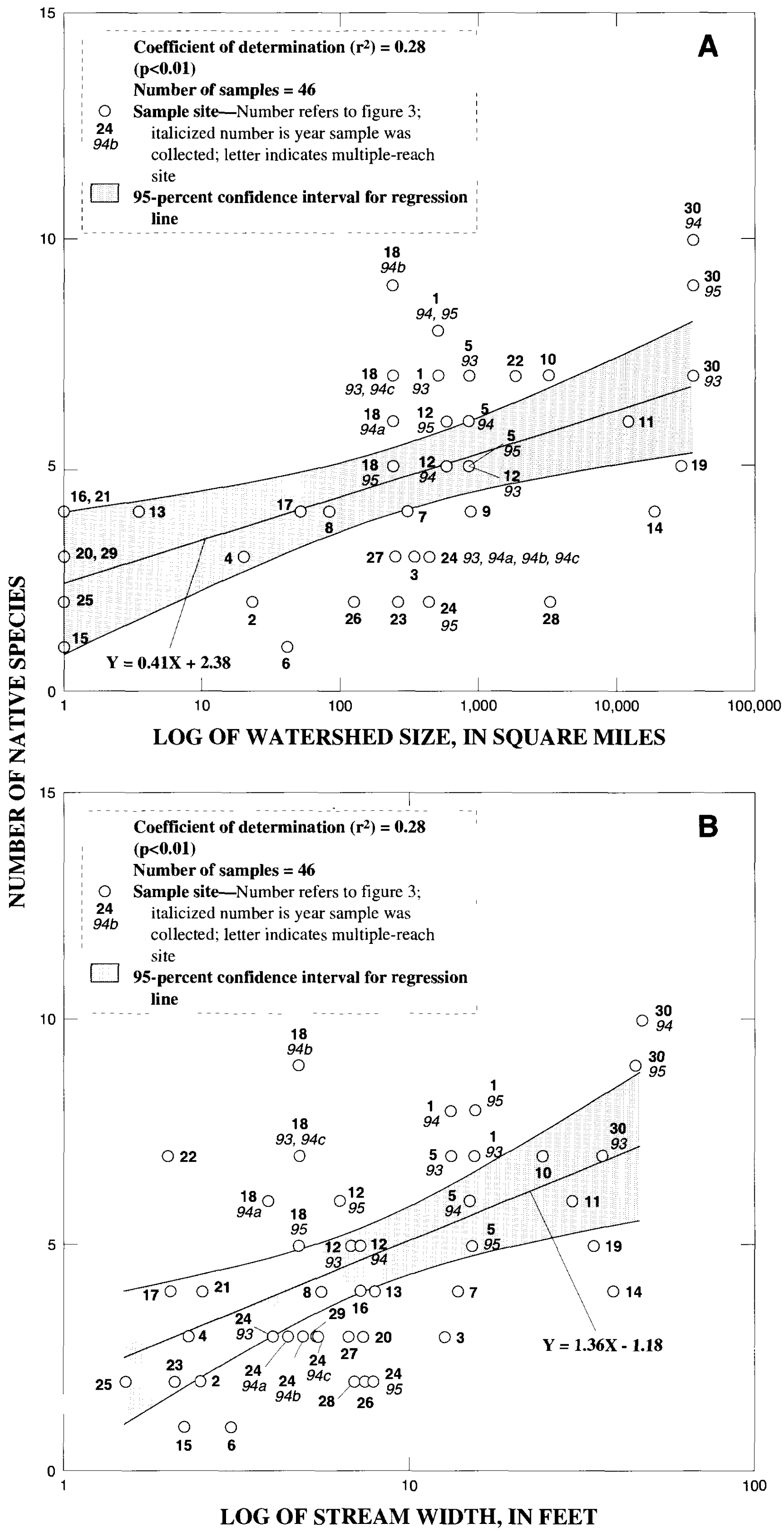


Figure 11. Relations among number of native fish species and watershed size and stream width, upper Snake River Basin. (Site locations shown in figure 3; site types shown in table 2; site 9 was excluded in figure 11B because of missing information)

utaries to main channels at lower elevations in a basin contained a greater number of species than did streams of similar size in the headwaters of a basin. They attributed this difference to the pool of immigrants available to colonize small tributaries from the larger streams at lower elevations in a basin. Another explanation may be that large river species do not prefer the year-round coldwater temperatures that these spring habitats provide.

The number of fish species also varied according to site type (figs. 11A and 11B and table 2), which would be expected because of large differences in stream size among the four site types. The number of fish species for agricultural and large river sites, which typically were larger than reference stream and spring sites, was significantly higher than for reference stream and spring sites. These differences illustrate the importance of stream size as a limiting variable with respect to using fish assemblage data as a measure of environmental conditions.

Comparison of Selected Fish Metrics Among Main-Stem Snake River and Major Tributary Sites

Habitats in the main-stem Snake River and major tributary sites have been degraded as a result of agricultural land use and water regulation by diversions and reservoirs (Maret, 1995). Ten sites were selected (fig. 12, A–F) to illustrate longitudinal changes in six fish metrics and differences in fish assemblages on the main-stem Snake River and major tributaries. All sites were located in watersheds where agricultural land use constituted 15 to 35 percent of the watershed and where streamflow was highly regulated by upstream diversions and reservoirs (table 2). The exception was Snake River at Flagg Ranch (site 1), which is located in a primarily forested watershed where streamflow is not highly regulated. In a downstream direction, corresponding to river mile and elevation, sites 1, 11, 14, 19, and 30 represented the main-stem Snake River, and sites 5, 10, 12, 18, and 28 generally represented agricultural site types (table 2). The river mile for tributary sites represented the tributary's confluence with the Snake River. The range of elevations for all sites was about 6,800 ft at Snake River at Flagg Ranch to about 2,500 ft at Snake River at King Hill. The six fish metrics were number of native species, percent introduced species, percent omnivores, percent common carp, percent salmonids, and percent coldwater-adapted species. Maximum metric values were used to characterize multiple-year and multiple-reach sites.

The number of native species would be expected to decrease with habitat degradation, which also may allow for the invasion of introduced species. The number of native species (fig. 12A) ranged from 2 for Malad River near Gooding (site 28) to 10 for Snake River at King Hill (site 30). The number of native species collected from Malad River near Gooding was distinctly lower than from other sites. The high variability of discharge for this site (discharge CV, table A, back of report) is at least a partial explanation for the low number of species. A low of four native species was collected from Snake River near Minidoka (site 14). Only 1 percent of the fish collected from site 14 were coldwater species (fig. 12F). A possible explanation for the absence of coldwater species may be that Lake Walcott, a relatively shallow impoundment immediately upstream from the collection site, may be causing increased water temperatures at the site.

Introduced species (fig. 12B) were collected from all main-stem and tributary sites. Metric values would be expected to increase with habitat degradation. Percent introduced species was relatively constant and ranged from 5 to 26 for all sites except Malad River near Gooding (site 28), where percent introduced species was about 60. Moreover, three introduced salmonid species, likely the result of past stockings, were collected from the most upstream reference site, Snake River at Flagg Ranch (site 1).

Percent omnivores (fig. 12C) for all sites ranged widely from 6 to 92. Metric values would be expected to increase with habitat degradation. Rock Creek at Twin Falls (site 18), a tributary to the Snake River, had the lowest percent omnivores. Salmonid and cottid species (table B, back of report), all of which are invertivores (table 3), were predominant at this site. The Snake River near Minidoka (site 14) and at King Hill (site 30) had the highest percent omnivores (59 and 92, respectively), owing primarily to the abundance of catostomids. For comparison, Hughes and Gammon (1987) used percent omnivores as a metric for evaluating trophic structure of fish assemblages in the Willamette River, a large, coldwater river in Oregon. They determined that fish assemblages exceeding 50 percent omnivores indicated habitat degradation, compared with less degraded reference habitats of the upper main-stem Willamette. Using their criteria, the predominance

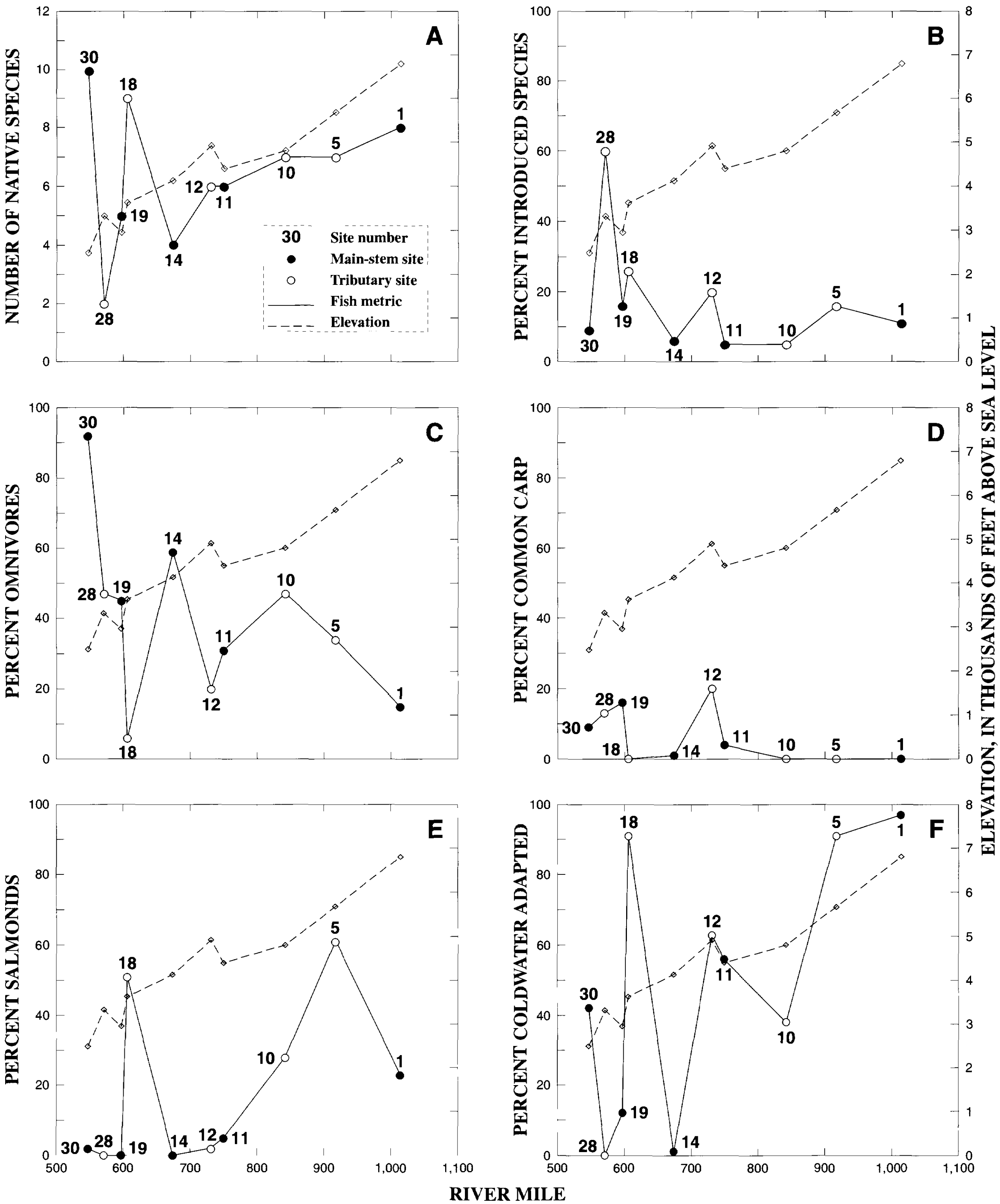


Figure 12. Selected fish metrics for five main-stem Snake River sites and five major tributary sites influenced by agricultural land use, from Snake River at Flagg Ranch, Wyoming, to Snake River at King Hill, Idaho. (Maximum metric values were used for sites with multiple samples. River mile for tributaries represents the confluence with the Snake River. Site names and locations shown in table 2 and figure 3; summary of fish metrics shown in table B, back of report)

of omnivores at these Snake River sites suggests an unbalanced trophic structure, possibly resulting from habitat degradation. In addition, percent omnivores ranged from 0 to 15 for the Snake River at Flagg Ranch (site 1, table B, back of report), suggesting that trophic structures for the Snake River near Minidoka and at King Hill sites are unbalanced, compared with this Snake River reference site.

Percent common carp (fig. 12D), a metric representing an introduced and highly tolerant species, also was used by Hughes and Gammon (1987). They determined that 10 percent common carp was a metric criterion representing conditions strongly deviating from reference conditions and indicating habitat degradation. Carp were collected from four main-stem and two tributary sites. Percent common carp was higher than 10 for Portneuf River at Topaz (site 12), Snake River near Buhl (site 19), and Malad River near Gooding (site 28). The presence of this species in these coldwater streams is a strong indication of habitat degradation, and this metric appears to be consistently responsive to environmental disturbance.

Percent salmonids (fig. 12E), a metric representing coldwater, intolerant species that are commonly present in the basin, ranged from 0 to 57. All main-stem and tributary sites were expected to support salmonid species on the basis of historical records and recent studies (Maret, 1995). Salmonids were not collected from Snake River near Minidoka (site 14), Snake River near Buhl (site 19), or Malad River near Gooding (site 28). The absence of salmonids at these locations may be indicative of habitat degradation. In contrast, percent salmonids collected from Snake River at Flagg Ranch (site 1), Salt River near Etna (site 5), and Rock Creek at Twin Falls (site 18) ranged from 23 to 61, percentages that would be expected at these sites.

Because most streams in the basin have been designated for beneficial use of coldwater biota (Maret, 1995), the fish assemblages would be expected to consist primarily of coldwater-adapted species (fig. 12F) in the absence of habitat degradation. Some main-stem Snake River sites near the lower end of the basin were not supporting a viable coldwater fishery, especially sites 14 and 19 (Minidoka and Buhl). Even though the fish assemblage for Snake River at King Hill (site 30) appeared to recover slightly, evidenced by collection of some coldwater species, salmonids were noticeably lacking in the fish assemblage, composing only 0 to 2 percent of the total number of fish collected. In addition, some of the tributaries to the middle reach of the Snake River, such as Malad River near Gooding (site 28), no longer supported a coldwater fishery. Analysis of the preceding metrics generally supports the current water-quality-limited designation for the middle reach of the Snake River between Milner Dam and King Hill.

Important Components to Include in an Index of Biotic Integrity (IBI)

Even though the objective of this study was primarily to characterize the fish assemblages and related environmental variables in the USNK, a number of important findings are applicable to developing an IBI. A wide range of fish metrics and environmental variables was collected and analyzed for this study. Results indicate that an IBI for the USNK will be simpler than versions previously developed for warmwater streams, which comprised 12 metrics (Karr and others, 1986), because the coldwater streams in the USNK contain fewer fish species than do warmwater streams. At least six fish metrics—number of native species, percent introduced species, percent omnivores, percent common carp, percent salmonids, and percent coldwater-adapted species—appear to respond to varying degrees of human influence on the Snake River and its major tributaries. Using a multimetric approach to develop an IBI will increase the probability of an accurate assessment (Fore and others, 1996).

In warmwater streams, the number of fish species generally declines with decreasing environmental quality and is reflected in the scoring of metrics used in an IBI (Karr and others, 1986). This assumption of a positive relation between species richness and biotic integrity does not extend to coldwater streams of the USNK. Coldwater reference streams of the USNK tend to contain fewer fish species than do sites affected by human activities, such as agricultural sites where tolerant species have been introduced. Lyons and others (1996) also noted that coldwater streams in Wisconsin contained fewer species than did warmwater streams and attributed this difference to thermal preferences of fish species. Many more species are adapted to a warmwater habitat than to a coldwater habitat. Only when the degradation becomes so severe that even warmwater introduced species are lost would species richness decline.

Generally, most types of watershed degradation increase summer water temperatures in streams (Doppelt and others, 1993). Percent coldwater-adapted species is therefore a particularly useful metric because warming of a stream provides a less favorable habitat for native coldwater species and a more favorable habitat for a larger number of relatively tolerant introduced warmwater species. Moyle (1986) also reported this shift from a few native coldwater species to many warmwater introduced species for degraded streams in California. Where colonization from downstream reaches is hindered by waterfalls or disjunct drainages such as the Big Lost River drainage, warmwater species may not replace coldwater species, and species richness may remain relatively low or may decline after degradation. In addition, many reservoirs in the USNK have been stocked with warmwater species and provide a refugium for warmwater species to colonize favorable habitats.

Ideally, stocked salmonids should not be included in the calculation of an IBI because their presence does not directly reflect biotic integrity. A stream regularly stocked with trout may or may not have high biotic integrity, and the presence of these salmonids would likely inflate final IBI scores because some of the metrics in a coldwater IBI would be influenced by salmonid abundance. During the USNK study, differentiation between natural and stocked fish at some sites was extremely difficult; therefore, all stocked fish were included in all metric calculations. Perhaps IDFG stocking records, along with physical appearance and size distribution, can be used in future studies to identify stocked fish.

Stream size was inversely related to elevation in the USNK study, and both variables were strongly related to fish assemblages. Consequently, selection and scoring of metrics for an IBI would be influenced by stream size and elevation. In addition, reference spring sites appeared to support a fish assemblage different from that of other site types, which may require some specific adjustments in an IBI.

The data collected during this study, in addition to data from other studies, particularly for small first- and second-order streams, will provide the framework for developing an IBI for the various streams of the USNK. Ultimately, development of an IBI will provide an understanding of probable fish assemblages in the absence of significant human disturbance. Perhaps the most important result of developing an IBI is that it will provide resource managers a formalized approach for establishing water-quality goals and evaluating the status of aquatic life beneficial uses.

SUMMARY

Fish assemblages and environmental variables were evaluated for 30 first- through seventh-order streams in the USNK, Idaho and western Wyoming. Data were collected as part of the National Water-Quality Assessment Program to characterize aquatic biota and associated habitats in surface water.

Land use in the basin comprises 50 percent rangeland, 23 percent forest land, and 21 percent agricultural land; the remainder is categorized as "other." Geographically, the basin is composed primarily of four ecoregions—the Snake River Basin/High Desert, 50 percent; Middle Rockies, 23 percent; Northern Basin and Range, 18 percent; and Northern Rockies, 9 percent. Streamflow in the Snake River and its major tributaries is highly regulated by dams and diversions, primarily for agricultural use and hydroelectric-power generation.

Large river, agricultural, and reference stream and spring sites in the basin were sampled. Sites represented various ecoregions and land use throughout the basin. Twenty-four environmental variables representing various spatial scales, from watershed characteristics to instream habitat measures, were examined and relations with fish assemblages evaluated.

Twenty-six fish species in the families Catostomidae, Centrarchidae, Cottidae, Cyprinidae, Ictaluridae, Percidae, and Salmonidae were collected. About 73 percent of the species collected from all sites were native species. The number of species collected from any one site ranged from 2 to 11, and the mean for all sites was 6. A total of 5,295 fish were collected during this study.

The greatest number of individuals and native species was collected from the Snake River at Flagg Ranch and Snake River at King Hill sites. Only 10 species were collected from the Snake River at King Hill, which is about one-half the number of native species that historically have been collected from this large river downstream from Shoshone Falls.

The greatest number of species (19) was collected from large rivers and the fewest (8) from springs. Species common to all site types included the mottled sculpin, rainbow trout, redside shiner, speckled dace, and Utah sucker. Shorthead sculpin, fathead minnow, and black bullhead were collected from only one site. Shoshone sculpin were also rare, collected from only a few springs near Hagerman. Species collected from

only reference stream sites were brook trout, shorthead sculpin, and Wood River sculpin. Fewer than 100 individuals and fewer than 5 species typically were collected from reference stream sites at high elevations in the drainage basins.

The difference between site types and the zoogeographic integrity coefficient index was not significant. The zoogeographic integrity coefficient index may not be a useful indicator of environmental disturbance where intolerant fish species such as salmonids commonly have been introduced and have become part of the resident fishery.

The ranges of Jaccard's coefficient of community similarity index values for multiple-year sites (1993–95) showed little temporal variability in fish assemblages, with the exception of Snake River at King Hill, where a low value of 0.46 was recorded. The similarity of the fish assemblages among multiple-reach sites indicated that the reaches sampled were representative of environmental conditions within that stream segment.

Cluster analysis of species occurrence data did not reveal any clear groupings corresponding to the four ecoregions in the basin. Accordingly, the distribution of species did not appear to be strongly correlated with ecoregion type.

The PCA loadings identified four principal components comprising groups of closely associated variables indicative of watershed size, elevation, percent agricultural land, and percent dissolved oxygen. Results of boxplot comparisons of environmental variables and PCA analyses showed that percent embeddedness, percent substrate fines, sinuosity, and specific conductance typically were higher for streams influenced by agricultural land use than for reference streams in forested and (or) rangeland watersheds.

Three general groupings of site types in the DCA ordination consisted of springs, reference streams, and agricultural/large rivers; however, there was a high overlap in fish assemblages among the site types. The species ordination showed that the highest scores on DCA axis 1 were associated with introduced warmwater species, which generally are more tolerant of habitat degradation than native salmonids are. The occurrence of these species corresponded to the large river and agricultural site types. Springs exhibited high site scores on DCA axis 2. These sites supported six or fewer species that usually included rainbow trout and Shoshone sculpin, an endemic species found only in spring habitats along the Snake River between Twin Falls and Hagerman. DCA also separated site types according to environmental variables that accounted for the greatest amount of variability in fish assemblages. Sites were separated along DCA axis 1 according to percent agricultural land, depth, water temperature, stream width, and discharge, and along DCA axis 2 by percent rangeland, elevation, and percent forest land.

The CCA ordination of site types separated sites in a manner similar to that of the DCA ordination. Large river and agricultural site types generally were spread along axis 1, and the reference stream and spring site types were spread along axis 2. Similar to the DCA ordination of sites, there was a high overlap in the kind of species among site types in the CCA ordination. Most sites in the CCA ordination were strongly correlated along axis 1 by watershed size and elevation and along axis 2 by percent forest land, percent agricultural land, and discharge CV. Most of the variability was accounted for by differences in elevation, watershed size, percent agricultural land, and discharge CV.

Both DCA and CCA identified land use (percent agricultural and forest land), stream size (width, watershed size), and elevation as important environmental variables related to fish assemblages in the basin. Similar to the results of cluster analysis, there was no correspondence between fish assemblages and ecoregions identified by DCA and CCA analyses. The lack of correspondence between fish assemblages and ecoregions could be the result of introduced species. For example, rainbow trout have been introduced throughout the basin and were collected from more than half the sites upstream from Shoshone Falls. These introductions greatly reduce the importance of native species in structuring the fish assemblages, especially in species-depauperate basins. In addition, results from DCA and CCA indicated that the spatial and temporal variability in fish assemblages and measured environmental variables was relatively low for multiple-year and multiple-reach sites.

Physical and chemical environmental factors varied according to site type. Kruskal-Wallis tests showed statistically significant differences among site types for all environmental variables except dissolved oxygen, dissolved oxygen saturation, pH, and width/depth. Median elevation was significantly higher for reference streams than for other site types. As expected, median stream widths for large river sites were significantly greater than for other site types. Median velocity among all site types was lowest for springs and was significantly lower than for large river and reference streams. Median velocities for agricultural sites were significantly lower than for large river sites. Median values for open canopy were lowest for springs, due primarily to the shading from rocky canyons and the presence of thick riparian vegetation. Agricultural and large river sites characteristically had open canopies, and medians were significantly higher for these sites than for reference stream sites. Median percent cover for springs was significantly higher than for the other three site types, due primarily to the predominance of large boulders and abundance of aquatic macrophytes. Median specific conductance was significantly lower for reference stream sites than for other site types. Median specific conductance was significantly higher for agricultural sites than for large river and reference stream sites. Median specific conductance for springs was not significantly different from that for agricultural or large river sites. Median percent substrate fines and percent embeddedness for reference stream sites were significantly lower than for agricultural and large river sites. Median embeddedness for springs was significantly lower than for agricultural and large river sites.

Fourteen fish metrics were summarized for all fish collections. Eight of the metrics that demonstrated significant differences were selected to best illustrate the relations among fish and site types. Median number of species for agricultural and large river sites were significantly greater than for reference stream and spring sites. Fewer introduced species were collected from many of the reference stream and spring sites than from agricultural sites. Springs typically contained only native species, with the exception of Devils Washbowl upstream from Shoshone Falls. Percent omnivores, including common carp, was higher for agricultural and large river sites than for reference stream and spring sites. In fact, common carp were collected only from agricultural and large river sites, and omnivores were collected only from two of the reference stream sites. The median number of intolerant species was significantly higher for reference stream sites than for large river and spring sites. Percent salmonids and percent cottids ranged from 0 to more than 80 percent for some site types. Large rivers typically contained few salmonids, and median values were significantly lower than those for agricultural and reference stream sites. The percent cottids was highest for reference stream and spring sites. Median percent cottids for agricultural and large river sites was significantly lower than for reference stream sites.

Overall, the number of fish species increased with increasing stream size. Similarly, the number of native species increased significantly as a function of watershed size and stream width. In addition, introduced species were collected from all main-stem and tributary sites, including the most upstream reference site, the Snake River at Flagg Ranch, where three introduced salmonid species were collected.

Several fish metrics indicated that some main-stem Snake River sites near the lower end of the basin were not supporting a viable coldwater fishery, especially the Buhl and Minidoka sites. Even though the fish assemblage at King Hill appeared to recover slightly, evidenced by collection of some coldwater species, salmonids were noticeably lacking. Six fish metrics—number of native species, percent introduced species, percent omnivores, percent common carp, percent salmonids, and percent coldwater-adapted species—appeared to respond to varying degrees of human influence on the Snake River and its major tributaries. In addition, some of the tributaries to the middle reach of the Snake River, such as the Malad River near Gooding, also did not support a coldwater fishery. The findings of this study support the water-quality-limited designation for the middle reach of the Snake River.

In this study, a wide range of fish metrics and environmental variables was collected multiple times at multiple sites across a wide geographic region representing different stream types. These types of data are needed to evaluate the biotic integrity of streams in the four ecoregions of the upper Snake River Basin. Unfortunately, such data sets are infrequently collected. Additional data on fish assemblages and environmental conditions for other sites are needed to develop an index of biotic integrity that accounts for the wide diversity of environmental conditions in the upper Snake River Basin. Tools such as the index of biotic integrity provide resource managers a formalized approach for establishing water-quality goals, assessing the status of aquatic life beneficial uses, and evaluating ecological changes resulting from human activities.

A common perception about aquatic ecosystems is that higher diversity equates with higher biotic integrity and, thus, better environmental quality. The results of this study demonstrate that a lower diversity of fish species may be indicative of a high-quality reference condition and, thus, high biotic integrity. This implies that management efforts to maximize fish diversity in coldwater streams of the upper Snake River Basin may not result in high biotic integrity.

This study demonstrates that some fish metrics are indicative of stream habitat and general water-quality degradation in the basin. The findings of this report will provide a framework for developing indices of biotic integrity by using fish assemblages to evaluate water quality of streams in the upper Snake River Basin.

REFERENCES CITED

Allan, J.D., and Flecker, A.S., 1993, Biodiversity conservation in running waters: Bioscience, v. 43, no. 1, p. 32–43.

Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, R.E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 28 p.

Angermeier, P.L., and Schlosser, I.J., 1989, Species-area relationships for stream fishes: Ecology, v. 70, p. 1450–1462.

Brennan, T.S., Jones, M.L., O'Dell, I., Lehmann, A.K., and Tungate, A.M., 1995, Water resources data, Idaho, water year 1994, v. 1, Great Basin and Snake River Basin above King Hill: U.S. Geological Survey Water-Data Report ID–94–1, 409 p.

Brockway, C.E., and Robinson, C.W., 1992, Middle Snake River water quality study, phase I, final report: Kimberly, University of Idaho, Idaho Water Resources Research Institute, Kimberly Research and Extension Center, 70 p.

Chandler, G.L., Maret, T.R., and Zaroban, D.W., 1993, Protocols for assessment of biotic integrity (fish) in Idaho streams: Boise, Idaho Department of Health and Welfare, Division of Environmental Quality, Water Quality Monitoring Protocols, Report no. 6, 40 p.

Chapman, D.W., 1988, Critical review of variables used to define effects of fines in redds of large salmonids: Transactions of the American Fisheries Society, v. 117, p. 1–21.

Clark, G.M., 1994, Assessment of selected constituents in surface water of the upper Snake River Basin, Idaho and western Wyoming, water years 1975–89: U.S. Geological Survey Water-Resources Investigations Report 93–4229, 49 p.

Doppelt, Bob, Scurlock, Mary, Frissell, Chris, and Karr, James, 1993, Entering the watershed—a new approach to save America's river ecosystems: Washington, D.C., Island Press, 462 p.

Dynesius, Mats, and Nilsson, Christer, 1994, Fragmentation and flow regulation of river systems in the northern third of the world: Science, v. 266, p. 753–762.

Elvira, B., 1995, Native and exotic freshwater fishes in Spanish river basins: Freshwater Biology, v. 33, p. 103–108.

Evermann, B.W., 1896, A preliminary report upon salmon investigations in Idaho in 1894, *in* Bulletin of the United States Fish Commission for 1895: Washington, D.C., U.S. Government Printing Office, v. 15, p. 253–284.

Fausch, K.D., Karr, J.R., and Yant, P.R., 1984, Regional application of an index of biotic integrity based on stream fish communities: Transactions of the American Fisheries Society, v. 113, p. 39–55.

Fisher, T.R., 1989, Application and testing of indices of biotic integrity in northern and central Idaho headwater streams: Moscow, University of Idaho, M.S. thesis, 180 p.

Fore, L.S., Karr, J.R., and Wisseman, R.W., 1996, Assessing invertebrate responses to human activities—evaluating alternative approaches: Journal of the North American Benthological Society, v. 15, no. 2, p. 212–231.

Frissell, C.A., Liss, W.J., Warren, C.E., and Hurley, M.D., 1986, A hierarchical framework for stream habitat classification—viewing streams in a watershed context: Environmental Management, v. 10, no. 2, p. 199–214.

Gallant, A.L., Whittier, T.R., Larsen, D.P., Omernik, J.M., and Hughes, R.M., 1989, Regionalization as a tool for managing environmental resources: Corvallis, Oreg., U.S. Environmental Protection Agency, EPA 600/3–89–060, 152 p.

Gauch, H.G., Jr., 1982, Multivariate analysis in community ecology: New York, Cambridge University Press, 298 p.

Gilbert, C.H., and Evermann, B.W., 1895, A report upon investigations in the Columbia River basin, with descriptions of four new species of fishes, *in* Bulletin of the United States Fish Commission for 1894: Washington, D.C., U.S. Government Printing Office, v. 14, p. 169–179.

Goldstein, R.M., 1981, Longitudinal succession in impact assessment of river system fish communities: Water Resources Bulletin, v. 17, no. 1, p. 75–81.

Gurtz, M.E., 1994, Design of biological components of the National Water-Quality Assessment (NAWQA) Program, *in* Loeb, S.L., and Spacie, Anne, eds., Biological monitoring of aquatic systems: Boca Raton, Fla., Lewis Publishers, p. 323–354.

Hayslip, G.A., ed., 1993, Region 10 in-stream biological monitoring handbook for wadable streams in the Pacific Northwest: Seattle, Wash., U.S. Environmental Protection Agency, Environmental Services Division, 75 p.

Heede, B.H., and Rinne, J.N., 1990, Hydrodynamic and fluvial morphologic processes—implications for fisheries management and research: North American Journal of Fisheries Management, v. 10, no. 3, p. 249–268.

Hughes, R.M., and Gammon, J.R., 1987, Longitudinal changes in fish assemblages and water quality in the Willamette River, Oregon: Transactions of the American Fisheries Society, v. 116, no. 2, p. 196–209.

Hughes, R.M., Heiskary, S.A., Matthews, W.J., and Yoder, C.O., 1994, Use of ecoregions in biological monitoring, *in* Loeb, S.L., and Spacie, Anne, eds., Biological moni-

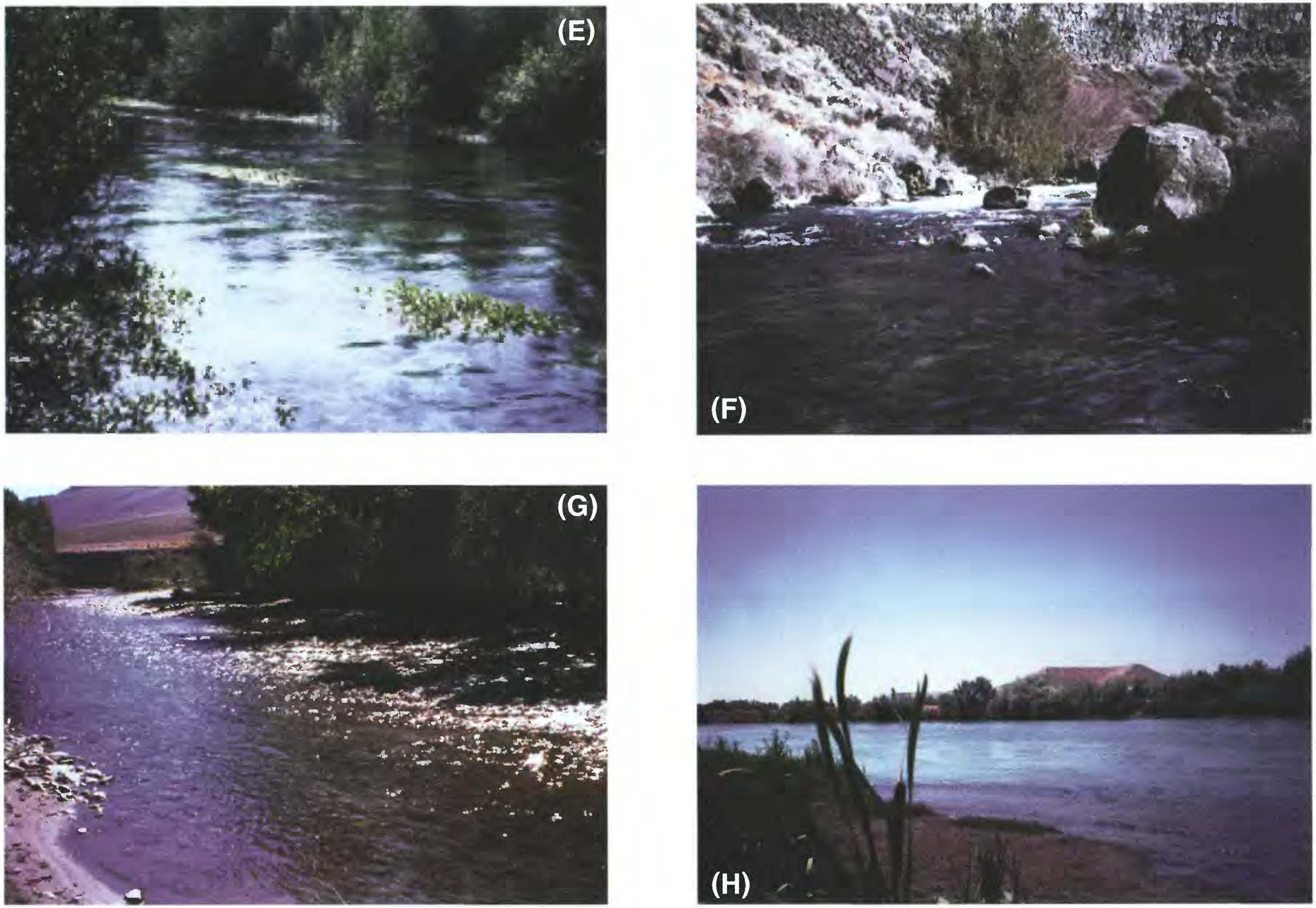
toring of aquatic systems: Boca Raton, Fla., Lewis Publishers, p. 125–151.
Hughes, R.M., and Larsen, D.P., 1988, Ecoregions—an approach to surface water protection: Journal of the Water Pollution Control Federation, v. 60, no. 4, p. 486–493.
Hughes, R.M., Larsen, D.P., and Omernik, J.M., 1986, Regional reference sites—a method for assessing stream potentials: Environmental Management, v. 10, no. 5, p. 629–635.
Idaho Conservation Data Center, 1994, Rare, threatened and endangered plants and animals of Idaho: Boise, Idaho Department of Fish and Game, 39 p.
Idaho Department of Health and Welfare, 1989, Idaho water quality status report and nonpoint source assessment, 1988: Boise, Idaho Department of Health and Welfare, Division of Environmental Quality, 170 p.
———1990, Idaho water quality standards and wastewater treatment requirements, title 1, chapter 2: Boise, Idaho Department of Health and Welfare, Division of Environmental Quality, 72 p.
———1995, The Middle Snake River nutrient management plan: Twin Falls, Division of Environmental Quality, South Central Idaho Regional Office, 176 p., 4 apps.
Jackson, D.A., and Harvey, H.H., 1989, Biogeographic associations in fish assemblages—local vs. regional processes: Ecology, v. 70, no. 5, p. 1472–1484.
Jongman, R.H.G., Ter Braak, C.J.F., and Van Tongeren, O.F.R., eds., 1995, Data analysis in community and landscape ecology: New York, Cambridge University Press, 299 p.
Karr, J.R., 1991, Biological integrity—a long-neglected aspect of water resource management: Ecological Applications, v. 1, no. 1, p. 66–84.
Karr, J.R., 1994, Biological monitoring—challenges for the future, *in* Loeb, S.L., and Spacie, Anne, eds., Biological monitoring of aquatic systems: Boca Raton, Fla., Lewis Publishers, p. 357–373.
Karr, J.R., and Dudley, D.R., 1981, Ecological perspective on water quality goals: Environmental Management, v. 5, p. 55–68.
Karr, J.R., Fausch, K.D., Angermeier, P.L., Yant, P.R., and Schlosser, I.J., 1986, Assessing biological integrity in running waters—a method and its rationale: Illinois Natural History Survey, Special Publication 5, 28 p.
Kjelstrom, L.C., Stone, M.A.J., and Harenberg, W.A., 1995, Statistical summaries of streamflow data for selected gaging stations in Idaho and western Wyoming through September 1990—volume 2: gaging stations with 5 to 9 years of record or that measure discharge from springs: U.S. Geological Survey Water-Resources Investigations Report 94–4070, 94 p.
———1996, Statistical summaries of streamflow data for selected gaging stations in Idaho and adjacent states through September 1990—volume 1: gaging stations with 10 or more years of record: U.S. Geological Survey Water-Resources Investigations Report 94–4069, 533 p.
Kuehne, R.A., 1962, A classification of streams, illustrated by fish distribution in an eastern Kentucky creek: Ecology, v. 43, no. 4, p. 608–614.
Leahy, P.P., Rosenshein, J.S., and Knopman, D.S., 1990, Implementation plan for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 90–174, 10 p.
Leonard, P.M., and Orth, D.J., 1986, Application and testing of an index of biotic integrity in small, coolwater streams: Transactions of the American Fisheries Society, v. 115, p. 401–414.
Lyons, John, Wang, Lizhu, and Simonson, T.D., 1996, Development and validation of an index of biotic integrity for coldwater streams in Wisconsin: North American Journal of Fisheries Management, v. 16, no. 2, p. 241–256.
Maret, T.R., 1995, Water-quality assessment of the upper Snake River Basin, Idaho and western Wyoming—summary of aquatic biological data for surface water through 1992: U.S. Geological Survey Water-Resources Investigations Report 95–4006, 59 p.
Maret, T.R., Robinson, C.T., and Minshall, G.W., 1997, Fish assemblages and associated environmental correlates in least-disturbed streams of the upper Snake River Basin, western USA: Transactions of the American Fisheries Society, v. 126, no. 2, p. 200–216.
Matthews, W.J., Hough, D.J., and Robison, H.W., 1992, Similarities in fish distribution and water quality patterns in streams of Arkansas—congruence of multivariate analyses: Copeia, v. 2, p. 296–305.
Maupin, M.A., 1995, Water-quality assessment of the upper Snake River Basin, Idaho and western Wyoming—environmental setting, 1980–92: U.S. Geological Survey Water-Resources Investigations Report 94–4221, 35 p.
Meador, M.R., 1992, Inter-basin water transfer—ecological concerns: Fisheries, v. 17, no. 2, p. 17–22.
Meador, M.R., Cuffney, T.F., and Gurtz, M.E., 1993a, Methods for sampling fish communities as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93–104, 40 p.
Meador, M.R., Hupp, C.R., Cuffney, T.F., and Gurtz, M.E., 1993b, Methods for characterizing stream habitat as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93–408, 48 p.
Miller, D.L., and others, 1988, Regional applications of an index of biotic integrity for use in water resource management: Fisheries, v. 13, no. 5, p. 12–20.
Moyle, P.B., 1986, Fish introductions into North America—patterns and ecological impacts, *in* Mooney, H.A., and Drake, J.A., eds., Ecology of biological invasions of North America and Hawaii: New York, Springer-Verlag

Publishers, p. 27–43. (Reprinted from Ecological Studies, v. 58.)
———1994, Biodiversity, biomonitoring, and the structure of stream fish communities, *in* Loeb, S.L., and Spacie, Anne, eds., Biological monitoring of aquatic systems: Boca Raton, Fla., Lewis Publishers, p. 171–186.
Omernik, J.M., and Gallant, A.L., 1986, Ecoregions of the Pacific Northwest: Corvallis, Oreg., U.S. Environmental Protection Agency, EPA 600/3–86/033, 39 p.
Osborne, L.L., and Wiley, M.J., 1992, Influence of tributary spatial position on the structure of warmwater fish communities: Canadian Journal of Fisheries and Aquatic Sciences, v. 49, p. 671–681.
Paller, M.H., 1994, Relationships between fish assemblage structure and stream order in South Carolina coastal plain streams: Transactions of the American Fisheries Society, v. 123, p. 150–161.
Platts, W.S., Megahan, W.F., and Minshall, G.W., 1983, Methods for evaluating stream, riparian, and biotic conditions: Ogden, Utah, U.S. Forest Service, General Technical Report INT–138, 70 p.
Poff, N.L., and Allan, J.D., 1995, Functional organization of stream fish assemblages in relation to hydrological variability: Ecology, v. 76, no. 2, p. 606–627.
Rabe, F.W., and Savage, N.L., 1977, Aquatic research natural areas in Idaho: Moscow, University of Idaho, Idaho Water Resources Research Institute, Research Technical Completion Report A–046–IDA, 103 p.
Rahel, F.J., 1990, The hierarchical nature of community persistence—a problem of scale: The American Naturalist, v. 136, no. 3, p. 328–344.
Rahel, F.J., and Hubert, W.A., 1991, Fish assemblages and habitat gradients in a Rocky Mountain-Great Plains stream—biotic zonation and additive patterns of community change: Transactions of the American Fisheries Society, v. 120, p. 319–332.
Richards, Carl, and Host, G.E., 1994, Examining land use influences on stream habitats and macroinvertebrates—a GIS approach: American Water Resources Association, Water Resources Bulletin, v. 30, no. 4, p. 729–738.
Robins, C.R., Bailey, R.M., Bond, C.E., Brooker, J.R., Lachner, E.A., Lea, R.N., and Scott, W.B., 1991, Common and scientific names of fishes from the United States and Canada: Bethesda, Md., American Fisheries Society Special Publication 20, 183 p.
Robinson, C.T., and Minshall, G.W., 1994, Biological metrics for regional biomonitoring and assessment of small streams in Idaho: Pocatello, Idaho State University, Stream Ecology Center, 113 p., 4 apps.
Rohlf, F.J., 1990, NTSYS-pc—numerical taxonomy and multivariate analysis system, version 1.60: Setauket, New York, Exeter Publishing [variously paged].
Rosgen, D.L., 1994, A classification of natural rivers: Catena, v. 22, p. 169–199.
Ruhl, P.M., 1995, Surface-water-quality assessment of the upper Illinois River Basin in Illinois, Indiana, and Wisconsin—analysis of relations between fish-community structure and environmental conditions in the Fox, Des Plaines, and Du Page River Basins in Illinois, 1982–84: U.S. Geological Survey Water-Resources Investigations Report 94–4094, 50 p.
Scott, W.B., and Crossman, E.J., 1973, Freshwater fishes of Canada: Ottawa, Fisheries Research Board of Canada, 966 p.
Sigler, W.F., and Sigler, J.W., 1987, Fishes of the Great Basin: Reno, University of Nevada Press, 425 p.
Simon, T.P., and Lyons, J., 1995, Application of the index of biotic integrity to evaluate water resource integrity in freshwater ecosystems, *in* Davis, W.S., and Simon, T.P., eds., Biological assessment and criteria—tools for water resource planning and decision making: Boca Raton, Fla., Lewis Publishers, p. 245–262.
Simpson, J.C., and Wallace, R.L., 1982, Fishes of Idaho: Moscow, The University Press of Idaho, 238 p.
Smith, G.R., 1981, Late Cenozoic freshwater fishes of North America: Annual Reviews of Ecology and Systematics, v. 12, p. 163–193.
Strahler, A.N., 1957, Quantitative analysis of watershed geomorphology: Transactions of the American Geophysical Union, v. 38, p. 913–920.
Ter Braak, C.J.F., 1986, Canonical correspondence analysis—a new eigenvector technique for multivariate direct gradient analysis: Ecology, v. 67, no. 5, p. 1167–1179.
———1988, CANOCO—a FORTRAN program for canonical community ordination by partial detrended canonical correspondence analysis, principal components analysis and redundancy analysis (version 2.1): Wageningen, The Netherlands, Ministry of Agriculture and Fisheries, Agricultural Mathematics Group, Technical Report LWA–88–02, 95 p.
Thurow, R.F., Corsi, C.E., and Moore, V.K., 1988, Status, ecology, and management of Yellowstone cutthroat trout in the upper Snake River drainage, Idaho: American Fisheries Society Symposium, v. 4, p. 25–36.
Tonn, W.M., 1990, Climate change and fish communities—a conceptual framework: Transactions of the American Fisheries Society, v. 119, p. 337–352.
U.S. Environmental Protection Agency, 1990, Biological criteria—national program guidance for surface waters: Washington, D.C., U.S. Environmental Protection Agency, Office of Water Regulations and Standards Report EPA–440/5–90–004, 57 p.
U.S. Geological Survey, 1975, Hydrologic unit map—1974, State of Idaho: Reston, Va., 1 sheet, scale 1:500,000.
———1986, Land use and land cover digital data from 1:250,000- and 1:100,000-scale maps; data users guide 4: Reston, Va., U.S. Geological Survey, 36 p.

———1989, Digital line graphs from 1:100,000-scale maps: Reston, Va., U.S. Geological Survey, 88 p.
U.S. Water and Power Resources Service, 1981, Water and Power Resources Service project data: Boise, Idaho, U.S. Water and Power Resources Service [Bureau of Reclamation], p. 583–1212.
Warren, M.L., Jr., and Burr, B.M., 1994, Status of freshwater fishes of the United States—overview of an imperiled fauna: Fisheries, v. 19, no. 1, p. 6–18.
Whittier, T.R., Hughes, R.M., and Larsen, D.P., 1988, Correspondence between ecoregions and spatial patterns in stream ecosystems in Oregon: Canadian Journal of Fisheries and Aquatic Sciences, v. 45, p. 1264–1278.
Wilkinson, Leland, 1992, SYSTAT for Windows—statistics, version 5: Evanston, Ill., SYSTAT, Inc., 750 p.
Wolman, M.G., 1954, A method for sampling coarse riverbed material: Transactions of the American Geophysical Union, v. 35, p. 951–956.

SUPPLEMENTAL INFORMATION

Photographs of sites representing the four major site types sampled in the upper Snake River Basin. (A) Site 1, Snake River at Flagg Ranch, reference stream site, sample collection date 9-7-94. (B) Site 5, Salt River near Etna, agricultural site, sample collection date 8-22-95. (C) Site 12, Portneuf River at Topaz, agricultural site, sample collection date 8-24-95. (D) Site 18, Rock Creek at Twin Falls, agricultural site, sample collection date 7-20-94.



Photographs of sites representing the four major site types sampled in the upper Snake River Basin—Continued. (E) Site 20, Briggs Spring near Buhl, reference spring site, sample collection date 4-21-94. (F) Site 21, Box Canyon Springs near Wendell, reference spring site, sample collection date 3-8-94. (G) Site 24, Big Lost River near Chilly, reference stream site, sample collection date 8-30-95. (H) Site 30, Snake River at King Hill, large river site, sample collection date 7-19-94.

Table A. Habitat characteristics for all sites in the upper Snake River Basin, 1993–95

[Site No.: a, b, and c refer to multiple-reach sites—a, upstream from reach; b, at reach; c, downstream from reach. Gaging-station name and number shown in table 2; site locations shown in figure 3. ft, feet; ft/s, feet per second; ft^3/s, cubic feet per second; CV, percent coefficient of variation estimates for discharge for each site, based on the period of record summarized by Kjelstrom and others (1995 and 1996; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; in., inches; —, missing data]

Site No. and year sampled	Reach length (ft)	Width (ft)	Depth (ft)	Width/depth	Velocity (ft/s)	Discharge (ft^3/s)	Discharge (percent CV)	Specific conductance (µS/cm)	Water temperature (°C)	pH	Dissolved oxygen (mg/L)	Percent dissolved oxygen saturation	Substrate size (in.)	Percent embeddedness	Percent substrate fines	Percent cover	Percent open canopy
1–93	1,690	154.2	2.0	77.0	1.77	353	34	263	9.6	8.3	9.0	101	3.1	44	6	4	78
1–94	1,690	131.6	2.1	63.7	.85	190	34	379	10.8	8.0	8.3	96	3.0	52	4	3	76
1–95	1,690	155.2	2.0	76.3	2.00	394	34	250	12.2	7.8	8.4	96	3.2	19.5	7	2	83
2–93	446	21.0	.8	26.7	1.25	7.8	41	402	2.5	7.8	10.7	101	5.0	36	15	28	61
3–93	1,483	126.6	2.0	62.3	2.46	316	28	357	5.6	7.9	10.2	102	5.0	24	14	4	72
4–93	623	23.0	1.0	22.6	2.10	30.4	40	343	13.6	8.6	10.4	130	5.0	38	10	17	76
5–93	1,519	131.9	3.0	43.7	2.43	810	30	495	13.3	7.9	9.3	110	1.6	58	44	9	95
5–94	1,519	149.6	2.3	65.1	1.35	353	30	483	11.1	7.9	7.0	101	1.6	62	19	10	94
5–95	1,519	151.6	.9	176.3	1.54	362	30	494	12.9	8.2	8.9	101	2.0	59	23	12	93
6–93	505	30.5	1.2	24.5	3.81	41	[1]15	129	8.2	8.1	8.9	99	2.2	31	19	16	58
7–93	787	138.5	1.6	84.4	2.85	548	24	140	11.6	8.5	8.8	102	18.0	14	4	15	61
8–93	581	55.8	.8	73.9	3.94	43.4	[2]29	172	6.8	8.3	9.0	91	7.0	18	5	15	72
9–93	—	—	—	—	—	744	24	320	14.7	8.5	8.3	102	—	—	—	—	—
10–93	2,395	243.5	4.8	51.2	2.07	1,830	37	200	16.4	7.7	7.2	88	.2	100	61	4	94
11–93	2,904	296.6	6.2	47.8	3.28	1,545	64	362	18.3	8.7	11.0	139	.2	66	58	4	79
12–93	1,152	72.2	3.3	21.8	1.31	173	31	669	18.7	8.1	6.9	90	1.5	88	83	15	94
12–94	1,152	67.9	2.8	24.6	.66	122	31	769	19.2	8.1	9.7	125	.1	98	92	13	93
12–95	1,152	63.0	3.3	19.2	.98	158	31	706	19.7	8.1	6.8	89	.1	99	90	13	96
13–93	1,516	79.7	3.3	24.3	2.10	142	7	485	14.7	8.3	9.8	113	.4	43	70	48	94
14–93	1,690	389.8	11.5	33.8	2.82	12,355	53	408	17.7	8.3	5.8	85	9.6	51	35	10	92
15–94	420	22.3	2.6	8.5	.23	9.9	[3]7	644	15.4	8.1	8.1	92	12.6	39	24	87	46
16–94	187	72.5	2.2	33.0	1.25	152	9	647	15.5	7.9	9.7	111	17.6	15	0	57	57
17–93	492	20.3	1.0	19.4	1.94	17.2	44	134	13.2	8.3	9.0	103	9.5	5	24	10	36
18–93	776	48.2	1.8	26.3	2.23	105	26	715	14.4	8.2	8.7	97	3.5	74	35	17	49
18–94a	758	39.0	2.6	15.3	1.15	123	26	712	17.7	8.0	7.7	92	1.1	80	43	9	51
18–94b	776	47.9	1.5	31.1	1.90	123	26	734	15.8	8.3	7.9	90	3.4	67	18	19	47
18–94c	633	48.2	2.0	23.7	1.05	123	26	762	16.2	7.8	8.1	91	2.2	76	26	19	60
18–95	776	47.9	1.6	29.2	2.79	145	26	733	15.5	8.3	8.9	107	3.3	90	29	19	48
19–93	4,216	341.2	15.4	22.1	1.41	3,510	54	553	17.9	8.3	9.0	105	3.1	80	76	13	84
20–94	778	66.9	1.5	43.4	.92	99.1	[3]7	458	14.5	8.0	8.9	97	4.6	25	41	97	72
21–94	387	25.3	1.3	18.8	1.28	29.2	5	406	14.5	8.1	8.8	98	20.0	8	14	83.6	53
22–93	371	20.0	1.4	14.2	1.31	20.4	36	236	15.2	8.3	7.4	86	14.9	45	30	32	60
23–93	492	24.9	1.7	14.3	2.40	83	22	445	13.3	8.4	8.3	97	1.2	42	25	11	77
24–93	994	73.5	1.8	40.7	3.64	243	41	170	14.5	8.6	7.6	98	4.1	46	8	5	58
24–94a	1,043	53.8	1.5	34.9	1.44	64.5	41	206	13.4	8.4	8.7	107	6.0	21	4	26	70
24–94b	994	54.5	1.4	37.7	1.31	64.5	41	205	12.3	8.7	9.2	109	4.7	40	8	12	54
24–95c	896	40.4	2.1	19.5	1.02	64.5	41	206	14.7	8.3	8.1	104	5.8	15	2	18	78
24–95	994	78.7	1.8	43.6	2.79	263	41	165	8.2	8.2	9.1	99	3.1	37	14	10	58
25–94	689	15.1	.6	24.2	.59	5.2	[3]7	378	15.4	8.0	8.4	94	1.2	63	66	30	22
26–93	922	69.6	1.3	54.4	2.99	145	26	122	7.7	7.6	8.1	90	4.0	6	12	10	71

Table A. Habitat characteristics for all sites in the upper Snake River Basin, 1993–95—Continued

Site No. and year sampled	Reach length (ft)	Width (ft)	Depth (ft)	Width/depth	Velocity (ft/s)	Discharge (ft^3/s)	Discharge (percent CV)	Specific conductance (μS/cm)	Water temperature (°C)	pH	Dissolved oxygen (mg/L)	Percent dissolved oxygen saturation	Substrate size (in.)	Percent embeddedness	Percent substrate fines	Percent cover	Percent open canopy
27–93	492	44.6	1.3	33.2	2.89	118	52	219	10.1	7.8	9.2	98	4.0	16	11	10	46
28–93	686	74.5	2.1	36.0	1.28	248	100	394	15.4	8.8	9.4	106	9.6	50	9	64	86
29–94	285	49.2	2.6	18.8	.49	25.3	[3]7	366	15.5	7.9	10.6	119	39.8	40	15	100	60
30–93	3,494	362.6	11.5	31.6	2.95	7,760	30	480	17.5	8.6	10.5	120	2.1	47	38	10	88
30–94	3,494	472.5	9.4	50.2	2.17	7,450	30	486	19.0	8.4	8.1	96	2.1	47	38	13	84
30–95	3,494	452.8	9.8	46.3	2.56	8,170	30	483	18.0	8.3	8.8	101	2.1	47	38	16	86

[1] Estimated from Warm River at Warm River (gaging-station No. 13044500).
[2] Estimated from Teton River near Driggs (gaging-station No. 13052200).
[3] Mean for Box Canyon and Blue Lakes Springs.

Table B. Summary of fish metrics, upper Snake River Basin, 1993–95

[Metrics were summarized using the information on each species from table 3. Site No.: a, b, and c refer to multiple-reach sites—a, upstream from reach; b, at reach; c, downstream from reach. Gaging-station name and number shown in table 2; site locations shown in figure 3. in., inches; <, less than; >, greater than]

Site No. and year sampled	No. of fish collected	No. of fish per minute electrofishing	No. of species	No. of native species	Percent anomalies	Percent introduced species	Percent common carp	Percent cottids	Percent salmonids	Percent juvenile salmonids (< 4 in. length)	Percent adult salmonids (> 8 in. length)	No. of intolerant species	Percent omnivores	Percent coldwater adapted
1–93	111	4	9	7	0	5	0	35	6	14	43	3	1	97
1–94	386	10	11	8	.3	11	0	38	23	42	4	5	15	85
1–95	243	4	8	8	1.0	5	0	12	18	20	30	3	0	64
2–93	70	6	2	2	7.0	0	0	53	47	0	61	2	0	100
3–93	47	2	3	3	0	0	0	91	6	33	0	2	0	100
4–93	127	5	3	3	0	0	0	76	24	39	3	2	0	100
5–93	104	3	9	7	1.9	14	0	9	57	22	61	5	34	66
5–94	159	5	7	6	4.4	16	0	30	61	37	45	4	9	91
5–95	76	2	6	5	5.2	5	0	47	32	12	83	4	21	70
6–93	66	6	4	1	0	59	0	41	59	59	13	4	0	100
7–93	67	2	5	4	0	13	0	76	13	33	11	2	0	100
8–93	86	7	5	4	0	1	0	84	16	7	50	4	0	100
9–93	126	8	4	4	0	0	0	66	3	100	0	2	0	96
10–93	111	5	10	7	.9	5	0	9	28	29	16	4	47	38
11–93	174	6	8	6	0	5	4	41	5	0	12	2	31	56
12–93	123	3	7	5	3.2	20	20	3	1	0	100	1	20	54
12–94	185	5	7	5	.5	16	15	10	1	0	100	1	15	62
12–95	115	4	8	6	2.6	12	10	9	2	0	100	1	13	63
13–93	72	2	6	4	4.1	13	0	38	36	12	69	4	30	70
14–93	79	2	7	4	5.0	6	1	0	0	0	0	0	59	1
15–94	49	3	2	1	18.4	80	0	0	80	26	18	1	20	80
16–94	116	9	4	4	0	0	0	9	3	50	25	1	0	38
17–93	89	2	4	4	2.2	0	0	0	11	0	50	1	0	82
18–93	157	4	8	7	1.9	20	0	27	32	27	41	2	6	87
18–94a	62	4	7	6	6.4	6	0	15	42	8	81	2	6	87
18–94b	176	8	10	9	1.7	14	0	18	51	39	10	2	2	85
18–94c	87	5	8	7	3.4	18	0	17	47	5	46	2	3	78
18–95	87	3	6	5	0	26	0	30	49	14	47	2	2	91
19–93	73	2	6	5	1.3	16	16	0	0	0	0	0	45	12
20–94	64	4	3	3	0	0	0	97	3	0	0	2	0	100
21–94	120	8	4	4	.8	0	0	29	45	13	20	2	26	74
22–93	57	1	8	7	0	0	0	33	11	67	0	2	0	88
23–93	38	3	2	2	0	0	0	71	29	54	18	2	0	100
24–93	25	2	3	3	0	0	0	84	16	0	50	3	0	100
24–94a	32	1	3	3	0	0	0	69	31	50	20	3	0	100

Table B. Summary of fish metrics, upper Snake River Basin, 1993–95—Continued

Site No. and year sampled	No. of fish collected	No. of fish per minute electrofishing	No. of species	No. of native species	Percent anomalies	Percent introduced species	Percent common carp	Percent cottids	Percent salmonids	Percent juvenile salmonids (< 4 in. length)	Percent adult salmonids (> 8 in. length)	No. of intolerant species	Percent omnivores	Percent coldwater adapted
24–94b	42	3	3	3	2.3	0	0	81	19	25	0	3	0	100
24–94c	79	2	3	3	0	0	0	80	20	12	31	3	0	100
24–95	35	2	2	2	0	0	0	83	17	100	0	2	0	100
25–94	57	5	2	2	0	0	0	44	56	72	16	2	0	100
26–93	65	1	3	2	0	2	0	65	35	65	9	3	0	100
27–93	126	8	5	3	.8	3	0	79	19	0	70	4	0	100
28–93	30	1	5	2	16.7	60	13	0	0	0	0	0	47	0
29–94	11	<1	3	3	0	0	0	82	0	0	0	1	0	100
30–93	666	12	8	7	.4	9	9	0	1	20	60	2	92	6
30–94	166	4	11	10	.6	6	6	11	2	0	0	2	56	40
30–95	259	9	11	9	2.3	5	4	4	0	0	0	0	44	42
Mean	115	4	6	5	2	10	2	39	23	24	31	2	14	76
Range	11–666	<1–12	2–11	1–10	0–18.4	0–80	0–20	0–97	0–80	0–100	0–100	0–5	0–92	0–100