ANALYSIS OF BIOLOGICAL DATA COLLECTED IN THE BULL RUN WATERSHED, PORTLAND, OREGON, 1978 TO 1983

By Daphne G. Clifton

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CONVERSION FACTORS

[For use of those readers who may prefer to use metric units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:]

Multiply inch-pound units	By	To obtain metric unit
	Length	
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square inch (in^2)	6.452	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
	Specific combination	
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
	Temperature	
degree Fahrenheit (°F)	(1/)	degree Celsius (°)

1/ Temp °C = (temp °F-32)/1.8.

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ABSTRACT

Bull Run streams are predominantly heterotrophic. Bull Run periphyton is dominated by penne diatom species. *Achnanthes minutissima* was dominant in 2nd-order streams and *Achnanthes lanceolata* was dominant in 3rd-order streams. Median total periphyton populations ranged from 1,100 to 2,800 cells/mm^2. Basin slope orientation and stream order may be major factors influencing species diversity, which ranged from 1.70 to 2.55.

Correlation analyses indicated that periphyton species had similar habitat preferences and that competition for space and nutrients occurred less often than expected by chance. Cluster analysis of periphyton species resulted in unique clusters for North Fork, South Fork, Lower Cougar, and South Fork above Cedar Creek. Species constancy analysis indicated that the dominant periphyton species were widely distributed.

Chironomidae, Hydracarina, and *Baetis* were the dominant benthic invertebrate taxa. Median totals for benthic invertebrate communities ranged from 270-770 organisms/ft^2. The generalists were the dominant functional group. Diversity values were significantly lower at North Fork (1.58) compared to the other sites (2.22 to 2.55), possibly due to higher annual sediment yields and turbidity at North Fork.

Significant associations occurred between invertebrates from different families and between invertebrates with different foraging strategies. A majority of the significant associations were between members of different functional groups. Most negative associations occurred between generalists and other groups, possibly due to competition, or because chironomids (the predominant generalists) have representatives in each of the functional groups. Cluster analysis showed that the North Fork benthic community was dissimilar to that of the other stations, probably due to chironomid abundance and lower species diversity. Constancy analysis showed that chironomids and baetids were widely distributed.

Bacteria and phytoplankton were positively correlated with stream temperature, specific conductance, pH, and dissolved solids. Phytoplankton were positively correlated with silica, orthophosphate and streamflow. Fecal coliform bacteria were directly associated with higher streamflow and turbidity, while fecal streptococcus bacteria were associated with lower streamflow and higher silica concentrations. Cluster analysis of instantaneous water-quality data resulted in formation of major clusters representative of average streamflow conditions, and minor clusters related to high or low streamflow conditions.

INTRODUCTION

The Bull Run watershed has served as the City of Portland's primary municipal water supply for nearly 100 years. The 102 square-mile Reserve is located about 25 miles east of Portland in the Mt. Hood National Forest. The U.S. Forest Service (USFS) pursued an active timber management program within the watershed from 1959 until 1976. Logging activities were suspended in 1976 due to a lawsuit concerning possible conflicts in management objectives. The watershed is currently being managed by the U.S. Forest Service and the Portland Water Bureau (PWB). Stated objectives are (1) to insure that pure drinking water is available to Portland users and (2) to manage the renewable resources in the basin.

Purpose and Scope

The U.S. Geological Survey, in cooperation with the PWB, began a 6-year monitoring program to define the hydrologic characteristics of the Bull Run River basin and to examine relations between stream water-quality and quantity in the basin. Daily and periodical water quality and quantity data were collected by the Survey and PWB at selected stream inflow sites to Reservoirs 1 and 2 during the 1978 to 1983 water years. Because minimal management activity occurred in the basin during the study period, original objectives to evaluate how logging activity affected water quality were redirected towards accurately defining water quality during the base period and identifying existing water-quality relations. Results of the analyses of these data by the Survey will be used by the USFS and PWB in development and evaluation of water-quality standards for the watershed. This report specifically addresses the biological data collected during the study.

Basin Description

The climate in the Bull Run River basin is typically maritime, with a mean air temperature of 52 °F and range of 9 to 102 °F during the 1978-83 water year period. Average annual precipitation for the same period ranged from 65.6 to 94.8 inches, with a mean of 80.45 inches measured at the headworks of Reservoir No. 2. Major rainfall and overland runoff occurs during the wet winter months.

Elevation in the basin ranges between 750 feet at the headworks and 4,600 feet on Hiyu Mountain. Major stratographic units in the Bull Run River basin include: (1) Columbia River basalt, which surrounds the reservoirs and the lower parts of the subbasins; (2) the Rhododendron formation, which forms vertical canyon walls where erosion is rapid, compared to other areas in the Bull Run basin, and which is prone to landslides in regions of chemical weathering; and (3) Pliocene and quaternary volcanic rock, which are the major geologic formations in the basin. A significant amount of area bordering the lower South Fork and parts of the lower North Fork drainage consists of the Rhododendron geologic formation. Quaternary landslide debris is found in the upper North Fork subbasin and is composed of boulders and fine debris derived from the Rhododendron formation and of pliocene volcanic rock (State of Oregon, 1974).

The Bull Run Basin consists of steep canyons with heavily forested slopes of predominately Douglas fir, Western hemlock and Western red cedar. Logging activities have included patch clear-cutting and partial cutting methods, accompanied by selective or broadcast slash-burning. Use of cable-highlead, -skyline, and -cat logging reduces impact of forestry activities on the terrain. Most of the 160 miles of access roads are paved to reduce erosion. Minimal road construction occurred during the study period. Hydroelectric power generators have recently been installed in both reservoir dams.

Data Collection Network

Collection of water-quality samples in the Bull Run watershed from 1978-83 (water years)[1] will be described in a later report (Rinella, written commun., 1985). Periphyton sampling was carried out at six sites from 1978-83: North Fork Bull Run, Lower Cougar Creek, Upper Cougar Creek, all on the north side of the Bull Run reservoirs; and South Fork Bull Run, South Fork above Cedar Creek, and Fir Creek, all on the south side of the reservoirs (table 1, fig. 1). The South Fork and Cougar Creek streams are represented by both upper and lower stream reaches. Some logging has occurred in the past in all basins except for Fir Creek. Benthic invertebrate sampling was carried out in 1978-81 in late summer low-flow conditions at North Fork Bull Run, South Fork Bull Run, Fir Creek, and Lower Cougar Creek. Stream sites located near reservoir-inflow points are perceived as integrators of upstream water-quality. Biological communities act more as long-term integrators of water quality than do instantaneous water-quality samples and may be more sensitive to management activities.

1/All dates in the text refer to water years, as defined in the Glossary.

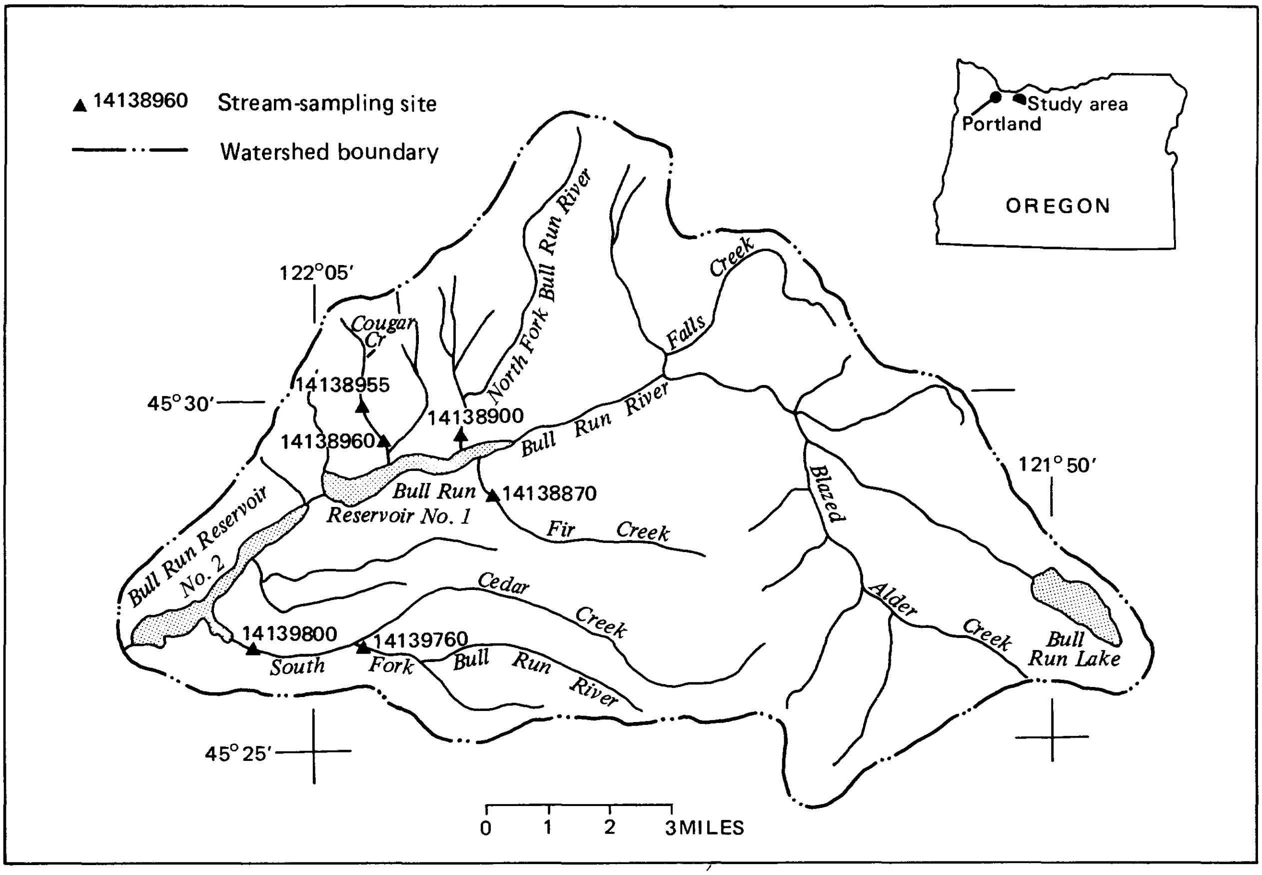

Figure 1.--Location of sampling sites in the Bull Run Watershed.

Table 1.--Summary of the U.S. Geological Survey data collection network in the Bull Run watershed

[USGS = U.S. Geological Survey; PWB = Portland Water Bureau]

Hydrologic Station	Name used in report	USGS identifier	PWB identifier	Hydrologic activity	Period of hydrologic record 1/	USGS continuous monitoring station 2/	Periodic Water Bureau station 3/	Intermittent USGS station	
								Periphyton	Benthic invertebrates
Continuous									
Fir Creek near Brightwood	Fir Creek	14138870	44	Stream gaging and satellite data relay	October 1975	X	X	X	X
North Fork Bull Run River near Multnomah Falls	North Fork	14138900	15	do.	August 1965	X	X	X	X
South Fork Bull Run River near Bull Run	South Fork	14139800	35	do.	October 1974	X	X	X	X
Partial-record									
Upper Cougar Creek near Bull Run	Upper Cougar Creek	14138955	63	none	October 1977			X	
Lower Cougar Creek near Bull Run	Lower Cougar Creek	14138960	12	Staff gage with crest-stage gage	October 1977		X	X	X
South Fork Bull Run River above Cedar Creek near Bull Run	South Fork above Cedar Creek	14139760	36	Staff gage with crest-stage gage	October 1977		X	X	

1/ Period of record through September, 1983.
2/ Thirty-minute recording of stage, water temperature, specific conductance, and daily or more frequent automatic sampling for suspended sediment.
3/ Instantaneous samples of water-quality constituents using a depth-integrated sampler and measurement of water stage using a staff gage.

METHODS

Biological sample preparation and analysis utilized methods described by Greeson and others (1977). Periphyton were collected on plastic slide substrates (size = 0.0423 foot-squared surface area, both sides). Substrates were placed parallel to the water surface with long axis to flow, attached to plexiglass "wings" fixed to a 12-inch long, 2-inch diameter PVC-pipe, and were suspended 1 to 2 inches below the water surface. Periphyton floats were located in areas with a sunny exposure and moderate streamflow near the gaging stations. Average time of exposure was 30 days for periphyton collected after 1979. Average time of exposure for the 1978-83 study period was 38 days. Periphyton samples were collected monthly from June through October. Some samples were lost or damaged due to high stream discharge or to application of copper sulfate to the streams prior to 1979 (see Glossary).

Because the nature of artificial substrates is different from the surfaces of natural substrates, it would be difficult to estimate instream primary production from the study of periphytic algal growth on artificial surfaces (Tippet, 1970). It does, however, provide a common surface for algal growth at all stations and thus allows comparison of results.

Slides for chlorophyll and biomass (ash weight and dry weight) analyses were sent to the Survey Laboratory in Atlanta, Georgia. Slides to be used for species identification of phycoperiphyton (plant components of the periphyton) were preserved in a 5 percent formalin-copper sulfate solution and were identified and counted by James Sweet from Aquatic Analysts, Portland, Oregon. The membrane filter method, a compound microscope, and identification keys by Collins and Kalinsky (1977), Hilliard (1966), Hustedt (1930), Javornicky (1976), Patrick and Reimer (1966, 1975), Prescott (1962), and by Smith (1950) were used.

Benthic invertebrate samples were collected once each year from 1977 to 1981 during low streamflow and elevated water temperatures in late July or early August (table 1). A Surber sampler (with mesh size of 0.210 mm, or 0.0083 inches) was used to collect three to four random samples at each station. Samples collected from each station were analyzed separately except for the 1977 collections, which were composited prior to analysis. Invertebrates attached to large rocks or bedrock within the square-foot Surber sampler were scraped off and collected in the net. All moveable rocks and vegetation and the contents of the net were placed into buckets, and organisms were removed with forceps or were washed into a 42 mesh-per-inch sieve (mesh-size openings of 0.351 mm, or 0.0138 inches). Specimans were preserved in 70 percent ethanol, then sorted and identified using an Olympus dissecting microscope and keys by Anderson (1976), Baumann and others (1977), Brown (1972), Cole and Schlinger (1969), Curran (1965), Edmundson (1959), Edmunds and others (1976), Henderson (1929, 1936), Holsinger (1972), Jewett (1979), Johannsen (1969), Merritt and Cummins (1978), Pennak (1978), Usinger (1956), and Wiggins (1977).

Benthic invertebrate identifications were made by Amy Emmett, Carol Savonen, and Jan Chappell, U.S. Geological Survey. Verifications were by Luis A. Fueste', U.S. Geological Survey; Tom Dudley, Neil Cobb and Chuck Hawkins, Oregon State University, Corvallis; Jerry Bell, Department of Environmental Quality, Portland; and by Rick Hafele, Portland, Oregon.

Periphyton and benthic invertebrate taxonomic and diversity data collected in the Bull Run watershed from 1978 to 1983 will be included in the annual data report published by the U.S. Geological Survey in 1985. Selected technical terms are defined in the Glossary. Statistical methods used in data analysis are given in Appendix I.

FACTORS AFFECTING STREAM BIOLOGY

When compared to the long-term record (1929-83), streamflow for the period was average, with no extreme streamflow events. The fact that there were no extreme events means that streamflow and water-quality data collected during the study period will not account for all of the expected natural variation in the Bull Run. Bull Run streams are characterized by low specific conductance, cool temperatures, and neutral to alkaline pH most of the year. Sixty to eighty percent of the total annual sediment load for the basins occurred in one percent of the time, or 3 or 4 days of the year (Rinella, 1985). These data are summarized in table 2.

Differences in geology, stream order, orientation, streamflow, temperature, canopy, competition between periphyton species, invertebrate grazing intensity, and man's activity in each subbasin may result in between-stream differences in dominant species. Although information is available for most of these factors, invertebrate grazing intensity and periphyton competition were not directly measured in this study. In addition, site-specific activity by man in each subbbasin is difficult to quantify. Other site characteristics are listed in table 3.

Although South Fork and North Fork are both 3rd-order streams with similar water-quality characteristics (table 2, 3), they differ in basin orientation, base flow (North Fork is higher), and in annual sediment yield and runoff per unit area (North Fork is greater; see Rinella, 1985). North Fork also has a greater median orthophosphate concentration compared to South Fork (0.007 versus less than 0.003 mg/L). These factors may influence the species composition of the biota found in these streams (table 4, 5 and 10). Fir Creek and South Fork above Cedar Creek are both 2nd-order streams on the south side of the Bull Run Reservoirs, but South Fork above Cedar Creek is much more shaded by steep canyon walls. Sluggish streamflow at this station in late summer is insufficient to support the periphyton sampler, which sinks to the stream bottom; for these reasons this station was discontinued in 1982.

Table 2.--Summary of surface water quantity and quality data collected at Bull Run stations, 1978 to 1983 water years

[Continuous daily data collection at North Fork and South Fork initiated in October 1978; * Indicates data summarized from table in Rinella, 1985; max = maximum; min = minimum; N = number of observations]

Constituent	Fir Creek*				North Fork*				South Fork*				Lower Cougar Creek			
	N	max	min	median	N	max	min	median	N	max	min	median	N	max	min	median
Stream [1/] temperature (°C)	343	14.0	0.0	7.0	350	13.0	0.0	7.0	348	16.0	0.0	7.5	332	19.0	0.0	7.5
Streamflow [2/] (cfs)	2191	616	1.9	22	2191	1910	9.1	43	2191	1550	8.0	70				
Streamflow [1/] (cfs)	366	916	1.9	22	368	2650	8.7	43	353	2100	10	65	300	553	.66	12
Annual daily mean streamflow (cfs)				36				71				108				
Turbidity [1/] (NTU)	322	8.4	.05	.18	343	75	.04	.20	325	12	.11	.24	310	27	.05	.13
Dissolved solids [1/] (mg/L)	279	46	6.1	22	288	119	10.7	26	289	53	12.5	26	275	271	9.2	16
Specific [1/] conductance (umhos at 25° C)	341	30	11	21	366	48	9	26	342	50	11	24	336	26	8	16
pH (units) [1/]	335	7.6	6.6	7.2	357	7.7	6.5	7.3	341	7.7	6.6	7.3	327	7.5	6.2	7.0
Nitrate as N [1/] (mg/L)	127	.19	<.01	.04	130	.13	<.01	.03	131	.12	<.01	.03	124	.15	<.01	.02
Orthophosphorus as P [1/] (mg/L)	126	.041	<.003	.003	122	.029	<.003	.007	124	.013	<.003	<.003	119	.020	<.003	.003
Dissolved silica as SiO_3 [1/] (mg/L)	123	14	4.8	9.3	126	19	4.0	11	123	16	4.9	10	118	11	4.3	6.9
Phyto-plankton [1/] (cells/ml)	275	350	2	51	276	553	4	70	278	268	1	75				
Periphyton [3/] chlorophyll-a (mg/m²)	19	19	0.1	2.4	20	57	.43	2.8	14	7.3	.41	3.5	20	17	0.1	3.0
Periphyton [3/] biomass-to-chlorophyll-a ratio	18	2000	61	390	17	1360	0	350	13	1460	11	280	20	1330	29	216
Total coliforms [1/] (col.per 100 ml)	302	116	<1	4	308	80	<1	2	304	122	<1	4	306	150	<1	4
Fecal coliforms [1/] (col. per 100 ml)	298	77	<1	1	306	66	<1	1	301	102	<1	1	305	135	<1	1
Fecal streptococci [1] (col. per 100 ml)	295	104	<1	1	304	70	<1	1	298	78	<1	1	301	140	<1	1

Table 2.--Summary of surface-water quantity and quality data collected at Bull Run stations, 1978 to 1983 water years--Continued

	Upper Cougar Creek				South Fork above Cedar Creek			
Constituent	N	max	min	median	N	max	min	median
Stream temperature [3] (°C)	18	14.6	5.4	10.5	11	14.8	8.8	10.8
Specific conductance [3] (umhos at 25°C)	17	22	14	16	10	25	21	23
pH (units) [3]	14	7.4	6.8	7.0	7	7.4	6.8	7.1
Periphyton chlorophyll-a [3] (mg/m²)	15	68	0.1	1.8	9	19	.22	3.6
Periphyton biomass-to-chlorophyll-a [3] ratio	14	3200	0	78	8	2540	128	204

[1] Periodic weekly value.

[2] Daily mean value.

[3] Periodic summer-month values.

Comparison between Lower Cougar and Upper Cougar Creek stations, 2nd-order streams with similar basin orientation on the North side of the reservoir, was of interest because of logging within the Lower Cougar drainage area during the sampling program.

The same types of benthic invertebrate habitats are available at all of the Bull Run stations sampled: a combination of riffles and pools, with stream bottoms of cobbles, large rocks, and bedrock.

In comparing Bull Run streams on the basis of biological and ecological characteristics, it should be noted that there are some differences that have not or cannot be measured and that there exists an innate variability associated with attempts to sample communities that are not static in time or location.

Table 3.--List of basin characteristics for Bull Run streams

Stream	Area (mi^2)	Length (mi)	Subbasin elevation (ft)		Orientation	Stream 1/ order
			Maximum	Minimum		
Fir Creek	5.8	8.8	4,200	1,400	W-NW	2
North Fork	8.4	13.8	4,000	1,000	S	3
Lower Cougar Creek	3.2	5.0	3,800	1,000	S	2
Upper Cougar Creek	--	--	3,800	1,700	S	2
South Fork	16.6	27.7	4,200	1,000	W	3
South Fork above Cedar Creek	4.6	8.4	3,500	1,400	W	2

1/ Based on a 1:125,000 scale U.S. Geological Survey map (see Glossary)

Table 4.--Dominant species and ecological characteristics of some abundant periphyton taxa collected in Bull Run streams, 1978-1983 water years

Dominant Periphyton Species

DIVISION
-Class (common name)
--Order
---Family
----Genus species

CHLOROPHYTA (green algae)
-Chlorophyceae
--Volvocales
---Chlamydomonadaceae
----*Chlamydomonas*-like
--Ulotrichales
---Ulotrichaceae
----*Ulothrix zonata*
----*Ulothrix* spp.
--Zygnematales
---Zygnemataceae
----*Spirogyra* spp.

Chrysophyta (yellow-brown algae)
-Bacillariophyceae (diatoms)
--Centrales (centric diatoms)
---Coscinodiscaceae
----*Melosira varians*
--Pennales (pennate diatoms)
---Fragillariaceae
----*Diatoma hiemale mesodon*
----*Fragillaria vaucheriae*
----*Hannea arcus*
----*Synedra rumpens*
---Achnanthaceae
----*Achnanthes lanceolata*
----*Achnanthes linearis*
----*Achnanthes minutissima*
----*Cocconeis placentula englypta*
---Gomphonemaceae
----*Gomphonema angustetum*
----*Gomphonema* spp.
---Cymbellaceae
----*Cymbella minuta*
---Nitzschiaceae
----*Nitzschia palaceae*

CYANOPHYTA (blue-green algae)
-Myxophyceae
--Chroococcaceae
---*Anacystis* spp.
---*Chroococcus* spp.

Ecological characteristics of abundant phycoperiphyton taxa
[Information from Patrick and Reimer, 1966; and Greeson, 1982; periphyton species identifications by James Sweet, Aquatic Analysts, Portland, Oregon]

Genus	pH (units)	Water temperature (°C)	Specific conductance (umhos/cm)	Alkalinity (mg/L)	Nitrate as N (mg/L)	Orthophosphorous as P (mg/L)
Diatoma	4.0-10.0	0.0-34.0	12-43,400	0-420	0.0-41.0	0.0-3.9
Gomphonema	4.3-10.0	0.0-36.0	12-37,400	0-491	.0-32.0	.0-3.9
Achnanthes	3.4- 9.7	0.0-33.5	10-37,400	0-480	.0-32.0	.0-3.5
Anacystis	3.7-10.0	0.0-36.0	10-48,000	0-500	.0-41.0	.0-3.9

Genus species	Distribution
Diatoma hiemale var. *mesodon*	Cool flowing water with fairly high nutrient content. Most common in winter.
Gomphonema angustatum	Usually in slow-moving water on hard substrates. More common in winter.
Achnanthes minutissima	Widely distributed. In fast-flowing oxygen-rich water high in calcium, at a wide range of temperature and pH.
Achnanthes lanceolata	A common species occurring under a wide range of ecological conditions, especially well-aerated water of neutral to alkaline pH. Characteristic of winter months. Does not occur in large numbers under conditions of heavy organic enrichment.
Achnanthes linearis	Apparently pH indifferent and halophobe, characteristic of winter months.
Anacystis	Can be found in high temperature water.
Hannaea arcus	Prefers cool flowing waters particularly in mountainous areas.

Seasonality of genera (Hynes, 1970)

Winter: *Achnanthes*, *Gomphonema*, *Navicula*, *Diatoma*, *Cocconeis*, *Synedra*
Spring: *Ulothrix*, *Navicula*, *Cocconeis*, *Synedra*, *Diatoma*
Summer: *Cymbella*, *Melosira*, blue-greens (*Oscillatoria*), greens (*Oedogonium*)
Fall: some spring genera

Table 5.--Summary of periphyton data collected in the Bull Run watershed, 1978-83

* Indicates that the standard deviation was equal to or greater than the sample mean; N indicates that one sample "outlyer" was eliminated before calculation of the mean; All indicates that all stations were included in the analysis; n indicates number of observations; NSD indicates no significant difference at P<.05; NF = North Fork, SF = South Fork, FC = Fir Creek, CC = South Fork above Cedar Creek, LC = Lower Cougar Creek, UC = Upper Cougar Creek.

Stream	Dominant species	Dominant species (percent of total population) median	Dominant species (percent of total population) mean	Total number (cells/mm²) median	Total number (cells/mm²) mean	Species diversity (Brillouin) median	Species diversity (Brillouin) mean	Species diversity (Brillouin) range	Species equitability median	Species equitability mean	Species equitability range	Algal class: Diatoms (percent) median	Algal class: Diatoms (percent) mean	Algal class: Greens (percent) median	Algal class: Greens (percent) mean	Algal class: Blue greens (percent) median	Algal class: Blue greens (percent) mean	Autotrophic index (percent greater than 100)
Fir Creek	*A. minutissima*	22	24	2800	3600	2.55	2.51	1.82-3.21	0.73	0.69	0.55-.85	100	93	0	6*	0	4*	73
	A. lanceolata	13	16															
	D. hiemale	14	18															
	G. angustatum	14	13															
North Fork	*A. lanceolata*	56	52	2600	5400*	1.70	1.75	.71-3.12	.53	.48	.19-.82	100	96	0	3*	0	1*	71
	H. arcus	4	11*															
Upper Cougar	*A. minutissima*	27	29	1100	1000	1.90	1.88	1.07-2.77	.64	.59	.31-.86	96	88	4	11*	0	.3*	40
	H. arcus	14	22															
	D. hiemale	21	23															
Lower Cougar	*A. minutissima*	51	48	1800	1900N	1.95	2.06	.74-2.90	.59	.50	.13-.77	94	88	6	13*	0	.2*	88
	S. rumpens	8	11															
	H. arcus	2	12*															
South Fork above Cedar Creek	*A. minutissima*	42	43	1200	2000	1.75	1.81	1.04-2.78	.51	.49	.42-.73	95	83	2	4*	0	13*	100
	G. angustatum	2	12*															
	Anacystis	0	12*															
South Fork	*C. placentula*	21	23	2100	2500N	2.55	2.49	1.46-3.47	.74	.66	.35-.83	100	98	0	2*	0	.2*	77
	A. lanceolata	15	15															
	A. linearis	8	11															
	A. minutissima	7	10															
	D. hiemale	.5	10*															

Table 5.--Summary of periphyton data collected in the Bull Run watershed, 1978-83--Continued

		Analysis of variance				
Stream station	Variables	F value	Probability greater than F	Scheffe's test		
All (n = 103)	Species diversity	4.95	0.0005	FC*NF	SF*NF	
	Species equitability	6.99	.0001	FC*NF	SF*NF	LC*NF
	Percentage blue-green algae	4.47	.0011			
	Percentage green algae	1.45	NSD			
	Percentage diatoms	1.37	NSD			
FC, CC, SF (n = 42)	Species diversity	5.74	.0066	FC*CC	SF*CC	
	Species equitability	9.95	.0003	FC*CC	SF*CC	
	Percentage blue-green algae	4.37	.0194			
	Percentage green algae	0.31	NSD			
	Percentage diatoms	1.71	NSD			
NF, LC, UC (n = 60)	Species diversity	1.20	NSD			
	Species equitability	1.95	NSD			
	Percentage blue-green algae	0.65	NSD			
	Percentage green algae	2.23	NSD			
	Percentage diatoms	1.50	NSD			

ANALYSIS OF BIOLOGICAL DATA

Periphyton (Phycoperiphyton)

Dominant Species and Ecological Characteristics

The Bull Run periphyton community is characterized by high percentages of diatoms. The numerically dominant species collected between June and October include *Achnanthes lanceolata*, *A. minutissima*, *Cocconeis placentula*, *Diatom hiemale* and *Hannaea arcus*; all are pennate diatoms in the Achnanthaceae and Fragillariaceae families (table 4 and 5). These are widely distributed, closely related species, with similar ecological requirements and wide tolerance ranges for physical-chemical constituents. Values for temperature, specific conductance, pH, alkalinity, nitrate, and phosphate in the Bull Run streams were well within published tolerance ranges for these genera (table 2 and 4). Therefore, these diatoms do not exhibit the criteria necessary for indicator species: narrow tolerance ranges for measurable water-quality constituents.

Median values for total periphyton density ranged from 1,100 cells/sq mm at Upper Cougar Creek to 2,800 cells/sq mm at Fir Creek (table 5). The greatest variability occurred at North Fork, with a mean periphyton density of 5,400 cells/mm^2 and a standard deviation of 6,400 cells/mm^2.

Numerically dominant species at each station are listed, in percent, in table 5. *Achnanthes minutissima* was numerically dominant in the second order streams (Fir Creek, Upper Cougar, Lower Cougar, South Fork above Cedar Creek), while *A. lanceolata* was dominant, or codominant in the 3rd-order streams (South Fork, North Fork), and at Fir Creek. *Cocconeis placentula* was dominant only at South Fork.

Species Diversity

Species diversity indices summarize information on the number of species, their relative abundances, and community structure. Mature, stable communities in heterogeneous habitats generally have higher diversity values than immature or unstable communities under fluctuating or unfavorable conditions. Values for relative evenness (equitability) are close to 1 when individuals are most uniformly distributed among species and close to 0 for the least even distribution (Zand, 1976; Appendix I). Factors potentially affecting diversity include season, habitat availability, predation, competition, climate, and productivity (Menge and Sutherland, 1976). Species diversity of periphyton communities in Bull Run streams was calculated using the Brillouin index and is summarized in table 5. Diversity values were determined to be predominantly normally distributed using univariate analysis (Glossary; Ray, 1982).

The highest median values for species diversity (2.55) and equitability (0.73, 0.74) occurred at Fir Creek and South Fork, where four to five species were codominant (each represented a mean of 10-24 percent of the community). These stations have similar orientation and are 2nd and 3rd order streams. North Fork and South Fork above Cedar Creek had lower median diversity values (1.70, 1.75) and equitability values (0.53, 0.51). At these stations, one species was numerically dominant (representing 42-51 percent of the community). The invertebrate genus *Baetis*, in the scraper and collector functional groups, was much more abundant in samples collected at Fir Creek and South Fork than at North Fork, where the "generalist" chironomid group was dominant. Heavy grazing by "scrapers" may reduce competition between diatom species and allow more types to coexist. The dominance of *A. lanceolata* at the North Fork site may result from a combination of water-quality factors, including higher mean suspended sediment, turbidity, and orthophosphate concentrations.

Analysis of variance (Appendix I) between the diversity values and between the equitability values showed a significant difference between the six periphyton stations at the .01 probability level ($P<.01$). Additional analyses using Scheffe's multi-comparison test showed South Fork and Fir Creek diversity values were significantly different from North Fork values and that South Fork, Fir Creek, and Lower Cougar Creek equitability values were significantly different from North Fork values (table 5). When sites were partitioned into north and south sides of the reservoir, a significant difference ($P<.01$) was found between the two groups, indicating that basin orientation may be one of the many factors influencing species distributions, although other water-quality, geologic and land-use factors may also affect these values. No significant difference was found among diversity or equitability values for the North-side stations (North Fork, Upper Cougar, and Lower Cougar Creek) using analysis of variance. However, there was a significant difference between Lower Cougar and Upper Cougar Creek and between North Fork and Upper Cougar Creek species diversity values at $P<.05$ using the t test for station pairs. Scheffe's test showed that South Fork above Cedar Creek was significantly different from the other south-side stations (South Fork and Fir Creek) for diversity and equitability values. This difference may result from higher numbers of blue-green algae; analysis of variance also showed a difference between these stations based on the percent of blue-green algae in the samples. Periphyton slides tended to sink to the bottom in the slow-moving water, so sampling conditions at South Fork above Cedar Creek may not be comparable to, or representative of sampling conditions at the other streams. Using the t test for station pairs, diversity values for Fir Creek and South Fork (located on the south side of the reservoirs, with west-facing slopes) were not significantly different.

Significant differences between stations located within the same subbasins (Upper versus Lower Cougar Creek, South Fork above Cedar Creek versus South Fork) indicate that stream order, along with logging activity in the Lower Cougar Creek subbasin, may be a factor influencing diversity values.

The paired basin approach used for defining baseline water-quality variability (see Rinella, 1985; and glossary) does not necessarily consider basin slope orientation or stream order and may not be the most suitable method for comparing biota in stream subbasins in the Bull Run watershed. Sampling methodologies for future work are included in the section entitled Applications of Biological Data.

Autotrophic Index

The autotrophic index, also called the biomass (ash-free dry weight) to chlorophyll-a ratio of the periphyton community, shows the relation between heterotrophic and autotrophic organisms. The ratio varies seasonally and locally with shifts in physical-chemical constituents and with loading of allochthanous (terrestrial) organic matter. Organic pollution or organic enrichment, clear-cutting, or high sediment load may also affect the ratio (Collins and Weber, 1978; Greeson and others, 1977). The index can be used to compare different streams or different reaches of a stream. In surface water with little degradable organic matter and with algae (autotrophs) the dominant group, the ratio is usually 50 to 100. As organic matter increases, so do the number of heterotrophs, usually more rapidly than the algal numbers increase, with a resulting ratio greater than 100. In deciduous forests and some coniferous forests studied by Vannote and others (1980), small headwater (1st to 3rd order) streams are generally heterotrophic (detrital-based); moderate sized streams (3rd to 4th -order streams or greater) are seasonally autotrophic.

Results of chlorophyll and biomass analyses show that Bull Run streams were predominantly heterotrophic, with 75 percent of the sample ratios greater than 100 and 20 percent greater than 500. The heterotrophic nature of these streams probably due to shading by vegetation and canyon walls and availability of allochthanous organic material in the predominantly headwater streams.

All of the biomass/chlorophyll-a ratios calculated for South Fork above Cedar Creek (located in a steep, shady canyon) were greater than 100 (table 2 and 5). This station also had the highest blue-green algal populations. Upper Cougar Creek was the only station with a median ratio of less than 100 (median value = 78). The autotrophic index may be useful in comparing effects of logging on reaches of a stream. Sixty percent of the index values for Upper Cougar Creek (not logged) were less than 100, while only 12 percent of the values for Lower Cougar Creek (logged during the study period) were less than 100 indicating that more heterotrophic organisms or organic material occurred at Lower Cougar Creek. Both Upper and Lower Cougar also had greater numbers of green algae than did the other stations.

Variability in the chlorophyll and biomass data collected in the Bull Run was high, with standard deviations greater than the mean values in many instances. Variability may increase with the length of time that slides are exposed in the stream, with differences in species' colonization rates, with sloughing off of populations during storm events, and with measurement of very small quantities of chlorophyll (Tilley and Haushild, 1975; Hynes, 1970; Horner and Welch, 1981).

Less than 5 mg/m^2 chlorophyll-a was measured in 64 percent of the Bull Run samples. Variability of chlorophyll-a on replicate slides was as high as variability due to seasonal differences in streams monitored by Tilley and Haushild (1975). A positive relation ($P<.05$) between days of exposure of periphyton substrate and total periphyton numbers was found for North Fork and Lower Couger Creek periphyton communities. Insect larvae and leaves, which may have reduced algal numbers and the surface area available for growth, were found on some periphyton slides. Accretion of sediment particles can also influence weight values.

Species Associations

Bull Run streams may be characterized biologically by using correlation and cluster analyses to study periphyton species' associations. Correlation analysis can show significant relations between different species and provide insight into how these relations might change in response to habitat changes, seasonal succession, or climatological change. One measure of the effect of man's impact in the future will be the resulting changes in these species association patterns. The cluster-analysis technique groups habitats (stations or seasons) based on similarities between species' occurrence and abundance. Changes in the cluster groupings among stations or seasons may be a measure of how man's activities have modified species' habitats.

The periphyton data set was reduced in size by including only those species that made up more than 10 percent of the population in any one sample. Data were standardized by representing original species counts as percentages of the total number in each sample. In this way the relative dominances of numerically abundant species could be compared. The distribution of standardized species' abundances was non-normal (determined by SAS univariate analyses; Ray, 1982).

Correlation analyses

Correlation analyses test the strength of a relation between two variables. The Kendall nonparametric correlation analysis (used for non-normalized populations) is based on the order (ranks) of pairs of observations; in this case, these pairs are the relative abundances of a species at different stations or dates. If all pairs are concordant (if each member of the pair varies in the same direction), Kendall's tau equals 1; if all pairs are discordant (vary in opposite directions) the value is -1. A probability of less than .10 ($P<.10$) indicates that there is a 90 percent chance that these variables are strongly related and not covarying by chance alone (Sokal and Rohlf, 1973; Appendix I).

Relative abundances of Bull Run periphyton species were analyzed by station, month, and year. Correlations ($P<.10$) between species, which occurred at least 50 percent of the time, indicated significant patterns of periphyton species associations in the Bull Run streams during the six year study (table 6).

The association of species pairs at individual stations (stream habitats) provides an index representing baseline data for Bull Run streams and incorporates the natural variation occurring over the study period. One measure of the effects of man's impact in the future will be the resulting changes in these species' association patterns. *Achnanthes* species were closely associated; at Fir Creek, South Fork Bull Run, and Lower Cougar Creek, *Achnanthes lanceolata* was associated with A. *linearis*, while *A. minutissima* was negatively associated with *Diatonia hiemale* at Fir Creek, Upper Cougar and Lower Cougar Creek. In the South Fork subbasin (including South Fork Bull Run and South Fork above Cedar Creek) *A. linearis* was associated with *Cocconeis placentula* and *D. hiemale* with *Hannaea arcus*. These species associations also occurred at Lower Cougar Creek and North Fork for *D. hiemale* and *H. arcus*.

Analysis of species correlations by month show background seasonal variability in species association patterns. Abundance of periphyton species are sensitive to yearly climatological changes, but the species' successional patterns repeat from year to year. Note that if a species is totally absent from the population, no correlation will occur with other species that are present. During July, August, and September, the warmer summer months, positive associations occurred between the dominant diatoms, including *Cocconeis placentula* with *Achnanthes linearis* and *A. lanceolata*, and *Diatoma hiemale* with *Hannaea arcus*. *C. placentula* was negatively associated with *Synedra rumpens*. Species not found to be associated during the warmest months (July and August) but which occurred together during the other months were *C. placentula* with *Nitzschia palaceae zonata* and *Gomphonema angustatum*. The green algae, *Chlamydomonas* and *Ulothrix* were positively correlated in July, September and October. Negative associations of *A. lanceolata* with *A. minutissima* and *S. rumpens* also occurred during several months.

Associations of species pairs by year indicate strong relations. Changes in these relations might indicate a basin-wide disturbance outside the range of yearly climatic variation established during the study period. Positive associations occurring in 80 to 100 percent of the years studied were *A. lanceolata* with *C. placentula*, and *Cymbella minuta* with *Fragillaria vaucheria*. Equally common negative associations occurred between *A. minutissima* with *A. lanceolata* and *C. placentula*. Less common associations, occurring 50 to 70 percent of the time, included *A. minutissima* with *Gomphonema* and *S. rubens*, *A. linearis* with *C. placentula* and *N. paleacea*, and *D. hiemale* with *H. arcus*. Equally common negative associations included *A. lanceolata* with *S. rubens*.

The greatest number of significant correlations between species by station occurred at Lower Cougar Creek, and the least number occurred at the Upper Cougar Creek and South Fork above Cedar Creek sites.

Table 6.--Kendall correlation coefficients between dominant periphyton species in Bull Run streams by station, by month, and by year

Significant correlations are reported at the P<.10 confidence level. Significant correlations to the P<.01 level are underlined. Lower case letters are negative correlations and upper case letters are positive correlations. Correlations are nonredundant. N indicates number of observations.

		STATIONS						MONTHS						YEARS					
Species	Species I.D.	Fir Creek	North Fork	Upper Cougar	Lower Cougar	South Fork above Cedar Creek	South Fork	JUN	JULY	AUG	SEPT	OCT	NOV	1978	1979	1980	1981	1982	1983
N		18	22	15	21	8	16	4	18	26	24	22	6	9	9	29	18	21	14
Achnanthes lanceolata	A.	Be	fjs	--	BcDJQR	DK	BDfjp	l	Dfj	cDehijlM	cDehjlnp	cDHp	l	cDjlnq	cD	cDHKlMn	cDepiMn	cDekl	cDel
Achnanthes linearis	B.	DegK			DJQR	EF	Cfij	p	DHj	Dfi	DK	DK	P	HI		Dfkjn	K	DK	DK
Achnanthes minutissima	C.	flo		fIJ	fjloq				fIl	dEK	dEHLN	cfkm	Hj	dLNQ	df	feHijkL	dEHILmP	kfH	d
Cocconeis placentula-englypta	D.	gil	i		JQR		fj	GIjK	Hl	el	Klp	iK	Kl	lnqr		Kn		K	Klp
Cymbella minuta	E.			GP	IqS		GK	Ij	G		GHIL	HIm			IJO	GHj	GIP	G	GS
Diatoma hiemale mesodon	F.	iL	JS		JL	JN	J		J	J	Jn			K	M	hj	J	J	H
Fragillaria vaucheria	G.		IS	PS	l			IjK	R		IS	HP				Hj		IR	I
Gomphonema spp.	H.		IP	L	N	L	IJ		I	L	ILNQ	GIP	j		LP	IjLN	I	N	I
Gomphonema angustatum	I.	S			q	r	J	jK	N						J	L		R	
Hannaea arcus	J.	l	KS		Q	L		k		L		Q	P	LQ				OL	
Nitzschia palaceae	K.	O														S		l	
Synedra rumpens	L.				PQ				QR	P	N			NQR		N	P	P	
Melosira varians	M.																		
Chlamydomonas-like species	N.				Q				Q		Q	PQR		PQR		M	S		
Spirogyra spp.	O.																	P	
Ulothrix spp.	P.			S							R	R				R			
Ulothrix zonata	Q.				R				R			R							
Anacystis spp.	R.																		
Chroococcus spp.	S.																		

The greatest number of significant correlations by year occurred in 1980, which was also when the greatest number of samples was collected. No apparent relation was found between number of periphyton species associations and amount of precipitation any year; 1979 and 1981 were drier years, whereas 1978 and 1983 were wetter years. However, a significant negative association between Achnanthes lanceolata and Synedra rumpens, which occurred in four out of six years, did not occur during the two dry years.

A greater number of significant positive correlations was found than could be expected by chance for all analyses by station (61), by month (73), or by year (84). The number of nonredundant significant correlations (at P<.10) between 19 species expected by chance alone would be 51 positive out of a possible 1,026 correlations. This number of positive correlations shows that species tend to be found together spatially (in similar habitats) and temperally because there are more positive associations than expected by chance. The number of significant negative correlations was less than expected by chance by station, month, and year (34, 48, and 48, respectively). Competition for space and nutrients by these species (negative associations) occurs less often than expected by chance. At North Fork, where one species, Achnanthes lanceolata is dominant, sedimentation on the substrate or other external factors may change the quality of the environment so that one species has a competitive advantage over the others.

A sampling program which monitors algal species upstream and downstream of man-caused activities (such as logging) over a period of time can document changing relations in periphyton assemblages as water quality changes. Large-scale changes in dominant species can indicate man-caused water-quality changes. Hansmann and Phinney (1973) found a close relationship between logging practices and algal communities in Oregon coastal streams. These populations included species common in the Bull Run watershed. Cocconeis placentula, Achnanthes minutissima, and Synedra rumpens (diatoms) were more abundant, while Achnanthes lanceolata was less abundant, or absent, several months after clear-cutting or patch-cutting than before logging. Chlamydomonas and Spirogyra (green algae) and Anabaena and Oscillatoria (blue-green algae) appeared for the first time in the watershed several months after clear-cutting occurred. The following conditions may prove useful for monitoring the impact of logging activity on Bull Run streams: presence of an abundance of green algae such as Ulothrix, Chlamydomonas, or Spirogyra; the abundance of C. placentula englypta; and the relative abundance of Achnanthes species, such as the disappearance of A. lanceolata from a population where it was previously abundant, because A. lanceolata is not abundant in large numbers under conditions of heavy organic enrichment (table 4).

Cluster analysis

Biological data sets are so large and uninterpreted species lists have so few applications that numerical analyses such as cluster analysis have been designed to reduce the complexity. Periphyton species for this study were grouped by station, by year, or by month. A resemblance measure (euclidean distances) was computed between all pairs of samples. Relative species abundances were used as the clustering criteria (Appendix I).

Cluster analysis groups stations, which represent stream habitats, based on similarities between species' occurrence and abundance. Changes in the station groupings, examined under unperturbed conditions, may be a measurement of management activities in specific subbasins. Table 7 shows the results of the cluster analysis of the Bull Run periphyton data by station. Clusters 1, 2, and 5 showed higher mean species diversity (2.31 to 2.41) than Clusters 3, 4, and 6 (1.54 to 1.94). With the exception of Clusters 1 and 2, each cluster was dominated by samples collected from one station, and these stations can be considered to form unique clusters: North Fork, South Fork, Lower Cougar Creek, and South Fork above Cedar Creek.

Cluster 5 had the highest mean species diversity (2.41) of all the clusters, with *Cocconeis placentula* as the dominant species (26 percent of the cluster) and *Achnanthes lanceolata*, *A. linearis* and *A. minutissima* as the co-dominant species (11 to 23 percent of the cluster). South Fork samples made up 75 percent of the observations in this cluster and, in addition, 75 percent of the South Fork samples were in this cluster.

The lowest mean species diversity (1.54) occurred in Cluster 3, and *Achnanthes lanceolata* was the dominant species (67 percent of the population). No other species made up more than 10 percent of this cluster. North Fork samples made up 94 percent of the observations in Cluster 3, and 70 percent of the North Fork periphyton samples collected were in this cluster. Dominants in Cluster 6, which accounted for only 2 percent of the total sample population (100 percent were South Fork above Cedar Creek samples), include *Anacystis* and *A. minutissima*, at 50 percent and 31 percent of the community, respectively.

The greatest number of observations (32 percent of the data set) were included in Cluster 2, which included samples from all the stations. A majority of the Upper Cougar Creek (53 percent) and Fir Creek (44 percent) samples were in this cluster. Codominant species included *Diatoma hiemale mesodon* (27 percent), *A. minutissima* and *Hannaea arcus*. *A. minutissima* was the dominant species in Cluster 4, representing 59 percent of the population, with observations from Lower Cougar Creek representing 65 percent of the samples in this cluster. Cluster 1 accounted for only 10 percent of the total sample population. Dominants included *A. minutissima* and *Gomphonema angustatum* at 25-30 percent of the population, with Fir Creek, Upper Cougar, and South Fork above Cedar Creek represented in the data set.

Table 7.--Summary of cluster analysis and species constancy in clusters of periphyton species collected in the Bull Run watershed, 1978-1983

[BDIV = Brillouin species diversity; E = equitability]

CLUSTER ANALYSIS

Cluster	Number of samples for each station: Fir Creek	North Fork	Upper Cougar	Lower Cougar	South Fork above Cedar Creek	South Fork	Species diversity: mean BDIV	mean E	Species abundance in clusters (mean percent): 5-9	10-24	25-49	50-100
1	6	0	2	0	2	0	2.35	0.69	Cymbella minuta Diatoma hiemale mesodon	A. lanceolata	Cocconeis placentula -englypta G. angustatum	
2	8	6	9	5	1	4	2.31	.61	Achnanthes lanceolata Synedra rumpens	A. minutissima Hannaea arcus	D. hiemale mesodon	
3	0	16	1	0	0	0	1.54	.45	Achnanthes minutissima			A. lanceolata
4	1	0	5	17	3	0	1.94	.48	Gomphonema angustatum			A. minutissima
5	3	1	0	0	0	12	2.41	.66		A. lanceolata A. linearis A. minutissima	C. placentula -englypta	
6	0	0	0	0	2	0	1.75	.45	Fragillaria vaucheria		A. minutissima	Anacystis

SPECIES CONSTANCY

Cluster	High constancy (greater than 50 percent)	Moderate constancy (25-50 percent)	Low constancy (10-24 percent)	Very low constancy (number of species less than 10 percent)
1	Cymbella minuta Gomphonema angustatum		A.lanceolata A.minutissima D.hiemale mesodon F.vaucheria Gomphonema sp. S.rumpens Chroococcus	10
2	Diatoma hiemale mesodon Hannaea arcus Ulothrix zonata Chroococcus	Synedra rumpens Ulothrix sp.	F.vaucheria C.minuta Gomphonema sp. G.angustatum N.palaceae Spirogyra sp.	7
3	Achnanthes lanceolata Melosira varians		C.placentula englypta D.hiemale mesodon H.arcus Ulothrix sp.	13
4	Chlamydomonas-like sp. Spirogyra sp.	Achnanthes minutissima Synedra rumpens Ulothrix sp.	C.minuta F.vaucheria Gomphonema sp. G.angustatum U.zonata H.arcus	8
5	Achnanathes linearis Cocconeis placentula englypta Nitzschia paleaceae		A.lanceolata A.minutissima C.minuta D.hiemale mesodon Gomphonema sp. S.rumpens	10
6	Anacystis sp.	Fragillaria vaucheria	A.minutissima Gomphonema sp. Ulothrix sp.	14

Cluster analysis of periphyton species abundance by year and by month (not shown) yielded no significant patterns, indicating that clusters formed by station are more unique than clusters formed by month or year. Thus in Bull Run streams temporal differences were not as important as spatial (stream habitat) differences in determining abundance and distribution of the major periphyton species, between June and October over the study period.

Species constancy analysis provides information on the role of rare species in cluster formation. Species not dominant in cluster analysis may be dominant in species constancy analysis due to their high constancy to one cluster. Species widespread in the basin show low or moderate constancy to any one cluster, while species with narrow distributions show high constancy to one cluster. Species constancy is represented by the ratio of the abundance of each species in each cluster to the total number of that species in all clusters (x 100). The index equals 100 when all members of a species in the population occur in a cluster and equals 0 when none occur. The index may indicate the degree to which species select or are limited to certain stream habitats (sites) and may indicate if species have wide or narrow distribution patterns. Changes in major species distributions may be a measure of man's activities in specific Bull Run subbasins. This analysis is modified from Boesch, 1977. Results are presented in table 7.

Clusters 1 and 2 contained species with high constancy to these clusters: *Cymbella minuta*, *Gomphonema angustatum*, *D. hiemale*, *H. arcus*, *Ulothrix zonata*, and *Chroococcus*, and also showed low constancy to other clusters. All stations were represented, and these species are generally widespread in the watershed. *Melosira varians* had 100 percent of its population contained within Cluster 3, showing a narrow distribution range; *Achnanthes lanceolata* also showed high constancy to this cluster, with 99 percent of its population represented. Cluster 3 contained a majority of North Fork samples and low species diversity.

Chlamydomonas and *Spirogyra* were unique to Cluster 4, which included Lower Cougar Creek (77 percent of its samples), Upper Cougar Creek (29 percent), and South Fork above Cedar Creek (37.5 percent of its samples). These green algae had quite low populations and probably specific habitat preferences. *Cocconeis placentula englypta* (73 percent) and *Achnanthes linearis* (74 percent) were unique species to Cluster 5, which contained predominantly South Fork periphyton samples. *Anacystis* had high constancy (99 percent) to Cluster 6, but did not show up in the constancy analysis of the other clusters, which indicates that these blue-green algae were probably isolated populations resulting from sampling conditions at this station and were not generally wide-spread in the streams sampled in the Bull Run watershed.

Percent Similarity

Two additional sites were selected and sampled at each station for one month during the summer of 1983 in order to verify that the periphyton populations collected at the main station over the study period were representative of periphyton populations within the stream reach. The two sites were located near the main site and had similar streamflow and solar radiation conditions. Two periphyton substrates were collected from each of the three periphyton floats to determine similarity between communities growing at the same site and on the same float (designated intrasite similarity) and similarity between communities growing at different sites (floats) but at the same station (designated intersite similarity). In addition, two substrates were collected each month from each station in order to monitor seasonal intrasite variability. Similarity between periphyton communities present at different stations was also determined using the similarity index.

A simple percent similarity index can document spatial and temporal homogeneity between stations and among sites at each station (Appendix I). The index value is 100 when all species are common and the distribution of individuals is the same on a percentage basis and is 0 when no species are in common. Results of the analysis are presented in table 8.

Results of percent similarity analyses between periphyton substrates collected at the same site (intrasite similarity) showed the similarity of these periphyton communities to be within the range of, or greater than, the similarity values for intersite communities at the same station (table 8). Mean intrasite values were 17-18 percent greater than intersite values at Fir Creek and South Fork and were 4 percent less at North Fork.

Similarity between stations was calculated using mean values of the percent species abundances at site A (if two slides were present). Percent similarity values between stations (interstation similarity) were generally lower than intra- or intersite similarity values for each station pair. Mean interstation values were from 30-91 percent different (the median value was 47 percent) from intrasite values, except for one low value of 16 percent between North Fork and Fir Creek in October.

Additional monthly samples are needed to determine whether percent similarity between stations and sites varies seasonally. Mean percent similarity values for the available data by month were: August, 52 percent; September, 65 percent; and October, 67 percent.

The data indicate that greater differences exist between stations, and between sampling dates at each station, than between sites at any one station, and that the main site is probably representative of the stream reach near the station. They also quantify the variability which can occur using this periphyton sampling method (using plexiglass slides attached to floats as substrates for periphyton growth).

Table 8.--Percent similarity of periphyton data collected from Bull Run stations in 1983

P = percent similarity, N = number of species in common, C = percent difference between mean intrasite and intersite percent similarity values for comparable sampling dates, D = percent difference between interstation similarity and mean intrasite similarity for stations with comparable sampling dates.

Similarity between sites

		Intrasite similarity					Intersite similarity			
Stream	Date (1983)	Site	P (pct)	N	Mean P (pct)	C (pct)	Sites	range (pct)	mean (pct)	N
Fir Creek	9-28	[A]	38	10			[A*B]	27-44	37	8-11
	9-28	[B]	76	10	60	17	[A*C]	41-53	44	9-12
	9-28	[C]	65	11			[B*C]	65-76	70	10-11
	10-26	[A]	71	11						
North Fork	8-11	[A]	45	9			[A*B]	32-73	50	9-10
	8-11	[B]	66	10	52	4	[A*C]	41-69	55	9-13
	8-11	[C]	44	11			[B*C]	48-68	58	10-11
	9-29	[A]	84	3						
	10-27	[A]	57	9						
Upper Cougar	9-29	[A]	50	8						
Lower Cougar	9-29	[A]	52	4						
	10-27	[A]	70	5						
South Fork	9-28	[A]	79	8						
	10-26	[A]	83	10	71	18	[A*B]	55-61	58	10-12
	10-26	[B]	59	10						

Similarity between stations

		Station											
		North Fork			Upper Cougar			Lower Cougar			South Fork		
Stream	Date (1983)	P (pct)	N	D (pct)	P (pct)	N	D (pct)	P (pct)	N	D (pct)	P (pct)	N	D (pct)
Fir Creek	9-28	50	3	30	36	8	34	19	6	66	40	7	43
	10-26	54	11	16		-			23	7	67		40
	10	44											
North Fork	8-11				26	6	-	38	8	-	33	10	-
	9-29				6	1	91	10	1	85	30	5	63
	10-27					-		15	6	76	33	8	48
Upper Cougar	8-11							58	6	-	60	7	-
	9-29							45	7	30	34	5	47
Lower Cougar	8-11										39	7	-
	9-29										23	4	65
	10-27										37	6	47

Similarity between seasons
(percent)

August P = 52 September P = 65 October P = 67

Benthic Invertebrates

Ecological Characteristics of Dominant Taxa and Functional Groups

The kinds of benthic invertebrates and functional (trophic) groups represented in a section of stream may reflect organic input and water quality conditions upstream. Environmental perturbation usually brings about a change in kinds of species and elimination of a few types; specialists may disappear and the more tolerant generalists may increase in abundance (Patrick, 1970).

A summary of the more abundant (at least 5 percent of the sample population) benthic invertebrate taxa and of the functional groups in the Bull Run is presented in table 9. Chironomids (midges), Hydracarina (water mites), and *Baetis* (mayfly larvae) were the numerically dominant taxa in the watershed. The ecological characteristics of the dominant benthic invertebrates are summarized in table 10.

Total numbers of benthic invertebrates collected in the Bull Run ranged from a median of 270 at Fir Creek to 770 organisms per square foot at North Fork (table 11). Variability in the benthic invertebrate data is due to sampling methods, the patchy distribution of organisms, and seasonal emergence of adults. Large numbers of samples often are required to detect statistically significant differences, which may or may not be ecologically significant (American Public Health Association and others, 1976). Benthic invertebrate samples collected for this study can provide baseline data for low-flow conditions, but are not extensive enough to define communities with respect to seasonal and high-flow events, or with regard to ongoing management activities. A 2-year sampling program to assess seasonal benthic invertebrate communities was initiated in the 1984 water year at the four major stations used in the current study; the data will be summarized in a later report.

Benthic invertebrate collections were assigned to functional groups (table 9) based on their morphological-behavioral adaptations for food processing (Cummins, 1973 and 1974; Meritt and Cummins, 1978). Shredders feed on coarse particulate organic material such as leaf litter with its associated microbes. Collectors gather or filter fine particulate organic material and microbes. Scrapers shear attached algae and organic matter from surfaces. Predators prey on other invertebrates. Generalists do any or all of the above. Chironomidae collected in the Bull Run were not identified to species and, because they probably included all functional groups, they were designated generalists.

Table 9.--Dominant taxa, and functional groups for Bull Run benthic invertebrates

[* indicates the taxonomic level used to determine functional group affinity. "GENERALISTS", not listed, include Chironimidae and Oligochata]

Dominant taxa

DIVISION
-Class
--Order
---Family (common name)
----Genus species

ANNELIDA
-Oligochaeta (worms)

ARTHROPODA

-Crustacea
--Ostracoda
--Copepoda
-Insecta
--Diptera
---Chironomidae (midges)
---Simulidae (blackflies)
---Tipulidae (craneflies)
----_Dicranota_
----_Antocha_
--Hymenoptera
---Sciaridae
--Tricoptera (caddis flies)
---Leptoceridae
----_Oecetis_
---Limnophilidae
----_Ecclisomyia_
--Plecoptera (stone flies)
---Perlidae
----_Acroneuria_

---Chloroperlidae
----_Hastoperla_
--Coleoptera (beetles)
---Elmidae [larvae]
---Dyticidae [larvae]
----_Oreodytes_ [larvae]
--Ephemeroptera (mayflies)
---Ephemerellidae
----_Ephemerella drunella_
---Baetidae
----_Baetis_
---Heptageniidae
----_Cinygmula_
---Leptophlebiidae
----_Paraleptophlebia_
-Arachnida (spiders)
--Hydracarina (mites)

Functional groups

SHREDDERS

HERBIVORES
-Insecta
--Tricoptera
---Leptoceridae
----_Oecetis_ *
---Brachycentridae
----_Micrasema_ *
--Ephemeoptera
---Ephemerellidae
----_Ephemerella_ *

DETRITIVORES
-Insecta
--Diptera
---Tipulidae
----_Antocha_ *
--Tricoptera
---Limnephilidae *
--Plecoptera
---Peltoperlidae *
---Nemouridae *

SCRAPERS

MINERAL
-Insecta
--Tricoptera
---Glossosomatidae
----_Glossosoma_ *
---Hydroptilidae *
--Plecoptera
---Chloroperlidae
----_Hastaperla_ *
--Coleoptera
---Elmidae *
--Ephemeroptera
---Baetidae *
---Heptageniidae
----_Epeorus iron_ *
----_Cinygma_ *
----_Cinygmula_ *
----_Rhithrogena_ *

ORGANIC
-Crustacea --Copepoda
---Harpactacoida *
-Insecta --Tricoptera
---Leptoceridae *
---Brachycentridae *
--Ephemeroptera
---Leptophlebiidae
----_Paraleptophlebia_ *

COLLECTORS

FILTER/SUSPENSION
ARTHROPODA
-Crustacea
--Ostracoda *
--Copopoda *
---Calanoida *
-Insecta
--Collembola *
--Diptera
---Dixidae *
---Simulidae *
---Culicidae *
----_Culiceta_ *
--Tricoptera
---Hydropsychidae
----_Hydropsyche_ *
----_Cheumatopsyche_ *

SEDIMENT/DEPOSIT
ANNELIDA
-Oligochaeta
ARTHROPODA
--Amphipoda
---Gammaridae *
-Insecta
--Diptera
---Ceratopogonidae *
---Ptycopteridae *
---Psychodidae
----_Psychoda_ *
--Coleoptera
---Heteroceridae *
--Ephemeroptera
---Ephemeridae *
---Leptophlebiidae *

PREDATORS

SWALLOWERS
PLATYHELMINTHES *
ARTHROPODA
-Crustacea --Copepoda
---Cyclopoda *
-Insecta
--Diptera
---Ceratopogonidae *
---Sciomyzidae *
---Empididae *
---Dolichopodidae *
---Tipulidae
----_Pedicia_ *
----_Hexatoma_ *
----_Dicranota_ *

--Tricoptera
---Hydropsychidae *
---Ryacophilidae
----_Rhyacophila_ *
--Plecoptera
---Perlodidae
----_Isoperla_ *
---Chloroperlidae
----_Hastaperla_ *
---Perlidae
----_Acroneuria_ *
----_Calineura_ *
--Coleoptera
---Staphylinidae *
---Hydraenidae *

PIERCERS
ARTHROPODA
-Arachnida
--Hydracarina *
-Insecta
--Diptera
---Sciarinae *
---Chaoboridae *
---Athericidae *
(Rhagionidae)*
--Coleoptera
---Dytiscidae
----_Oreodytes_ *
--Hymenoptera *

COLLECTORS

FILTER/SUSPENSION
--Tricoptera
----_Arctopsyche_ *
---Lepidostomatidae *
---Psychomyiidae *
---Hydroptilidae
----_Ochotrichia_ *
---Philopotamidae *
---Limnephilidae
----_Ecclisomyia_ *
----_Neothremma_ *
----_Apatania_ *
---Phryganeidae *
---Calamoceritidae *
---Polycentropodidae *
---Brachycentridae *
----_Brachycentrus_ *
--Plecoptera
---Chloroperlidae *
--Ephemeroptera
---Siphlonuridae *
---Ephmerellidae
----_Ephemerella_ *

SEDIMENT/DEPOSIT
--Ephemeroptera
---Baetidae *
---Heptageniidae
----_Stenonema_ *
----_Epeorus iron_ *
----_Cinygma_ *
----_Cinygmula_ *
----_Rhithrogena_ *
---Ephemerellidae
----_Ephemerella_ *

Table 10.--Summary of ecological characteristics of the major benthic invertebrates collected in Bull Run streams, 1978-81

[Modified from Pennak (1978) and Merritt and Cummins (1978)]

Benthic invertebrate	Characteristic
Ephemeroptera (mayfly nymphs)	Found in a wide variety of standing and running water habitats; however the greatest diversity can be found in rocky-bottomed 2nd- and 3rd-order streams, and mayfly nymphs occur where there is an abundance of oxygen. The length of nymphal life for most mayflies is 3-6 months; some baetidae may produce several broods per year. Long emergence periods are characteristic of mayfly families in the Pacific Coastal area.
Plecoptera (stonefly nymphs)	Primarily associated with clean and cool running waters. Seasonal succession of emerging species occurs throughout most of the year except in regions with a dry or freezing season.
Tricoptera (caddisfly larvae)	Occur in most types of freshwater habitats. Most species eat plant material, such as diatoms attached to rocks or decaying plant tissue. They generally show little selectivity of food, but are highly specialized in the manner and location in which the food is obtained.
Coleoptera (adult or larval beetles)	Inhabit a broad spectrum of aquatic habitats. Most are substrate-dwellers (except Hydrophilidae and Dytisidae). Feeding habits are variable between species.
Diptera (fly larvae)	Occur in almost every type of habitat and feed on a wide range of plant, animal and detrital food. Members of the family Tipulidae (cranefly larvae) are widespread, and members of the family Chironomidae (midge larvae) are abundant in most aquatic habitats. The number of species present may be very large and usually accounts for at least 50 percent of the combined macroinvertebrate species composition. Benthic invertebrate communities typically contain chironomid species groups, representing all the major trophic functional catagories.
Hydracarina (water mites)	Generally substrate dwellers of both lakes and streams.

Table 11.--Summary of benthic invertebrate data collected in the Bull Run watershed, 1977-81 water years

[* indicates that the standard deviation was equal to or greater than the sample mean; N = number of samples; NSD = no significant difference at P<.05; NSDN = NSD with unequal cell sizes; NF = North Fork, SF = South Fork, FC = Fir Creek, LC = Fir Creek, LC = Lower Cougar Creek; All = all four stations]

Stream	Taxon: Dominant taxon	Taxon: Population (pct/ft^2)		Functional groups: Dominant functional group	Functional groups: Population (pct/ft^2)		Total population organisms/ft^2		Brillouin species diversity			Species equitability		
		median	mean		median	mean	median	mean	median	mean	range	median	mean	range
Fir Creek	Chironomidae	48	46	Generalist.	51	49	270	497	2.54	2.22	1.16-3.07	0.52	0.50	0.38-.60
	Baetis sp.	14	21	Mineral/scraper sediment/deposit collector.	21	26								
North Fork	Chironomidae	82	76	Generalist.	80	76	770	931	1.45	1.58	.70-2.79	.30	.32	.12-.56
Lower Cougar Creek	Chironomidae	38	37	Generalist.	47	44	460	601	2.30	2.55	1.73-3.41	.59	.54	.36-.67
	Baetis sp.	16	18	Mineral/scraper sediment/deposit collector.	21	20								
	hydracarina	12	13	Piercer-predator.	12	15								
South Fork	Chironomidae	35	35	Generalist.	36	37	670	970	2.55	2.54	1.71-3.43	.52	.53	.46-.64
	Baetis sp.	22	23	Mineral/scraper sediment/deposit collector.	30	32								
	hydracarina	12	16	Piercer-predator.	12	16								

Stations	Variable	Analysis of variance: F value	Analysis of variance: Probability greater than F	Analysis of variance: Scheffe's test		
All (N = 51)	Diversity	7.80	0.0003	LC*NF	SF*NF	
	Equitability	13.90	.0001	LC*NF	SF*NF	FC*NF
	Percent chironomids	16.78	.0001			
NF, LC (N = 21)	Diversity	11.74	.0028			
	Equitability	14.71	.0011			
	Percent chironomids	24.95	.0001			
FC, LC, SF (N = 39)	Diversity	1.60	NSD			
	Equitability	.95	NSD			
	Percent chironomids	2.11	NSD			
FC, SF (N = 30)	Diversity	2.97	NSD			
	Equitability	1.91	NSD			
	Percent chironomids	4.31	NSD			

Vannote and others (1980) hypothesized in studies of eastern (United States) hardwood forests that shredders and collectors are codominant in headwater streams, scrapers and collectors in midsized (seasonally autotrophic) streams, and collectors in large-sized streams. The predator component changes little with stream order. Therefore, in the predominantly headwater streams sampled in the Bull Run, the shredders and collectors would be expected to be codominant. Generalists were the dominant functional group and were most abundant at North Fork where chironomids were maximally abundant (table 11). Scrapers and collectors were second in abundance, followed by piercer-predators. Fewer shredders were present than expected from the stream continuum theory (Vannote and others, 1980), although some chironmid larvae may be shredders. Sampling also occurred mid-summer when the shredder's diet of coarse particulate (terrestrial) organic material may have already been processed. Fewer deciduous trees (and associated leaf-litter) and more conifers are present in Northwest forests (compared to eastern hardwood forests) and therefore less large organic particulate material may be available for shredders to process.

Diversity

Diversity values for benthic invertebrates in Bull Run streams represent the typical yearly summer low-flow stream communities at these stations. Diversity (Appendix I) was first calculated by site for each Bull Run station and calculated again for a composite sample which included all sites at that station. Benthic invertebrates were most diverse at South Fork and Fir Creek (2.55, 2.54) and least diverse at North Fork (1.45), based on median values of all analyses. Diversity analysis of noncomposited sites resulted in mean diversity values shown in table 11. When sites were composited prior to analysis, resulting mean diversity values for each station were 2.53, 1.53, 2.89, and 2.99 for Fir Creek, North Fork, Lower Cougar and South Fork stations, respectively. Kaesler and others (1978) indicate that diversities of small replicated samples give a better indication of environmental conditions between stations than do single large samples and that they are more representative of the spatial heterogeneity of the stream bed and the patchy distributions of the invertebrate colonists. In Bull Run streams the resulting mean diversity was lower when diversity was calculated for individual sites, except at North Fork. Wilhm (1970) reported the range in diversity values of benthic invertebrates to be between 3 and 4 in clean streams and from 0.4 to 1.5 in polluted water. Lower diversity values at North Fork may simply be a result of not identifying chironomids to genus or species. Changes in diversity values resulting from perturbation may show up as higher or lower diversities, depending on where along the successional-continuum these communities fall and on the type of perturbation. Clear-cutting and slash-burning near streams may cause large nutrient inputs, a more open canopy, and a more productive system. Scour near large logging debris during high flow might drastically alter community habitat. Communities may or may not return to pre-management conditions.

Analysis of variance (Appendix I) of noncomposited benthic invertebrate diversity values showed a significant difference between mean diversity and mean equitability values at the four stations. Additional analyses using Scheffe's multi-comparison test showed a significant difference between North Fork versus South Fork and North Fork versus Lower Cougar Creek for benthic invertebrate diversity, and between North Fork versus South Fork, Lower Cougar Creek and Fir Creek for equitability (table 11). A significant difference ($P<.01$, F test) was also found when stations were partitioned into two groups representing the north side and south side of the reservoir (not shown), indicating that basin orientation may be one of many factors influencing species distributions. No significant difference was found between mean diversity or equitability values for South Fork and Fir Creek benthic communities or between Cougar Creek versus Fir Creek or South Fork benthic communities. Diversity and equitability values at North Fork were low compared to those of the other stations, which may be due to the higher annual sediment yields and instantaneous turbidity at that station (Rinella, 1985) or may be due to chironomid abundance.

Associations Between Taxa and Between Functional Groups

Correlation analyses can show significant relations between major benthic invertebrates or their functional groups. Cluster analysis groups stations (habitats) based on similarities between occurrence and abundance of invertebrates. Changes in these cluster groupings may be a measure of how environmental perturbation modifies benthic invertebrate habitat.

The benthic invertebrate data set was reduced in size for cluster and correlation analyses by including only those taxa greater than 5 percent of the population, for a total of 21 taxa in any one sample. All functional group data were used in the analyses. Original taxa and functional group counts were converted to percentages of the total number in each sample.

Correlation analysis of benthic invertebrate taxa

Correlation analysis of benthic invertebrate data collected from different streams in a watershed can be used to help characterize how these streams fit into the stream continuum theory, where diversity and uniform processing rates result from resource partitioning through habitat partitioning (utilization of different areas of a stream) and temporal partitioning (species replacement through the year). Species also coexist due to different foraging strategies in seasonally fluctuating conditions (Vannote and others, 1980; Townsend and Hildrew, 1979). Because Bull Run benthic invertebrate samples were collected only once a year in the late summer low-flow period, temporal partitioning will not be examined in this report. Correlation analyses between dominant benthic invertebrate taxons from Fir Creek, North Fork, South Fork, and Lower Cougar Creek are presented in table 12. The Kendall nonparametric correlation test (Appendix I) was used because the distribution of standardized species and functional group abundance was non-normal, as determined by univariate analysis.

Table 12.--Correlations of benthic invertebrate taxons collected in the Bull Run watershed, 1978-1981 water years, using Kendall correlation analysis

[Upper case letters represent positive correlations and lower case letters represent negative correlations. Significant correlations are reported at the P<.10 confidence level. FC = Fir Creek, NF = North Fork, LC = Lower Cougar Creek, SF = South Fork stations; N = number of observations; n = number of taxa]

		Station				Water Year				
Organism	Code ID	FC N=14	NF N=12	LC N=9	SF N=16	1977 N=3	1978 N=10	1979 N=11	1980 N=13	1981 N=15
Oligochaeta	A	FhJQ	F	bFLQ	dFR	CE	m	bG		P
Chironomidae	B	dghNOR	eikP	lOqR	dghK	ot	eghu	lN	ehi	dgPu
Microsema	C	fg			E	E				N
Dicranota	D	GH	GMOS		fM				MO	H
Simulidae	E		HIK		gSu		BH	HU	bK	
Ostracoda	F	hjmS	gp	L	JR		J	h		R
Hydracarina	G	nr	fO	hiJ	kMU		bHU			p
Baetis	H	j	IKp	r	u	J	EGU			pr
Acroneuria	I		K	j						
Paraleptophlebia	J	RST		Q			FT	Qu	U	O
Antocha	K								UE	
Oecetis	L			Q				b		
Ephemerella (Drunella)	M		O				O		ODS	
Ecclisomyia	N	R	PR					B	OR	
Sciaridae	O		R			T	T		RS	J
Cinygmula	P	RT	S	T						
Copepoda	Q									
Oreodytes	R							U		
Rhithrogena	S	T								
Hastoperla	T									
Elmidae	U									

	Correlations of 21 benthic invertebrate taxa				
	Total nonredundant correlations[1/]	Correlations expected by chance at P<.10 (.10T)		Resulting correlations in the Bull Run	
Correlations	(T)	Positive	Negative	Positive	Negative
By station (C = 4 stations)	840	42	42	53	34
By year (C = 5 years)	1,050	52	52	43	24

[1/] $T=[1/2(n^2-n)]*C$

Results of the analysis of benthic invertebrate associations at two or more stations show that significant positive correlations ($P<.10$) occurred between invertebrates from different families and with different foraging strategies (table 12, 13). Oligochates were positively correlated with ostracods and copepods. Although they are all collectors, oligochates are deposit feeders, whereas ostracods and copepods are filter feeders. Chironomids, generalists, were correlated with Sciaridae and *Oreodytes* (beetles), both piercer predators. *Dicronota* (craneflies) are found together with Hydracarina (water mites). Although they are both predators, the cranefly larvae swallow their prey whole, whereas the mites pierce their prey. *Dicranota* were also correlated with *Ephemeralla* (mayflies), which are herbivore collectors. A mayfly (*Cinygmula*), a collector/scraper, was positively correlated with a stonefly (*Hastoperla*), which is a predator/scraper. A caddisfly (*Ecclisomyia*), a collector, was positively correlated with a predacious beetle (*Oreodytes*). Significant negative correlations included Chironomidae versus the mayfly (*Baetis*) and the mite (Hydracarina), and *Dicranota*, indicating that these taxa are scarce where chironomids are common. Correlations of benthic invertebrate taxa by station resulted in a greater number of positive correlations (53) and fewer negative correlations (34) than expected by chance, indicating a greater number of organisms with similar habitat preferences than expected by chance (table 11).

The correlation of benthic invertebrates by year resulted in few significant correlations occurring at least two times, and the number of significant positive (43) or negative (24) correlations was less than expected by chance. This small number of correlations may be due to the difficulty of replicating sampling conditions each year, especially seasonal emergence patterns. Chironomidae were negatively correlated with Hydracarina and *Baetis*, as in correlations by station, and with Elmidae and Simulidae. Simulidae were positively correlated with *Baetis*, while Sciaridae (adult flies) were positively correlated with *Ephemerella* and *Hastoperla*.

Correlation analysis of functional groups

Correlation of functional groups by station resulted in the majority of significant positive associations between members of different functional groups; organisms with different foraging strategies, such as sediment/deposit collectors and mineral scrapers, shared the same habitat (table 12). Most negative correlations occurred between the generalists and the other functional groups, such as the collectors, scrapers and predators, probably due to competition. Similar relations occurred when correlating by year but also included positive associations of detritivore shredders with piercer predators and negative associations between generalists and mineral scrapers.

Table 13.--Kendall correlation analysis of the benthic invertebrate functional groups in the Bull Run Watershed, 1977 to 1981

Significant correlations are reported to P<.10 significance level. Upper case letter indicates significant positive, and lower case letter indicates significant negative correlation. FC = Fir Creek, NF = North Fork, LC= Lower Cougar Creek, SF = South Fork; N indicates number of observations.

		Station				Water year			
Functional group	ID code	FC N=14	NF N=12	LC N=9	SF N=16	1978 N=10	1979 N=11	1980 N=13	1981 N=15
herbivore shredder	A		CG				G	d	CD
detritivore shredder	B		CGHi				Hi	C	H
filter suspension shredder	C	h	F				e	FGi	D
sediment deposit collector	D	Ei	Ei	Ehi	E	E	Ei	GHi	Ei
mineral scrapers	E	fGi		h		Hi		i	i
organic scrapers	F		GH					i	
swallower predators	G		H						
piercer predators	H		i		i	i	i		
generalists	I								
shredders	AB		GH i				GH i		
collectors	CD	i	i	EF gh i		EF i		GH i	EF i
scrapers	EF.	i		gh		GH i		i	i
predators	GH.		i		i	i	i	i	
generalists	I.								

	Correlations of nine benthic invertebrate functional groups				
		Correlations expected by chance at P<.10		Resulting correlations in the Bull Run	
Correlations	Total nonredundant correlations at P<.10	Positive	Negative	Positive	Negative
By station (4)	144	7	7	15	10
By year (4)	144	7	7	15	16

Correlation of the nine benthic invertebrate functional groups by station resulted in a greater number of significant positive (15) and negative (10) correlations than expected by chance, while correlation by year resulted in more significant positive (15) and negative (16) correlations than expected by chance. The number of correlations shows that different functional groups probably share the same habitat by utilizing resources in different ways.

The greatest percentage of chironomids and generalists occurred at North Fork, which has historically been affected by weakened slopes and a slide area upstream of the sampling station (table 11). Highly erodable banks of fine clay material (from the Rhododendron geologic formation) periodically slide into the water during the rainy season and cause elevated turbidities and sediment concentrations. Rinella (1985) found that annual sediment yields at North Fork were three times the yields for South Fork and Fir Creek; instantaneous turbidity and total solids concentrations were higher at North Fork compared to the the other sites. Stauffer and others (1976), in a field study in the Roanoke River, Virginia, found that a gradual silting of artificial substrates with time was accompanied by an increase in numbers of dipterans and a decrease in numbers of tricopterans (caddis flies), plecopterans (stoneflies), and coleopterans (beetles). Slack and others (1982) related stream benthos abundance and diversity on artificial substrates to the amount of organic detritus in a Salmon River, Idaho study. Rabeni and Minshall (1977) found, in field experiments with artificial substrates in Idaho streams, that a light coating of silt reduced some species' populations, but that the substrate-detritus interaction was also a major influence on insect microdistribution. Higher mean annual sediment loads in the North Fork, compared to Fir Creek and South Fork, may be partly responsible for greater chironomid abundance at that site.

Cluster analysis of benthic invertebrate taxa

Results of benthic invertebrate cluster analysis by station and by year are presented in table 14. Cluster 1 (with 14 percent of the observations) included samples collected from Lower Cougar Creek and South Fork and had the highest mean diversity and equitability (3.23 and 0.65, respectively) of all the clusters. Oligochaeta, Ostracoda, Chironomidae, Hydracarina, and *Baetis* accounted for 5 to 24 percent of the cluster. Cluster 5 included the majority of the North Fork samples (83 percent) and had the lowest mean diversity and equitability (1.46 and 0.29, respectively) of all the clusters. Only the chironemids were dominant, with the largest mean abundance in any of the samples at 81 percent. The observations in Cluster 4 included the only station, South Fork, with Hydracarina (water mites) as the dominant taxon (55 percent of the cluster population). The Surber net sampling efficiency was probably low for these mites because of their small size; their presence in the samples may not be strictly quantitative, but is probably relative to the populations present. Clusters 2, 3, and 6 included observations from South Fork, Fir Creek, and Lower Cougar Creek, with the greatest number of observations in Cluster 6 (33 percent) and with Chironomidae, Hydracarina, or *Baetis* the dominant taxon.

Table 14.--Summary of cluster analysis and constancy in clusters of benthic invertebrate taxa and cluster analysis of functional groups collected in the Bull Run watershed, 1978-1981

[BDIV = Brillouin species diversity index, E = equitability]

Cluster analysis of benthic invertebrate taxa

Cluster	Station identity in each cluster				Mean diversity in cluster		Species abundance in clusters (in mean percent)			
	Fir Creek	North Fork	Lower Cougar Creek	South Fork	BDIV	E	5-9 pct	10-24 pct	25-49 pct	50-100 pct
1	0	0	4	3	3.23	0.65	Oligochaeta Ostracoda	Chironomidae Hydracarina *Baetis*		
2	3	0	1	3	1.92	.48		Chironomidae Hydracarina		*Baetis*
3	2	1	1	3	2.52	.52	Simuliidae Hydracarina		Chironomidae *Baetis*	
4	0	0	0	2	2.01	.50	*Baetis*	Chironomidae		Hydracarina
5	1	10	0	0	1.46	.29				Chironomidae
6	8	1	3	3	2.34	.50	Ostracoda Hydracarina	*Baetis*		Chironomidae

Species constancy of benthic invertebrate taxa

Cluster	High contancy (greater than (50 percent)	Moderate constancy (25-50 pct)	Low constancy (10-24 pct)	Very low constancy (Number of taxa less than 10 percent)
1	Oligochaeta *Oecetis* Copepoda *Oreodytes* *Acroneuria*	Ostracoda *Paraleptophlebia*	Hydracarina *Ephemerella drunella* Elmidae *Baetis*	10
2	*Dicranota*	*Baetis*	Chironomidae *Microsema* Hydracarina *Ephemerella drunella* Elmidae	14
3	Simuliidae *Antocha*	*Acroneuria*	Chironomidae Ostracoda *Baetis* *Paraleptophlebia* *Oecetis* *Ephemerella drunella* *Ecclisomyia*	11
4	Hydracarina Elmidae	*Dicranota* *Ephemerella drunella*	*Paraleptophlebia*	16
5	Sciaridae	Chironomidae *Ecclisomyia* *Oreodytes*	Oligochaeta *Cinygmula* *Rhithrogena*	14
6	*Microsema* *Cinygmula* *Rhithrogena* *Hastoperla*	Ostracoda *Antocha* *Ecclisomyia*	Oligochaeta Chironomidae Hydracarina *Paraleptophlebia* *Ephemerella drunella* Copepoda Elmidae	7

Table 14.--Summary of cluster analysis and constancy in clusters of benthic invertebrate taxa and cluster analysis of functional groups collected in the Bull Run watershed, 1978-1981--Continued

Cluster analysis of functional groups								
	Station identity in each cluster				Taxa abundance in clusters (in mean percent			
Cluster	Fir Creek	North Fork	Lower Cougar Creek	South Fork	5-9 percent	10-24 percent	25-49 percent	50-100 percent
1	9	1	5	6	sediment/deposit-collectors	mineral scrapers piercer predators		generalists
2	0	10	0	0	sediment/deposit-collectors			generalists
3	0	0	0	2		mineral scrapers generalists		piercer-predators
4	2	0	1	1		sediment/deposit-collectors	mineral scrapers generalists	
5	2	0	0	3		piercer-predators generalists	sediment/deposit-collectors mineral scrapers	
6	1	1	3	4		filter/suspension- and sed/deposit-collectors mineral scrapers piercer predators	generalists	

Benthic invertebrate taxa were clustered by year, but no obvious pattern in the taxa assignments to clusters was apparent. Cluster analysis of benthic invertebrate taxonomic groups showed that North Fork was dissimilar to the other stations because of the abundance of chironomids and the lower diversity.

Chironomidae showed low constancy in most of the clusters, but moderate constancy in Cluster 5, showing that this group has a wide distribution in the Bull Run streams. *Baetis*, which was dominant in Cluster 2, also showed moderate constancy in that cluster and low constancy in other clusters, indicating a wide distribution. Hydracarina showed high constancy in Cluster 4 where it was dominant, demonstrating a somewhat restricted distribution. Many other taxa with low profiles in cluster analysis were predominant in constancy analysis. Each cluster can be characterized by taxa with high constancy to that cluster. These taxa probably have narrow distribution ranges, specific habitat requirements, small isolated populations, or patchy emergence patterns; they include the following: Oligochaeta, *Oecetis*, Copepoda, *Oreodytes*, *Acroneuria*, *Dicronota*, Simulidae, *Antocha*, Elmidae, Sciaridae, *Microsema*, *Cinygmula*, *Rhithrogena*, and *Hastoperla*. Note that because of their small size or fragility Copepoda, Ostracoda and Oligochaeta population counts should be considered to be only qualitative.

Cluster analysis of functional groups

Functional groups were clustered by station, with the results shown in table 14. Cluster 1 (with 41 percent of the observations) included samples from Fir Creek, Lower Cougar Creek, and South Fork, with generalists dominant (54 percent of the population) and sediment/deposit collectors, mineral scrapers, and piercer predators all codominant (9 to 11 percent of the population). North Fork represented 100 percent of the observations in Cluster 2, with generalists dominant (forming 82 percent of the cluster population). Clusters 3 to 6 included quite similar cluster populations in terms of functional groups, except for Cluster 3 where piercer predators were dominant. Generalists, mineral scrapers, and sediment/deposit collectors made up 10 to 49 percent of the benthic communities, whereas piercer predators and filter/suspension collectors made up 10 to 24 percent. North Fork showed the least representation in these clusters. Results of cluster analysis of benthic invertebrate data using functional groups showed that North Fork was dissimilar from the other stations because of the preponderance of generalists at that station.

ASSOCIATIONS BETWEEN PHYSICAL-CHEMICAL CHARACTERISTICS OF WATER AND BIOLOGICAL CONSTITUENTS

Correlation Analysis of Weekly Samples

Analysis of the relationships between physical-chemical characteristics of water and biological constituents may contribute to an understanding of the periphyton and benthic invertebrate association patterns described in the preceding sections. The following constituents, collected weekly by the Portland Water Bureau in the Bull Run watershed (table 1), were used in the correlation analyses: total phytoplankton, total coliform bacteria, fecal coliform bacteria, fecal streptococcus bacteria, stream discharge, water temperature, specific conductance, pH, dissolved silica, dissolved solids, hydroxylated aromatic compounds (HAC'S), turbidity, total nitrate, and orthophosphate (U.S. Geological Survey, 1978-1983). These data are summarized in table 2. Univariate analysis (Ray, 1982) of this data set, and of the logarithmic transformations of the data, showed that many constituents were not normally distributed. Consequently, the nonparametric Kendall correlation analysis procedure was used. Bacteria "less-than" values were assigned half the lower limit of detection. Phytoplankton, total coliform bacteria, fecal coliform bacteria, fecal streptococcus bacteria and stream discharge values were converted to natural logarithms (Ln) prior to analysis. Results of analyses on North Fork, South Fork, Fir Creek, and Lower Cougar Creek data are presented in table 15.

Correlation analyses of biological and physical-chemical constituents over all stations and water years resulted in significant positive correlations of the biological constituents with temperature, specific conductance, pH, and dissolved solids. In addition, stream temperature, specific conductance, dissolved solids, silica, and pH were all positively correlated, as were streamflow and turbidity.

Table 15.--Summary of Kendall correlation analysis between biological data and water-quality constituents for weekly instantaneous samples collected in the Bull Run watershed from 1978-1983

T = water temperature; C = specific conductance; Q = stream discharge; DS = dissolved solids; SI = silica; NTU = turbidity; N = nitrate; P = orthophosphate; HAC = hydroxylated aromatic compounds; PT = total phytoplankton; TC = total coliform bacteria; FC = fecal coliform bacteria; FS = fecal streptococci bacteria; n = number of observations (years, stations, or months analyzed); symbols in table represent correlations significant at P<.05: for analyses by year and by station, * and = represent significant positive and negative correlations occurring for 5 to 6 out of n = 6 observations, and + and - represent significant positive and negative correlations respectively for 3 to 4 out of 6 observations; for analyses by month, * and = are significant positive and negative correlations respectively for 8 to 12 out of n = 12 observations, whereas + and - are positive and negative correlations respectively for 4 to 7 out of 12 observations.

		Biological versus water-quality constituents									
		T	C	pH	Q	DS	SI	NTU	N	P	HAC
All sites and years (total n = 1)	PT	*	*	*	*	*	*		=	*	
	TC	*	*	*		*			*		
	FC	*	*	*	*	*		*	*	=	*
	FS	*	*	*	=	*	*		*		=
By year (total n = 6)	PT	*	*	*	*	*	*		-	+	
	TC	*	+	+		+			+		
	FC	*						+			
	FS	*	*	*	=	*	+		+		
By station (total n = 6)	PT	*	*	*	=	+	+				
T	C	*	*	*	-		+				
	FC	*	*	*	-			+			
	FS	*	*	*	=	*	*				
By month (total n = 12)	PT		+	+	*	+					
	TC		-	=	+						
	FC		-	-	*		-	+			
	FS	+	-				-				

		Water quality versus water-quality constituents						
		T	C	pH	Q	DS	SI	NTU
All sites and years (total n = 1)	T		*	*	=	*	*	=
	C			*	=	*	*	
	pH				=	*	*	
	Q					=	=	*
	DS						*	*
	SI							
By year (total n = 6)	T		*	*	=	*	*	-
	C			*	-	*	*	
	pH				-	*	*	
	Q					-	-	*
	DS						*	
	SI							
By station (total n = 6)	T		*	*	=	*	*	-
	C			*	=	*	*	-
	pH				=	*	*	-
	Q					=	=	*
	DS						*	-
	SI							=
By month (total n = 12)	T				-		-	
	C			*		*	*	
	pH				+	*	*	+
	Q					+		*
	DS						*	*
	SI							

Negative correlations occurred for streamflow versus stream temperature, specific conductance, dissolved solids, silica and pH. These constituents respond to seasonal and dilution changes. In addition, specific conductance and dissolved solids are inversely related to stream discharge (Rinella, 1985). Discharge-concentration regression models developed by Rinella (1985) resulted in good to excellent fits for instantaneous specific conductance, total solids, total silica, and turbidity.

Other significant positive correlations included phytoplankton with silica, orthophosphate (both necessary for growth of diatoms), and streamflow. Dissolution of rocks and soils maintains the concentrations of available dissolved silica and phosphorus; concentrations decrease during periods of low streamflow and abundant diatom populations (Hynes, 1970). Use of nitrates by phytoplankton would explain the negative correlations between these two constituents (table 15); Hynes (1970) states that the concentration of nitrate in streams is low because these ions are rapidly taken up by plants.

The increased shearing force at higher streamflows may cause more periphytic algae to be sloughed off into the stream; many phytoplankton are probably recruits from periphyton. Both communities are difficult to assess due to their relationship, the effects of streamflow on the community density, and different sampling methodologies. The Portland Water Bureau laboratory generally identified phytoplankton to genus, while the Survey identified to species. The most common genuses in both sample sets collected at the key stations were *Achnanthes*, *Diatoma hiemale*, *Melosira*, *Gomphonema*, *Navicula*, *Fragillaria*, *Cymbella*, *Synedra*, *Hannaea arcus*, and *Cocconeis placentula*. Periphyton, grown on a substrate suspended just below the water's surface, are measured as number per unit area and represent growth of a population over a month's duration. Phytoplankton represent an instantaneous sample collected at one point in time and are measured as number per unit volume of water. Periphyton were collected at low flow to avoid possible loss of the sampling apparatus, which can be caught in debris and washed away during storm events. Phytoplankton are collected year-round.

Fecal coliform bacteria were positively correlated with streamflow, turbidity, and HAC'S and were negatively correlated with orthophosphate. Conditions which bring about greater streamflow may also bring about greater turbidity; increased runoff may wash fecal coliform bacteria into the stream. Fecal streptococci bacteria were associated with lower streamflows and HAC'S and were positively correlated with silica; high levels of in-stream and near-stream animal activity occur during the warm dry summer months.

Correlation analysis by year, to determine whether water-quality relationships showed yearly variations, were similar to analyses of all data, but included fewer significant correlations of bacteria with other water-quality constituents.

Table 16.--Cluster analysis of instantaneous water-quality data collected in the Bull Run watershed, 1978-1983

[* = high values in range; + = mid-range values; - = low values in range]

Cluster	Station (number of observations) Fir Creek	North Fork	Lower Cougar Creek	South Fork	Water-quality constituents (including biological data) Total phyto-plankton	Total coliforms	Fecal coliforms	Fecal strep.	Stream temper-ature	Specific conduc-tance
1	137	170	18	168	-	-	-	-	+	+
2	18	34	4	28	+	*	*	*	*	*
3	13	6	1	14	-	*	*	*	+	-
4	36	63	253	44	+	-	-	-	+	*
5	20	16	22	9	*	-	-	-	*	*
6	146	104	38	90	-	-	-	-	-	-
Range of cluster-means for constituents:					Number per ml 31-307	Colonies per 100 ml 7-90	Colonies per 100 ml 1-78	Colonies per 100 ml 1-73	°Celsius 5.8-10.5	Microsiemens/cm at 25°C 22-33

Cluster	Water-quality constituents (including biological data) pH	Log of stream discharge	Total silica	Dissolved solids	Turbidity (NTU)	Total nitrate	Total phos-phate
1	+	+	+	-	-	-	+
2	*	+	+	*	*	+	-
3	-	-	-	-	*	*	-
4	*	+	*	+	-	-	*
5	+	-	*	*	-	-	*
6	-	*	-	-	+	+	-
Range of cluster-means for constituents:	pH units 7.2-7.4	cfs 3.2-3.7	mg/L 9.6-14	mg/L 23-34	NTU 0.1-0.5	mg/L 0.02-0.09	mg/L 0.004-0.012

Correlation analysis by station, to determine whether basin-wide water-quality relationships were also typical of individual stations, were similar to analyses including all data, except that phytoplankton, total coliform and fecal coliform bacteria data were negatively correlated with streamflow. The correlation of biological and other water-quality data by month resulted in many fewer significant correlations compared to the total data set (table 15).

Significant relationships atypical of the basin-wide pattern included the following. Temperature showed significant negative correlations with silica in fall and winter; pH showed positive correlations with streamflow in summer and fall. Bacteria were negatively correlated (in the fall and winter months) with specific conductance and pH compared to the significant positive correlation in the analysis using all the data. The atypical correlation patterns in the monthly analyses probably resulted from many factors, including the small size of the monthly data sets and the seasonality of the data.

Cluster Analysis of Weekly Samples

Cluster analysis of instantaneous water quality and biological constituents may contribute towards an understanding of the basis for periphyton and benthic invertebrate cluster analysis patterns. If water-quality constituents form similar clusters, by station, then biological cluster patterns may be partly determined by measured differences in water-quality constituents.

Cluster analysis resulted in the majority (60 percent) of samples collected from Fir Creek, North Fork, and South Fork) showing in Clusters 1 and 6 (table 16). These clusters were characterized by low phytoplankton and bacteria populations and by low to midrange values for the other water-quality constituents (except for higher discharge in Cluster 6). The majority (75 percent) of the Lower Cougar Creek (the only actively logged subbasin) samples were in Cluster 4, which represented 27 percent of the total sample population. This cluster was characterized by low bacteria and midrange phytoplankton populations, low- to midrange levels for water temperature, streamflow, dissolved solids, turbidity and nitrate, and by high levels for specific conductance, pH, silica and total phosphate. Clusters 1, 4, and 6 probably represent average streamflow conditions for the period. The other three clusters represented only 13 percent of the total sample population at all stations and included high levels for many constituents; these are probably indicative of samples collected during summer and early fall, during low to moderate streamflow conditions.

When water quality and biological data were clustered by month (not shown), 84 percent of the observations were in two clusters, representative of average streamflow conditions, and the remainder were in clusters with mid- to high-range values representative of low- to high-flow conditions. Forty percent of the water-quality low flow data were in clusters representing July through October samples, while 37 percent of the moderate flow data were in a cluster including most samples collected between November and March.

Instantaneous water-quality and biological data collected between June and October were clustered (table 17) in order to compare results with the same time period covered for the periphyton cluster analyses (table 7). When data were clustered by station, the majority of Fir Creek, North Fork, and South Fork observations were in Clusters 1 and 3 (70-80 percent) with low phytoplankton and bacteria counts and with midrange to high levels of other constituents for the period. The majority of Lower Cougar Creek samples were in Cluster 6 (75 percent) with high-range values for phytoplankton, midrange values for temperature and nitrates, and low levels of other constituents. When only water-quality data were clustered (not shown), Fir Creek (a 2nd order stream) also formed a separate cluster with midrange temperature and low levels of other constituents, whereas North and South Fork (both 3rd order streams) clustered together. These clusterings are probably related to water-quality differences related to stream size (flow) and stream order. Cluster analysis of these data by month (not shown) yielded a fairly even distribution of observations between the months in each cluster, indicating that monthly differences during the summer low-flow period are not as important in cluster formation as station differences based on stream order or other factors.

Cluster analysis of monthly periphyton species data was compared to cluster analyses of weekly water-quality data over the same summer period, with different results. North Fork clustered separately and South Fork and Fir Creek clustered together when periphyton species and benthic invertebrate taxa were used as the entities to be clustered. North Fork, South Fork, and Fir Creek (to some extent) clustered together when water-quality data was used as the clustering criteria. Lower Cougar Creek, however, clustered separately in both analyses. These differences resulted partly from measurable differences in physical-chemical constituents related to hydrology and climate and partly from other factors. These factors may include the response of periphyton and benthic invertebrate communities to environmental disturbances related to subbasin geology, land-use, and to complex hydrogeochemical and biological interactions. Slight changes in the amount of sediment deposition and turbidity in a subbasin, possibly related to erosion or other factors, may affect the substrate and water quality enough to give one species a competitive advantage and thus reduce diversity.

Table 17.--Cluster analysis of instantaneous water-quality data collected in the Bull Run watershed from June through October, 1978 to 1983

[* = high values in range; + = mid-range values; - = low values in range]

	Station (number of observations)				Water-quality constituents (including biological data)					
Cluster	Fir Creek	North Fork	Lower Cougar Creek	South Fork	Total phyto-plankton	Total coliforms	Fecal coliforms	Fecal strep.	Stream temper-ature	Specific conduc-tance
1	59	22	16	25	-	+	-	-	+	+
2	4	6	12	1	*	+	-	-	-	-
3	66	106	3	99	-	-	-	-	+	*
4	14	10	2	9	*	*	*	+	*	+
5	15	6	7	2	+	*	+	*	-	-
6	8	32	118	20	+	-	-	-	*	-
Range of cluster means for constituents:					Number per ml 32-410	Colonies per 100 ml 6-98	Colonies per 100 ml 2-84	Colonies per 100 ml 6-76	°Celsius 8.9-11.8	Microsiemens/cm at 25°C 23-32

	Water-quality constituents (including biological data)						
Cluster	pH	Log of stream discharge	Total silica	Dissolved solids	Turbidity (NTU)	Total nitrate	Total phos-phate
1	+	+	+	+	-	+	-
2	-	-	-	-	-	-	+
3	*	*	*	*	+	+	*
4	+	+	*	*	*	-	-
5	-	+	+	*	*	*	-
6	-	-	-	-	-	+	-
Range of cluster means for constituents:	pH units 7.1-7.4	cfs 2.1-3.0	mg/L 9.5-12	mg/L 23-30	NTU 0.16-0.29	mg/L 0.03-0.08	mg/L 0.003-0.007

APPLICATION OF BIOLOGICAL DATA

Changes in either water quality or in biological quality (or both) in response to man's activities may indicate a subbasin- or basin-wide disturbance. Biota may be more or less sensitive to man's activities than are water-quality constituents, depending on the magnitude and persistence of the change in water-quality constituents. Biological communities usually act as long-term integrators, while water-quality measurements provide instantaneous information on short-term change. A small but persistent change in magnitude of a water-quality constituent may not be detectable statistically yet be accumulative and measurable in the biota. A large magnitude change over a short time period (1/2 day) has only a 1 in 14 chance of being observed in weekly sampling, while the biota accumulate these effects, integrating them over time. Also, the biota may show a longer "recovery" time from environmental perturbation. The relations of cause-effect between aquatic biota and water-quality characteristics or land-use activities is still not well known.

The extent of the biotic responses may depend upon the type of management activity. Clear-cutting and slash-burning would probably cause the largest change in periphyton communities by increasing available nutrients and by opening up the canopy. Large areas of blow-down from windstorms may increase the amount of large organic debris (such as logs) within the streams. Movement of uprooted trees into the streams would increase the movement of sediment into and within streams and would modify the habitat available for benthic invertebrates.

To determine if a management activity will cause a significant change in the identified Bull Run periphyton community, a comparable data set should be analysed. Data should be collected for 2-3 years at the established reservoir inflow stations described in this study during and following the planned activity. Periphyton would be collected at monthly intervals during the low-flow months and identified to species; changes in major species associations or in diversity would be examined. Concurrent collection of periphyton at an established, undisturbed station (such as Fir Creek) could provide information on natural variation and climatic change during the period.

If the management activity occurs at a stream site far removed from the established station, an additional sampling scheme should be used. Although the established stations (located near reservoir inflows) may act as integrators of upstream water quality and define quality of water entering the reservoirs, they would not show the magnitude of change occurring at the site of ongoing activity. In this case, two sampling stations with similar orientation, flow, solar radiation, and substrate could be selected above and below the proposed management activity. Preferably a set of samples should be collected at both stations one summer prior to the planned activity.

To optimize sampling, duplicate slides (used to measure natural variability) could be collected at both stations every two weeks between July and September; slides should also be collected at the established station. In highly productive systems, which may be true of logged areas, it is recommended that periphyton slides be collected every two weeks; in streams with lower productivity, every four weeks is usually sufficient. However, there may be significant differences in species data on slides of different exposure time, and there is probably a succession of species colonizing the slides (Tippet, 1970). Only slides with similar exposure times should be compared.

The benthic invertebrate analyses described in this report provide general information on late summer low-flow benthic invertebrate communities which may respond to major perturbation in the subbasins. However, data are not extensive enough to define natural variation in communities with respect to seasonal and high-flow events. An ongoing (1984-85 water year) seasonal study by the Survey may help provide this information.

During and following a major management activity in a selected subbasin, continued seasonal sampling of benthic invertebrates (four samples at a station) over a 1-2 year period at on established reservoir inflow station would provide a data set to compare to the background data set. An undisturbed established station should be monitored at the same time to measure effects of natural and climatic variation; however, natural and climatic effects may be different for different streams. Changes in diversity or in benthic-invertebrate-association patterns from the background data may be a measure of the extent of management activity or may be due to a combination of natural or climatic change and the activity. Previous studies by Stauffer and others (1976), Slack and others (1982), and Rabeni and Minshall (1977), have shown that stream benthic communities respond to increased levels of suspended sediment, silt, and organic matter in streams.

Evaluation of the effects of management activities on benthic invertebrate populations should include some duplicate sampling effort just upstream and downstream of the activity for a period during and following the activity, similar to that of the periphyton program. Pre-management samples at both stations would provide background data with which to measure natural background variation. Differences in diversity and the benthic invertebrate community between the downstream station and the upstream undisturbed station can be related to management activity, with the natural variability due to climate and flow variations being common factors to both stations. For a better definition of the benthic invertebrate community, Chironomids should be identified to genus or, if possible, to species, because they form such a major component of the benthic community.

SUMMARY

The Bull Run periphyton community is dominated by pennate diatom species including *Achnanthes lanceolata*, *A. minutissima*, *Cocconeis placentula englypta*, *Diatoma hiemale mesodon*, and *Hannaea arcus*. These species are closely related, widely distributed, and have broad tolerance ranges.

Median values for total periphyton densities ranged from 1,100 to 2,800 cells/mm^2. *A. minutissima* was dominant in 2nd order streams (South Fork above Cedar Creek, Fir Creek, Lower and Upper Cougar Creeks), *A. lanceolata* was dominant or codominant in 3rd order streams (South Fork and North Fork), and *C. placentula* was dominant only at South Fork. Most green algae species were collected at the Cougar Creek stations, and most blue-green algae species were collected at the South Fork above Cedar Creek station. Periphyton species diversity ranged from 1.70 for North Fork to 2.55 for Fir Creek and South Fork stations. Species diversities were not significantly different between South Fork and Fir Creek (located on the south-side of the reservoir, with west-facing slopes) and between North Fork and Lower Cougar Creek (located on the north side of the reservoir, with south-facing slopes). Comparison of species diversity between north and south-side reservoir stations resulted in a significant difference, which indicates that basin orientation influences species diversity. Significant differences between sites located within the same subbasins (Upper versus Lower Cougar Creek, South Fork above Cedar Creek versus South Fork) indicate that stream order may also influence diversity.

Results of chlorophyll analyses show that Bull Run streams are predominantly heterotrophic. Although the autotrophic index shows variability under natural conditions, it can be used to compare the effects of logging on different reaches of a stream. Sixty percent of the index values for Upper Cougar Creek (not logged) were less than 100, whereas only 12 percent of the values for Lower Cougar Creek (logged during the study period) were less than 100. These results indicate more heterotrophs and organic material at Lower Cougar Creek than in the unlogged headwaters.

Species associations included *Achnanthes lanceolata* and *A. linearis* in the smaller headwater streams (at Fir Creek, Upper and Lower Cougar Creek), and *A. linearis* with *Cocconeis placentula* at South Fork, South Fork above Cedar Creek, and Lower Cougar Creek. *Diatoma hiemale mesodon* and *Hannaea arcus* were closely associated at the North Fork, South Fork, South Fork above Cedar Creek, and Lower Cougar Creek stations. Relations between species varied seasonally, possibly due to competition or herbivory or to differences in tolerance ranges, resulting in a succession of species colonizing the substrate. Associations between dominant diatoms occurred in July, August and September, whereas green algae were positively correlated in July, September and October.

Common positive species associations by year were *A. lanceolata* with *C. placentula* and *Cymbella minuta* with *Fragillaria vaucheria*. Common negative associations occurred between *A. minutissima* and *A. lanceolata*, and *C. placentula*. Future changes in these associations may indicate a basin-wide environmental disturbance.

Other studies in the Oregon Coast Range have shown that common Bull Run periphyton species can be used to monitor the impact of man's activities, such as logging, on stream basins. An abundance of green algae (such as *Ulothrix*, *Chlamydomonas*, or *Spirogyra*), the population dynamics of *Cocconeis placentula englypta*, and the relative abundance of *Achnanthes* species (such as the disappearance of *A. lanceolata* from a community where it was previously abundant) may all be indicators of a major change in the system.

Cluster analysis of periphyton species resulted in unique clusters for the North Fork, South Fork, Lower Cougar, and South Fork above Cedar Creek stations, as well as two clusters which included a combination of stations. The South Fork cluster was the most diverse and the North Fork cluster the least diverse. Spatial differences had a greater influence than temporal differences on the abundance and distribution of the major species during the June and October low-flow period. Constancy analysis showed that most of the dominant periphyton taxa were also widely distributed in the watershed. Taxa with limited distributions included *Melosira varians*, *Chlamydomonas sp.*, *Achnanthes linearis*, and *Anacystis sp.*

Results of intrasite and intersite similarity analysis between periphyton sites indicate that (1) greater differences exist between stations and between sampling dates at each station than between sites at any one station and (2) the main sampling site at each station is representative of the periphyton in that stream reach.

Chironomidae, Hydracarina, and *Baetis* were the dominant benthic invertebrate taxa in late summer samples collected in the Bull Run watershed. Chironomids were most abundant at North Fork, but were common at all the sites. The median total number of invertebrates ranged from 270 to 770 organisms/ft^2. The generalists were the dominant functional group, whereas shredders were least abundant, possibly indicating a scarcity of large organic particulate material at the sites.

The diversity of benthic invertebrates was significantly lower at North Fork compared to South Fork, Fir Creek, and Lower Cougar Creek. Higher annual sediment yields and instantaneous turbidity at North Fork may have reduced species diversity and increased the dipteran (Chironomidae) population. Comparison of diversity between north-side and south-side reservoir stations resulted in a significant difference; basin orientation may be one factor influencing benthic invertebrate distribution.

Significant associations occurred between invertebrates from different families and between invertebrates with different foraging strategies; and a greater number of benthic invertebrates than expected by chance showed similar habitat preferences. Few significant correlations by year may indicate the difficulty of replicating sampling conditions each year or may indicate an actual change in the community between years.

Most of the significant correlations between functional groups occurred between members of different functional groups, indicating that organisms with different foraging strategies are sharing the same habitat. Most negative correlations occurred between generalists (mostly Chironomidae) and other functional groups, possibly due to competition or because the chironomid species share their own complement of all functional groups.

Cluster analysis of benthic invertebrate taxa and their functional groups showed that North Fork was dissimilar to the other stations, probably due to the preponderance of chironomids (generalists) and lower diversity at that station. Constancy analysis showed that benthic invertebrate taxa generally have more localized populations than do periphyton taxa and that both chironomids and baetids are widely distributed in the basin. Taxa that are more localized or restricted include Oligochaeta, *Oecetis*, Copepoda, *Oreodytes*, *Acroneuria*, *Dicronota*, Simulidae, *Antocha*, Elmidae, *Sciaridae*, *Microsema*, *Cinygmula*, *Rhithrogena*, and *Hastoperla*.

Correlations between weekly instantaneous water-quality and biological samples resulted in significant positive associations of bacteria and phytoplankton with stream temperature, specific conductance, pH, and dissolved solids. Phytoplankton were also correlated with silica, orthophosphate, and streamflow. Increased shearing forces at higher streamflow probably cause more attached algae to be sloughed off into the stream. Recruitment of fecal coliform bacteria occurred with higher streamflow and turbidity, whereas recruitment of fecal streptococci bacteria occurred at lower streamflow. Hydrologic events and seasonal changes were more important than differences between stations or years in determining relations between water-quality constituents. Correlations of water-quality data by station, year or month, which were atypical of the basin-wide pattern, probably resulted from the smaller size of the data sets and the seasonality of the data.

Cluster analysis of the instantaneous water-quality data showed that North Fork, South Fork, and Fir Creek data tended to cluster together, but Lower Cougar Creek data formed a separate cluster. When taxa were used as the clustering criteria, North Fork data clustered separately from the other stations. The results of the cluster analysis of periphyton and benthic invertebrate taxa between stations were partly a result of measurable physical-chemical differences between the streams, of hydrologic and climatological events, and partly due to other factors such as subbasin geology and land use.

GLOSSARY OF SELECTED BIOLOGICAL TERMS

[Definitions were obtained or modified from Greeson and others (1977), American Public Health Association and others (1976), Hynes (1970), and Steen (1971).]

Allochthanous--terrestrial organic material which enters a stream and is used as a food source; detritus.

Autotrophic--the classification of organisms (mostly plants) which can synthesize organic matter from inorganic substances, commonly through photosynthesis.

Autotrophic index--biomass to chlorophyll-a ratio.

Autochthanous--food material which is produced within a stream, by autotrophic organisms.

Ash-free weight(AFW)--a biomass measurement of periphyton, calculated as follows:

AFW = (dry weight - ash weight)/substrate area

Benthic invertebrates (benthos)--invertebrates that live on, in, or near the substrate. In streams this group may include larval and adult insects, annelids, water mites, and crustaceans, molluses, and others.

Biomass--The amount of living matter present at any given time (standing crop).

Coliform Bacteria--Used as indicators of pollution, characterized as aerobic, and facultative anaerobic, gram-negative, nonspore-forming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35 degrees C.

Community--An association of interdependent plants and animals in a given area in which the various species are more or less interdependent upon each other.

Copper Sulfate--An algicide which was used to control phytoplankton growth in Bull Run reservoirs prior to 1979, when U.S. Geological Survey project personnel requested that treatment be stopped. Large bags of powdered copper sulfate were dumped into Bull Run streams just upstream from the reservoirs, generally at the bridges, four times each year starting in May. North and South Fork Bull Run, Lower Cougar Creek, and Fir Creek were all treated. There was no treatment in 1979 after the periphyton floats were installed (late May). Application of copper sulfate prior to May 1979 may have affected periphyton and benthic invertebrate communities.

Correlation--Describes the degree to which two variables covary (vary together).

Dominant--Designating an organism or group of organisms which, by their size or numbers, determine the character of a community. Subdominant organisms are less important in determining community character compared to dominant organisms.

Ecology--Study of the relations between organisms and their environment.

Emergence--Escape of an insect from a cocoon or pupa.

Fecal Coliform Bacteria--That part of the coliform group that is present in the gut or feces of warmblooded animals. Samples are incubated in a nutrient medium at 44.5 °C for 24 hours.

Fecal Streptococcal Bacteria--Found in the gut of warmblooded animals, their presence in natural waters is an indicator of fecal contamination. Samples are incubated in a nutrient medium at 35 °C for 48 hours. In conjunction with fecal coliform bacteria, fecal streptococcal bacteria can verify the existence of fecal pollution and the possible source (if a point source). Lamka and Seidler (1985) found that the fecal coliform to fecal streptococcus bacteria ratio was of no use in defining nonpoint source pollution in the Oregon streams they studied.

Functional Groups--A classification of aquatic benthic invertebrates based on their morphological-behavioral adaptations for food gathering and processing. Shredders feed on coarse particulate organic material (greater than 1 mm) such as leaf litter, and associated microbes. Collectors gather or filter fine particulate organic material(0.5 um - 1 mm) and microbes. Scrapers shear attatched algae and organic matter from surfaces. Predators prey on other invertebrates. Generalists do any or all of the above; this group is amnivorous.

Heterotrophic organisms--a group of organisms (including hyphomycetes fungi, certain bacteria, insects, and snails) which cannot manufacture their own food, and which requires organic material as a source of nutrition.

Omnivorous--Feeding on both plant and animal food.

Paired basin approach--used to define baseline water-quality variability. In the Bull Run watershed, Fir Creek serves as the control basin, where no man-caused activities such as logging have occurred. The statistical difference between the paired linear regression response of the control basin compared to another subbasin during calibration period (baseline conditions in which water-quality data related to streamflow defines normal hydrologic variability) and the treatment period (intensive man-caused activity in selected subbasins) is determined in the paired basin approach (Rinella, 1985).

Periphyton--An aquatic community of autotrophic and heterotrophic organisms living on or attached to submerged surfaces, and useful in assessing water quality in specific stream locales. An artificial substrate can be used to collect quantitative samples of periphyton with a uniform, controlled surface type, area, and orientation. In streams, this group may include algae, protozoans, bacteria, and invertebrates.

Perturbation--Disturbance.

Phycoperiphyton--The plant component of the periphyton.

Regression--Describes the dependence of a variable Y on an independent variable X in terms of a linear function.

Site--Specific sampling locations within a stream reach; where 3-4 replicate or representative sites in the stream were sampled at each station.

Station--Identification of the location of the gaging and other water-quality sites set up by the Survey in the Bull Run watershed; identified by downstream order number.

Stream order--1st order streams have no tributaries. When two 1st-order streams meet, they become a 2nd-order stream. Two 2nd-order streams meet to form a 3rd order stream, and so on. According to Leopold and others (1964), 1st order streams are the smallest marked on a 1:24,000-scale map. According to Hynes (1970), in moist areas, a 1:250,000 scale can be used. In this study, a Survey 1:125,000-scale map was used to determine stream order.

Succession--The sequence of communities which replace one another in a given area.

Taxon (Taxa)--A taxonomic group of any rank or size (for example a species or a genus).

Univariate analysis--Tests the hypothesis that the population mean is 0 and the probability of a greater absolute value. A Student's "t" value, standard deviations, and a normal probability plot are provided in the SAS package (Ray, 1982).

Water Year--The 12-month period, October 1 through September 30, designated by the calendar year in which it ends.

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APPENDIX I

Equations used in biological analyses

BRILLOUIN'S SPECIES DIVERSITY INDEX [Zand (1976), Courant (1937)]

The following formula was used to calculate species diversity:

$$H=C/N[\log N!/(n_1 !\ n_2 !\ \ldots n_s !)]$$

where N is the total number of individuals in the collection, s is the number of species, and n (i=1,2,...s) is the number of individuals in the i-th species. Calculations were in natural-base logarithms; C = 1/(ln 2) was used to convert the results to base 2 logarithms ("bits").

The calculation of maximum and minimum values for H used the following equations:

$$Hmax=C/N * [\log(N!/(m+1)^r\ (m!)^s\ )]$$

where $m=\text{integer} * (N/s)$,and $r= N-(s*m)$

$$Hmin=C/N * [\log(N!/(N-(s-1))!]$$

Relative evenness or equitability provides an evaluation of uniformity of distribution of individuals among species, and is calculated as follows:

$$e = \frac{H-Hmin}{Hmax-Hmin}$$

The Stirling approximation to the log of the factorial was used to compute H, Hmax, and Hmin:

$$\text{Log}(X!) = 1/2 \log(2n) + (X+0.5)\log(X)-X$$

Results were compared to calculations using factorials, and Stirling's approximation resulted in diversity and relative evenness values accurate to 4 decimal places.

SINGLE CLASSIFICATION ANALYSIS OF VARIANCE (Sokal and Rolhf, 1973)

The analysis of variance (ANOVA) tests whether two or more sample means could have come from populations with the same parametric mean with respect to a given variable. In this case, the means of the periphyton species diversities measured at each station are compared using the F test. If the mean values at different stations are significantly different, the assumption can be made that they were sampled from different populations. In a single classification, ANOVA, groups of samples are classified by a single criterion: different stations from which the samples were collected. All groups in the ANOVA need not have the same sample size. Where only two samples are being analysed, the t test can be used to test the significant difference between means.

The distribution used in ANOVA is the F distribution, a theoretical probability distribution, with its shape determined by two values for degrees of freedom (as long as the variances are equal) which may come from the same or different populations. The assumptions of ANOVA include: (1) random sampling, that the colonization of the periphyton slides by algal species in a stream was probably patchy, as were the stream benthic invertebrate communities; (2) independence of "treatment" effects, where individual stations on different streams were the "treatments"; (3) homogeneity of variance (homoscedasticity) which was tested for Bull Run samples using the variance ratios of samples, which were determined to be not significantly different; and (4) normality, in which univariate analysis of the diversity values showed they were predominantly normally distributed; only a very skewed distribution would have a marked effect on the significance level of the F test.

Scheffe's multiple comparison procedure was used to test all main-effect means.

In a single classification ANOVA, groups of samples are classified by a single criterion; in this case the criteria used were the different stations from which the samples were collected. The following formulas were used to calculate ANOVA using the F test:

$$SS_t = \Sigma^a \; \Sigma^n Y^2 - (1/(a*n))*(\Sigma^a \; \Sigma^n Y)^2$$

$$SS_g = (1/n) \; \Sigma^a(\Sigma^n Y)^2 - (1/(a*n))(\Sigma^a \Sigma^n Y)^2$$

$$SS_w = SS_t - SS_g$$

$$F = \frac{SS(g)/(a-1)}{SS(w)/a(n-1)}$$

where

SS = sum of squares

SS_t = total SS

SS_g = among groups

SS_w = within groups

a = number of groups analysed

n = number of individuals in samples

n (for unequal sample sizes) $n = (1/(a-1))*(\Sigma n_i - (\Sigma n_i^2/\Sigma n_i))$

Another method of solving a Model I two-sample ANOVA is the t-test of the difference between two means. The t distribution differs from the normal in that it assumes different shapes dependent on the number of degrees of freedom ((n-1), where n is the sample size), approaching the normal distribution as the number of degrees of freedom approaches infinity. This test is often used with small sample sizes. Calculation of the t-test is as follows:

$$t = \frac{\bar{Y}_1 - \bar{Y}_2}{\sqrt{n(s_1^2 + s_2^2)}}$$

where

$\bar{Y}$ = mean value
s^2 = variance
n = number of individual samples

The t-test assumes variances are not significantly different, using variance ratios.

CLUSTER ANALYSIS

[Ray (SAS, 1982), Boesch (1977)]

The periphyton and benthic invertebrate data set were analysed using the SAS FASTCLUS procedure, which forms disjoint clusters (not a tree structure) by placing each object into only one cluster. This method is suitable for large data sets (100 to 100,000 observations). In small data sets the results may be sensitive to the order of observations. A set of points called cluster seeds is selected as a first guess of the means (K-means) of the clusters. The clustering is done on the basis of euclidian distances computed from one or more numeric values. Entities are points in euclidian space and, when grouped, are defined by the coordinates of the centroid, or geometic center of the points in the group. Close observations are usually assigned to the same cluster, while observations that are far apart are assigned different clusters.

The optimum number of clusters formed generally ranges from two to a tenth of the total number of observations. A plot of the number of clusters versus a cubic clustering criterion (CCC; SAS, 1982) will indicate good clustering if the peaks with the CCC are greater than 2 or 3. The Bull Run data set showed CCC peaks between 5 and 8 (and above) for periphyton and benthic invertebrate data, and the total number of observations ranged from 50 to 100 for the data sets. An optimum cluster number (6) was selected which would be compatible with both the periphyton and benthic invertebrate data sets.

KENDALL'S COEFFICIENT OF RANK CORRELATION

[Sokall and Rohlf (1973), Connover (1980)]

The Kendall test is based on the order (ranks) of the observations and must be used with independent and continuous variables. The formula for Kendall's coefficient of rank correlation if there are no ties in the ranks is:

$$\text{tau} = N/n(n-1)$$

where n is the sample size and N is a count of ranks. The quantity N measures how well the second variable corresponds to the order of the first variable.

With ties in the ranks, the coefficient of rank correlation is calculated:

$$\text{tau} = \frac{N}{\sqrt{[n(n-1)-\Sigma T_1][n(n-1)-\Sigma T_2]}}$$

where T_1 and T_2 are the sums of correction terms for ties in the ranks of variable Y1 and Y2. A T-value equal to t(t-1) is computed for each group of t tied variates and summed over m such groups.

PERCENT SIMILARITY

[Whittaker, 1967]

$$PS_{ab} = 100 - 0.5 \sum_{i=1}^{s} |a_i - b_i|$$

where

a = site a
b = site b
i = species 1 to s number of species

This percent similarity index is used to compare relative species abundance at different sites. The index value is 100 when all species are common and the distribution of individuals is the same on a percentage basis, and 0 when no species are in common.