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NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Scientific Investigations Report 2006-5300

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By Christine M. Albano and Elise M.P. Giddings

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FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources (http://www.usgs.gov/). Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity *and* quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) program to support national, regional, and local information needs and decisions related to water-quality management and policy (http://water.usgs.gov/nawqa). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA program aims to provide science- based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units (http://water.usgs.gov/nawqa/ nawqamap.html). Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings (http://water.usgs.gov/nawqa/natsyn.html).

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA program recognizes that a national assessment by a single program cannot address all water- resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Associate Director for Water

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Conversion Factors, Datums, and Abbreviated Water-Quality Units

SI to Inch/Pound

Multiply	By	To obtain
	Length	
micrometer (µm)	3.937×10^{-5}	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Volume	
milliliter (ml)	0.06102	cubic inch (in^3)
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
cubic meter (m^3)	35.31	cubic foot (ft^3)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). Altitude, as used in this report, refers to distance above the vertical datum. Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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

$$°F = (1.8 \times °C) + 32.$$

Concentrations of chemical constituents in water are reported only in metric units, either in milligrams per liter (mg/L) or micrograms per liter (µg/L). Specific conductance is reported in microsiemens per centimeter at 25 degrees Celsius (µS/cm).

Characterization of Habitat and Biological Communities at Fixed Sites in the Great Salt Lake Basins, Utah, Idaho, and Wyoming, Water Years 1999-2001

By Christine M. Albano and Elise M.P. Giddings

Abstract

Habitat and biological communities were sampled at 10 sites in the Great Salt Lake Basins as part of the U.S. Geological Survey National Water-Quality Assessment program to assess the occurrence and distribution of biological organisms in relation to environmental conditions. Sites were distributed among the Bear River, Weber River, and Utah Lake/Jordan River basins and were selected to represent stream conditions in different land-use settings that are prominent within the basins, including agriculture, rangeland, urban, and forested.

High-gradient streams had more diverse habitat conditions with larger substrates and more dynamic flow characteristics and were typically lower in discharge than low-gradient streams, which had a higher degree of siltation and lacked variability in geomorphic channel characteristics, which may account for differences in habitat. Habitat scores were higher at high-gradient sites with high percentages of forested land use within their basins. Sources and causes of stream habitat impairment included effects from channel modifications, siltation, and riparian land use. Effects of hydrologic modifications were evident at many sites.

Algal sites where colder temperatures, less nutrient enrichment, and forest and rangeland uses dominated the basins contained communities that were more sensitive to organic pollution, siltation, dissolved oxygen, and salinity than sites that were warmer, had higher degrees of nutrient enrichment, and were affected by agriculture and urban land uses. Sites that had high inputs of solar radiation and generally were associated with agricultural land use supported the greatest number of algal species.

Invertebrate samples collected from sites where riffles were the richest-targeted habitat differed in species composition and pollution tolerance from those collected at sites that did not have riffle habitat (nonriffle sites), where samples were collected in depositional areas, woody snags, or macrophyte beds. Invertebrate taxa richness, pollution tolerance, and trophic interactions at riffle and nonriffle sites responded differently to environmental variables.

Fish communities were assessed in relation to the designated beneficial use for aquatic life for each site. Fish-community sites in basins where agriculture and urbanization were prevalent consistently had poorer conditions than sites with forest and rangeland uses. Warm temperatures appear to be limiting most native fish species, and more introduced, warmwater fish species were present at sites with warmer temperatures. Ranges of environmental conditions where native species were present or absent were identified.

The farthest-upstream site in each of the three basins had better ecological condition overall, as indicated by the integrity of habitat and the presence of more sensitive algae, invertebrate, and fish species than were observed at sites downstream. The farthest-downstream site in each of the three basins showed the poorest ecological condition, with more tolerant organisms present, degraded habitat and water-quality conditions, and a high degree of effects from agriculture, grazing, and urbanization. Of the mid-basin sites, the site most affected by urbanization had more degraded biological condition than the agricultural indicator site of similar basin size.

Introduction

The U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) program was implemented in 1991 to assess the quality of the Nation's ground- and surface-water resources and to identify spatial and temporal trends in water quality at local, regional, and national scales (Gilliom, and others, 1995). The NAWQA approach is multidisciplinary and includes the collection of physical, chemical, and biological data. The Great Salt Lake Basins (GRSL) study unit was 1 of 15 study units selected to begin data collection in 1997.

The objectives of this study are to evaluate water quality in the GRSL study unit in terms of its ability to support aquatic biological communities and to provide a foundation upon which water managers may base their efforts to sustain favorable water-quality conditions in these basins. This study examines the relations among surrounding land use, hydrology, water chemistry, habitat, and biological communities. Natural and anthropogenic factors that relate to the occurrence and distribution of aquatic biological communities are identified, and an attempt is made to differentiate the effects of these factors on aquatic habitat and biota.

The GRSL study unit covers 37,600 km^2, covering much of northern Utah and extending into southeastern Idaho and southwestern Wyoming (*fig. 1*). In a national context, the

EXPLANATION

RB ○ **Fixed sampling site**—Letters indicate abbreviated site name

SMFK	Bear River below Smiths Fork, near Cokeville, Wyoming
PESC	Bear River at Pescadero, Idaho
CUB	Cub River near Richmond, Utah
COR	Bear River near Corinne, Utah
COAL	Weber River near Coalville, Utah
PLAIN	Weber River near Plain City, Utah
CREST	Little Cottonwood Creek at Crestwood Park, near Salt Lake City, Utah
LCCJOR	Little Cottonwood Creek at Jordan River, near Salt Lake City, Utah
JOR	Jordan River at Salt Lake City, Utah
RB	Red Butte Creek, at Fort Douglas, near Salt Lake City, Utah

Figure 1. Location of Great Salt Lake Basins study unit and fixed sampling sites.

study unit is representative of the semiarid environment of the Western United States. The study unit consists of three major drainage basins: the Bear River, the Weber River, and the Utah Lake/Jordan River. The headwaters of all three basins originate in the Uinta Mountains, a part of the Middle Rocky mountains Physiographic Province, and terminate in the Basin and Range Physiographic Province, forming deltas at Great Salt Lake. These basins extend across varied landscapes including the Wyoming Basin, Northern Basin and Range, and the Wasatch and Uinta Mountains ecoregions. Land use within the study unit is primarily agriculture and rangeland, with increasing urbanization in the lower basin areas (Baskin and others, 2002).

Ten fixed (permanently established sites where surface-water and ecological data are collected) sampling sites were selected in the Great Salt Lake Basins study unit to provide baseline physical, chemical, and biological data for a range of land-use and physiographic settings present within the basins, and to place these conditions within local and national contexts. The 10 fixed sampling sites (*fig. 1*) are described in *table 1*. Four sites each were located in the Bear River basin and the Utah Lake/Jordan River basin, and two sites were located in the Weber River basin. Seven of the sampling sites are designated as “indicator” sites, which were chosen to represent one or two dominant land-use types within the basin, such as urban, agricultural, forest, or rangeland (Baskin and others, 2002). The remaining three sites are located at the mouths of each of the three major drainage basins in the study area and are designated as “integrator” sites, which are intended to represent the cumulative effects of mixed land uses within each of these basins (Baskin and others, 2002).

Purpose and Scope

The objectives of this report are to provide an evaluation of water quality in the GRSL in terms of its ability to support aquatic biological communities, and to provide a foundation upon which water managers may base their efforts to sustain good water-quality conditions in these basins. This report examines the relations among surrounding land use, hydrology, water chemistry, habitat, and biological communities at 10 sampling sites in the GRSL study unit during the summers of 1999-2001. Natural and anthropogenic factors that relate to the occurrence and distribution of aquatic biological communities are identified, and an attempt is made to differentiate the effects of these factors on aquatic habitat and biota.

Quantitative and qualitative algal and macroinvertebrate samples were collected, and fish and habitat surveys were conducted annually at each site during the 3-year study period. Biological and physical habitat conditions were assessed using calculated metrics, and were compared among sites that vary in basin land use and physiography to assess the influence of these factors on ecological conditions. Spatial and temporal variation at selected sites also were examined to assess the usefulness of variables and metrics used to describe environmental conditions and biological communities. The results of this study will help managers to choose the best indicators of biological and water-quality conditions for water-quality monitoring and assessment.

Table 1. Description of fixed sampling sites in the Great Salt Lake Basins study unit, Utah, Idaho, and Wyoming

[Ecoregion: WYB, Wyoming Basin; CBR, Central Basin and Range; WUM, Wasatch and Uinta Mountains; Dominant land use: FR, forest and rangeland; AG, agricultural; MX, mixed; UR, urban]

Site name	Site	U.S. Geological Survey site ID	Drainage basin	Area of drainage basin, in square kilometers	Altitude, in meters	Ecoregion	Dominant land use[1]
Bear River below Smiths Fork, near Cokeville, WY	SMFK	10038000	Bear River	6,330	1,871	WYB	FR
Bear River at Pescadero, ID	PESC	10068500	Bear River	9,580	1,801	WYB	FR
Cub River near Richmond, UT	CUB	10102200	Bear River	575	1,353	CBR	AG
Bear River near Corinne,UT	COR	10126000	Bear River	18,300	1,282	CBR	MX/AG
Weber River near Coalville, UT	COAL	10130500	Weber River	1,100	1,709	WUM	FR
Weber River near Plain City, UT	PLAIN	10141000	Weber River	5,370	1,282	CBR	MX/UR
Little Cottonwood Creek at Crestwood Park near Salt Lake City, UT	CREST	10167800	Utah Lake - Jordan River	93	1,381	WUM	UR
Little Cottonwood Creek at Jordan River near Salt Lake City, UT	LCCJOR	10168000	Utah Lake - Jordan River	117	1,297	CBR	UR
Jordan River at 1700 South at Salt Lake City, UT	JOR	10171000	Utah Lake - Jordan River	9,090	1,286	CBR	MX/UR
Red Butte Creek at Fort Douglas near Salt Lake City, UT	RB	10172200	Utah Lake - Jordan River	19	1,646	WUM	FR

[1]Based on multi-resolution land characteristics, 1994.

Acknowledgments

The authors wish to acknowledge and thank the individuals in the field, office, and laboratory that assisted in the production of this report. Invertebrate taxonomic and abundance data were provided by the Biological Group at the USGS National Water Quality Laboratory in Denver, Colorado. Algal taxonomic and abundance data were provided by the Phycology Section of the Academy of Natural Sciences Patrick Center for Environmental Research in Philadelphia, Pennsylvania. Voucher collections of invertebrates and algae are deposited at the National Water Quality Laboratory and Academy of Natural Sciences, respectively. Michael Golden and Chet Barney of Utah State University, and Larry Brown of the USGS assisted in the identification of fish species. Several individuals assisted with sampling efforts during the study period, including Elise Boeke of the U.S. Fish and Wildlife Service, and Terry Short, Bert Stolp, Shane Wright, Nathan Grossman, Cynthia Hayek, Christopher Wilkowske, Peter Haraden, Michael Enright, Tyler Meadows, Aaron Norton, Courtney Neuffer, and Heidi Hadley of the USGS. Geographic Information Systems support was provided by Robert Baskin and Tim McKinney. Terry Short, Terry Maret, Steven Goodbred, Doyle Stephens, Stephen Porter, and Thomas Cuffney of the USGS provided expertise and technical assistance in data analyses. Anne Brasher and David Peterson of the USGS provided technical review comments on earlier drafts of this report. Michael Freeman and Lovina Abbott assisted with revisions on later drafts of this report. Joseph Gardner and Stefanie Dragos provided manuscript layout and graphic design of the report. Connie Allen provided editorial review comments, and Ellen Hardy provided a technical edit of the manuscript.

Methods of Data Collection

The collection of biological samples with supporting chemical and physical data was targeted toward characterizing sites during low-flow conditions. Habitat, algae, and invertebrate samples were collected concurrently from mid- to late August 1999 and 2000, and in mid-July 2001. Fish samples were collected in August 1999 and in September 2000 and 2001. Water-chemistry samples were collected monthly in 1999 and 2000 at all of the sites, but only at selected sites in 2001. A summary of sample scheduling by type and site is contained in *table A-1* in appendix A.

Water Chemistry

Water-chemistry samples were collected throughout the 3 years of sampling by following standard NAWQA protocols (Shelton, 1994). Water quality samples that were collected in August of the year biological samples were collected were used in data analyses for this study. Water samples were collected and analyzed for nutrients and major ions at all sites. Pesticides, trace metals, and volatile organic compounds (VOCs) were analyzed at selected sites. Detailed information on water-chemistry sampling methods for this study are published in Gerner (2003). Water quality data are available in the USGS National Water Information System database and the USGS NAWQA Data Warehouse. These databases are subject to periodic review and possible revision. Major ion, nutrient, trace metal, dissolved and suspended organic carbon, and sediment data also are available in USGS Water-Data Reports (Herbert and others, 1999, 2000, and 2001).

Discharge and Physical Properties

All sites are located at USGS streamflow-gaging stations where continuous stage and discharge data were recorded throughout the 3-year study period except at the Cub River, where data were recorded from October 1998 through September 2000. Most of the sites have longer periods of record for stage and discharge that were available for comparison with flow conditions during the sampling period. Field measurements including pH, dissolved oxygen concentration, water temperature, and specific conductance were recorded at the time of sampling. Continuous temperature data were collected at all of the sites with submersible temperature sensors equipped with data loggers. Temperature records were incomplete for Weber River at Coalville in 1999 and 2000 because of equipment problems, and for Cub River in 2001 because temperature monitoring was discontinued at this site in September 2000.

Habitat

Habitat was characterized at three spatial scales: basin, segment, and reach, as described by Fitzpatrick and others (1998). The basin is the largest spatial scale and includes the area of land in which water and dissolved materials may be transported into the drainage network upstream of the site. The stream segment is located within the basin and is defined as a stream section that is relatively homogenous physically, chemically, and biologically. The reach is the smallest spatial scale characterized, represents the greatest homogeneity in physical and chemical conditions, and is the primary focus in habitat characterization and biological data collection.

Reach lengths were determined according to guidelines outlined in Fitzpatrick and others (1998). These guidelines were (1) lengths should be set to maximize the number of geomorphic channel units (pools, riffles, and runs) included in the reach, (2) lengths should be set to include one full meander wavelength (Leopold, Wolman, and Miller, 1964), and (3) the length should be 20 times the average wetted width of the stream and range between 150 m and 500 m for wadeable streams and 300 m and 1,000 m for nonwadeable streams.

Basin

Basin-scale characteristics such as area, land use, physiographic province, and dominant ecoregion were determined for the drainage basin of each site. Basin boundaries were manually delineated by using USGS 7.5-minute 1:24,000-scale topographic maps. Information on land-use types was derived from satellite images obtained from the National Land-Cover data set produced by the Multi-Resolution Land Cover Characteristics Consortium in Sioux Falls, South Dakota. Dominant ecoregions for each basin are from Omernik (1987) and physiographic provinces are from Fenneman (1931).

Segment

A summary of the segment-scale characteristics defined from USGS 1:24,000-scale topographic maps is contained in *table B-1* in appendix B. Segment boundaries were set to minimize or exclude major natural features such as tributaries and changes in gradient or sinuosity, and water-management features such as lakes, dams, inflows, and diversions that could potentially disrupt the homogeneity of the segment. With these factors taken into consideration, boundaries generally were set at tributary junctions unless a substantial change in gradient or sinuosity was observed.

Segment boundaries, altitudes, and measurements of the valley side-slope gradient were manually determined by visual inspection of maps (Fitzpatrick and others, 1998). Valley lengths and curvilinear channel lengths of each stream segment were digitized from the maps, as were distances from sites to upstream water-management features that could potentially affect water quality. The segment gradient was calculated as the difference in altitude between upstream and downstream boundaries, divided by the curvilinear channel length. The sinuosity of the stream segment was calculated as the curvilinear channel length divided by the valley length.

The overall size of the stream and its drainage area were classified for each of the stream segments by using the Shreve (1967) method to determine the upstream and downstream links. Shreve stream link was calculated as the cumulative sum of tributaries that enter a stream segment and was determined for junctions upstream and downstream of the segment by using both intermittent (dashed blue lines on map) and perennial (solid blue lines on map) streams from 1:24,000 topographic maps. Diversions marked on maps such as irrigation canals and other modified systems demote the stream segment by an order of one.

Reach

Reach-level habitat characteristics were obtained through field measurements at the sites, as described by Fitzpatrick and others (1998). The water-surface gradient was calculated by surveying the altitude change between reach boundaries and dividing by the reach length. The presence and type of channel modifications along the reach were noted, and the distance to a reference site from the upstream and downstream ends of the reach were measured and recorded. The length of individual geomorphic channel units within the reach also were measured and recorded. Measurements of the percentage of daily solar radiation reaching the center of the stream were taken with a solar pathfinder at three points along the reach. Stage measurements were obtained from stream gages at the time of sampling to determine the discharge during the sampling period.

Eleven equidistant transects were located along each reach, where detailed habitat characteristics data were collected. Transect-level characteristics consisted of measurements relating to riparian canopy cover, instream habitat cover, near-bed channel characteristics, channel morphology, and hydrology. At each transect three instream depth and velocity measurements were recorded in addition to visual observations of habitat cover, substrate type, embeddedness, and silt deposition. Bank characteristics including canopy angles (overall canopy cover), riparian canopy cover (near-bank canopy cover), riparian land use, bank substrate, bank height, and bank vegetative cover were measured for each side of the stream. More information on the methods used to characterize stream habitat are available in Fitzpatrick and others (1998).

Algae

Algae samples were collected at each site in conjunction with the collection of habitat data. Two quantitative and one qualitative sample were collected at most sites. Quantitative samples were collected from two habitat types: (1) richest-targeted habitat (RTH) such as riffles, woody snags, and leaf surfaces; and (2) depositional-targeted habitat (DTH). Samples were collected from five locations along the reach and composited for identification and enumeration. Qualitative multihabitat (QMH) samples were collected from all habitat types present.

Algae samples were collected by using methods described by Porter and others (1993). At five sites, riffles were selected as the RTH. Five rocks were collected from each of five riffles in each reach and scraped free of algae. The area from which algae was scraped was measured with the foil template method described in Porter and others (1993). All 25 collections were composited and homogenized. At four sites, woody snags were selected as the RTH. Two to three snag sections were removed from each of five locations throughout the reach, and algae was scraped from the snags. The area sampled was determined by calculating the surface area of the snags. At one site (Bear River near Pescadero, ID) plant leaves were substituted for snags. Microhabitat data including depth, stream velocity, and embeddedness were collected and recorded at each sampling site.

Each composited RTH algae sample was divided into three subsamples. Two 5- to 10-ml subsamples were collected and filtered through a 0.45-μm glass-fiber filter for determination of ash-free dry mass (AFDM) and chlorophyll-a. AFDM analyses were done by the USGS National Water Quality Lab (NWQL) in Denver, Colorado. Chlorophyll-a samples were analyzed at the USGS Utah Water Science Center in-house laboratory and the USGS NWQL using high-pressure liquid chromatography methods. The remainder of the sample was preserved in formalin and sent to the Academy of Natural Sciences for identification and enumeration (Charles and others, 2002).

Epipelic (silt substrate) and episammic (sand substrate) algae DTH samples were collected from depositional areas at five sites along the reach with a spatula and petri dish to collect equal-sized, discrete samples at each site. The composite sample was preserved in 3- to 5-percent formalin and sent to the Academy of Natural Sciences for identification and enumeration.

QMH samples were composed of discrete collections of periphyton collected from each of the habitat types present in the reach, including epilithic (rock), epidendric (wood), epiphytic (plant), episammic (sand), and epipelic (silt) habitat types. Collections of microalgae from each habitat type were proportionally composited into one sample on the basis of the prevalence of each habitat type. Macroalgae were collected by visual inspection and composited separately. Samples were preserved in formalin and sent to the Academy of Natural Sciences for identification.

Invertebrates

Semiquantitative RTH and qualitative QMH invertebrate samples were collected at the time of habitat and algae sampling following methods described by Cuffney and others (1993a, 1993b). Invertebrate RTH samples were collected in approximately the same location as the algal RTH samples. At five sites, riffle habitats were sampled by dislodging invertebrates from the substrate and collecting them in a modified surber sampler (Slack sampler) with a 425-µm mesh net. Five samples were collected from a 0.25-m^2 area in each of five riffles. At the five sites that lacked riffles, RTH samples were collected from woody snag habitat at two sites, from macrophyte beds at two sites, and from depositional habitat at one site. Microhabitat characteristics including depth, velocity, substrate type, and embeddedness were recorded for each sampling site. Samples were preserved by using 10-percent buffered formalin and sent to the USGS NWQL for identification and enumeration (Moulton and others, 2000).

QMH samples were collected from all habitat types present within the reach and composited into one sample. Samples were collected from different habitat types by visual inspection of substrates and capture by using a D-frame kick net with 210-µm mesh. Samples were preserved with 10-percent buffered formalin and sent to the USGS NWQL for identification.

Fish

Fish surveys were completed at all of the sites in 1999, except for the Jordan River and Red Butte Creek. Jordan River fish data were collected in 2000, and information on fish communities in Red Butte Creek was obtained from the Utah State Division of Wildlife Resources for 1996. Fish surveys were conducted by using a two-pass electrofishing method (Meador, Cuffney, and Gurtz, 1993). Seine hauls supplemented electrofishing at sites SMFK and COAL. Backpack electrofishing equipment was used in smaller streams, and towed barge or boat equipment was used for larger streams.

Methods of Data Analysis

Water Chemistry

Water-chemistry data that were collected closely in time to the day of biological sampling were used in data analysis. Nutrient and major-ion values below the detection limit were assumed to have negligible concentrations and were reported as one-half the reporting value in this analysis.

Discharge and Physical Properties

Analysis of hydrologic data consisted of statistical summaries of annual discharge (Herbert and others, 1999, 2000, 2001), and interpretation of hydrographs of mean daily discharge during the 3-year sampling. Summary statistics of annual discharge were used in correlation analyses with habitat, temperature, and biological-community data. Hydrographs were used to illustrate seasonal and annual variation in discharge.

Field parameters were measured between 0900 and 1330 hours. It is important to note that pH, temperature, and dissolved-oxygen concentration have strong temporal variation and may not be directly comparable among sites because they were recorded on different days and at different times (Allan, 1995).

Daily temperature values were statistically summarized on an annual basis and for the summer (June 15 – September 15). Temperature statistics were used in correlation analyses with habitat, hydrologic, and biological-community data. Summary statistics were not calculated for datasets where greater than 20 percent of the data were missing. Because temperature data were incomplete for the Weber River at Coalville in 1999 and 2000, temperature data from 2001 were used in conjunction with analyses of biological data for all 3 years this site was sampled. This was done under the assumption that yearly temperature variation at this site is negligible relative to temperature variation among different sites.

Habitat

Habitat data collected at each of the transects were summarized for each reach with basic statistics to determine averages and variations in conditions. Habitat data were related to aquatic communities through correlation analyses. At sites PESC and COR, turbidity and deep-water conditions prevented thorough characterization of channel substrate, depth, and velocity, and estimates for these characteristics were based on qualitative observations and on previous measurements of the channel cross section made by USGS personnel during similar flow conditions.

For correlation analysis, transformations using $\log_{10}$, natural log, or arcsine square-root were used where appropriate to approximate a normal distribution of data prior to correlation analyses. Pearson's correlation, which assumes a normal distribution of data, was used to determine relations among transformed environmental variables. Pearson's correlation coefficient (r) was used to measure the strength of these relations. Significant correlations were reported at the 95-percent confidence level, with *p* values less than or equal to 0.05. Although scatter plots show nontransformed data, correlation coefficients are reported for normally distributed, transformed data.

Several habitat-quality assessment tools are currently available to provide a qualitative overview of habitat suitability for aquatic biota. The U.S. Environmental Protection Agency (EPA) provides guidance on the assessment of stream habitat based on a multimetric index of seven instream and three riparian characteristics in the Rapid Bioassessment Protocol (Barbour and others, 1999). These guidelines were used to assess data collected on habitat conditions at each site. Although this assessment was implemented after the collection of habitat data, data collection outlined in NAWQA protocols was sufficient to satisfy all of the categories of habitat conditions used in the EPA habitat assessment protocol.

Sites were separated into two groups: six high-gradient streams with water-surface gradients greater than 0.1 percent, and four low-gradient streams, which were assessed with different parameters. Seven habitat characteristics were used to evaluate all streams in both data sets: (1) stable habitat cover (woody debris, boulders, undercut banks, etc.), (2) percentage of occurrence of sediment deposition (siltation), (3) channel flow status, (4) type and degree of channel alteration, (5) bank stability, (6) riparian zone land-use type, and (7) bank vegetation protection. High-gradient streams also were evaluated by using percentage of embeddedness, riffle frequency, and variation in the velocity-depth regime. Low-gradient streams were evaluated by using pool substrate, pool variation, and channel sinuosity. Scores were assigned for each of the 10 habitat characteristics and summed for an overall habitat-quality score for each site, with higher scores representing higher quality habitat conditions relative to the other sampling sites. Scores were subdivided into "instream" and "riparian" components to discern how these individual components affected overall scores. Overall scores from the 10 sites were grouped into quartiles, and habitat quality for each of the four groups was designated as optimal, suboptimal, marginal, and poor.

Algae

Algal-community characteristics were summarized both qualitatively and quantitatively. Qualitative characteristics of communities include species richness (the number of species collected in a sample), and the identity of all species occurring at a given site. Abundances of algal cells were standardized to relative abundances (percentage of total abundance) for a quantitative comparison of communities among sites. Species diversity was calculated individually for RTH and DTH samples by using Simpson's index (Krebs, 1999).

Two-Way Indicator Species Analysis (TWINSPAN; Hill, 1979) was used to group and compare algal communities collected in RTH samples at each site. This is a hierarchical clustering technique that classifies both sites and species. Both qualitative and quantitative aspects of the data are considered in the classification. First, sites are classified according to similarities in species abundances among communities using relative abundances of 0, 2, 5, 10, and 20 percent as cut levels for the classification. Species that have very strong associations with a site grouping are identified and termed indicator species. Once the sites are classified, species are arranged in order based on the degree to which species are confined to a specific site group. Thus, site groups with distinct community assemblages are arranged near the edge of the classification, and those with more overlap in species are arranged near the center. This analysis was done using PC-Ord version 4.21 statistical software (McCune and Meffort, 1999).The maximum number of site divisions was set at three, and the maximum number of indicator species was set at five.

Autoecological data were compiled for individual algae species collected (Lange-Bertalot, 1979; Lowe, 1974; Bahls, 1993; and Van Dam and others, 1994). Analysis of variance was used to compare species assemblages among site groups determined by TWINSPAN. Physical and chemical conditions also were compared among site groups using analysis of variance to discern patterns in the distribution of algal species.

Invertebrates

Taxonomic data from invertebrate samples initially were analyzed by using Invertebrate Data Analysis Software (IDAS) version 2.0.6 (Cuffney, 2003), a program specifically designed to systematically resolve taxonomic ambiguities and calculate metrics for NAWQA qualitative and quantitative invertebrate data. Taxonomic ambiguities occur when organisms from the same sample, or group of samples, are not classified to the same taxonomic level. This introduces complications when interpreting or comparing taxonomic data for one or more samples. These ambiguities can be resolved in a number of ways. For this study, the lowest level of identification information was retained at the genus level because relatively few taxa were identified to the species level. Ambiguities were resolved on a sample-by-sample basis using options available in IDAS, and remaining ambiguities among samples for a single site were manually resolved.

Resolution of taxonomic ambiguities was slightly different for quantitative and qualitative samples. For quantitative samples, rare taxa were deleted if they composed less than 10 percent of the sample, or less than one percent of the total abundance. Ambiguous taxa occurring at multiple life stages were handled to maintain abundance-data integrity by using the option that deletes higher forms of the taxon (for example: Family) and distributes lower forms of the taxon (for example: Genus) based on their relative abundance. For qualitative samples, the option that deletes ambiguous taxa at higher classification levels but retains the identity of the same taxon at a more specific classification level was used to resolve ambiguities because this option maintains a high integrity of taxa richness data by minimizing redundancy among different taxonomic levels (T. Cuffney, U.S. Geological Survey, oral commun., 2003).

Community metrics, including those calculated for taxa richness (the number of different taxa), abundance (the number of organisms), percentage richness, and percentage abundance, were calculated using IDAS after ambiguities were resolved. Pollution tolerance (the ability of the assemblage to withstand poor water quality or habitat conditions) and diversity (the number and proportional distribution of taxa within the assemblage) indices also were calculated with this software. Pollution tolerance values were an average of regional tolerance values provided in the EPA Rapid Bioassessment Protocol (Barbour and others, 1999). Simpson's diversity index (eq 1) was chosen as a measure of diversity for invertebrate samples. These metrics and indices were used to compare community characteristics among samples and groups of samples.

$$D_S = 1-(\Sigma n(n-1))/N(N-1)) \qquad (1)$$

where:

D_S is Simpson's diversity,
N is the total number of individuals in the sample, and
n is the abundance of an individual taxon,

TWINSPAN analysis was used to group and compare RTH invertebrate samples on the basis of taxa presence and abundance as previously described for the analysis of algal data. Community metrics and environmental conditions were compared between two groups determined by the first division from TWINSPAN using analysis of variance. Spearman's Rank correlations (α=0.05 level of significance) were used to determine relations among community metrics and environmental characteristics because many invertebrate community metrics did not have normal distributions, even when transformed.

Fish

For each sample, the weight and the standard and total length of the first 30 fish of each species were measured and recorded. Additional fish of the same species were enumerated, but no length or weight data were recorded. Fish were inspected for anomalies and identified by a taxonomic specialist before being released. Fish that could not be identified in the field were retained for identification in the laboratory by a designated expert (Walsh and Meador, 1998).

Fish species collected in the basins were classified according to origin, tolerance to pollution, thermal optima, trophic guild, and adult habitat preferences on the basis of information on specific species obtained from Zaroban and others (1999), Chandler and others (1993), Barbour and others (1999), Sigler and Sigler (1996), and Maret (1997). Fish-community data were reported as relative abundance of species or individuals.

Temporal and Spatial Variation in Habitat and Biological Communities

Principal Components Analysis (PCA) was used to analyze temporal and spatial variation in habitat within and among selected sites (Jongman and others, 1995). Eleven noncolinear habitat characteristics were selected through correlation analysis. These variables were then $\log_{10}$ transformed and used in PCA.

Species-presence and relative-abundance data from fish surveys and RTH invertebrate and algae samples were $\log_{10}$ transformed and analyzed using cluster analysis to determine differences within sites and among sites. Morisita's modified coefficient of similarity and a centroid grouping measure were used in the cluster analysis. Results were plotted in dendrograms to give a visual representation of similarity at and among sites. Simpson's index was used to measure diversity in species assemblages for comparing variation within and among sites.

Characterization of Fixed Sites

The ecology of the fixed sampling sites in the GRSL can be characterized by describing the environmental setting, hydrology, water quality, and habitat at sites within the basins, and by considering how these factors may be influencing the corresponding condition of biological communities. Each of these components is considered individually and in relation to each other to provide a comprehensive characterization of stream conditions in the GRSL.

Environmental Setting of Fixed Sites

The environmental setting of the GRSL is affected by a multitude of natural and human factors that influence the physical, chemical, and biological condition of streams. Different combinations of climate, physiography, vegetation, soil type, land use, and water use create a wide range of environmental conditions among sites. In general, human factors such as land and water use are limited by natural factors, such as physiography and climate. For example, in the GRSL, more developed types of land use such as urban and agricultural occur in the flat, lowland areas of the basins, and forest and rangeland uses dominate in the more mountainous regions.

Bear River Basin

The Bear River basin (*fig. 2*) extends through the Wyoming Basin and Northern Basin and Range ecoregions. Four of the sampling sites are located in this basin. Site CUB (Cub River near Richmond, Utah), is located on the Cub River, a tributary of the Bear River, and the other three sites, SMFK (Bear River below Smiths Fork near Cokeville, Wyoming), PESC (Bear River at Pescadero, Idaho), and COR (Bear River near Corinne, Utah) are located along the main channel. Land use within the basin primarily consists of undeveloped forest and rangeland uses in the higher-altitude Wyoming Basin ecoregion, while land use in the lower-altitude Central Basin and Range ecoregion consists of rangeland, agriculture, and a small (less than 1 percent) percentage of urban land use.

The upper and lower sections of the Bear River are separated by Bear Lake, which is used for water storage for irrigation and power generation. The Bear Lake diversion system is a significant feature on the Bear River and a major controlling factor of downstream flows. The network of diversions present for regulating water at Bear Lake is shown in *figure 3*. During most of the year, water is diverted from the Bear River into Mud Lake, which is separated from Bear Lake by a dike spanning the northern edge of Bear Lake. Depending on downstream water demands, water is either stored in Mud Lake or released into the Bear Lake outlet canal to rejoin the main channel of the Bear River 31 km downstream from the outlet (*table 2*). During spring runoff, surplus water entering Mud Lake is released into Bear Lake for additional storage. Water can then be pumped from Bear Lake into the outlet canal as needed.

Site SMFK (*fig. 4*) is the farthest upstream site on the Bear River and is located at an altitude of 1,871 m. Land use in the basin upstream from this site consists of 75 percent rangeland, and this site is considered to be a forest/rangeland indicator for the GRSL. The stream segment for this site has a moderate water-surface gradient of 0.34 percent, which is a higher gradient than reaches just above this site have. This segment also has a low sinuosity coefficient, which indicates that the stream follows a relatively straight path through the valley.

Site PESC (*fig. 5*) is located 31 km downstream from the Bear Lake/Mud Lake outlet at an altitude of 1,801 m. The Bear Lake diversion network is the dominant water-management feature for this site. Land use in the basin upstream from this site is 70 percent rangeland, and this site is designated as a forest/rangeland indicator site. This stream segment has a water-surface gradient of 0.05 percent, which is much lower than that of the upstream site. The segment has a relatively low sinuosity when compared to other low-gradient streams within the GRSL, and flows through a moderately sloped valley. The reach is wide, highly exposed, and surrounded by a mixture of mostly grassland with wetland, pasture, and shrubs along the stream channel.

Site CUB (*fig. 6*) is a tributary to the Bear River and is located 6.3 km upstream of the confluence at an altitude of 1,353 m. Land use in the basin upstream from this site is 34

Table 2. Water-management features with the potential to affect water quality at fixed sampling sites in the Great Salt Lake Basins study unit

[Collected from USGS 7.5-minute topographic maps, 1:24,000 scale; for site abbreviations see table 1; EPA, U.S. Environmental Protection Agency; N/A, not applicable]

Site	Upstream distance from site (kilometers)	Feature description
SMFK	169.8	Woodruff Narrows Reservoir
PESC	30.5	Bear Lake via Bear Lake Outlet Canal
	36.9	Stewart Dam, diversion through Rainbow Canal into Mud Lake
CUB	15.3	Wastewater-treatment plant inflow
	17.3	Industrial waste ponds
	25.4	Cub Canal diversion
COR	63.5	Cutler Reservoir
COAL	17.8	Rockport Reservoir
PLAIN	1.3	Wastewater-treatment plant inflow
	11.7	Slaterville diversion dam
	12.5	Ogden Canal inflow
	54.1	Stoddard diversion
CREST	2.1	Union and East Jordan Canal diversion
	5.2	Water-treatment plant diversion
LCCJOR	1.0	Tailings pile, EPA superfund site
	6.2	Salt Lake and Jordan Canal inflow
	10.6	East Jordan Canal inflow
	11.3	Diversion
JOR	3.3	Central Valley wastewater-treatment plant inflow
	9.3	South Valley wastewater-treatment plant inflow
	20.3	Jordan Canal return inflow
	24.2	Slag pile
	26.3	Tailings ponds, EPA Superfund site
	48.0	Jordan Narrows dam
	63.5	Utah Lake
RB	N/A	none

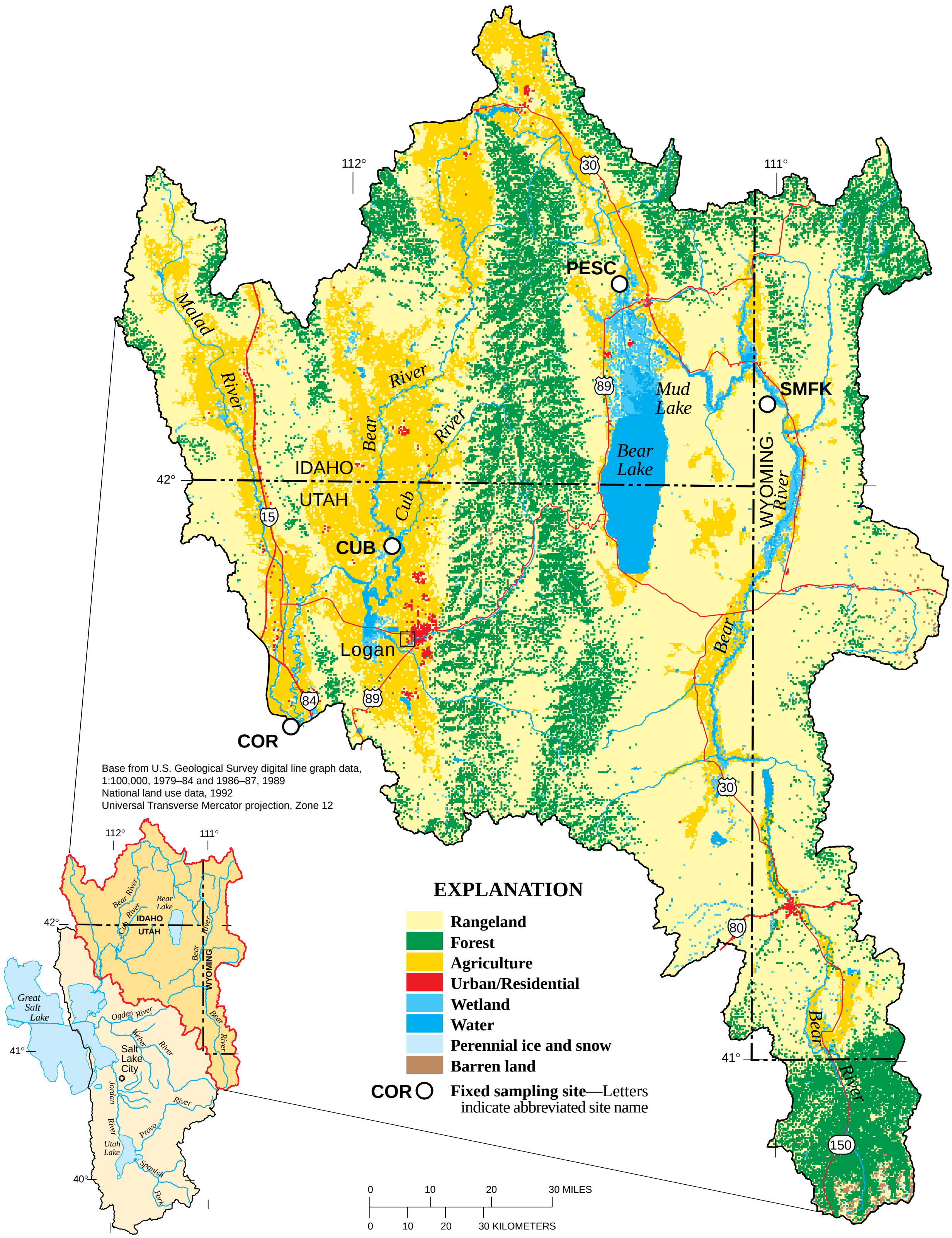

Figure 2. Land use and location of fixed sampling sites in the Bear River basin.

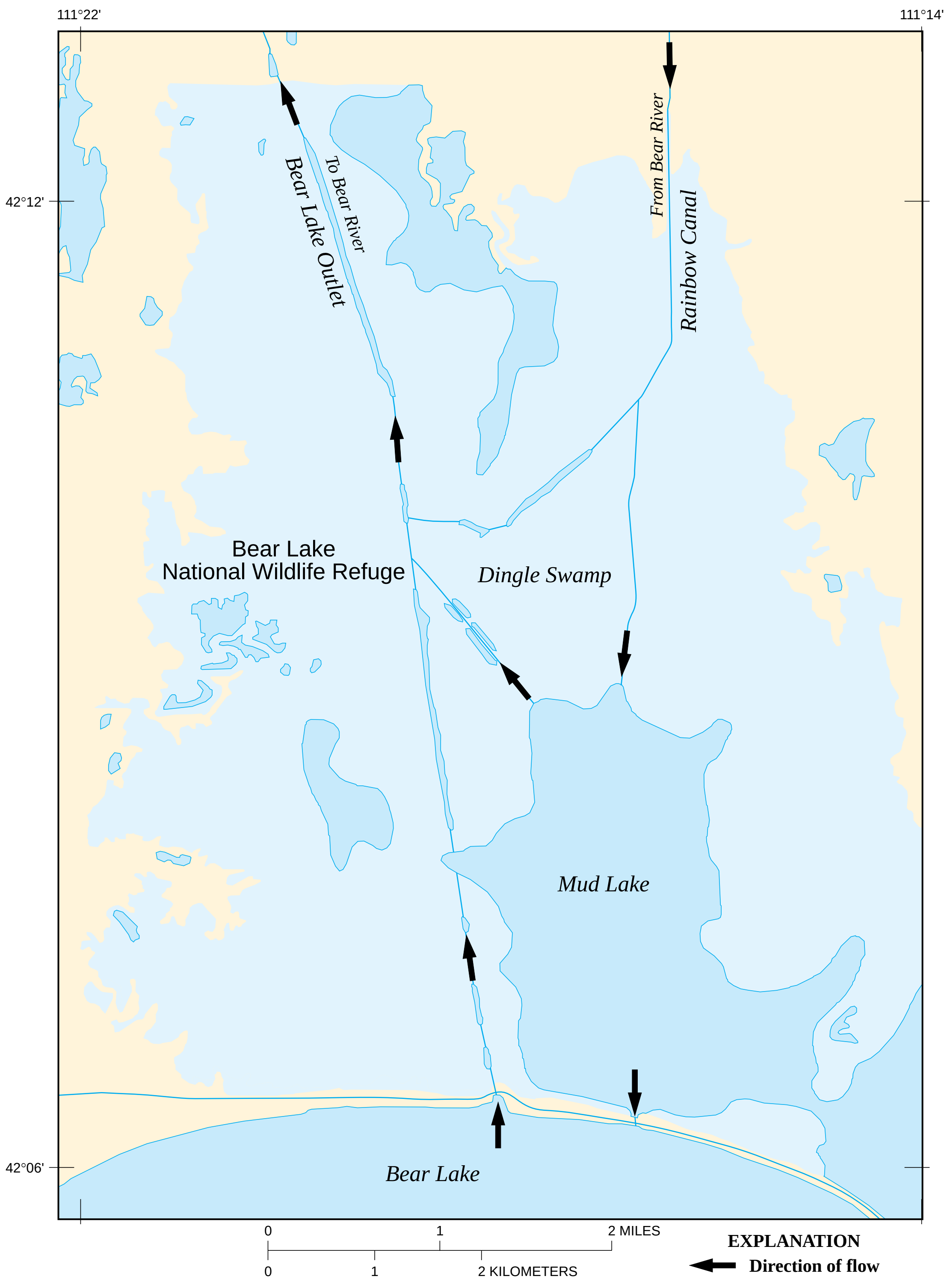

Figure 3. Diversion network for regulation of the Bear River at Bear Lake, Idaho.

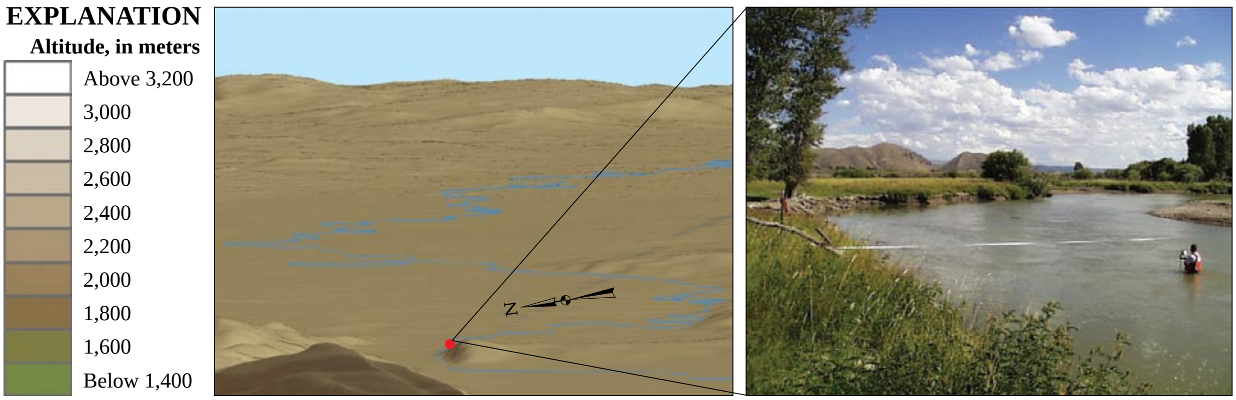

Figure 4. Fixed sampling site at Bear River below Smiths Fork near Cokeville, Wyoming.

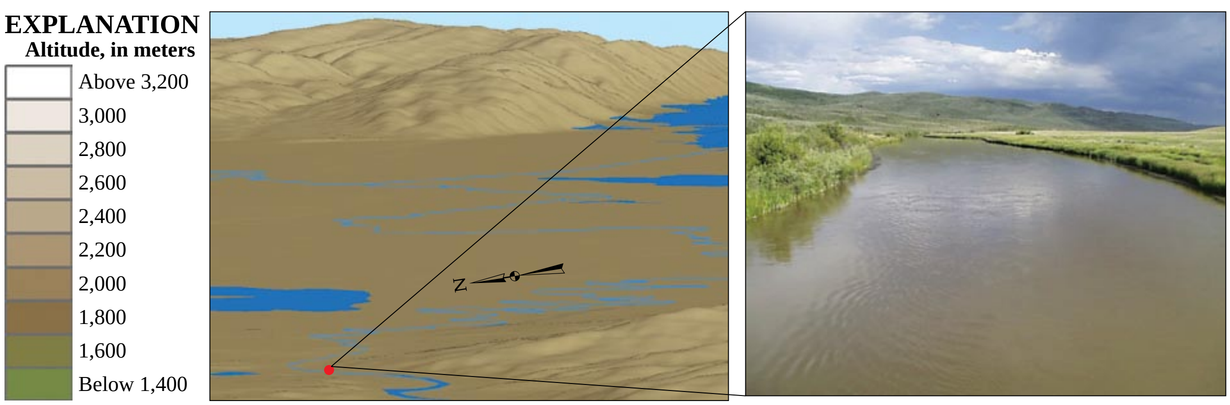

Figure 5. Fixed sampling site at Bear River at Pescadero, Idaho.

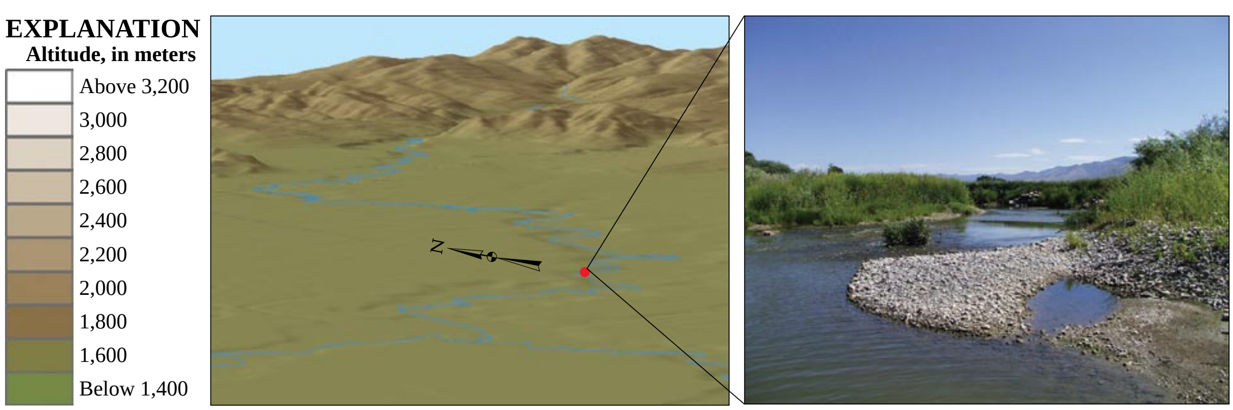

Figure 6. Fixed sampling site at Cub River near Richmond, Utah.

percent agricultural, and this site is designated as an agricultural indicator site. Significant upstream water-management features include a wastewater-treatment plant about 15 km upstream and a diversion dam to the Cub Canal about 25 km upstream. This segment of the Cub River has a water-surface gradient of 0.19 percent and has a much smaller drainage basin than the other Bear River sites. Site CUB is located in the midst of cropland, pasture, and grassland, with sparsely vegetated streambanks that leave the stream relatively exposed to sunlight. In the summer of 2000, significant alterations of the stream channel were completed in a cooperative restoration effort by private, local, State, and Federal agencies. Wingdams were built along meanders, trees were planted, and steep, undercut banks were graded to improve bank stability and reduce streambank erosion (Utah Watershed Program, 2002).

Site COR (*fig. 7*) represents stream conditions affected by a mixture of land uses within the Bear River basin and is located 34 km upstream from Great Salt Lake at an altitude of 1,282 m. The dominant water-management feature at this site is Cutler Dam, which is used for power generation, and is located 63.5 km upstream. This segment of the Bear River has a low gradient of about 0.02 percent, and has a very high sinuosity coefficient, which indicates that the stream follows a meandering course.

Weber River Basin

The Weber River basin is located in the Wasatch and Uinta Mountains ecoregion. The basin mainly consists of forest and rangeland with less than 5 percent each of agriculture and urban land use (*fig. 8*). Two sampling sites are located in this basin. Site COAL (Weber River near Coalville, UT) is a forest-rangeland indicator site, and site PLAIN (Weber River near Plain City, UT) represents a mixture of land uses, including forest, rangeland, agricultural, and urban.

Site COAL (*fig. 9*) is located between two large reservoirs at an altitude of 1,709 m. Rockport Reservoir is 18 km upstream and Echo Reservoir is just downstream from the site. Land use within the basin upstream of this site is 61 percent forested and 32 percent rangeland, and the riparian area along the reach mainly consists of pasture with some shrubs and woodland. The stream segment has a moderate gradient of about 0.36 percent and flows through a moderately sloped valley.

Site PLAIN (*fig. 10*) is at an altitude of 1,282 m and represents the mixture of land uses within the Weber River basin. This stream segment has a low gradient of 0.08 percent and flows through a relatively flat valley before converging with Great Salt Lake 21 km downstream from the site. A wastewater-treatment plant located 1 km upstream contributes flow to this site, and the Slaterville diversion dam located 12 km upstream diverts water into the Layton and Willard canals. The riparian area surrounding this site is a mixture of cropland, shrubs and woodland, and pasture. Although this site is located in an agricultural area, it is heavily influenced by urban land use because the stream flows through an urban area just upstream from the site.

Utah Lake/Jordan River Basin

The Jordan River is the link between Utah Lake and Great Salt Lake and runs along the floor of Salt Lake Valley. The dominant ecoregions within the Utah Lake/Jordan River basin are the Wasatch and Uinta Mountains at higher altitudes, with lower altitude areas dominated by the Central Basin and Range ecoregion. Like the Bear and Weber River basins, headwaters originate in the Middle Rocky Mountains Physiographic Province and terminate in the Basin and Range Province. Four of the sampling sites are located within the Utah Lake/Jordan River basin (*fig. 11*): CREST (Little Cottonwood Creek at Crestwood Park near Salt Lake City, UT), LCCJOR (Little Cottonwood Creek at Jordan River near Salt Lake City, UT), JOR (Jordan River at 1700 South at Salt Lake City, UT), and RB (Red Butte Creek at Fort Douglas, near Salt Lake City, UT). Land use in this basin consists of a mixture of forested, agricultural, rangeland, and urbanized areas. All of the sites except for RB are in urban areas, and sampling efforts at these sites were targeted toward assessing effects from urbanization.

Site CREST (*fig. 12*) is at an altitude of 1,381 m and is the upstream urban indicator site on Little Cottonwood Creek, with 10 percent of the upstream basin consisting of urban land use. This site is 5 km downstream from a water-treatment

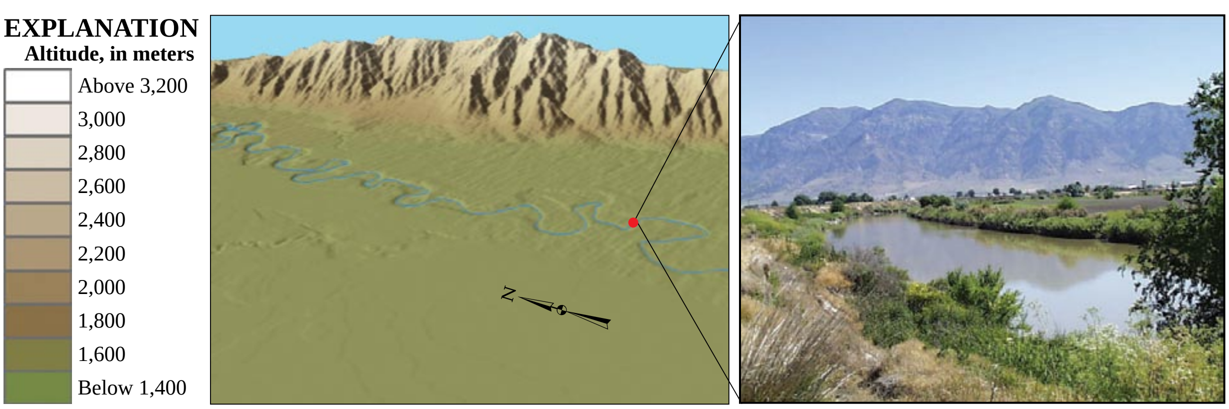

Figure 7. Fixed sampling site at Bear River near Corinne, Utah.

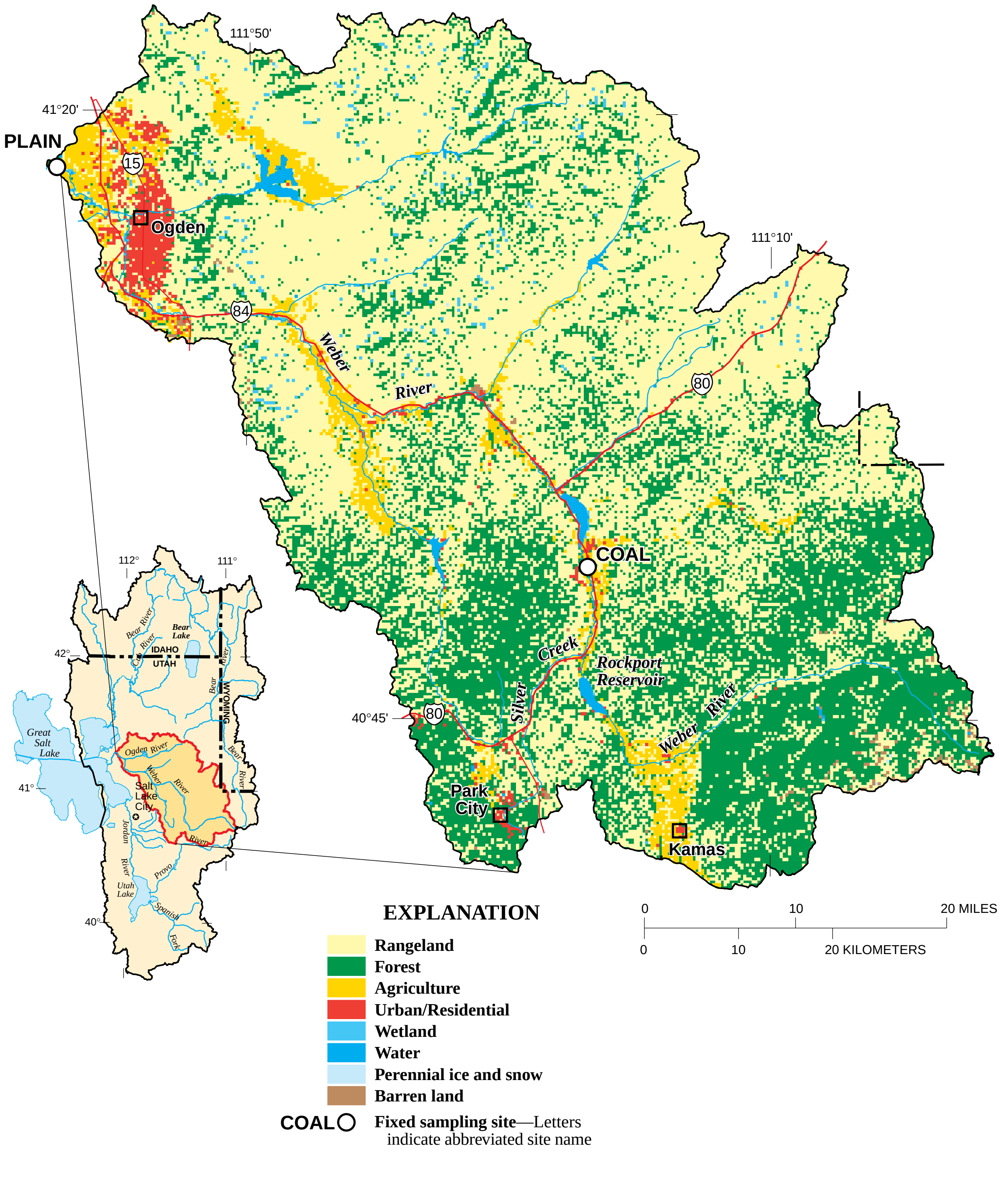

Figure 8. Land use and location of fixed sampling sites in the Weber River basin.

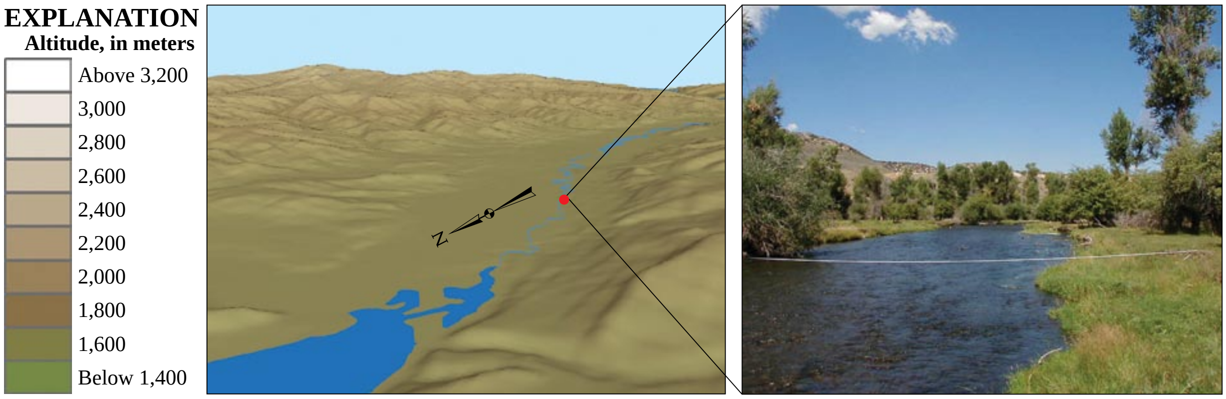

Figure 9. Fixed sampling site at Weber River near Coalville, Utah.

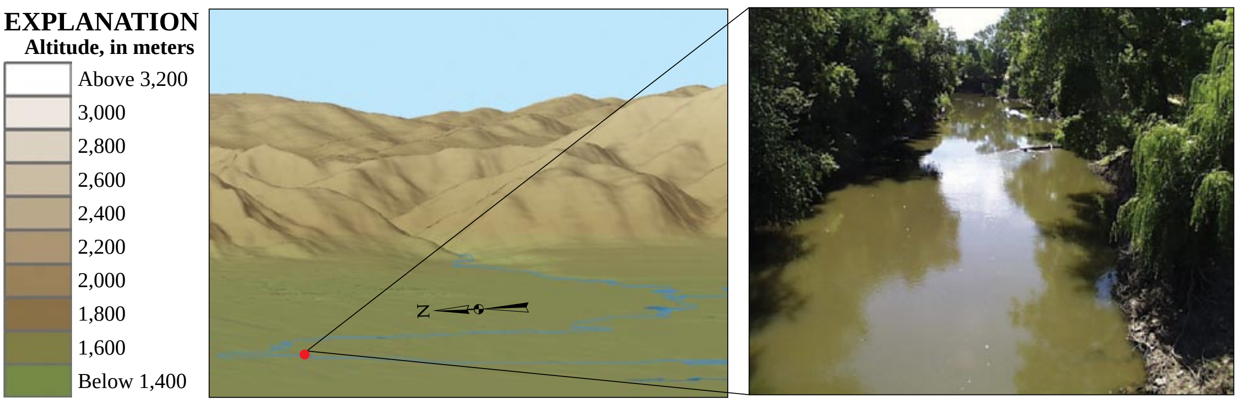

Figure 10. Fixed sampling site at Weber River near Plain City, Utah.

plant where water is regularly diverted for municipal use. As a result, inflows sometimes consist solely of local groundwater discharge. The gradient for this stream segment is 1.65 percent, and the valley sides are gently sloped. The segment is located at the base of the Wasatch Mountains and represents a transitional zone in the stream gradient where it changes from high to low gradient as it reaches the valley floor. The riparian area at this site consists of a wide band of shrubs and woodland surrounded by urban residential land use.

Site LCCJOR (*fig. 13*) is about 9 km downstream from site CREST and 1 km upstream from the confluence with the Jordan River at an altitude of 1,297 m. The gradient in this stream segment is lower than that of the upstream segment, at 0.48 percent. This site is more heavily affected by urbanization than the upstream site, with 26 percent of the upstream basin consisting of urban land use. Several diversions and exchanges of water alter flow regimes in Little Cottonwood Creek between these two sites. Because the dynamics of these exchanges are subject to changes in municipal and agricultural water demands, they vary seasonally and are unpredictable on a short time scale. The stream also flows adjacent to a smelter tailings pile about 1 km upstream from the site, which is an EPA superfund site. Along this segment, the riparian area consists of a narrow band of trees surrounded by commercial/industrial urban land use.

Site JOR (*fig. 14*) is a mixed land-use integrator site for the Utah Lake/Jordan River basin. This site is at an altitude of 1,286 m and is about 63 km downstream from its source, Utah Lake. Although there is a large percentage of forest, rangeland, and agricultural land use within the Utah Lake/Jordan River basin, this site is most heavily influenced by urbanization (Baskin and others, 2002). The Jordan River flows through industrial areas and receives inflows from two wastewater-treatment plants. It also undergoes numerous diversions and exchanges of water. Discharge at this site is completely regulated. Most of the water is diverted 1 km upstream of the study site into a surplus canal for the purpose of flood control, resulting in much lower flows than would occur naturally. Minimum flows are maintained at this site to satisfy water rights for downstream water users, and about

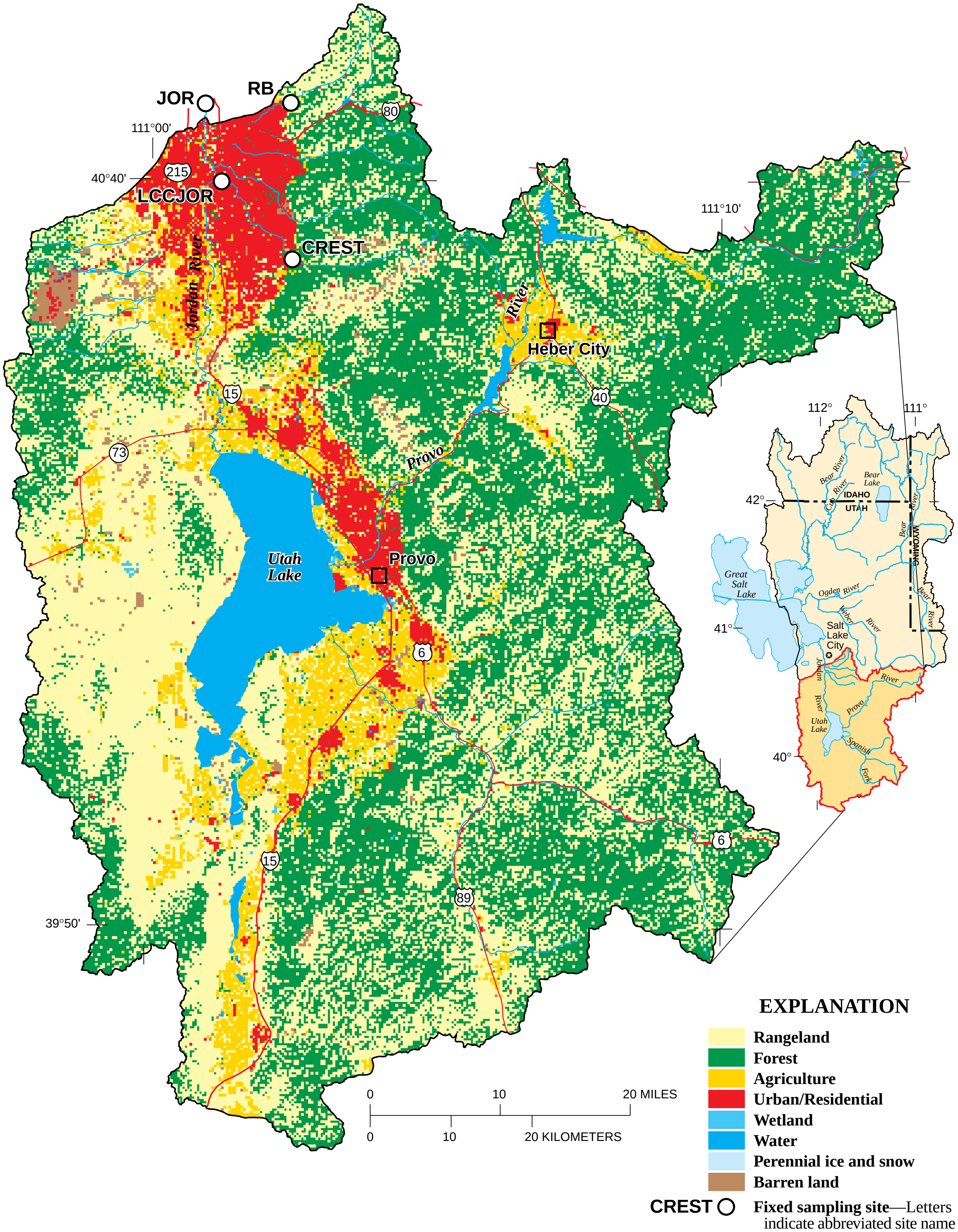

Figure 11. Land use and location of fixed sampling sites in the Utah Lake/Jordan River basin.

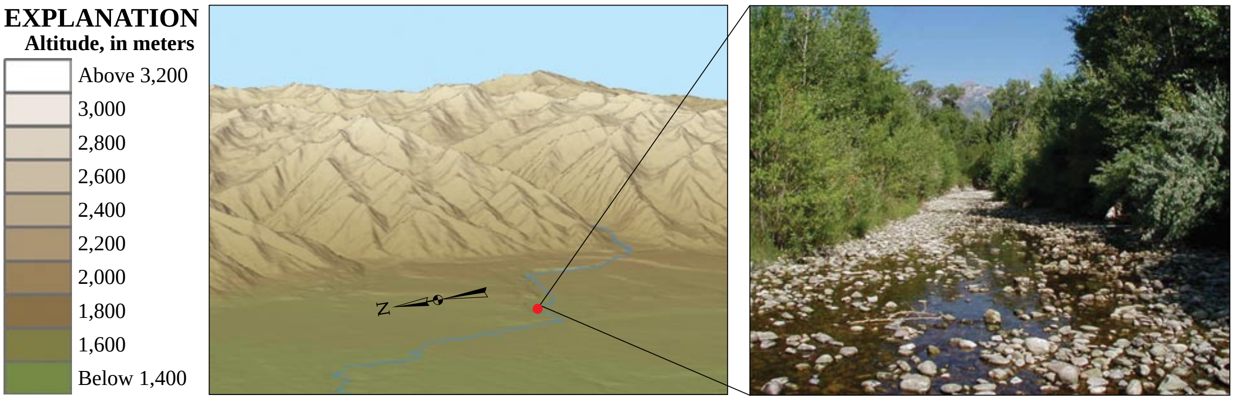

Figure 12. Fixed sampling site at Little Cottonwood Creek at Crestwood Park near Salt Lake City, Utah.

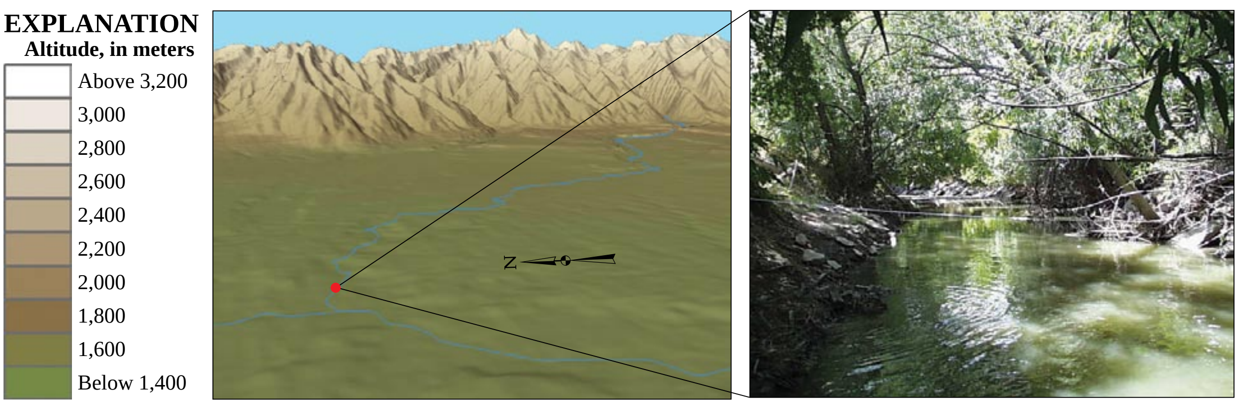

Figure 13. Fixed sampling site at Little Cottonwood Creek at Jordan River near Salt Lake City, Utah.

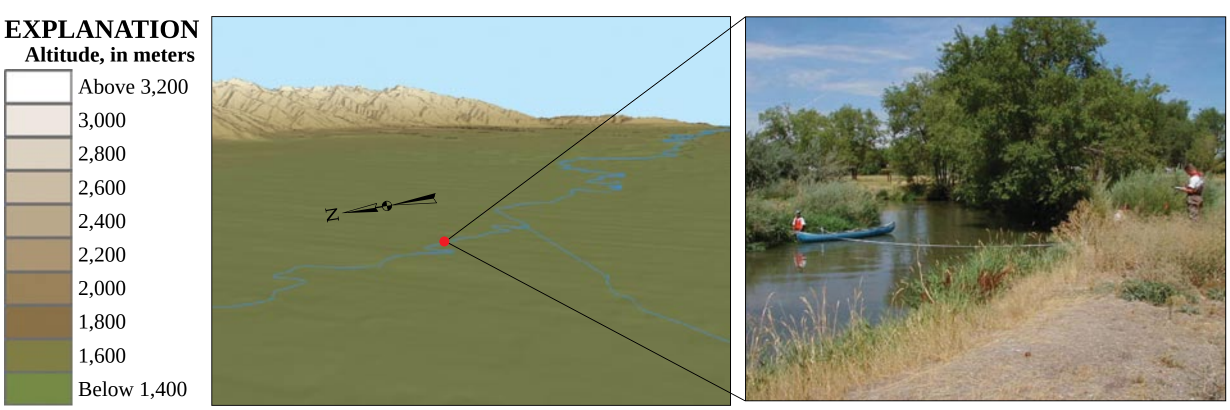

Figure 14. Fixed sampling site at Jordan River at 1700 South at Salt Lake City, Utah.

1,420 m^3 of water was released during each year of the study. This segment of the stream has a low gradient of 0.024 percent and flows primarily through commercial and industrial areas along the valley floor.

Site RB (*fig. 15*) is at an altitude of 1,646 m on a small mountain stream that is relatively unaffected by anthropogenic activities. The site is in a U.S. Forest Service Research Natural Area, and public access is restricted to maintain the integrity of the natural ecosystem. The upstream basin consists of 56 percent rangeland and 44 percent forested land, and RB is designated as a forest/rangeland indicator site. The stream segment of this site has a high gradient of 5.7 percent and is surrounded by steeply sloped valley walls and dense shrubs and woodland.

Hydrology and Streamflow Regulation

Selected hydrologic data for fixed sampling sites in the GRSL are contained in *table 3* (Herbert and others, 1999, 2000, 2001). Stream discharge at sites within the GRSL study unit correlates significantly with drainage basin area ($r = 0.92$, $p < 0.0001$) (*fig. 16*). Discharge at site JOR was lower than expected from this correlation because of the large upstream diversion. Annual mean discharge in water year 1999 ranged from 0.155 m^3/s at site RB to 72.7 m^3/s at site COR. Compared to long-term records, discharge was higher than average in 1999 and lower than average in 2000 and 2001 (*fig. 17)*.

Extensive regulation of rivers in the GRSL, including impoundments, diversions, and exchanges of water, has a strong influence on streamflow dynamics and water quality (Baskin and others, 2002). All of the sites in the GRSL, with the exception of RB, have flows that are regulated to some degree. Rivers within the basins are regulated for several reasons, including power generation, agricultural and municipal use, and flood control (Utah Division of Water Resources, 1992, 1997). Regulation affects seasonal runoff patterns as well as maximum and minimum flows throughout the year. The natural flow regime of rivers within the basins generally consists of peak flows during the spring from snowmelt runoff, followed by base-flow conditions in the late summer and early fall when snowmelt is complete and surface runoff

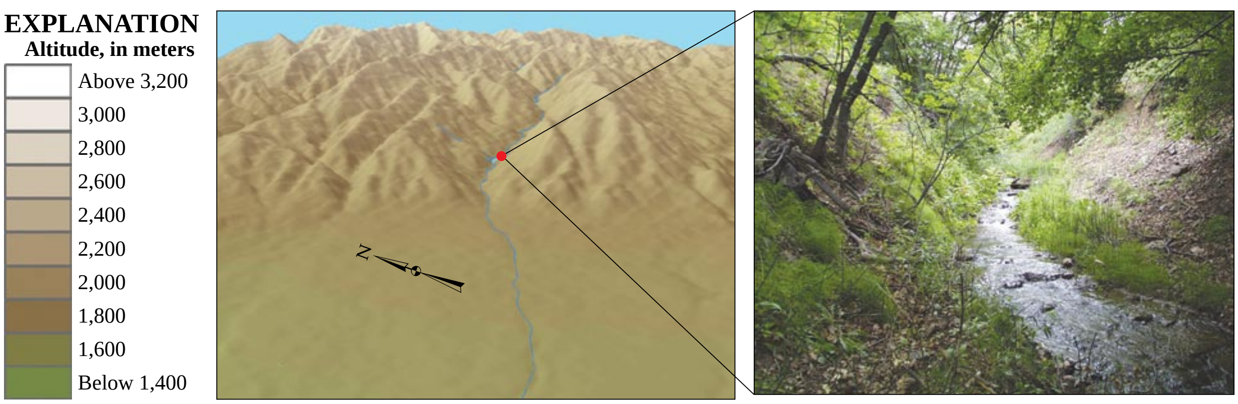

Figure 15. Fixed sampling site at Red Butte Creek at Fort Douglas, near Salt Lake City, Utah.

Table 3. Selected hydrologic data for fixed sampling sites in the Great Salt Lake Basins study unit

[Annual statistics for all sites except for JOR are for October 1, 1998, through September 30, 1999. For site JOR, annual statistics are for October 1, 1999, through September 30, 2000; for site abbreviations see table 1; data from Herbert and others (1999, 2000, 2001)]

Site	Annual discharge (million cubic meters)	Annual mean discharge, (cubic meters per second)	Highest daily mean discharge (cubic meters per second)	Lowest daily mean discharge (cubic meters per second)	Annual 7-day minimum discharge (cubic meters per second)	Coefficient of variation of daily mean discharge (percent)
SMFK	615	19.5	81.0	4.98	5.32	89.0
PESC	946	30.1	44.5	12.6	14.9	24.7
CUB	162	5.13	26.9	0.963	1.10	125
COR	2,300	72.7	170	11.8	23.7	47.6
COAL	237	7.50	37.1	2.29	2.41	83.4
PLAIN	555	17.6	91.2	1.98	2.21	118
CREST	30.6	0.968	10.2	0.00198	0.00906	226
LCCJOR	40.4	1.28	10.1	0.0708	0.0765	175
JOR	111	3.51	5.01	0.190	0.252	32.6
RB	4.89	0.155	0.623	0.0510	0.0623	89.6

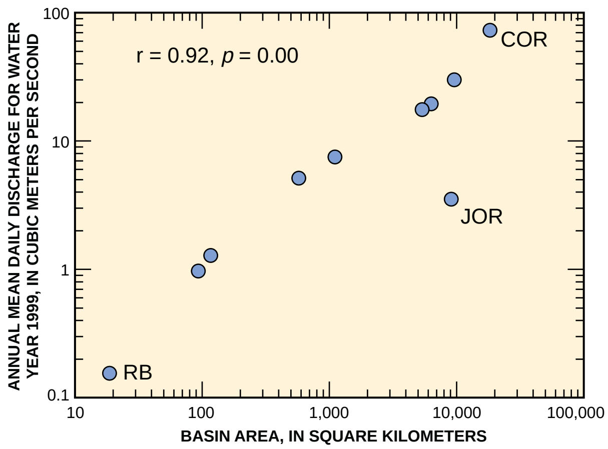

Figure 16. Relation between annual mean daily discharge and basin area for fixed sampling sites in the Great Salt Lake Basins study unit, 1999.

is minimal (Baskin and others, 2002). Although this pattern persists despite regulation in some streams within the basins, it is masked in others where streamflow is highly regulated (*fig. 17*).

The hydrograph for site SMFK displays the expected runoff pattern from a site in the Bear River basin that is less affected by regulation. Flows begin to rise in early March, with peak flow occurring in early June. Base-flow conditions persist throughout the rest of the year at this site. Sites PESC and COR (both on the main stem of the Bear River) are both located downstream from dams and are substantially affected by regulation for power generation and releases for irrigation. Both sites display erratic flow patterns that are more strongly influenced by releases from upstream reservoirs rather than by seasonal runoff patterns. At these two sites, flows throughout the winter months are high relative to base-flow conditions, and peak flows are controlled and reduced by upstream impoundment for power generation and irrigation reserves. At site COR, large daily fluctuations also are evident as a result of power generation at Cutler Dam.

Regulation of water in the Weber River basin is primarily in the form of diversions for irrigation. Although there are several reservoirs upstream of both Weber River sites, seasonality in flows is still observed at both sites. Even though much of the water is diverted for irrigation during the summer, irrigation return flows also supplement streamflow during this period.

In the Utah Lake/Jordan River basin, regulation of water is mainly in the form of diversions for municipal use, irrigation, and flood control. Diversions of 133 million gallons (503,500 m^3) per day for municipal water use (Utah Division of Water Resources, 1997) upstream from site CREST, and irrigation diversions and return flows upstream from site LCC-JOR, substantially affect discharge at both Little Cottonwood Creek sites. Although seasonal patterns are still observed, the rate of discharge at these sites in the summer months is lower than would be expected in the absence of upstream water diversions. Site JOR lacks the natural seasonality in its runoff patterns because discharges are maintained at this site exclusively for downstream water rights, while excess water is diverted into the Jordan River surplus canal for flood control 1 km upstream. In the GRSL, the effects of regulation on the natural flow regime is generally manifested in three ways: (1) steadied flows that lack natural seasonal peaks and troughs are maintained at sites PESC, COAL, and JOR, where flows are regulated primarily to sustain downstream water rights, (2) large and abrupt daily fluctuations in flows at site COR are the result of water releases for power generation that occur upstream, and (3) reduced flows at site CREST are the result of water diversions upstream for municipal water use, with complete dewatering of the channel during some parts of the year when water use is high and natural flow conditions are low. Diversions also occur upstream from sites PLAIN, LCC-JOR, and CUB; however, supplemental irrigation return flows result in less dramatic effects on flow conditions at these sites.

Temperature

Water temperature is an important component of habitat for aquatic organisms. Seasonal changes in water temperature can act as a cue for life-stage changes and determine the distribution of aquatic biota according to temperature tolerances and optima for different species (Allan, 1995). Several environmental factors influence water temperature in streams, including the relative contribution of flow from ground water and surface-water runoff, air temperature, discharge, and stream surface-area exposure to solar radiation (Allan, 1995). Annual and summer (June 15 – September 15) temperature data measured at each of the sampling sites are summarized in *table 4*.

Altitude and discharge appear to be the predominant factors that account for variation in stream temperature among sites. Site altitude and mean annual temperature are significantly correlated (r =-0.69, p = 0.03). Sites at higher altitudes are exposed to lower air temperatures and therefore have lower water temperatures. Although a significant correlation, site altitude does not account for all of the variation among annual mean temperatures at the 10 sites, and it can be inferred that other factors such as exposure to solar radiation, riparian shading, stream width, and discharge also may influence stream temperature at these sites.

A strong relation exists between discharge and water-temperature variation. Daily temperature variation (daily range) decreases with stream size (r = -0.70, p = 0.03), and seasonal variation (standard deviation of daily mean) increases with stream size (r= 0.93, p = 0.00). Water volume is a likely explanation for this relation. Larger volumes of water retain heat for a longer period of time, which results in a smaller diurnal change in temperature. This relation between water volume and temperature carries implications toward the effects of streamflow regulation on stream temperature regimes, and

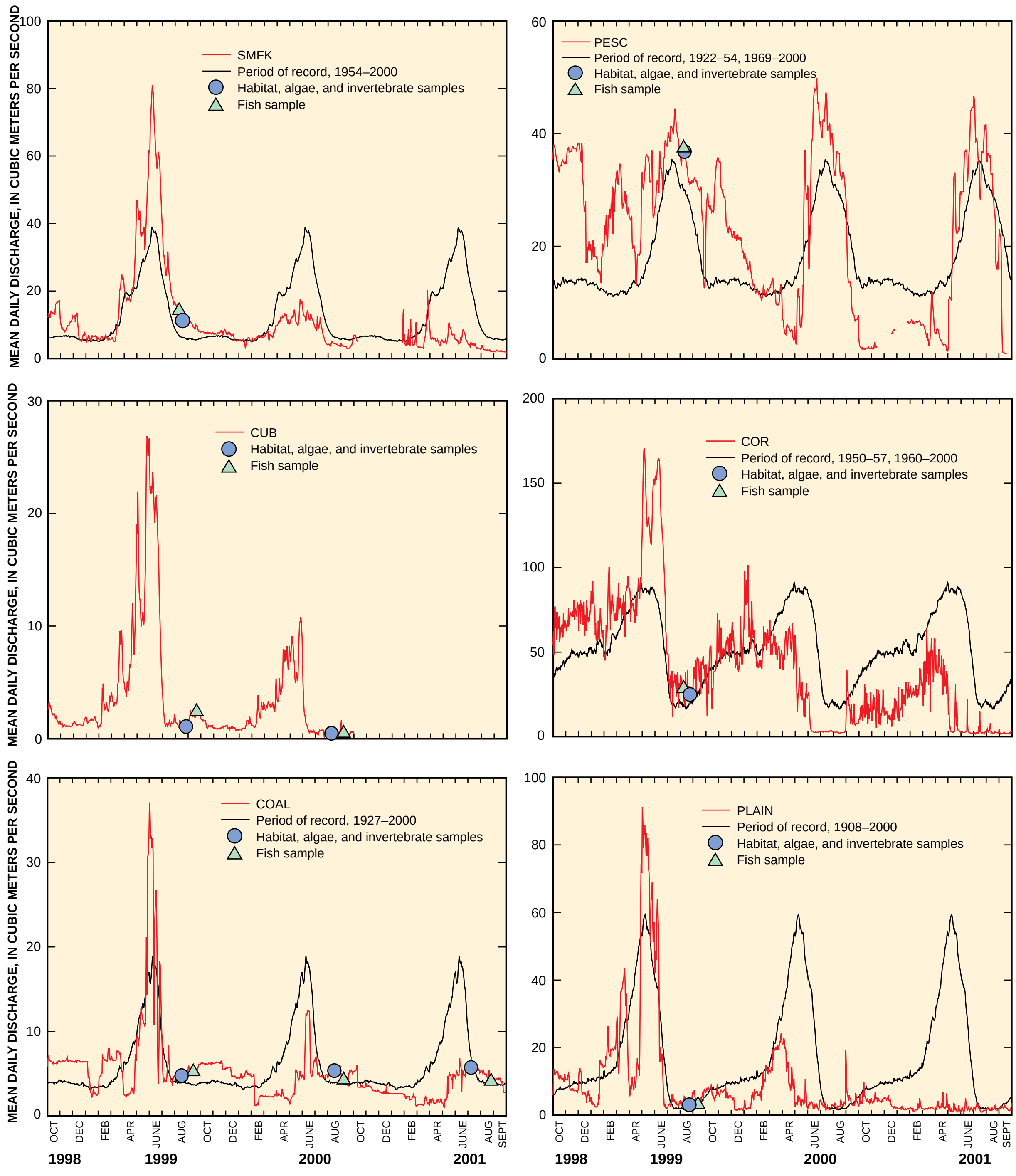

Figure 17. Mean daily discharge, including period-of-record means for comparison purposes, and date when ecological samples were collected at fixed sampling sites in the Great Salt Lake Basins study unit.

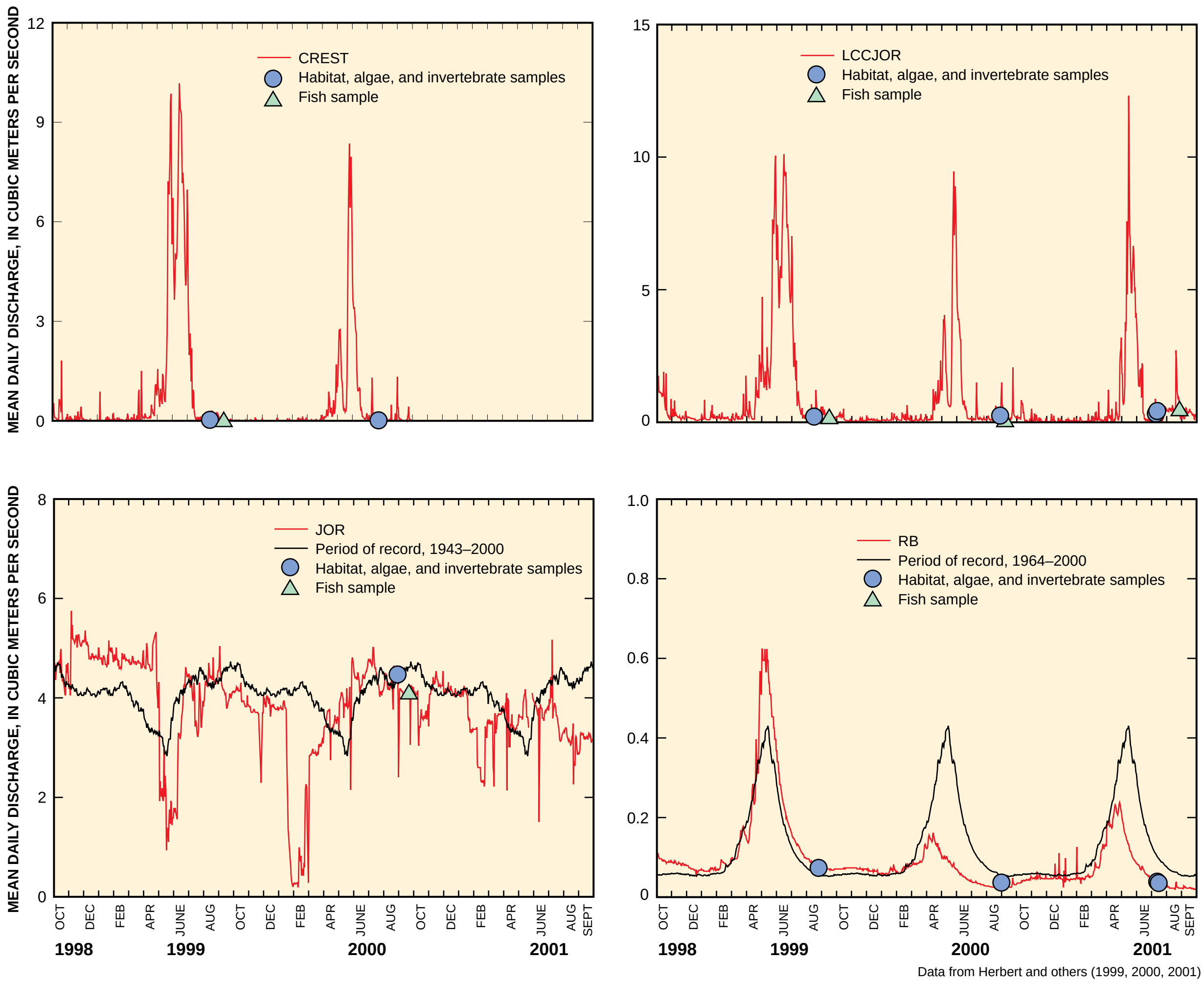

Figure 17. Mean daily discharge, including period-of-record means for comparison purposes, and date when ecological samples were collected at fixed sampling sites in the Great Salt Lake Basins study unit—Continued.

Table 4. Selected temperature data for fixed sampling sites in the Great Salt Lake Basins study unit

[Temperature reported in degrees Celsius. Annual temperature data from October 1, 1998, to September 30, 1999; summer temperature data from June 15, 1999, to September 15, 1999, unless otherwise indicated; for site abbreviations see table 1]

Site	Annual mean temperature	Summer mean temperature	Daily temperature range		Maximum daily mean temperature (highest mean recorded)	Minimum daily mean temperature (lowest mean recorded)	Standard deviation daily mean temperature	Annual degree days
			Annual mean	Summer mean				
SMFK	7.9	16.8	2.0	3.0	19.7	0.0	7.1	2,560
PESC	9.4	19.4	1.3	1.9	21.9	.1	8.0	3,000
CUB	10.2	17.7	2.6	4.3	21.5	.2	6.1	3,150
COR	11.6	21.9	1.2	1.9	25.5	.0	8.4	3,670
COAL[1]	8.5	16.0	5.0	6.7	18.5	.0	6.2	3,120
PLAIN	10.9	19.2	1.7	2.0	22.3	1.4	6.4	3,400
CREST	8.4	14.7	4.7	7.5	20.7	.0	5.8	2,410
LCCJOR	10.7	17.9	3.3	3.7	22.0	.1	5.6	3,900
JOR[2]	14.7	21.2	2.4	3.1	23.3	5.7	5.1	4,920
RB	6.3	11.2	2.9	3.3	12.5	.0	3.8	2,150

[1]Summarizes annual temperature data from October 1, 2000, to September 30, 2001, and summer temperature data from June 15, 2001, to September 15, 2001.

[2]Summarizes annual temperature data from October 1, 1999, to September 30, 2000, and summer temperature data from June 15, 2000, to September 15, 2000.

consequently on stream biota, which will be discussed later in this report.

There was no significant correlation between stream temperature and reach-scale characteristics, such as riparian shading, velocity, depth, and stream width. This likely indicates that these factors have a small influence on stream temperature variation among sites relative to air temperature and discharge. Smaller-scale habitat characteristics such as these likely have a more significant influence on local temperature variation within a reach.

Habitat

Selected reach-scale characteristics for each site are listed in *table 5*. All of the sites except for PESC and JOR were sampled at near base-flow conditions. Mean daily discharge and sample dates for each site are shown in *figure 17*. Discharge at the time of sampling ranged from 0.0279 m^3/s at site CREST on Little Cottonwood Creek to 36.8 m^3/s at site PESC on the Bear River (Herbert and others, 1999, 2000, 2001).

Stream discharge was the primary determinant of reach-scale characteristics such as stream velocity, water depth, and wetted channel width that were measured during habitat sampling. The extreme (highest and lowest) discharge and velocity values (mean velocity ranged from 0.175 m/s at site CREST to 0.844 m/s at site PESC) were the result of upstream water regulation. Low-flow conditions at site CREST resulted from upstream diversions, and high-flow conditions at site PESC resulted from releases from Bear Lake. Mean depth ranged from 0.1 m at site CREST to 2.1 m at site COR. Mean channel width ranged from 2.1 m at site RB to 48.7 m at site COR.

Channel width-to-depth ratios represent the relative shape of the channel and indicate shallow- or deep-water habitat conditions. Ratios range from 10.3 at site JOR to 83.9 at site CREST, which indicates deep-water habitat at site JOR on the Jordan River, and shallow-water habitat at site CREST on Little Cottonwood Creek. The exceptionally high width-to-depth ratio calculated for site CREST is a result of upstream water reclamation that leaves a small volume of water passing through a wide channel bed that has the capacity to hold a much greater volume of water.

Water-surface gradient, in addition to discharge, is an important environmental factor that influences physical characteristics of streams such as hydrology, channel morphology, and substrate (Leopold, Wolman, and Miller, 1964). In general, there is an inverse relation between water-surface gradient and basin area. Because the topography of the GRSL is so varied, a wide range of water-surface gradients exists among streams. Reach-scale water-surface gradients range from 0.01 percent at site PESC to 5.21 percent at site RB. Four sites can be distinguished from the rest as low-gradient streams, all of them having less than 0.1 percent slope: the most downstream site in each of the basins (COR, PLAIN, and JOR), and PESC. Reach and segment gradients are strongly correlated, indicating that overall, reach gradients accurately represented the gradient of the entire stream segment.

There is a strong correlation ($r = 0.90$, $p < 0.001$) between the number of geomorphic channel units (GCUs) and water-surface gradient, which indicates that higher-gradient streams are more varied with respect to GCUs. GCUs represent different combinations of channel substrate, water depth, and water velocity and provide different types of habitat for

Table 5. Selected reach-scale habitat characteristics for the fixed sampling sites in the Great Salt Lake Basins study unit

[e, estimated; ec, indicates calculation included at least one estimated value; PA, pasture; SW, shrubs and woodland; CR, cropland; UR, urban; GR, grassland; N/A, not applicable; for site abbreviations see table 1]

Habitat characteristic	Site									
	SMFK	PESC	CUB	COR	COAL	PLAIN	CREST	LCCJOR	JOR	RB
Water-surface gradient (percent)	0.15	0.01	0.33	0.01	0.24	0.05	1.92	1.48	0.03	5.21
Reach length (meters)	300	800	198	1,176	235	300	150	171	150	150
Reach sinuosity (dimensionless)	1.22	1.02	1.22	1.52	1.52	1.11	1.05	1.07	1.73	1.11
Mean channel width (meters)	23.6	51.8	11.4	48.7	16.6	19.9	7.0	6.1	12.2	2.1
Mean bankfull width (meters)	34.3	57.6	23.1	57.2	21.2	25.3	12.2	9.0	13.8	4.6
Mean bank height (meters)	1.7	2.1 e	1.6	1.7	1.3	3.6	1.1	1.5	2.1	.6
Mean depth (meters)	.8	1.2 e	.6	2.1	.7	1.1	.1	.4	1.2	.2
Mean velocity (meters per second)	.756	.844e	.335	.421e	.725	.232	.175	.212	.427	.401
Reach surface area (square meters)	7,090	41,500	2,260	57,300	3,900	5,980	1,050	1,040	1,830	316
Mean channel width:depth (dimensionless)	28.3	42.5 ec	19.4	22.7	23.7	18.8	83.9	14.2	10.3	10.9
Mean cross-sectional area (square meters)	19.7	63.2 ec	7.3	100.0	10.6	21.3	.6	2.6	14.4	.4
Mean bankfull width:depth (dimensionless)	21.1	96.8 ec	16.0	35.9	17.1	7.2	12.0	6.0	6.8	7.5
Bank Stability Index[1]	14	11 ec	15	12	14	16	10	14	12	12
Occurrence of silt (percent)	0	100 e	9	100 e	0	15	0	0	30	0
Mean embeddedness (percent)	47	N/A	67	N/A	30	N/A	18	67	N/A	48
Dominant substrate type	small cobble	silt (e)	coarse gravel	Silt (e)	small cobble	sand	small cobble	coarse gravel	sand	large cobble
Near-bank canopy closure (percent)[2]	6	94	11	17	17	76	55	84	71	68
Open riparian canopy (percent)[3]	91	96	77	77	71	43	54	18	57	22
Annual mean daily radiation (percent)[4], 1999	97	99	96	98	83	53	43	11	75	20
Dominant riparian land use	PA/SW	GR/SW	CR	CR	PA	PA/CR/SW	SW/UR	UR	UR	SW

[1]Index calculated using multiple factors including bank angle, percentage of vegetative cover, bank height, and substrate type.

[2]Measured at each transect near left and right edges of wetted channel, according to methods outlined in Fitzpatrick and others, 1998.

[3]Measured at each transect from the thalweg of the stream, according to methods outlined in Fitzpatrick and others, 1998, reported as percentage of 180 degrees.

[4]Calculated using solar pathfinder measurements taken at middle and end transects, and averaged for the entire reach.

aquatic biota. The percentage composition of GCUs for each reach is shown in *figure 18*. The four low-gradient sites are distinguished from the rest by a lack of riffles. All of the low-gradient sites are composed entirely of a run except for PLAIN on the Weber River, which is composed mainly of a deep pool. In contrast, all of the high-gradient sites contain all three types of GCU (run, riffle, and pool).

Channel characteristics such as substrate and embeddedness are very different between the high- and low-gradient sites, and reach-scale water-surface gradient and dominant substrate size are significantly correlated (r = -0.86, $p < 0.001$) (*fig. 19*). Substrates of low-gradient sites consisted of either sand or silt. The dominant substrate types at high-gradient sites were either cobble or gravel, and embeddedness ranged from 18 to 67 percent. Cobble and gravel substrates with low embeddedness create optimal habitat conditions for certain benthic organisms because there is greater interstitial space available for these organisms to inhabit (Allan, 1995).

Riparian shading is lower in the Bear River and Weber River basins and higher in the Utah Lake/Jordan River basin. Open canopy increases with mean channel width (r = 0.80, p = 0.01) but also may be attributed to riparian land use practices. On the basis of qualitative observations, riparian vegetation along reaches located in urban areas was denser than along reaches in rural areas. With the exception of site RB on Red Butte Creek, the percentage of open canopy decreases as the percentage of urbanization within the basin increases (*fig. 20*).

Historically, riparian vegetation of the Central Basin and Range ecoregion typically consisted of shrubs (Omernik,

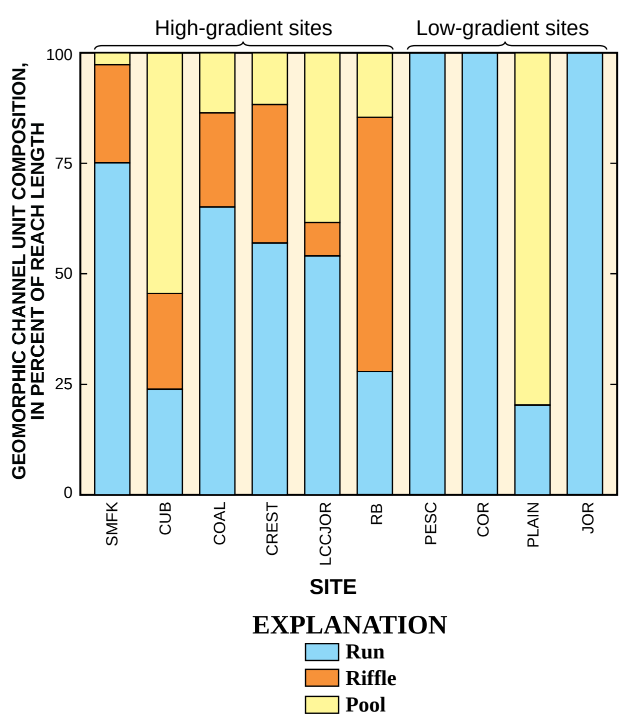

Figure 18. Geomorphic channel units for fixed sampling sites in the Great Salt Lake Basins study unit.

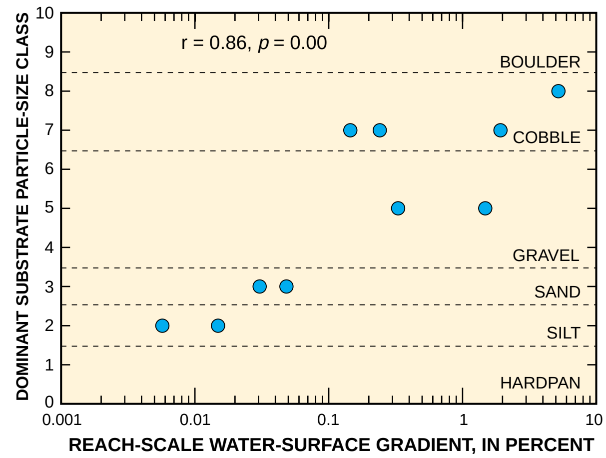

Figure 19. Relation between dominant substrate particle size and reach-scale water-surface gradient for the fixed sampling sites in the Great Salt Lake Basins study unit.

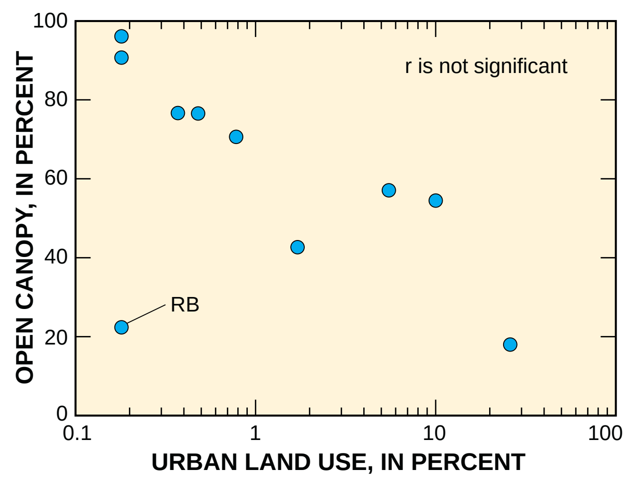

Figure 20. Relation between percentage of open riparian canopy and urban land use for the fixed sampling sites in the Great Salt Lake Basins study unit.

1987). In urban areas, trees and other vegetation have been planted for aesthetic reasons, increasing riparian shading. In contrast, riparian areas in nonurban areas have been cleared for agriculture or grazing, resulting in more open canopies. These changes can have significant effects on inputs of energy and matter into the stream by influencing bank erosion, nutrient inputs, and exposure to solar radiation.

Habitat Evaluation

Selected habitat variables were used to evaluate conditions at each site by using EPA Rapid Bioassessment Protocols (Barbour and others, 1999). Habitat-quality index scores for the sites ranged from 41 at site PESC on the Bear River to 154 at site RB on Red Butte Creek *(table 6)*. Lower scores indicate

Table 6. Habitat-quality index scores for the fixed sampling sites in the Great Salt Lake Basins study unit

[Index was adapted from Barbour and others, 1999; for abbreviations see table 1]

High-gradient sites	Available habitat cover	Instream characteristics					Bank/ riparian characteristics				Instream characteristics score	Bank/ riparian characteristics score	Overall score	Rating
		Sediment deposition	Channel-flow status	Embeddedness	Velocity/ depth regime	Riffle frequency	Channel alteration	Bank stability	Riparian land use	Bank-vegetation protection				
SMFK	7	20	5	11	3	7	20	8	6	2	73	16	89	Marginal
CUB	13	19	10	6	20	7	10	6	4	2	85	12	97	Suboptimal
COAL	12	20	8	14	4	7	20	8	2	4	85	14	99	Optimal
CREST	8	20	0	17	15	10	10	12	14	2	80	28	108	Optimal
LCCJOR	10	20	16	6	16	3	4	8	2	0	75	10	85	Marginal
RB	14	20	20	11	13	16	20	10	20	10	114	40	154	Optimal
Low-gradient sites	**Available habitat cover**	**Sediment deposition**	**Channel-flow status**	**Pool substrate**	**Pool variation**	**Channel sinuosity**	**Channel alteration**	**Bank stability**	**Riparian land use**	**Bank-vegetation protection**	**Instream characteristics score**	**Bank/ riparian characteristics score**	**Overall score**	**Rating**
PESC	0	0	4	0	1	0	4	10	6	16	9	32	41	Poor
COR	9	0	8	0	16	14	4	6	4	4	51	14	65	Poor
PLAIN	10	17	11	0	5	3	20	6	4	4	66	14	80	Poor
JOR	11	14	20	1	8	20	0	10	2	10	74	22	96	Suboptimal

more-degraded habitat conditions, and higher scores indicate better habitat conditions. Sites were divided into four quartiles on the basis of overall scores and were evaluated relative to each other. Sites PLAIN, PESC, and COR (all large river sites) had poor habitat, SMFK and LCCJOR had marginal habitat, CUB and JOR had suboptimal habitat, and CREST, COAL and RB had optimal habitat.

Site PESC (a forest-rangeland site on the Bear River) scored the lowest of all the sites. Although this site received high scores for the three riparian characteristics, it received exceptionally low scores for most of the instream characteristics and, therefore, rated in the “poor” category. Sites COR and PLAIN (both sites with mixed land uses within their basins) also scored in the “poor” category because of low scores for both instream and bank/riparian characteristics.

Sites LCCJOR and SMFK scored in the “marginal” category, each for different reasons. Site LCCJOR (a high-intensity urban site on Little Cottonwood Creek) scored the lowest of all sites for bank/riparian characteristics, but adequate flow and velocity-depth combinations prevented this site from scoring in the “poor” category. Site SMFK (a forest-rangeland site on the Bear River) scored in the “marginal” category because of poor velocity/depth combinations and a lack of bank vegetation.

Sites JOR and CUB both scored in the suboptimal category. Site JOR was the only low-gradient, mixed land-use site that did not score in the “poor” category. An overall higher score at this site relative to other low-gradient sites is a result of higher scores for reach sinuosity, channel flow status, and sediment deposition. High scores in these categories compensated for the low scores received at this site for riparian land use and for extensive channel modifications. Site CUB (an agricultural site on the Cub River) scored as “suboptimal” despite poor bank/riparian scores because of high scores for instream characteristics.

Sites COAL, CREST, and RB scored in the “optimal” category. Site COAL (a forest-rangeland site on the Weber River) received high scores for instream characteristics despite the lower scores it received for riparian characteristics. Site CREST (a low-intensity urban site on Little Cottonwood Creek) also scored as “optimal” despite a score of 0 for channel flow status. Cumulative high scores for several bank/riparian and instream characteristics allowed this site to maintain a high ranking of habitat quality. Site RB (a forest-rangeland site on Red Butte Creek) scored high for both instream and bank/riparian characteristics and ranked the highest of all sites.

Causes of Impaired Stream Habitat

Causes of impaired stream habitat included effects from channel modifications, siltation, and riparian land use. Effects of hydrologic modifications are evident at many sites where flows have been reduced, or natural seasonal variability has been eliminated, and are manifest in altered temperature variability and changes in habitat conditions such as streamflow velocity, depth, substrate type, and wetted channel shape. Sites located in urbanized areas had more riparian cover than those in rural areas because trees have been planted in urban areas and vegetation has been reduced at sites affected by grazing and agriculture.

In general, the high-gradient sites had higher overall scores than the low-gradient sites. This can be attributed primarily to two instream characteristics used in the index: sediment deposition and substrate availability. Low-gradient sites in the GRSL have greater sediment deposition and lower substrate availability than high-gradient sites. Finer sediments are expected to occur naturally in lower-gradient streams (three of the four low-gradient sites are located within areas with Pleistocene-age lake-sediment deposits, and larger substrates are not available); however, this result can be exacerbated by upstream surface and streambank erosion caused by channel modifications or anthropogenic activities that degrade the buffering capacity of riparian areas through removal of bank vegetation (Allan, 1995).

Although the habitat-quality index is primarily a qualitative tool, associations can be established among the index and habitat variables that were not used to calculate the index. Patterns in the occurrence of high- or low-quality habitat can be extracted from surrounding environmental conditions in the GRSL. For example, high-gradient, low-discharge streams coincide with better-quality habitat. It is difficult to determine whether this is a result of anthropogenic or natural causes. High-gradient, low-discharge streams generally have larger substrates, a greater number of GCUs, and less fine-grained sediment deposition than low-gradient, high-discharge streams. All of these characteristics provide preferential habitat conditions to a great diversity of aquatic organisms and have significant correlations with the habitat-quality index. High-gradient streams generally are less affected by anthropogenic activities because the topography of the area often limits human activities such as urbanization, grazing, and agriculture that affect streams lower in the basins. In contrast, all of the low-gradient sites are heavily impacted by human activities.

The relation between habitat quality and percentage of forested land use is shown in *figure 21*. Sites with less forested land use also have poorer habitat quality. Although there is no significant correlation between habitat quality and the individual percentages of rangeland, agricultural, and urban land use types within the basins, the significant correlation between habitat quality and forested land use ($r = 0.63$, $p = 0.05$) indicates that an increase in a mixture of rangeland, agricultural, and urban land uses may negatively affect habitat quality.

The wide-ranging effects of hydrologic modifications are evident in the habitat-quality index as indicated by the highly variable scores in hydrologic measures. Channel-flow status (a measure of the shape and volume of wetted habitat) scores ranged from 0 to 20, with both extremes represented by sites that are subject to intense regulation. Site CREST received a score of 0 (the lowest score) for this variable because a substantial amount of the water was diverted upstream from this site, leaving a wide, shallow channel and low habitat volume. Site JOR, where channel flows remain fairly steady as a result of intense regulation, had a score of 20 (the highest score). Pool variation and sinuosity at site PESC were low, a result of channelization and flow regulation.

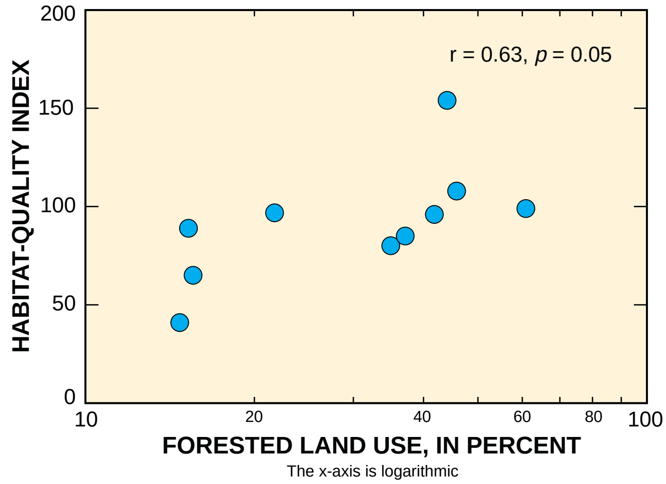

Figure 21. Relation between habitat quality index and the percentage of forested land use for the fixed sampling sites in the Great Salt Lake Basins study unit.

Instream habitat conditions are determined primarily by physical factors such as altitude, stream size, and stream gradient, with more diverse habitat conditions occurring at higher-gradient sites where substrate size, flow velocity, and depth are more varied. Instream habitat diversity at large, low-gradient sites is naturally limited by small substrate size and uniform flow. These low-gradient sites are generally more affected by anthropogenic activities than are the higher-gradient sites.

Instream habitat also has been affected by anthropogenic activities. In some cases, as with site LCCJOR, channelization of streams in urban areas has affected habitat availability at sites by reducing stream sinuosity and causing homogeneous flow conditions consisting primarily of deep runs. Water regulation that maintains steady conditions (at sites PESC and JOR) also has resulted in homogeneous high-flow conditions that are maintained throughout the summer, when low-flow conditions naturally occur. Flows below dams and diversions (as at site COR) are punctuated by abrupt changes in flow that may contribute to heavy siltation and flushing of macrophyte and woody debris habitats at these sites. Hydrologic modifications that reduce flow have resulted in the loss of habitat volume, increased temperature ranges, and reduced depth and velocity.

Natural riparian habitat is generally sparse in the Basin and Range ecoregions; however, differences in riparian habitat were observed between urban and agricultural areas within the basins, with denser riparian cover occurring in urban areas (sites LCCJOR, CREST, and PLAIN) as a result of smaller stream width and the planting of vegetation along stream corridors. Riparian vegetation in other basin areas may be reduced as a result of land-use activities such as grazing and agriculture (sites SMFK, COAL, CUB, and COR), which may suppress the growth of shrubs and trees along stream corridors.

Algae

Algae samples were collected in the RTH in order to provide information on biological assemblages and environmental conditions present in habitats that theoretically support the greatest number of taxa. Samples from DTH were collected to target algal communities that are exposed to chemical conditions in streambed sediments that often endure over long periods of time (Porter and others, 1993). QMH samples were collected to compile a list of species present within the reach.

Description of Algal Communities

A summary of the occurrence of algal species at the sampling sites is contained in *table C-1* in appendix C. On the basis of combined results from all algae samples, algal species from six phyla were identified during the study, including Cyanophyta (blue-green algae), Chlorophyta (green algae), Euglenophyta (euglenas), Chrysophyta (yellow-green algae), Rhodophyta (red algae), and Pyrrhophyta (dinoflagellates). Diatom species (Chrysophyta) and cyanophytes were the most abundant phyla collected at the 10 sites. Species from three phyla, Chrysophyta, Chlorophyta, and Cyanophyta, were collected at every site. Euglenophyta (8 species), Pyrrhophyta (2 species), and Rhodophyta (2 species) were collected less frequently than the other three phyla, and were not collected at all sites. Diatoms accounted for the greatest richness in species collected, with 11 families and 244 species. The phylum Chlorophyta was represented by 11 families and 36 species, and the phylum Cyanophyta was represented by 3 families and 18 species.

Combined results from the three types of algae samples collected at each site included 221 species at the 10 sites, with 89 additional species identified in samples collected in 2000 and 2001 for a total of 310 species. Nine algal species were collected at every site, all of them benthic diatoms. Species common to all sites were *Achnanthes lanceolata*, *Achnanthidium minutissimum*, *Encyonema minutum*, *Gomphonema olivaceum*, *Gomphonema parvulum*, *Nitzschia fonticola*, *Nitzschia linearis*, *Nitzschia palea*, and *Synedra ulna*. Although these species were present at all sites, they do not account for the greatest densities (in cells/cm^3) of species collected. *Calothrix parietina* and *Amphithrix janthina*, both nitrogen-fixing species in the Nostocaceae family of cyanophytes, accounted for the greatest density of algae in all of the quantitative samples combined.

Qualitative and quantitative data collected for algal communities at each site are shown in *table 7*, and selected ecological information for richest targeted habitat samples is presented in *table 8*. On the basis of combined qualitative and quantitative samples, species richness ranged from 62 species at RB and COAL to 105 species at SMFK. Diversity (the number and proportional distribution of species within the community) of algal communities was measured quantitatively with the Simpson's Diversity Index, and values ranged from 0.33 (lowest diversity) at JOR to 0.95 (highest) for species diversity at CUB.

Bear River Basin

Site SMFK had the greatest total species richness of all the sites (105 species), and the greatest algal biovolume and abundance of all the RTH samples. This site also had the greatest species richness of all the DTH samples with 65 species; however, the RTH sample collected at this site had few species (37 species) relative to RTH samples from other sites. Epilithic RTH sample abundance was dominated by *Calothrix parietina*, and epipelic DTH sample abundance was dominated by an unknown cyanophyte.

Site PESC had 101 species, based on combined (RTH, DTH, and QMH) samples. The RTH sample had the lowest abundance of all the sites but one of the highest richness values, with 52 species present, most of which were diatoms. The RTH sample at this site was collected from epiphytic habitats because of a lack of riffles and woody snags within the reach. *Achnanthidium minutissimum*, a pollution-intolerant benthic diatom, was the dominant species in the RTH sample, composing 27 percent of cell abundance in this sample. Species richness of the DTH sample was similar to that of the RTH sample, with 54 species; however, 79 percent of the DTH sample abundance was composed of unknown cyanophyte species, resulting in an uneven distribution of taxa, and thus, low diversity.

Site CUB had a total of 85 species and had the most-diverse RTH sample. The most-abundant species in both RTH and DTH samples from this site was *Schizothrix calcicola*, a benthic cyanophyte species. The DTH sample from this site had the highest algal cell abundance and biovolume of all of the quantitative samples collected; however, the RTH sample had the lowest algal biovolume of all samples collected in the study.

Ninety-seven species were collected at site COR. This site had the highest species richness of all RTH samples, with 58 species. The RTH sample at this site was collected from woody snags because of a lack of riffle habitat. Diversity was low for the RTH sample as a result of dominance in cell abundance by *Calothrix parietina*, which composed 79 percent of the sample. An unknown *Anabaena* species composed 51 percent of the DTH sample at this site. Both of these algae taxa are nitrogen-fixing cyanophyte species. *Anabaena* are sestonic algae species that can be highly productive and can potentially bloom excessively to create nuisance conditions (S. Porter, U.S. Geological Survey, written commun., 2002).

Weber River Basin

Site COAL was one of the least species-rich sites with only 62 species collected. The most abundant species in both quantitative samples collected at this site was *Calothrix parietina*, which composed 69 percent and 24 percent of the RTH and DTH samples, respectively. The DTH sample from this site had greater richness and diversity than the RTH sample.

Table 7. Selected algal-community data collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[RTH, richest targeted habitat; DTH, depositional targeted habitat; cm^3/m^2, cubic centimeters per square meter; $cells/cm^2$, cells per square centimeter; for site abbreviations see table 1]

Site	Species richness from combined qualitative and quantitative samples	Sample type	Habitat type sampled	Biovolume (cm^3/m^2)	Cell abundance ($cells/cm^2$)	Species richness	Simpson's diversity	Dominant phylum	Relative abundance of dominant phylum (percent)	Dominant species	Relative abundance of dominant species (percent)
SMFK	105	RTH	Epilithic-Riffle	24.4	$6.20x 10^6$	37	0.56	Cyanophyta	68	*Calothrix parientina*	65
		DTH	Epipelic	33.7	$7.96x 10^6$	65	.49	Cyanophyta	71	Unknown cyanophyte	71
PESC	101	RTH	Epiphytic	12.3	$3.09x 10^5$	52	.86	Chrysophyta	69	*Achnanthidium minutissimum*	27
		DTH	Epipelic	2.8	$4.49x 10^6$	54	.38	Cyanophyta	86	Unknown cyanophyte	79
CUB	85	RTH	Epilithic-Riffle	2.5	$6.97x 10^6$	43	.93	Chrysophyta	76	*Schizothrix calcicola*	15
		DTH	Epipelic	120	$3.33x 10^6$	59	.79	Cyanophyta	63	*Schizothrix calcicola*	43
COR	97	RTH	Epidendric	4.1	$1.69x 10^6$	58	.38	Cyanophyta	79	*Calothrix parientina*	79
		DTH	Epipelic	9.1	$4.98x 10^6$	52	.66	Cyanophyta	78	*Anabaena* sp.	51
COAL	62	RTH	Epilithic-Riffle	7.7	$5.97x 10^6$	22	.49	Cyanophyta	72	*Calothrix parientina*	69
		DTH	Epipelic	30.9	$5.53x 10^6$	45	.90	Chrysophyta	67	*Calothrix parientina*	24
PLAIN	87	RTH	Epidendric	5.9	$2.35x 10^6$	42	.85	Chrysophyta	51	*Hydrocoleum brebissonii*	34
		DTH	Epipelic/ Episammic	13.0	$3.86x 10^6$	59	.71	Cyanophyta	53	*Amphithrix janthina*	53
CREST	65	RTH	Epilithic-Riffle	13.7	$4.66x 10^6$	31	.50	Cyanophyta	69	*Amphithrix janthina*	68
		DTH	Episammic	24.6	$7.01x 10^6$	37	.89	Chrysophyta	84	*Achnanthidium minutissimum*	25
LCCJOR[1]	104	RTH	Epidendric	5.1	$1.78x 10^6$	32	.82	Chrysophyta	73	*Rhoicosphenia curvata*	27
		DTH	Episammic	9.8	$3.47x 10^6$	59	.90	Chrysophyta	62	*Calothrix parientina*	25
JOR[2]	100	RTH									
		DTH	Epipelic	3.9	$3.04x 10^6$	64	.33	Cyanophyta	82	Unknown cyanophyte	82
RB	62	RTH	Epilithic-Riffle	5.2	$1.21x 10^6$	33	.78	Cyanophyta	43	*Calothrix parientina*	43
		DTH	Epipelic	2.7	$8.46x 10^5$	32	.90	Chrysophyta	73	*Calothrix parientina*	24

[1]No RTH sample available for 1999; data reflects samples collected in 2000.

[2]Only one quantitative sample was collected because depositional habitat also was RTH.

Site PLAIN generally was high in species richness and diversity for both quantitative samples, with a total of 87 species collected. The RTH sample at this site was collected from woody snags, and the most abundant species in the sample was *Hydrocoleum brebissonii*, a motile, benthic cyanophyte, which accounted for 34 percent of the cell abundance for the sample. The most abundant species in the DTH sample was *Amphithrix janthina*, a nitrogen-fixing cyanophyte species that accounted for 53 percent of the cell abundance for the sample.

Utah Lake/Jordan River Basin

Site CREST had a total of 65 species from the combined samples and had low species richness for both quantitative samples. *Amphithrix janthina* was the most abundant species in the RTH sample and composed 68 percent of the sample. The DTH sample was more diverse, with the most abundant species, *Achnanthidium minutissimum*, composing 25 percent of the sample.

Site LCCJOR was one of the richest sites, with 104 species of algae collected. Data collected from the reach during the year 2000 were used for analysis of algal communities at this site because the RTH sample from 1999 was lost in shipping. The RTH sample at this site was collected from woody snags and was relatively low in richness as compared to the other sites. Most of the species were collected in qualitative and depositional samples at this site. The most abundant species collected in the RTH sample composed 27 percent of the total abundance and was identified as *Rhoicosphenia curvata*, a eutrophic benthic diatom species (Van Dam and others, 1994). *Calothrix parietina* was the most abundant species in the DTH sample and composed 25 percent of the sample.

Site JOR had a high overall species richness of 100 despite only one sampled habitat for RTH and DTH samples. Only qualitative and DTH samples were collected for this site because the RTH-type available within this reach was composed of fine sediments and was, therefore, also a depositional sample. An unknown cyanophyte composed 82 percent of the quantitative sample at this site, making this the least diverse of all of the samples collected.

Site RB had one of the lowest overall species richness, with 62 species collected. Both quantitative samples were dominated by *Calothrix parietina*, which composed 43 percent and 23 percent of RTH and DTH samples, respectively. Both quantitative samples at this site had relatively high diversity in comparison with other sites despite having low species richness.

Algal Communities as Indicators of Water Quality

Several algal indices are commonly used to evaluate water quality (Van Dam and others, 1994; Bahls, 1993). These indices are based on species attributes of algal assemblages. According to tolerance and preference for physical and chemical conditions, the presence of different algal species can indicate short-term environmental conditions. For example, the dominance of nitrogen-fixing algae may be an indicator of low-nutrient conditions. The dominance of motile species may indicate a high occurrence of silt deposition because these species are able to move upward as silt is deposited along the bottom of the channel. The presence of species that are intolerant of poor water-quality conditions, such as low oxygen concentrations, or the presence of organic pollutants, can indicate the persistence of high-quality water conditions. The relative abundance of taxa collected in RTH samples with these attributes are presented in *table 8*.

Quantitative data from RTH samples were used to compare water-quality conditions at sites according to species presence and abundance. Although specific species of algae were widely distributed, TWINSPAN analysis of the RTH samples based on entire assemblages divided sites into three groups that appear to coincide with differences in basin and riparian land use. The first division differentiated SMFK, COAL, and RB (Group A: forest-rangeland sites) from the rest of the sites (eigenvalue = 0.3180). The second division separated JOR, CUB, COR, and PESC (Group B: sites influenced by agricultural land use that receive high inputs of solar radiation), from LCCJOR, CREST, and PLAIN (Group C: sites influenced by urbanization; eigenvalue = 0.3848).

TWINSPAN site-group divisions were made according to differences between entire species assemblages and were distinguishable by the presence and abundance of three algal species. *Calothrix parietina* was an indicator species for group A (forest-rangeland) sites. This nitrogen-fixing species of blue-green algae was the dominant taxon at all of these sites. This site group also was distinctive in the absence of *Nitzschia amphibia*, a motile, eutrophic diatom that is moderately tolerant of low oxygen conditions and organic pollution (Van Dam and others, 1994). *Amphithrix janthina*, a nitrogen-fixing blue-green algae, was observed in relatively high abundance in group C (urban) sites and was absent in RTH samples from the other two site groups.

Site Group Characteristics

Group A sites (sites SMFK, COAL, and RB) were the farthest-upstream sampled sites in each of the three basins, all of which have forest/range land use. Environmental conditions that are characteristic of group A sites include relatively low-nutrient conditions in high-altitude, cold-water streams. Sites in this group were distinct from the other two site groups in terms of chloride concentrations, which were lower at group A sites (*fig. 22*). Group A sites also are characterized as having larger substrate, lower embeddedness, and less silt deposition relative to other site groups.

Group B sites were the three lower Bear River basin sites (sites PESC, CUB, and COR) and JOR. These four sites all had the greatest percentage of rangeland/agricultural land use within their basins. Although there is a high percentage of agricultural land use within the basin of site JOR, the chemical characteristics at this site are mostly influenced by urban land use (Gerner, 2003). This site may have grouped with

Table 8. Selected richest-targeted habitat algal-community data collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1]

Site	Pollution Tolerance (Bahl's Index)	Relative abundance of cells intolerant to high salinity and chloride concentrations (percent)	Relative abundance of cells intolerant to low-oxygen conditions (percent)	Relative abundance of cells intolerant to organic pollution (percent)	Relative abundance of nonmotile cells (percent)	Relative abundance of nitrogen-fixing cells (percent)	Relative abundance of nitrogen-heterotrophic cells (percent)
SMFK	2.80	88.7	86.3	84.3	87.1	65.0	11.3
PESC	2.52	85.3	64.7	70.3	57.2	.0	11.0
CUB	2.02	71.3	30.7	37.3	39.0	.0	42.3
COR	1.74	32.0	18.0	14.7	86.0	79.0	31.3
COAL	2.50	98.0	51.7	55.3	83.0	69.0	6.7
PLAIN	2.19	89.3	48.0	55.7	30.0	12.0	28.3
CREST	2.17	88.0	28.7	36.3	77.0	68.0	18.7
LCCJOR[1]	2.41	54.8	48.5	49.3	59.0	20.0	39.5
JOR	2.15	59.7	38.2	40.2	6.6	.0	39.0
RB	2.55	94.0	62.0	75.0	67.0	43.0	3.7

[1]No RTH sample available for 1999; data reflects samples collected in 2000.

group B sites rather than the urban sites because of the effects of physical habitat characteristics on algal distribution. High percentages of daily solar radiation, siltation, and embeddedness, and high turbidity are characteristic of stream reaches in agricultural areas of the GRSL and of sites in this group. The similarity in algal assemblages between site JOR and the lower Bear River basin sites may be a result of nitrogen and phosphorus enrichment, which are higher at these sites than at other sites within the basins (Gerner, 2003).

Group C sites were the two Little Cottonwood sites (sites CREST and LCCJOR) and PLAIN, all of which are influenced by urban land use. Site PLAIN has a mixture of land uses within the basin, including agriculture and rangeland, but is heavily influenced by urbanization as it flows through an urban area just upstream of the sampling site. Common environmental characteristics for these sites include low altitude, low velocity, moderate siltation, and high canopy cover with low percentages of daily solar radiation relative to other sites in the basins. Sites in this group had low pH values relative to other sites, and all had less than 100-percent dissolved oxygen saturation, which indicates that relative to other sites, algal communities at these sites may be less productive or that the biological oxygen demand at these sites may be greater than primary production of oxygen by algal communities.

Algal Species Assemblage Characteristics

In general, group A (forest-rangeland) sites had higher relative abundances of diatom species intolerant of low dissolved-oxygen saturation, high salinity and chloride concentrations, and organic pollution than did sites in groups B (sites influenced by agricultural land use that receive high inputs of solar radiation) and C (sites influenced by urbanization) (*fig. 23*). Group B and C sites had higher relative abundances of diatom species that require high concentrations of organic nitrogen for metabolic processes (nitrogen-heterotrophic). Bahls' (1993) Index (an overall measurement of pollution tolerance) indicates that group A sites are once again distinct from the other two groups. Overall, group B and C sites showed similar ranges for ecological characteristics, and no substantial difference was detected between these two site groups.

On the basis of information obtained for all periphyton species collected in RTH samples, group A sites had high relative abundances of nitrogen-fixing species, which indicates an algal community response to the oligotrophic conditions observed at these sites. In contrast, all of the group B sites, with the exception of site COR, had no nitrogen-fixing algae (*fig. 23*). Site COR had the highest relative abundance of nitrogen-fixing algae of all the sites despite having relatively high nitrogen concentrations. A possible explanation for this may be that at site COR it is difficult for algae to capture nitrogen as a result of interspecies competition because of the low surface area-to-volume ratio of the channel and high water velocities at this site.

The relative abundance of nonmotile species was generally high for group A sites and varied within the other two site groups. The high relative abundance of these algae may be explained by the lack of siltation at these sites relative to other sites. Despite excessive siltation at sites COR and PESC, these two sites had 86 percent and 57 percent nonmotile algae cells, respectively. A possible explanation is that RTH sam-

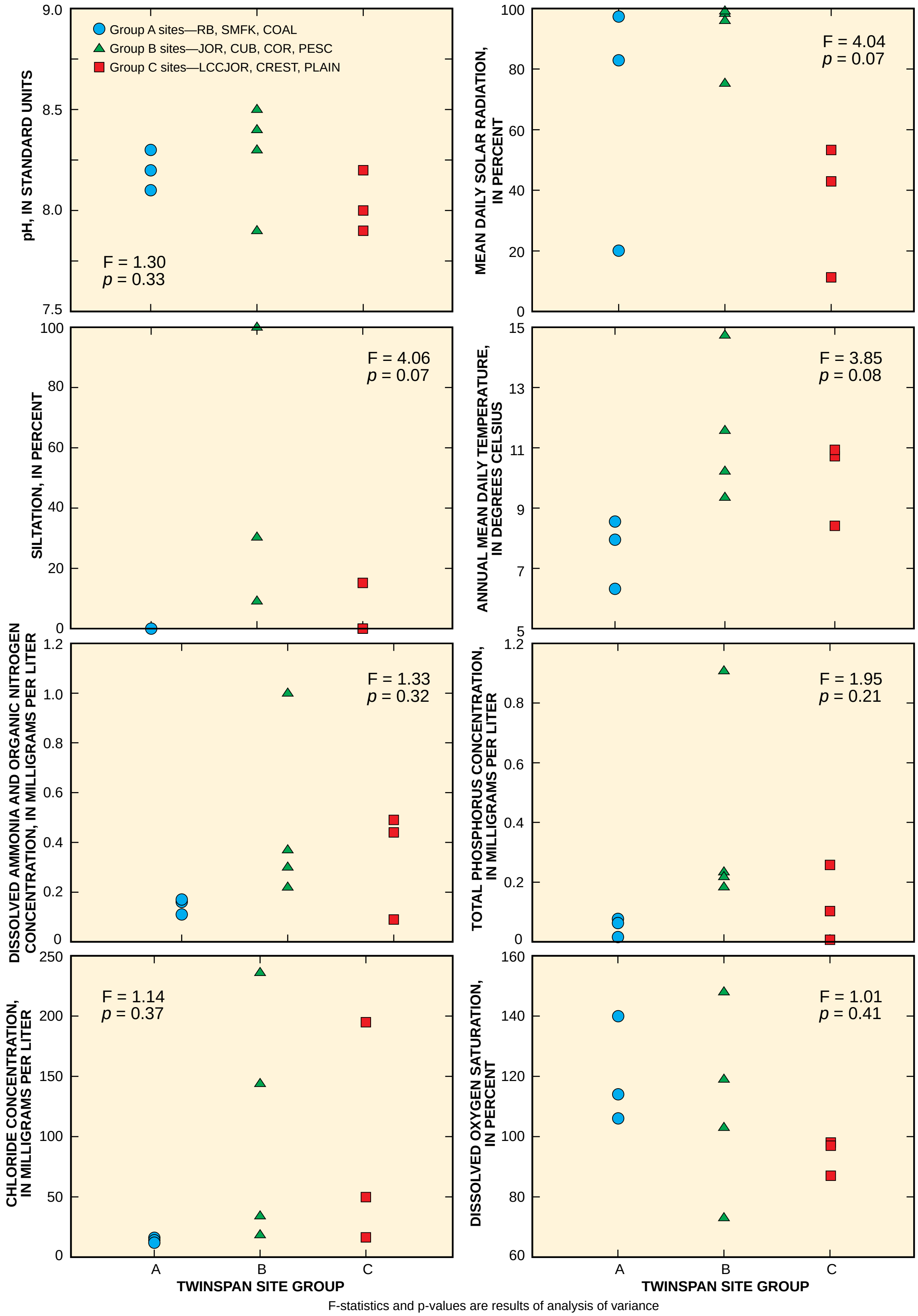

Figure 22. Environmental characteristics of site groups determined by TWINSPAN analysis of richest-targeted-habitat algal samples based on species presence and abundance, for the fixed sampling sites in the Great Salt Lake Basins study unit.

(Group A sites are forest-rangeland, Group B sites are high-agriculture, and Group C sites are high-urban.)

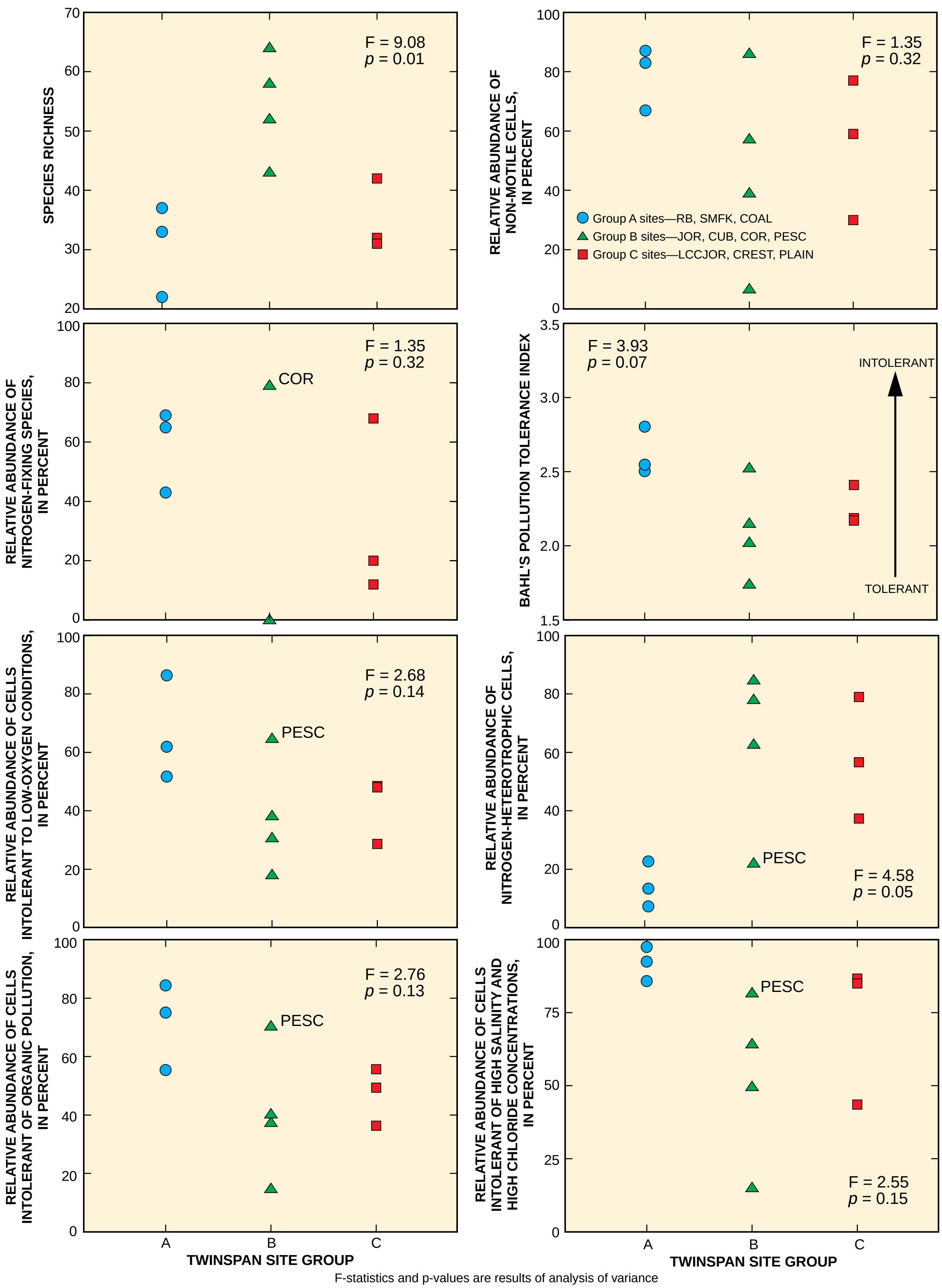

Figure 23. Characteristics of diatom species assemblages for site groups determined by TWINSPAN analysis of richest-targeted-habitat algal samples for the fixed sampling sites in the Great Salt Lake Basins study unit. (Group A sites are forest-rangeland, Group B sites are high-agriculture, and Group C sites are high-urban.)

ples were taken from leaves and woody snags at these sites, and may be less affected by siltation than algae attached to substrates along the channel bed. Group B sites generally had greater species richness than did the other two groups. Environmental data support this result because agricultural sites (group B) receive a higher percentage of daily solar radiation and higher nutrient concentrations, providing optimal growth conditions for a wide variety of algal species, than group A and C sites receive. Although the abundance of algae at group A sites may be limited primarily by low nutrient conditions, abundance at group C sites may be limited by low light conditions.

It is interesting to note that although site groupings appear to be based primarily on differences in water chemistry, habitat plays a significant role in the distribution of species at some of the sites. For example, the species assemblage at site PESC (epiphytic, plant habitat) was more similar to that at COR (epidendric, wood habitat) than at SMFK (epilithic, rock habitat), even though in terms of nutrient and major ion concentrations, sites PESC and SMFK have greater similarities (Gerner, 2003). Several ecological characteristics of species assemblages at site PESC (from group B) are similar to those in group A, which can be expected because these sites are chemically similar. Because site PESC did not group with group A sites as based on species assemblage, habitat availability may be more important than water chemistry in determining species assemblages at this site. Physical characteristics at sites PESC and COR are controlled largely by upstream water regulation, and these results support the idea that algal communities are responding to these conditions.

Algal communities in RTHs differed among groups of sites with different land use, temperature, nutrient enrichment, and solar energy inputs. Water chemistry and temperature were the most important factors determining algal assemblages in RTH; however, habitat availability appears to be a factor at site PESC, where the species assemblage was more similar to site COR than to site SMFK, despite similar water chemistry and temperature at sites SMFK and PESC. Species that are intolerant to organic pollution, low dissolved oxygen concentration, and high salinity dominated at the high-altitude, high-gradient sites (SMFK, COAL, and RB), where land use is primarily undeveloped, temperatures are cold, and nutrient concentrations are low. These sites also had characteristically high abundances of nonmotile and nitrogen-fixing species of algae. At sites where developed land uses are more prevalent, the relative abundance of species tolerant to organic pollution, low dissolved oxygen concentration, and high salinity was higher; however, significant differences in these metrics among sites dominated by agricultural and urban land uses were not detected. Sites influenced by agricultural land use that also receive greater solar radiation input (PESC, COR, CUB, and JOR) had higher RTH species richness than urban sites (PLAIN, LCCJOR, and CREST), which are more heavily shaded. Although algal communities at urban sites may be light-limited, those at undeveloped sites (RB, COAL, and SMFK), may be limited by a lack of nutrients and cold temperatures.

Invertebrates

Invertebrate life cycles typically last a couple of months to a couple of years (Merritt and Cummins, 1996). As a result, invertebrate community assemblages can indicate the persistence of conditions over a longer period than a single water sample or point measurement can. Metrics that describe pollution tolerance, diversity, dominance, and trophic (food web) interactions of invertebrate communities are commonly used in water-quality assessment to describe water-quality conditions, and were also used for this analysis. Pollution tolerance indices have been derived from a number of sources, including the EPA Rapid Bioassessment Protocol (Barbour and others, 1999), and can be used to describe water quality on the basis of the presence and abundance of taxa commonly associated with different water-quality conditions. Diversity and dominance within invertebrate communities often can indicate the overall diversity of available habitat, as well as the frequency and severity of physical and chemical disturbances to the ecosystem (Barbour and others, 1999). The presence and abundance of invertebrates adapted to obtain a certain type of food from the surrounding environment (trophic level) may be an indicator of the dominant food source available (Merritt and Cummins, 1996).

Natural factors such as altitude, stream gradient, and air temperature can control invertebrate distribution by determining availability of habitat and physical and chemical properties such as water temperature and dissolved oxygen concentrations. Lower gradient streams are less turbulent and generally occur at lower altitudes where temperatures are warmer. These physical characteristics generally result in lower concentrations of dissolved oxygen. Consequently, invertebrates sensitive to low dissolved oxygen concentrations may be naturally less abundant in these streams. Alternatively, invertebrates poorly adapted to cope with fast velocities and large substrates may be less abundant in the higher-gradient streams that were sampled.

Description of Invertebrate Communities

In 1999, 230 invertebrate taxa were collected from combined qualitative and quantitative samples, with 57 additional taxa collected in multiple-year and multiple-reach samples from 5 of the sites. Invertebrates representing 10 phyla and 14 classes were collected, with the greatest richness and abundance of invertebrates composed of insect taxa. *Hydropsyche* sp. (a caddisfly) was the only taxon identified to the genus level that was collected at every site. *Cricotopus* sp., *Polypedilum* sp., *Thienemanniella* sp., *Simulium* sp., (all dipteran taxa), and the *Baetis* sp. mayfly also were widespread, and were collected at most of the sites. *Cricotopus*, *Baetis*, and *Hydropsyche* accounted for the greatest abundance of taxa col-

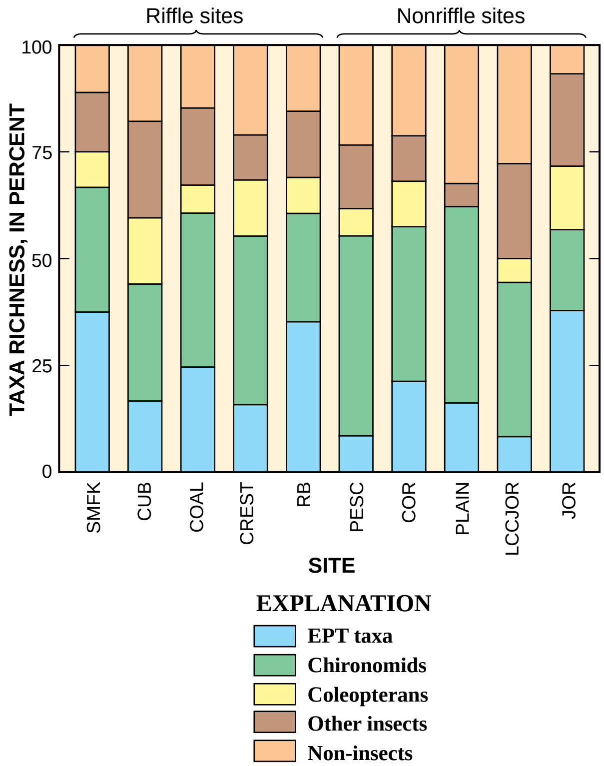

Figure 24. Taxonomic divisions of invertebrates collected from the fixed sampling sites in the Great Salt Lake Basins study unit.

lected in RTH samples. Taxonomic divisions of invertebrates collected from qualitative samples are summarized in *figure 24*, and a listing of the invertebrate taxa collected at the fixed sampling sites is contained in *table C-2* in appendix C.

A summary of characteristics describing dominance, richness, abundance, and pollution tolerance of invertebrate communities on the basis of qualitative and quantitative samples is presented in *table 9*. Pollution-tolerance values for each site are calculated as the mean of pollution-tolerance values assigned to each taxon in the community and range from 1 to 10 (1 being the least tolerant and 10 being the most tolerant). The pollution-tolerance values that were used are those provided in Barbour and others (1999), and the values represent the tolerance of taxa to water-quality and habitat conditions. Pollution-tolerance values based on taxa presence and absence from combined qualitative and quantitative samples ranged from 4.15 at site RB to 6.09 at site PESC.

Bear River Basin

A high diversity in available habitats coupled with cold temperatures at site SMFK provided favorable conditions for high taxa richness at this site, which had 72 taxa. Riffles were sampled as the RTH, and most of taxa richness was from Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). This included 27 EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa and 21 chironomids (true flies). The most abundant taxa collected in RTH samples were *Cricotopus* sp. (a chironomid), *Hydropsyche* sp. (a caddisfly), and slightly less abundant *Baetis* sp. and *Tricorythodes* sp. (mayflies). Pollution-tolerance values were low for this site on the basis of qualitative and quantitative samples, indicating that water-quality conditions supported a high percentage of pollution-intolerant taxa at this site.

Although the reach at site PESC lacked riffle and pool habitats, the presence of sloughs along the channel margins provided additional habitat for invertebrates, and this site also had the highest overall taxa richness, with 84 taxa. Sloughs were present at sites PESC, SMFK, and COAL, and all of these sites also had relatively high taxa richness. The high taxa richness at site PESC may also be attributable to the steady hydrologic conditions that persist at this site during the summer months as water is released from Bear Lake. It is possible that the lack of hydrologic disturbance coupled with the proximity of this site to the wetland areas surrounding Bear Lake could enable a greater number of taxa to colonize and persist within this reach.

Taxa richness at site PESC was composed mainly of chironomids (23) and EPT (14) taxa, but this site was also rich in Coleopterans (beetles) (13) and noninsect (15) taxa. Naididae (oligochaete worms) and *Ferrissia* sp. (a gastropod) were the most abundant taxa in the RTH sample, with *Cricotopus* sp. and *Paratanytarsus* sp. (chironomids) present at lower abundances. The pollution-tolerance value for site PESC on the basis of qualitative taxa richness was the highest of all the sites, but values based on RTH richness and abundance were closer to the median for all the sites. The high pollution-tolerance value for the qualitative sample is somewhat unexpected on the basis of water-quality conditions, which are relatively good at this site. This value is probably indicative of the limited habitat conditions within this reach.

At site CUB, 61 taxa were collected, with the greatest richness coming from chironomid taxa (22 taxa), and also a high richness coming from EPT taxa (15 taxa). This site had the greatest invertebrate density on the basis of RTH samples, which were collected in riffles, with the highest abundance composed of *Hydropsyche* sp. (caddisfly) and *Baetis* sp. (mayfly). Both of these genera are commonly associated with fast-moving water (Merritt and Cummins, 1996). Mean velocities at invertebrate sampling locations at CUB averaged 0.40 m/s, compared with a range of 0.09 m/s to 0.73 m/s for all the sites. These genera also are considered to be the most tolerant of the Trichopteran and Ephemeropteran families (Barbour and others, 1999). *Cheumatopsyche* sp. (caddisfly), and Simuliidae (black fly) , both taxa that are associated with swift water, and *Polypedilum* sp (chironomid) also were abundant at this site. Site CUB was one of three sites (LCCJOR and JOR were the other two) where water-quality samples were analyzed for the presence and concentration of seven insecticides. Four insecticides were detected in water from at least one sample, but concentrations did not exceed guidelines for the protection of aquatic life (Gerner, 2003).

Site COR had the most limited habitat of all the sites (composed entirely of a deep run) and had a low taxa rich-

Table 9. Selected invertebrate-community data for the fixed sampling sites in the Great Salt Lake Basins study unit

[EPT, Ephemeroptera, Plecoptera, and Trichoptera families; FC, filter-collector; GC, gather-collector; SH, shredder; RF, riffle, NR, nonriffle; MB, macrophyte beds; for site abbreviation see table 1]

Community characteristic	Site									
	SMFK	PESC	CUB	COR	COAL	PLAIN	CREST	LCCJOR	JOR	RB
Combined qualitative and quantitative samples										
Taxa richness	72	84	61	38	71	47	47	37	36	74
EPT taxa richness (percent)	37	17	24	16	35	8	21	16	8	38
Tolerance based on richness	4.82	6.09	5.38	5.98	5.20	6.05	5.56	5.97	5.91	4.15
Quantitative samples										
Richest-targeted-habitat type	RF	MB	RF	NR	RF	NR	RF	NR	MB	RF
Density (individuals per square meter)	1,1293	17,312	40,547	506	18,232	7,870	10,486	2,982	7,259	4,215
Taxa richness	24	27	22	20	25	24	26	25	24	31
EPT taxa richness (percent)	58	22	36	15	36	8	31	16	8	35
Simpson's diversity	.86	.83	.83	.58	.87	.86	.73	.83	.75	.88
Dominant taxa	*Cricotopus* sp.	Naididae	*Hydropsche* sp.	*Polypedilum* sp.	Simuliidae	*Dicrotendipes* sp.	*Cricotopus* sp.	*Caecidotea* sp.	*Cricotopus* sp.	*Baetis* sp.
Relative abundance of dominant taxa	24.5	28.9	27.9	63.2	26.5	25.4	46.1	34.9	38.7	23.2
Dominant functional feeding group	FC	GC	FC	SH	FC	GC	SH	GC	SH	GC
Relative abundance of dominant functional feeding group	41.6	48.0	51.4	69.9	41.1	63.9	48.9	58.1	39.3	73.2
Tolerance based on richness	4.05	5.94	5.15	5.61	4.87	5.99	5.13	6.11	6.02	4.35
Tolerance based on abundance	4.75	5.83	4.86	6.01	5.26	6.24	5.89	6.23	6.26	4.95

ness of 38 on the basis of the qualitative sample, most of which was composed of chironomids and noninsect taxa. Although taxa richness of the RTH sample was low (with 20 taxa) compared to other sites where nonriffle habitats were sampled, site COR had lower pollution-tolerance values than the other two large river sites that were heavily influenced by anthropogenic activities (PLAIN and JOR). Site COR had higher pollution-tolerance values than PESC, a large river site with mainly forest and rangeland cover. Site COR had the lowest abundance of taxa collected in an RTH sample and had the highest dominance by a single taxa of all of the sites, with *Polypedilum* sp. (a chironomid) composing 63 percent of the RTH sample. Naidids (oligochaete worms) and *Glyptotendipes* sp. (a chironomid) also were abundant in the RTH sample. The low abundance and high dominance exhibited here may be indicative of the effects of highly variable flows that result from upstream regulation for power generation. This contrasts with site PESC, where hydrologically stable conditions have enabled a large number of taxa to colonize habitats within the reach. At site COR, continual fluctuation in stage causes disturbance to macrophyte growth and woody debris that serve as potential habitat for invertebrates.

Weber River Basin

The site COAL qualitative sample had high EPT (25) and total taxa richness (71), both indicators of good stream water quality and likely a product of cold temperatures and diverse habitat availability. Most of the richness was composed of EPT and chironomid taxa, with a high richness in coleopteran (beetles) taxa as well. Riffles were sampled as the RTH, and taxa associated with fast moving waters such as Simuliidae (black flies) were dominant, with *Eukiefferiella* sp. (a chironomid) and *Baetis* sp. (a mayfly) at lower abundances. Overall, pollution-tolerance values on the basis of qualitative and quantitative samples were low, which indicate conditions favorable to pollution-intolerant invertebrates.

Limited habitat availability, warm temperatures, and relatively poor water quality at site PLAIN are evident with high pollution-tolerance values and lower invertebrate taxa richness (47 taxa) relative to the upper site (COAL). EPT richness was low for qualitative and quantitative samples, with only four EPT taxa collected in the combined samples. Most of the taxa richness at this site consisted of chironomids and noninsect taxa. The dominant taxa collected in woody snag RTH samples, all of which are chironomids, include *Dicrotendipes* sp., *Cricotopus* sp., and *Parakiefferiella* sp.

Utah Lake/Jordan River Basin

Site CREST had a relatively low overall taxa richness with 47 taxa collected, most likely a result of habitat conditions that were limited to shallow riffles. However, EPT taxa in qualitative and quantitative samples were 16 percent of the total, a moderate amount. Taxa composition differed from other high-gradient sites, probably in response to reduced velocities and shallow water because of the high volume of water that is diverted just upstream of this site. Site CREST also had high chironomid and noninsect taxa richness, which may indicate effects from urbanization, as discussed above. The dominant taxon in the RTH sample was *Cricotopus* sp., with high abundances of *Ceratopsyche* sp. (a caddisfly) and *Eukiefferiella* sp.

Invertebrate samples collected at site LCCJOR indicated that this site had impaired water-quality conditions. Taxa richness and abundance were low at this site, and pollution tolerance was high (on the basis of both qualitative and quantitative samples). EPT richness was limited to six taxa, and most of the taxa richness was composed of chironomids and noninsect taxa. Coleopterans and odonates were absent from this site. Abundance was low in the depositional RTH sample, and *Caecidotea* sp. (an isopod) was the dominant taxon, with high relative abundances of *Hydropsyche* sp. and turbellarians (flatworms). Habitat is limited at this site, and despite being one of the higher-gradient streams in the study unit, channelization has reduced the availability of riffle habitat within this reach and also limited the types of invertebrates present here. This site was one of the three sites (the others were JOR and CUB) where water-quality sampling for pesticides was conducted. Three insecticides were detected in water at this site (diazinon, malathion, and carbaryl) and exceeded some aquatic life guidelines (Gerner, 2003), which may contribute to impairment in this invertebrate community beyond limitations imposed by habitat alterations and poor water quality. In addition, metal concentrations in sediments of depositional areas at this site exceeded aquatic-life criteria for arsenic, cadmium, copper, lead, silver, and zinc (Waddell and Giddings, 2004).

The invertebrate community at site JOR also indicated impaired water-quality conditions, with the lowest EPT and total taxa richness (36) and high pollution-tolerance values. Temperatures are warm and habitat is limited at this site. In addition, several insecticides were detected in water-quality samples (Gerner, 2003), and metal concentrations including arsenic, cadmium, copper, lead, silver, and zinc were elevated in sediments (Waddell and Giddings, 2004). Taxa richness mainly consisted of chironomids and noninsects. The RTH sample was collected in macrophyte beds and was dominated by the burrowing chironomids *Cricotopus* sp., with high relative abundances of Naididae (oligochaete worms) and Simuliidae (black fly) taxa.

In contrast to other sites in the Utah Lake/Jordan River basin, the invertebrate community sample at RB had high EPT (28) and total taxa richness (74), and low tolerance to pollution. Most of the taxa collected were EPT, with a high richness of other insect taxa such as dipterans and coleopterans. The dominant taxon collected at this site was *Baetis* sp., with high abundances of the chironomids *Microspectra* sp., *Tventana* sp., *Eukiefferiella* sp., and Simuliidae. Cold water conditions, fast velocities, and high habitat diversity have likely facilitated the success of a high number of taxa at this site.

Habitat Specificity of Invertebrate Communities

TWINSPAN analysis of RTH samples revealed a distinction between invertebrate communities collected in riffle habitats (sites SMFK, CUB, COAL, CREST, and RB) and those that were collected in nonriffle woody-snag (sites PLAIN, and COR), macrophyte-bed (sites PESC and JOR), and depositional (LCCJOR) habitats (eigenvalue = 0.5224). Invertebrate assemblages in these two groups were very habitat specific, with 45 taxa unique to riffle (RF) samples, 37 taxa unique to nonriffle (woody snags, macrophyte beds, or depositional habitat) samples, and only 28 of the 105 nonrare taxa collected were present in both riffle and nonriffle samples.

Although it is evident from these results that microhabitat type plays an important role in invertebrate community composition, riffle and nonriffle sites have significant differences in physical and chemical characteristics that may also affect invertebrate community composition (*fig. 25*). Sites where riffle habitats were sampled were generally at higher altitudes, were colder, had higher gradients, had higher microhabitat froude numbers (a measurement of flow characteristics based on depth, velocity, and the acceleration of gravity), and had larger dominant substrates. These cold, shallow, and turbulent conditions provide a plentiful supply of dissolved oxygen that is necessary for the survival of many specialized invertebrates. Sites where woody-snag, macrophyte, or depositional habitats were sampled because of a lack of riffle habitat were generally large, warm, low-gradient streams with higher nutrient concentrations and more uniform geomorphology. Invertebrates that are adapted to these substrate types, as well as those tolerant to high siltation, are generally more successful in this type of stream environment (Allan, 1995).

Overall, differences in taxa composition and pollution-tolerance values were significant between riffle and nonriffle sites; however, taxa richness, abundance, and dominance metrics were similar between the two habitat groups (*fig. 26*). EPT taxa were higher in richness at riffle sites, and Plecoptera taxa were completely absent from nonriffle samples. Noninsect taxa were more abundant in nonriffle sites, and the ratio of EPT:Chironomidae abundance was lower for these sites, which indicates that chironomids also were more abundant at these sites. Riffle sites had higher richness of intolerant taxa than nonriffle sites.

Taxa Assemblages in Nonriffle Habitat

Nonriffle habitat includes woody snags, macrophyte beds, and depositional habitat. The initial division of invertebrate samples by habitat type identified four chironomids (*Dicrotendipes* sp., *Chironomus* sp., *Nanocladius* sp., and *Thienemanniella* sp.), as well as noninsect taxa such as Naididae and Turbellaria as the indicator species for the nonriffle site group (PESC, COR, PLAIN, LCCJOR, and JOR). *Dicrotendipes* sp., naidids, and turbellarians are pollution tolerant, sediment-burrowing taxa that are commonly associated with warm slow-moving water, and fine sediments (Merritt and Cummins, 1996). The second division of the nonriffle site group by TWINSPAN (eigenvalue = 0.5013) notably did not separate samples collected from woody snags and samples collected in macrophyte beds, but instead separated sites JOR and LCCJOR from the other three sites. Sites JOR and LCCJOR had lower discharge than sites PLAIN, COR, and PESC and

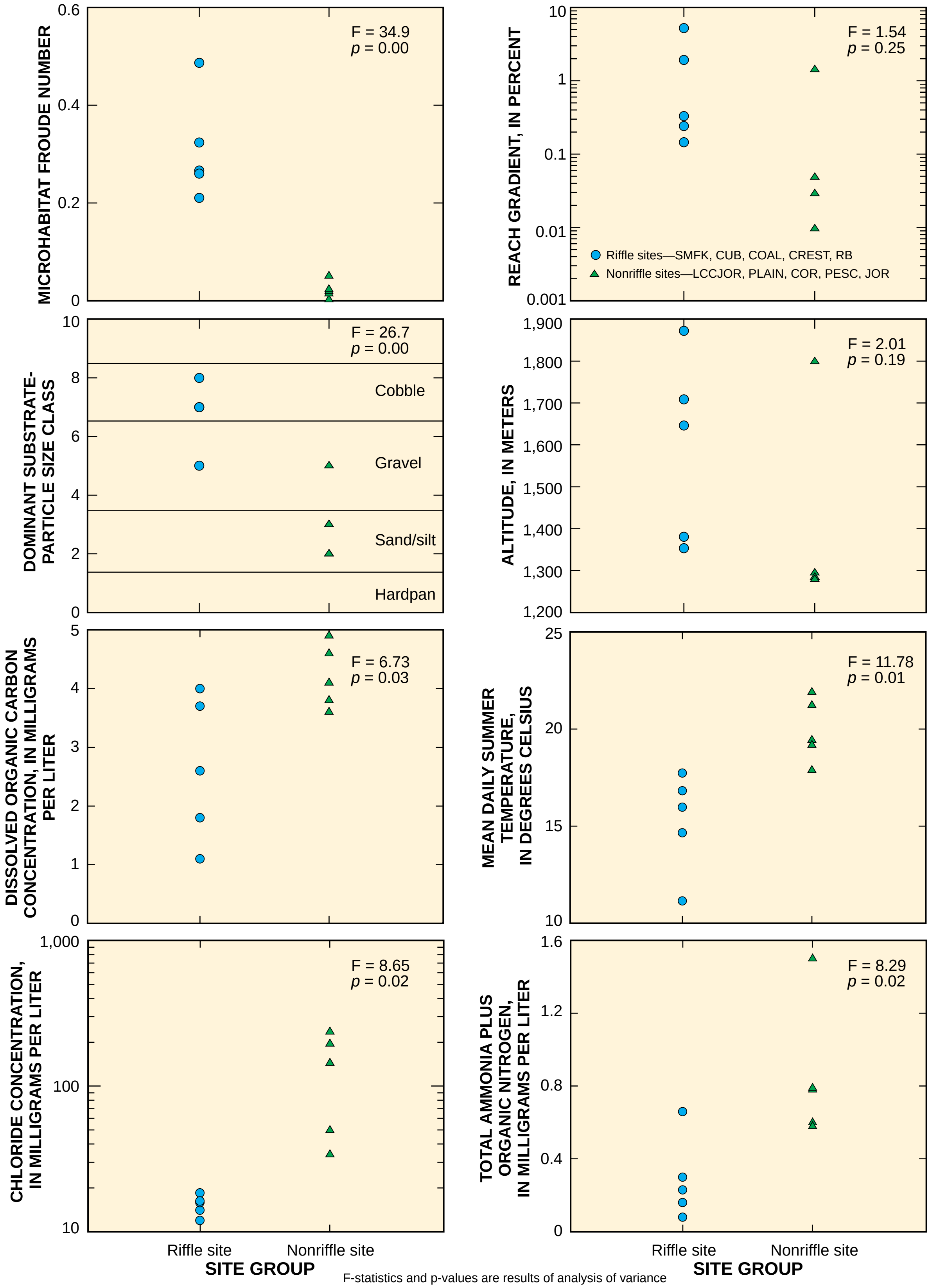

Figure 25. Environmental characteristics of riffle and nonriffle site groups determined by TWINSPAN analysis of richest-targeted-habitat invertebrate samples for the fixed sampling sites in the Great Salt Lake Basins study unit.

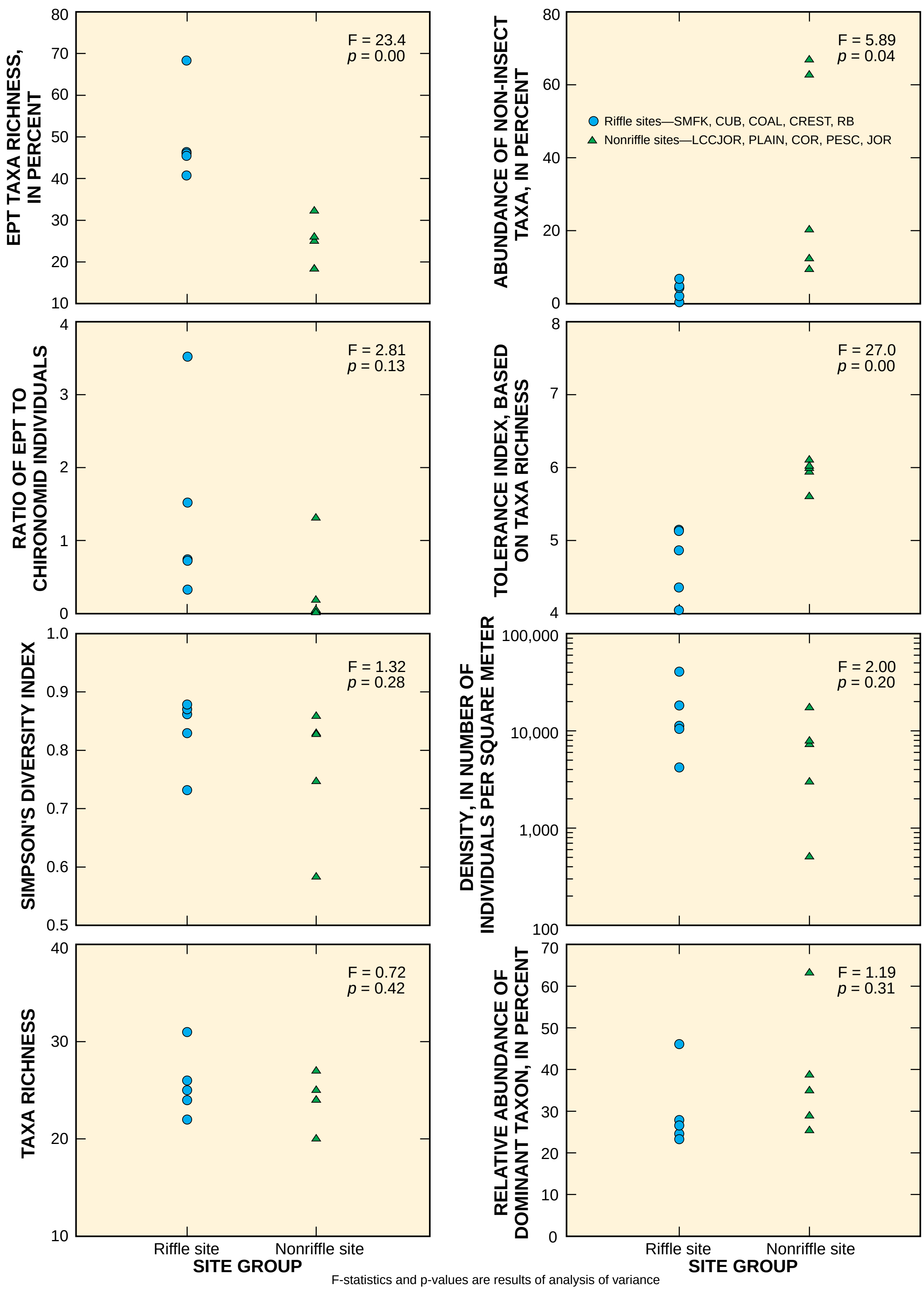

Figure 26. Characteristics of taxa assemblages for riffle and nonriffle site groups determined by TWINSPAN analysis of richest-targeted-habitat invertebrate samples for the fixed sampling sites in the Great Salt Lake Basins study unit.

are the most urbanized sites in the study unit. *Rheocricotopus* sp. (chironomid) was the indicator species associated with this division and was present at sites LCCJOR and JOR but absent from the other three sites. *Rheocricotopus* sp. also was collected at two other sites in the Utah Lake/Jordan River basin, RB and CREST, which indicates that zoogeographic distribution of this organism may be limiting it to the Utah Lake/Jordan River drainage basin rather than an association with urbanization.

Taxa Assemblages in Riffle Habitat

Taxa common to riffle sites but absent from nonriffle sites were all from the insect taxonomic class and included the midge larvae *Eukiefferiella* sp. and *Tvetenia* sp. and species with specialized adaptations for fast-moving water, such as members of the family Simuliidae (black fly larvae), *Optioservus* sp. (elmid beetle), *Baetis* sp. (mayfly), and *Cheumatopsyche* sp. (caddisfly). The second TWINSPAN division of the riffle site group separated site CREST from the rest of the sites by using the absence of *Polypedilum* sp. from this site as an indicator (eigenvalue = 0.4181). Site CREST also differed from the four other riffle sites in having a low abundance of *Baetis* sp. and an absence of Simuliidae, *Optioservus* sp., *Cheumatopsych*e sp., and *Tventenia* sp. Because cobble-sized substrates were sampled at all riffle sites, it can be inferred that different flow dynamics from slower velocities at this site, rather than substrate differences, is most likely the reason for the large difference in species assemblage in this sample as compared to other riffle samples.

Habitat-Specific Responses of Invertebrate Communities to Environmental Conditions

The habitat specificity displayed by invertebrate communities in the two habitat types (riffle and nonriffle) overwhelms differences in communities resulting from environmental conditions; therefore, associations of invertebrate community characteristics with land use and water quality were limited to comparisons among sites with the same available habitat types. Furthermore, environmental conditions may be more limited, or more variable, in one habitat type than in another, resulting in different invertebrate community responses. For these reasons, the riffle and nonriffle site groups will be examined independently regarding their response to environmental conditions.

Richness

Taxa richness at riffle sites decreased with increasing mean daily summer temperature and increased with increasing segment gradient. Although gradient and temperature are inversely correlated, it is likely that they are both important in determining invertebrate community structure (*fig. 27*). This response in taxa richness was observed at the nonriffle sites, but the correlation was not as strong. At sites PESC and JOR, the two sites where macrophyte beds were sampled, taxa richness was higher per temperature or gradient (*fig. 27*) than at sites with woody-snag or depositional habitat. This may be the result of hydrologically stable conditions and the proximity of these sites to upstream wetland habitat.

Pollution Tolerance

Richness and abundance of pollution-tolerant invertebrates were generally greater for the nonriffle sites than for the riffle sites. Within each of the site groups, differences in

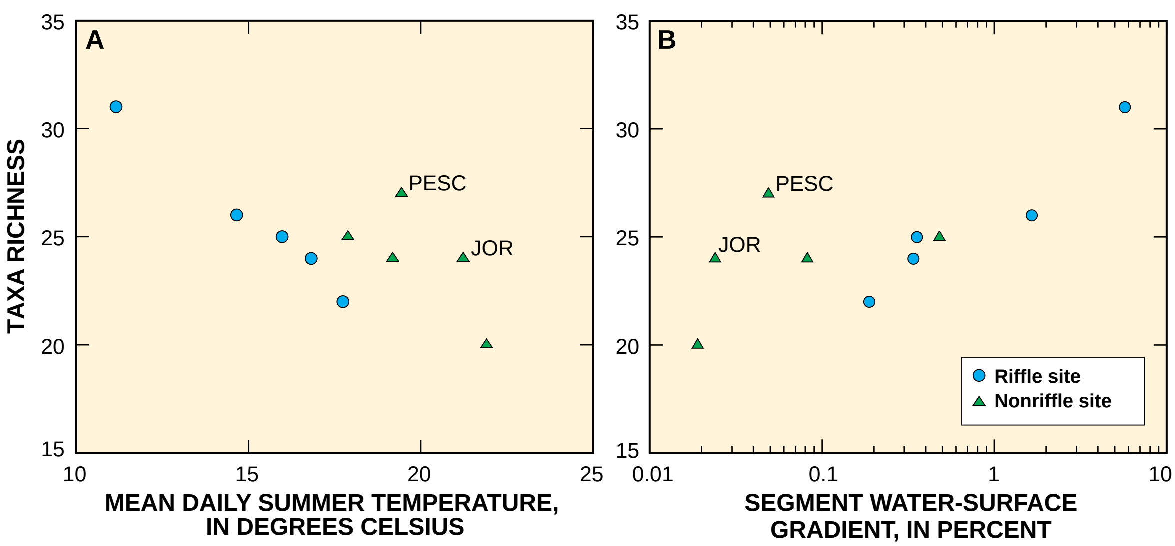

Figure 27. Relation between taxa richness in richest-targeted-habitat invertebrate samples and (A) mean daily summer temperature and (B) segment water-surface gradient of the fixed sampling sites in the Great Salt Lake Basins study unit.

pollution tolerance of invertebrate communities may be related to the type of land use within the basin. Within the riffle group of sites, the forest/rangeland sites (SMFK, COAL, and RB) consistently had fewer pollution-tolerant invertebrate taxa than the agricultural site (CUB) and the urban site (CREST). CREST had the highest abundance of pollution-tolerant invertebrates of all of the riffle sites. Within the nonriffle site group, the urban site (LCCJOR) and the two mixed land-use sites that are substantially influenced by urbanization (PLAIN and JOR) had the greatest richness and abundance of pollution-tolerant invertebrates (*fig. 28*). In contrast, the forest/rangeland site (PESC), and the mixed land use site, influenced by agricultural land use (COR), had fewer pollution-tolerant invertebrates. These results indicate that urbanization within the basins may be having a deleterious affect on invertebrate communities more than other types of land use.

Trophic Interactions

The occurrence and abundance of taxa adapted to a specific mode of food acquisition (trophic guild, or location in the food web) can indicate the source and availability of nutrients in the environment (Allan, 1995). Taxa known as collectors use fine particulate organic matter as a food source, while shredders feed upon coarse particulate organic matter in a stream. Scrapers typically feed on periphyton scraped from the surfaces of organic substrates. Predators and parasites feed upon living tissue, and omnivores gain nutrients through a variety of sources.

In general, community composition by functional feeding group for RTH samples did not differ substantially between riffle and nonriffle sites (*fig. 29*). Gather-collectors (GC), shredders (SH), and filter-collectors (FC) accounted for the greatest abundance of taxa collected. Samples from riffle sites did have slightly higher abundances of filter-collector taxa, while samples from nonriffle sites had slightly higher abundances of shredder taxa.

Taxa classified as filter-collectors capture fine particles for food by filtering them from fast currents. Both groups of sites showed an increase in percentage of filter-collector taxa richness with increased concentrations of total phosphorus, and abundance of filter-collector taxa increased with increasing concentrations of organic nitrogen and dissolved organic carbon (*fig. 30*). An increased percentage in richness of filter-collector taxa was observed at riffle sites with faster microhabitat velocities; however, this variable appears to be less important for nonriffle sites. Riffle sites were generally lower in nutrient concentrations, and high velocities probably compensate for the less abundant food sources by increasing delivery of particles. In contrast, high velocities may not be as important for nonriffle sites, where organic matter is more readily available.

The composition of invertebrate communities in RTHs differed primarily by the habitat type that was sampled. Communities in riffle habitats were less tolerant to pollution and had greater percentages of EPT taxa. Community samples collected in nonriffle (woody snags, macrophyte beds, or depositional) habitats had greater percentages of chironomids and noninsect taxa, lower percentages of EPT taxa, and higher tolerance to pollution. Richness, abundance, and dominance did not differ significantly between communities collected in the two habitats. Invertebrate communities in RTHs at urban sites in the Jordan River basin were distinctive from other sites where similar habitats were sampled.

Invertebrate community response to environmental variables differed between riffle and nonriffle habitats. By examining communities in these two habitat types separately, sensitivity of communities to water-quality conditions can be better understood. Taxa richness in riffle communities showed a stronger response to temperature and gradient than was observed in other types of habitat. Tolerance of invertebrate communities to urbanization and chloride concentrations differed between the two types of habitat. Trophic interactions also differed between the two habitat types with a greater percentage of filter-collectors present in riffle habitats and greater percentages of shredder taxa collected in woody snags and macrophyte beds. Richness and abundance of filter-collectors responded to nutrient concentrations in both types of habitat, and to microhabitat velocity in riffle habitats.

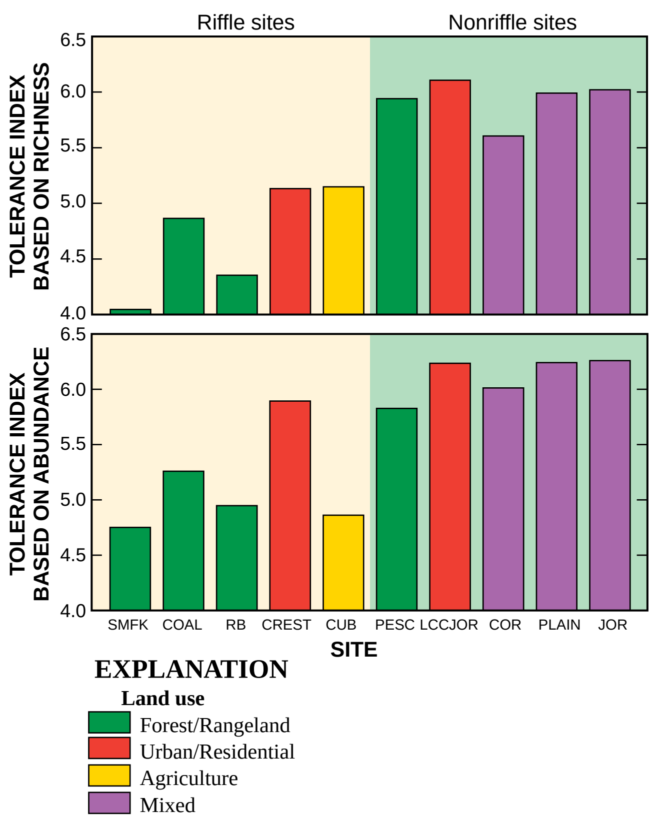

Figure 28. Pollution-tolerance index based on richness and abundance of pollution-tolerant invertebrates at the fixed sampling sites in the Great Salt Lake Basins study unit.

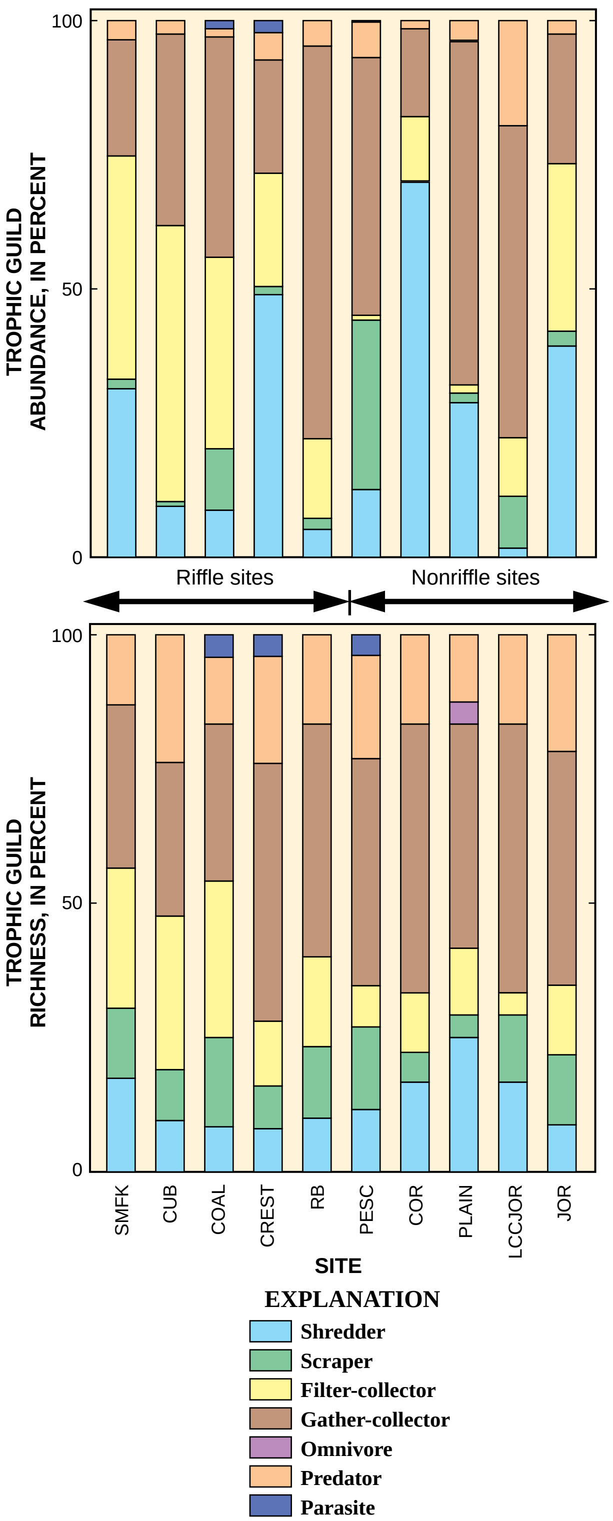

Figure 29. Trophic guild composition of invertebrate communities in richest-targeted-habitat-invertebrate samples based on taxa abundance and richness for the fixed sampling sites in the Great Salt Lake Basins study unit.

Fish

A listing of fish taxa collected at the fixed sampling sites is contained in *table C-3* in appendix C. Fish samples were collected at all of the sites in 1999, except for RB and JOR. Site JOR was sampled in 2000, and information on fish species at site RB in 1996 was obtained from the Utah Division of Wildlife Resources. Additional samples were collected at sites COAL, LCCJOR, and CUB in 2000 and 2001. For the sake of simplicity only the samples collected at these sites in 1999 will be used for comparison with other sites; however, the identity of additional species observed in multiple samples is included in the section on factors influencing the distribution of native fish species.

Description of Fish Communities

During the 3-year sampling period, 19 samples were collected and 29 species in 10 families were identified at the 10 sites (*table 10*). Seventeen native species are believed to occur in the GRSL (Giddings and Stephens, 1999), and 10 of these were collected during this study, belonging to the Catostomidae (suckers), Salmonidae (trout and whitefish), Cyprinidae (carps and minnows), and Cottidae (sculpins) families. Although all native species to the GRSL are considered adapted to cool- and cold-water conditions, introduced cold- and warm-water species also have become well established in some of the larger streams (Giddings and Stephens, 1999).

Six of the samples collected contained nine species, which was the maximum number of species collected in one sample. The minimum number of species collected at any site was one cutthroat trout (Oncorhynchus clarki) at site RB (D.Wiley, Utah Division of Wildlife Resources, oral commun., 2001). The Cyprinidae family was represented by nine species, the largest number of any family collected, and the Poeciliidae, Percichthyidae, and Clupeidae were represented by one species in each family. The redside shiner (Richardsonius balteatus), a minnow, was the most abundant species of fish collected within the GRSL and accounted for 41 percent of the 10,911 fish that were collected during 1999-2001. Common carp (Cyprinus carpio) accounted for the greatest proportion (76 percent) of the biomass of fish collected during this study. The relative abundance of fish families at each site is shown in *figure 31*.

Species richness, community composition, feeding and habitat preference, fish condition, and abundance are all important factors in assessing the overall health of fish communities (Barbour and others, 1999). Species richness can indicate a variety of available habitats. However, because cold-water streams are naturally low in species richness, a large number of species may be an indicator of the presence of nonnative warm-water species as a result of degraded habitat or water quality (Barbour and others, 1999). The trophic guilds represented in fish communities are an indicator of the available food sources and can indicate the health of other

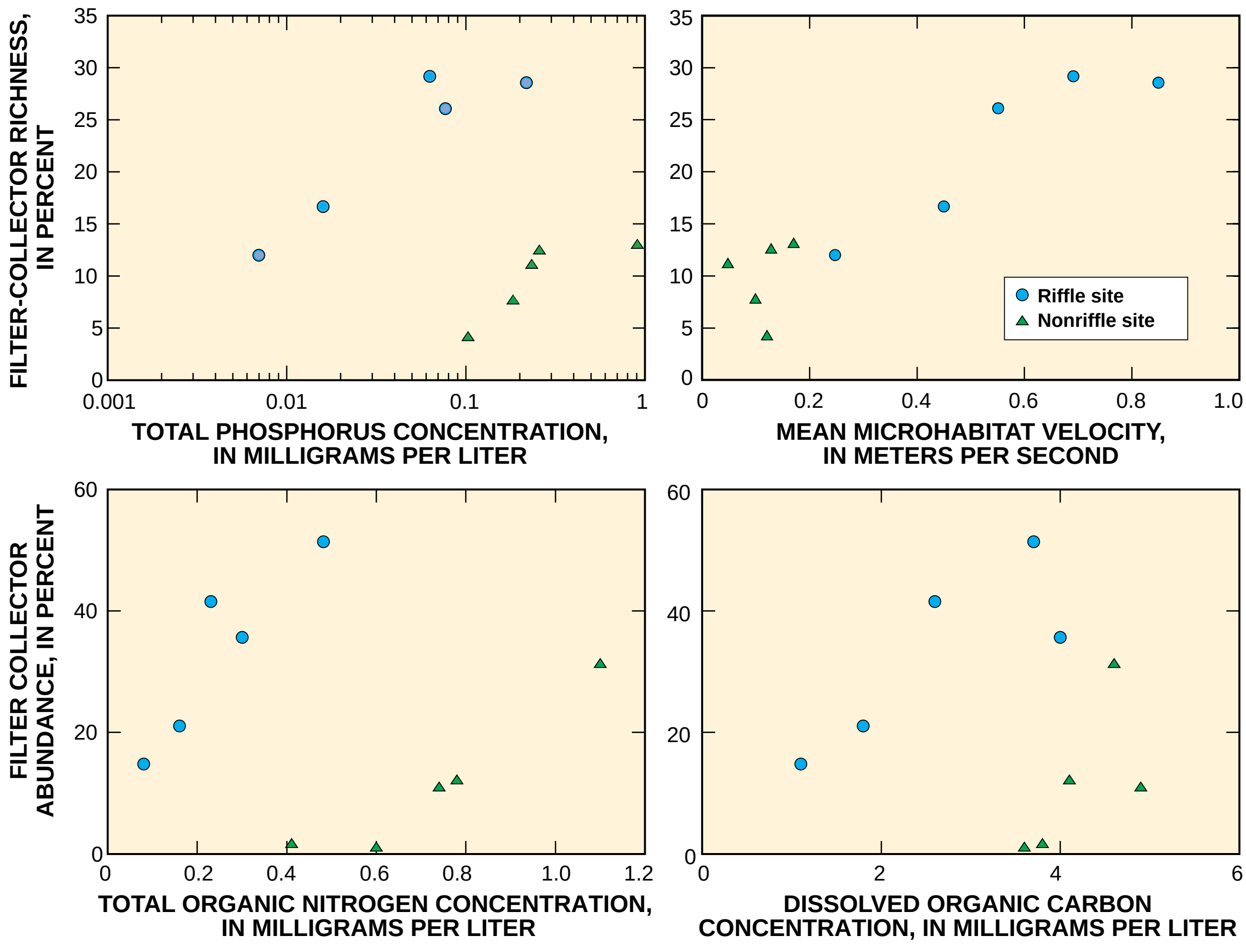

Figure 30. Relation between the percentage of filter-collector invertebrate taxa in richest-targeted-habitat invertebrate samples and streamflow velocity and selected nutrient concentrations at the fixed sampling sites in the Great Salt Lake Basins study unit.

biological communities such as algae and invertebrates. A dominance by omnivores within a fish community can indicate degradation of macroinvertebrate communities (Allan, 1995). The habitat preference of collected fish also provides an indication of the integrity of habitat and food sources available. Fish condition can be indicated by the presence of anomalies such as deformities, eroded fins, lesions, tumors, and parasites. Frequent occurrence of such anomalies may indicate degradation in habitat or water-quality conditions (Barbour and others, 1999). Fish communities were also assessed in relation to the designated beneficial use for aquatic life for each site.

Bear River Basin

Site SMFK is designated as a cold-water fishery, and the fish collected there reflect this beneficial-use designation. Six of the nine species collected were native. This site had few fish with anomalies (2 percent), two omnivorous species, and one tolerant species. The redside shiner, a native water-column species that often inhabits aquatic plant beds, was the most abundant species collected. This site was one of two sites where sculpins (*Cottus* sp.) were collected. Because sculpins require good water-quality conditions, cold temperatures, and sufficient riffle habitat for survival (Sigler and Sigler, 1996), their presence indicates that these conditions exist here.

Site PESC is also designated as a cold-water fishery; however, the fish community at this site is more degraded than that at site SMFK. Common carp (*Cyprinus carpio*), an introduced omnivorous fish, was the most abundant species collected in the sample. Overall, fewer species were collected at this site than at site SMFK, and a higher percentage of introduced and omnivorous species were present. In addition, this site had the highest percentage (38 percent) of fish with anchor worms and other anomalies in the Bear River basin.

Site CUB is designated as a warm-water game fishery, and five of the nine species of fish that were collected were warm-water species. This site did support two cold-water species: brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*). Only two native species were collected: Utah sucker (*Catostomus ardens*) and longnose dace (*Rhinicthys cataractae*). Overall, the fish community at this site was one of

Table 10. Selected fish-community data for the fixed sampling sites in the Great Salt Lake Basins study unit

[Trophic guild: H, herbivore; O, omnivore; I, invertivore; C, carnivore; Tolerance: Indicates tolerance to organic and thermal pollution: I, indifferent; T, tolerant; S, sensitive; Origin: N, native; I, introduced. Ecological data compiled from Chandler and others, 1993; Sigler and Sigler, 1996; and Zaroban and others, 1999; for site abbreviations see table 1]

Site	Family	Common name	Scientific name	Trophic guild	Tolerance	Origin	Temperature preference	Adult habitat	Number of individuals	Relative abundance (percent)
SMFK	Catostomidae	Bluehead sucker	*Catostomus discobolus*	H	I	N	cool	benthic	1	1
	Catostomidae	Mountain sucker	*Catostomus platyrhynchus*	H	I	N	cool	benthic	2	2
	Catostomidae	White sucker	*Catostomus commersoni*	O	I	I	warm	benthic	2	2
	Cottidae	Paiute sculpin	*Cottus beldingi*	I	I	N	cold	benthic	2	2
	Cyprinidae	Common carp	*Cyprinus carpio*	O	T	I	warm	benthic	8	9
	Cyprinidae	Redside shiner	*Richardsonius balteatus*	I	I	N	cool	water column	70	76
	Salmonidae	Brown trout	*Salmo trutta*	I/C	I	I	cold	hider	1	1
	Salmonidae	Cutthroat trout	*Oncorhynchus clarki*	I	S	N	cold	water column	4	4
	Salmonidae	Mountain whitefish	*Prosopium williamsoni*	I	I	N	cold	benthic	2	2
PESC	Catostomidae	White sucker	*Catostomus commersoni*	O	I	I	warm	benthic	8	15
	Cyprinidae	Common carp	*Cyprinus carpio*	O	T	I	warm	benthic	29	53
	Cyprinidae	Redside shiner	*Richardsonius balteatus*	I	I	N	cool	water column	1	2
	Salmonidae	Brown trout	*Salmo trutta*	I/C	I	I	cold	hider	3	5
	Salmonidae	Cutthroat trout	*Oncorhynchus clarki*	I	S	N	cold	water column	2	4
	Salmonidae	Mountain whitefish	*Prosopium williamsoni*	I	I	N	cold	benthic	12	22
CUB	Catostomidae	Utah sucker	*Catostomus ardens*	O	T	N	cool	benthic	20	8
	Centrarchidae	Black crappie	*Pomoxis nigromaculatus*	O	T	I	warm	water column	1	0
	Centrarchidae	Largemouth bass	*Micropterus salmoides*	C	I	I	warm	water column	4	2
	Cyprinidae	Common carp	*Cyprinus carpio*	O	T	I	warm	benthic	22	9
	Cyprinidae	Fathead minnow	*Pimephales promelas*	O	T	I	warm	water column	48	19
	Cyprinidae	Goldfish	*Carassius auratus*	O	T	I	warm	benthic	3	1
	Cyprinidae	Longnose dace	*Rhinichthys cataractae*	I	I	N	cool	benthic	133	54
	Salmonidae	Brown trout	*Salmo trutta*	I/C	I	I	cold	hider	2	1
	Salmonidae	Rainbow trout	*Oncorhynchus mykiss*	I	S	I	cold	hider	14	6
COR	Clupeidae	Gizzard shad	*Dorosoma cepedianum*	O	I	I	warm	water column	48	42
	Cyprinidae	Common carp	*Cyprinus carpio*	O	T	I	warm	benthic	59	52
	Cyprinidae	Grass carp	*Ctenopharyngodon idella*	H	I	I	warm	water column	4	4
	Ictaluridae	Channel catfish	*Ictalurus punctatus*	O	T	I	warm	benthic	1	1
	Percidae	Walleye	*Stizostedion vitreum*	C	I	I	cool	water column	1	1
COAL	Catostomidae	Utah sucker	*Catostomus ardens*	O	T	N	cool	benthic	2	1
	Cottidae	Mottled sculpin	*Cottus bairdi*	I	I	N	cool	benthic	140	58
	Cyprinidae	Riffle daces	*Rhinichthys sp.*	I	I	N	cool	benthic	12	5
	Salmonidae	Brown trout	*Salmo trutta*	I/C	I	I	cold	hider	12	5
	Salmonidae	Mountain whitefish	*Prosopium williamsoni*	I	I	N	cold	benthic	72	30
	Salmonidae	Rainbow trout	*Oncorhynchus mykiss*	I	S	I	cold	hider	3	1
PLAIN	Catostomidae	Utah sucker	*Catostomus ardens*	O	T	N	cool	benthic	1	0
	Centrarchidae	Green sunfish	*Lepomis cyanellus*	I	T	I	warm	water column	6	1
	Centrarchidae	Largemouth bass	*Micropterus salmoides*	C	I	I	warm	water column	5	0
	Clupeidae	Gizzard shad	*Dorosoma cepedianum*	O	I	I	warm	water column	43	4
	Cyprinidae	Goldfish	*Carassius auratus*	O	T	I	warm	benthic	7	1
PLAIN	Cyprinidae	Speckled dace	*Rhinichthys osculus*	I	I	N	cool	benthic	1	0
	Cyprinidae	Spottail shiner	*Notropis hudsonius*	I	I	I	warm	water column	1,047	93
	Ictaluridae	Black bullhead	*Ameiurus melas*	O	T	I	warm	hider	2	0
	Poeciliidae	Mosquitofishes	*Gambusia sp.*	I	T	I	warm	water column	15	1

Table 10. Selected fish-community data for the fixed sampling sites in the Great Salt Lake Basins study unit—Continued

Site	Family	Common name	Scientific name	Trophic guild	Toler-ance	Origin	Tempera-ture prefer-ence	Adult habitat	Number of individuals	Relative abundance (percent)
CREST	Catostomidae	Mountain sucker	*Catostomus platyrhynehus*	H	I	N	cool	benthic	465	37
	Cyprinidae	Longnose dace	*Rhinichthys cataractae*	I	I	N	cool	benthic	792	63
LCC-JOR	Catostomidae	White sucker	*Catostomus commersoni*	O	I	I	warm	benthic	26	18
	Centrarchidae	Green sunfish	*Lepomis cyanellus*	I	T	I	warm	water column	19	13
	Cyprinidae	Common carp	Cyprinus carpio	O	T	I	warm	benthic	43	29
	Cyprinidae	Fathead minnow	*Pimephales promelas*	O	T	I	warm	water column	27	18
	Cyprinidae	Goldfish	*Carassius auratus*	O	T	I	warm	benthic	3	2
	Cyprinidae	Longnose dace	*Rhinichthys cataractae*	I	I	N	cool	benthic	9	6
	Cyprinidae	Speckled dace	*Rhinichthys osculus*	I	I	N	cool	benthic	12	8
	Percichthyidae	White bass	*Morone chrysops*	C	I	I	warm	water column	5	3
	Salmonidae	Rainbow trout	*Oncorhynchus mykiss*	I	S	I	cold	hider	3	2
JOR	Catostomidae	White sucker	*Catostomus commersoni*	O	I	I	warm	benthic	17	65
	Cyprinidae	Goldfish	*Carassius auratus*	O	T	I	warm	benthic	1	4
	Cyprinidae	Common carp	*Cyprinus carpio*	O	T	I	warm	benthic	8	31
RB	Salmonidae	Cutthroat trout	*Oncorhynchus clarki*	I	S	N	cold	water column	10	100

the more degraded, with a high percentage of omnivorous and tolerant fish species. Anchor worm parasites and other anomalies were observed on about 10 percent of the fish collected. Habitat preferences of fish species were evenly balanced among benthic, water column, and hiders, which indicates that a favorable diversity of instream habitat conditions exist for fish.

The fish community at site COR also was very degraded and consisted entirely of introduced species. Omnivores accounted for 96 percent of the fish collected at this site. This was the only site where no sucker species were collected, possibly as a result of the prevalence of silt along the stream bottom, which may blanket food sources for benthic species such as the suckers. Gizzard shad (*Dorosoma cepedianum*) and common carp (*Cyprinus carpio*) dominated this community and composed 98 percent of the total abundance of fish collected. This site is designated as a warm-water fishery, and all species collected with the exception of the walleye (*Stizostedion vitreum*), which prefers cool water temperatures, are adapted to warm-water conditions (Zaroban and others, 1999). Habitat preferences of fish species collected were water column and benthic, but hiders were absent. In contrast to other sites that also had degraded habitat and water-quality conditions, a low percentage (about 3 percent) of fish with anomalies was observed.

Weber River Basin

Site COAL is designated as a cold-water fishery and many cold- and cool-water species including mottled sculpin (*Cottus bairdi*), brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), and mountain whitefish (*Prosopium williamsoni*) were collected there. No warm-water species were collected, and four of the six species collected were native. Most of the fish collected use invertebrates as their main source of food (Zaroban and others, 1999). Benthic species accounted for the greatest number of fish collected, and no water-column species were collected at this site. Only one percent of the fish collected had anomalies. Overall, the fish community collected here was one of the least degraded.

Site PLAIN is protected for warm-water nongame fish, and seven of the nine species collected at this site were introduced warm-water fish. No sensitive species were collected here, and five of the species were considered tolerant to thermal and organic pollution. Most of the species collected were water-column species, as would be expected because of the available habitat, which consisted of a deep pool; however, a few benthic and hider species also were present. The spottail shiner (*Notropis hudsonius*), a small schooling fish, accounted for 93 percent of the fish collected at this site. The high occurrence of tolerant and warm-water species of fish indicates that water-quality conditions are degraded at this site; however, this site does support its beneficial designated use as a warm-water, nongame fishery.

Utah Lake/Jordan River Basin

The fish community collected at site CREST reflects the habitat limitations at this site during low flow. Only two species of fish, longnose dace (*Rhinichthys cataractae*) and

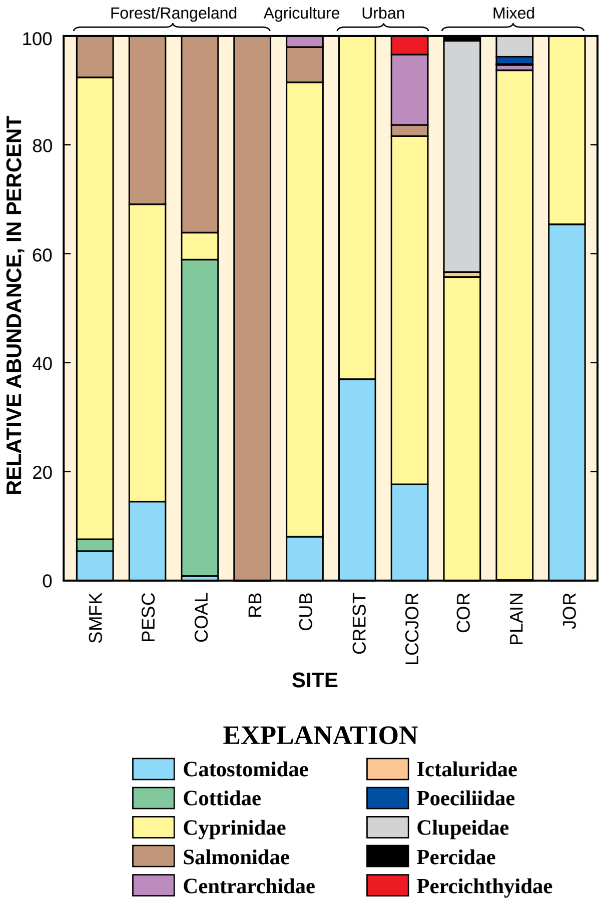

Figure 31. Relative abundance of fish families collected at the fixed sampling sites in the Great Salt Lake Basins study unit. (Sites are grouped by dominant land use.)

mountain sucker (*Catostomus platyrhynchus*) were collected. Both of these fish are small-bodied benthic species and may be the only types of fish able to survive in the shallow conditions at this site. These fish were present in high abundances, with 465 suckers and 792 dace collected. Site CREST is designated as a cold-water fishery, but neither of these species is considered a cold-water fish.

Site LCCJOR is designated as a cold-water game fishery; however, the fish collected at this site were heavily degraded with respect to this beneficial use. The fish sample collected was composed mainly of introduced warm-water species such as common carp (*Cyprinus carpio*), goldfish (*Carassius auratus*), white sucker (*Catostomus commersoni*), and green sunfish (*Lepomis cyanellus*). Of the nine species collected, four were tolerant to thermal and organic pollution. Rainbow trout (*Oncorhynchus mykiss*), a cold-water species, was the only sensitive species collected; however, it is unlikely that there is a reproducing population of this species in this segment of the stream. A mixture of species with different feeding and habitat preferences was collected, which indicates that habitat and food sources are sufficient within the reach to support a diverse fish community. Temperature and water-quality conditions, however, are likely limiting the types of fish able to survive at this site.

Site JOR provides an example of a fish community existing in degraded waters. The community observed at site JOR was composed of three introduced, omnivorous species that were either tolerant of or insensitive to degraded water quality. The percentage of fish with anomalies collected at JOR was the highest of all of the sampling sites (54 percent). This site and site COR were the only sites that had no native fish species.

Site RB presents a unique situation for the analysis of fish community structure because it is currently being managed to reestablish the endangered Bonneville cutthroat trout (*Oncorhynchus clarki*) population. In 1983, 1986, and 1987 the stream was chemically treated to remove all fish species, and Bonneville cutthroat trout were subsequently transplanted into the stream (D. Wiley, Utah Division of Wildlife Resources, oral commun., 2002). Despite the lack of diversity in fish species at this site, the fact that this stream can support this highly sensitive species indicates good water-quality and habitat conditions.

Comparison of Fish Communities in Streams Designated for Cold- and Warm-Water Aquatic Life

In the GRSL, the Utah, Wyoming, and Idaho State Divisions of Water Quality designate beneficial use water-quality criteria for different stream segments *(table 11)*. Stream segments that do not meet these criteria are placed on the EPA 303(d) list of impaired waters. Among the sampling sites, six are designated for cold-water game fish and associated species within the food chain, three are designated for warm-water game fish, and one is designated to support nongame fish. Because of the different criteria for these sites, different types of fish may be expected to occur among sites with different beneficial-use designations.

The maximum allowable temperature for the support of cold-water game fish is 20˚C in Utah (Utah Department of Environmental Quality, 2002) and Wyoming (Wyoming Department of Environmental Quality, 2001), and 25˚C in Idaho (L. Van Avery, Idaho Department of Environmental Quality, oral commun., 2002). For the support of warm-water game fish, the limit is 27˚C in Utah and 30˚C in Wyoming. These criteria generally were determined on the basis of naturally occurring stream temperatures from historical observations and the potential to maintain these temperatures through current management practices. Some fixed sites are currently listed on the 303(d) list of impaired waters for not meeting the criteria with certain chemical constituents (Utah Department of Environmental Quality, 2000); none of the fixed sites are currently listed for not meeting water-temperature criteria.

The range of mean daily and maximum daily water temperatures for June through August 1999 (for the year 2000 at site JOR and for the year 2001 at site COAL) are shown in

Table 11. Utah, Wyoming, and Idaho State Department of Environmental Quality beneficial-use classification, source of beneficial-use impairment, and water temperature criterion for the fixed sampling sites in the Great Salt Lake Basins study unit

[Class: 3A, Protected for cold-water game fish and aquatic life including associated food chain aquatic organisms; 3B, Protected for warm-water game fish and aquatic life including associated food chain aquatic organisms; 3C, Protected for warm-water nongame fish and aquatic life including associated food chain aquatic organisms; site abbreviations are in table 1]

Site name	Class	Source of beneficial-use impairment identified by total maximum daily load analyses (if applicable)	Maximum water temperature criterion (degrees Celsius)
SMFK	3A		20
PESC	3A	sediments	[1]25
CUB	3B		27
COR	3B	phosphorus	27
COAL	3A		20
PLAIN	3C		27
CREST	3A	dissolved solids	20
LCCJOR	3A	dissolved solids	20
JOR	3B		27
RB	3A		20

[1]Site is in Idaho, where temperature criterion for cold-water fisheries is 25 degrees Celsius.

figure 32. All of the cold-water sites, except for RB and PESC, frequently exceeded the temperature criteria. The daily temperature at sites CREST and LCCJOR regularly exceeded the criteria for cold-water streams during the summer. Site PESC would regularly exceed the criteria as a cold-water fishery if it were located in Wyoming or Utah; however, in Idaho it does not exceed the criterion (25˚C) for Idaho streams.

The relative abundance of cold-, cool-, and warm-water fish species collected at the sampling sites is shown in *figure 33*. Although cold-water streams would be expected to support mostly cold-water and cool-water aquatic life, this was not the case at site LCCJOR, where 67 percent of the sample was composed of warm-water fish species. No cold-water species were collected at site CREST, and at site LCCJOR less than 15 percent of the sample was composed of cold-water fish species (stocked rainbow trout). The streams protected for warm-water aquatic life (Utah Class 3B) all supported greater than 50 percent warm-water species.

Condition of Fish Communities

An index was used to summarize the condition of fish communities in the GRSL using four metrics that describe fish-community composition (percentage of introduced species), trophic interactions (percentage of omnivorous species), tolerance (percentage of tolerant species), and anomalies (percentage of fish with deformities, eroded fins, lesions, or tumors) (*fig. 34*).

In general, fish-community condition was better at forest/rangeland sites than at sites lower in the basins with land-use development such as urban and agriculture. Sites CREST, COAL, and SMFK scored the highest, and mixed land-use sites COR and JOR scored the lowest on the community condition index. The percentage of introduced species varied greatly among sites and was a dominant factor in overall index scores, and the percentage of introduced fish species increased from upstream to downstream within each of the basins. The percentage of fish with anomalies varied from 0 to 35 percent. Site RB was not included in the fish-community condition index because data on the occurrence of anomalies were not available; however, assuming that all fish collected were in good health, this site would have an index score equivalent to that of site CREST.

Factors Affecting the Distribution of Native Fish

The largest source of variance in the fish-condition index (*fig. 34*) was in the percentage of introduced species at each site. The percentage of fish communities composed of introduced species ranged from zero at sites RB and CREST to 100 percent at sites JOR and COR. Fish communities at sites COAL and SMFK were both composed of 23 percent introduced species, site PESC of 50 percent introduced species, and sites CUB, PLAIN, and LCCJOR each supported 67 percent introduced species.

There is a significant ($r = 0.86$, $p = 0.001$) relation between annual degree days (the sum of daily mean water temperatures for one year) of stream temperature and the percentage of introduced species collected at each site. In general, an increase in the percentage of introduced species is seen with increasing temperature. Species native to the GRSL are adapted to cool and cold water and some species are susceptible to decline with increasing stream temperatures (Sigler and Sigler, 1996). This indicates that temperature may be an important factor limiting the distribution of native species.

Species native to the GRSL that were collected during the study included three sucker species: Utah sucker (*Catostomus ardens*), bluehead sucker (*Catostomus discobolus*), and mountain sucker (*Catostomus platyrhynchus*); two salmonid species: mountain whitefish (*Prosopium williamsoni*) and cutthroat trout (*Oncorhynchus clarki*); three cyprinid species: redside shiner (*Richardsonius balteatus*), longnose dace (*Rhynichthys cataractactae*), and speckled dace (*Rhynichthys osculus*); and two cottid species: mottled sculpin (*Cottus bairdi*) and Paiute sculpin (*Cottus beldingi*). Species in the sucker family were the only native fish that were widely distributed among sites. Native salmonids, cottids, and cyprinids appear to have more specific habitat requirements and were present only at about half of the sites. The range of selected environmental variables where native species were present or absent is summarized in *table 12*.

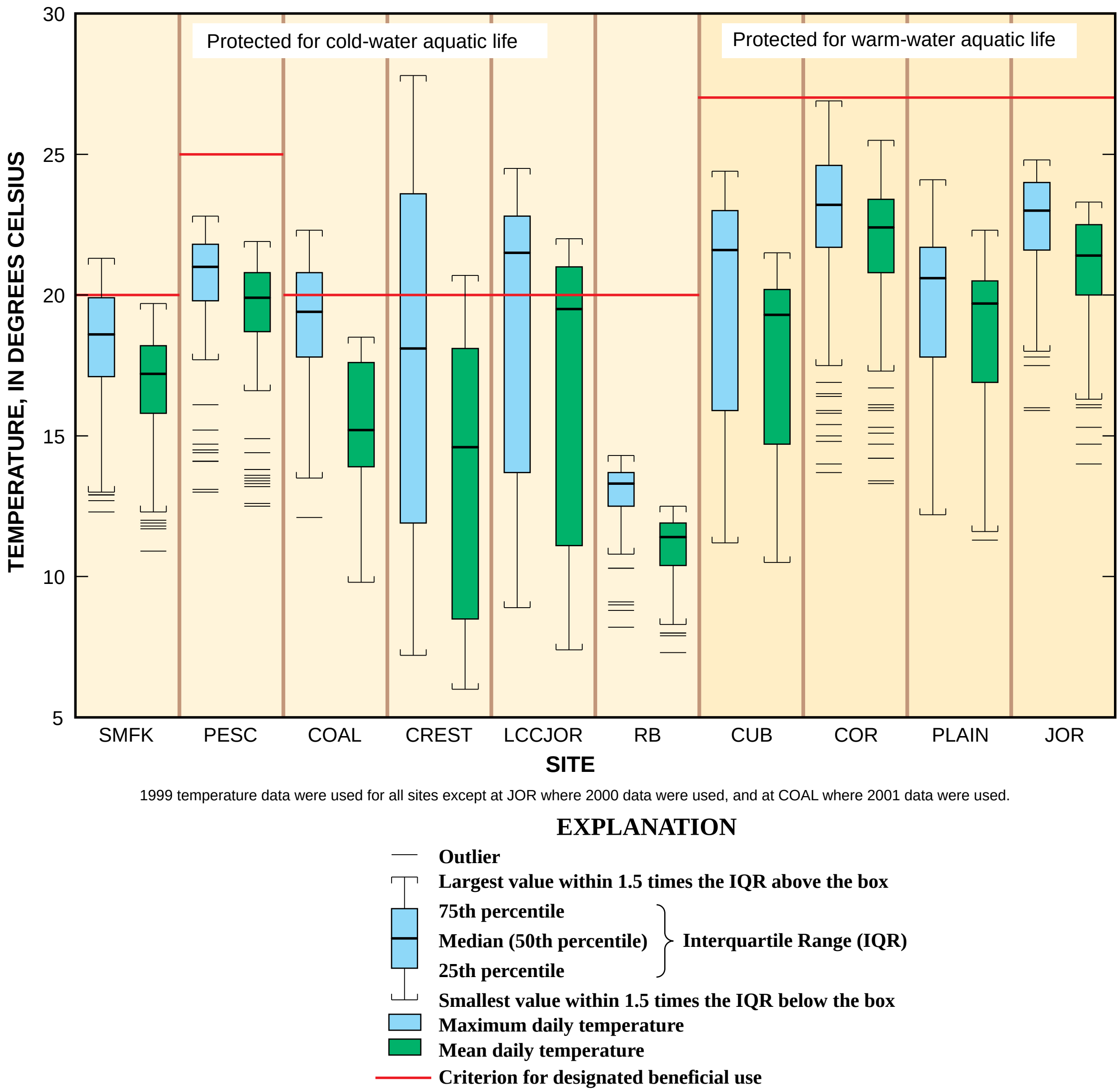

Figure 32. Mean daily and maximum daily temperature range for June - August at the fixed sampling sites in the Great Salt Lake Basins study unit.

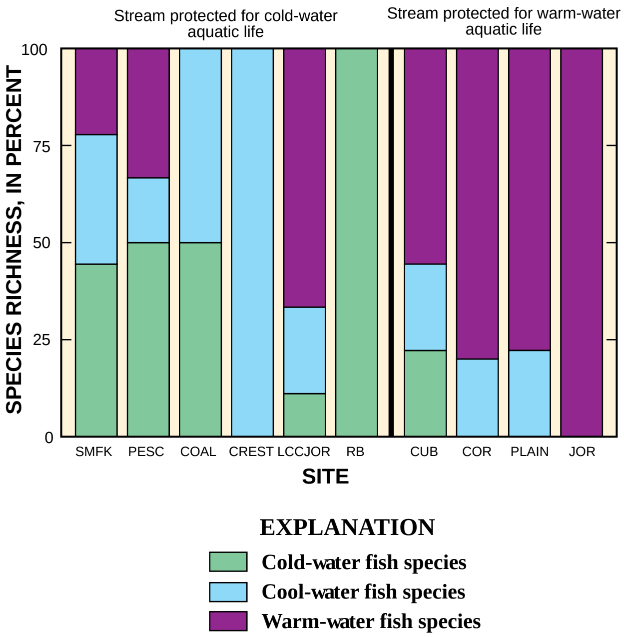

Figure 33. Percentage of cold-, cool-, and warm-water fish species collected at the fixed sampling sites in the Great Salt Lake Basins study unit.

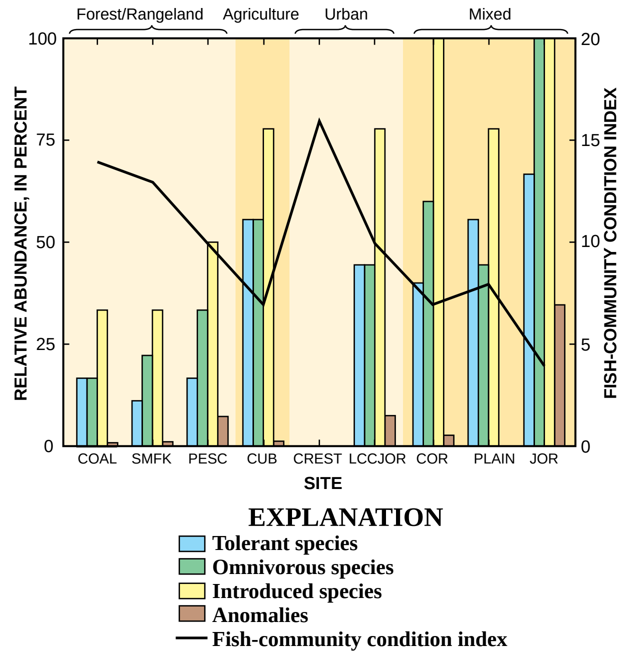

Figure 34. Fish-community condition index metrics and scores for the fixed sampling sites in the Great Salt Lake Basins study unit.

(Sites are grouped by dominant land use. Site RB was not included because data on anomalies were not available.)

The occurrence of salmonid species is typically an indicator of cold-water conditions, and most salmonids are sensitive to the effects of human activities. Native salmonid species were collected at four sites: SMFK, PESC, COAL, and RB. Distinctive conditions at these sites are high altitude, low annual mean maximum temperatures, and high streamflow velocities.

The occurrence of benthic insectivores such as sculpins and dace may indicate the quality of benthic-habitat conditions (Barbour and others, 1999). Native benthic insectivores were collected at six sites: SMFK, CUB, COAL, PLAIN, CREST, and LCCJOR. Sculpins were collected only at SMFK and COAL. Siltation appears to be an important factor determining the distribution of sculpins and dace, and they were not collected at sites with greater than 20 percent siltation. Sculpins were collected only at sites where no silt was present, which indicates that these species may be more sensitive than dace. Sculpins also appear to be more sensitive than dace to water temperature, specific conductance, and dissolved oxygen concentration (*table 12*), which may account for the more limited distribution of sculpins relative to dace.

The redside shiner (Richardsonius balteatus) is considered to be a “wide-ranging” native (Sigler and Sigler, 1996) but was collected at only 4 of the 10 sites: SMFK, PESC, CUB, and COAL. This species was collected at low-gradient, larger-discharge sites that receive a high percentage of daily solar radiation. This species was not collected at sites where there were few emergent macrophytes available for habitat cover.

In summary, fish species that are native to the GRSL appear to be limited in their distribution among the sites sampled. Of the 29 species of fish collected, only 10 of these were native to the GRSL, and many of these were only collected at a couple of sites. Although specific habitat requirements of individual species may be a limiting factor for some native species, it is evident that temperature plays a predominant role in shaping fish communities in the GRSL. There is a distinct trend of more introduced species and fewer native species at sites with warmer temperatures.

Summary of Ecological Conditions at Fixed Sites in the Great Salt Lake Basins

Sites SMFK, RB, and COAL had the highest quality in biological communities and habitat of the sites sampled. All of these sites were forest/rangeland indicator sites, although they each have some type of human modification. Site RB was the least affected of the three sites, and this was reflected in excellent habitat quality, and algae and invertebrate communities of high integrity. The fish community at this site has been managed heavily for the reintroduction of cutthroat trout and cannot be assessed as a natural community. Sites SMFK and COAL are both large river sites. Site COAL has been subject to hydrologic modifications, but habitat conditions still rank high, and water temperatures and water-chemistry conditions

Table 12. Range of selected environmental variables for which native fish were either present or absent for the fixed sampling sites in the Great Salt Lake Basins study unit

[m/s, meters per second; m^3/s, cubic meters per second; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; for site abbreviations, see table 1]

Environmental variable	Native salmonids		Sculpins	
	Present, N=4	Absent, N=6	Present, N=2	Absent, N=8
	Range	Range	Range	Range
Mean velocity (m/s)	0.402 - 0.844	0.177 - 0.427	0.725 - 0.756	0.177 - 0.844
Gradient (percent)	.006 - 5.21	.0150 - 1.92	.145 - .241	.06 – 5.21
Sample discharge, (m^3/s)	.0736 - 36.82	.0275 - 24.92	4.786 - 11.27	.0275 - 36.82
Silt occurrence (percent)	0 - 100	0 - 100	0 - 100	0 - 100
Daily solar radiation (percent)	20 - 99	11 - 98	83 - 97	11 - 99
Observations of aquatic macrophytes (percent)	0 - 2	0 - 2	0 - 2	0 – 5
Altitude (meters)	1,646 - 1,871	1,282 - 1,381	1,709 - 1,871	1,282 - 1,801
Riffle (percent)	0 - .8	0 - .3	.2 - .2	0 - .6
Annual mean maximum daily temperature (degrees Celsius)	8.0 - 11.3	11.6 - 16.0	9.0 - 11.3	8.0 - 16.0
Dissolved oxygen concentration (mg/L)	7.60 - 11.60	5.80 - 10,80	9.10 - 11.60	5.80 - 10.80
Specific conductance (µS/cm)	308 - 616	245 - 1,620	308 - 484	245 - 1,620
Habitat Quality Index Score	41 -154	65 - 108	89 - 99	41 - 154
Environmental variable	Dace		Redside shiner	
	Present, N=5	Absent, N=5	Present, N=4	Absent, N=6
	Range	Range	Range	Range
Mean velocity (m/s)	.177 - .725	.402 - .844	.335 -.844	.177 - .427
Gradient (percent)	.0480 - 1.92	.006 - 5.21	.006 - .331	.0150 - 5.21
Sample discharge, (m^3/s)	.0275 - 4.786	.074 - 36.8	1.08 - 36.8	.0275 - 24.92
Silt occurrence (percent)	0 - 15.15	0 - 100	0 - 100	0 - 100
Daily solar radiation (percent)	11 - 96	20 - 99	83 - 99	11 - 98
Observations of aquatic macrophytes (percent)	0 - 5	0 - 2	0 - 5	0 -2
Altitude (meters)	1,282 - 1,709	1,282 - 1,871	1,353 - 1,871	1,282 - 1,646
Riffle (percent)	0 - .3	0 - 58.0	0 - .2	0 - .6
Mean annual maximum daily temperature (degrees Celcius)	11.3 - 12.6	8.0 - 1,603	9.0 - 11.8	8.0 - 16.0
Dissolved oxygen concentration (mg/L)	7.70 - 11.60	5.80 - 10.80	7.60 - 11.60	5.80 - 10.80
Specific conductance (µS/cm)	245 - 1,300	484 - 1,620	308 - 616	245 - 1,620
Habitat Quality Index Score	80 - 108	41 - 154	41 - 99	65 - 154

are favorable for biological communities. Site SMFK has less direct hydrologic modification, but the riparian area has been heavily affected by grazing and has resulted in marginal habitat conditions at this site. Water-quality and temperature conditions are good at this site, however. Algae and invertebrate communities at these sites reflected the relatively undisturbed physical and chemical conditions, with a high richness and a high percentage of sensitive species. Fish communities ranked high on selected metrics with a high percentage of native and intolerant species and a low occurrence of anomalies. Overall, both the habitat and biological communities at these sites point to relatively good conditions among the range of sites sampled.

At the other end of the spectrum, the three large river sites (JOR, COR, and PLAIN) had a mixture of agriculture, urban, and rangeland, and had relatively tolerant biota and degraded habitat conditions. All of these sites have been subject to a multitude of human effects, including influences of agriculture and urban land use, hydrologic modifications, and wastewater discharges. Nutrient concentrations generally are enriched and the degree of siltation is high at these sites. Habitat conditions are limited and affected by alterations of the natural flow regime, although site JOR has more diverse habitat than the other two. The biological communities collected at these sites were dominated by tolerant species. The fish communities consisted of an abundance of omnivorous and introduced species; however, the number of fish with anomalies varied among the sites. Invertebrate communities had low overall richness at sites JOR and COR. Richness was slightly higher at site PLAIN. Sites PLAIN and JOR were dominated by tolerant organisms, with EPT taxa composing only 8 percent of the overall richness at the sites. Site COR had a slightly less tolerant community, but was still poor compared with other sites sampled. Algae communities at sites COR and JOR had relatively high richness, which is often the case when sites are enriched with nutrients. Diatom communities at all three sites were dominated by species tolerant of organic pollution, eutrophication, and high chloride and ion concentrations. Both the algae and invertebrate communities at these sites were dominated by only a few species.

The remaining sites were more varied with respect to their physical, chemical, and biological conditions. Sites CREST and LCCJOR are both urban sites but are subject to different intensity of urban land uses. Conditions at site CREST are dominated by hydrologic alterations. Because surface water from the upstream watershed is diverted above this site, water at the site originates mostly as ground water, resulting in good water quality and low temperatures. Habitat conditions were ranked as optimal despite very low flow conditions during the time of sampling. On the basis of observations of bank stabilization downstream, lack of depositional areas, and large discharge during spring runoff, high streamflow velocities appear to occur during runoff conditions, which could limit stable biological communities at this site. The fish community was dominated by small-bodied organisms that are able to survive high velocities during spring runoff as well as the summer low-flow conditions of less than 0.02 m^3/s. Invertebrate communities at CREST are of moderate pollution tolerance, and although richness is somewhat low overall, percentage of richness as sensitive species is moderate. Algae communities at the site, however, have low richness and high dominance by one taxa. Tolerance values for diatoms were moderate.

Site LCCJOR had a more egradated biological community than site CREST. Water quality at this site was poorer than that at the upstream site, with turbid conditions and high concentrations of nutrients and chloride. Water temperatures regularly exceeded the temperature criterion for this site and habitat conditions overall were marginal. Hydrologic conditions fluctuated widely in response to storms and there was a large difference between peak and low flows. The fish community at the site was dominated by a wide variety of tolerant organisms, mostly nonnative and omnivorous (generalist feeding habits), and had a high percentage of fish with external anomalies. Invertebrates at the site were among the most tolerant collected and were low in richness and abundance. In addition, diatom taxa were dominated by eutrophic and tolerant species.

Site CUB was the only agricultural site sampled. Biological conditions at the site appeared to be degraded in comparison to the forest/rangeland sites SMFK, COAL, and RB but were not as degraded as the mixed land-use sites or site LCCJOR, a similarly sized stream in an urban area. Habitat conditions were suboptimal, including poor bank and riparian condition and siltation in the reach. These conditions were specifically addressed by habitat restorations through a cooperative restoration effort by private, local, State, and Federal agencies in 2000 (Utah Watershed Program, 2002). Water quality at the site showed some enrichment of nutrients. Algal community richness and diversity were moderate. The community was similar to that at other sites with some nutrient enrichment and a high percentage of solar radiation. Motile algal cells were abundant, and relative abundance of tolerant diatoms was high. Invertebrate communities exhibited moderate pollution-tolerance values. Richness and relative richness of sensitive taxa were not as high as the least disturbed sites, but were higher than at the other sites sampled. Fish communities at the site indicated more degraded conditions than the benthic invertebrate and algal communities. A high percentage of fish were tolerant, omnivorous, and nonnative, and there was a high percentage of fish with anchor worm parasites and other anomalies. However, habitat preferences of fish species were evenly balanced between benthic, water column, and hiders, indicating that a favorable diversity of instream habitat conditions for fish exists. Although currently classified as a warm-water stream, it is likely that historically this stream supported cold-water species.

Site PESC also had mixed results. The dominant feature of this site is its position below the outlet from Bear Lake. As a result, the hydrologic regime of the site is highly altered. Water-quality conditions are similar to those at site SMFK, which is located upstream, although water temperatures are warmer. Habitat at the site is poor, largely as a result of the alterations to flow regime, which has created homogeneous, low-velocity conditions in the summer. The fish community at the site was in better condition overall than communities at most of the sites sampled, except for sites SMFK and COAL. Tolerant and nonnative species have gained a foothold here, but natives and cold-water-adapted species are still present. A high percentage of fish with anchor worm parasites is likely a result of the prevalence of this condition upstream in Bear Lake. Invertebrate communities showed some signs of degradation. Although species richness was high, richness of sensitive taxa was moderately low, and pollution-tolerance values were similar to those of more degraded sites. Algae communities were low in overall abundance but had high richness values. In contrast to invertebrates, relative abundance of intolerant diatoms was high.

Temporal and Spatial Variation at Fixed Sites

Sites COAL, CUB, LCCJOR, and RB were sampled for 3 consecutive years (1999-2001) to assess temporal variability in habitat, and chemical and biological conditions within the reach. Habitat surveys and concurrent collection of algae and invertebrate samples were completed in mid-August in 1999 and 2000, and in mid-July in 2001. Data for site CREST was collected in 2000 as part of a synoptic study and is also included in the analysis of temporal variability. At three sites, CUB, LCCJOR, and RB, multiple reaches were sampled to assess spatial variability in habitat and biological community assemblages within the stream segment and to assess sampling error resulting from methods or sampling crews. Fish samples also were collected for spatial and temporal analysis at sites COAL, CUB, and LCCJOR.

Habitat

Three sampling reaches were chosen within each stream segment, and variability of chemical and hydrologic characteristics among reaches was assumed to be minor. Physical habitat, such as bank and riparian characteristics and the structural components of the channel bed, however, did vary among reaches depending upon the characteristics of the stream, and these differences may be greater in some land-use settings than others. In contrast, temporal variability of habitat characteristics within the same reach may be mostly attributed to differences in discharge.

A summary of average conditions and relative variation in selected habitat characteristics at sites where multiple reaches were sampled and multiple samples were collected is presented in *table 13*. Overall, variation was low (less than 30 percent) for channel shape and bank characteristics. Siltation and dominant substrate characteristics were highly variable, which may be attributed to sampling methods that involved estimating substrate prevalence and size.

In general, riparian characteristics had low variation both temporally and spatially. Temporal variation in percentage of open canopy was greater than spatial variability at sites LCCJOR and RB. This indicates that there may be a considerable margin of error involved with this measurement because this characteristic would not be expected to change significantly between years in the absence of major changes to the riparian area of the reach. For both of these sites, the greater variation is a result of much higher measurements of open canopy in 1999 than in later years.

As expected, temporal variation in discharge was high at many of the sites, with an average variance of 58 percent. Instantaneous discharge and daily mean discharge for the day habitat was sampled each year at the five sites is shown in *figure 35*. Site COAL had the lowest variation (10 percent) in discharge among years, and site CREST had the greatest variation (89 percent), with discharge that was more than four times greater in 1999 than in 2000.

Average temporal variation in daily mean discharge was 50 percent, with most of the variation a result of considerably higher daily mean discharge in 1999 than in 2000. The daily mean discharge in 2001 was similar to that of year 2000 at sites RB and LCCJOR and lower than that at site COAL. Analysis of discharge upstream from site COAL indicates that this is a result of flow regulation at Rockport Reservoir.

Temporal variation in the percentage of silt was considerably higher than spatial variation (*table 13*). Although this measure of silt is based on estimated observations and is therefore somewhat subjective, variation may reflect real conditions. Temporal variation may be explained by differences in discharge, as well as temporal proximity to storm runoff. Siltation increased over time as annual discharge decreased at all of the sites (except for site CREST). No silt was observed at site CREST in either year it was sampled, which may be because water at this site mostly consisted of ground-water discharge from nearby seeps and springs.

The percentage of occurrence of aquatic macrophyte habitat cover had high temporal variation (*table 13*). An increase in their occurrence was especially evident at sites CUB and COAL, where they were much more prevalent in 2001 than in previous years. A possible explanation for this is that while high flows in 1999 likely reduced the amount of aquatic vegetation, low flows in 2000 and 2001 allowed these plants to gradually increase. This high variation in macrophyte abundance was not as evident at the other three sites, which may be due to a high percentage of canopy cover limiting macrophyte growth at these sites. In addition, no consistent relation was detected between temporal variation in nutrient concentrations and macrophyte growth at these sites.

Variation Within and Among Sites

Because spatial and temporal variation were substantial for some habitat characteristics, PCA was used to determine whether this variation was significant relative to variation among different sites. Eleven noncolinear habitat variables were chosen through correlation analysis to compare spatial and temporal variability within and among sites. The variables describe the range of environmental conditions at the sites and included channel morphology, hydrologic measures, and riparian, instream habitat, and substrate characteristics – measures known to influence occurrence and distribution of aquatic biota in streams. The 11 variables are mean velocity (MV), mean channel width (MCW), percentage silt (SILT), Bank Stability Index (BSI), dominant substrate (DOMSUB), percentage of aquatic macrophytes (AM), percentage riffle (RIFF), percentage pool (POOL), mean channel width-to-depth ratio (MCWD), percentage summer solar radiation (SUMRAD), and variability of depth (CVMD).

The first four PCA axes accounted for 28, 23, 18, and 14 percent, respectively, of the total variation explained by these 11 variables (*table 14*). A graphical summary of the first two axes determined by PCA is shown in *figure 36*. Habitat variables are plotted as vectors and sites are plotted as points. Vector length represents the relative contribution of each variable to the variation in data for the first two axes, and the placement of sites on the plot is determined by the similarity of environmental characteristics at the sites. Points closer together are more similar than points farther apart from each other. PCA variable loadings listed in table 14 indicate the influence of each variable on the placement of sites along each axis. The first axis separates sites according to measurements of channel shape, substrate, and solar radiation. Sites to the right of axis 1 are wider and shallower and have more solar radiation and larger average substrates than sites on the left. Axis 2 separates sites according to measurements of siltation. Sites near the top (CUB) have higher amounts of silt, less stable banks, and more variation in channel shape. Sites near the bottom (CREST) have very little siltation, homogeneous channel width, and stable banks. Overall, the multiple-year and multiple-reach samples collected at each site were arranged in distinct groupings, which indicates that within-site

Table 13. Spatial and temporal variation of habitat characteristics for the fixed sampling sites in the Great Salt Lake Basins study unit

[cv, coefficient of variance; MY, multiple-year sample; MR, multiple-reach sample; N/A, not applicable; —, no data; m³/s, cubic meters per second; m, meter; for site abbreviations, see table 1]

Habitat characteristic	Calculation	Site (MY)					Average cv	Site (MR)			Average cv
		CUB	COAL	CREST	LCCJOR	RB		CUB	LCCJOR	RB	
Water-surface gradient (percent)	mean	0.33	0.24	1.92	1.48	5.21		0.36	0.75	3.81	
	cv	N/A	N/A	N/A	N/A	N/A	N/A	35.6	87.0	30.2	50.9
Sample discharge (m^3/s)	mean	.66	5.36	.02	.42	.05		.46	.75	.05	
	cv	54.2	9.7	89.1	88.1	47.8	57.8	10.9	24.0	0	11.6
Annual mean discharge (m^3/s)	mean	128.7	183.7	24.5	29.6	3.4		—	22.5	2.4	
	cv	57.5	40.3	56.4	45.7	53.0	50.6	N/A	N/A	N/A	N/A
Reach sinuosity (dimensionless)	mean	1.2	1.6	1.0	1.1	1.1		1.1	1.1	1.1	
	cv	3.6	7.6	2.5	1.4	1.4	3.3	6.8	10.7	2.5	6.7
Mean channel width (meters)	mean	10.4	17.3	6.7	6.1	2.1		10.5	6.1	2.1	
	cv	9.5	3.4	7.7	2.4	3.4	5.3	11.0	6.5	5.3	7.6
Mean bankfull width (meters)	mean	20.3	22.9	12.1	9.1	4.7		15.7	9.0	3.5	
	cv	22.7	6.6	1.1	3.0	24.5	11.6	13.6	12.1	3.9	9.9
Mean bank height (meters)	mean	1.6	1.4	1.0	1.6	.7		1.3	1.4	.6	
	cv	6.9	7.6	10.7	2.4	26.5	10.8	7.0	16.3	7.7	10.3
Mean depth (meters)	mean	.5	.6	.1	.5	.2		.3	.4	.1	
	cv	14.5	7.4	7.5	12.5	24.0	13.2	28.6	24.7	11.7	21.7
Mean velocity (m/s)	mean	.22	.70	.18	.27	.34		.2	.32	.26	
	cv	44.8	8.2	70.5	17.8	19.9	32.2	20.3	22.5	17.7	20.2
Mean channel width:depth (dimensionless)	mean	26.5	31.7	83.4	17.4	16.2		41.6	18.8	18.5	
	cv	23.9	8.9	9.3	11.8	30.2	16.8	16.9	27.2	14.6	19.6
Mean bankfull width:depth (dimensionless)	mean	14.4	17.0	13.0	6.0	7.1		12.1	6.7	6.0	
	cv	19.8	3.6	11.2	2.6	6.2	8.7	11.9	12.0	11.7	11.9
Bank Stability Index	mean	14.5	13.6	9.8	13.4	12.8		13.8	13.3	14.1	
	cv	5.7	3.6	8.9	4.8	4.8	5.6	3.3	6.8	3.9	4.7
Occurrence of silt (percent)	mean	26	1	0	9	9		26	24	12	
	cv	57	173	0	145	88	93	52	14	44	36
Mean embeddedness (percent)	mean	74	46	22	67	73		64	58	77	
	cv	20	35	24	27	33	28	10	13	2	25
Dominant substrate type	mean	silt	cobble	cobble	gravel	irregular hard-pan		sand	gravel	irregular hard-pan	
	cv	41.7	16.7	9.4	45.8	16.6	26.0	78.7	50.0	13.4	47.4
Near-bank canopy closure (percent)	mean	14	13	56	88	72		31	89	71	
	cv	38	26	3	4	5	15	57	7	13	25
Open riparian canopy (percent)	mean	78	73	51	9	15		71	6	10	
	cv	2	4	10	81	41	28	12	51	4	22
Mean daily summer solar radiation (percent)	mean	90	92	80	10	27		92	31	19	
	cv	14	9	5	44	28	20	8	54	76	46
Occurrence of aquatic macrophyte habitat (percent)	mean	13	23	0	1	4		51	4	3	
	cv	127	107	0	173	108	103	34	132	35	67

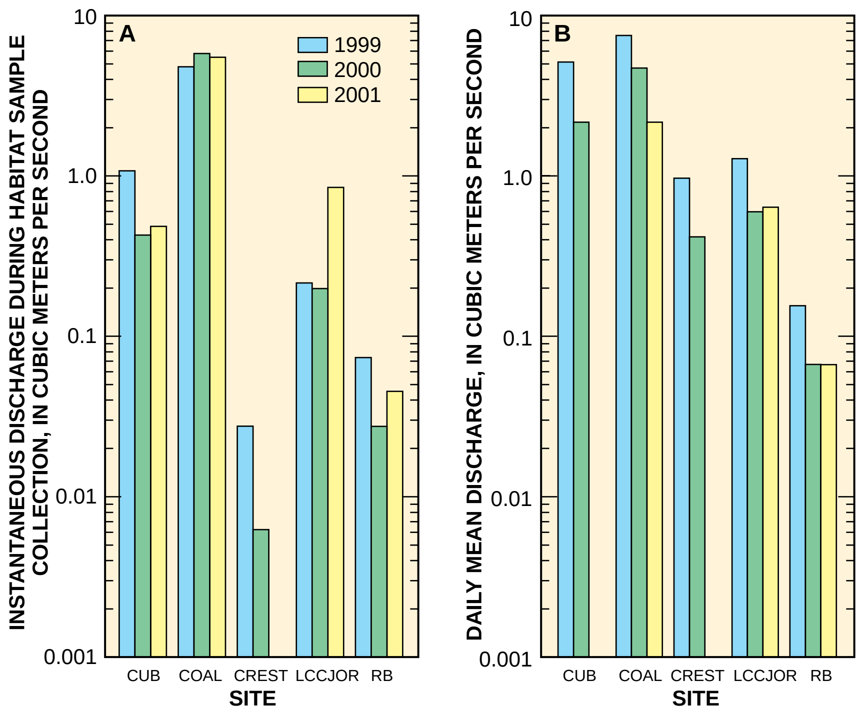

Figure 35. Temporal variation in (A) instantaneous discharge for the day on which habitat was sampled and (B) daily mean discharge at five fixed sampling sites in the Great Salt Lake Basins study unit.

Table 14. Results of principal components analysis of spatial and temporal variation in habitat characteristics at sites CUB, COAL, CREST, LCCJOR, and RB in the Great Salt Lake Basins study unit

[PCA, principal components analysis; CV, coefficient of variance; site abbreviations are in table 1. Bold indicates variable loadings greater than 0.4]

Habitat variable	Description	PCA Axis 1	PCA Axis 2	PCA Axis 3	PCA Axis 4
	Eigenvalues				
Eigenvalues		3.11	2.51	1.95	1.54
Percentage		28.25	22.85	17.76	14.03
Cumulative percentage		28.25	51.10	68.86	82.89
	PCA variable loadings				
MCW	Mean channel width	**.47**	.25	.11	-.17
MV	Mean velocity	.05	.03	.32	**-.69**
CVMD	CV mean depth	.06	**.46**	-.14	.04
MCWD	Mean channel width: depth	**.44**	-.14	.13	.37
BSI	Bank Stability Index	-.21	**.45**	.10	-.35
SILT	Percentage of silt	-.24	**.45**	.11	.35
DOMSUB	Dominant substrate size	**.47**	-.10	-.20	-.22
AM	Aquatic macrophytes	.07	.32	**.52**	.19
RIFF	Percent riffle	-.24	-.26	**.45**	.07
POOL	Percent pool	.06	.33	**-.48**	.04
SUMRAD	Percent solar radiation June-August	**.45**	.13	.29	.15

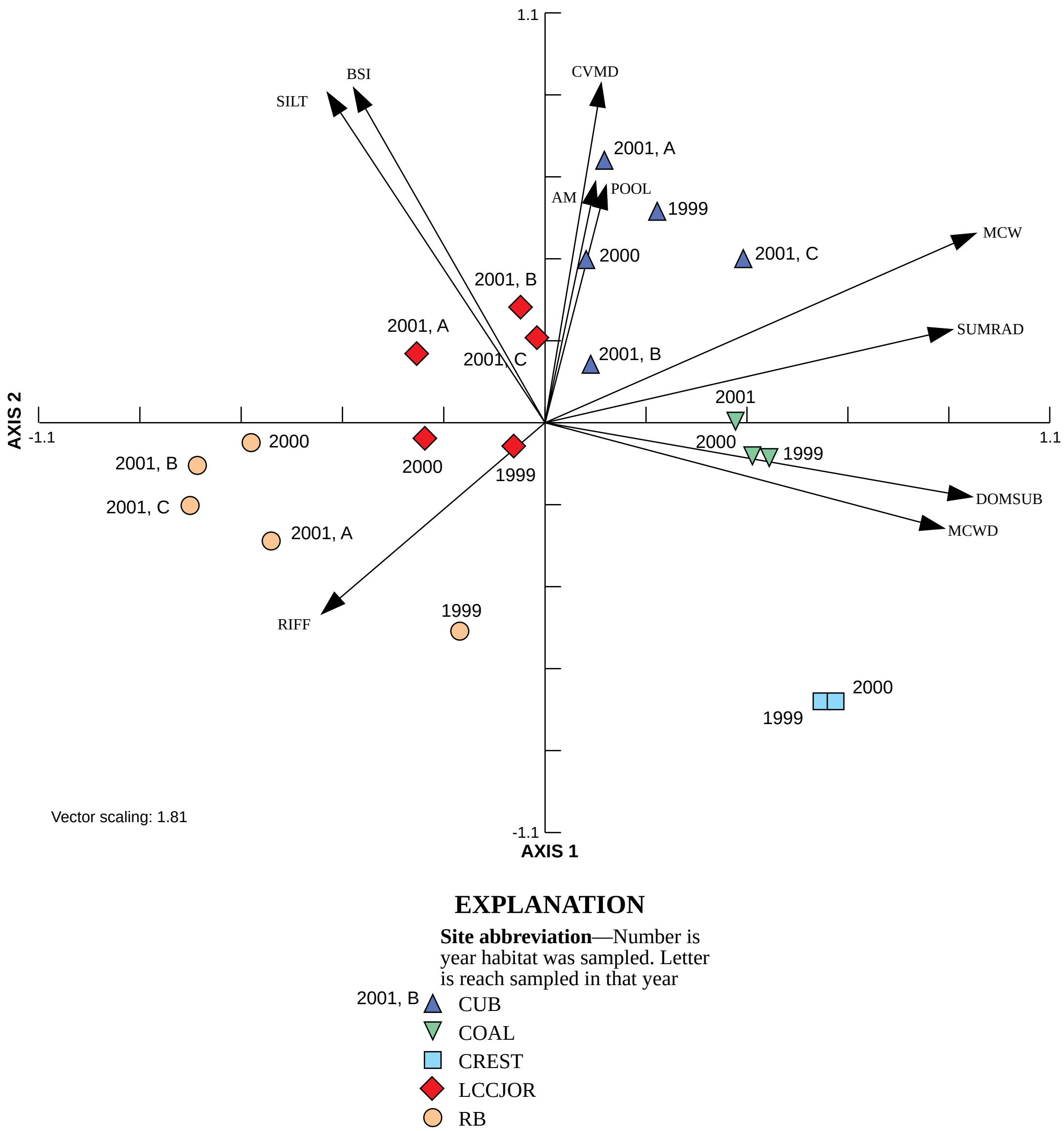

Figure 36. Principal Components Analysis ordination diagram for habitat variables sampled at five fixed sampling sites in the Great Salt Lake Basins study unit.

spatial and temporal variation was much lower than variation among sites.

Environmental conditions at site RB were somewhat different in 1999 when evaluated in comparison to other samples collected from the site. This is mainly because of a difference in substrate characterization in the 1999 sample, which can be attributed to subjectivity in observations of substrate dominance. It is likely that substrates did not differ greatly between 1999 and later samples.

Samples from sites COAL and CREST grouped particularly closely, indicating that within-site temporal variation at both of these sites was low for most of the environmental variables used in PCA. Under the premise that differences in discharge may account for most of the temporal variation at a given site, these results would be expected for site COAL because discharge did not vary greatly because of the proximity of this site to Rockport Reservoir. In contrast, discharge varied greatly at site CREST. Variation in the discharge-related variables such as depth, channel width, channel width-to-depth ratio, and velocity also would be expected to be substantial at this site; however, this was not the case for the first three variables (mean velocity did have large relative variation). This is likely because flows throughout this reach during sampling did not “fit” the morphological characteristics of the channel, which had been shaped by much higher flows. Consequently, relations between flow and wetted channel shape are somewhat unique at this site relative to relations at other sites in the basins. These results indicate that although discharge was highly variable at site CREST, the differences were still small enough that they did not affect other characteristics of the stream channel. Overall, site CREST is very different from other sites in the study with respect to the 11 variables used in PCA.

Algae

Morisita's modified coefficient of similarity (Jongman and others, 1995) was used to compare algal-community samples collected at sites COAL, RB, CUB, LCCJOR, and CREST. Overall, the algal composition of samples collected at the same site in different reaches and years was more similar than the composition of samples collected at different sites. The sample collected in 2001 at site COAL was the only exception and was distinctly different from the other two samples collected in 1999 and 2000. This is mainly a result of changes in abundances of three species of algae. *Calothrix parietina* was absent in 2001 but was the dominant species collected in 1999 and 2000 and composed 60 to 70 percent of the total cell abundance. Instead, algal samples were dominated by *Amphithrix janthina* and *Hydrocoleum brebissonii*, benthic cyanophytes that composed 11 and 31 percent of total abundance, respectively. Both of these species were absent from RTH samples at site COAL in previous years.

Although species composition did not differ substantially spatially or temporally at most sites, some algal community and species autoecological metrics had wide ranges and all the sites are not distinctly different because of this information. In general, abundance and biomass metrics were highly variable (coefficients of variance greater than 50 percent), and richness and diversity metrics were less so, with coefficients of variance ranging from 4.2 percent to 26.9 percent (*table 15*).

For some tolerance metrics, certain sites are clearly distinguishable from other sites. For example, site LCCJOR is consistently lower than other sites in abundance of taxa that are intolerant to high salinity conditions. In addition, site RB is consistently higher than other sites in abundance of taxa that are intolerant to organic pollution and to low-oxygen conditions. In general, the more heavily disturbed sites, CUB and LCCJOR, had similar ranges of values for metrics, and the less-disturbed sites, COAL, CREST, and RB, had ranges similar to each other. These results indicate that small differences among sites may go undetected when using a metric approach, but large differences can be detected with these measures.

Invertebrates

On the basis of Morisita's modified coefficient of similarity, variation in species occurrence and abundance in multiple invertebrate RTH samples collected at the same site was smaller than differences among the five sites where multiple samples were collected (sites COAL, RB, CUB, LCCJOR, and CREST). Once again, the 2001 assemblage at site COAL appears to differ from those collected in 1999 and 2000. The dominant taxon at site COAL was different each year; however, in 1999 and 2000, samples were dominated by taxa adapted to exploit fast currents such as Simuliidae and *Baetis* sp., while in 2001 the dominant taxon was a physid snail, an algae grazer. This change may indicate an alteration in the invertebrate assemblage in response to the greater macrophyte growth and lower discharge that were observed at this site in 2001.

Overall, invertebrate community metrics had less within-site variation than fish and algae metrics; however, variation among sites for several of the metrics, especially those derived from RTH samples, also was low *(table 16)*. As with the algal samples, richness and diversity metrics were less variable (coefficients of variance generally were less than 20 percent) than abundance metrics.

Richness and diversity of RTH samples did not differ substantially among sites; however, differences were detected by using the metric for RTH EPT-percent richness between consistently low EPT richness at site LCCJOR, where mostly depositional snag samples were collected, and the rest of the sites, where riffles were sampled. Pollution-tolerance metrics based on richness and abundance distinguished between the most- and least affected sites (LCCJOR and RB); however, smaller differences could not be detected with these measures.

Richness metrics based on qualitative samples performed better than RTH metrics in terms of distinguishing sites from one another. The two urban sites on Little Cottonwood Creek (CREST and LCCJOR) could be distinguished by using total taxa richness based on qualitative samples because these sites consistently had lower taxa richness than sites COAL, CUB, and RB. EPT-percent richness and pollution-tolerance metrics distinguished the least-affected sites, COAL and RB, from moderately affected sites CUB and CREST. These metrics also separated CUB and CREST from LCCJOR, a more heavily disturbed site, although some overlap in ranges did occur. These results indicate that these metrics are useful in detecting small differences in water-quality conditions.

Fish

Comparison of fish-community samples with Morisita's modified coefficient of similarity revealed greater variation among sites than in multiple samples from the same site. The 1999 sample from CUB was the only sample that did not group with other samples from the same site. CUB was different in 1999 because it had several species that were not present in other samples, including black crappie (*Pomoxis nigromaculatus*), rainbow trout (*Oncorhynchus mykiss*), goldfish (*Carassius auratus*), and largemouth bass (*Micropterus salmoides*), and also had a larger population of longnose dace (*Rhynicthys cataractae*). This sample also differed in that it had no redside shiners (*Richardsonius balteatus*) or green sunfish (*Lepomis cyanellus*), which were collected in all of the samples in later years.

Table 15. Summary of spatial and temporal variation of algal-community samples for five fixed sampling sites in the Great Salt Lake Basins study unit

[cv, coefficient of variance; MY, multiple-year sample; MR, multiple-reach sample; RTH, richest targeted habitat; mg/m², milligrams per square meter; cells/cm², cells per square centimeter; site abbreviation in table 1]

Community characteristic	Calculation	Site abbreviation					Average cv	Site abbreviation			Average cv
		CUB	COAL	CREST	LCCJOR	RB		CUB	LCCJOR	RB	
		MY	MY	MY	MY	MY		MR	MR	MR	
Biomass											
Chlorophyll-a (mg/m²)	mean	105.0	57.8	26.7	26.8	94.7		169.7	39.9	110.1	
	cv	84.6	123.5	89.9	151.3	112.6	112.4	21.6	108.1	39.2	56.3
Richness											
Species richness from combined samples	mean	97.3	78.0	60.5	96.0	56.7		104.3	99.7	55.7	
	cv	11.5	21.2	10.5	13.5	8.3	13.0	3.6	4.9	4.1	4.2
Species richness - RTH sample	mean	44.3	33.3	25.5	41.0	26.3		51.3	44.3	24.7	
	cv	20.5	30.0	30.5	31.0	22.3	26.9	6.0	32.4	2.3	13.6
Abundance											
Cell abundance (cells/cm²)	mean	2.23×10^6	4.23×10^6	4.83×10^6	1.03×10^6	3.04×10^6		2.38×10^6	1.85×10^6	5.57×10^6	
	cv	59.6	63.2	5.0	103.0	54.3	57.0	22.4	122.7	27.4	57.5
Diversity											
Simpson's Diversity	mean	.9	.6	.6	.8	.5		.9	.8	.6	
	cv	2.7	29.5	26.1	5.2	40.8	20.8	1.0	5.9	27.0	11.3
Dominance											
Relative abundance of dominant species (percent)	mean	17.3	53.3	54.9	28.3	65.6		20.8	32.1	57.7	
	cv	40.7	36.8	34.1	4.5	29.5	29.1	18.1	11.0	32.0	20.4
Additional metrics											
Pollution tolerance (Bahl's Index)	mean	2.1	2.4	2.4	2.2	2.5		2.4	2.1	2.6	
	cv	14.3	6.3	11.9	13.5	8.0	10.8	1.1	9.3	5.8	5.4
Relative abundance of cells intolerant to high salinity and chloride concentrations (percent)	mean	.7	.9	.9	.5	.9		.8	.5	1.0	
	cv	8.7	11.1	4.6	7.7	21.7	10.8	5.2	12.3	1.5	6.3
Relative abundance of cells intolerant to low-oxygen conditions (percent)	mean	.4	.5	.5	.4	.6		.5	.3	.7	
	cv	21.1	9.3	53.3	53.2	8.1	29.0	3.3	35.5	10.7	16.5
Relative abundance of cells intolerant to organic pollution (percent)	mean	.5	.6	.5	.4	.8		.6	.3	.8	
	cv	26.9	16.7	38.3	51.0	11.4	28.9	2.8	29.0	10.4	14.0
Relative abundance of nonmotile cells (percent)	mean	54.1	71.0	71.8	62.3	83.8		72.6	62.3	71.7	
	cv	29.9	19.7	10.6	7.0	17.4	16.9	3.0	16.6	33.1	17.6
Relative abundance of nitrogen-fixing cells (percent)	mean	13.2	49.1	54.9	29.7	65.6		19.6	29.1	57.0	
	cv	106.5	66.8	34.1	45.7	29.5	56.5	39.1	64.7	34.2	46.0

Table 16. Summary of spatial and temporal variation of invertebrate-community samples for five fixed sampling sites in the Great Salt Lake Basins study unit

[cv, coefficient of variance; MY, multiple-year sample; MR, multiple-reach sample; RTH, richest targeted habitat; EPT, Ephemeroptera, Plecoptera, and Trichoptera families; site abbreviation in table 1]

Community characteristic	Calculation	Site (MY)					Average cv	Site (MR)			Average cv
		CUB	COAL	CREST	LCCJOR	RB		CUB	LCCJOR	RB	
Species richness from combined samples	mean	66.0	69.0	45.0	41.0	72.0		61.0	40.0	67.3	
	cv	9.5	83.6	41.4	9.8	8.7	35.8	11.1	4.9	1.8	5.9
Species richness - RTH sample	mean	21.7	25.3	24.0	23.3	30.3		26.0	24.0	27.3	
	cv	16.2	6.0	11.8	12.4	29.7	15.9	9.8	11.0	15.0	11.9
Abundance per square meter	mean	39,877	24,728	13,572	20,194	9,351		27,978	6,113	4,849	
	cv	10.3	23.0	32.2	150.3	102.3	42.0	42.8	116.9	40.4	66.7
Simpson's Diversity	mean	.7	.9	.7	.7	.9		.9	.8	.9	
	cv	19.8	2.3	10.9	13.1	2.3	8.8	4.5	9.4	6.2	6.7
Percent abundance of dominant genus	mean	43.2	27.4	52.0	46.6	25.7		28.1	34.9	27.0	
	cv	44.5	3.3	16.1	21.8	12.1	19.0	23.1	25.8	30.5	26.5
Percent abundance of EPT taxa	mean	72.9	27.3	13.6	6.7	35.4		57.9	6.9	41.3	
	cv	11.9	48.1	92.1	154.2	7.4	39.8	23.1	7.2	13.2	14.5
EPT taxa richness	mean	7.0	8.7	6.5	2.3	9.7		7.0	2.3	9.3	
	cv	14.3	6.7	32.6	65.5	15.8	17.3	8.7	43.3	6.9	19.6
Pollution tolerance based on sample richness	mean	5.3	5.0	5.7	6.3	4.6		5.6	6.5	4.5	
	cv	7.9	13.1	14.2	10.0	5.2	10.1	1.4	6.5	3.1	3.7

Spatial and temporal variation in fish-community samples are summarized in *table 17*. Species richness had low variation and was similar among sites. Variation was higher for abundance data, but some distinctions could still be made among sites. For example, site LCCJOR consistently had lower abundances of fish collected, probably because this site had fewer small schooling fish and more large fish than other sites.

Overall, tolerance metrics showed several distinctions among the three sites where multiple samples of fish were collected, despite high within-site variation for several of these metrics. Distinctions exist among the three sites in percentage abundances of omnivorous fish and the percentage of species adapted to warm-water conditions. Site LCCJOR also was distinct from the other two sites by consistently having a larger percentage abundance of fish with anomalies. Site COAL was distinct in having fewer pollution-tolerant species than the other two sites.

Temporal and Spatial Variation of Habitat and Biota

Overall, small differences in water-quality conditions among sites were not detected with algae ecological metrics; however, large differences between the least- and most-affected sites could be detected. With invertebrate metrics, smaller differences in water quality among sites could be detected by using richness and pollution-tolerance metrics based on qualitative samples of invertebrate assemblages. Fish-community tolerance, trophic guild, and temperature-preference metrics also performed well in distinguishing sites from each other despite high within-site variation.

With few exceptions, spatial and temporal variation of habitat and biological communities at the selected sites were small enough that differences between sites could still be detected. Among the metrics used to describe biological communities, those based on measurements of species richness and tolerance were generally less variable than those based on abundance, indicating that these metrics may be more reliable measurements for long-term monitoring.

Summary

Ten sites were sampled in the Great Salt Lake Basins to document the occurrence and distribution of algae, invertebrates, fish, and associated physical and chemical conditions. This study was conducted to enhance the understanding of the relations among chemical, physical, and biological components of stream ecosystems and to examine the relative importance of natural and anthropogenic factors on water-quality conditions in the Great Salt Lake Basins study unit of Utah, Idaho, and Wyoming as part of the U.S. Geological Survey National Water-Quality Assessment program. The relative effects of physical habitat and water chemistry on biological communities were elucidated to provide water managers with a solid, scientific framework on which to make decisions and establish goals relating to water quality.

Table 17. Summary of spatial and temporal variation of fish-community samples at three fixed sampling sites in the Great Salt Lake Basins study unit

[cv, coefficient of variance; MY, multiple-year sample; MR, multiple-reach sample; site abbreviation in table 1]

Community characteristic	Calculation	Site (MY)			Average cv	Site (MR)		Average cv
		CUB	COAL	LCCJOR		CUB	LCCJOR	
Biomass (grams per minute sampled)	mean	5,558	297	962		980	1,233	
	cv	21	24	28	32	33	32	32
Species richness	mean	8	7	7		8	8	
	cv	13	16	21	16	20	20	20
Abundance (fish captured per minute sampled)	mean	11.5	5.9	1.6		31.7	1.3	
	cv	95.0	40.2	25.7	53.6	44.0	11.2	27.6
Simpson's Diversity	mean	.6	.6	.7		.4	.7	
	cv	23.8	10.1	9.2	14.4	35.6	24.1	29.9
Percent abundance of dominant species	mean	59	54	39		75	49	
	cv	26	11	23	20	14	40	27
Pollution-tolerant species richness	mean	5	1	4		5	4	
	cv	12	0	16	9	20	25	23
Percent abundance of native fish	mean	81	91	6		90	7	
	cv	21	8	122	51	3	97	50
Percentage of species adapted to warm-water conditions	mean	50	0	73		52	65	
	cv	13	0	15	9	6	4	5
Percent abundance of fish with anomalies	mean	5	1	18		1	8	
	cv	85	54	94	78	8	86	42
Percent abundance of omnivorous fish	mean	24	2	69		15	57	
	cv	55	98	24	59	44	47	56
Fish Condition Index	mean	8.0	14.3	7.3		9.3	9.0	
	cv	12.5	8.1	41.7	24.9	16.4	19.2	17.8

The environmental setting of the sampling sites varies in altitude, ecoregion, land use, and hydrologic and climatic conditions. Basins of high-altitude sites in the Wyoming Basin and Wasatch and Uinta Mountain ecoregions are composed mainly of undeveloped land uses such as forest and rangeland, while basins of low-altitude sites in the Central Basin and Range ecoregion have greater percentages of developed land uses, such as agriculture and urban. Agricultural land use and high discharge are associated mostly with sites in the Bear River basin, while urban land use and smaller streams are associated mostly with sites in the Utah Lake/Jordan River basin.

Streamflow at all sites except for RB are affected by hydrologic modifications, and the effects on flow regimes occur in three ways: (1) steady flows that lack natural seasonal peaks and troughs are maintained at sites PESC, COAL, and JOR, where flows are regulated primarily to sustain downstream water rights; (2) large and abrupt daily fluctuations in flows at site COR are the result of water releases for power generation that occur upstream; (3) reduced flows at site CREST are the result of water diversions upstream for municipal water use, with complete dewatering of the channel during certain times of the year when water use is high and natural flow conditions are low. Diversions also occur upstream from sites PLAIN, LCCJOR, and CUB; however, supplemental irrigation return flows result in less dramatic effects on flow conditions at these sites.

Instream habitat conditions are determined primarily by environmental factors such as altitude, stream size, and stream gradient, with more diverse habitat conditions occurring at higher-gradient sites where substrate size, flow velocity, and depth are more varied. Instream habitat diversity at large, low-gradient sites is naturally limited by small substrate size and uniform flow. These low-gradient sites are generally more affected by anthropogenic activities than are the higher-gradient sites.

Instream habitat also has been affected by anthropogenic activities. In some cases, as with site LCCJOR, channelization of streams in urban areas has affected habitat availability at sites by reducing stream sinuosity and causing homogeneous flow conditions composed primarily of deep runs. Water regulation that maintains steady conditions (at sites PESC and JOR) has resulted in homogeneous high-flow conditions that are maintained throughout the summer, when low-flow conditions naturally occur. Flows below dams and diversions (as at site COR) are punctuated by abrupt changes in flow that may contribute to heavy siltation and flushing of macrophytes and woody debris at these sites. Hydrologic modifications that reduce flow have resulted in the loss of habitat volume, increased temperature ranges, and reduced depth and velocity.

Natural riparian habitat is generally sparse in the Basin and Range ecoregions; however, differences in riparian habitat were observed among urban and other land uses within the basins, with denser riparian cover occurring in urban areas (sites LCCJOR, CREST, and PLAIN) as a result of smaller stream width and the planting of vegetation along stream corridors. Riparian vegetation in other basin areas may be reduced as a result of land-use activities such as grazing and agriculture (sites SMFK, COAL, CUB, and COR), which may suppress the growth of shrubs and trees along stream corridors.

Combined qualitative and quantitative algae samples consisted of 221 species collected at the 10 sites with 89 additional species collected in multiple-reach and multiple-year samples for a total of 310 species. Nitrogen-fixing species of blue-green algae were the most abundant type of algae collected, although benthic diatoms accounted for the greatest taxon richness. Taxon richness ranged from 62 to 105 species per site.

Algal communities in richest targeted habitats differed among groups of sites with different land use, temperature, nutrient enrichment, and solar energy inputs. Water chemistry and temperature were the most important factors determining algal assemblages in richest targeted habitat. However, habitat availability appears to be a factor at site PESC, where the species assemblage was more similar to that at site COR than to that at site SMFK, despite similar water chemistry and temperature at sites SMFK and PESC. Species that are intolerant to organic pollution, low dissolved oxygen concentration, and high salinity dominated at the high-altitude, high-gradient sites (SMFK, COAL, and RB), where land use is primarily undeveloped, temperatures are cold, and nutrient concentrations are low. These sites also had characteristically high abundances of nonmotile and nitrogen-fixing species of algae. At sites where developed land uses are more prevalent, the relative abundance of species tolerant to organic pollution, low dissolved oxygen concentrations, and high salinity was higher; however, significant differences in these metrics among sites dominated by agricultural and urban land uses were not detected. Sites influenced by agricultural land use that also receive greater solar radiation input (PESC, COR, CUB, and JOR) had higher RTH species richness than did urban sites (PLAIN, LCCJOR, and CREST), which are more heavily shaded. Although algal communities at urban sites may be light limited, those at undeveloped sites (RB, COAL, and SMFK) may be limited by a lack of nutrients and cold temperatures.

In 1999, 230 invertebrate taxa were collected in combined qualitative and quantitative (richest targeted habitat) samples, with 57 additional taxa collected in multiple-year and multiple-reach samples that were collected at 5 of the sites. Invertebrates representing 10 phyla and 14 classes were collected, with the greatest richness and abundance of invertebrates consisting of insect taxa. Mayflies, caddisflies, and chironomids accounted for the greatest abundance of taxa collected. Taxa richness ranged from 36 taxa at site JOR to 84 taxa at site PESC.

The composition of invertebrate communities in richest targeted habitats differed primarily by the habitat type that was sampled. Communities in riffle habitats were less tolerant to pollution and had greater percentages of EPT taxa. Communities collected in nonriffle (woody snags, macrophyte beds, or depositional) habitats had greater percentages of chironomids and noninsect taxa, lower percentages of EPT taxa, and higher tolerance to pollution. Richness, abundance, and dominance did not differ significantly between communities collected in the two habitats. Invertebrate communities in richest targeted habitats at urban sites in the Jordan River basin were distinctive from other sites where similar habitats were sampled.

Invertebrate community response to environmental variables differed between riffle and nonriffle habitats. By examining communities in these two habitat types separately, sensitivity of communities to water-quality conditions can be better understood. Taxa richness in riffle communities showed a stronger response to temperature and gradient than was observed in other types of habitats. Tolerance of invertebrate communities to urbanization and chloride concentrations differed between the two types of habitat. Trophic interactions also differed between the two habitat types with a greater percentage of filter-collectors collected in riffle habitats and greater percentages of shredder taxa collected in woody snags and macrophyte beds. Richness and abundance of filter-collectors responded to nutrient concentrations in both types of habitat, and to microhabitat velocity in riffle habitats.

During the study, 29 species of fish were collected, 10 of which are native to the Great Salt Lake Basins. Native species collected included cutthroat trout, mountain whitefish, mottled sculpin, Paiute sculpin, longnose dace, speckled dace, redside shiner, Utah sucker, bluehead sucker, and mountain sucker. Species richness increased along a downstream gradient, with an increase in temperature and discharge. Introduced warm-water species were more prevalent at lower-altitude, low-gradient sites. Fish-community condition was good at forest-rangeland sites and poor at integrator sites. Stream temperature may be a major factor limiting the distribution of native cool- and cold-water species of fish. Some sites frequently exceed the temperature criteria for their designated beneficial use as cold-water fisheries, and fish communities at these sites consist of less than 15 percent cold-water species.

Although native species of suckers were widespread, native salmonids, sculpins, and cyprinids showed more specific habitat requirements and were only present at a few sites. Native salmonids are sensitive to temperature and velocity and were only collected at sites where average velocities were high and temperatures were low. Sculpins and dace occupy similar ecological niches and appear to be sensitive to water quality, temperature, and siltation. Sculpins appear to be more sensitive than dace to these conditions. Redside shiners were collected at large, low-gradient sites with high solar radiation and abundant macrophyte habitat cover.

Overall, within-site spatial and temporal variation in habitat and biological community composition was lower than variation among sites. Richness and tolerance metrics were less variable than abundance metrics for algae, invertebrates, and fish and may be more useful in detecting differences among sites. Overall, small differences in water-quality conditions among sites were not detected with algae ecological metrics; however, large differences between the least- and most-affected sites could be detected. By using invertebrate metrics, smaller differences in water quality among sites could be detected with richness and pollution-tolerance metrics based on qualitative samples of invertebrate assemblages. Fish-community tolerance, trophic guild, and temperature preference metrics also performed well in distinguishing sites from each other despite high within-site variation.

References Cited

Allan, J.D., 1995, Stream ecology, Structure and function of running waters: London, Chapman and Hall, 388 p.

Bahls, L.L., 1993, Periphyton bioassessment methods for Montana streams (revised January 1993): Helena, Mont., Department of Health and Environmental Sciences, Water Quality Bureau, 38 p. plus appendices.

Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B., 1999, Rapid Bioassessment Protocols for use in streams and wadeable rivers: Periphyton, benthic macroinvertebrates and fish (2d ed.): Washington, D.C., U.S. Environmental Protection Agency, Office of Water, EPA 841-B-99-002.

Baskin, R.L., Waddell, K.M., Thiros, S.A., Giddings, E.M., Hadley, H.K., Stephens, D.W., and Gerner, S.J., 2002, Water-quality assessment of the Great Salt Lake Basins, Utah, Idaho, and Wyoming-- Environmental setting and study design: U.S. Geological Survey Water-Resources Investigations Report 02-4115, 47 p.

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

Charles, D.F., Knowles, C., and Davis, R.S., eds., 2002, Protocols for the analysis of algal samples collected as part of the U.S. Geological Survey National Water-Quality Assessment Program: Philadelphia, Academy of Natural Sciences, Patrick Center for Environmental Research, Report No. 02-06, 124 p.

Cuffney, T.F., 2003, User's manual for the National Water-Quality Assessment program Invertebrate Data Analysis System (IDAS) software: Version 3.0: U.S. Geological Survey Open-File Report 03-172, 103 p.

Cuffney, T.F., Gurtz, M.E., and Meador, M.R., 1993a, Methods for collecting benthic invertebrate samples as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93–406, 66 p.

Cuffney, T.F., Gurtz, M.E., and Meador, M.R., 1993b. Guidelines for the processing and quality assurance of benthic invertebrate samples collected as part of the National Water-Quality Assessment Program: U.S.Geological Survey Open-File Report 93-407, 80 p.

Fenneman, N.M., 1931, Physiography of the Western United States: New York, McGraw-Hill, 534 p.

Fitzpatrick, F.A., Waite, I.R., D'Arconte, P.J., Meador, M.R., Maupin, M.A., and Gurtz, M.E., 1998, Revised methods for characterizing stream habitat in the National Water-Quality Assessment Program: U.S. Geological Survey Water-Resources Investigations Report 98-4052, 45 p.

Gerner, S.J., 2003, Water quality at fixed sites in the Great Salt Lake Basins, Utah, Idaho, and Wyoming, water years 1999-2000: U.S. Geological Survey Water-Resources Investigations Report 03-4236, 67 p.

Giddings, E.M., and Stephens, D.W., 1999, Selected aquatic biological investigations in the Great Salt Lake Basins, 1875-1998: U.S. Geological Survey Water-Resources Investigations Report 99-4132, 42 p.

Gilliom, R.J., Alley, W.M., and Gurtz, M.E., 1995, Design of the National Water-Quality Assessment Program—Occurrence and distribution of water-quality conditions: U.S. Geological Survey Circular 1113, 33 p.

Herbert, L.R., Allen, D.V., Wilberg, D.E., and Tibbetts, J.R., 1999, Water resources data for Utah: U.S. Geological Survey Water-Data Report UT-99-1, 340 p.

Herbert, L.R., Wilberg, D.E., and Tibbetts, J.R., 2001, Water resources data for Utah: U.S. Geological Survey Water-Data Report UT-01-1, 440 p.

Herbert, L.R., Wilberg, D.E., Tibbetts, J.R., and Allen, D.V., 2000, Water resources data for Utah: U.S. Geological Survey Water-Data Report UT-00-1, 380 p.

Hill, M.O., 1979, TWINSPAN – A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes: Ithaca, N.Y., Cornell University, 90 p.

Jongman, R.H., Ter Braak, C.J., and Van Tongeren, O.F., 1995, Data analysis in community and landscape ecology: Cambridge, United Kingdom, Cambridge University Press, 299 p.

Krebs, C.J., 1999, Ecological methodology (2d ed.): Menlo Park, Calif., Benjamin/Cummings, 620 p.

Lange-Bertalot, H., 1979, Pollution tolerance of diatoms as a criterion for water quality estimation: Nova Hedwigia, v. 64, p. 285-304.

Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964, Fluvial processes in geomorphology: New York, Dover Publications, 522 p.

Lowe, R.L., 1974, Environmental requirements and pollution tolerance of freshwater diatoms: Cincinnati, Ohio, U.S. Environmental Protection Agency, Office of Research and Development, EPA-670/4-74-005, 334 p.

Maret, T.R., 1997, Characteristics of fish assemblages and related environmental variables for streams of the upper Snake River basin, Idaho and western Wyoming, 1993–95: U.S. Geological Survey Water-Resources Investigations Report 97–4087, 50 p.

McCune, B., and Meffort, M.J., 1999, PC-ORD, multivariate analysis of ecological data, version 4.21: MjM Software Design, Gleneden Beach, Oreg., 237 p.

Meador, M.R., Cuffney, T.F., and Gurtz, M.E., 1993, 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.

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

Moulton II, S.R., Carter, J.L., Grotheer, S.A., Cuffney, T.F., and Short, T.M., 2000, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Processing, taxonomy, and quality control of benthic macroinvertebrate samples: U.S. Geological Survey Open-File Report 00-212, 49 p.

Omernik, J.M., 1987, Ecoregions of the conterminous United States, map supplement: Annals of the Association of American Geographers, v. 77, no. 1, p. 118-125.

Porter, S.D., Cuffney, T.F., Gurtz, M.E., and Meador, M.R. 1993. Methods for collecting algal samples as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93-409, 39 p.

Shelton, L.R., 1994, Field guide for collecting and processing stream-water samples for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 94-455, 50 p.

Shreve, R.L., 1967, Infinite topologically random channel networks: Journal of Geology, v. 75, p. 178-186.

Sigler, W.F., and Sigler, J.W., 1996, Fishes of Utah, a natural history: Salt Lake City, Utah, University of Utah Press, 375 p.

Utah Department of Environmental Quality, 2000, Utah's Year 2000 303(d) List of Waters: Salt Lake City, Utah, Division of Water Quality, 77 p.

Utah Department of Environmental Quality, 2002, Division of Water Quality Rules – Title R317: Salt Lake City, Utah, Division of Water Quality, 77 p.

Utah Division of Natural Resources, 1992, Utah State water plan – Bear River basin: Salt Lake City, Utah Department of Natural Resources.

Utah Division of Water Resources, 1997, Utah State water plan – Jordan River basin: Salt Lake City, Utah Department of Natural Resources.

Utah Watershed Program, 2002, Report 8 -- Cub River: Utah State University Extension and Utah Association of Conservation Districts, 1 p.

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

Waddell K.M., and Giddings, E.M., 2004, Trace elements and organic compounds in sediment and fish tissue from the Great Salt Lake Basins, Utah, Idaho, and Wyoming, 1998-99: U.S. Geological Survey Water-Resources Investigations Report 03-4283, 46 p.

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

Wyoming Department of Environmental Quality, 2001, Wyoming surface water quality standards: Water quality rules and regulations: Cheyenne, Wyoming, Water Quality Division, 54 p.

Zaroban, D.W., Mulvey, M.P., Maret, T.R., Hughes, R.M., and Merritt, G.D., 1999, Classification of species attributes for Pacific Northwest freshwater fishes: Northwest Science, vol. 73, no. 2, p. 81-93.

Appendix A

Table A-1. Summary of sample-collection schedule at fixed sampling sites in the Great Salt Lake Basins study unit

[X indicates sample was collected in the Great Salt Lake Basins study unit; for site information see table 1]

Sample type	Sample schedule	Subsample type	Bear River basin				Weber River basin		Jordan River/Utah Lake basin			
			SMFK	PESC	CUB	COR	COAL	PLAIN	CREST	LCCJOR	JOR	RB
Habitat - Segment			X	X	X	X	X	X	X	X	X	X
Habitat - Reach	1999		X	X	X	X	X	X	X	X		X
	2000				X		X		X	X	X	X
	2001				X		X			X		X
	Multiple-reach				X					X		X
Fish	1999		X	X	X	X	X	X	X	X		
	2000				X		X			X	X	
	2001				X		X			X		
	Multiple-reach				X					X		
Invertebrates	1999	Qualitative	X	X	X	X	X	X	X	X		X
		Quantitative	X	X	X	X	X	X	X	X		X
	2000	Qualitative			X		X		X	X	X	X
		Quantitative			X		X		X	X	X	X
	2001	Qualitative			X		X			X		X
		Quantitative	X	X	X		X			X		X
	Multiple-reach				X					X		X
Algae	1999	Biomass		X	X	X	X	X	X	X		X
		Qualitative	X	X	X	X	X	X	X	X		X
		Quantitative	X	X	X	X	X	X	X	X		X
	2000	Biomass			X		X		X	X		X
		Qualitative			X		X		X	X	X	X
		Quantitative			X		X		[1]X	X	[2]X	X
	2001	Biomass	X	X	X		X		X	X		X
		Qualitative			X		X			X		X
		Quantitative	X	X	X		X			X		X
	Multiple-reach				X					X		X

[1] Richest targeted habitat (RTH) sample collected, only.

[2] Depositional targeted habitat (DTH) sample collected, only.

Appendix B

Table B-1. Selected segment-scale habitat characteristics for fixed sampling sites in the Great Salt Lake Basins study unit

[Source: USGS 7.5-minute topographic maps, 1:24,000 scale; NC, indicates value was not calculated; for site abbreviations see table 1]

Site	Valley length (kilometers)	Curvilinear length (kilometers)	Sinuosity (dimensionless)	Gradient (percent)	Shreve link[1]	Mean valley sideslope gradient (percent)
SMFK	3.3	3.3	1.01	0.339	1956	11.74
PESC	11.2	12.3	1.10	.049	NC	12.20
CUB	6.1	8.9	1.45	.188	109	4.74
COR	4.9	10.4	2.11	.019	NC	.56
COAL	4.8	6.7	1.39	.356	360	2.73
PLAIN	4.6	4.9	1.07	.082	2,378	.94
CREST	3.0	3.0	1.00	1.650	16	4.90
LCCJOR	1.2	1.3	1.14	.480	15	3.01
JOR	4.4	6.2	1.40	.024	NC	.44
RB	1.2	1.3	1.02	5.719	20	36.4

[1]Calculated according to methods outlined in Shreve (1967).

Appendix C

Table C-1. Algal taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Taxon / Site	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Phylum Family *Genus species*																									
Cyanophyta																									
Chroococcaceae																									
Chroococcus limneticus					X	X	X																		
Coelosphaerium kuetzingianum											X														
Merismopedia punctata										X												X			
Merismopedia tenuissima						X																			
Nostocaceae																									
Amphithrix janthina				X	X	X	X				X	X	X	X	X	X	X	X	X					X	X
Anabaena affinis						X	X												X						X
Anabaena oscillarioides										X										X		X			
Anabaena sp.	X		X	X				X	X	X		X	X			X									
Anabaena variabilis								X													X				
Calothrix parientina	X				X			X	X	X						X	X	X	X	X	X	X	X	X	X
Nostoc commune					X	X	X				X						X		X				X	X	X
Oscillatoriaceae																									
Hydrocoleum brebissonii	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Lyngbya epiphytica				X																					
Microcoleus lyngbyaceus				X																					
Oscillatoria limosa			X																						
Schizothrix arenaria															X										
Schizothrix calcicola	X	X	X		X		X	X	X	X	X			X	X	X									
(undetermined)																									
Unknown cyanophyte	X	X		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
Chlorophyta																									
Chaetophoraceae																									
Stigeoclonium lubricum								X		X	X								X						
Stigeoclonium sp.																					X				
Chlorococcaceae																									
Characium ambiguum						X																			
Cladophoraceae																									
Cladophora glomerata	X	X	X	X	X	X	X				X		X	X			X	X				X	X		
Desmidiaceae																									
Closterium acerosum					X	X			X												X			X	
Closterium moniliferum										X		X								X	X				
Closterium pseudolunula	X																								
Closterium setaceum																				X					
Closterium venus												X													
Cosmarium impressulum												X	X	X		X									
Cosmarium margaritatum																			X						
Cosmarium repandum					X	X	X																		
Cosmarium subcostatum						X																			
Cosmarium subcrenatum	X																								
Cosmarium tinctum						X																			

Table C-1. Algal taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Taxon / Site	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Phylum Family *Genus species*																									
Cosmarium trilobulatum				X																					
Hydrodictyaceae																									
Pediastrum boryanum				X	X	X	X						X	X		X									
Pediastrum tetras					X	X																			
Microsporaceae																									
Microspora tumidula	X																								
Oedogoniaceae																									
Oedogonium sp.		X		X	X	X	X			X			X								X				
Oocystaceae																									
Ankistrodesmus falcatus					X		X				X					X									
Selenastrum gracile									X				X												
Scenedesmaceae																									
Actinastrum hantzschii					X	X																			
Coelastrum microporum					X	X							X												
Scenedesmus abundans						X	X											X							
Scenedesmus acuminatus					X	X																			
Scenedesmus acutus														X											
Scenedesmus dimorphus									X	X		X	X	X											
Scenedesmus ecornis		X		X	X	X	X			X	X	X	X												
Scenedesmus obliquus										X															
Scenedesmus quadricauda				X	X	X	X						X	X		X									
Scenedesmus spinosus	X				X					X															
Ulvaceae																									
Schizomeris sp.													X												
Zygnemataceae																									
Mougeotia sp.								X																	
Spirogyra sp.			X	X	X	X	X		X	X								X							
(undetermined)																									
Unknown chlorophyte			X	X					X	X		X	X	X		X					X				
Euglenophyta																									
Euglenaceae																									
Euglena acus				X																					
Euglena polymorpha					X	X																			
Euglena sp.				X				X		X	X	X				X									
Lepocinclis ovum	X				X						X	X			X										
Lepocinclis sp.				X						X	X														
Phacus sp.																		X							
Trachelomonas hispida										X															
Trachelomonas volvocina										X															
Chrysophyta																									
Achnanthaceae																									
Achnanthes biasolettiana										X			X	X	X	X	X	X	X	X					
Achnanthes conspicua					X																				
Achnanthes deflexa							X										X								
Achnanthes delicatula	X						X	X								X									
Achnanthes exigua	X							X																	
Achnanthes lanceolata	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Achnanthes minutissima				X										X											

Table C-1. Algal taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Site	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
Taxon / Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Phylum																									
Family																									
Genus species																									
Achnanthes petersonii								X																	
Achnanthes pusilla			X	X						X			X	X		X				X					
Achnanthes subhudsonis kraeuselii		X	X					X																	
Achnanthidium affine				X										X											
Achnanthidium minutissimum	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cocconeis neodiminuta			X	X						X						X				X	X	X			
Cocconeis pediculus	X	X	X	X	X	X	X	X	X	X	X								X	X	X	X	X	X	X
Cocconeis placentula	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Cocconeis scutellum								X																	
Karayevia clevei							X																		
Lemnicola hungarica							X	X																	
Biddulphiaceae																									
Pleurosira laevis								X		X					X	X	X	X	X	X					
Diatomaceae																									
Asterionella formosa		X						X	X		X	X			X				X						
Diatoma mesodon													X	X	X	X		X		X	X			X	X
Diatoma moniliformis		X						X			X		X	X	X	X	X	X	X	X			X	X	X
Diatoma tenuis											X						X	X	X						
Diatoma vulgaris	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X		X	X
Fragilaria brevistriata inflata																				X		X			
Fragilaria capucina	X	X		X	X		X	X	X		X		X	X	X		X	X	X	X	X		X	X	X
Fragilaria crotonensis											X			X											
Fragilaria fasciculata		X																							
Fragilaria leptostauron		X								X										X					
Fragilaria nanana																X									
Fragilaria vaucheriae	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	
Hannaea arcus	X	X											X	X	X	X	X	X	X						
Meridion circulare	X		X														X	X			X		X	X	X
Opephora olsenii	X	X						X		X								X		X					
Staurosira construens	X	X	X	X	X	X	X	X	X	X	X		X	X	X		X	X	X		X	X			
Staurosirella leptostauron											X														
Staurosirella pinnata				X	X	X				X	X						X						X		
Synedra acus											X		X		X						X				
Synedra dilatata	X																								
Synedra parasitica		X					X	X							X		X				X		X		
Synedra rumpens	X							X		X				X		X	X		X						
Synedra ulna	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tabularia tabulata																	X	X	X						
Epithemiaceae																									
Epithemia sorex	X			X					X	X					X										
Rhopalodia brebissonii																X									
Rhopalodia gibba																							X	X	X
Melosiraceae																									
Melosira ambigua		X		X				X		X															
Melosira varians	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X					
Naviculaceae																									
Amphipleura pellucida	X																								

Table C-1. Algal taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Taxon — Site	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Phylum																									
Family																									
Genus species																									
Amphora libyca	X	X			X	X	X	X				X			X	X	X	X	X	X		X		X	X
Amphora montana			X									X				X	X		X	X					
Amphora ovalis	X										X					X	X			X				X	X
Amphora pediculus	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X
Amphora perpusilla				X						X						X				X		X			
Amphora veneta					X	X	X									X	X	X							
Anomoeoneis sphaerophora					X																				
Caloneis amphisbaena		X									X	X													
Caloneis bacillum	X	X	X						X	X		X	X	X	X	X	X	X	X		X	X	X	X	X
Caloneis branderii		X												X	X	X	X	X	X	X		X	X	X	X
Caloneis schumanniana					X																X				
Caloneis ventricosa	X									X															X
Craticula accomoda			X		X		X									X				X					
Craticula cuspidata			X	X	X	X	X								X	X	X		X						
Craticula halophila				X								X													
Cymbella affinis	X	X	X	X	X	X	X	X	X	X	X	X			X	X									
Cymbella caespitosa											X														
Cymbella cistula																		X							
Cymbella hebridica							X																		
Cymbella minuta				X										X											
Cymbella muelleri									X																
Cymbella sinuata	X	X	X	X					X	X		X	X	X	X	X				X	X	X			
Cymbella tumida	X	X																							
Cymbella turgidula	X																								
Diadesmis confervacea																									X
Diploneis oblongella		X							X										X		X	X	X	X	
Diploneis pseudovalis		X																							
Encyonema auerswaldii	X	X						X		X			X		X	X				X					
Encyonema minutum	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		
Encyonema prostratum				X		X		X		X						X							X		
Encyonema reichardtii									X	X	X		X				X	X	X						
Encyonema silesiacum			X		X	X	X		X	X	X	X	X	X	X	X	X	X	X						
Encyonopsis microcephala	X	X		X			X								X										
Entomoneis alata																				X					
Fallacia indifferens																	X	X							
Fallacia pygmaea	X		X	X	X	X	X	X			X				X	X	X	X	X	X					
Frustulia vulgaris															X	X					X		X	X	X
Gomphoneis eriense variabilis																		X							
Gomphonema acuminatum		X																							
Gomphonema affine		X					X	X			X	X													
Gomphonema angustum	X			X					X	X						X				X					
Gomphonema clavatum							X																		
Gomphonema gracile											X														
Gomphonema insigne						X																	X		X
Gomphonema kobayasii	X	X	X		X	X	X					X					X	X	X	X					
Gomphonema micropus					X		X				X						X	X	X				X	X	X
Gomphonema minutum			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X				X		

Table C-1. Algal taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Site	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Taxon: **Phylum** / Family / *Genus species*																									
Gomphonema olivaceoides													X		X										
Gomphonema olivaceum	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gomphonema parvulum	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
Gomphonema pumilum							X																		
Gomphonema subclavatum				X									X												
Gomphonema truncatum	X				X	X	X		X	X	X						X		X			X			
Gyrosigma acuminatum						X																	X	X	
Gyrosigma attenuatum										X															X
Gyrosigma nodiferum	X	X						X				X				X				X		X			
Luticola goeppertiana								X																	
Luticola mutica													X				X			X					
Mastogloia elliptica																		X	X						
Mastogloia smithii																									
Navicula agrestis				X																					
Navicula arvensis				X						X				X				X		X		X			
Navicula atomus	X	X	X		X		X		X	X	X	X		X	X		X	X	X	X	X	X	X	X	X
Navicula bacilloides	X																								
Navicula biconica	X		X	X			X	X	X		X	X	X			X					X		X	X	X
Navicula canalis				X	X		X	X								X		X	X						
Navicula capitata	X	X	X	X	X	X	X	X				X			X	X	X	X	X	X					
Navicula capitatoradiata	X	X	X	X	X	X	X	X	X	X		X			X	X	X	X	X	X					
Navicula cari										X							X								
Navicula caterva	X	X	X	X	X	X	X		X	X		X				X				X	X	X			
Navicula cincta				X		X														X					
Navicula citrus		X																							
Navicula cryptocephala	X	X						X		X			X		X	X	X			X					
Navicula cryptotenella	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Navicula decussis	X		X	X	X	X	X				X	X													
Navicula elginensis									X			X													
Navicula erifuga	X	X	X	X	X		X	X				X			X	X		X	X	X			X		
Navicula exigua signata	X	X	X									X													
Navicula exilis		X																		X					
Navicula germainii	X	X	X				X	X							X	X			X	X					
Navicula goeppertiana																				X					
Navicula gregaria	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
Navicula helensis																							X	X	X
Navicula ignota		X				X		X		X			X	X					X		X	X	X	X	X
Navicula kotschyi					X																		X		
Navicula lanceolata	X	X	X	X	X	X	X	X	X		X	X			X	X	X	X	X	X	X		X	X	X
Navicula laterostrata																	X								
Navicula lenzii	X															X					X	X			
Navicula longicephala																			X						X
Navicula lundii													X					X							
Navicula menisculus	X	X	X		X	X	X	X				X					X			X	X	X	X	X	X
Navicula minima	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Navicula molestiformis	X		X		X							X						X					X	X	X
Navicula perminuta																	X								
Navicula pseudoanglica	X							X				X													
Navicula pupula																X				X					

Table C-1. Algal taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Taxon	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Phylum																									
Family																									
Genus species																									
Navicula radiosa tenella				X																					
Navicula recens	X					X	X	X					X		X	X	X		X	X	X				
Navicula reichardtiana	X	X	X	X	X	X	X		X	X	X	X				X	X		X	X	X	X	X	X	X
Navicula salinarum				X													X								
Navicula saprophila					X													X					X	X	X
Navicula schroeteri	X	X	X	X				X				X			X	X									
Navicula seminulum									X	X		X								X	X				
Navicula subminuscula		X	X	X	X	X	X	X				X	X		X		X		X	X		X			
Navicula symmetrica																	X	X	X						
Navicula tenelloides	X	X	X					X				X				X			X						
Navicula tripunctata	X	X	X	X	X	X	X	X	X	X	X	X			X	X				X	X	X	X	X	X
Navicula trivialis	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X			X				
Navicula veneta	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X			X	
Navicula viridula	X	X	X	X		X	X	X				X				X		X	X	X					
Navicula wildii			X																	X					
Neidium binodeforme		X																							
Neidium dubium		X								X	X	X													
Pinnularia borealis																			X						
Pinnularia brebissonii		X																							
Pinnularia gibba																				X					
Pinnularia interrupta																		X							
Pinnularia microstauron																	X								
Placoneis clementis					X																				
Pleurosigma delicatulum																	X								
Pleurosigma salinarum															X										
Reimeria sinuata					X	X	X				X						X	X	X					X	
Rhoicosphenia curvata	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X
Sellaphora pupula	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X		X				
Sellaphora seminulum		X	X		X	X	X				X	X	X				X		X	X		X		X	
Stauroneis smithii	X																	X			X				
Nitzschiaceae																									
Bacillaria paradoxa							X	X		X					X	X	X	X	X	X				X	
Cylindrotheca gracilis																X									
Denticula elegans		X																							
Denticula tenuis	X																X	X							
Hantzschia amphioxys		X			X													X	X						
Nitzschia acicularis	X	X	X	X	X	X	X	X			X	X				X	X	X	X	X					
Nitzschia amphibia	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X	X		X			
Nitzschia angustata					X	X	X										X							X	
Nitzschia archibaldii	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
Nitzschia bita																	X		X						
Nitzschia capitellata	X		X		X		X	X				X	X		X		X		X	X					
Nitzschia clausii	X	X	X					X							X										
Nitzschia compressa vexans																			X						
Nitzschia constricta																X				X		X			
Nitzschia desertorum					X	X	X												X	X					
Nitzschia dissipata	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Nitzschia dubia						X									X	X	X		X						
Nitzschia filiformis																		X	X	X					

Table C-1. Algal taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Taxon / Site	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Phylum Family *Genus species*																									
Nitzschia flexoides																	X								
Nitzschia fonticola	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Nitzschia frustulum																		X	X	X					
Nitzschia gracilis					X																				
Nitzschia hantzschiana					X	X	X																		X
Nitzschia heufleriana				X																					
Nitzschia inconspicua	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X
Nitzschia intermedia					X	X																			
Nitzschia levidensis		X													X										
Nitzschia linearis	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X				X	X	X			
Nitzschia palea	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
Nitzschia pellucida										X										X					
Nitzschia perminuta					X		X						X				X	X	X						
Nitzschia pusilla			X	X				X		X						X	X			X	X	X			
Nitzschia recta	X	X	X		X			X				X							X		X			X	X
Nitzschia reversa								X												X					
Nitzschia sigma															X										
Nitzschia sigmoidea	X	X		X	X	X	X	X			X		X		X		X	X	X		X	X	X	X	X
Nitzschia siliqua		X		X				X				X				X				X	X	X			
Nitzschia sociabilis	X		X			X	X					X	X		X			X				X			
Nitzschia solita	X	X	X		X	X	X	X				X						X							
Nitzschia umbonata			X	X	X		X	X																	
Simonsenia delognei																		X	X					X	X
Tryblionella apiculata	X	X	X	X	X	X	X	X	X			X			X	X	X	X	X	X					
Tryblionella calida	X	X	X	X	X	X	X	X		X		X			X		X	X	X	X					
Tryblionella levidensis																			X						
Surirellaceae																									
Cymatopleura solea	X	X			X	X	X			X	X	X	X			X	X	X		X					
Surirella angusta	X	X	X	X	X	X	X	X				X	X	X						X					
Surirella brebissonii	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X						
Surirella brightwellii																	X								
Surirella minuta	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X
Surirella peisonis			X							X					X										
Surirella robusta																				X					
Synuraceae																									
Synura sp.																X									
Thalassiosiraceae																									
Aulacoseira ambigua							X										X	X	X						
Aulacoseira granulata				X	X	X								X		X	X		X	X					
Cyclostephanos invisitatus					X	X																			
Cyclostephanos tholiformis																			X						
Cyclotella sp.	X																								
Cyclotella atomus			X	X	X	X	X	X			X	X			X	X	X	X	X				X		
Cyclotella glomerata		X		X		X	X	X				X			X		X	X	X						
Cyclotella meneghiniana	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
Cyclotella ocellata							X	X												X					
Cyclotella radiosa									X	X						X				X	X				
Stephanodiscus alpinus								X																	

Table C-1. Algal taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Taxon / Site	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Phylum																									
Family																									
Genus species																									
Stephanodiscus hantzschii	X	X	X					X			X						X		X						
Stephanodiscus minutulus																				X					
Stephanodiscus niagarae		X								X	X														
Stephanodiscus parvus				X						X	X			X											
Thalassiosira weissflogii	X			X				X				X				X	X	X	X	X					
Vaucheriaceae																									
Vaucheria sp.					X	X	X			X											X	X			X
Rhodophyta																									
Batrachospermaceae																									
Batrachospermum sp.									X			X													
Chantransiaceae																									
Audouinella violacea	X	X		X			X							X	X	X	X	X	X		X	X	X		X
Pyrrhophyta																									
Oxytoxaceae																									
Ceratium carolinianum																X									
Ceratium hirudinella																X	X	X							

Table C-2. Invertebrate taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Taxon	Site	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
	Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
	Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Phylum **Class** **Order** Family *Genus* sp.																										
Porifera										X						X										
Cnidaria																										
Hydrozoa																										
Hydroida																										
Hydridae																										
Hydra sp.			X															X								
Platyhelminthes																										
Turbellaria													X			X	X	X	X	X	X	X			X	X
Nemertea																										
Enopla																										
Hoplonemertea																										
Tetrastemmatidae																										
Prostoma sp.			X										X													
Nematoda		X	X		X		X	X		X			X	X				X		X						
Nematomorpha																								X		
Bryozoa				X				X	X																	
Mollusca																										
Gastropoda															X											
Mesogastropoda																										
Valvatidae																										
Valvata sp.						X																				
Hydrobiidae																	X	X	X			X	X	X	X	X
Fluminicola sp.		X				X																				
Basommatophora																										
Ancylidae			X																							
Ferrissia sp.			X			X							X			X					X					
Lymnaeidae									X			X			X			X								
Fossaria sp.				X																						
Pseudosuccinea sp.			X	X	X	X	X						X													X
Stagnicola sp.					X	X				X	X	X		X	X											
Physidae			X		X	X	X		X	X	X	X			X		X	X	X		X					
Physella sp.		X	X	X	X	X	X	X		X	X	X			X			X	X	X	X					
Planorbidae			X					X	X						X				X							
Gyraulus sp.			X			X		X				X		X	X	X		X		X						
Menetus sp.													X													
Planorbella sp.		X							X																	
Bivalvia																					X					
Paleoheterodonta																										
Margaritiferidae																										
Margaritifera sp.						X																				
Unionidae						X																				
Veneroida																										
Corbiculidae																										
Corbicula sp.													X					X	X							
Sphaeriidae						X								X												
Pisidium sp.										X	X	X					X	X	X	X		X	X	X	X	X
Sphaerium sp.		X																								

Table C-2. Invertebrate taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Taxon / Site	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Phylum																									
Class																									
Order																									
Family																									
Genus sp.																									
Annelida																									
Oligochaeta	X								X		X		X	X	X	X	X	X	X			X	X		X
Lumbriculida																									
Lumbriculidae													X	X		X	X	X					X	X	
Haplotaxida																									
Haplotaxidae																									
Haplotaxis sp.																								X	
Tubificida																									
Naididae	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X		X			
Tubificida																									
Tubificidae		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Enchytraeida																									
Enchytraeidae									X		X		X	X	X	X	X	X	X			X	X	X	X
Hirudinea																		X							
Rhynchobdellae																									
Glossiphoniidae																									
Helobdella sp.	X				X		X		X	X	X				X		X								
Arhynchobdellae																									
Erpobdellidae		X	X	X	X	X	X		X	X	X		X	X	X	X	X	X	X						
Arthropoda																									
Arachnida		X	X		X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Malacostraca																									
Decapoda																									
Cambaridae				X						X		X													
Orconectes sp.												X													
Isopoda																									
Asellidae																X									
Caecidotea sp.										X	X	X			X	X	X	X	X	X					
Amphipoda						X													X						
Crangonyctidae																									
Crangonyx sp.															X	X				X					
Gammaridae																									
Gammarus sp.		X	X			X																			
Hyalellidae																									
Hyalella sp.	X	X	X	X	X	X	X	X	X	X	X														
Insecta																									
Collembola								X									X	X	X						
Ephemeroptera					X		X		X	X	X														
Leptophlebiidae	X								X		X										X	X		X	
Choroterpes sp.	X																								
Paraleptophlebia sp.										X											X	X	X		
Ephemeridae																									
Hexagenia sp.	X	X																							
Polymitarcyidae																									
Ephoron sp.	X	X	X	X																					
Caenidae																									
Caenis sp.		X																							

Table C-2. Invertebrate taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Taxon	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Phylum																									
Class																									
Order																									
Family																									
Genus sp.																									
Ephemerellidae	X										X										X	X			
Attenella sp.									X	X	X														
Drunella sp.	X		X										X								X	X	X	X	X
Ephemerella sp.																								X	
Serratella sp.													X												
Leptohyphidae																									
Tricorythodes sp.	X	X	X	X	X	X	X		X	X	X				X					X					
Ameletidae																									
Ameletus sp.																					X				
Baetidae	X		X	X	X	X	X	X		X	X										X	X	X	X	X
Acentrella sp.	X																								
Baetis sp.	X		X	X	X	X	X	X	X	X	X	X	X	X	X						X	X	X	X	X
Callibaetis sp.	X	X		X	X	X	X		X									X	X						
Diphetor sp.																							X	X	
Heptageniidae	X		X		X			X			X										X	X			
Epeorus sp.													X								X		X	X	X
Heptagenia sp.	X			X					X											X					
Nixe sp.									X	X															
Rhithrogena sp.	X																								
Stenonema sp.		X	X					X																	
Odonata																									
Calopterygidae																									
Hetaerina sp.																				X					
Coenagrionidae		X			X	X	X			X		X								X					
Ischnura sp.		X																							
Aeshnidae																									
Aeshna sp.		X	X		X	X	X			X								X	X	X					
Gomphidae	X																								
Gomphus sp.																				X					
Ophiogomphus sp.	X															X									
Plecoptera																					X	X	X	X	X
Nemouridae																					X	X			X
Amphinemura sp.																							X	X	
Malenka sp.																					X	X			
Zapada sp.																					X	X	X	X	X
Chloroperlidae			X																						
Sweltsa sp.													X								X	X			
Perlidae																					X				X
Hesperoperla sp.	X																				X	X	X		X
Claassenia sp.	X								X	X															
Perlodidae									X												X				
Isoperla sp.									X	X	X														
Skwala sp.			X						X	X															
Isogenoides sp.	X																								
Pteronarcyidae																									
Pteronarcella sp.	X								X	X															
Pteronarcys sp.	X																								

Table C-2. Invertebrate taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Taxon	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Phylum / **Class** / **Order** / Family / *Genus* sp.																									
Hemiptera																									
Corixidae		X			X	X			X									X	X						
Callicorixa sp.		X		X																					
Cenocorixa sp.					X																				
Corisella sp.		X	X	X	X								X						X						
Hesperocorixa sp.										X															
Palmacorixa sp.		X																							
Sigara sp.	X	X	X	X	X	X	X		X	X	X	X													
Trichocorixa sp.	X	X	X	X	X		X			X															
Gerridae			X[1]			X[1]	X[1]		X[1]	X[1]		X[1]		X[1]		X[1]				X[1]			X		X
Aquarius sp.		X				X	X					X	X												
Gerris sp.				X																					
Limnoporus sp.		X		X																					
Notonectidae																									
Notonecta sp.					X																				
Megaloptera																									
Sialidae																									
Sialis sp.		X			X	X	X																		
Trichoptera									X																
Glossosomatidae																									
Culoptila sp.																X									
Protoptila sp.		X																							
Hydroptilidae					X	X	X				X										X	X			
Hydroptila sp.		X		X	X	X	X			X	X		X	X	X	X	X	X	X		X	X	X	X	X
Mayatrichia sp.									X																
Neotrichia sp.	X																								
Ochrotrichia sp.		X					X		X		X											X	X	X	
Rhyacophilidae																									
Rhyacophila sp.											X			X							X	X	X	X	X
Philopotamidae																									
Wormaldia sp.																					X		X		X
Hydropsychidae	X		X	X	X	X	X	X	X	X	X	X	X	X	X			X	X		X				X
Arctopsyche sp.									X	X											X			X	
Ceratopsyche sp.	X	X					X		X	X			X	X							X	X		X	
Cheumatopsyche sp.	X		X	X	X	X	X		X	X		X									X				
Hydropsyche sp.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X
Polycentropodidae																									
Polycentropus sp.				X	X																				
Psychomyiidae																									
Psychomyia sp.									X	X															
Brachycentridae																									
Brachycentrus sp.	X	X	X	X	X	X	X		X	X	X														
Micrasema sp.																					X	X	X	X	X
Lepidostomatidae																									
Lepidostoma sp.										X				X		X					X		X	X	X
Limnephilidae									X		X													X	
Amphicosmoecus sp.			X																				X	X	X

Table C-2. Invertebrate taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Taxon	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Phylum																									
Class																									
Order																									
Family																									
Genus sp.																									
Onocosmoecus sp.	X										X														
Hesperophylax sp.		X							X	X	X														
Psychoglypha sp.																							X		X
Leptoceridae														X											
Ceraclea sp.																									
Nectopsyche sp.	X	X	X	X	X										X										
Oecetis sp.													X	X											
Helicopsychidae																									
Helicopsyche sp.											X														
Lepidoptera				X																			X	X	
Coleoptera																									
Amphizoidae																									
Amphizoa sp.										X												X		X	
Dytiscidae		X							X[1]		X[1]		X[1]	X											
Agabus sp.		X				X			X		X		X	X											
Ilybius sp.		X																							
Coptotomus sp.							X																		
Liodessus sp.	X	X	X			X		X																	
Oreodytes sp.	X												X												
Laccophilus sp.		X		X	X		X	X																	
Gyrinidae																									
Gyrinus sp.		X	X						X	X	X	X	X							X					
Haliplidae																						X			
Brychius sp.	X										X										X	X	X	X	
Haliplus sp.	X	X			X																				
Hydraenidae																									
Hydraena sp.																					X				
Hydraenidae																									
Ochthebius sp.		X																							
Staphylinidae																					X	X			
Helophoridae																									
Helophorus sp.		X				X	X	X	X			X													
Hydrophilidae					X																				
Ametor sp.									X												X	X	X	X	X
Berosus sp.							X																		
Enochrus sp.		X		X	X																				
Laccobius sp.		X		X	X	X																			
Tropisternus sp.				X	X	X	X																		
Dryopidae																									
Helichus sp.																							X		X
Elmidae				X	X					X											X	X		X	X
Cleptelmis sp.		X																			X	X	X	X	X
Dubiraphia sp.	X	X	X	X	X	X	X																		
Heterelmis sp.																				X					
Heterlimnius sp.																					X	X	X	X	X
Microcylloepus sp.				X		X		X																	
Narpus sp.														X							X	X	X	X	X

Table C-2. Invertebrate taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Taxon	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Phylum																									
Class																									
Order																									
Family																									
Genus sp.																									
Optioservus sp.	X		X	X	X	X	X		X	X	X								X		X				
Stenelmis sp.								X																	
Zaitzevia sp.				X						X											X	X	X	X	
Curculionidae						X					X	X									X	X	X	X	
Diptera					X[1]	X	X[1]				X[1]						X[1]				X[1]		X		X
Blephariceridae																				X					
Ceratopogonidae						X	X	X	X								X	X				X	X		X
Probezzia sp.					X																	X			
Dasyhelea sp.																			X						
Chironomidae	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]
Apedilum sp.															X										
Chironomus sp.	X	X	X	X	X	X			X			X	X	X	X	X	X	X	X	X					
Cladopelma sp.		X														X									
Cryptochironomus sp.	X	X	X	X	X	X	X			X		X		X	X	X	X	X	X	X					
Dicrotendipes sp.		X	X	X	X		X	X				X	X		X	X	X	X	X	X					
Endochironomus sp.		X										X													
Glyptotendipes sp.								X				X								X					
Harnischia sp.		X																							
Microtendipes sp.	X		X	X	X	X	X				X														
Parachironomus sp.		X				X	X	X									X			X					
Paracladopelma sp.			X										X												
Paralauterborniella sp.	X																								
Paratendipes sp.									X	X													X	X	X
Phaenopsectra sp.	X		X	X	X	X			X	X	X	X	X	X	X	X	X	X	X						
Polypedilum sp.	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X			X	X	X	X	X	X
Sergentia sp.	X								X				X												
Stenochironomus sp.								X				X													
Stictochironomus sp.	X									X															
Xestochironomus sp.												X													
Pseudochironomus sp.										X		X													
Cladotanytarsus sp.																									
Micropsectra sp.		X					X						X				X	X	X		X	X		X	
Paratanytarsus sp.		X		X	X	X	X					X							X	X					
Rheotanytarsus sp.	X		X	X	X	X	X									X					X			X	X
Tanytarsus sp.			X						X										X			X	X	X	
Diamesa sp.																							X		
Pagastia sp.									X	X	X		X	X							X	X	X	X	X
Pseudodiamesa sp.																									X
Acricotopus sp.		X																							
Brillia sp.			X	X						X	X	X	X		X						X	X			
Cardiocladius sp.									X	X						X									
Corynoneura sp.			X							X															
Cricotopus sp.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X			
Eukiefferiella sp.	X		X		X		X		X	X	X		X	X			X	X			X	X	X	X	X
Limnophyes sp.					X												X		X			X			
Nanocladius sp.		X			X	X		X				X			X	X	X		X						
Paracladius sp.	X																								

Table C-2. Invertebrate taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Taxon	Site	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
	Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
	Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Phylum																										
Class																										
Order																										
Family																										
Genus sp.																										
Parakiefferiella sp.									X				X			X										
Parametriocnemus sp.										X	X		X	X	X	X		X		X		X				
Parorthocladius sp.																						X				
Psectrocladius sp.																										
Pseudosmittia sp.																				X						
Rheocricotopus sp.								X						X		X	X	X		X	X	X	X			
Thienemanniella sp.		X	X	X	X		X		X	X	X		X	X	X	X	X		X		X					
Tvetenia sp.		X		X	X	X			X	X	X	X										X	X			X
Zalutschia sp.				X																						
Monodiamesa sp.		X		X	X		X				X												X	X	X	X
Odontomesa sp.							X			X		X													X	
Prodiamesa sp.			X								X	X											X			
Brundiniella sp.																						X	X		X	
Derotanypus sp.			X																							
Psectrotanypus sp.													X													
Radotanypus sp.												X											X			
Ablabesmyia sp.			X	X	X	X								X			X									
Pentaneura sp.				X	X	X	X	X																X	X	X
Procladius sp.		X	X		X	X	X	X								X	X	X	X	X						X
Tanypus sp.			X															X								
Dixidae																							X		X	
Dixa sp.																						X	X		X	X
Dixella sp.								X																X		
Psychodidae																			X			X	X			
Psychoda sp.																		X	X							
Ptychopteridae																										
Ptychoptera sp.																						X	X	X	X	X
Simuliidae		X		X	X	X	X	X		X	X	X			X			X	X	X	X	X	X	X	X	X
Simulium sp.		X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
Tipulidae																	X					X	X		X	X
Tipula sp.			X			X				X		X		X	X							X	X	X		X
Antocha sp.										X	X	X												X	X	X
Dicranota sp.					X						X											X	X	X	X	X
Hexatoma sp.		X		X							X											X	X	X	X	X
Limnophila sp.																							X	X		
Limonia sp.																							X			
Ormosia sp.																								X		
Athericidae																										
Atherix sp.										X		X														
Empididae		X[1]	X[1]								X[1]	X[1]										X		X[1]		X[1]
Clinocera sp.																						X	X	X		
Wiedemannia sp.																						X				
Hemerodromia sp.			X	X	X		X									X						X	X			X
Neoplasta sp.		X																					X	X	X	X
Ephydridae									X				X				X									
Muscidae				X																		X	X			
Stratiomyidae																			X				X		X	

Table C-2. Invertebrate taxa collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1; X indicates that the species was collected]

Taxon	Site	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST		LCCJOR					JOR	RB				
	Reach	A	A	A			B	C	A	A			A	A		A			B	C	A	A			B	C
	Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	2000	1999	2000	2001	2001	2001	2000	1999	2000	2001	2001	2001
Phylum																										
Class																										
Order																										
Family																										
Genus sp.																										
Caloparyphus sp.																						X	X	X		X
Euparyphus sp.			X																					X		X
Odontomyia sp.			X																							
Tabanidae							X																			
Tabanus sp.					X																					

[1]Ambiguous taxon that is a taxon in a dataset that is reported at more than one level within the taxonomic hierarchy.

Table C-3. Fish taxa and number of individuals collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1]

Taxon	SMFK	PESC	CUB					COR	COAL			PLAIN	CREST	LCCJOR					JOR	RB
Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	1999	2000	2001	2001	2001	2000	1999
Reach	A	A	A	A	A	B	C	A	A	A	A	A	A	A	A	A	B	C	A	A
Order / **Family** / *Scientific name* / common name																				
Clupeiformes																				
Clupeidae																				
Dorosoma cepedianum																				
gizzard shad								48				43								
Cypriniformes																				
Cyprinidae																				
Carassius auratus																				
goldfish			3									7		3	1		1	2	1	
Ctenopharyngodon idella																				
grass carp								4												
Cyprinus carpio																				
common carp	8	29	22	38	165	133	141	59						43	26	22	12	30	8	
Notropis hudsonius																				
spottail shiner												1,047								
Pimephales promelas																				
fathead minnow			48		1	3								27	57	6	1	4		
Rhinichthys cataractae																				
longnose dace			133	373	61	235	126			26	2		792	9			6			
Rhinichthys osculus																				
speckled dace												1		12						
Rhinichthys sp.																				
riffle daces									12											
Richardsonius balteatus																				
redside shiner	70	1		450	1,105	985	1,878			2										
Catostomidae																				
Catostomus ardens																				
Utah sucker			20	85	119	143	24		2	7	14	1								
Catostomus commersoni																				
white sucker	2	8											465	26	22				17	
Catostomus discobolus																				
bluehead sucker	1																			
Catostomus platyrhynchus																				
mountain sucker	2									92	12			2			1	1		
Siluriformes																				
Ictaluridae																				
Ameiurus melas																				
black bullhead				1	3	7						2								
Ictalurus punctatus																				
channel catfish								1												
Salmoniformes																				
Salmonidae																				
Oncorhynchus clarki																				
cutthroat trout	4	2																		[1]10
Oncorhynchus mykiss																				
rainbow trout			14						3					3						
Prosopium williamsoni																				

Table C-3. Fish taxa and number of individuals collected at the fixed sampling sites in the Great Salt Lake Basins study unit

[For site abbreviations see table 1]

Taxon		SMFK	PESC	CUB					COR	COAL			PLAIN	CREST	LCCJOR					JOR	RB
	Year	1999	1999	1999	2000	2001	2001	2001	1999	1999	2000	2001	1999	1999	1999	2000	2001	2001	2001	2000	1999
	Reach	A	A	A	A	A	B	C	A	A	A	A	A	A	A	A	A	B	C	A	A
Order																					
Family																					
Scientific name																					
common name																					
mountain whitefish		2	12							72	224	97									
Salmo trutta																					
brown trout		1	3	2	5	1	17			12	21	22							1		
Atheriniformes																					
Poeciliidae																					
Gambusia sp.																					
mosquitofishes							5	22					15								
Scorpaeniformes																					
Cottidae																					
Cottus bairdi																					
mottled sculpin										140	477	161									
Cottus beldingi																					
paiute sculpin		2																			
Perciformes																					
Percichthyidae																					
Morone chrysops																					
white bass															5	2	15	16	1		
Centrarchidae																					
Lepomis cyanellus																					
green sunfish					9	7	4	2					6		19	13	4	8	1		
Micropterus dolomieu																					
smallmouth bass											1	10				1					
Micropterus salmoides																					
largemouth bass				4									5								
Pomoxis nigromaculatus																					
black crappie				1														1			
Percidae																					
Perca flavescens																					
yellow perch												27					3	1	2		
Stizostedion vitreum																					
walleye									1												

[1] Fish collected by Utah Department of Natural Resources, Division of Wildlife Resources, in 1996.

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