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STREAM BIOLOGICAL ASSESSMENTS (BENTHIC MACRO INVERTIBRATES FOR WATERSHED ANALYSIS): MID-SOL DUC WATERSHED CASE STUDY

by
Robert W. Plotnikoff

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WASHINGTON STATE
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ECOLOGY

Stream Biological Assessments (Benthic Macroinvertebrates) for Watershed Analysis

Mid-Sol Duc Watershed Case Study

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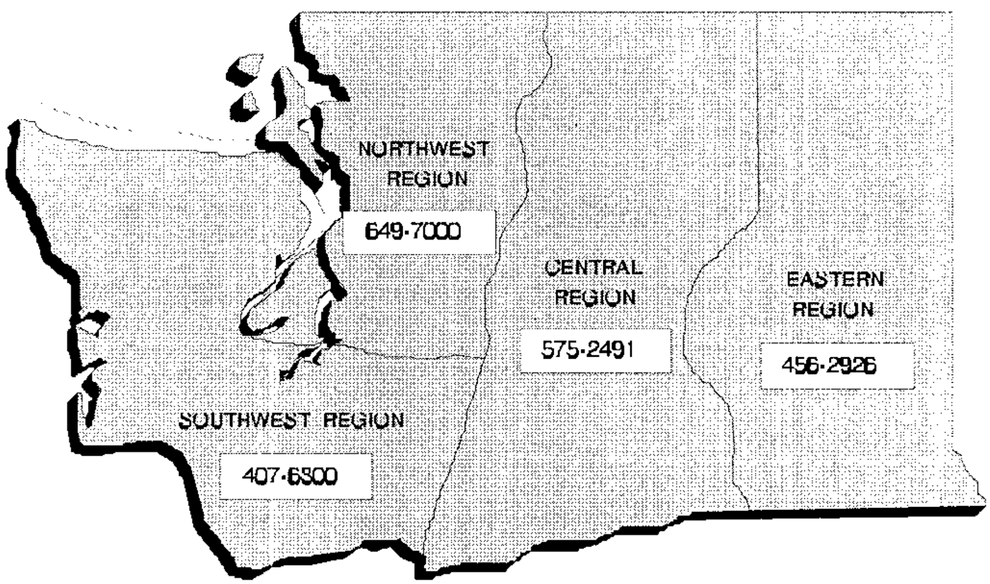

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Mid-Sol Duc Watershed Case Study

prepared by
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Abstract

A method was developed for surveying current biological conditions in a watershed and interpreting the results. The biological condition of five streams was compared to several watershed scale assessments.

Benthic macroinvertebrate communities were evaluated using biometric analysis and site condition was determined using diagnostic flow charts. The survey of benthic macroinvertebrates identified three categories of risk from further changes to current watershed condition. Biological response to temperature and sediment condition were identified as influential physical features to macroinvertebrates in this watershed.

Minor impairment to the biological community was identified at sites where physical changes to the stream were not obvious. Macroinvertebrate surveys in five stream settings were able to describe the vulnerability of stream biota and the physical variables that would further degrade the communities.

Part I Introduction and Methods

Introduction

Organization of this Project

This report is organized under two main categories: 1) Part I (Introduction and Methods), and 2) Part II (Sol Duc Case Study). Part I contains a description of how and why biological information is advantageous in evaluating overall health of streams. Part II contains data from a limited survey of several Mid-Sol Duc Watershed streams. Both parts of the report provide a detailed view of how biology is a beneficial tool in describing watershed health. Format in Part I of this biological assessment document uses terms and organization similar to some modules in the Watershed Analysis Manual (WFPB, 1995).

Purpose for Bioassessment in Watershed Analysis

Water quality of a stream can be measured with physical, chemical, and biological information. Surface water information (e.g., temperature, pH, dissolved oxygen) is commonly used in water quality surveys, but can miss past events that would have resulted in criteria violations. The long-term residence of macroinvertebrates in streams make biological descriptions an effective complement to water quality characterization. Stream macroinvertebrates respond to physical changes that can be related to impacts from logging in watersheds.

Stream biology is usually the most sensitive indication of stream degradation. Changes to the chemical and physical characteristics of a stream are significant if the aquatic life is affected. Processes and functions in streams that are altered by human intervention can be reflected in the biological community (Karr, 1997). The consequences of change in a community influence its biological integrity.

In order to describe the biological integrity of freshwater streams, a standard definition was adopted. Karr and Dudley (198 1) suggested the following to describe a system that has biological integrity:

> "a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region."

Different groups of aquatic organisms have been used in biological assessment programs: fish (Plafkin et al., 1989), benthic macroinvertebrates (Clark and Maret 1993; Mulvey et al., 1992; Plotnikoff, 1994), amphibians (Bury and Corn, 1991), periphyton (Bahls, 1993), sediment diatoms (Dixit and Smol, 1994), macrophytes and plankton. Single groups of aquatic organisms respond to impacts based on sensitivity and fate of chemical pollutants and changes in physical habitat. Important characteristics that make groups suitable for monitoring include: diversity and ease of sampling, consistently responsive to change, and can identify a source of impact. Benthic macroinvertebrates are a suitable aquatic group to use for monitoring stream biological condition in the Pacific Northwest. As a group, they provide important information to successful monitoring programs.

Critical Questions

Analysis of the benthic macroinvertebrate community provides direct evaluation of stream ecosystem condition. Community attributes address: 1) type and quantity of available food, 2) physical stream channel condition, and 3) riparian condition. Detecting stream degradation through community response is evaluated here and is the basis for the following critical questions:

Biological Condition

- What are the characteristics of minimally disturbed macroinvertebrate communities for stream types similar to those that have been degraded? ("minimally disturbed" conditions are found in portions of a watershed that are known to have minimal human activity)

- Do the resident biota reflect the hydrologic and physical conditions of a stream?

- Can changes in the macroinvertebrate community be related to logging and road-building (e.g., sediment deposition, landslides, temperature increases)?

These questions are used to evaluate key biological conditions in the watershed and to identify components of streams that are vulnerable to future impact. Repeated biological monitoring is used to measure the effectiveness of restoration efforts in the watershed.

Assumptions

Variability in Macroinvertebrate Communities

Populations and Communities

Macroinvertebrate populations have a "patchy" distribution in streams (their abundance varies by location in a stream). Localized abundance of a population is a result of a favorable combination of physical and chemical stream conditions. These naturally occurring combinations do not occur everywhere and tend to favor select invertebrate populations.

A community is an aggregation of several macroinvertebrate populations. Expressions used to describe communities (e.g., total number of species) are not as variable between locations in a stream as are population expressions. A community expression is less variable because a species function can be filled by others in time or space. For example, the species in community A may share 75 percent of the same species in community B, 25 percent remaining different between the two. Yet the total number of species in both communities could be the same. The species composition of two communities could be different, but number of species the same.

Environmental Factors as Sources of Variability

The changing stream environment influences where and when macroinvertebrates will reach a community condition potential. Seasons are characterized by changes in climate which, in turn, influence stream conditions. Water temperature varies by season and regulates growth of macroinvertebrate species. It's more common to identify temperature-related effects on biota between streams than within the same stream reach.

Volume of water in a stream (cfs), or flow, is influenced by seasonal climate patterns. Seasons when snowmelt or rain are dominant sources of water directly correspond with intensity and frequency of physical disturbance in the stream channel. High current velocities and greater volumes of water moves rock and wood substrates on which macroinvertebrates make their home. Changes in timing and intensity of high flows can be due to human influence and is manifested at the stream reach level by increased variability in the biotic community.

Macroinvertebrate distribution in a stream reach also corresponds with food availability. Food that originates from within the stream (attached algae) is dependent on seasonal water conditions *(i.e.,* temperature, nutrients) and length of daylight. Food that falls into the stream from outside sources (sticks, leaves, twigs) is an important energy contribution to ecosystems when primary production (algae growth) declines. The division between origin of food sources ensures a constant energy base throughout a year. A continuum of macroinvertebrate community condition is maintained and varies between seasons, but not within a season.

Consistent benthic macroinvertebrate response to stream and riparian alteration are used to evaluate community condition and diagnose causes of degradation. The following assumptions outline the basis for macroinvertebrate community analysis:

Assumptions for Analyzing Communities

- Benthic macroinvertebrate communities respond consistently to stream disturbance (e.g., sedimentation, riparian alteration).

- Characteristics of the community (or "metrics") change from the least disturbed condition when physical habitat is destabilized by adjacent land uses.

- Species richness (total no. of species) and the Ephemeroptera, Plecoptera, Trichoptera Index (EPT Index) decrease when coarse substrate is filled with tine-grained sediments. Reduction of substrate variety results in fewer available microhabitats for macroinvertebrate colonization. Stream scour and sedimentation of the stream bottom are common sources of degradation following some logging activities.

- Riparian canopy removal that alters stream temperature also influences the presence of cold-water taxa (e.g., Plecoptera). Temperature peaks influence the: 1) survival of cold-water species, and 2) the consumable allochthonous (e.g., leaves, sticks, twigs) food source (a reduction with riparian tree harvest) (Ward, 1984; Stewart and Stark, 1989).

- Macroinvertebrate taxa that live two or more years in the aquatic phase *(i.e.,* some Plecoptera taxa) indicate perennial stream flow.

- Macroinvertebrate species that are multivoltine (many generations per year) indicate the periodic nature of water availability in a stream channel or severe disturbance. Multivoltine species are typically resistant to intense and frequent natural and anthropogenic disturbance.

Overview of Approach and Products

Biological metrics are generated from macroinvertebrate data collected in a stream reach. Individual biometrics describe specific attributes of the community and have unique ecological significance. Interpretation of stream community condition uses all biometrics. Individual biometrics help determine the type of degradation or change to the physical environment, that result from forest management activities.

Stream biological condition is evaluated on the basis of forest management activities and the different effects they have on streams. Sample sites are selected within a watershed beginning with least disturbed through those that show signs of stream channel degradation. These sets of streams have similar characteristics in sub-basin geology and channel segment type.

Biological assessment in Watershed Analysis is a screening tool that also addresses vulnerability of the resource. The type of sites chosen should include: 1) identification of sensitive channel segment types, and 2) stream segments where logging and road-building are present.

Qualifications

Qualified personnel that will conduct biological assessments can have two levels of experience. Visual assessments of the stream macroinvertebrate communities require more experience with invertebrate ecology. Training Level 1 requires the evaluation of stream biota by quantitative methods and is less reliant on specialized training. Training Level 2 reflects the specialized training necessary to conduct reliable surveys in the absence of quantitative sample collection.

Education and Training: Level 1

Bachelor's Degree in aquatic entomology or ecology, *or* in a related field such as fisheries science, zoology, limnology, etc.

At least two years of field experience in conducting stream assessments, interpretation of environmental information (especially biological), and design of monitoring or survey programs. Familiar with the ecology of aquatic insects and use of taxonomic keys. Able to accurately identify most aquatic insects to genus.

Education and Training: Level 2

Master's Degree in aquatic entomology or ecology, or in a related field.

A substantial amount of field experience and preparation of peer reviewed work should accompany. Familiar with the ecology of aquatic insect species. Able to interpret a complex matrix of environmental information (biological, physical, and chemical variables). Four years of experience conducting stream assessments and ability to accurately identify most aquatic insects to species.

Methods

Background Information

Maps & Physical Patterns

Several types of information are necessary for planning the biological surveys. Site selection for sampling is intended to represent stream segments at risk within the watershed. Site location should coincide with those in other Watershed Analysis modules: Mass Wasting (mass wasting map units and hazard units), Surface Erosion (soil erosion potential), Hydrologic Change (land use and vegetative cover), Stream Channel Assessment (channel segment map), Riparian Condition and Fish Habitat Condition.

Watersheds will have different physical settings. Site selection for biological surveys will consider the unique aspects of a watershed, especially when choosing the reference condition (complete description under "Level 1 Assessments").

Taxonomic Keys

High quality biological information depends on the quality and confidence in identification of species. A good set of taxonomic reference materials are required to accurately identify all macroinvertebrates. Two categories of taxonomic keys exist: 1) general keys describing several orders, and 2) specialized keys and taxonomic notes describing single orders or species. The following is a list of useful literature that describes both general and specialty taxonomic keys.

General Taxonomic Keys

- (Merritt and Cummins, 1996) An Introduction to the Aquatic Insects of North America, 3rd ed.
- (Pennak, 1978) Freshwater Invertebrates of the United States
- (Usinger, 1963) Aquatic Insects of California with keys to North American genera and California Species
- (Edmondson, 1959) Freshwater Biology
- (Stehr, 1987) Immature Insects, Volume I
- (Thorp and Covich, 1991) Ecology and Classification of North American Freshwater Invertebrates

Specialty ***Taxonomic Keys***

- (Needham et al., 1935) The Biology of Mayflies
- (Edmunds et al., 1976) The Mayflies of North and Central America
- (Jensen, 1966) The Mayflies of Idaho (Ephemeroptera)
- (Baumann et al., 1977) The Stoneflies (Plecoptera) of the Rocky Mountains
- (Stewart and Stark, 1989) Nymphs of North American Stonefly genera (Plecoptera)
- (Wiggins, 1996) Larvae of the North American Caddisfly genera (Trichoptera), 2nd ed.
- (McAlpine et al., 1981) Manual of Nearctic Diptera, Volume 1
- (Burch, 1982) Freshwater Snails (Mollusca: Gastropoda) of North America

Several publications are available that detail species identification for a variety of macroinvertebrate Orders. A list of these publications can be found in Clark (1991). This document is periodically updated to include taxonomic literature that is recently available.

Analysis Procedure

Vulnerability of Macroinvertebrates to Stream Degradation

Macroinvertebrates are dependent on microhabitat conditions (cobbles in riffles or fine grains in pools) in a stream. Human activity that degrades microhabitat beyond natural variation is a significant change and has consequences to resident biota. Stream macroinvertebrates respond to small changes in the physical habitat and warn of long-term cumulative impact.

Vulnerability of the macroinvertebrate community to stream degradation is determined through taxa that have specialized living requirements. An estimate of the likelihood with altered required living conditions *(i.e.,* the specialized taxa) indicates the proportion of taxa in a community sensitive to unexpected change. Specialized taxa include those that belong to groups who are: cold-water obligates, intolerant to sedimentation, or long-lived (two or more years). The greater the number of specialized taxa in a community, the more vulnerable a biological community is to unexpected change.

Selection and Characterization of Survey Sites

- What land uses occur in the watershed?
- What are the stream (channel) types of each macroinvertebrate survey site?
- Are particular stream types in the watershed sensitive to physical/riparian alterations?
- Which biometrics respond to apparent degradation in streams?

Level 1 Assessments

Location of Survey Sites

Available information from watershed analysis modules or other sources (see information types in "Background Information" section) set the framework for building a candidate list of survey sites. Consultation with personnel familiar with the physical condition of the watershed is necessary while developing a list of sites. The final list should reflect a gradient of stream conditions in order to predict which combinations of physical and biological features are vulnerable to poor forest management activities.

Reference Site Criteria

In the absence of biological criteria for determining health of a stream, it is necessary to choose reference sites within the watershed. A set of guidelines for identifying reference sites follows these steps (Larsen, Personal Communication):

- map potential areas where reference sites are expected,
- evaluate whether candidate reference areas are concentrated in one part of the watershed or are in a variety of locations (candidate sites may not be physically comparable to degraded sites if they are unique to a small portion of the watershed),
- eliminate areas with relatively high human modifications (past and present),
- field visits: verify current conditions of each site,
- choose reference sites that approximate stream type and setting as those that will be surveyed for suspected degradation.

Consultation with regional and local biologists could add valuable background information in the search for reference sites.

Habitat Identification

Samples are collected from riffles and pools. Sediment impacts occur in both habitats and result in a disturbed stream channel.

Definitions for riffles and pools within stream reaches are important for two reasons. Consistency in stream habitat identification is critical when more than one survey team is collecting benthic macroinvertebrates, and when site comparisons are being made.

Riffles are defined as portions of a stream characterized by broken surface water. The riffle habitat can be shallow where substrate materials rise above the surface of the water or can be deeper where large substrate particles (boulders) cause surface water turbulence. Pool habitat has more variable condition than does riffle habitat. Pools may be identified as: 1) side channel eddies, 2) deep standing water at the side of a channel, or 3) the zone of stagnant water behind a large boulder (i.e., better characterized as a zone of deposition). Criteria for designation of pools are: 1) presence of depositional materials (inorganic and organic), 2) absent or diminished water velocity, and 3) relative homogeneity of substrate materials. Streams in mountainous regions often have high gradients and conform to a cascade-pool stream channel configuration. Riffles and pools are identified in these streams based on their unique habitat types within a particular reach. A riffle and pool are relative designations of water type and are determined on a site-specific basis. Record the unique properties of a habitat type when it is atypical.

Sampling Benthic Macroinvertebrates within a Stream Reach

Stream reach length is defined as approximately 40X the average stream width. This reach length is representative of the variety of stream habitat that exists within the stream channel (Kaufmann and Robison, 1994). The lower end of the stream reach is randomly located and always begins at the base of a riffle. A stream reach should be no longer than 500 meters when surveying broad, wadeable channels.

Location of four riffle sites and four pool (or depositional) sites are identified within the stream reach and sampled for benthos. Identification of riffle and pool sites for benthic macroinvertebrate sampling is critical for accurately representing the variety of species that occur within a reach.

The collector locates riffle and pool sites by visually identifying four different riffle habitats and four different pool habitats. Site location for sampling is based on stratification by stream channel features. Stratification of riffle habitat is based on:

- water depth
- substrate composition
- position within a riffle (e.g., head or foot).

Stratification of pool habitat is based on:

- water depth
- location of the pool within the stream channel (e.g., side-channel eddy, depositional zone behind a boulder, mid-channel depression).

Physical identification of collection locations are made by placing one flag at each riffle and pool site. The flags are labeled R1 through R4 and represent each of the riffle replicates. Pool replicates are labeled P1 through P4. All riffle and pool locations are reviewed by all surveyors in the field team before sampling begins.

Acquisition of the maximum number of species enables a more complete interpretation of biological information at a site. Observations addressing water quantity, water quality, habitat quality, natural influences, and anthropogenic influences are made by examining the biological community.

Collection of Macroinvertebrate Samples

Sampling begins at the lowermost riffle location and progresses upstream to the next collection site. Contamination of downstream collection sites with drifting macroinvertebrates will result if collection does not progress in an upstream direction.

Benthic macroinvertebrates are collected from riffles with a D-frame kicknet. Net mesh size on the collection net should be 500 micrometers (0.5 mm). The net is one foot wide and has a net length of about two feet. Area of collection at each riffle and pool site is one foot wide (the kicknet width) and two feet upstream of the kicknet mouth. The D-frame kicknet is placed flat on the substrate and a 1 foot x 2 foot area upstream of the net is disturbed by hand (a one foot x two foot square may be placed on the stream bottom to ensure uniformity of collection area between surveyors and between sites). Shortly following, the collector scrubs the surface of each rock with a scrub-brush to remove clinging benthic animals. After a rock is scrubbed, it is placed outside of the sampling area. All rocks within the sample area should be scrubbed and then the sample area is disturbed with the foot, digging deeper into the substrate. Sampling activity per riffle site should take a minimum of two minutes.

Riffle samples are stored in separate containers after collection. Maintaining each riffle sample in individual containers is recommended for measuring within-reach variability and for detecting significant differences between control and treatment sites. If the samples are to be composited, it is good practice to empty each riffle sample after they are collected into the storage container. This will ensure that sampled material is not lost while collecting material from the remaining riffle sites. Field samples are stored in 85 percent ethanol.

Pool samples are more difficult to collect. Escapement of benthic-dwelling animals is possible with the absence of a steady current. The D-frame kicknet is placed on the stream bottom and a 1 foot x 2 foot area upstream of the collection net is disturbed by foot. Stream bottom material will be suspended in the water column, particularly the organic material, and is actively "scooped" up with the collection net. Scooping requires removal of the net from the stream bottom and collecting as much suspended material as possible from the water column. The net should follow a path of 1 foot x 2 feet through the water column when collecting the suspended material. Disturbance of the substrate and scooping with the net is done several times to ensure collection of most material in the pool collection area. Collection at each pool location within a reach is continued for a period of two minutes.

Sample Sorting

Samples collected from the field are sorted in the laboratory. The riffle and pool samples collected at each site are sub-sampled. Macroinvertebrates are removed from a minimum of two squares randomly chosen in a tray that has 30 squares. The individual squares are 6 cm x 6 cm and the overall dimension of the tray is 30 cm x 36 cm. The sample material is spread evenly on the base of the grid tray. All organisms are removed from randomly chosen squares until a minimum of 500 macroinvertebrates are picked and the process is continued to include all remaining in the squares. Macroinvertebrates that have been sub-sampled are stored in 70 percent ethanol.

Tuxonomic Identification

All freshwater macroinvertebrates are identified to at least the generic level and to species where existing taxonomic keys are available. Taxa groups normally identified to higher taxonomic levels include: Chironomidae, Simuliidae, Lumbriculidae, Naididae, select families of Coleoptera, Planariidae, and Hydracarina (suborder). In a case where any one of these taxonomic groups are dominant in the stream reach, they should be identified to genus.

Quality Assurance for Laboratory Work

The sub-sampling procedure is evaluated by resorting field samples. Normally, 10 percent of the benthic macroinvertebrate samples are checked for precision under quality assurance. Discrepancies between sorting results indicates the need for:

- more thorough distribution of sample materials in the sub-sampling tray,
- special attention given to easily missed taxa when sorting.

Accuracy of taxonomic identification is verified from ten percent of the samples collected in a project. Sub-samples may be provided to qualified taxonomists for re-identification. Difficult taxa are sent to museum curators whose specialty includes members of a particular Order. Site samples that are re-identified correspond with the sites used to evaluate the sub-sampling procedure.

Physical Habitat Measurement and Water Chemistry

Evaluation of physical characteristics of the stream reach include: water quantity, channel morphology, and substrate composition. Riparian canopy shading the stream surface is also measured. The variables measured are physical characteristics of a stream reach likely to be influenced by changes to the riparian corridor and watershed land use such as water temperature or dominant substrate size.

The field forms in Appendix A outline physical and chemical variables measured at each stream. Surface water variables are measured with electronic meters. Qualitative observations are recorded for conspicuous odor or color of surface water and sediment. Additional visual information is recorded with photographs and detailed field notes.

Stream reach profile, stream discharge, substrate composition, current velocity, and canopy cover are detailed physical observations. The potential for bedload movement (shear stress), at various flow levels can be estimated at most reaches by methods described in the Hydrology Module (WFPB, 1995). The relationship between the physical environment and biological condition provides clues for the type and source of degradation in streams.

Calculating the Biological Metrics

Descriptions of the aquatic insect community are called biometrics. Each of the biometrics characterize an attribute (structural or functional) of the community. Many biometrics are available for describing macroinvertebrate communities. The following are appropriate for watershed analysis: species richness, EPT Index (Ephemeroptera, Plecoptera, Trichoptera Index), % Ephemeroptera (except Baetidae), % Plecoptera, % Ephemerellidae, % Dominant taxa (3, 2 and 1 species), % Scrapers, % Shredders, % Perlidae, % Pteronarcyidae, % Hydropsychidae, % Simuliidae, Peltoperlidae, Perlidae, % Chironomidae, % Brachycentridae, % Baetidae, % Diptera and % Tanytarsini and Orthocladiini.

Species richness	Count all of the distinct species identified in the sample (if the extent of identification is order or family, count these as distinct species).
EPT Index	Count the total number of distinct species in the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies).
% Ephemeroptera (except Baetidae)	*Step 1*. Add all density estimates for species in the mayfly order (except density estimates for species in the family Baetidae), *Step* 2. Divide by the total density estimate for the sample, *Step* 3. Multiply by 100.
% Plecoptera	*Step* I. Add all density estimates for species in the stonefly order, *Step 2*. Divide by the total density estimate for the sample, *Step* 3. Multiply by 100.
% Ephemerellidae	*Step* 1. Add all density estimates for species in the mayfly family Ephemerellidae, *Step 2*. Divide by the total density estimate for the sample, *Step* 3. Multiply by 100.
% Dominant Taxa	*Step* 1. Identify the most abundant individual species, *Step* 2. Divide by the total density estimate for the sample, *Step* 3. Multiply by 100. (also include the next two most abundant individual species with the single most abundant and repeat Steps 2 & 3 = % 3 Dominant Taxa)
% Scrapers	*Step* 1. Add density estimates for species functionally classified as "scrapers" (see Merritt and Cummins 1996), Repeat *Step 2 & Step 3.*
% Shredders	*Step 1*. Add density estimates for species functionally classified as "shredders" (see Merritt and Cummins 1996), Repeat *Step 2 & Step 3.*

% Perlidae	*Step* 1. Add density estimates for species belonging to the Perlidae stonefly family, Repeat *Step 2 & Step 3.*
% Pteronarcyidae	*Step* I. Add density estimates for species belonging to the Pteronarcyidae stonefly family, Repeat *Step 2 & Step 3.*
% Hydropsychidae	*Step 1.* Add density estimates for species belonging to the Hydropsychidae caddisfly family, Repeat *Step 2 & Step 3.*
% Simuliidae	*Step* I. Add density estimates for species belonging to the Simuliidae blackfly family, Repeat *Step 2 & Step 3.*
Peltoperlidae	Indicate presence/absence of species that belong to the stonefly family Peltoperlidae.
Perlidae	Indicate presence/absence of species that belong to the stonefly family Perlidae.
% Chironomidae	*Step* I. Add density estimates for species belonging to the Chironomidae midge family, Repeat *Step 2 & Step 3.*
% Brachycentridae	*Step* 1. Add density estimates for species belonging to the Brachycentridae caddisfly family, Repeat *Step 2 & Step 3.*
% Baetidae	*Step* 1. Add density estimates for species belonging to the Baetidae mayfly family, Repeat *Step 2 & Step 3.*
% Diptera	*Step 1.* Add density estimates for species belonging to the order Diptera (midges, blackflies, and mosquitoes), Repeat *Step 2 & Step 3.*
% Tanytarsini & Orthocladiini	*Step* 1. Add density estimates for species belonging to the midge tribes Tanytarsini and Orthocladiini, Repeat *Step 2 & Step 3.*

Interpreting the Biological Condition (Biological Metrics)

Each biometric relates to stream quality. Evaluation of several biometrics enables biological information to be used as a diagnostic tool. The following are brief interpretations for each biometric:

Structural Attributes

Species Richness	Total number of species in the sample (indicates the variety of living spaces available to aquatic insects).
EPT Index	Presence of taxa generally considered to be sensitive to alterations in stream quality (mainly cold-water taxa).
% Ephemeroptera	Most of the mayfly taxa are sensitive to any alterations of stream condition (except Baetidae), especially to input of toxic point source pollution.
% Plecoptera	Stonefly taxa are limited to cool water streams with adequate dissolved oxygen concentrations.
% Ephemerellidae	Larger representation of species generally indicates a greater habitat complexity.
% Dominant taxa	The proportion of the three-, two-, and single most dominant species in the community are calculated. Scores of 50-60 percent or greater indicate instability in the community and that a stressor is present.
% Baetidae	A relatively tolerant family of mayflies that live in a wide range of stream types. High numbers in a community represent a decline in habitat & water quality.
% Tanytarsini & Orthocladiini	Midge larvae generally found in running water and are a well-represented group in freshwaters. High numbers indicate intermittent flow pattern and/or sedimentation.
% Diptera	Relatively tolerant group of invertebrates that are associated with sedimentation of fines and/or nutrient enrichment.
% Perlidae	A stonefly family that requires cool water temperature and a variety of mid-range substrate sizes.
Peltoperlidae taxa	A rare stonefly specialist that is found in aquatic moss. The moss (presence/absence) traps organic particles consumed by these species. Indicates habitat integrity.

Functional Attributes

% Scrapers	Taxa that indicate the presence of primary productivity (i.e., periphyton)
% Shredder taxa	Taxa that indicate high retention of organic matter and presence of allochthonous input (e.g., leaves, sticks).
% Hydropsychidae	A widely-distributed filtering caddisfly that appears in greater numbers with rising suspended particulates.
% Simuliidae	High densities usually indicate a high concentration of suspended organics in the water column.
% Brachycentridae	A caddisfly group intolerant of temperature increases and sedimentation. Requires stable and large substrates for attachment and a modest concentration of suspended organic particles as a food source.

Life History Attributes

% Pteronarcyidae	A long-lived species that is moderately tolerant of disturbance Requires cooler water temperatures and consumes coarse particulate organic matter (shreds leaves).
Perlidae Taxa	A long-lived predatory family of stoneflies that requires cool water and a variety of coarse gravel and cobble substrate.
% Chironomidae	Ubiquitous family in freshwater streams; often responds to degradation with density increases. Species in this family have short complete life cycles and can survive in temporary aquatic habitats.

Interpreting Biological Information

Stream degradation, if present, is determined by examining the response of each biometric, Changes in biometrics have ecological relevance and are used to diagnose the origin of degradation. Flow charts for identifying stream degradation are located in Appendix B. Flow charts and interpretation of data is summarized in Part II Sol Duc Case Study.

Biological surveys are often limited to a few site visits. The sites chosen for sampling should reflect a gradient of human influence, including minimally-disturbed, to identify type and severity of impact. These biological surveys are intended to provide a cumulative assessment of stream reach health.

Level 2 Assessments

Level 2 assessments of benthic macroinvertebrates involve greater knowledge of invertebrate ecology. Conducting biological assessments at this level in watershed analysis is a rapid survey. An investigator should be familiar on-site with benthic macroinvertebrate: 1) behavior, 2) feeding relationships, and 3) habitat preferences. Level 2 analysis for biological assessment is a good reconnaissance exercise in preparation for designing a diagnostic survey program.

Summary Data

A description of benthic macroinvertebrate condition and stream channel characteristics, including water quality, are provided in several tables. The summary data are arranged in tables that are found in Part II Sol Duc Case Study (Table 1-4 and Table 8).

Confidence in Assessment

Site selection must adequately represent a continuum of stream reach conditions, *a priori*. Identification of benthic macroinvertebrate taxa should meet the minimum quality assurance guidelines. Each of the summary data tables should be completed to provide accurate characterization of current biological conditions.

Part II Sol Duc Case Study

Introduction

Five sites were surveyed in the Mid-Sol Duc Watershed Assessment Unit (WAU) for the purpose of demonstrating how to evaluate biological conditions and how condition interpretation compares with other module conclusions. Some of the steps in analyzing data from the raw biological data matrix were introduced in Part I. The data are compiled and organized in Part II for interpreting biological condition and relating this to stream health. The relationship to stream health is based on known physical and chemical requirements of macroinvertebrates collected from a site and identifying the species not present.

Methods and Materials

Study Sites

Benthic macroinvertebrate samples were collected at five sites from the mid-Sol Duc watershed (Figure 1). Samples were collected in April 1995. Macroinvertebrate sampling is recommended during late summer through early fall for the following reasons: 1) streams are wadeable during low flow, 2) most invertebrates are at the latter stages of development and are easily identified, and 3) species collected represent the most recent stream disturbance(s).

However, sampling was conducted earlier in this study to determine the applicability of biological monitoring during other times of the year when watershed analysis was likely to occur. Site locations were chosen to coincide with surveys completed for other Watershed Analysis modules.

The Bockman Creek and Kugel Creek sub-watersheds were evaluated using several of the watershed analysis modules. Littleton Creek was evaluated with a single channel condition module. The description of resource condition using the modules was based on entire sub-watersheds. In contrast, the biological assessment evaluated condition of multiple stream reaches within a sub-watershed. Biological assessment evaluated resource condition at a smaller scale than did the other modules.

Stream reaches were chosen to represent heavily logged areas, a least disturbed area, and conditions that fell in between. Kugel Creek assessment had an upstream intact forest site and a downstream logged site. Bockman Creek assessment had an upstream logged site and a downstream re-growth site. Littleton Creek was a least disturbed site without logging in the drainage and served as a control.

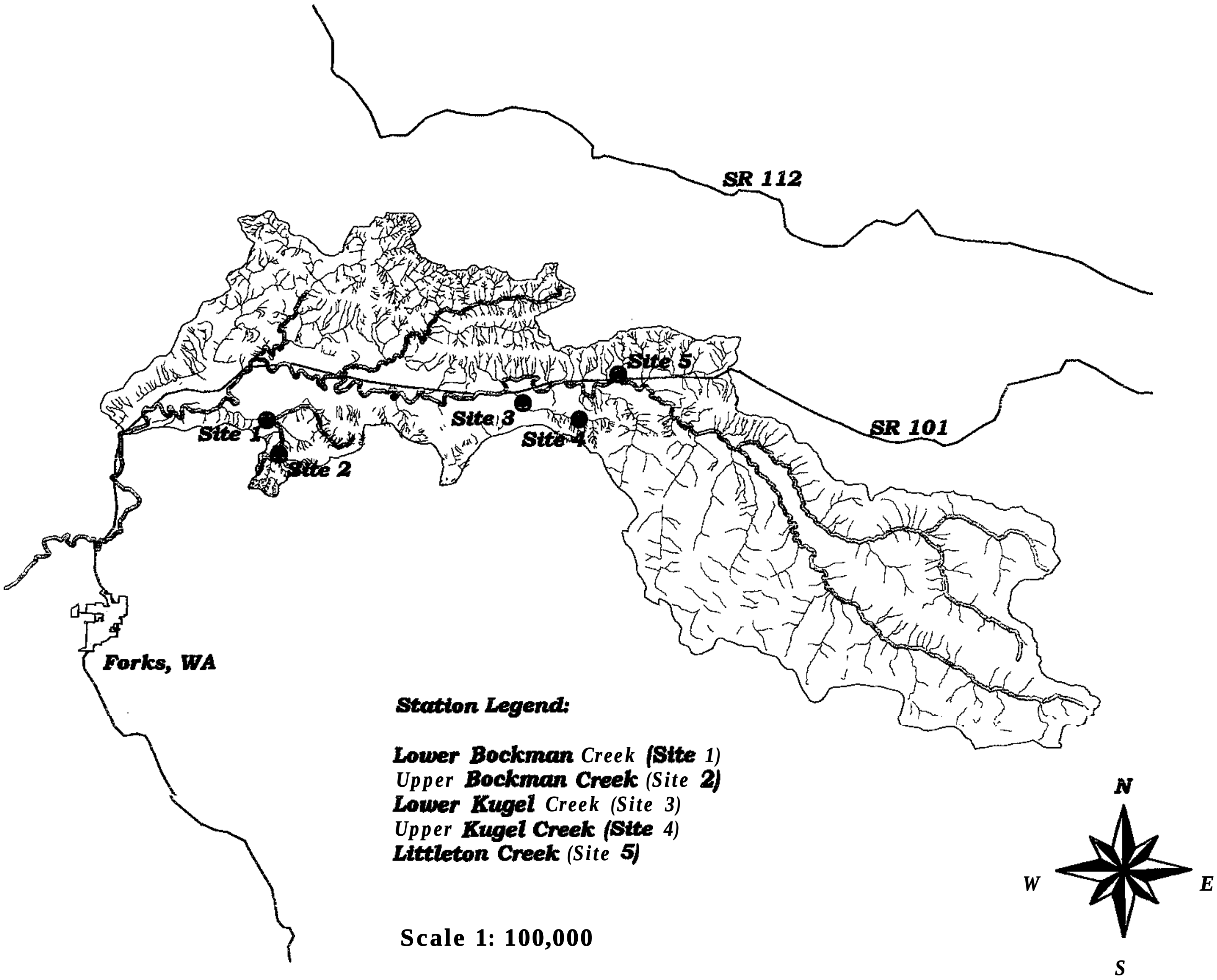

Figure 1. Biological survey site locations for the mid-Sol Duc watershed analysis project.

Personnel

Five stream sites were sampled in three days. A field crew of four, including a senior biologist, averaged two site surveys per day. A minimum of three field crew could achieve similar results. A senior biologist should always be present at the surveyed sites. The cost to conduct this survey is itemized in-Appendix C.

Sampling

The protocol for sampling macroinvertebrates was described in Part I. Physical measurements of the stream channel were co-located with the four macroinvertebrate samples collected at a reach. Identification of stream degradation and its source is possible with the close spatial association between biological sample collection and channel characterization.

Results and Discussion

Biometric Results

Biometrics were calculated for the replicate samples and composited pool sample (Appendix D) at a site. Each biometric in riffle and pool samples is arranged under three categories describing stream quality: a) Instream Condition Analysis, b) Water Quantity Analysis, and c) General Indicators (Table 1). Physical and biological characteristics were recorded for each riffle location sampled in the stream reach (Table 2).

Some of the biometrics in Table 1 were highlighted with bold type and underlined. These data represent the "high", and in some cases the "low", range of biometric scores from all samples collected in the watershed. High/low designations were introduced in the Diagnostic Flow Charts (Appendix B) for interpreting biometrics results.

High and low score ranges for each biometric were determined by ranking all observations. Vertical lines were drawn at the right of each data summary to represent biometric ranges for each site (Appendix E). A "high" score designation for a biometric was determined when:

- at least three-of-four biometric scores for a site exceeded the 25^{th} percentile of all observations from mid-Sol Duc sites, and
- at least one-of-four scores exceeded the 75^{th} percentile of the same set of observations

Failure to satisfy both conditions resulted in a "low" biometric score.

Differences in biometric ranges for each site should be generated to associate biological response with physical and chemical characteristics. Similar biometric ranges at all sites would preclude the association of a biological response with the source of degradation. Diagnosis of subtle impacts would then be difficult to detect.

Table 1. Ranges for key biometrics in riffle and pool habitats for each survey site of the mid-Sol Duc watershed.

	Bockman Creek				Kugel Creek				Littleton Creek Control	
	Site 1		Site 2		Site 3		Site 4		Site 5	
	Riffle	Pool	Riffle	Pool	Riffle	Pool	Riffle	Pool	Riffle	Pool
A. Instream Condition Analysis										
1. Habitat Complexity										
Species Richness	**34-40**	36	**21-43**	31	16-19	22	13-26	17	17-26	24
% Ephemerellidae	1.9-4.8	14.5	1.2-2.5"	11.8	O-9.9	0	0.9-9.5	0	O-9.0	1.4
Periidae	present		present		present		present		present	
2. Food Quality										
% Pteronarcyidae	**0**	**0**	**0**	**0**	**0**	**0**	**0-1.4**	**0**	**0-7.1**	2.7
% Shredders	0.8-3.1	44.8	1.4-2.9	44.6	1.7-4.6	29.0	**1.6-8.2**	19.8	3.6-14.0	6.8
Peltoperlidae	absent		absent		absent		absent		**present**	
% Hydropsychidae	**2.0-4.8**	0	1.7-1.9	4.0	o-1.2	0	**0**	**0**	**4.6-7.9**	1.4
% Simuliidae	1.3-3.8	0	0.2-4.4	0	o-11.5	0	1.6-18.9	0	o-9.5	0
% Scrapers	67.8-84.0	3.5	57.6-76.9	1.8	41.7-78.2	7.3	28.8-49.1	4.2	16.4-60.6	20.3
% Brachycentridae	0	0	0	0	0	0	0	0	**1.12**	0

Note: All highlighted data indicates a high biometric range except for data marked with an (*) which indicates a low range of observations.

Table 1 (Continued). Ranges for key biometrics in riffle and pool habitats for each survey site of the mid-Sol Duc watershed.

	Bockman Creek				Kugel Creek				Littleton Creek Control	
	Site 1		Site 2		Site 3		Site 4		Site 5	
	Riffle	Pool	Riffle	Pool	Riffle	Pool	Riffle	Pod	Riffle	Pool
B. Water Quantity Analysis										
1. Flow										
Pteronarcyidae	absent		absent		absent		**present**		**present**	
Perlidae	**present**		**present**		**present**		**present**		**present**	
% Simuliidae	1.3-3.8	0	0.2-4.4	0	o-11.5	0	1.6-18.9	0	o-9.5 0	0
% Tanytarsini & Orthocladiini	1.2-4.8	17.2	2.3-4.0	10.5	0-3.0	7.3	o-1.9	26.0	0-3.9	2.7
2. Temperature										
% Plecoptera	4.6-6.5	3.5	3.5-7.0	3.3	10.9-43.3	1.5	16.4-39.7	47.9	13.5-29.9	40.5
% Ephemeroptera (except Baetidae)	35.1-56.2	18.6	**35.2-50.8**	12.5	23.0-48.5	8.7	15.2-31.7	4.2	7.3-28.8	18.9
% Diptera	1.7-10.1	57.2	6.2-10.8	**92.8**	1.5-12.6	59.4	1.6-24.2	18.8	O-15.8	14.9
% Baetidae	23.9-38.1	0.7	16.9-40.1	0	11.7-35.4	0	**14.3-20.4***	0	7.3-33.3	5.4
3. Habitat Availability										
% Chironomidae	1.4-6.1	**47.6**	3.5-5.4	86.9	o-3.3	**56.5**	0-2.7	7.3	o-3.9	5.4
% Baetidae	23.9-38.1	0.7	16.9-40.1	0	11.7-35.4	0	**14.3-20.4***	**0**	7.3-33.3	5.4

Table 1 (Continued). Ranges for key biometrics in riffle and pool habitats for each survey site of the mid-Sol Duc watershed

	Bockman Creek				Kugel Creek				Littleton Creek Control	
	Site 1		Site 2		Site 3		Site 4		Site 5	
	Riffle	Pool	**Riffle**	Pool	**Riffle**	Pool	**Riffle**	Pool	**Riffle**	Pool
C. General Indicators										
% 3 Dominant Taxa	53.2-68.7	38.6	59.7-67.1	76.1	49.2-62.1	37.7	50.7-71.4	65.6	43.9-63.6	43.2
% 2 Dominant Taxa	47.5-58.6	28.3	44.7-60.1	68.0	35.4-51.7	26.1	34.3-57.1	58.3	34.9-60.0	35.1
% 1 Dominant Taxon	29.4-45.5	14.5	30X-38.7	41.4	20.0-36.7	14.5	17.6-36.5	42.7	20.5-54.6	25.7
EPT Index	**22-26**	9	13-27	10	12-15	6	9-17	9	**15-19**	15

Table 2. Physical and biological characteristics for repeated samples collected from each survey site in the mid-Sol Duc watershed.

Site	Invertebrate Density (no./2.0 ft^2)	Temperature (°C)	Depth (m)	Wetted Width (m)	Flow (cfs)	Dominant Substrate	Sub-dominant Substrate	Canopy Cover (% closed)
Site 1								
riffle 1	396	6.0	0.13	4.57	7.42	Cobble (58%)	C. Gravel (22%)	62%
riffle 2	800		0.12	6.10		F. Gravel (56%)	C.Gravel (36%)	16%
riffle 3	749		0.06	5.49		Cobble (66%)	C. Gravel (28%)	40%
riffle 4	539		0.18	7.92		C. Gravel (38%)	F. Gravel (36%)	47%
Site 2								
riffle 1	678	7.0	0.08	8.23	5.97	F. Gravel (70%)	C. Gravel (28%)	56%
riffle 2	173		0.13	3.96		F. Gravel (64%)	C. Gravel (36%)	51%
rime 3	479		0.14	7.92		F. Gravel (52%)	C. Gravel (44%)	57%
riffle 4	686		0.15	6.71		C. Gravel (46%)	Cobble (42%)	47%
Site 3								
riffle 1	101	8.0	0.17	3.96	7.96	Cobble (38%)	C. Gravel (38%)	40%
rime 2	65		0.26	5.49		C. Gravel (48%)	Cobble (32%)	51%
riffle 3	60		0.28	4.57		Cobble (40%)	C. Gravel (40%)	66%
rime 4	87		0.12	4.57		C. Gravel (58%)	Cobble (26%)	40%
Site 4								
riffle 1	132	7.1	0.17	6.40	8.62	Cobble (50%)	C. Gravel (28%)	16%
riffle 2	63		0.09	4.57		F. Gravel (40%)	C. Gravel (38%)	29%
rime 3	108		0.22	3.96		Cobble (40%)	Boulder (30%)	54%
riffle 4	73		0.27	3.05		Cobble (42%)	Boulder (26%)	60%
Site 5								
riffle 1	127	7.0	0.11	2.74	3.40	Cobble (46%)	C. Gravel/Boulder (23%)	75%
rime 2	66		0.14	4.57		Cobble (66%)	C. Gravel (20%)	71%
rime 3	55		0.16	3.05		Cobble (60%)	C. Gravel (20%)	84%
riffle 4	89		0.12	5.18		Cobble (62%)	C. Gravel (26%)	56%

A gradient of stream conditions should be sampled in a watershed to characterize the variety of biological communities associated with each. The performance of each biometric can be properly evaluated from response to high-quality and low-quality stream conditions. Failure to represent high quality sites diminishes the potential for detecting real impacts to stream biota and for conserving sensitive habitats.

Interpretation of Results and Problem Identification in Riffles

Results were interpreted based on the arrangement of biometrics in the Diagnostic Flow Charts (Appendix B). Interpretation of biological condition was focused on sites with highlighted biometrics (Table 3). The discussion provided for each biometric was repeated from the dichotomies offered in the Diagnostic Flow Charts (Appendix B). Stream reach condition was carefully summarized to help identify type and source of impact. Complete summaries and interpretations of the biological condition are in Table 3. The reporting of results and interpretation are arranged by a common group of stream characteristics important to macroinvertebrates in forested regions.

Stream quality problems were summarized in Table 4. Stream characteristics were evaluated for six categories (habitat complexity, food quality, flow, temperature, habitat availability, and overall health). A simple assessment index was used to evaluate site biological condition in each category (*e.g.*, "+" = optimal condition; "-" = degraded condition; "0" = condition was indeterminate). Indeterminate markers meant that two or more biometrics had conflicting interpretations. Biometrics that measured habitat availability (i.e., available habitat following sedimentation) and temperature, identified degradation in pool habitat.

Condition assessment of sites was decided from the interpretation summaries of Table 3. The assessment index, with three categories, translated a discussion of biological condition into a visual summary (Table 4).

Comparison to Results from other Modules

The benthic biological communities are integrators of stream condition over longer periods of time (one or two years). Community characteristics are used to reflect the physical and chemical composition of stream condition. Evaluation of community condition can be compared to results from some of the watershed analysis modules.

Some of the modules, such as Mass Wasting, measure large scale events in watersheds. The resulting effects can be measured at a smaller scale within the stream channel. Measurable change in the biological community depends on proximity to and time elapsed from a large-scale disturbance. The purpose for comparing biological condition to each module is to determine biological relevance of physical and chemical change in streams.

Table 3. Interpretation of relevant biometric responses describing health of riffle habitat at the survey sites of the mid-Sol Duc watershed.

Biometrics	Interpretation
A. Instream Condition Analysis	
i. Habitat Complexity	
Species Richness %Ephemerellidae	Lower- (Site 1) and upper-Bockman Creek (Site 2) contained greater habitat complexity. Species richness more variable at upper-Bockman Creek riffle habitat.
Perlidae	Predatory stoneflies that require complex habitat including flat-sided, free matrix stones were found at all sites.
2. Food Quality	
% Pteronarcyidae % Shredders	Consistent presence of shredder stoneflies indicate an intact deciduous canopy and instream leaf litter accumulation at upper-Kugel Creek (Site 4) and Littleton Creek (Site 5)
Peltoperlidae	Rare peltoperlid stoneflies in Littleton Creek (Site 5) were supplied with high quality depositional organic material trapped in aquatic moss.
% Hydropsychidae % Simuliidae	A small quantity of suspended organics present in the water column at most sites. The filtering invertebrates were best represented at Lower Bockman Creek (Site 1) and Littleton Creek (Site 5). The filtering caddis, *Hydropsyche sp.*, is a tolerant taxon and was found at lower-Bockman Creek. *Parapsyche elsis* is an indicator of high quality, cold-water habitat and was found at Littleton Creek.
% scrapers	The abundant scraper representation at lower-(Site 1) and upper-(Site 2) Bockman Creek sites indicated a more open riparian canopy and/or increased dissolved phosphorus concentrations.
% Brachycentridae	The filter-feeding caddisfly was present at Littleton Creek (Site 5) indicating the co-occurrence of large substrates and suspended organics.

Table 3 (Continued). Interpretation of relevant biometric responses describing health of riffle habitat at the survey sites of the mid-Sol Duc watershed.

Biometrics	Interpretation
B. Water Quantity Analysis	
1. Flow	
Pteronarcyidae Perlidae	Perennial supply of cool water at all sites.
% Simuliidae % Tanytarsini & Orthocladiini	No indication of intermittent or low flow problems at any sites. Short-lived taxa groups were not dominant at any site.
2. Temperature	
% Plecoptera % Ephemeroptera (except Baetidae)	Temperature-sensitive groups present at all riffle sites. Thermal stress to intolerant organisms possible in isolated habitat.
% Diptera	Temperature-tolerant taxa dominant at the upstream-Bockman Creek (Site 2) site
% Baetidae	Baetid mayflies dominant at lower-(Site I) and upper-Bockman Creek (Site 2) and lower-Kugei Creek (Site 3). Isolated temperature problems may occur.
3. Habitat Availability	
% Chironomidae	Sand-dominated or finer substrate in pools at lower-(Site I) and upper-Bockman Creek (Site 2) sites and lower-Kugel Creek (Site 3). Riffle samples at upper-Bockman Creek had the largest chironomid representation. These riffles may have contained a larger volume of sand in spaces of the dominant substrate.
% Baetidae	Fine sediment either present in larger quantities or transported through riffles. Lower-(Site I) and upper-Bockman Creek (Site 2), and lower-Kugel Creek (Site 3) sites were influenced by sand substrates.

Table 3 (Continued). Interpretation of relevant biometric responses describing health of riffle habitat at the survey sites of the mid-Sol Duc watershed.

Biometrics	Interpretation
C. General Indicators	
% 3 Dominant Taxa	Lower-(Site 1) and upper-Bockman Creek (Site 2) were dominated by scrapers and sediment-tolerant invertebrates. Lower-Kugel Creek (Site 3) dominated by sediment-tolerant taxa. Biological conditions at lower- and upper-Bockman Creek and lower-Kugel Creek riffles indicate sediment effects.
% 2 Dominant Taxa	Same pattern as for % 3 Dominant Taxa.
% 1 Dominant Taxon	Same pattern as for % 2 Dominant Taxa.
Pattern for Dominant Taxa	Coldwater-obligate taxa dominant in Littleton Creek (Site 5). Tolerant, ubiquitous mayfly taxa dominant at lower-(Site I) and upper-Bockman Creek (Site 2) sites and lower Kugel Creek (Site 3).
EPT Index	Large number ofgenerally sensitive taxa in riffles at lower-(Site 1) and upper-Bockman Creek (Site 2) and Littleton Creek (Site 5).

Table 4. Identification of site problems in riffle and pool habitat. Condition of the stream characteristic is determined by interpreting biological information (biometrics) from a site. A (+) indicates optimal stream condition, (-) indicates a degraded stream condition, and (0) indicates that stream condition was indeterminate.

Site	Habitat Complexity	Food Quality 1°	Food Quality 2°	Flow	Temperature	Habitat Availability	Overall Health
Site 1	+	+		+	0	-[2]	+
Site 2	+	+		+	-[1]	-[2]	
Site 3	0			+	+	-[2]	
Site 4	0		+	+	+	+	
Site 5	0		+	+	+	+	+

Note: "Food Quality" 1°=primary production food source (algae); 2°=secondary production food source (leaves)

[1] the pool habitat community almost entirely composed of temperature-tolerant organisms.

[2] pool habitat was composed primarily of fines that could be transported in high flow conditions.

Stream characteristics and biological conditions were related to several watershed analysis modules. The relationships were based on the type of stream degradation described in a module and the part of a biological community that responds to the change.

Table 5. Biological assessments were compared to a select group of modules. Equivalencies between the watershed analysis modules and stream characteristics, as addressed through biological assessment, are listed:

Watershed Analysis Module	Stream Characteristic (Biological Assessment)
a. Mass Wasting	Habitat Complexity General Indicators
b. Surface Erosion	Habitat Availability Habitat Complexity
c. Hydrologic Change	Flow Habitat Complexity
d. Riparian Shade	Temperature Food Quality

Difference in results between biological condition and the watershed analysis module should consider the vulnerability of aquatic life and individual life stages to degradation. The living space of stream biota is modified by changes to characteristics of the stream channel. Many combinations of the characteristics will produce adequate living conditions and may be a reason for some of the disagreements between biological interpretations and individual modules. The environmental resource can either be overprotected or underprotected based on interpretation of conditions.

Biological community vulnerability was rated as low-, moderate- or high risk from further degradation to current watershed condition. Interpretation of the vulnerability rating was based on the following:

Low risk — If the biological assessment described a community with cold-water taxa and key functional groups like "shredders".

Moderate risk — If the biological assessment described a community with isolated examples of degradation related to water temperature and sedimentation.

High risk: If the biological assessment described a community with obvious signs of degradation related to temperature and sedimentation.

Description of biological condition supplemented the interpretations from other modules and emphasized the significance of aquatic life in changing stream environments.

Table 6. Vulnerability of macroinvertebrate biota to further degradation from current conditions in the watershed.

Module	Site & Number	Condition	Biological Community Vulnerability
a. Mass Wasting (Hazard)	1. Lower Bockman	Moderate	Moderate risk
	2. Upper Bockman	Moderate	High risk
	3. Lower Kugel	High	High risk
	4. Upper Kugel	High	Low risk
	5. Littleton	Low	Low risk
b. Surface Erosion (Hazard)	1. Lower Bockman	High	Moderate risk
	2. Upper Bockman	High	High risk *
	3. Lower Kugel	High	High risk *
	4. Upper Kugel	High	Low risk
	5. Littleton	Low	Low risk
c. Hydrologic Change	1. Lower Bockman	High (low flows)	High risk
	2. Upper Bockman	High (low flows)	High risk
	3. Lower Kugel	High (peak flows)	High risk
	4. Upper Kugel	High (peak flows)	Low risk
	5. Littleton	Low (peak & low flows)	Low risk
d. Riparian Shade (Vulnerability)	1. Lower Bockman	Low	Moderate risk
	2. Upper Bockman	Low	High risk
	3. Lower Kugel	Low	High risk
	4. Upper Kugel	Low	Low risk
	5. Littleton	Low	Low risk

* Biotic condition degraded.

Note: "Condition" ratings from the modules report the potential for stream features to change based on recent evaluation of data.

Table 7. Comparison between fish habitat condition of streams and vulnerability of macroinvertebrate biota to further degradation at sites.

Module	Site	Condition (Fines in Substrate)	('Temperature)	Biological Community Vulnerability
Fish Habitat (Vulnerability)	1. Lower Bockman	High	High	Moderate
	2. Upper Bockman	High	High	High
	3. Lower Kugel	High	Low	High
	4. Upper Kugel	High	Low	Low
	5. Littleton	Low	Low	Low

Most of the vulnerability ratings for the macroinvertebrate surveys agree with stream conditions evaluated for fish habitat suitability. Fish habitat conditions were made with surrogate measures of physical properties in each stream. Predicting biological condition without direct measurement of biota appears to be possible where stream condition is obvious. However, predicting stream condition *a priori* may be deceiving, especially when the impact of recent disturbance events are not visible.

What the Biological Communities say about Stream Health

A narrative biological condition summary was constructed for each site (Table 8). The summary included a description of stream degradation and detailed interpretations based on presence of rare species.

The Bockman Creek drainage was sampled at two locations, an upstream logged site and a downstream regrowth site. The biological community indicated the influence of open canopy channels at both sites. Water temperature and sediment degradation was responded to by stream biology at the upper site. The downstream site had isolated temperature and sediment problems.

In contrast, the biological community at the upstream Kugel Creek site was influenced by the quality and quantity of vegetation in the riparian zone. Taxa that collectively measure stream integrity (mayflies, stoneflies, caddisflies) were poorly represented at the lower Kugel Creek site. There was evidence that a substantial amount of erosion (gravel transport and scouring) occurred at this stream reach.

A minimally disturbed site, Littleton Creek, was dominated by cold-water taxa. Rare taxa present in riffles indicated habitat integrity (stability). The biological community reflected an intact riparian vegetation zone.

Table 8. Summary of stream quality for survey sites in the mid-Sol Duc watershed. Summaries were based on the problems identified in riffle and pool habitat.

Site 1 (lower-Bockman Creek)	Detection of isolated temperature and sediment problems. Some locations dominated by temperature- and sediment- tolerant invertebrates. Co-dominance by scrapers indicates presence of an open vegetation canopy.
Site 2 (upper-Bockman Creek)	Influence of temperature and large quantities of sand in pool habitat. More sediment-tolerant and temperature-tolerant taxa present in riffles. Co-dominance by scrapers indicates presence of an open vegetation canopy.
Site 3 (lower-Kugel Creek)	Sediment- and temperature-tolerant taxa dominant in riffles. Sensitive taxa (mayflies, stoneflies, caddisflies) poorly represented.
Site 4 (upper-Kugel Creek)	Coldwater-dwelling stoneflies present and function as leaf litter processors. Leaf litter is an important component of the upstream Kugel Creek site food base. Boulder substrate present and reduces living space for invertebrates.
Site 5 (Littleton Creek)	Coldwater-dwelling stoneflies and caddisflies, and rare stoneflies indicate habitat integrity. Leaf litter an important food source.

Conclusions

The sampling strategy for the mid-Sol Duc Watershed Analysis case study provided an effective assessment of current conditions. Additionally, interpretation of current biological condition in the select mid-Sol Duc sites was used to assess vulnerability to further degradation. Direct measurement of stream biota concluded macroinvertebrate community condition generally agreed with stream condition assessments from other watershed analysis modules.

Detecting degradation generally requires comparison of samples along a gradient from heavily impacted to pristine or unimpacted (reference sites). The single visit at each site (no repeat sampling the following year) made biological information useful only as a screening tool.

The time of year chosen for surveying sites influenced the usefulness of biological information as an assessment method. Some important considerations were:

- time of year when invertebrates are large enough to easily identify,
- a majority of the species that inhabit a stream reach are in the aquatic form:
- efficient collection of biota occurs during the low flow and possibly most stressful time of the year.

Although this survey was conducted in April 1995 (beginning of spring), the number of species collected and species composition was similar to surveys conducted in nearby watersheds later in the year (Plotnikoff and Ehinger 1997).

Benthic macroinvertebrates identified low, moderate, and heavy impacts at select survey sites in the mid-Sol Duc watershed. The ability of macroinvertebrates to reflect these differences in stream condition makes them useful in monitoring trends over time.

Recommendations

- Comparison of benthic macroinvertebrate condition between seasons (e.g., spring and late summer). The flexibility of using macroinvertebrate monitoring effectively in different seasons should be evaluated. Sample collecting during some periods of the year may result in poor description of the biological community.

- Benthic macroinvertebrates should be used to monitor the "effectiveness" of water resource management.

Acknowledgements

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APPENDIX A

Field Forms

Waterbody Name: __________

Location/Station #: __________

Major Basin: __________

Dominant Land Use: __________

Date/Time: __________

Weather: __________

Latitude/Longitude: __________

Investigators: __________

SURFACE WATER INFORMATION			
Parameters	**Measurement (Qualifiers)**		
Temperature			
pH		Calibration or Calibration Check:	
Conductivity			
Dissolved Oxygen Sample Time:	Bottle no.	mL of titrant	Correction factor
Qualitative Observations			
Water Clarity			
Water Odors			
Sediment Odors			
Surface Films			

Field Notes:	
Photograph:	
Photograph:	

SUBSTRATE MEASUREMENTS

Substrate Parameter	Riffle 1	Riffle 2
Depth (m)		
Size Class (# intersections)		
Bedrock (smooth)		
Bedrock (rough)		
Boulder (250 to 4000 mm)		
Cobble (64 to 250 mm)		
Coarse Gravel (16 to 64 mm)		
Fine Gravel (2 to 16 mm)		
Sand (0.06 to 2 mm)		
Silt/Clay/Muck (not gritty)		
Wood (any size)		
Other (comment)		

SUBSTRATE MEASUREMENTS

Substrate Parameter	Riffle 3	Riffle 4
Depth (m)		
Size Class (# intersections)		
Bedrock (smooth)		
Bedrock (rough)		
Boulder (250 to 4000 mm)		
Cobble (64 to 250 mm)		
Coarse Gravel (16 to 64 mm)		
Fine Gravel (2 to 16 mm)		
Sand (0.06 to 2 mm)		
Silt/Clay/Muck (not gritty)		
Wood (any size)		
Other (comment)		

Comments:

CANOPY COVER MEASUREMENTS

DENSIOMETER (count open intersections)

Direction	Riffle 1	Riffle 2	Riffle 3	Riffle 4
Center (up)				
Center (down)				
Center (left)				
Center (right)				
Left Bank				
Right Bank				

HUMAN INFLUENCE

O = not present

B = on bank

C = within 10m

P = > 10m

Disturbance	Left Bank	Right Bank
Dike/Riprap		
Buildings		
Pavement		
Road/Railroad		
Pipes (inlet/outlet)		
Landfill/Trash		
Park/Lawn		
Row Crops		
Pasture/Range		
Logging Operations		

Substrate measurements are made with a 60 cm diameter hoop and at least 50 observations within the sample area.

STREAM REACH PROFILE

Transect	Wetted Width (riffles)	Bankfull Width (riffles)	Maximum Depth (riffles)	Residual Pool Depth (Dp-Dc=RPD)			Stream Gradient (Clinometer)
				Dp	Dc	RPD	
Riffle 1							
Riffle 2							
Riffle 3							
Riffle 4							

STREAM DISCHARGE

Observation (Circle units)	Width (m or ft)	Depth (m or ft)	Velocity (m/s or ft /s)	Flag	Comments
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Residual Pool Depth: Dp=maximum depth of pool, Dc=depth at pool crest (or tailout), RPD=residual pool depth

Qualitative Habitat Assessment Survey - Visual Analysis
Riffle/Run Prevalence

Site Name:	Site No:	Date:	Evaluator Initial:	
Habitat Parameter	**Optimal**	**Sub-Optimal**	**Marginal**	**Poor**
1. Substrate-Percent Fines (fraction < 6.35mm)	< 10% (1 6.20)	10.20% (11-15)	20 - 50% (6-10)	> 50% (0-5)
2. Instream Cover (cobble gravel, large woody debris, undercut banks. macrophytes)	> 50% (16-20)	30 - 50% (11-15)	10 - 30% (6-10)	< 10% (0-5)
3. Embeddedness (Riffle) (gravel, cobble, boulder particles)	0 - 25% (16-20)	25.50% (11-15)	50 - 75% (6-10)	> 75% (0-5)
4. Velocity/Depth	all habitats: i)slow/deep ii)slow/shallow iii)fast/deep iv)fast/shallow (16-20)	3 of 4 (1 I-15)	2 of4 (6-10)	I of4 (0-5)
5. Channel Shape	trapezoidal (11-15)	rectangular (6-10)		inverse trapezoidal (O-5)
6. Pool/Riffle Ratio (distance between riffles/stream width)	5 - 7 (frequent sequence) (12-15)	7 - 15 (less frequent) (8-11)	15-25 (Infrequent riffle) (4-7)	> 25 (homogeneous) (O-3)
7. Width to Depth Ratio (wetted width/depth)	< 7 (12- 15)	815 (S-11)	15 - 25 (4-7)	> 25 (O-3)
8. Bank Vegetation (streambank coverage)	> 90% (9-10)	70 - 89% (6-8)	50 - 79% (3-5)	< 50% (0-2)
9. Lower Bank Stability (evidence of erosion)	Stable (9-10)	Little Erosion (6-8)	Mod. Erosion (3-5)	Unstable (0-2)
0. Disruptive Pressures (evidence of vegetation disruption on streambanks:	Minimal (all remains) (9-10)	Evident (60-90%) (6-8)	Obvious (30-60%) (3-5)	High (< 30%) (0-2)
1. Zone of Influence (width of riparian zone)	≥4 x BFW (BFW=Bankfull Width) (9-10)	≥2 & <4 (6-X)	≥1 & <2 (3-5)	little or none (0-2)
2. Successional Stage (forested sites only)	old-growth (9- IO)	young (6-8)	pole sapplings (3-5)	seedlings/ clearcut (0-2)

Stream Cross-Section Profile

Observation No.	Width (m or ft)	Riffle 1	Riffle 2	Riffle 3	Riffle 4
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
30					
31					
32					
33					
35					
36					
37					
38					
39					
40					
41					
42					
43					
44					
45					

(vertical, equidistant measurements from bankful horizontal line to stream bottom)

Current Velocity

(m/sec or ft/sec)

Transect	Velocity
Riffle 1	
Riffle 2	
Riffle 3	
Riffle 4	

APPENDIX B

Diagnostic Flow Charts

A. Instream Condition Analysis

Metric	Response	Ecological Condition	Diagnosis
1. Habitat Complexity			
Species Richness % Ephemerellidae	high	habitat complexity.	1. no effects.
	low	habitat complexity reduced	1. excess sediment deposition. 2. depositional zone.
Perlidae	present	cobble predominant (64-250 mm).	1. flat-sided, free matrix stones.
	absent	small, easily transported substrate sizes.	1. excess sediment deposition. 2. deposition zone.
2. Food Quality			
% Pteronarcyidae % Shredders	high	conditioned leaf litter abundant.	1. riparian canopy present (deciduous). 2. abundant accumulation of instream leaf litter.
	low	quantity or quality of leaf litter low.	1. riparian canopy absent. 2. instream leaf litter with adsorbed contaminants.
Peltoperlidae	present	abundant, conditioned organics in fine substrates.	I. high quality depositional material.
	absent	organics absent in fine substrates (e.g., sand).	I. introduced sediment to the stream channel.
% Hydropsychidae % Simuliidae	high	abundant, suspended organic particulates.	1. increased runoff resulting from canopy removal. 2. eroding stream banks.
	low	consumeable organic particulates in low concentrations.	I. stable channel, intact riparian vegetation.
% Scrapers	high	abundant periphyton growth.	1. increased solar radiation to stream. 2. riparian canopy removal.
	low	low or absent primary production,	1. riparian canopy intact. 2. silt or clay fines cover periphyton substrate.
% Brachycentridae	high	suspended plant/animal material.	1. stable instream habitat (interstitial habitat). 2. moderate-low erosion.
	low	low availability of consumeable organics.	1. erosion of inorganic materials. 2. unstable substrate material.

B. Water Quantity Analysis

	Response	Ecological Condition	Diagnosis
1. Flow			
Pteronarcyidae Perlidae	present	long-lived; taxa with semi-voltine life cycle (i.e., 2 years)	1. perennial stream. 2. continuous water volume in stream channel.
	absent	community composed of univoltine/multivoltine taxa.	1. intermittent stream. 2. sub-surface flow; excessive sediment load to a stream reach.
% Simuliidae % Tanytarsini & Orthocladiini	high	community dominated by short-lived taxa.	1. surface flow present for a portion of the year. 2. groundwater regime altered by land "se.
	low	community primarily composed of longer-lived taxa.	1. water volume in channel supports a diverse community.
2. Temperature			
% Plecoptera % Ephemeroptera (except Baetidae)	high	continuous supply of cool surface water.	1. adequate water supply/riparian canopy.
	low	surface water approaches or exceeds thermal tolerances.	1. temperature elevated (canopy removal/decreased water supply).
% Diptera	high	surface water approaches or exceeds thermal tolerances.	1. temperature elevated (canopy removal/decreased water supply).
	low	surface water temperatures suitable for intolerant taxa.	1. continuous supply of cooler water to the channel,
% Baetidae	low	surface water temperatures suitable for intolerant taxa	1. continuous supply of cooler water to the channel.
	high	surface water approaches or exceeds thermal tolerance	1. temperature elevated (canopy removal/decreased water supply).
3. Habitat Availability			
% Chironomidae	high	pool, depositional zone.	1. absence of riffles. 2. current velocity low; instream debris present.
	low	riffle, erosional zone.	1. absence of slackwater.
% Baetidae	low	riffle, erosional zone.	2. instream debris absent or removed.
	high	pool, depositional zone	1. interstitial spaces filled with sediment. 2. fine sediment dominant on stream bottom.

C. General Indicators

	Response	Ecological Condition	Diagnosis
% Dominant Taxa	high	water quality impact; taxa with a competitive advantage.	1. physical/chemical alteration of stream channel or surface water.
	low	no impact.	
EPT Index	high	no impact.	
	low	water quantity, chemical quality or physical condition have been altered.	1. substrate embeddedness increased. 2. riparian canopy removal. 3. temperature impact. 4. loss of substrate size diversity.

APPENDIX C

Itemized Cost for the Project

Appendix C. Itemized cost for the project

Personnel			
	Field	2 Technicians x 3 days	$ 920.00
		1 Senior Biologist x 3 days	$ 700.00
	Report Writing	1 Senior Biologist x 1 month (Note: Writing time for this developmental document was six months.)	$3,700.00
Sample Analysis		25 samples x $125.00/sample	$3,125.00
Travel		Per diem & lodging x 3 personnel	$ 255.00
		Mileage	$ 150.00
Equipment		Goods & Services	$ 200.00
		Replacement Equipment	$ 150.00
Total			$9,200.00

APPENDIX D

Table of Biometric Data

Appendix D. Biometrics for sites including riffle replicates and pool habitat.

stream	site	Date	Habitat	Density (no./2 ft^2)	no. of species	no. of EPT	P1DOM	P2DOM	P3DOM	D1TAXON	D2TAXON	D3TAXON	%Plecoptera
Bockman Creek	1	05-Apr-95	Riffle	396.00	40	22	34.60	52.02	65.91	Baetis bicaudatus	Cinygmula sp.	Epeorus sp.	5.05
Bockman Creek	1	OS-Apr.95	Riffle	799.93	37	26	30.90	57.41	63.88	Cinygmula sp.	Baetis bicaudatus	Baetis bi/tricaudatus	6.47
Bockman Creek	1	05-Apr-95	Riffle	749.32	40	26	29.39	47.52	53.24	Baetis bicaudatus	Cinygmuia sp.	Baetis tricaudatus	4.58
Bockman Creek	1	05-Apr-95	Riffle	539.46	34	25	45.47	58.64	68.72	Cinygmula sp.	Baetis bicaudatus	Baetis tricaudatus	4.73
Bockman Creek	1	05-Apr-95	Pool	145.00	36	9	14.48	28.28	38.62	Ephemerella inermis/infrequens	Brillia sp.	Limnephilidae	6.21
Bockman Creek	2	05-Apr-95	Riffle	637.82	43	26	30.80	55.49	64.56	Raetis bicaudatus	Cinygmuia sp.	Baetis tricaudatus	6.96
Bockman Creek	2	05-Apr-95	Riffle	173.00	21	13	38.73	60.12	67.05	Cinygmula sp.	Baetis bicaudatus	Baetis tricaudatus	3.47
Bockman Creek	2	OS-Apr.95	Rime	479.00	33	21	32.78	47.39	59.71	Cinygmuia sp.	OLIGOCHAETA	Baetis bicaudatus	5.43
Bockman Creek	2	05-Apr-95	Riffle	686.28	41	27	32.56	52.91	60.47	Cinygmuia sp.	Baetis bicaudatus	Epeorus sp.	4.84
Bockman Creek	2	05.Apr.95	Pool	152.00	31	10	32.89	44.74	52.63	Heterlimnius sp.	Ephemerella inermis/infrequens	Limnephilidae	3.29
Bockman Creek	2	05-Apr-95	Pool	222.00	26	6	41.44	68.02	76.13	Polypedilum sp.	Paratendipes sp.	Stempellinella sp.	0.45
Kugel Creek	3	03-Apr-95	Riffle	101.00	19	14	33.66	48.51	61.39	Cinygmula sp.	Baetis tricaudatus	Baetis bicaudatus	10.89
Kugel Creek	3	03-Apr-95	Riffle	65.00	18	15	20.00	35.38	49.23	Baetis bicaudatus	Baetis tricaudatus	Chloroperlinae	18.46
Kugel Creek	3	03.Apr.95	Rime	60.00	16	12	36.67	51.67	61.67	Chloroperlinae	Cinygmula sp.	Baetis bicaudatus	43.33
Kugel Creek	3	03-Apr-95	Rims	87.00	17	14	33.33	49.43	62.07	Baetis tricaudatus	Cinygmula sp.	Neaviperla sp.	20.69
Kugel Creek	3	03-Apr-95	Pool	69.00	22	6	14.49	26.09	37.68	Heleniella sp.	Onocosmoecus unicolor	Heterlimnius sp.	1.45
Kugel Creek	4	04-Apr-95	Riffle	132.00	26	16	26.52	45.45	54.55	Chloroperlinae	Prosimulium sp.	Baetis bicaudatus	30.30
Kugel Creek	4	04.Apr.95	Rime	63.00	13	9	36.51	57.14	71.43	Chloroperlinae	Cinygmula sp.	Baetis bicaudatus	39.68
Kugel Creek	4	04-Apr-95	Riffle	108.00	20	17	17.59	35.19	50.93	Cinygmuia sp.	OLIGOCHAETA	Chloroperlinae	20.37
Kugel Creek	4	04-Apr-95	Rime	73.00	17	14	17.81	34.25	50.68	Cinygmula sp.	Baetis tricaudatus	OLIGOCHAETA	16.44
Kugel Creek	4	04-Apr-95	Pool	96.00	17	9	42.71	58.33	65.63	Chloroperlinae	Onocosmoecus unicolor	Ceratopogoninae sp.	47.92
Littleton Creek	5	04-Apr-95	Riffle	127.00	26	18	20.47	34.65	44.09	Baetis hicaudatus	Chloroperlinae	Prosimulium sp.	29.92
Littleton Creek	5	04-Apr-95	Riffle	66.00	21	19	24.24	34.85	43.94	Baetis bicaudatus	Cinygmula sp.	Baetis tricaudatus	22.73
Littleton Creek	5	04-Apr-95	Rime	55.00	17	15	54.55	60.00	63.64	OLIGOCHAETA	Parapsyche elsis	Rhithrogena sp.	14.55
Littleton Creek	5	04-Apr-95	Riffle	89.00	23	18	22.47	39.33	47.19	Baetis bicaudatus	OLIGOCHAETA	Parapsyche elsis	13.48
Littleton Creek	5	04-Apr-95	Pool	74.00	24	15	25.68	35.14	43.24	Chloroperlinae	Calineuria californica	Cinygmula sp.	40.54

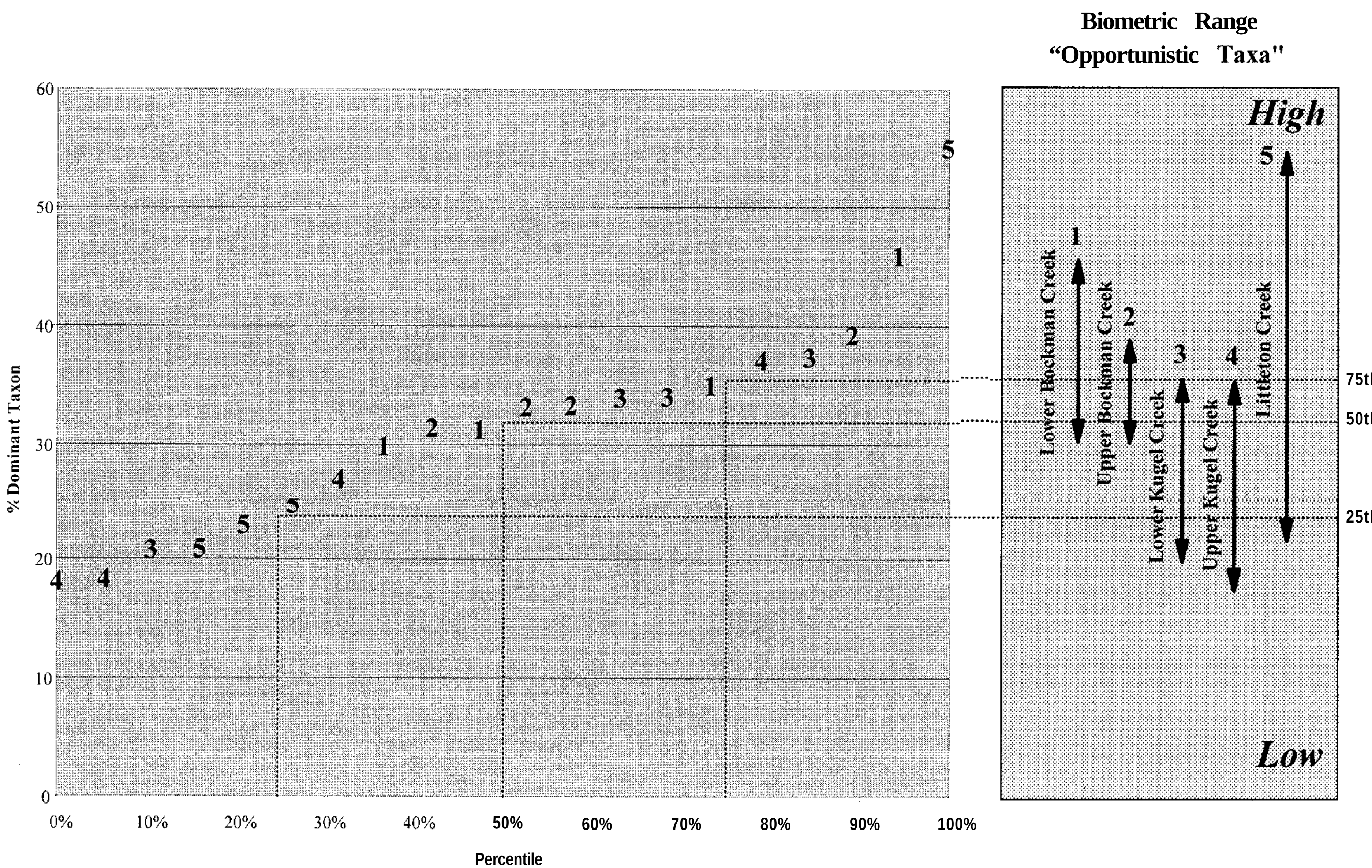
Appendix D. Biometrics for sites including riffle replicates and pool habitat.

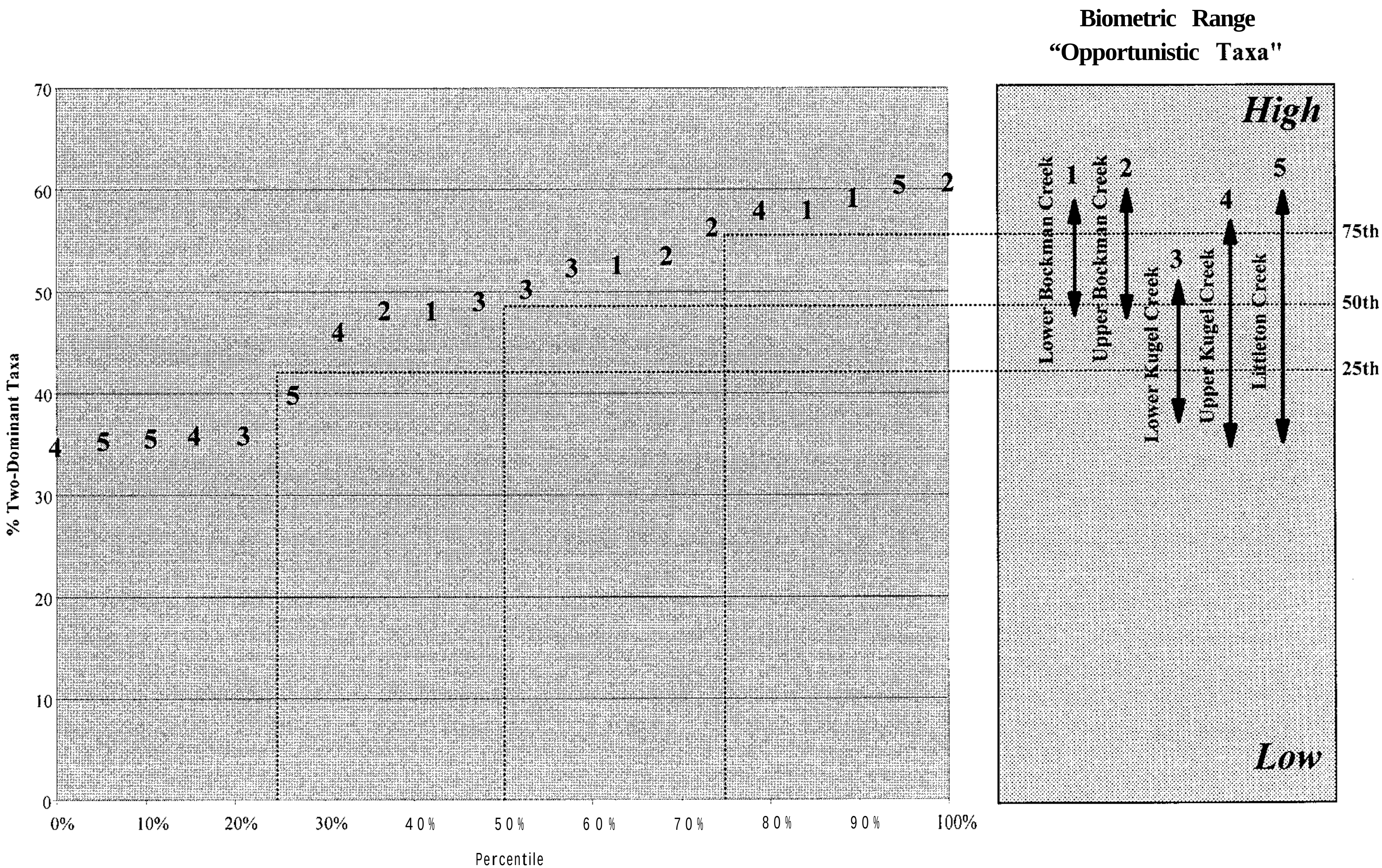
%Chironomidae	%Shredders	%Scrapers	%Ephemerellidae	%Baetidae	%Pteronarcyidae	%Perlidae	%Brachycentridae	%Hydropsychidae	%Simuliidae	%Ephemeroptera	%Diptera
6.06	2.53	73.74	2.53	38.13	0.00	0.51	0.00	2.02	1.26	73.23	10.10
I.88	1.46	78.08	1.88	37.37	0.00	0.63	0.00	4.80	1.25	75.57	3.55
4.39	3.05	67.75	4.77	35.69	0.00	0.95	0.00	3.44	3.82	73.28	9.92
I.44	0.82	83.95	2.06	23.87	0.00	0.21	0.00	3.70	0.00	80.04	1.65
47.59	44.83	3.45	14.48	0.69	0.00	0.69	0.00	0.00	0.00	19.31	57.24
4.22	I.48	74.26	2.53	40.08	0.00	1.27	0.00	1.90	4.43	75.32	10.76
3.47	2.89	76.88	1.16	28.32	0.00	0.58	0.00	1.73	2.31	74.57	7.51
5.43	1.67	57.62	1.46	16.91	0.00	0.84	0.00	1.67	0.63	60.96	7.72
5.04	1.36	72.09	1.36	26.16	0.00	0.58	0.00	1.94	0.19	76.91	6.20
27.63	32.89	1.32	11.84	0.00	0.00	0.00	0.00	3.95	0.00	12.50	32.24
86.94	44.59	1.80	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.45	92.79
2.97	I.98	78.22	9.90	28.71	0.00	0.99	0.00	0.99	0.00	77.23	2.97
0.00	4.62	67.69	7.69	35.38	0.00	1.54	0.00	0.00	1.54	67.69	1.54
3.33	1.67	41.67	3.33	I1.67	0.00	5.00	0.00	0.00	5.00	43.33	10.00
1.15	4.6"	54.02	0.00	33.33	0.00	1.15	0.00	1.15	11.49	56.32	12.64
56.52	28.99	7.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.70	59.42
2.27	5.30	28.79	0.76	14.39	0.00	1.52	0.00	0.00	18.94	29.55	24.24
0.00	1.59	47.62	9.52	14.29	0.00	1.59	0.00	0.00	1.59	46.03	1 9
0.93	5.56	49.07	0.93	20.37	0.00	0.93	0.00	0.00	2.78	so.93	3.70
2.74	8.22	42.47	1.37	16.44	I.37	1.37	0.00	0.00	8.22	42.47	10.96
7.29	19.79	4.17	0.00	0.00	0.00	3.13	0.00	0.00	0.00	4.17	18.75
3.94	14.96	43.31	0.79	24.41	7.09	1.57	0.00	4.72	9.45	44.09	15.75
0.00	9.09	60.61	0.00	33.33	1.52	3.03	0.00	4.55	0.00	62.12	0.00
0.0"	3.64	16.36	0.00	7.27	0.00	3.64	0.00	5.45	0.00	14.55	0.00
0.00	5.62	51.69	8.99	25.84	2.25	2.25	1.12	7.87	1.12	47.19	4.49
s.41	6.76	20.27	I.35	5.41	2.70	9.46	0.00	1.35	0.00	24.32	14.86

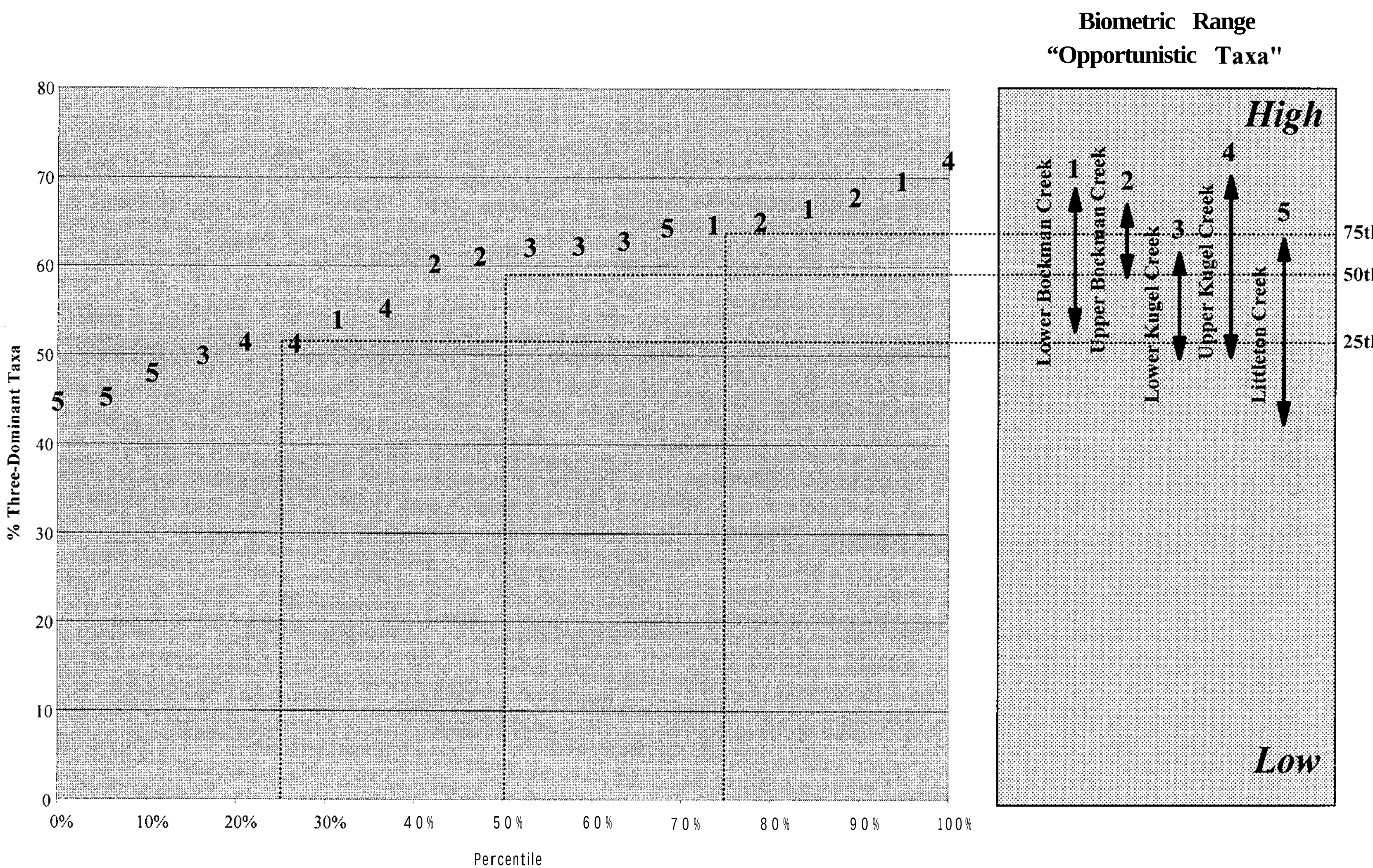
APPENDIX E

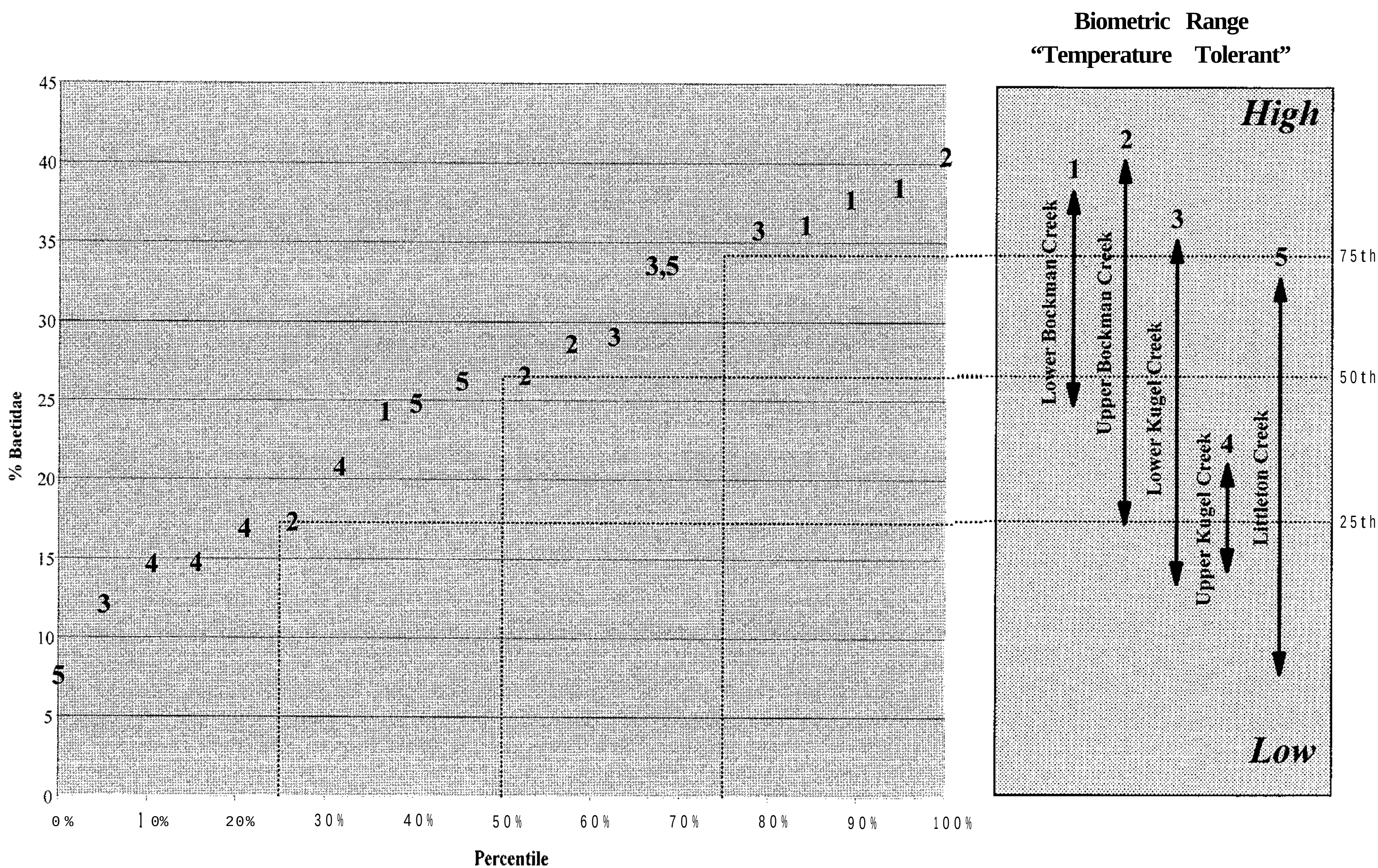
Biometric Ranges for Sites (mid-Sol Duc Survey)

Note: Biometric range lines depict four observations for each site. Some of the values are the same for multiple sites.

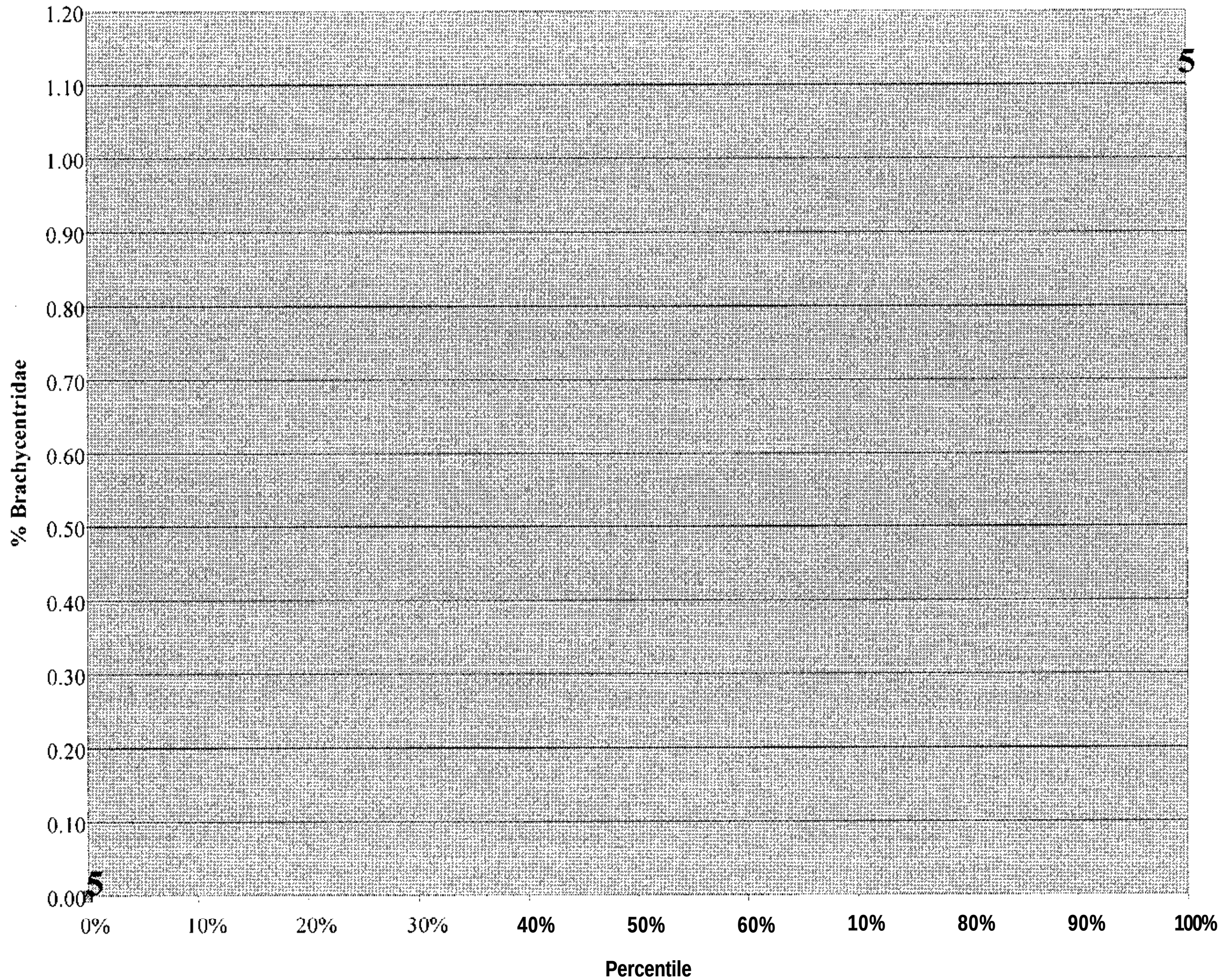

Biometric Range
"Opportunistic Taxa"
% Dominant Taxon
Percentile
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
10
20
30
40
50
60
High
Low
Lower Bockman Creek
Upper Bockman Creek
Lower Kugel Creek
Upper Kugel Creek
Littleton Creek
75th
50th
25th


Biometric Range
"Opportunistic Taxa"
% Two-Dominant Taxa
Percentile
High
Low
Lower Bockman Creek
Upper Bockman Creek
Lower Kugel Creek
Upper Kugel Creek
Littleton Creek
75th
50th
25th

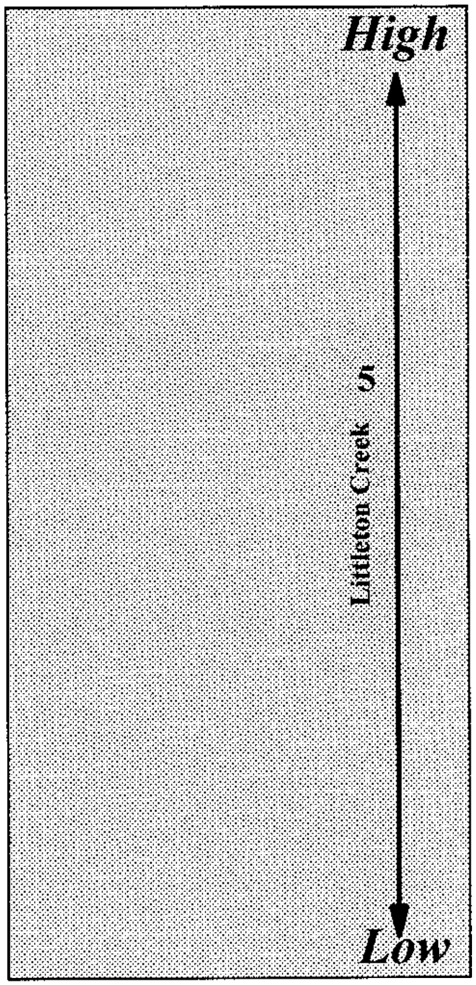

Biometric Range
"Opportunistic Taxa"
High
Low
Lower Bockman Creek
Upper Bockman Creek
Lower Kugel Creek
Upper Kugel Creek
Littleton Creek
75th
50th
25th
% Three-Dominant Taxa
Percentile
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
10
20
30
40
50
60
70
80

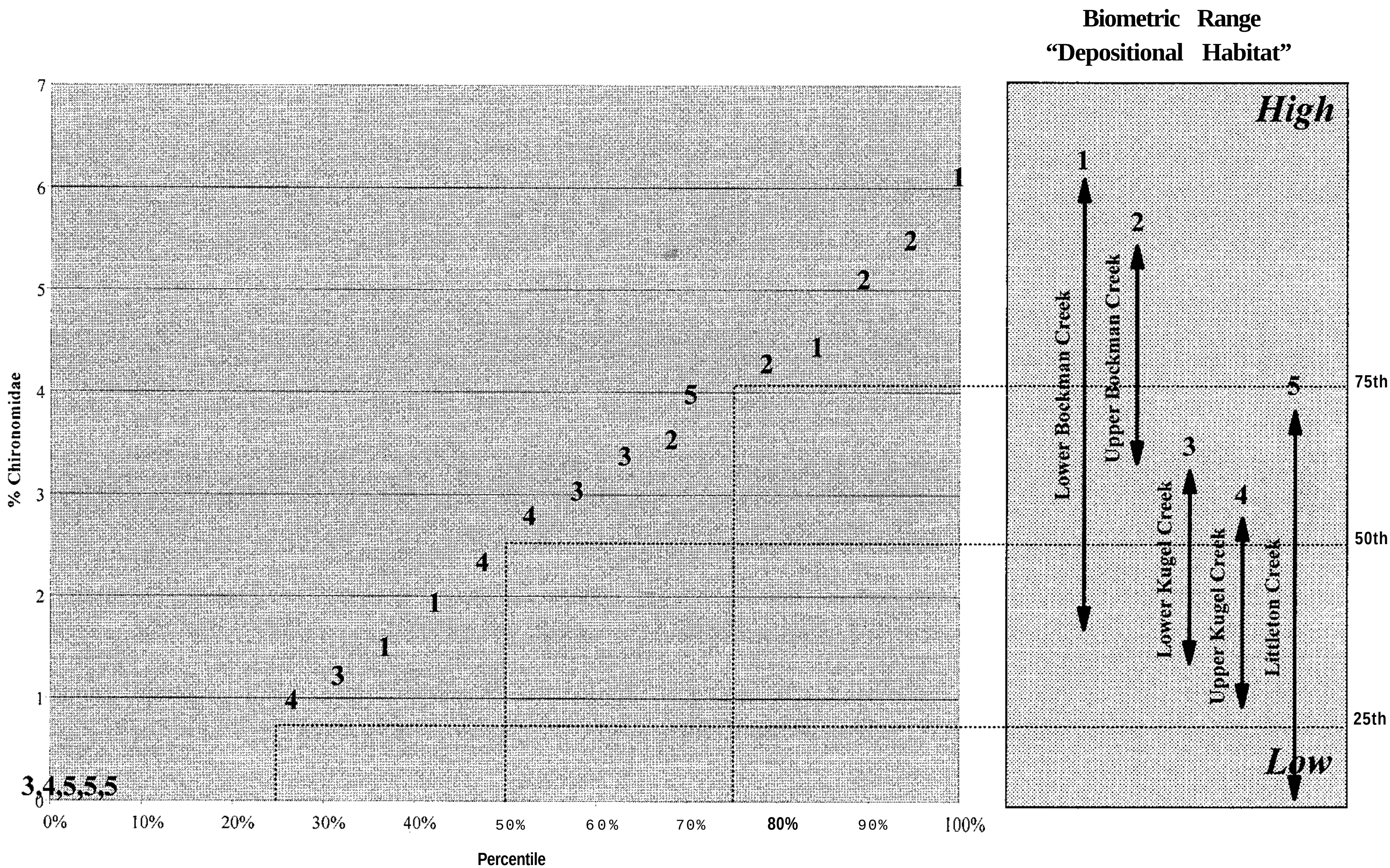


Biometric Range
"Temperature Tolerant"
High
Low
Lower Bockman Creek
Upper Bockman Creek
Lower Kugel Creek
Upper Kugel Creek
Littleton Creek
75th
50th
25th
% Baetidae
Percentile
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

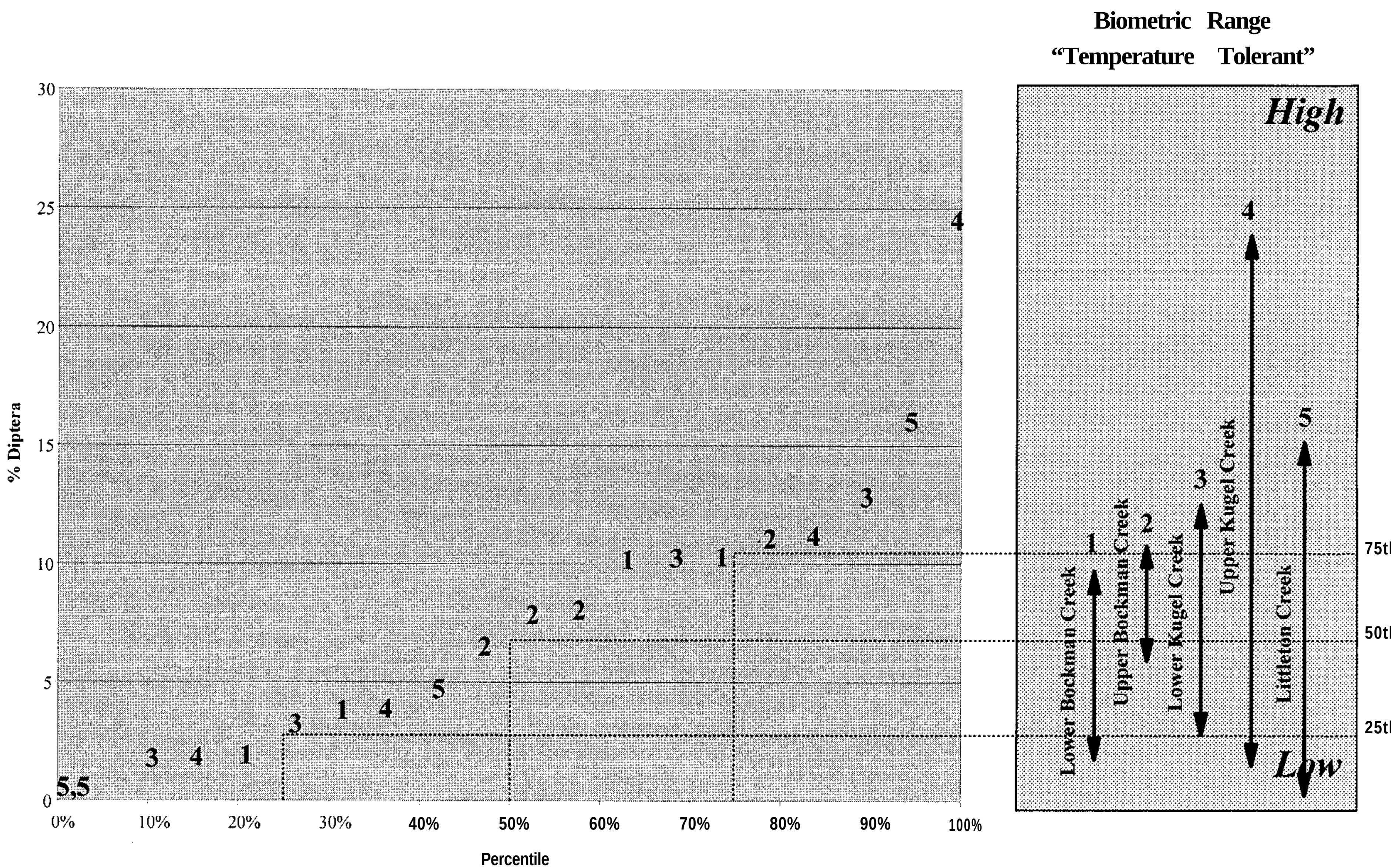


Biometric Range
"Food Quality"

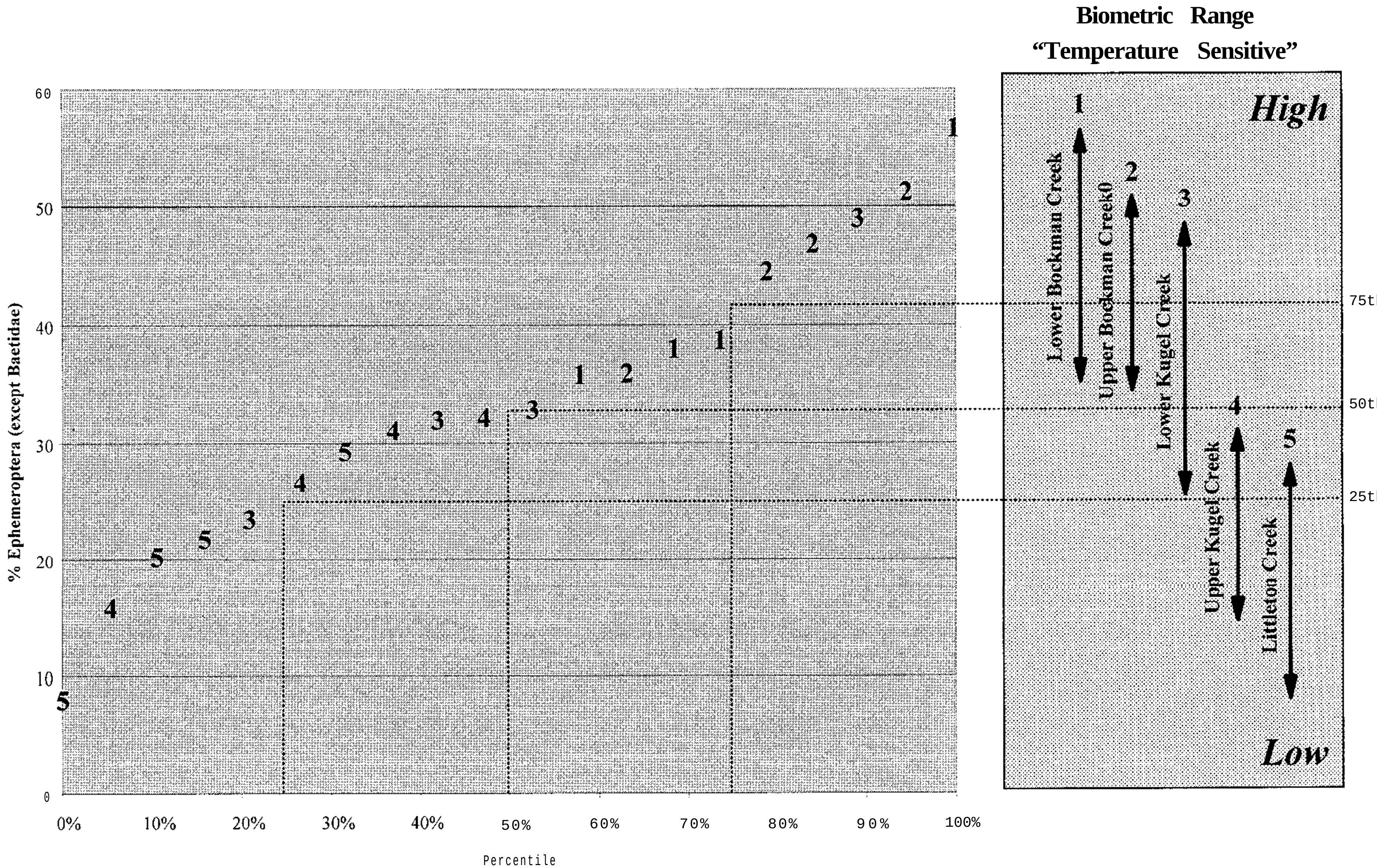


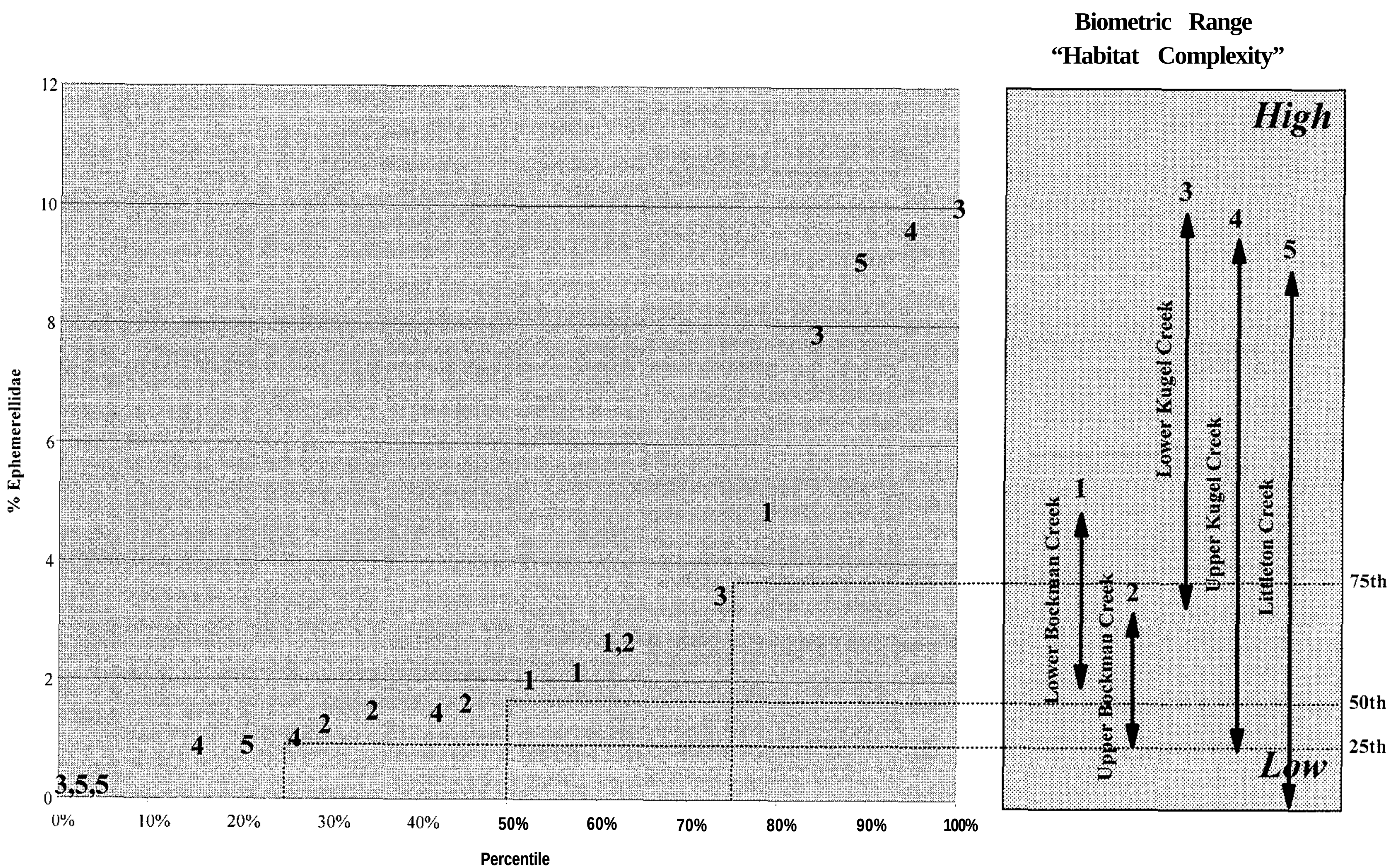


Biometric Range
"Depositional Habitat"
High
Low
75th
50th
25th
Lower Bockman Creek
Upper Bockman Creek
Lower Kugel Creek
Upper Kugel Creek
Littleton Creek
% Chironomidae
Percentile
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
1
2
3
4
5
6
7
3,4,5,5,5

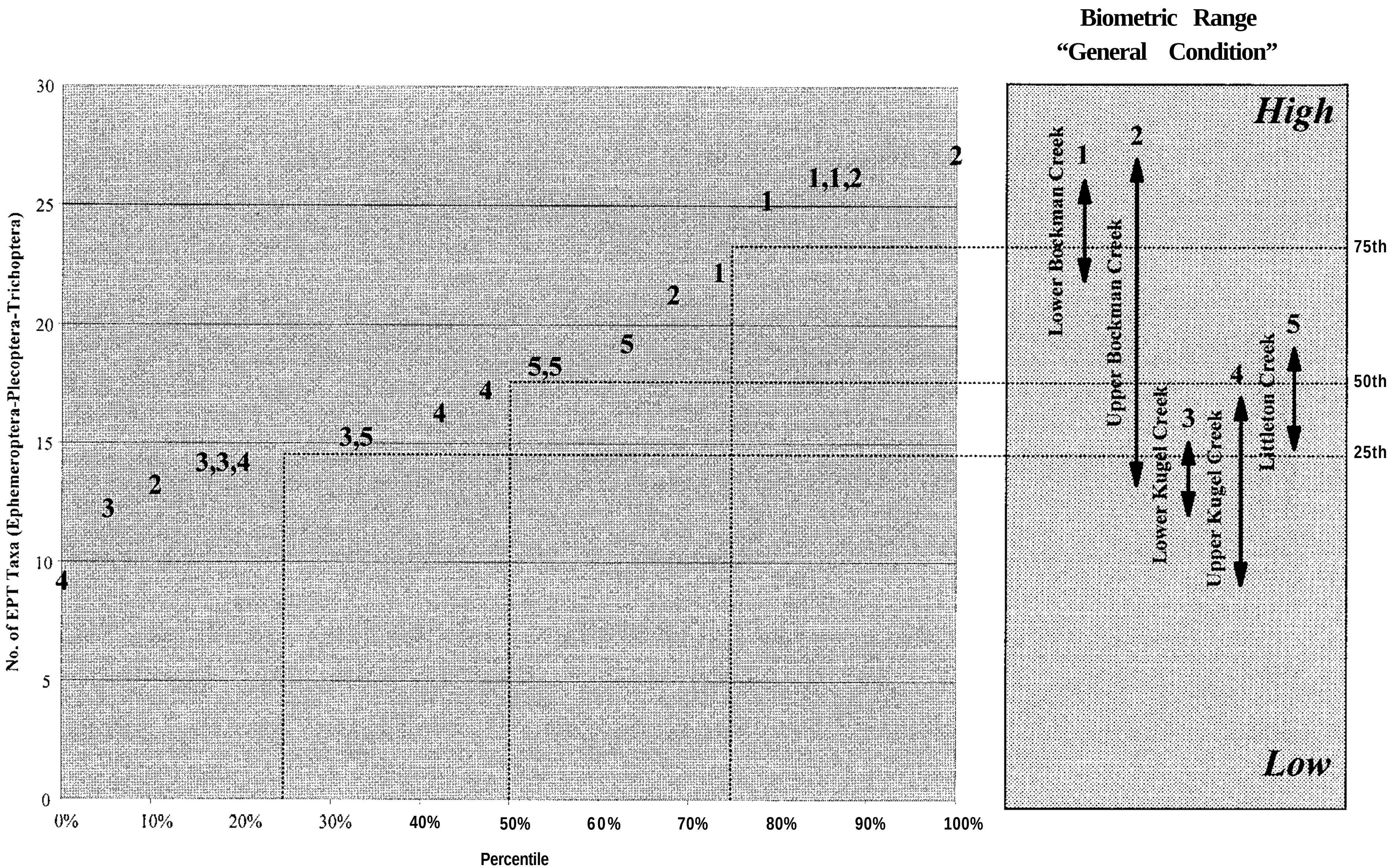


Biometric Range
"Temperature Tolerant"
High
Low
% Diptera
Percentile
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
5
10
15
20
25
30
75th
50th
25th
Lower Bockman Creek
Upper Bockman Creek
Lower Kugel Creek
Upper Kugel Creek
Littleton Creek
5,5

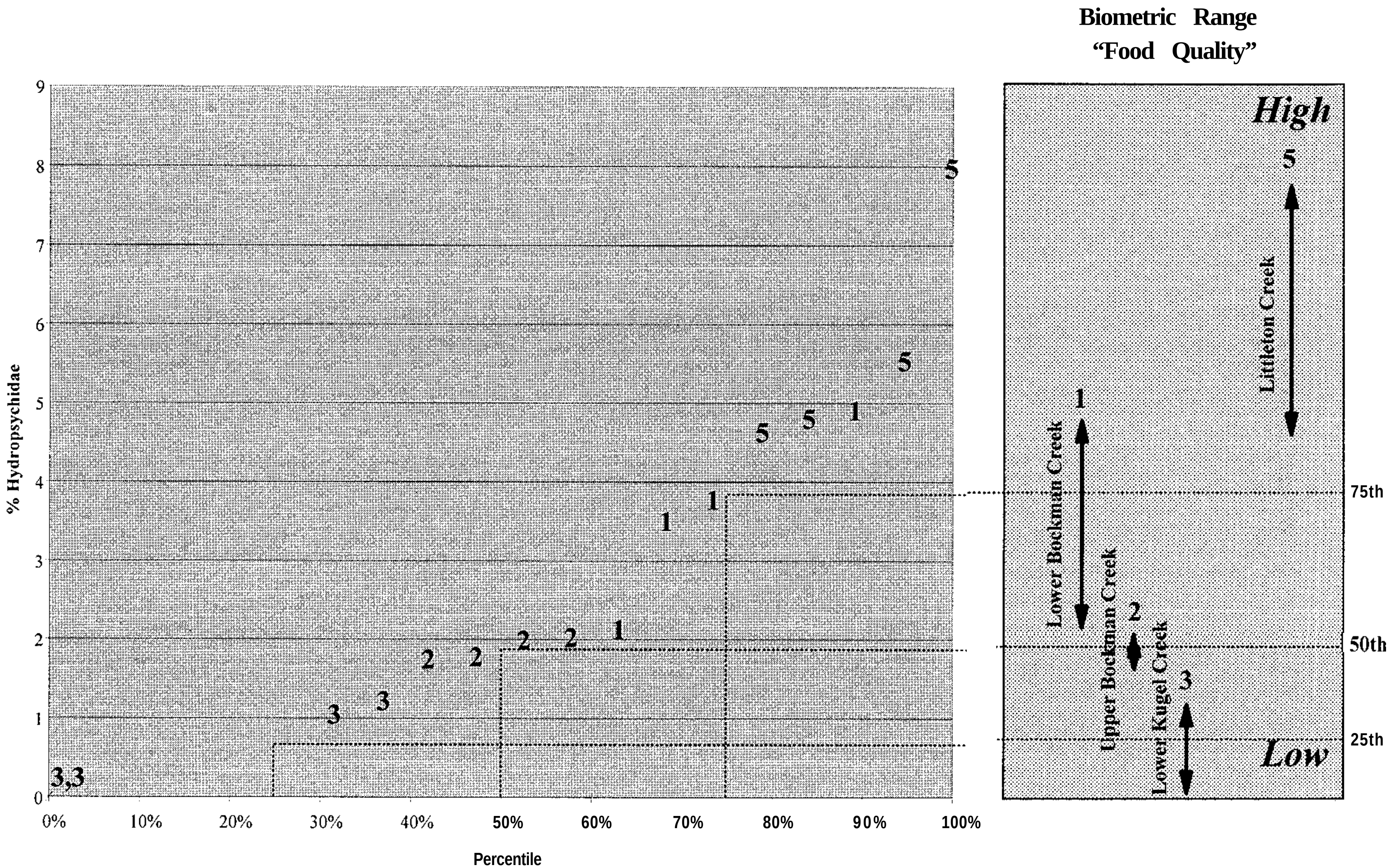

Biometric Range
"Temperature Sensitive"
High
Low
1 Lower Bockman Creek
2 Upper Bockman Creek0
3 Lower Kugel Creek
4 Upper Kugel Creek
5 Littleton Creek
75th
50th
25th
% Ephemeroptera (except Baetidae)
0
10
20
30
40
50
60
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percentile



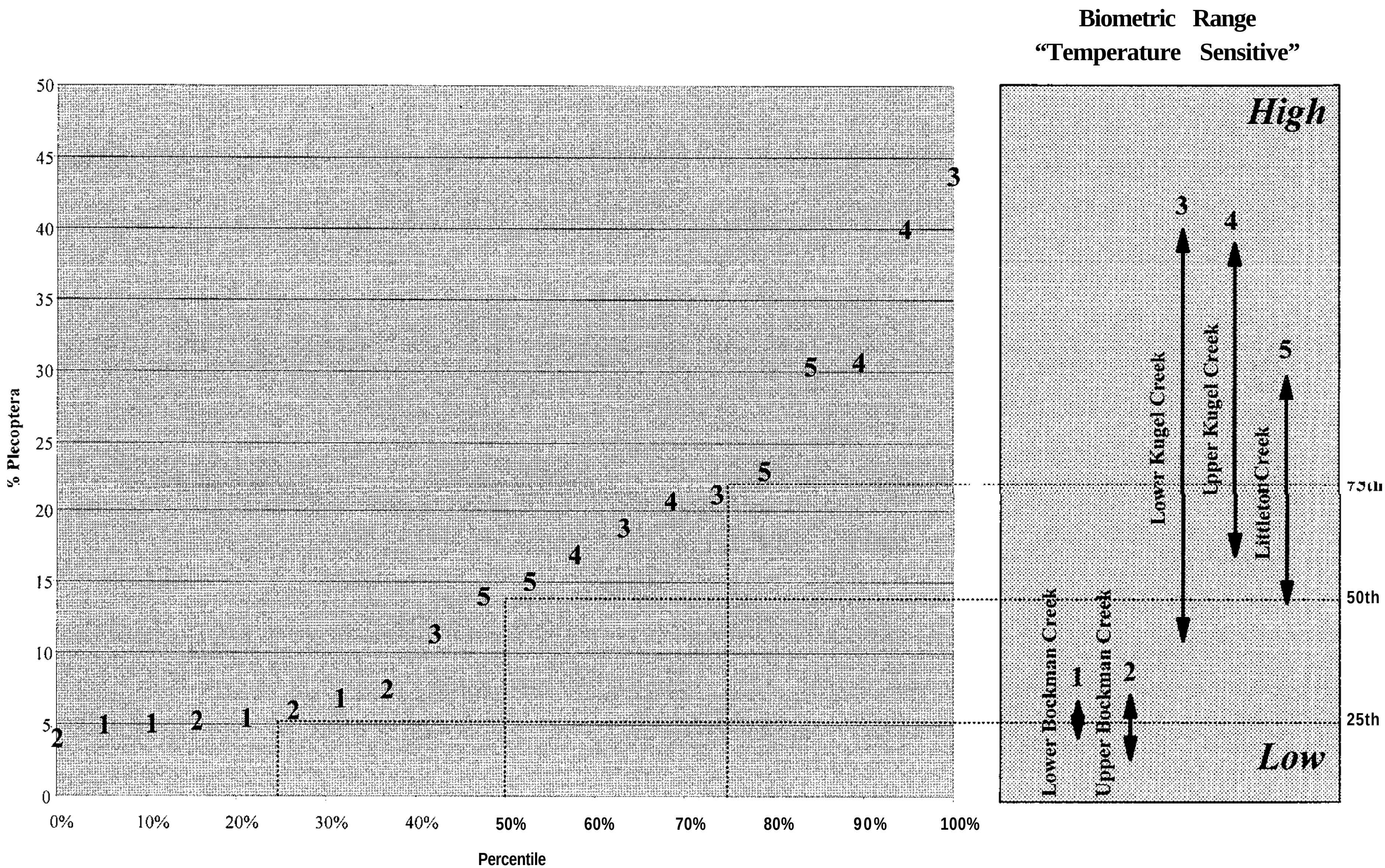
Biometric Range
"Habitat Complexity"
High
Low
Lower Bockman Creek
Upper Bockman Creek
Lower Kugel Creek
Upper Kugel Creek
Littleton Creek
75th
50th
25th
% Ephemerellidae
Percentile
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%



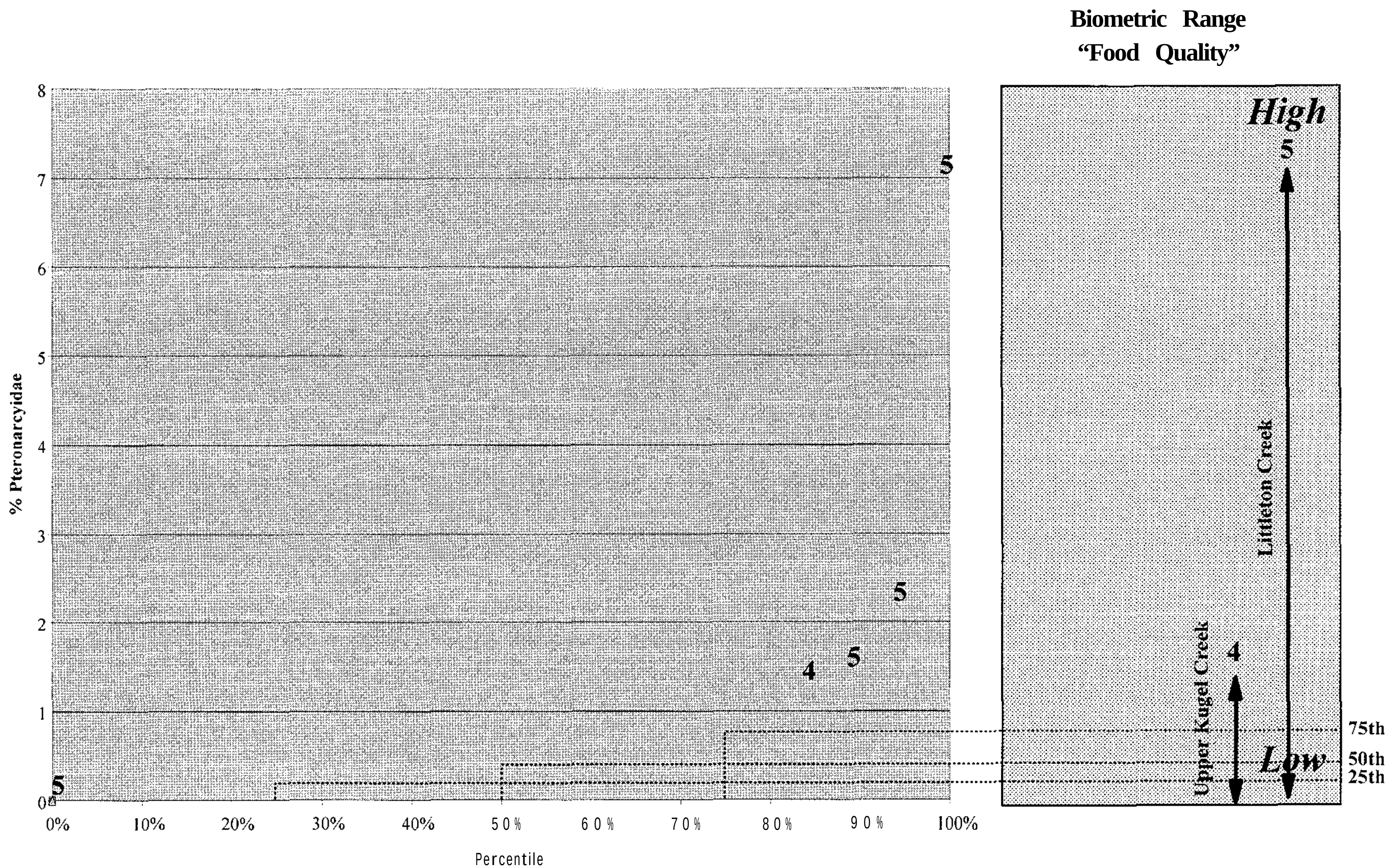
Biometric Range
"General Condition"
High
Low
Lower Bockman Creek
Upper Bockman Creek
Lower Kugel Creek
Upper Kugel Creek
Littleton Creek
75th
50th
25th
No. of EPT Taxa (Ephemeroptera-Plecoptera-Trichoptera)
Percentile
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
5
10
15
20
25
30
1,1,2
3,3,4
3,5
5,5



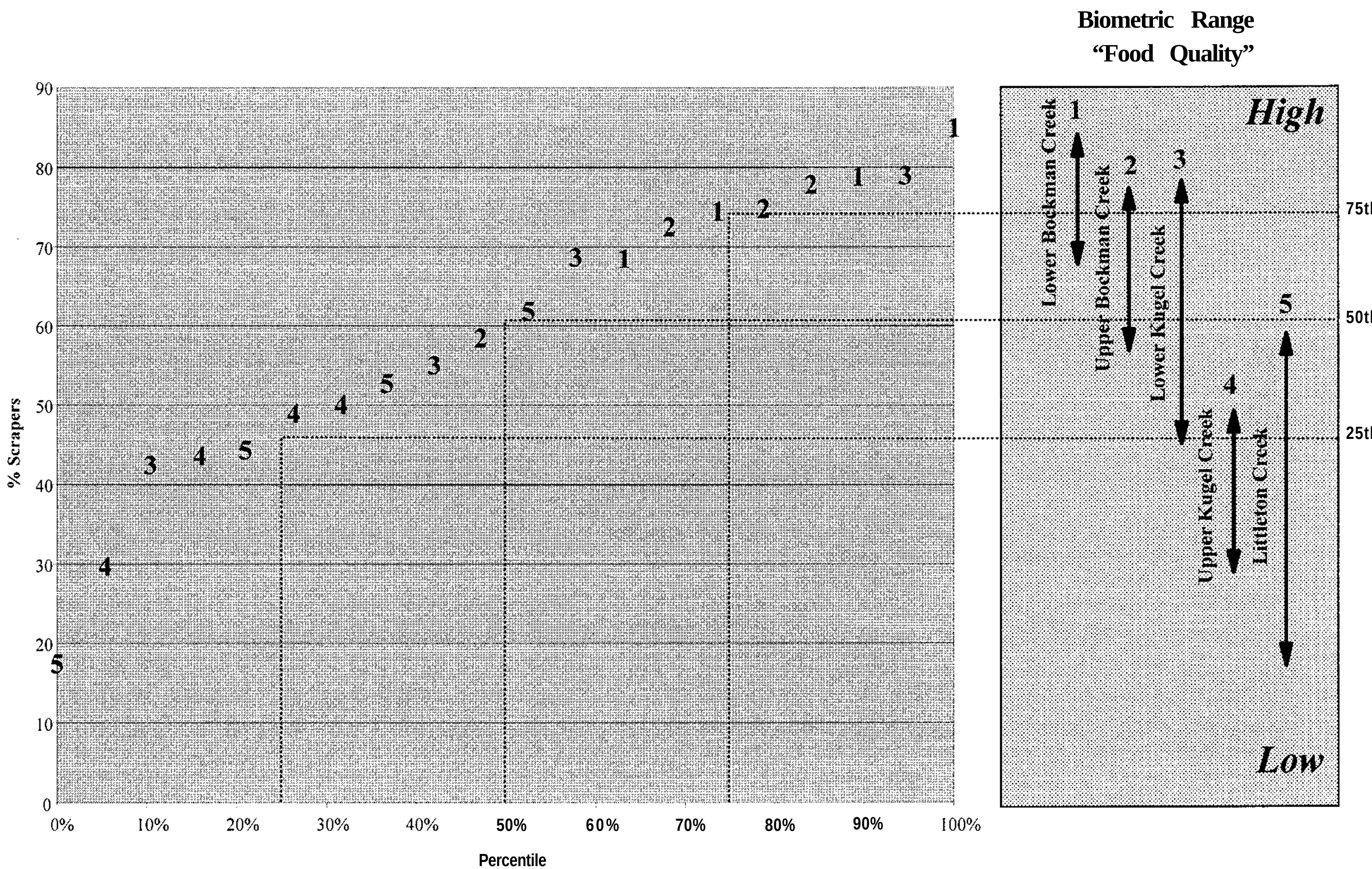
Biometric Range
"Food Quality"
High
Low
75th
50th
25th
Littleton Creek
Lower Bockman Creek
Upper Bockman Creek
Lower Kugel Creek
% Hydropsychidae
Percentile
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
3,3



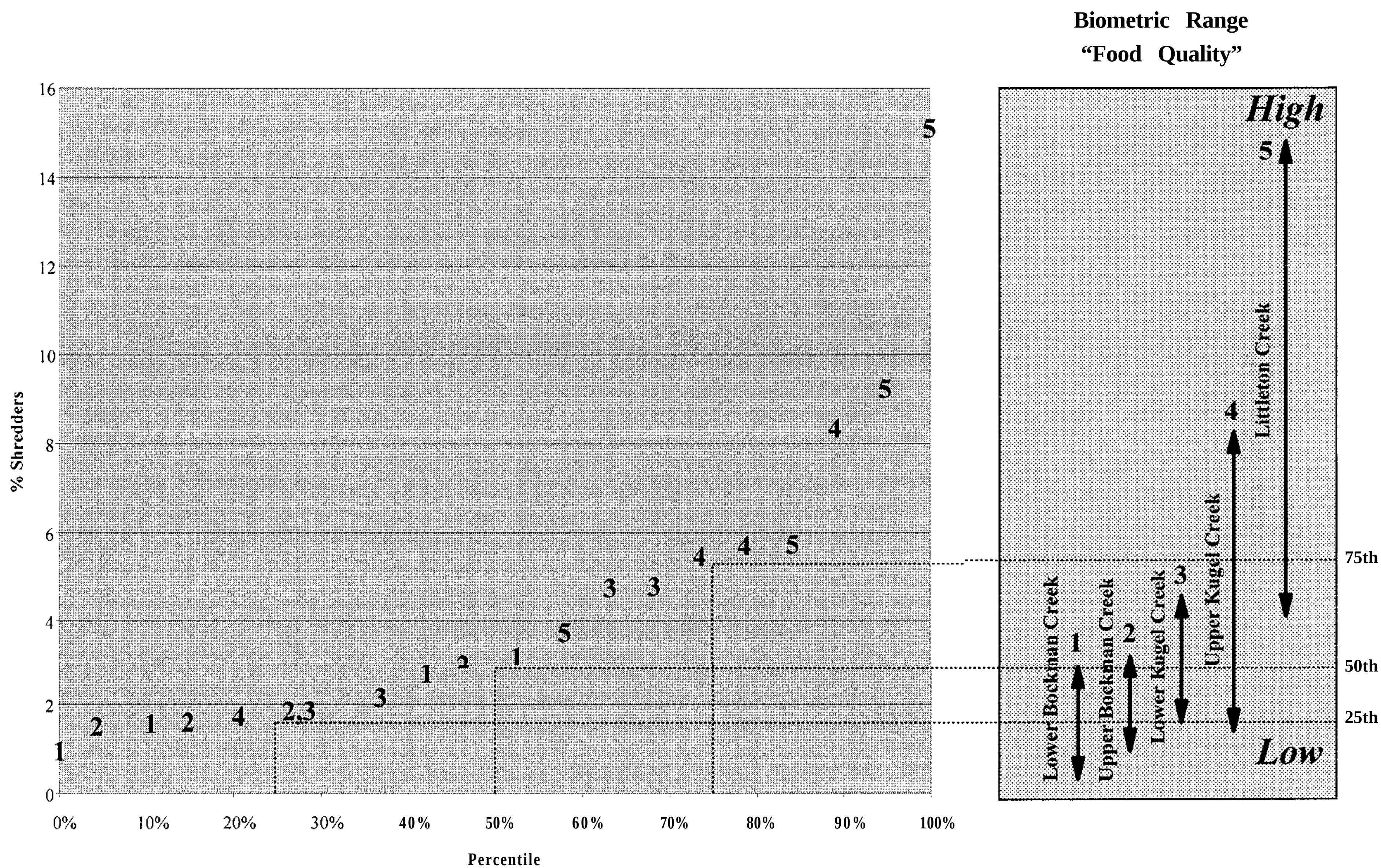
Biometric Range
“Temperature Sensitive”
High
Low
75th
50th
25th
Lower Kugel Creek
Upper Kugel Creek
Littleton Creek
Lower Bockman Creek
Upper Bockman Creek
% Plecoptera
Percentile
0
5
10
15
20
25
30
35
40
45
50
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

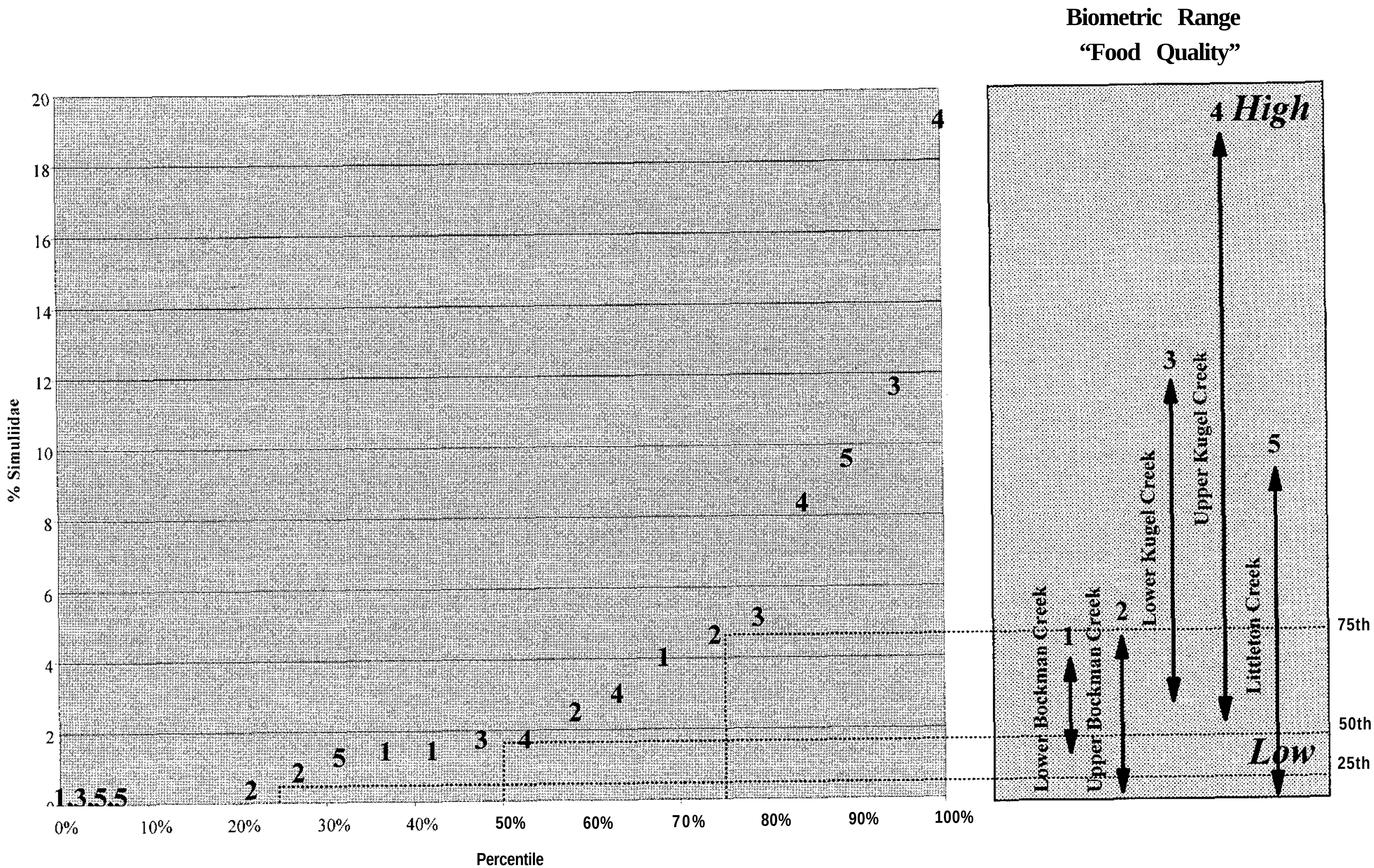


Biometric Range
"Food Quality"
% Pteronarcyidae
Percentile
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
1
2
3
4
5
6
7
8
High
Low
Littleton Creek
Upper Kugel Creek
75th
50th
25th

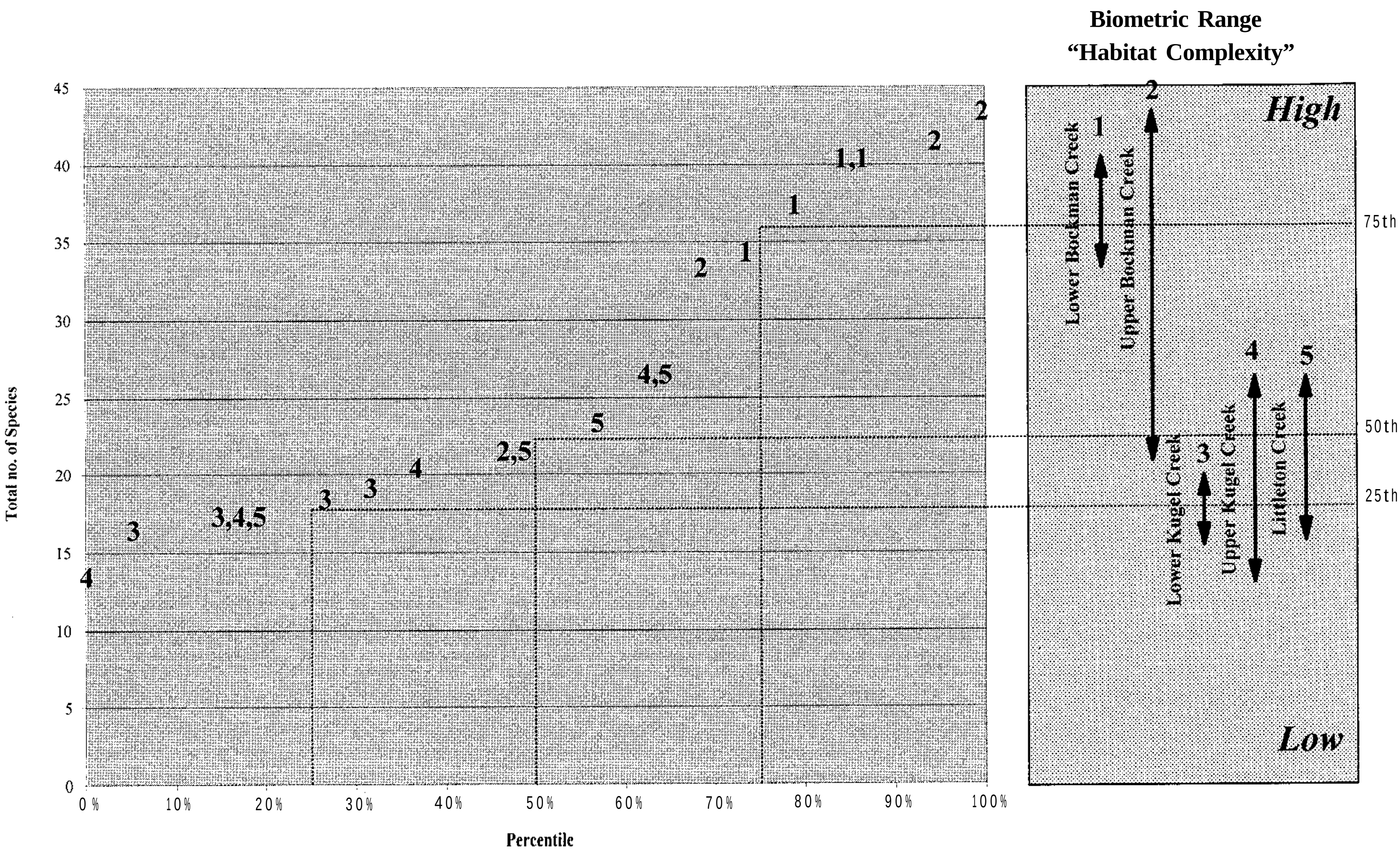


Biometric Range
"Food Quality"
High
Low
75th
50th
25th
Lower Bockman Creek
Upper Bockman Creek
Lower Kugel Creek
Upper Kugel Creek
Littleton Creek
% Scrapers
Percentile
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%


Biometric Range
"Food Quality"
% Shredders
Percentile
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
2
4
6
8
10
12
14
16
High
Low
75th
50th
25th
Lower Bockman Creek
Upper Bockman Creek
Lower Kugel Creek
Upper Kugel Creek
Littleton Creek
1
2
3
4
5
2,3



Biometric Range
"Food Quality"
% Simuliidae
Percentile
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
20
18
16
14
12
10
8
6
4
2
0
High
Low
75th
50th
25th
Lower Bockman Creek
Upper Bockman Creek
Lower Kugel Creek
Upper Kugel Creek
Littleton Creek



Biometric Range
"Habitat Complexity"
High
Low
Lower Bockman Creek
Upper Bockman Creek
Lower Kugel Creek
Upper Kugel Creek
Littleton Creek
75th
50th
25th
Total no. of Species
Percentile