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The Relationship Between Stream Macroinvertebrates and Salmon in the Quilceda/Allen Drainage

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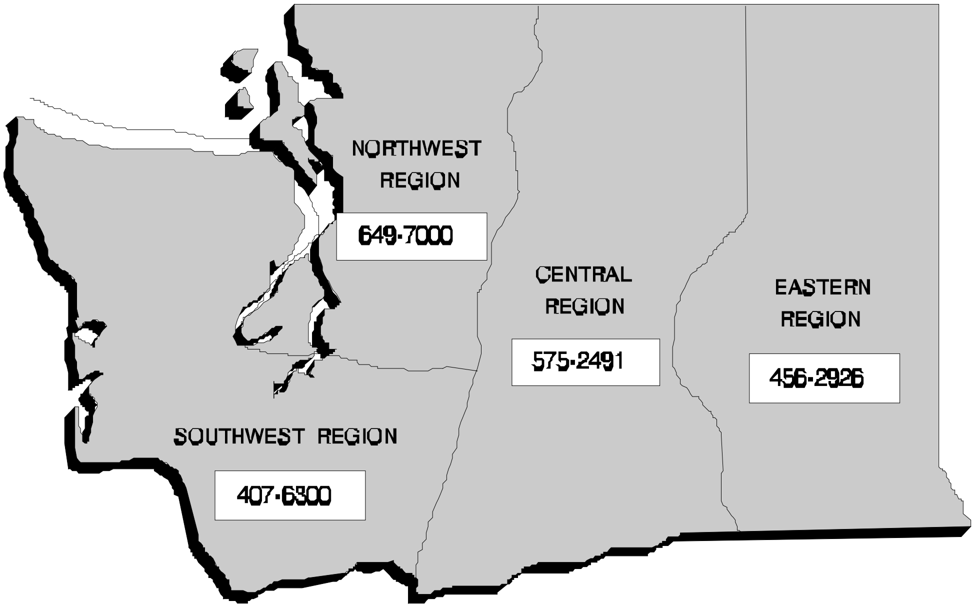

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The Relationship Between Stream Macroinvertebrates and Salmon in the Quilceda/Allen Drainage

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Abstract

Stream macroinvertebrates were surveyed at several reaches in the Quilceda/Allen drainage to establish their value as an indicator of stream quality for salmon use. Four benthic samples were collected each from riffle and pool habitat. Quantitative physical measurements, along with water quality measurements, were made of the stream channels. High quality biological conditions were found at sites where the riparian corridor was visually intact. These sites had a high percentage of coarse gravel and cobble-sized stream bottom substrate. Additionally, canopy shading was related to biological condition of stream macroinvertebrate communities. Coho salmon (*Oncorhynchus kisutch*) use is not reported to occur in stream reaches that were severely degraded, physically and chemically. The response by the macroinvertebrate community to channel degradation was coincident with changes in reported salmon use.

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Introduction

Streams contain a wealth of biological organisms. The benthic macroinvertebrates (aquatic insects) are a major component of this life in streams and are often used to measure stream health. Healthy streams maintain biological community attributes and functions that support biota in a pattern identifiable as a natural, non-degraded condition. Macroinvertebrate community characterization is an inexpensive way to measure stream quality, much like those methods relying on water quality samples.

Stream-dwelling invertebrates are affected by physical, chemical, and other biological variables in their environment. Macroinvertebrate communities respond with some type of signal to changes in these environmental variables. Signals from the macroinvertebrate community, that are associated with a likely cause, provide a very effective way for identifying measures needed to protect important stream resources.

Benthic macroinvertebrates generally inhabit a localized area of a stream throughout their life cycle. Therefore, the individual organisms are continually exposed to any changes that occur in the chemical and physical environment (Rosenberg and Resh, 1993). Continuous exposure to the localized condition presents an historical view of a stream's quality. As a result, monitoring stream biology can also serve as an early warning system to deteriorating stream health. Conversely, macroinvertebrates can be used to monitor stream improvement as it occurs over the longer time period.

Objectives for this project were to:

- provide a demonstration of the practical application of biological assessment techniques in an urbanizing basin,
- provide a baseline for determining trends in the basin,
- determine the availability of food organisms for salmon over a range of land uses,
- investigate the association between biological measures and known water quality problems,
- gather information that can be used in convincing public officials of the need for action, and
- gather diagnostic information that can be used in identifying and solving problems.

Methods

Description of Study Area

Quilceda Creek and Allen Creek are small drainages that discharge near the mouth of the Snohomish River Basin (Figure 1). Their combined drainage area is about 44 square miles in Marysville, Arlington, and the Tulalip Indian Reservation. Originally, about two-thirds of the watershed area was upland forest. About one-third of the area was wetland, primarily marsh and swamp in the Marysville Trough lowlands and the large estuarine marsh at the mouth of Quilceda Creek. Smaller forested wetlands occurred at the headwaters and within the ravines of Quilceda and Allen Creeks.

Early development by Europeans involved ditching and draining the lowlands for agriculture. Suburban and urban development followed more recently. In the process, about 75 to 85 percent of the watershed's wetlands have been drained and filled (Carroll, 1998).

Wetland loss combined with increased impervious surfaces result in rapid stormwater runoff and increased flash flooding. These storm flows often carry a high sediment load from land-clearing activities and can cause permanent alterations in physical habitat characteristics of the stream. Impervious surfaces also reduce groundwater recharge, resulting in lower summer flows. This affect can be significant, since during dry weather groundwater contributes between 46 and 60 percent of the combined flow of the Mainstem and Middle Fork Quilceda Creek (Larson and Marti, 1996). In addition, development often encroaches directly on riparian corridors, altering stream banks and removing vegetation. Removing streamside vegetation eliminates the shading that helps keep water temperatures cool, reduces food (e.g., leaves and terrestrial insects) for aquatic organisms, and removes a source of large woody debris that provides habitat structure.

Sampling Sites

Sites that were sampled for benthic macroinvertebrates in the Quilceda Creek and Allen Creek drainages are shown in Figure 1. The site number, name, and reason for monitoring are listed in Table 1.

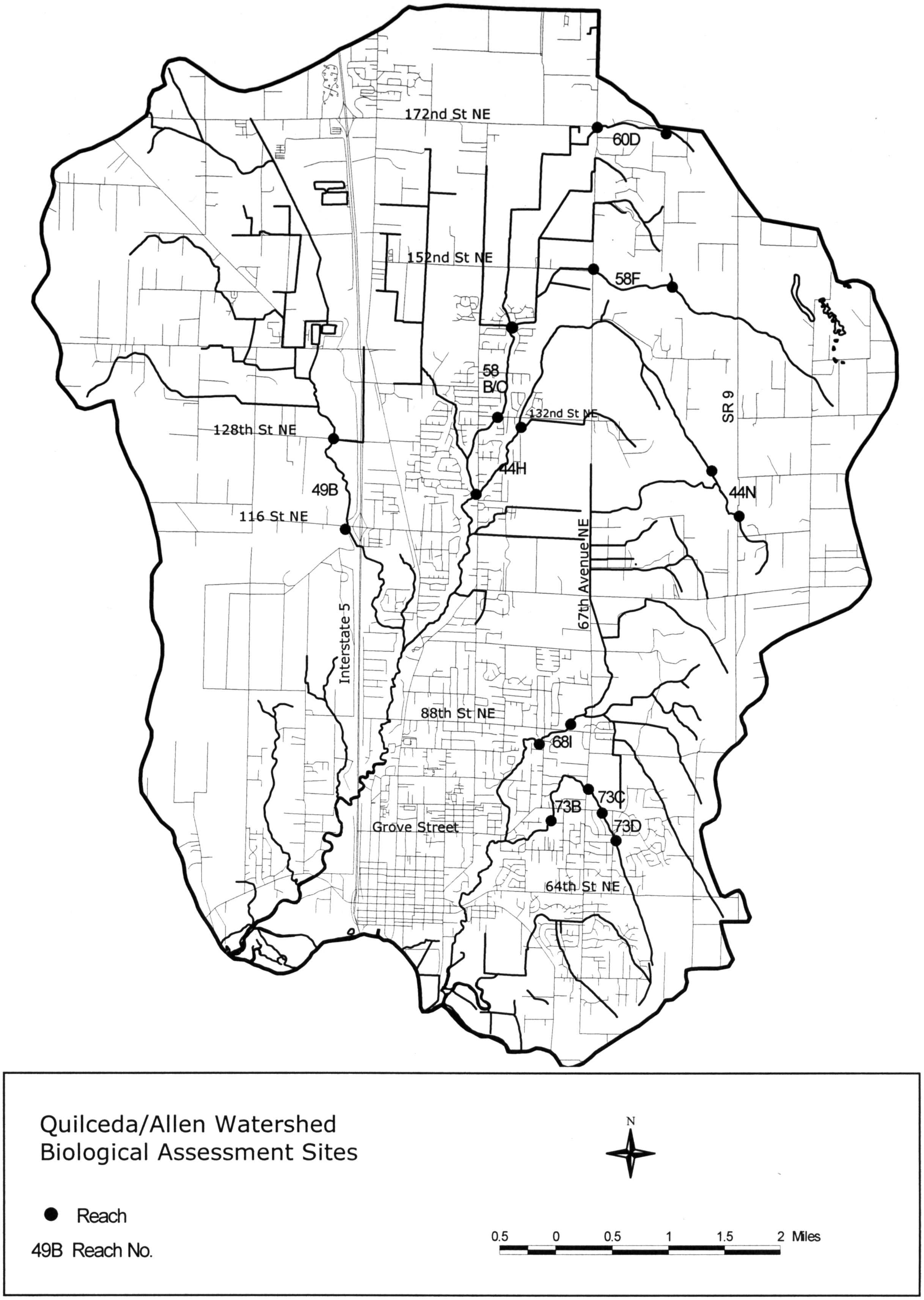

Figure 1. Biological Assessment Sites for the Quilceda/Allen Watershed.

Table 1. Sites selected for biological monitoring in the Quilceda/Allen Project.

Site #	Stream Name	Location	Land Use
44H	Quilceda Creek	51st Ave. NE	suburban landscaping
44N	Quilceda Creek	Route 9, Quilceda	(forest buffer) reference site
49B	Quilceda Creek	Dirt Bike Area	dirt bikes, upstream agriculture
58B	M.F. Quilceda Creek	Meadow Creek subdivision	stream rehabilitation, development
58F	M.F. Quilceda Creek	Wade Road	(buffer) logged, upstream gravel mining
60D	Edgecomb Creek	Edgecomb Creek	(forest buffer) culvert erosion, runoff
68I	Allen Creek	Cedarcrest Middle School	upstream agriculture, construction
73B	Munson Creek	67th Ave. NE	development
73C	Munson Creek	Golf Course	dam, golf course
73D	Munson Creek	76th Ave. NE	new development

Field Sampling

Environmental Variables

A standard set of variables was measured at each stream site. Table 2 lists variables measured and the scale of measurement (reach and site-specific). Organization of the variables at each scale was similar to those of Carter *et al*. (1996). The field forms used to record measurements at each stream are in Appendix A.

Table 2. Physical and chemical variables measured at each stream and their scale of measurement (reach and site-specific).

Scale of Measurement	
Reach	**Site-specific**
Gradient	Depth
Flow	% Cobble
Wetted Width	% Coarse Gravel
Bankfull Width	Current Velocity
Water Temperature	% Canopy Cover
Dissolved Oxygen	
Conductivity	
pH	

Stream Habitat

Stream reaches contain two easily identified and contrasting habitats: riffles (broken surface water) and pools (slow-moving or eddying water). The primary reason for surveying these two habitats was to measure habitat-specific signals from stressed invertebrate communities.

Multiple samples were collected at each stream site. Four biological samples were collected in riffle habitat and four samples were collected in pool habitat. First, collection locations in riffle habitat were selected based on the following criteria:

- depth of riffle,
- substrate size, and
- location within a riffle area of the stream (forward, middle, back).

Sampling among several riffles in a stream increased representation of physical differences in this habitat. Also, the sampling design was expected to generate a larger number of benthic macroinvertebrate taxa from a reach. Variations in physical condition of the riffle habitat provided an opportunity to collect both common and rare taxa.

Benthic macroinvertebrates were collected at four locations in pool habitat. The locations within a reach were determined by finding representative combinations of the following variables:

- depth of pool, and
- location within the channel (side, middle, behind a boulder/woody debris).

Absence of flowing water in pool habitat resulted in low sampler efficiency. Most stream bottom samplers rely on flowing water to direct macroinvertebrates into a collection net. In the absence of flowing water, loss of individual organisms increased. Benthic organisms collected from pools provided reliable synoptic lists of taxa, but not community characterizations dependent on density estimates.

Habitat-Specific Degradation

Separate riffle and pool samples were collected at all sites. Riffle and pool invertebrate assemblages were compared in order to identify: (1) differences based on habitat type, (2) stream conditions under which differences occur, and (3) whether identification of a difference between habitats is useful information.

Sampling Stream Macroinvertebrates

Stream benthic macroinvertebrates were sampled from reach lengths forty times the average width. Macroinvertebrate samples were collected from riffle and pool habitats with a D-Frame kicknet (sampling area=2.0 ft^2). A device fastened to the base of the D-Frame kicknet enclosed a one-foot by two-foot area in front of the sampler. The substrate in the enclosed area was removed and scrubbed with a brush to dislodge invertebrates into the collection net. Samples from each habitat type were stored in ethanol-filled containers.

Macroinvertebrate samples from most sites were composited into a single riffle sample and a single pool sample. As part of the data quality objectives, approximately 10 percent of total sites monitored in a year were included as part of an evaluation of community variability within a stream reach. Replicate samples were stored in separate containers at each of these streams. A detailed description of the stream survey protocols can be found in Plotnikoff (1994).

Laboratory Sample Analysis

Macroinvertebrate samples were sorted and identified by an independent laboratory (Wisseman, 1998). Samples were either sorted whole or, in the case of large sediment volumes, sub-sampled so that only a fraction of the original was analyzed. Most of the macroinvertebrates were identified to genus, including the Chironomidae, and a few to species where the taxonomy was well known.

Quality assurance procedures included: 1) re-sorting of individual samples that required sub-sampling, and 2) re-identification of these same samples. A fraction (10 percent) of the total number of project samples were subjected to these quality assurance procedures. Taxonomic literature used to identify the macroinvertebrates included peer-reviewed and published documents.

Macroinvertebrate Data Analysis

Site Condition and Ranking

The benthic macroinvertebrate data was used to calculate several biometrics. Biometrics are expressions of structural or functional community characteristics. An example of a structural characteristic would be “species richness” where the biometric is calculated from a simple count. The functional characteristics (*e.g.*, percent predators) describe the feeding behavior or activity of the macroinvertebrate species.

Ranking of site biological condition was based on the Karr and Chu’s (1997) Benthic Index of Biological Integrity (B-IBI). We used nine of the suggested biometrics to construct a B-IBI value for each habitat type (pool and riffle) at a site. The biometrics used in calculating the index value are in Table 3.

Table 3. Biometrics used to construct the Benthic Index of Biotic Integrity (B-IBI).

Metric	Response to Degradation	Scoring Boundaries 1	3	5
Total number of taxa	Decrease	<10	10-20	>20
Number of Ephemeroptera taxa	Decrease	<3	3-5.5	>5.5
Number of Plecoptera taxa	Decrease	<3	3-5.5	>5.5
Number of Trichoptera taxa	Decrease	<2	2-4.5	>4.5
Number of long-lived taxa	Decrease	<0.5	0.5-2	>2
Number of intolerant taxa	Decrease	<0.5	0.5-2	>2
% of individuals in tolerant taxa	Increase	>50	20-50	<20
% of predator individuals	Decrease	<5	5-10	>10
% dominance (2 or 3 taxa)	Increase	>75	50-75	<50

A high B-IBI score indicates a healthy stream condition and a lower score indicates the presence of stream degradation. The possible range of B-IBI scores are nine through forty-five.

Sources of Stream Degradation

Changes in a stream's physical or chemical characteristics are often reflected in the biological communities. Macroinvertebrates are heavily influenced by factors that effect their food source, substrate (living space), water temperature, and current velocity (Hynes 1970). Individual biometrics are sensitive to changes in these factors and respond to degradation of stream resources.

We examined each biometric and how site condition was ranked by the individual biometric. The physical or chemical changes that would prompt a biological signal were compared with the biometric sensitive to that change. Biometric response to specific stream degradation type is listed in Table 4. These biological/degradation source associations are general guidelines for explaining community condition at each sampling site.

Table 4. Biometrics and the type of degradation reflected from a response to physical or chemical changes in a stream reach.

Biometric	Type of Degradation
Total number of taxa	loss of living space (*e.g.*, sediment deposition)
Number of Ephemeroptera taxa	increase in surface water temperature
Number of Plecoptera taxa	increase in surface water temperature
Number of Trichoptera taxa	loss in deposited organic material or increase in algae growth
Number of long-lived taxa	loss or decline in continuous supply of cool water
Number of intolerant taxa	a change in the chemical or physical characteristics of a stream
% of individuals in tolerant taxa	a change in the chemical or physical characteristics of a stream
% of predator individuals	loss of living space and change in flow dynamics
% dominance (2 or 3 taxa)	response to severe physical or chemical impacts to a stream

Biometrics are analyzed individually by first selecting calibration sites. The calibration sites should represent unimpaired stream locations and also visually impaired locations. A biometric is effective in identifying stream degradation when it responds to clear differences in stream quality. Once each biometric is tested from a set of data, the presence of degraded stream reaches and source of degradation can be determined.

Macroinvertebrates and Salmon Habitat

Benthic macroinvertebrates reflect stream qualities such as: physical characteristics, chemical characteristics, and severity of the most recent physical disturbance. Likewise, anadromous fish species have a preference for stream conditions that are, in part, determined by their living requirements at individual life stages. Those physical and chemical characteristics of streams that are optimal for macroinvertebrate communities can be related to optimal conditions for life stages and species of salmon.

Macroinvertebrate communities that were considered in good condition were compared to reported stream reach use by salmon (Carroll and Smith, 1999). The relationship between macroinvertebrate community condition and salmon use was used as a benchmark. Streams that had poor community conditions were further examined for physical or chemical differences that could explain why they did not meet expectations for their designated salmon use.

Results

Site Condition and Ranking

Benthic macroinvertebrate community scores (*i.e.*, Benthic Index of Biotic Integrity) were highest at the forested sites in the Quilceda/Allen drainage (Edgecomb Creek-60D, Middle Fork Quilceda Creek-58F, and Quilceda Creek-44N). Stream habitat such as pools and riffles had poor benthic community conditions in reaches below a golf course and major suburban development. The Benthic Index range was greater for riffle communities than in pool communities (Figure 2).

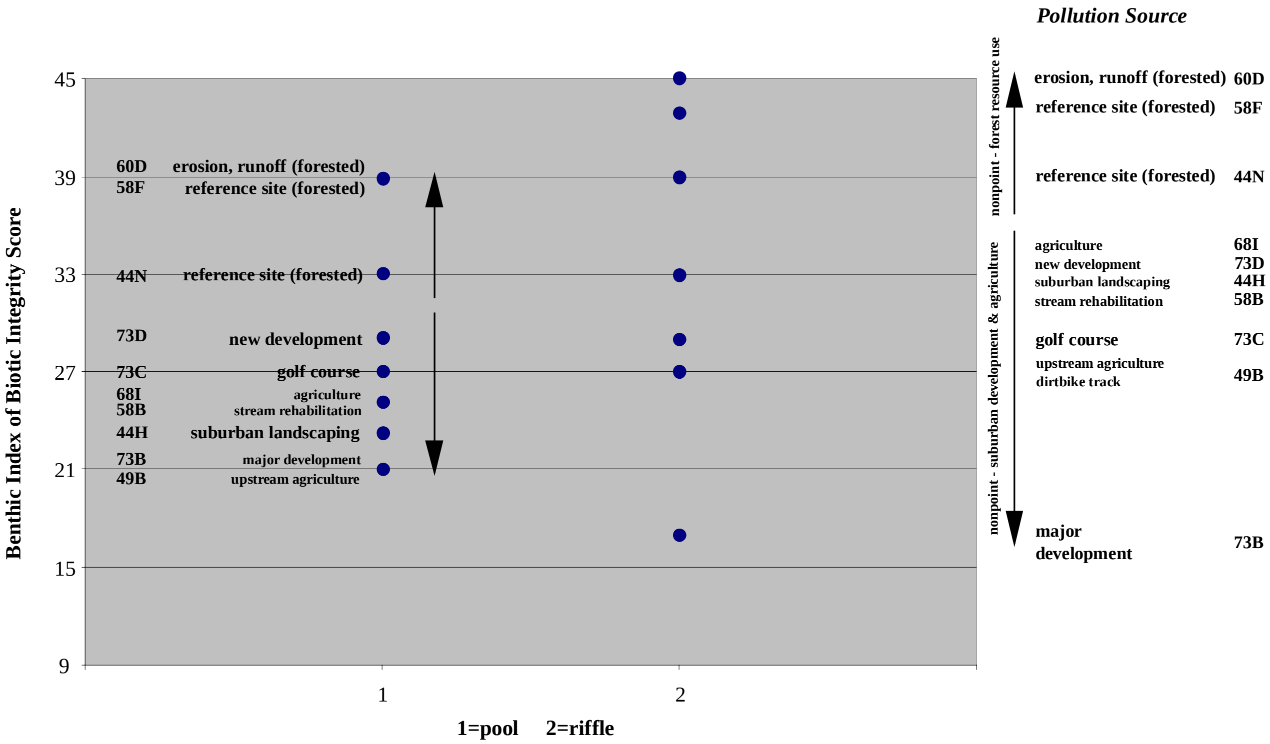

Figure 2. Benthic Index of Biotic Integrity scores for sites in the Quilceda/Allen drainage and the land uses associated with each site.

The numeric ranges for seven of the individual metrics were similar in riffle and pool habitat (Appendix C). Species found in riffle habitat were different from those found in pool habitat even though metric ranges were similar in both. The “number of Plecoptera” was greater in riffles and the “percent of individuals in tolerant taxa” was greater in pools.

Sources of Stream Degradation

The total number of taxa at each stream site was influenced by quantity of cobble substrate (Appendix B-1). Percentage of coarse gravel substrate did not have as strong an influence on providing living space for more taxa (Appendix B-2).

Plecoptera taxa, or stoneflies, had more representatives in the heavily canopied stream reaches (Appendix C). Of the stonefly taxa present at each site, more than 75 percent were shredders (Appendix D). This functional feeding group processes fallen leaves in streams and begins the transfer of biomass downstream.

Intact riparian canopy (*i.e.*, percent canopy shading) positively influenced the number of mayfly (Ephemeroptera) species, caddisfly (Trichoptera) species, and percentage of predators in the benthic community (Appendix B-3, B-4, and B-5). Stream corridors that were protected by vegetation also had substrate types that promoted greater varieties of species in each of these taxonomic groups. Streams with fewer species in riffle habitat had less canopy shading and less cobble and coarse gravel substrate. Canopy shade over the stream corresponded with the number of intolerant taxa (Appendix B-6).

Surface water conductivity was low at reference sites Edgecomb Creek (60D), Middle Fork Quilceda Creek (58F), and Quilceda Creek (44N). Stream reaches adjacent to (Munson Creek, 73C) and below the golf course (Munson Creek, 73B) had the highest water conductivities. Streams with the highest conductivities were also dominated by three taxa (Appendix B-7). These taxa were considered tolerant to living in fine sediments or were filtering suspended organic particles from the water column (collector-filterers). Intolerant taxa were identified from stream reaches that had moderate- to low water conductivities (Appendix B-8).

The diverse benthic communities at reference sites contained more of the intolerant taxa identified in this drainage network. Stream conditions that favored higher numbers of taxa provided important living space for benthic animals that were intolerant to physical change in the channel and corridor. In stream reaches where dominance of three taxa was high, diversity of the benthic community was lower. Stream channel changes and proliferation of tolerant benthic taxa pre-empted the naturally occurring species diversity.

Macroinvertebrates and Salmon Habitat

Stream reach use by salmon (Carroll and Smith, 1999) included spawning, rearing, and a separate designation called resident (Figure 3). Coho salmon (*Oncorhynchus kisutch*) used streams for spawning and rearing with high riffle B-IBI scores (Benthic Index of Biotic Integrity). Chum salmon (*Oncorhynchus keta*) used streams that were of moderate quality (mid-range B-IBI scores) for spawning. The poorest quality streams (low B-IBI score) did not have coho salmon spawning or chum salmon using the reach. Resident cutthroat trout (*Oncorhynchus clarki*) were reported from all sites sampled for benthic macroinvertebrates.

Relationships between physical conditions at stream reaches and the corresponding biological condition were compared. Cobble and coarse gravel substrates were compared with the total number of taxa collected from a stream site (Figure 4 and Figure 5). The

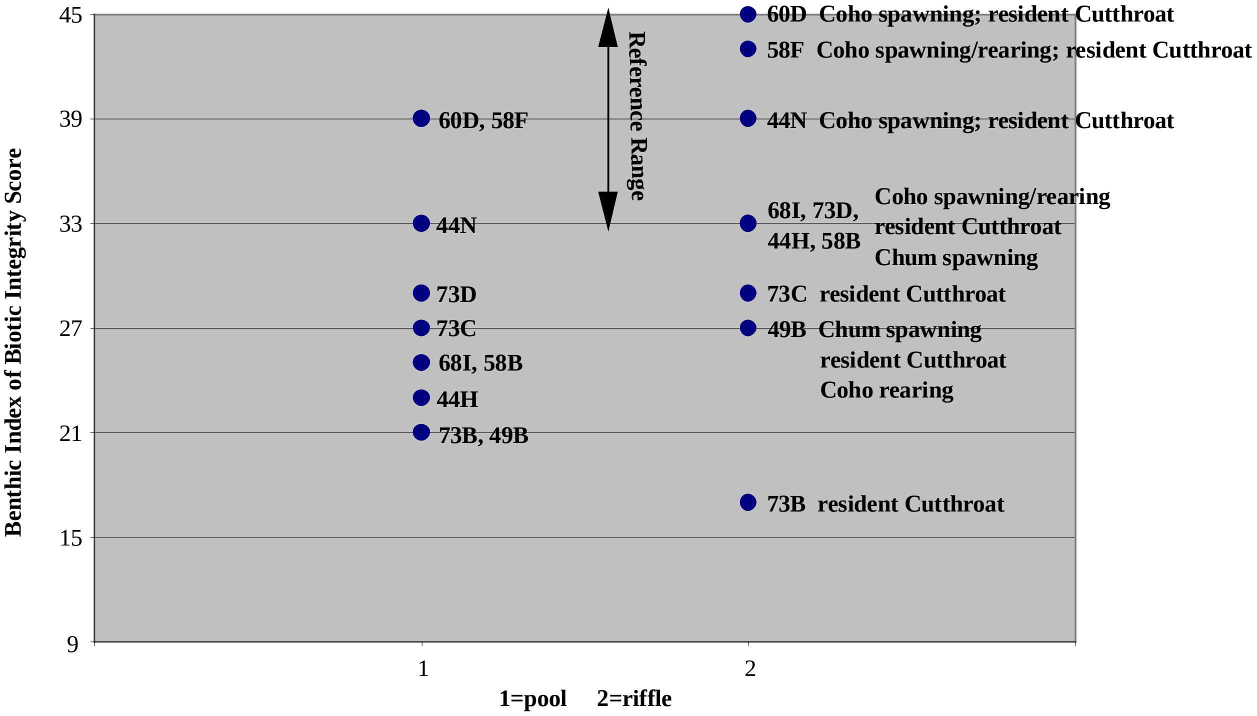

Figure 3. Reported stream reach use by salmon at sites in the Quilceda/Allen drainage.

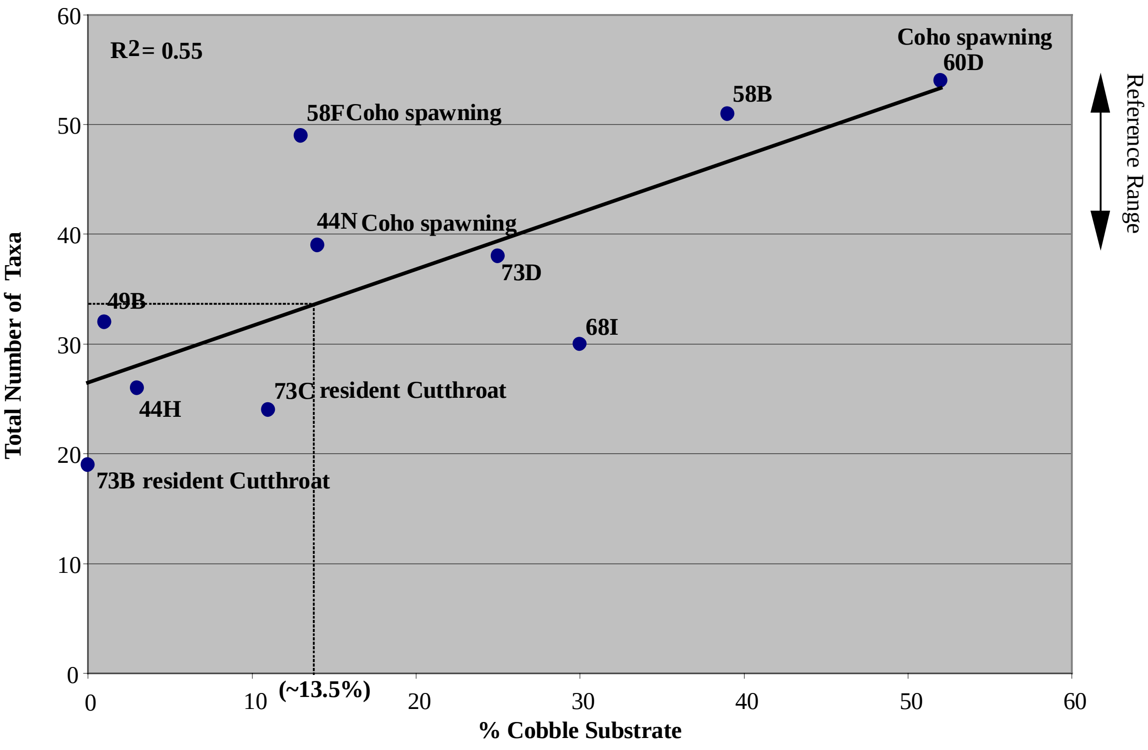

Figure 4. Threshold for minimum amount of cobble substrate in forested, reference streams of the Quilceda/Allen drainage.

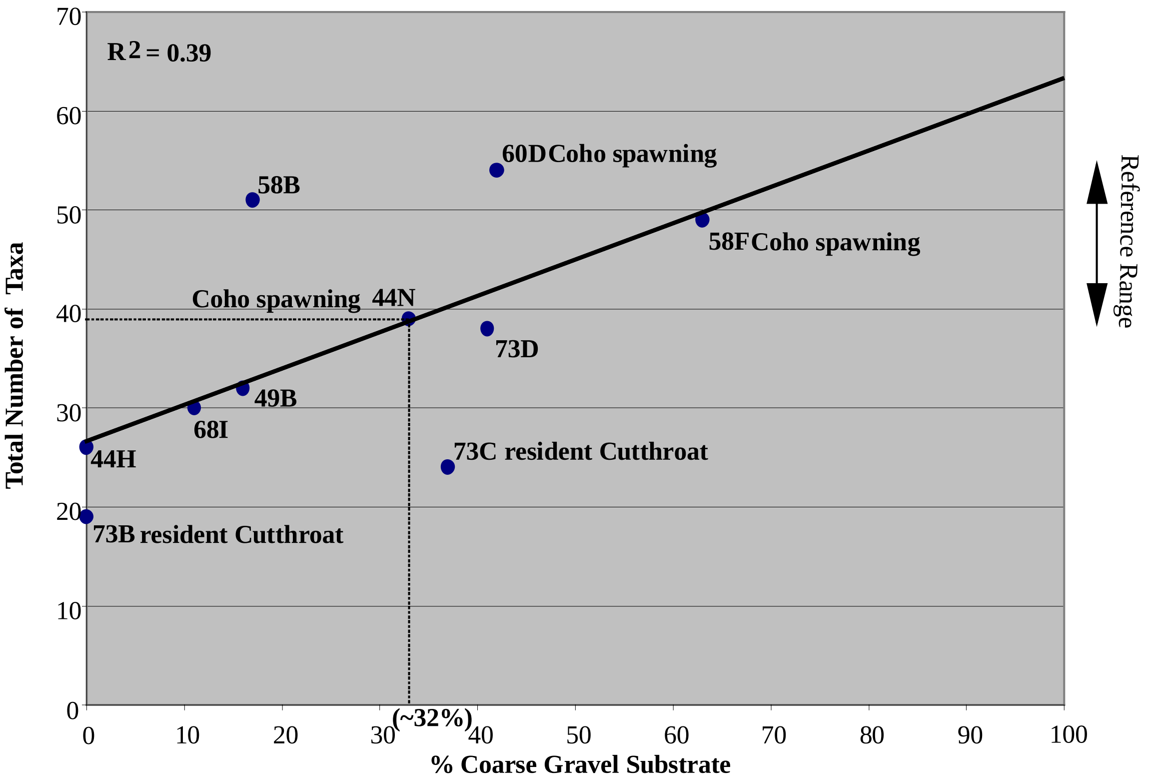

Figure 5. Threshold for minimum amount of coarse gravel substrate in forested, reference streams of the Quilceda/Allen drainage.

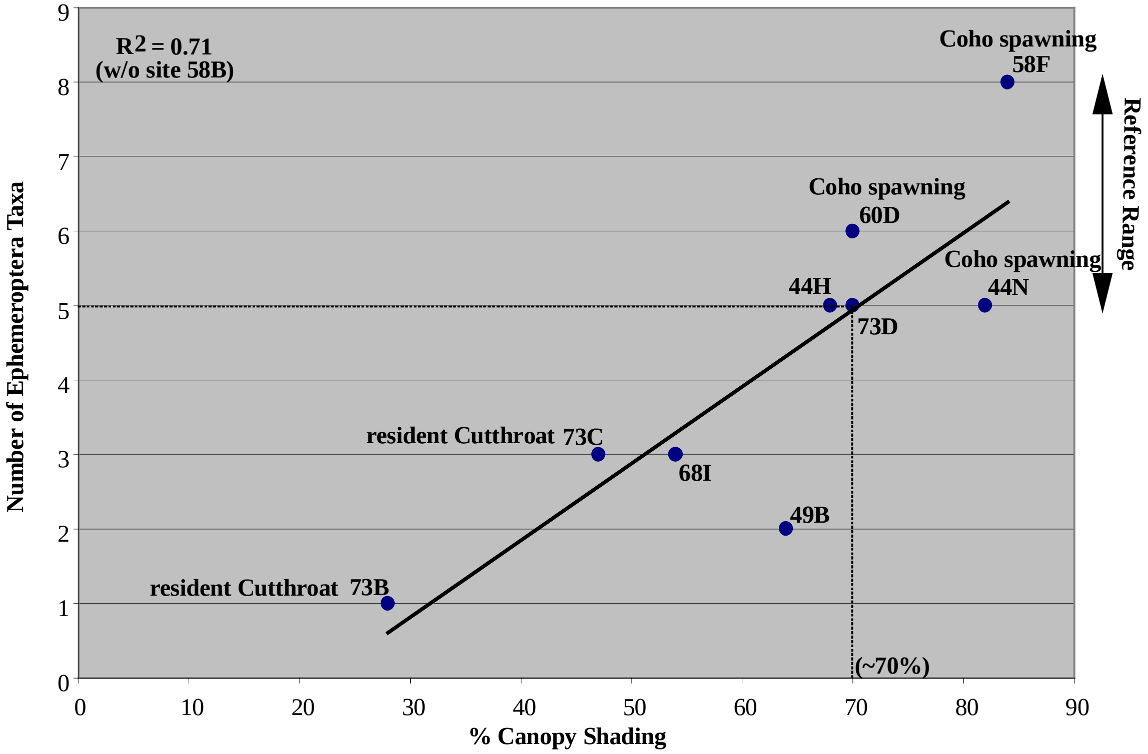

Figure 6. Threshold for minimum amount of canopy shading at forested, reference streams of the Quilceda/Allen drainage.

amount of canopy shading was compared with the number of mayfly (Ephemeroptera) taxa collected at each site (Figure 6).

Reference condition thresholds were identified with the lowest quantified value for each physical variable at the following sites: 44N (Quilceda Creek), 58F (Middle Fork Quilceda Creek), and 60D (Edgecomb Creek). Sites that had a larger quantity of cobble, coarse gravel, or canopy shading were considered to be in better condition. Proportion of cobble substrate that identified a reference condition was ~13.5 percent (Figure 4). Proportion of coarse gravel substrate that identified a reference condition was ~32 percent (Figure 5). Canopy shading was at least 70 percent to qualify as a reference condition (Figure 6).

Biological Properties of Benthic Communities

Certain properties of biological communities can be used to indicate stream quality. The comparison between total number of taxa occurring at a site and the dominance of the three best-represented taxa, indicates the diversity and variety of available living resources. An inverse relationship between total number of taxa and dominance was identified (Appendix B-9). The number of intolerant taxa increased with the greater number of taxa collected from a site (Appendix B-10). The diversity of taxa at a site was related to the number of specialist taxa or those that are considered sensitive to environmental impacts.

Discussion

Site Condition and Ranking

Benthic communities were best in undisturbed stream reaches of the Quilceda/Allen drainage. Biological condition of stream reaches is partly determined by intensity and quantity of local and upper watershed disturbance. Areas sampled that had moderate or no visible streamside activity scored highest in biological condition. These sites were compared against the moderate- and low-scoring sites for type of known surrounding land uses.

Sites where benthic communities indicated moderate-impairment were land uses established several years prior to the survey. At least partial riparian corridors were intact and land use was not directly adjacent the stream. The worst biological condition in a stream occurred where major development of the landscape reached the streamside. Watershed areas that suffered continuous soil disturbance (*e.g.*, dirt bike track and major development) reflected the degradation to the stream through the benthic community.

More Plecoptera or “stoneflies” were found in riffles than in pools at reference sites in the Quilceda/Allen drainage. Stoneflies prefer cold water and a high diversity of substrate types as a living space. The greater variety at three sites suggest stream reaches that have not been degraded from surrounding activities that cause water temperature increases or deposition of fine materials in riffles.

Pool habitat is a place commonly associated with deposition of fine materials and, consequently, substrate that is suitable for burrowing. Pool habitat at four sites had more taxa than in riffles. Moderate streamside activity was associated with the biologically rich pool habitat. As is often the case, moderate disturbance of the physical habitat opens new living space (Townsend *et al.* 1997). Animals that do well in a changing environment tend to be tolerant to degradation and can quickly colonize available habitat.

Sources of Stream Degradation

Available living space is an important determining factor of richness in a macroinvertebrate community. Size of substrate material on stream bottoms in the Quilceda/Allen drainage that had more cobble generally supported a greater variety of taxa. Interstitial spaces (spaces between the rocks) are filled with particles of other size classes and organic food (detritus) sources (Minshall 1984; Minshall and Minshall 1977). Reference streams in this drainage had intact riparian zones that were a potential food source for these macroinvertebrates. Additionally, larger substrate particles tend to protect macroinvertebrates from the effects of floods by: 1) providing refuge from swift currents, and 2) resisting movement with the higher current velocities (Allan 1995).

Stoneflies were present in greater varieties at the healthy stream sites. The majority of these taxa were functionally classified as shredders (consume leaves, sticks, and twigs). Taxa such as stonefly shredders serve an important and sometimes dominant role in canopied streams (Cummins *et al.* 1989). Their reduction or disappearance from stream reaches resulted from inadequate or absent streamside vegetation. The same observations were made by Wallace *et al.* (1997) where significant decreases in abundance and biomass of shredders were measured when leaf litter was excluded from stream reaches.

Canopy shading of the stream was an integral characteristic of the reference reaches. Streamside vegetation appeared to maintain normal function of ecosystem characteristics in the Quilceda/Allen drainage. Streams without vegetation cover had a lower percentage of coarse substrate, greater quantities of conductive fine inorganic material reaching the stream, and a low macroinvertebrate diversity. Quantity of streamside vegetation is an important characteristic for maintaining biological integrity of the macroinvertebrate community in the drainage.

Surface water conductivity was high at stream reaches with moderate- to heavy streamside activity. May *et al.* (1997) identified a strong direct relationship between baseflow conductivity and amount of urbanized area in a watershed. Fine soil and other constituents that are washed into the stream during rain events and through groundwater can elevate water conductivity. Stream reaches below a golf course (73C) and major development (73B) had the highest conductivity. This resulted in a few tolerant taxa dominating the macroinvertebrate community.

Macroinvertebrates and Salmon Habitat

Coho salmon (*Oncorhynchus kisutch*) spawning and rearing (Carroll and Smith, 1999) occurred at the highest quality forested sites in the Quilceda/Allen drainage (60D, 58F, 44N). Healthy macroinvertebrate communities in near-natural conditions were collected from stream reaches that had both spawning and rearing coho salmon. Environmental needs of benthic macroinvertebrates were directly related to those of the coho salmon.

The physical condition of high quality salmon stream reaches was characterized by three variables: proportion of cobble, proportion of coarse gravel, and canopy shading. Characteristics of the macroinvertebrate community were related to these variables so that limiting physical factors could be identified. The thresholds for each variable outlined the minimum requirements that would maintain natural biological conditions in each stream.

The low quantity of coarse gravel at Allen Creek (68I) may have resulted from the upstream agriculture identified along this reach. This site had a proportion of cobble comparable to the reference conditions. Dominant substrate types were cobble and fine sediment. Sediment transport from agricultural activities upstream may have been one source of suspended sediment. Munson Creek (73C) had a lower proportion of cobble and lacked adequate shading. This combination of physical conditions may be a result of long-term degradation from activity at the nearby golf course.

Other investigations of Puget Sound, Washington streams have identified a B-IBI threshold for “natural” streams (May *et al.* 1997). A natural stream has an impervious surface area in a watershed of less than five percent. Coho salmon spawning and rearing activity in these streams was present where B-IBI scores were 33 and higher.

Coho salmon activity was diminished or had disappeared in the Quilceda/Allen drainage streams with scores less than a B-IBI score of 33. Typically, in Puget Sound streams, coho outnumber the cutthroat trout under natural conditions (Lucchetti and Fuerstenberg 1993). Resident cutthroat trout used all of the stream reaches visited by this survey, but were more abundant than coho salmon at the most degraded sites (Carroll and Smith, 1999).

Biological Properties of Benthic Communities

Reference sites that had high numbers of taxa also had lower dominance of individual taxa. Biota in stressed ecosystems are usually dominated by a few tolerant taxa, but lose the intolerant or “specialist” taxa. This inverse relationship between total number of taxa and dominance of the community by few species was found among sites in the Quilceda/Allen drainage. Major development of the landscape near streams substantially affected biological conditions. Examining dominance of future macroinvertebrate collections from the Quilceda/Allen drainage will be a good indicator of stream degradation.

Periodically, species-rich communities contain many examples of individuals that are intolerant to changes in the ecosystem. Although there were deviations from a direct relationship between number of taxa and intolerant taxa, the expectation for healthy biological conditions would be that diverse communities contain “specialist” species. Living requirements are usually modified by a stream’s resistance to flooding and drought. The appearance of macroinvertebrate specialist taxa indicates a complex, stable habitat condition and abundant food resources.

Conclusions

- The best macroinvertebrate community conditions occurred in stream reaches where the riparian corridor was visually intact. Even with some impacts associated with surrounding land uses such as road runoff, culvert erosion, and/or upstream logging an intact forested riparian buffer can preserve a relatively healthy macroinvertebrate community.

- Stream biota were most affected by land uses that visually reached the wetted portion of the channel. The physical disposition of the activity acted as a linkage for pollutants to reach the stream.

- Key characteristics for good sites were presence of: 1) cobble substrate, 2) coarse gravel substrate, and 3) canopy shading. All of these conditions were present beyond a minimum threshold at two sites that had been logged and showed signs of erosion from culverts. These sites were considered as references following analysis of the biological information.

- Three categories of biological condition were described: 1) high quality (minimal impact to key physical characteristics of the stream corridor), 2) moderate quality (diminished macroinvertebrate species richness and signs of long-term affects from nearby land uses), and 3) low quality (poor biological conditions and obvious visual connections between stream and source of pollution).

- Coho salmon activity diminished in streams whose B-IBI scores were 33 and lower. Degraded stream reaches were used by resident cutthroat and not by salmon.

- Analysis of the macroinvertebrate community provides a consistent evaluation of aquatic resources that accurately reflects land use impacts on the aquatic ecosystem.

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Appendix A

Field Survey Forms

(BACK-OF-PAGE PLACEHOLDER FOR DUPLEX PRINTING)

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:	

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

SUBSTRATE MEASUREMENTS

Substrate Parameter	Riffle 1	Riffle 2
DEPTH (M)		
SIZE CLASS (		
BEDROCK (SMOOTH)		
BEDROCK (ROUGH)		
BOULDER (250-4000 MM)		
COBBLE (64-250 MM)		
COARSE GRAVEL (16-64 MM)		
FINE GRAVEL (2-16 MM)		
SAND (0.06-2 MM)		
SILT/CLAY/MUCK (NOT GRITTY)		
WOOD (ANY SIZE)		
OTHER (COMMENT)		

SUBSTRATE MEASUREMENTS

Substrate Parameter	Riffle 3	Riffle 4
DEPTH (M)		
SIZE CLASS (		
BEDROCK (SMOOTH)		
BEDROCK (ROUGH)		
BOULDER (250-4000 MM)		
COBBLE (64-250 MM)		
COARSE GRAVEL (16-64 MM)		
FINE GRAVEL (2-16 MM)		
SAND (0.06-2 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				
Center (left)				
Center				
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 Cross-Section Profile					
Observatio 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					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					

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

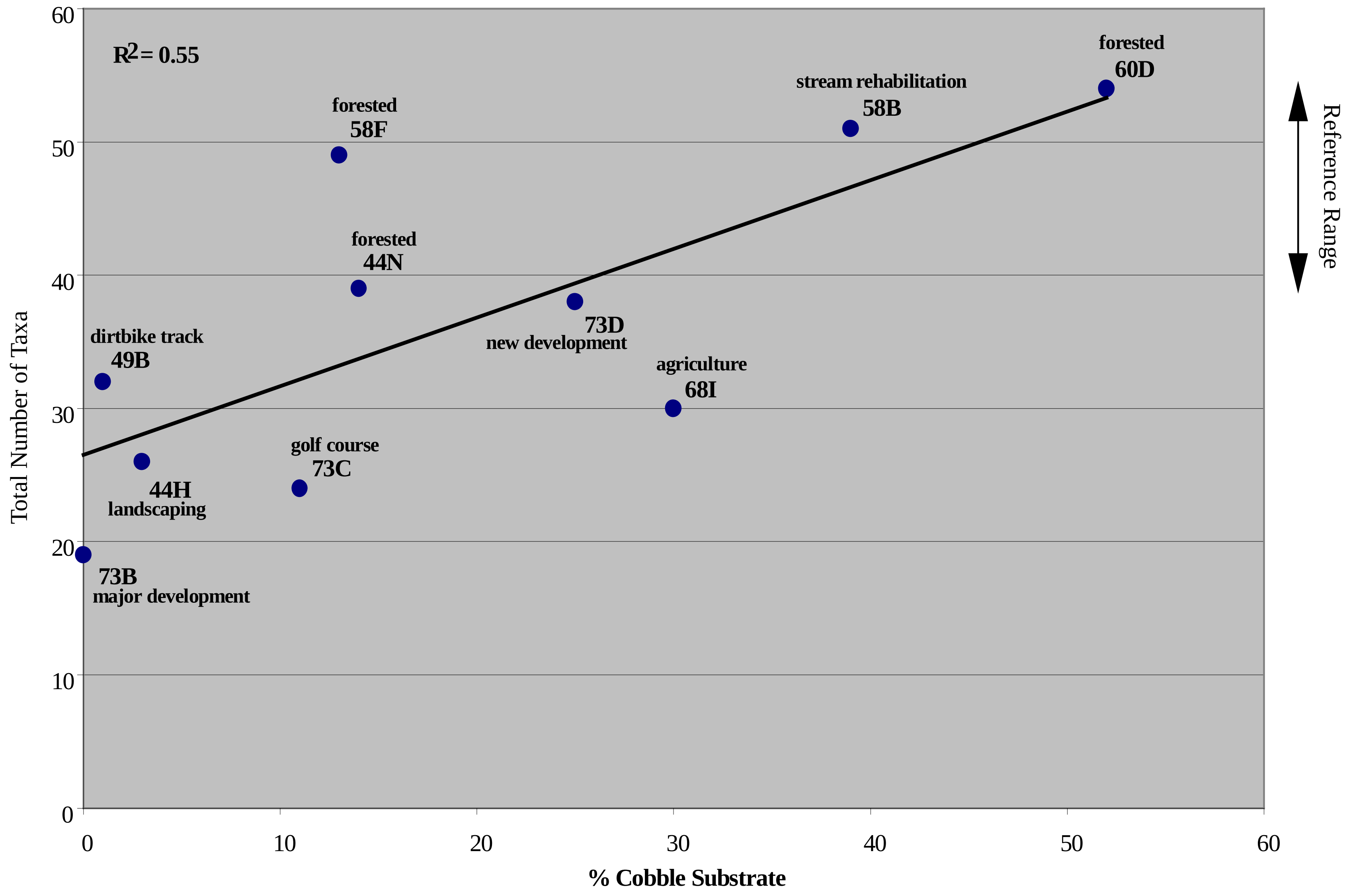
Current Velocity (m/sec or ft/sec)	
Transect	Velocity
Riffle 1	
Riffle 2	
Riffle 3	
Riffle 4	

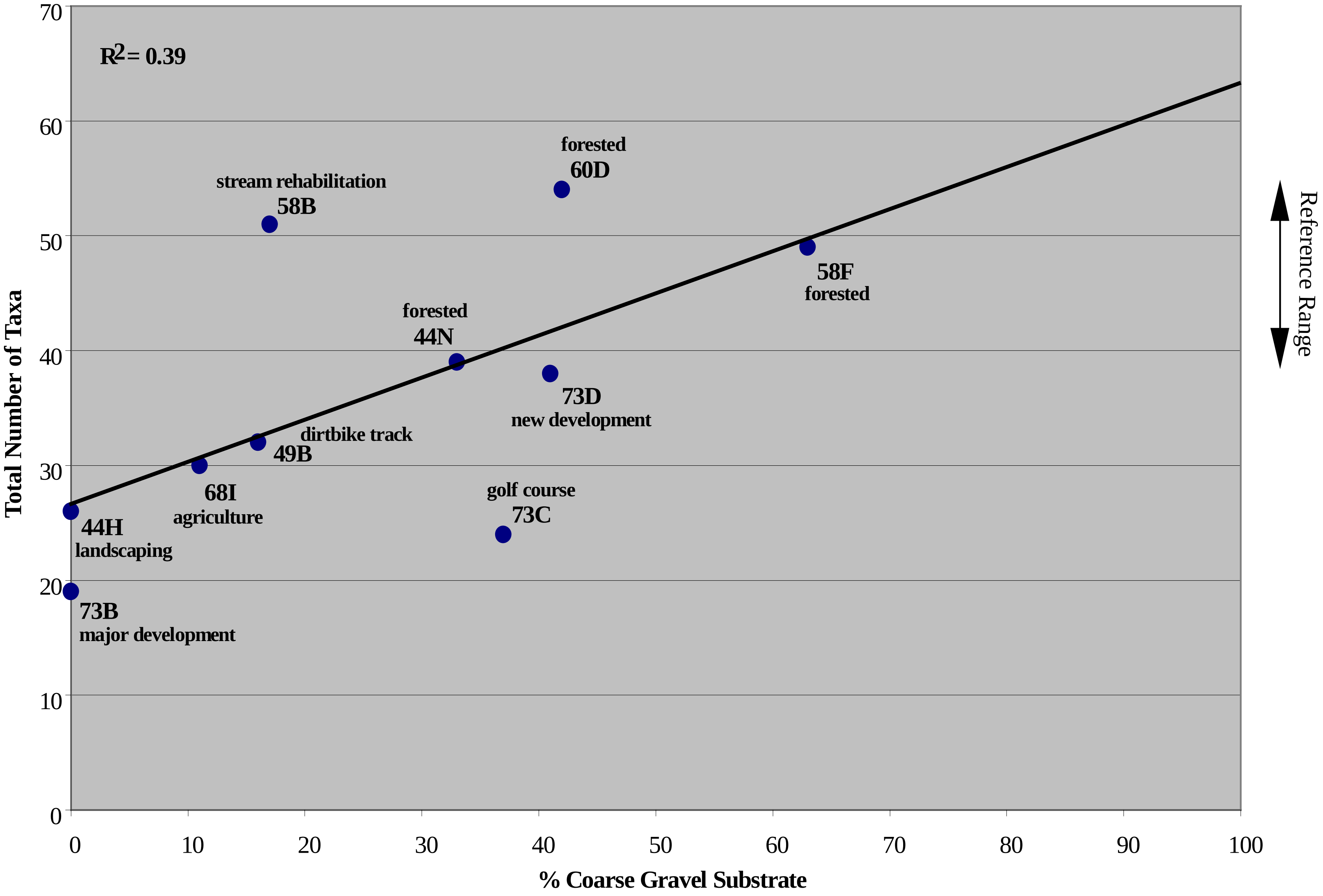
Qualitative Habitat Assessment Survey – Visual Analysis
Riffle/Run Prevalence

Site Name:	Site No.:	Date:	Evaluator Initial:	
Habitat Parameter	**Optimal**	**Sub-Optimal**	**Marginal**	**Poor**
1. Substrate-Percent Fines (fraction < 6.35mm)	< 10% (16-20)	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	<u>All habitats</u>: i)slow/deep ii)slow/shallow iii)fast/deep iv)fast/shallow (16-20)	3 of 4 (11-15)	2 of 4 (6-10)	1 of 4 (0-5)
5. Channel Shape	Trapezoidal (11-15)	Rectangular (6-10)		Inverse trapezoidal (0-5)
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) (0-3)
7. Width to Depth Ratio (wetted width/depth)	< 7 (12-15)	8 – 15 (8-11)	15 – 25 (4-7)	> 25 (0-3)
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)
10. 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)
11. Zone of Influence (width of riparian zone)	≥ 4 x BFW (BFW = Bankfull Width) (9-10)	≥ 2 & < 4 (6-8)	≥ 1 & < 2 (3-5)	<u>Little</u> or <u>None</u> (0-2)
12. Successional Stage (forested sites only)	Old-growth (9-10)	Young (6-8)	Pole saplings (3-5)	Seedlings/ Clearcut (0-2)

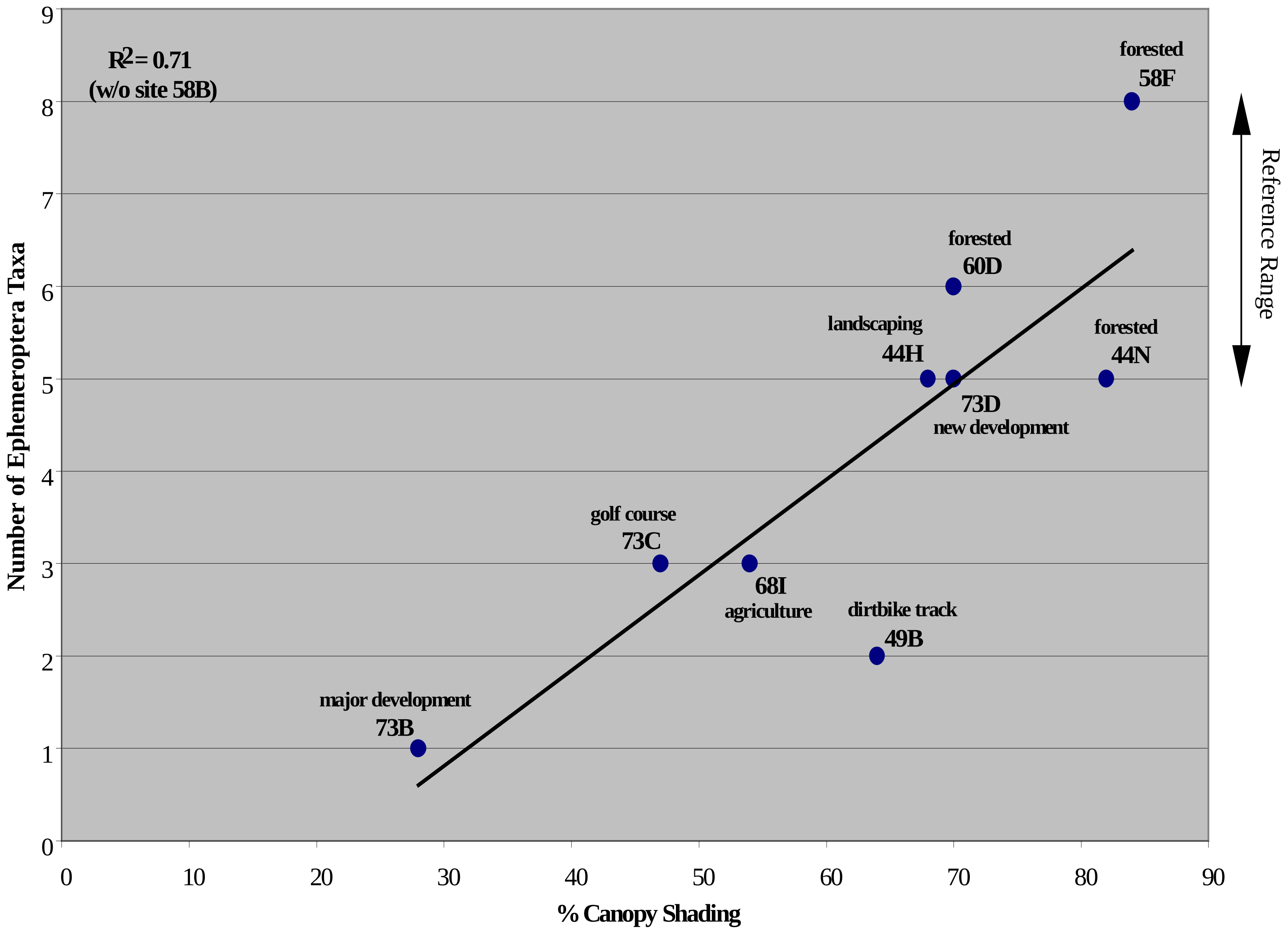
Appendix B

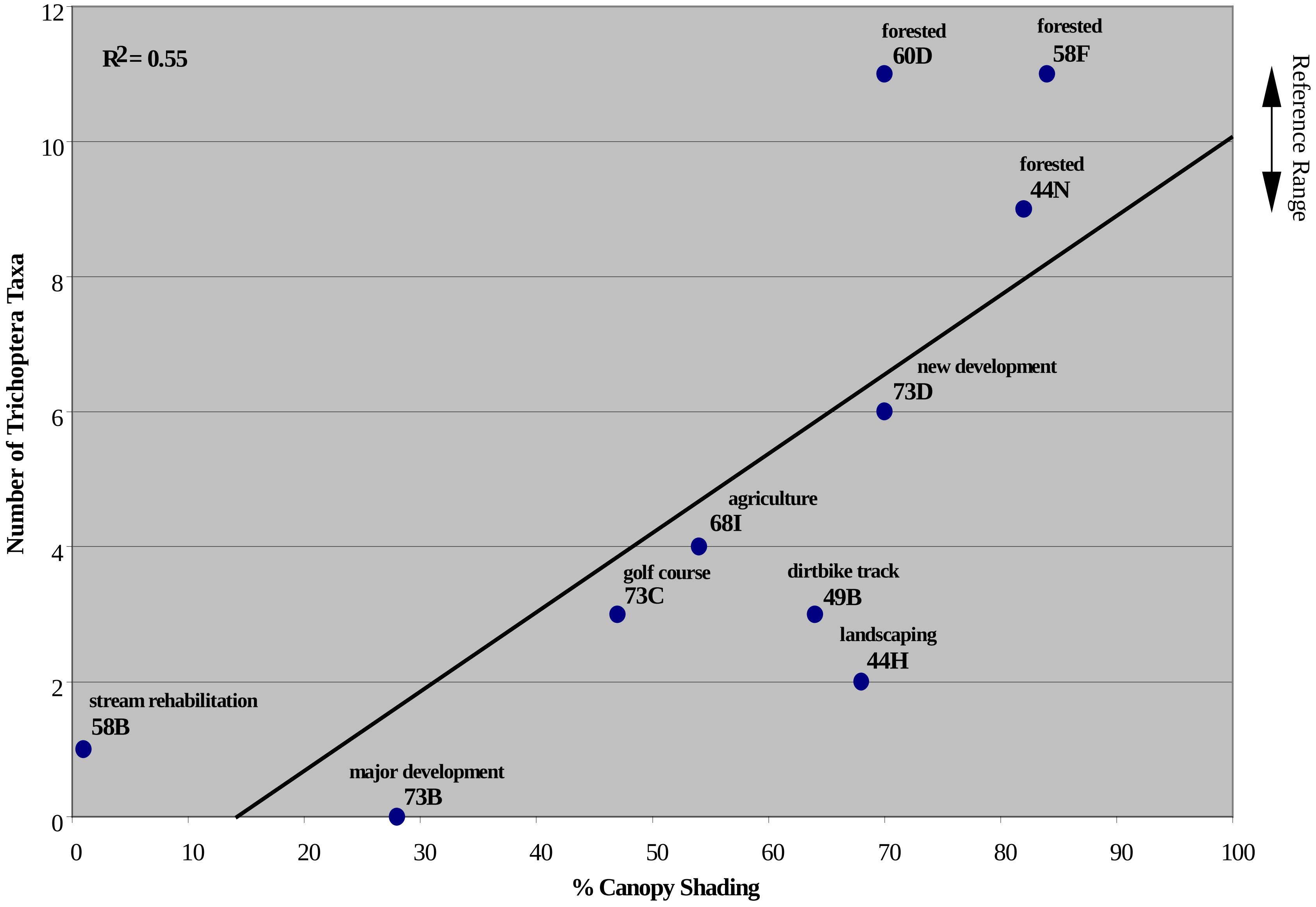
Biological Condition and Relationships to Land Use, Stream Reach Condition, and Salmon Use

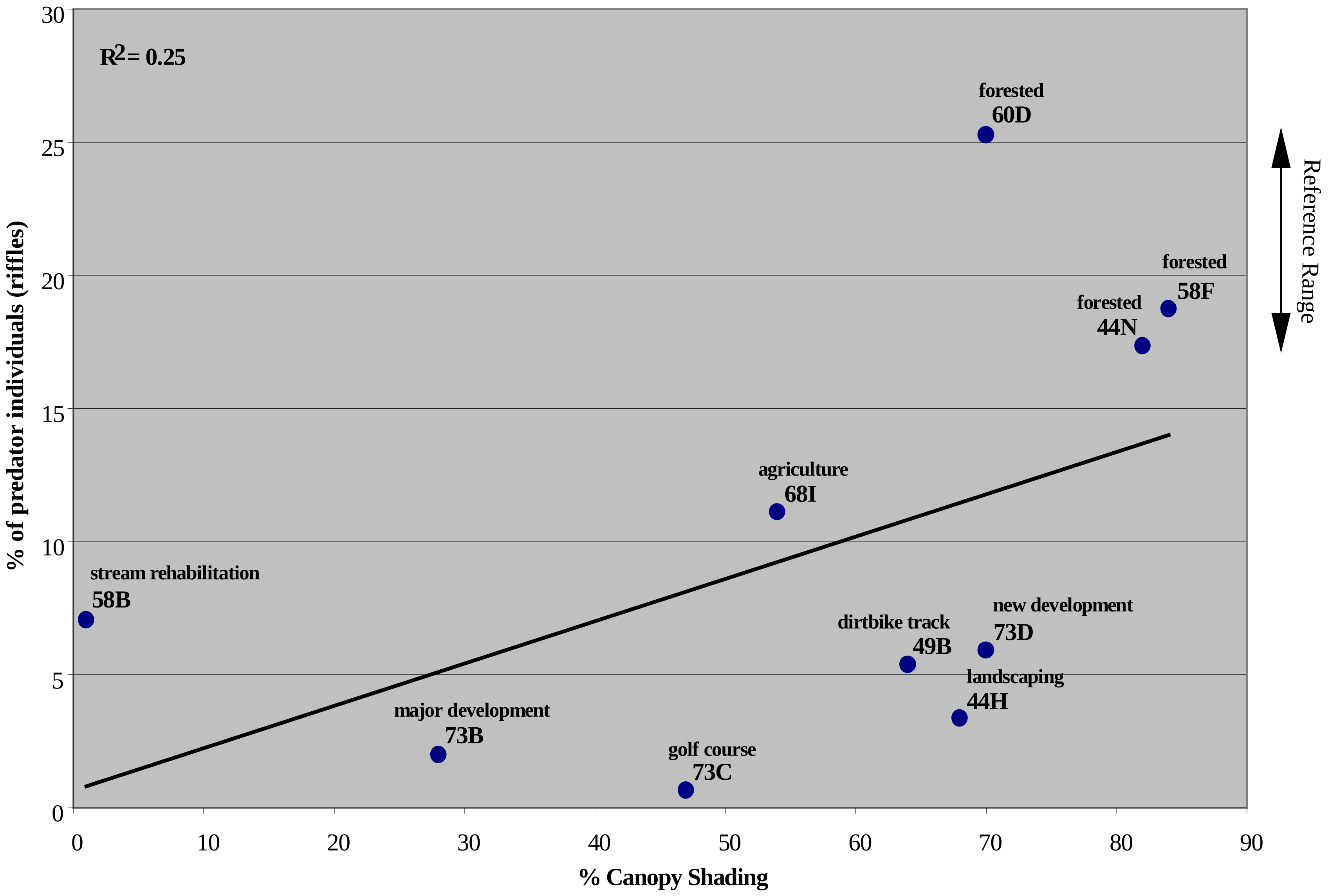

R2= 0.55
forested
60D
stream rehabilitation
58B
forested
58F
forested
44N
73D
new development
agriculture
68I
dirtbike track
49B
golf course
73C
44H
landscaping
73B
major development
Reference Range
Total Number of Taxa
% Cobble Substrate
0
10
20
30
40
50
60
0
10
20
30
40
50
60

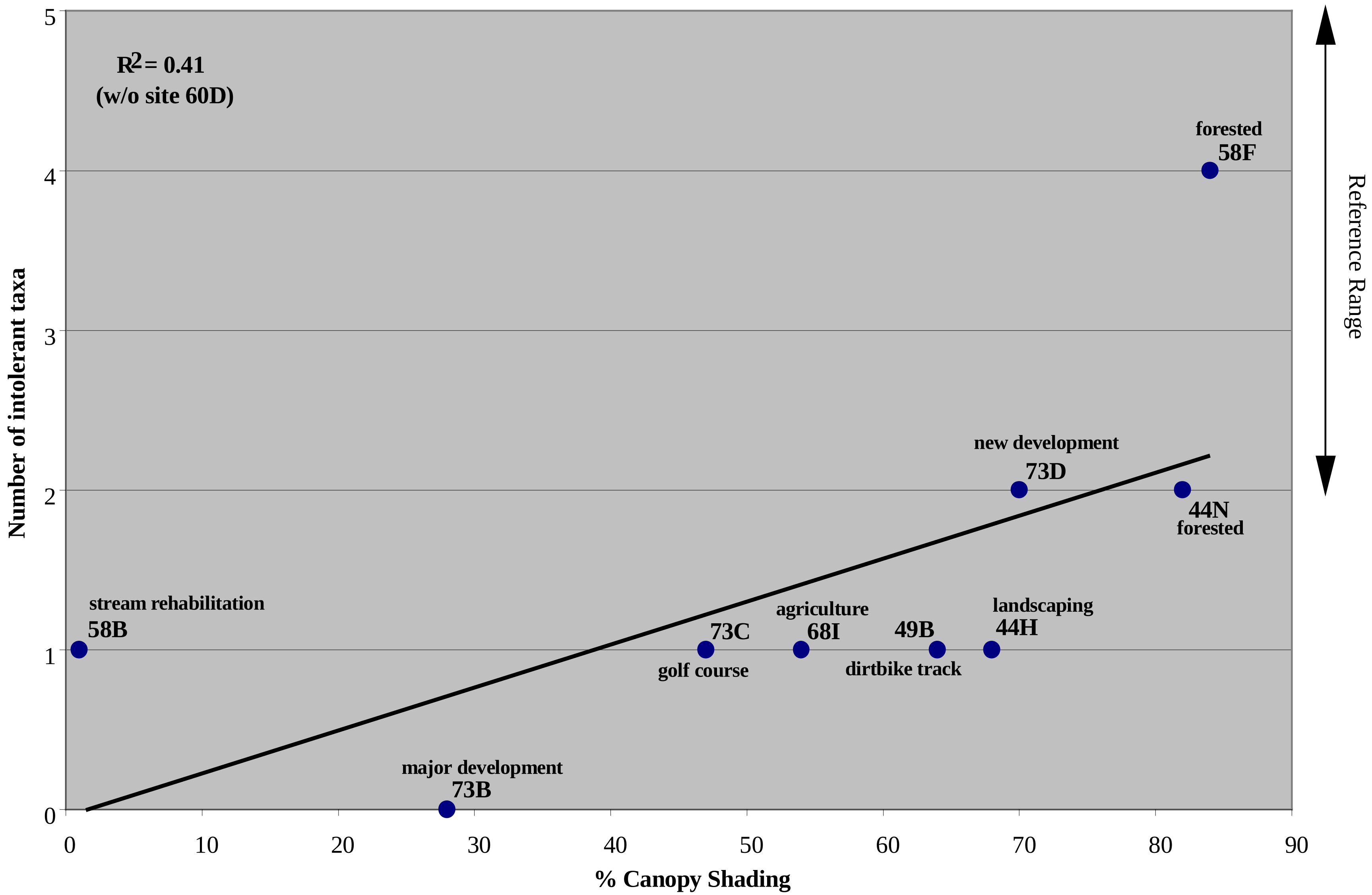


R2= 0.39
Total Number of Taxa
% Coarse Gravel Substrate
0
10
20
30
40
50
60
70
0
10
20
30
40
50
60
70
80
90
100
stream rehabilitation
58B
forested
60D
58F
forested
forested
44N
73D
new development
dirtbike track
49B
68I
agriculture
golf course
73C
44H
landscaping
73B
major development
Reference Range

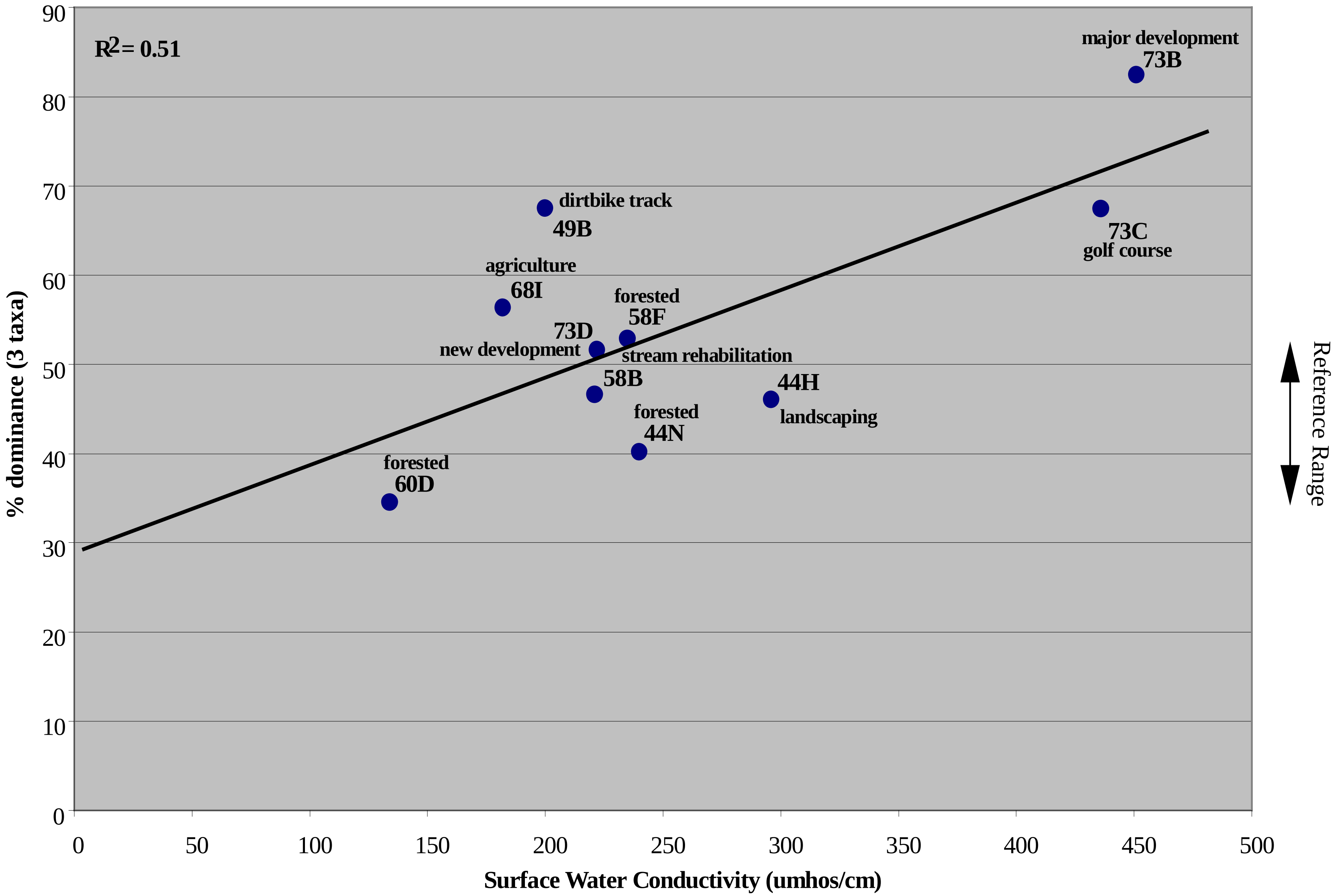

R2 = 0.71
(w/o site 58B)
Number of Ephemeroptera Taxa
% Canopy Shading
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40
50
60
70
80
90
forested
58F
forested
60D
landscaping
44H
forested
44N
73D
new development
golf course
73C
68I
agriculture
dirtbike track
49B
major development
73B
Reference Range


R2= 0.55
forested
60D
forested
58F
forested
44N
new development
73D
agriculture
68I
golf course
73C
dirtbike track
49B
landscaping
44H
stream rehabilitation
58B
major development
73B
Reference Range
Number of Trichoptera Taxa
% Canopy Shading
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70
80
90
100

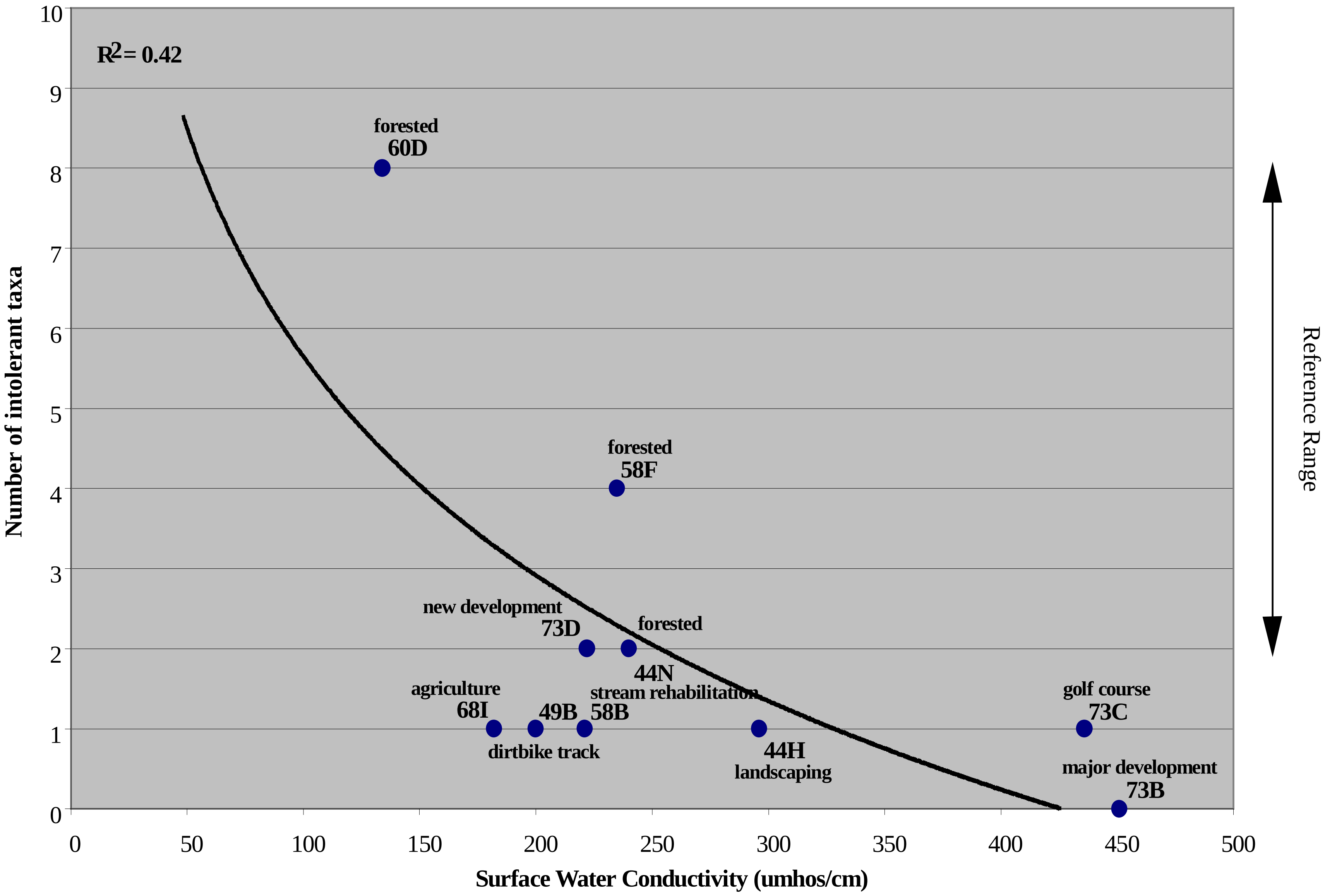

R2= 0.25
forested
60D
forested
58F
forested
44N
agriculture
68I
stream rehabilitation
58B
dirtbike track
49B
new development
73D
landscaping
44H
major development
73B
golf course
73C
Reference Range
% of predator individuals (riffles)
% Canopy Shading
0
5
10
15
20
25
30
0
10
20
30
40
50
60
70
80
90

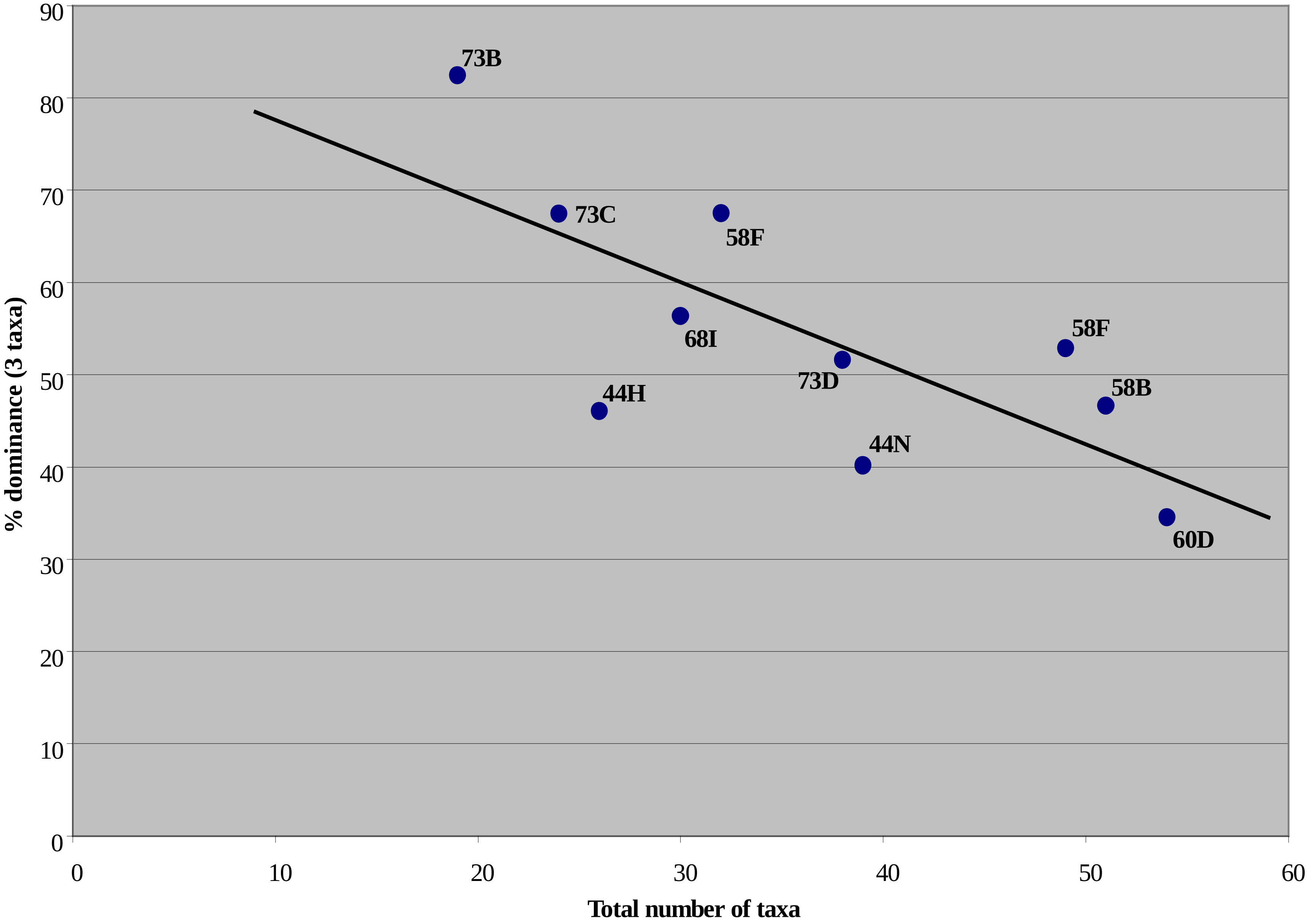


$R^2 = 0.41$
(w/o site 60D)
forested
58F
new development
73D
44N
forested
stream rehabilitation
58B
73C
golf course
agriculture
68I
49B
dirtbike track
landscaping
44H
major development
73B
Reference Range
Number of intolerant taxa
0
1
2
3
4
5
% Canopy Shading
0
10
20
30
40
50
60
70
80
90

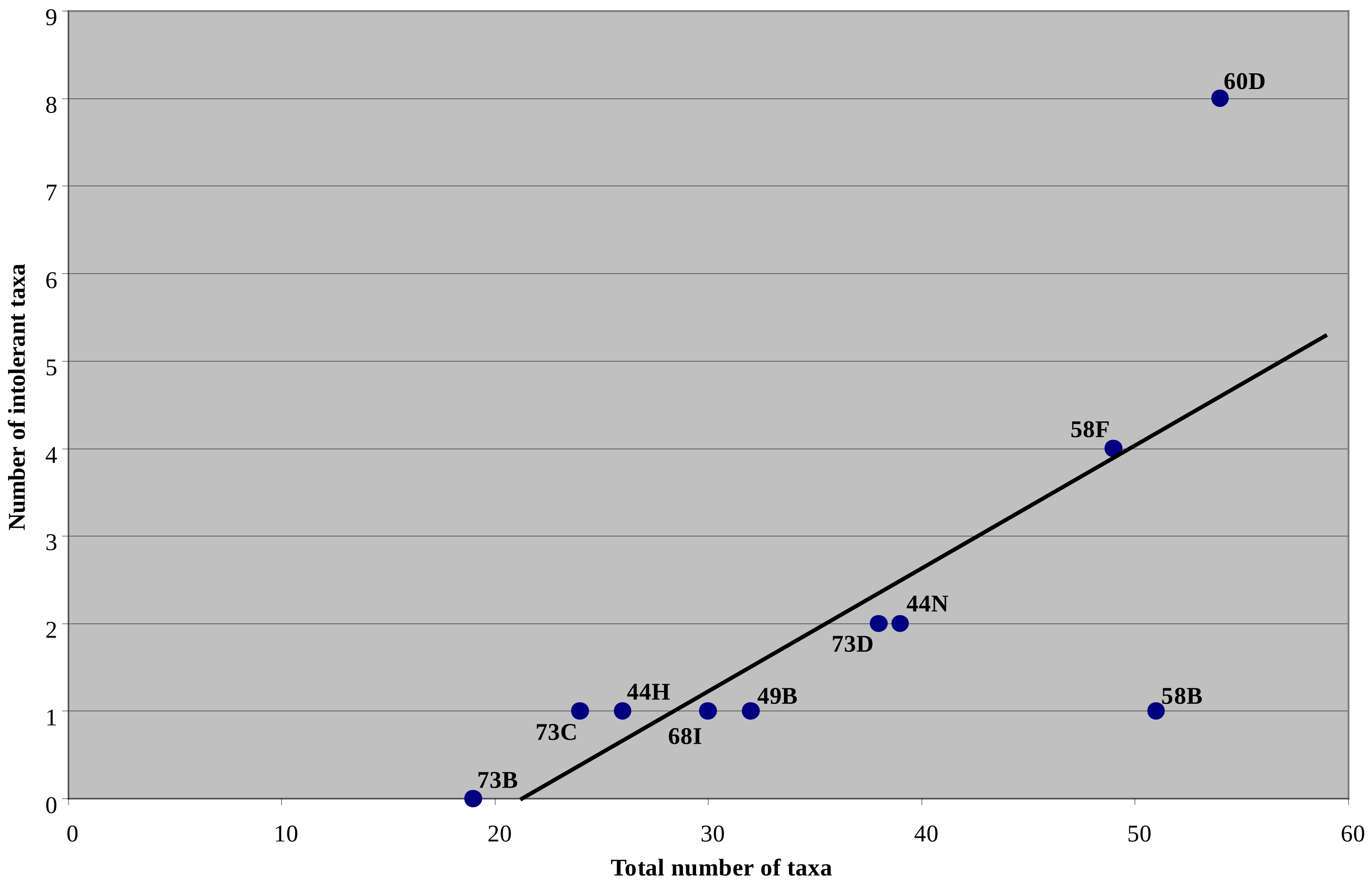


R2= 0.51
major development
73B
dirtbike track
49B
73C
golf course
agriculture
68I
forested
58F
73D
new development
stream rehabilitation
58B
44H
landscaping
forested
44N
forested
60D
Reference Range
% dominance (3 taxa)
0
10
20
30
40
50
60
70
80
90
0
50
100
150
200
250
300
350
400
450
500
Surface Water Conductivity (umhos/cm)


R² = 0.42
Number of intolerant taxa
Surface Water Conductivity (umhos/cm)
Reference Range
0
1
2
3
4
5
6
7
8
9
10
0
50
100
150
200
250
300
350
400
450
500
forested
60D
forested
58F
new development
73D
forested
44N
agriculture
68I
49B
58B
stream rehabilitation
dirtbike track
44H
landscaping
golf course
73C
major development
73B

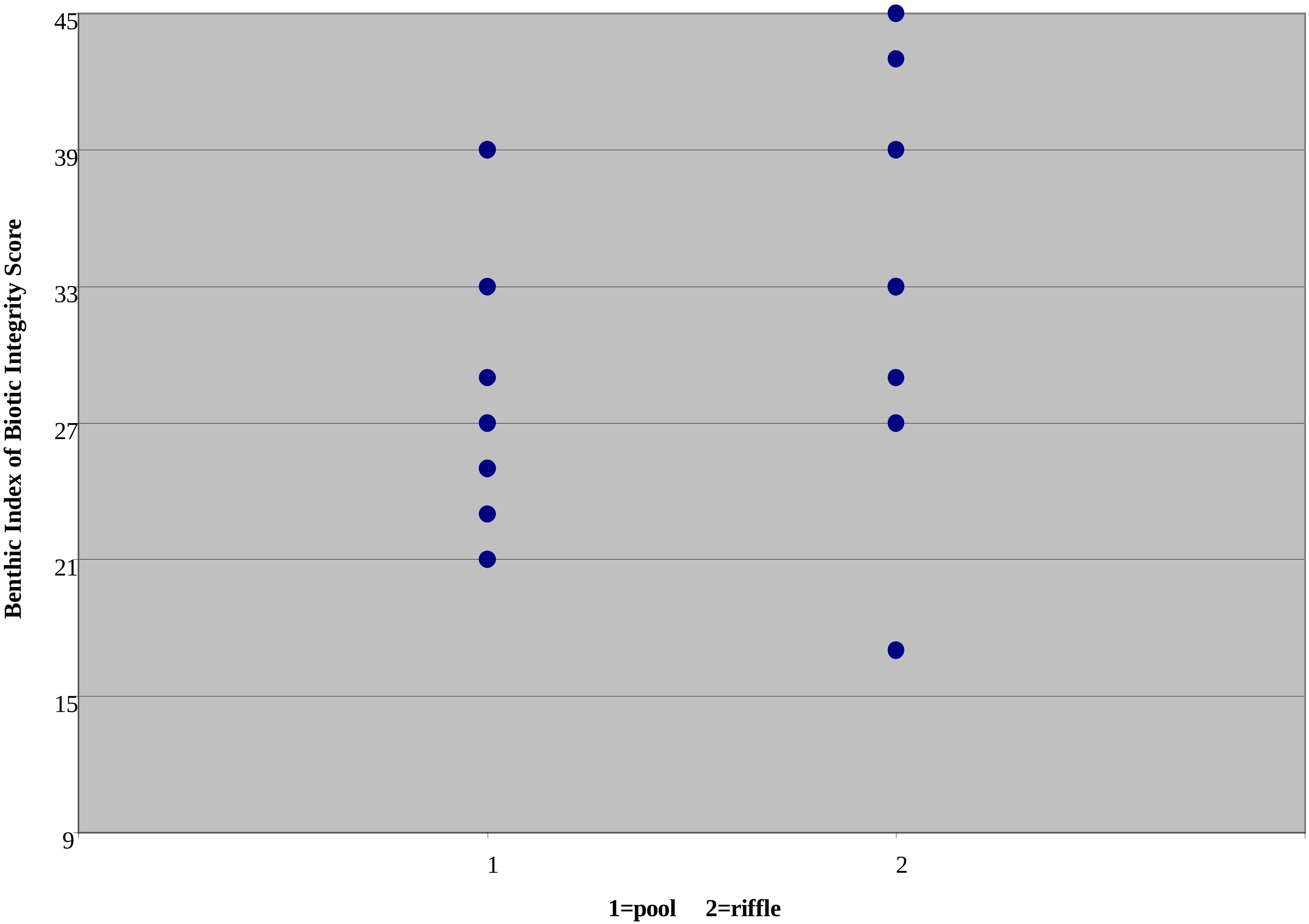


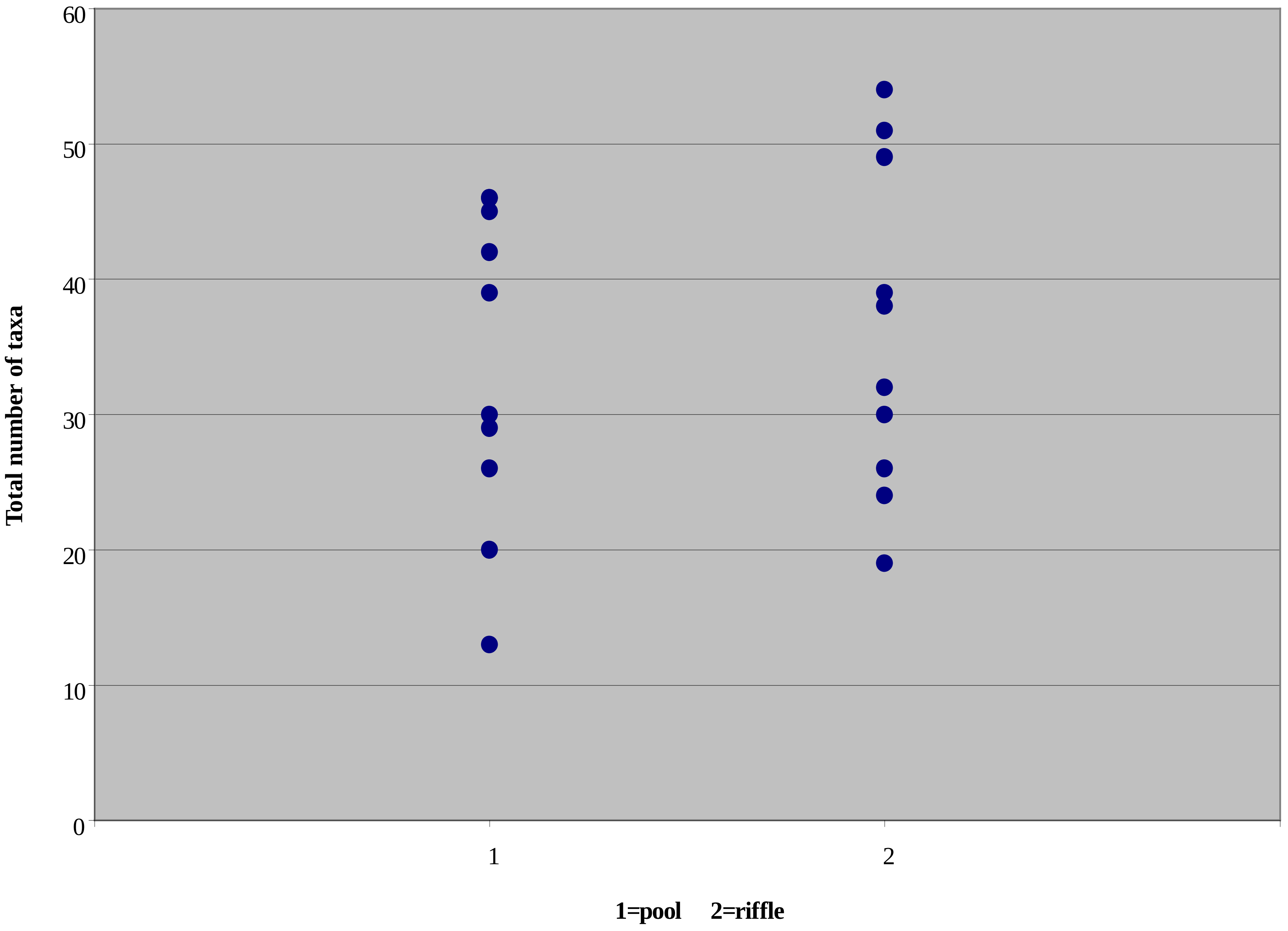
73B
73C
58F
68I
58F
73D
58B
44H
44N
60D
% dominance (3 taxa)
0
10
20
30
40
50
60
70
80
90
0
10
20
30
40
50
60
Total number of taxa

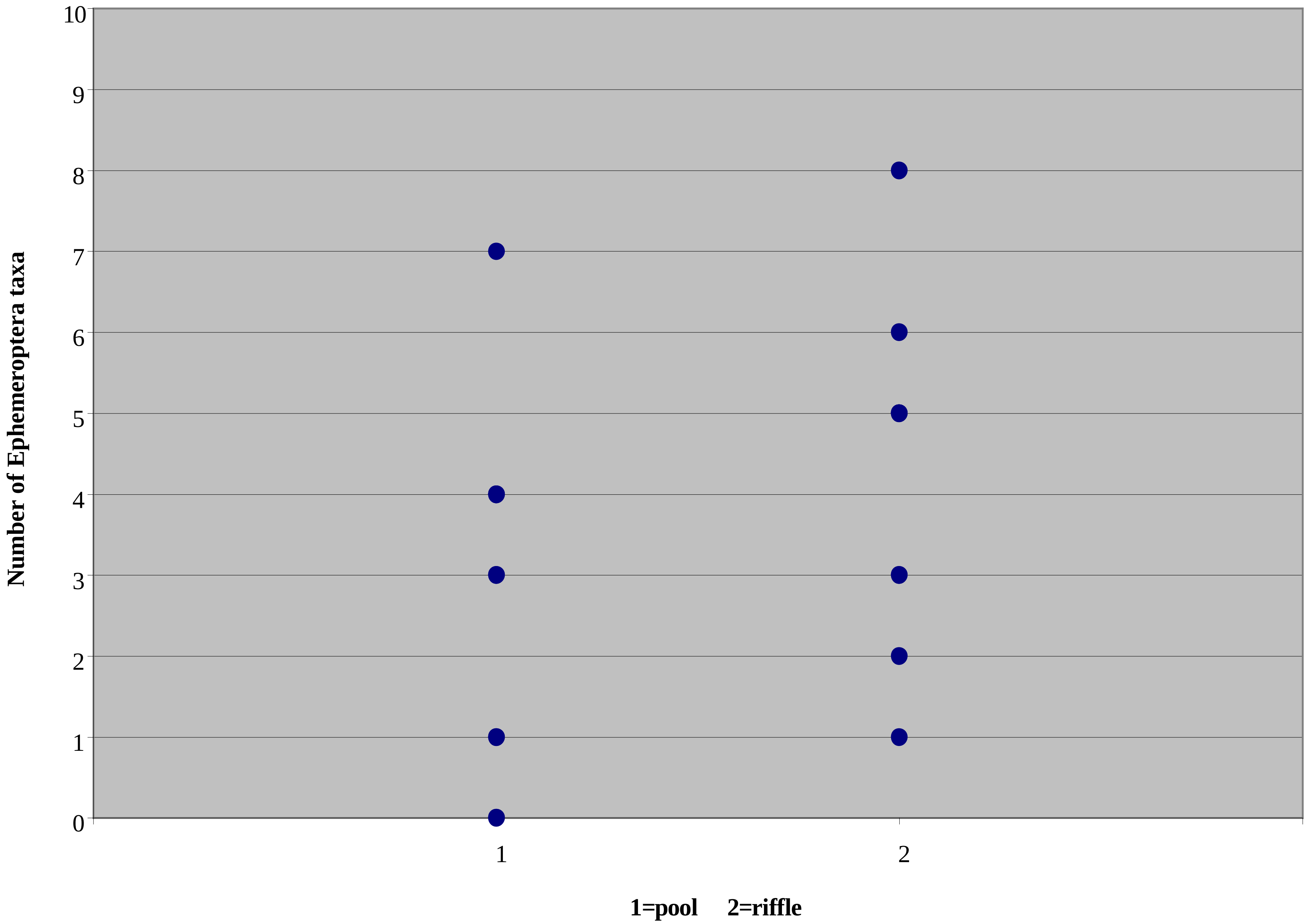

Number of intolerant taxa
9
8
7
6
5
4
3
2
1
0
0
10
20
30
40
50
60
Total number of taxa
60D
58F
44N
73D
44H
49B
58B
73C
68I
73B

Appendix C

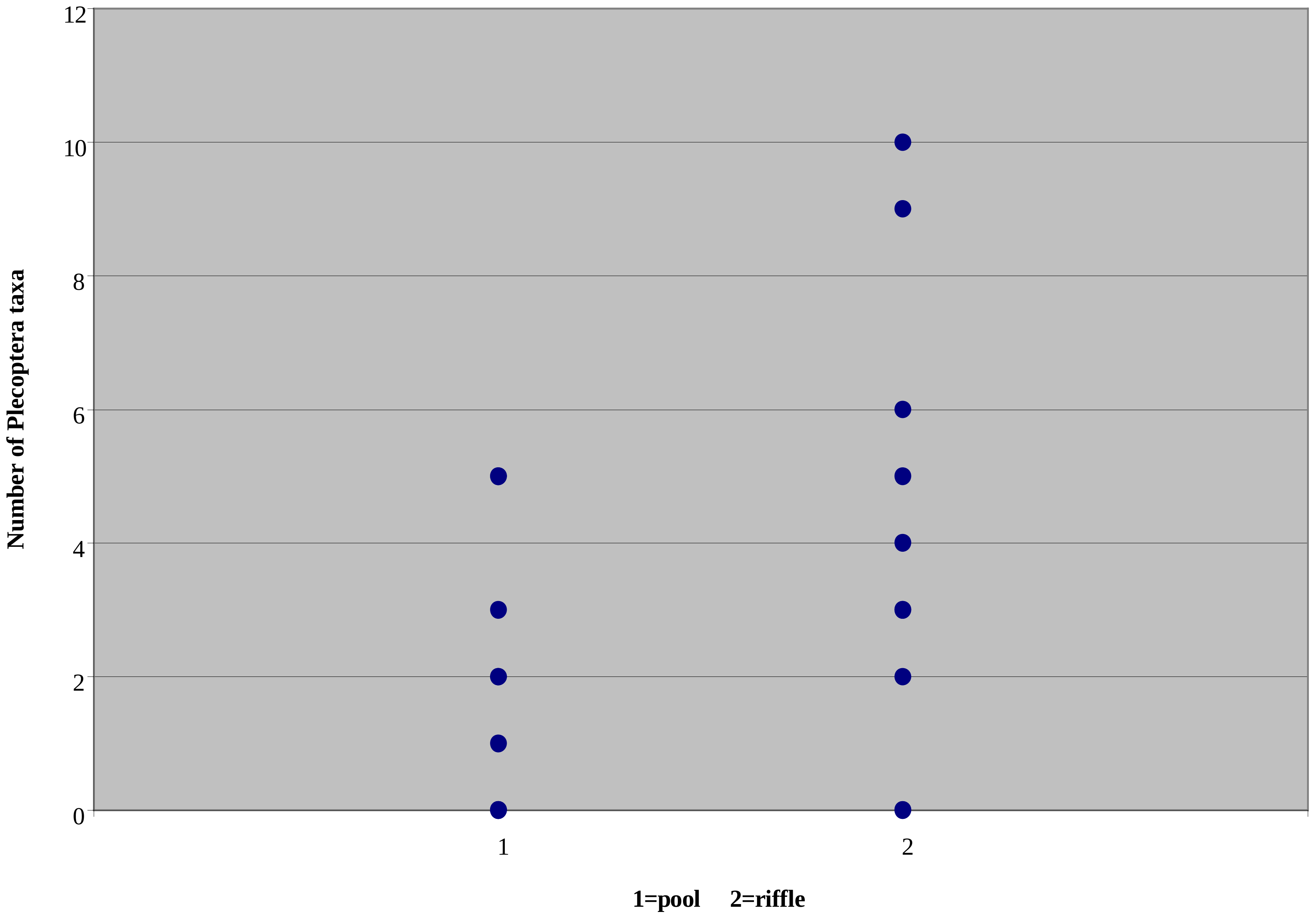
Biological Conditions in Riffle and Pool Habitat


Benthic Index of Biotic Integrity Score
45
39
33
27
21
15
9
1
2
1=pool 2=riffle

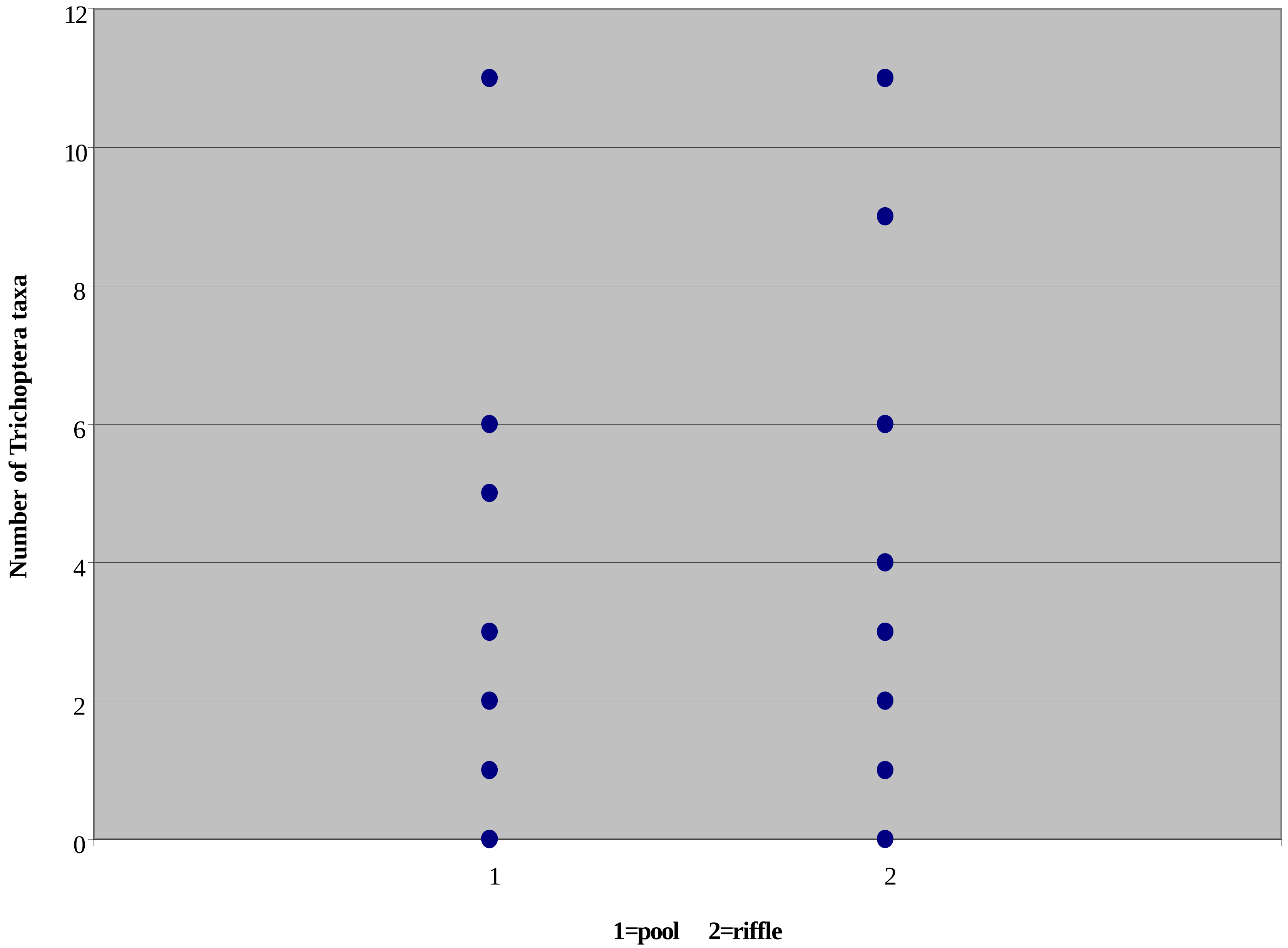

60
50
40
30
20
10
0
Total number of taxa
1
2
1=pool 2=riffle

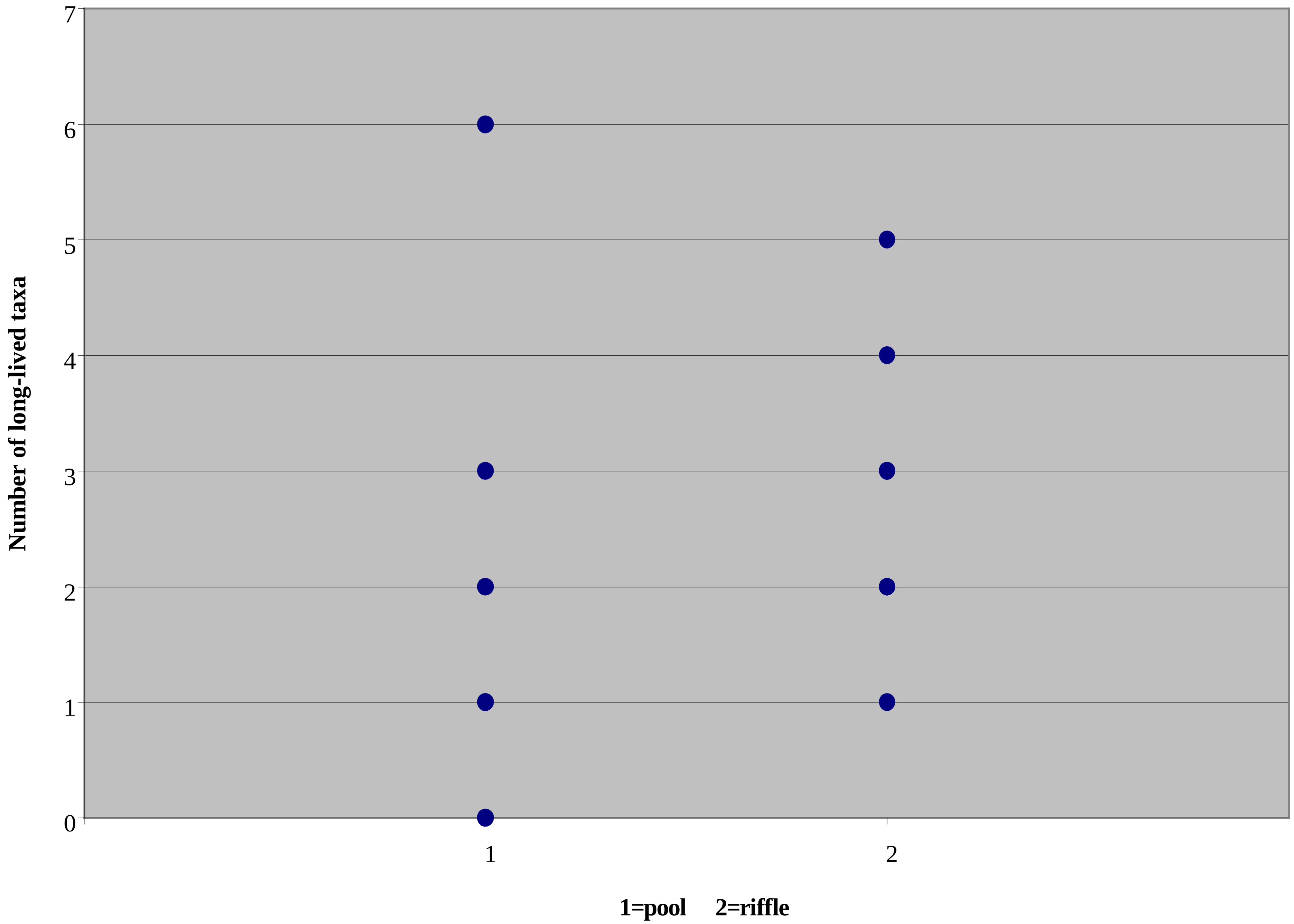


10
9
8
7
6
5
4
3
2
1
0
Number of Ephemeroptera taxa
1
2
1=pool 2=riffle

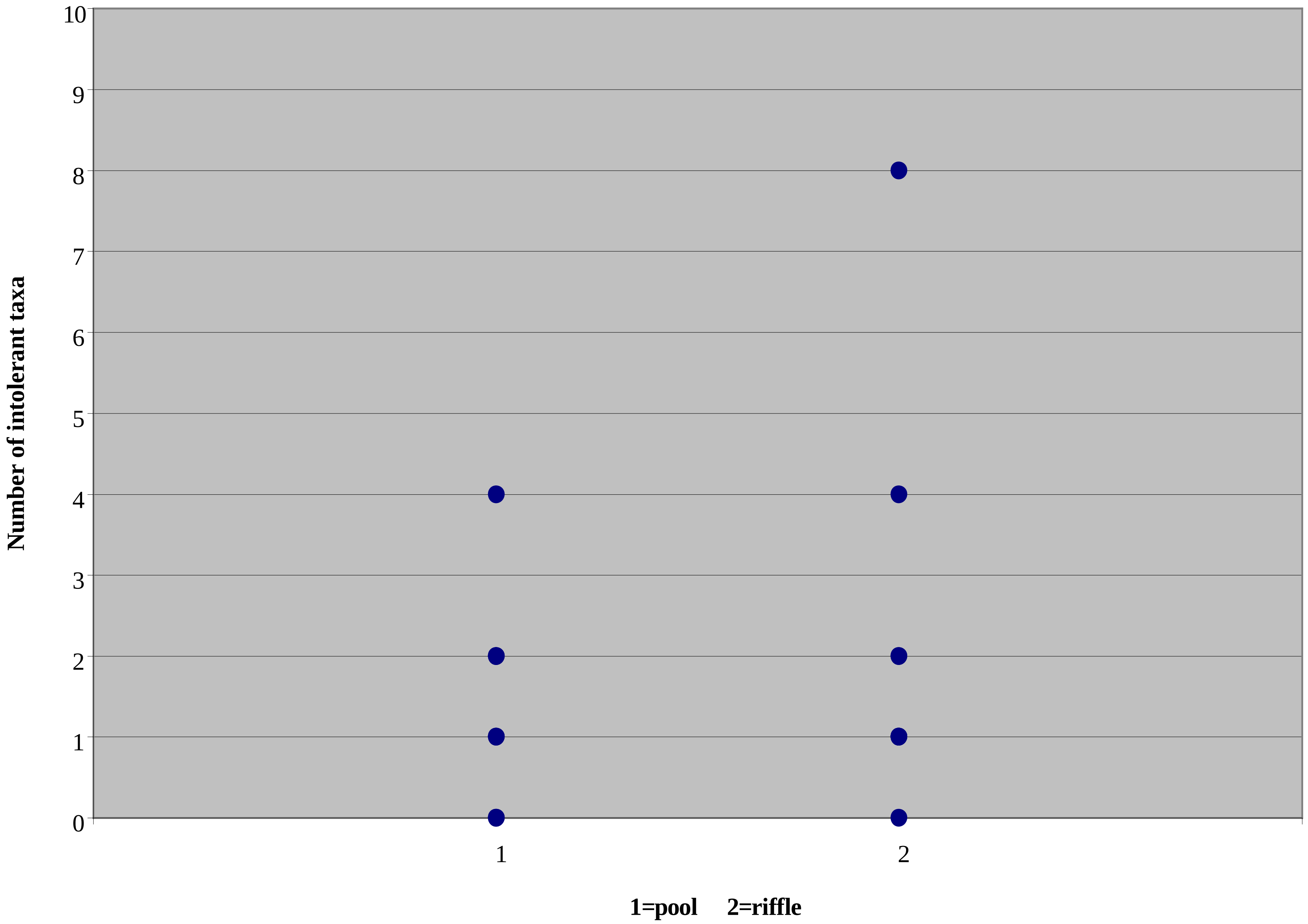


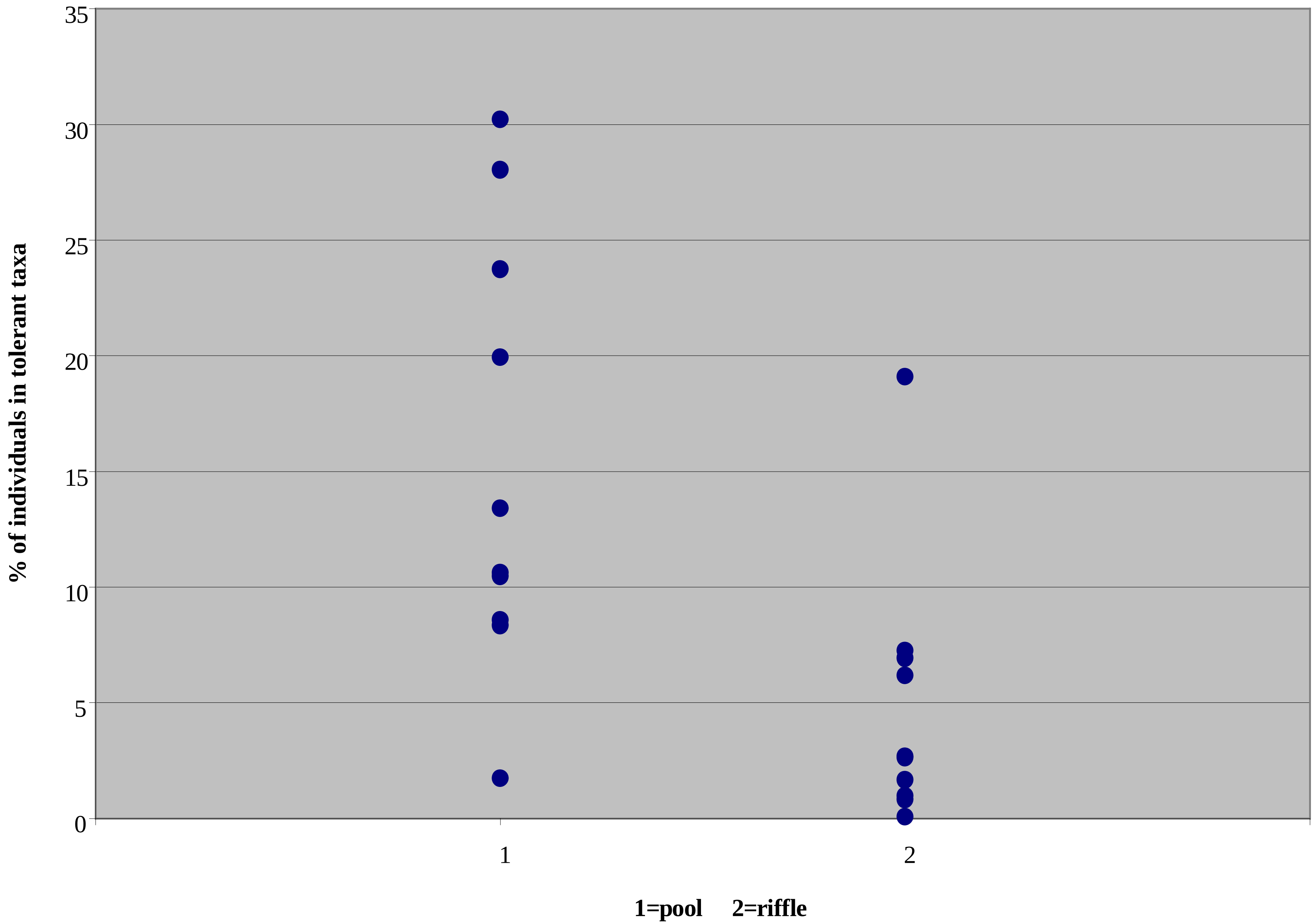
12
10
8
6
4
2
0
Number of Plecoptera taxa
1
2
1=pool 2=riffle

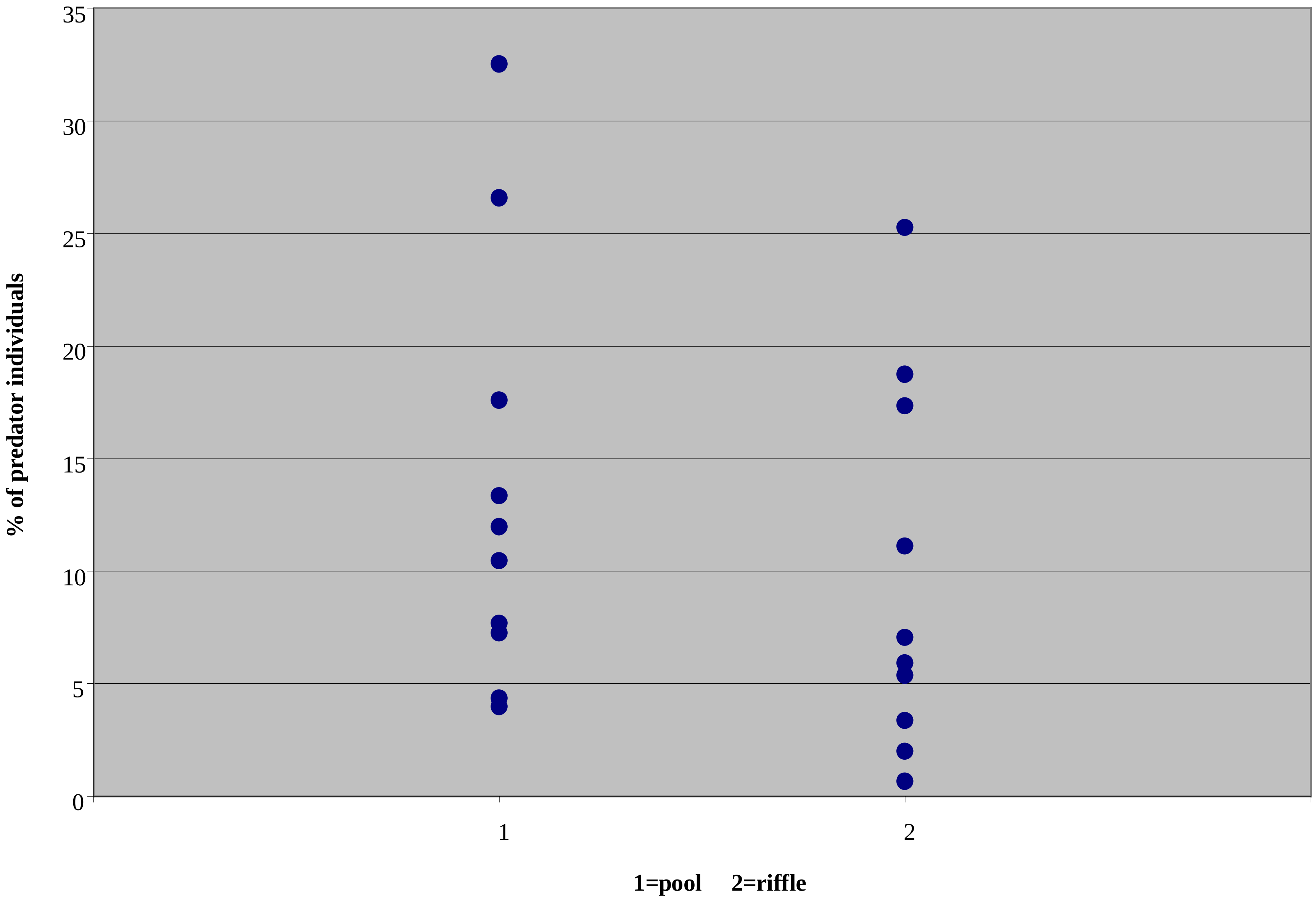

Number of Trichoptera taxa
12
10
8
6
4
2
0
1
2
1=pool 2=riffle

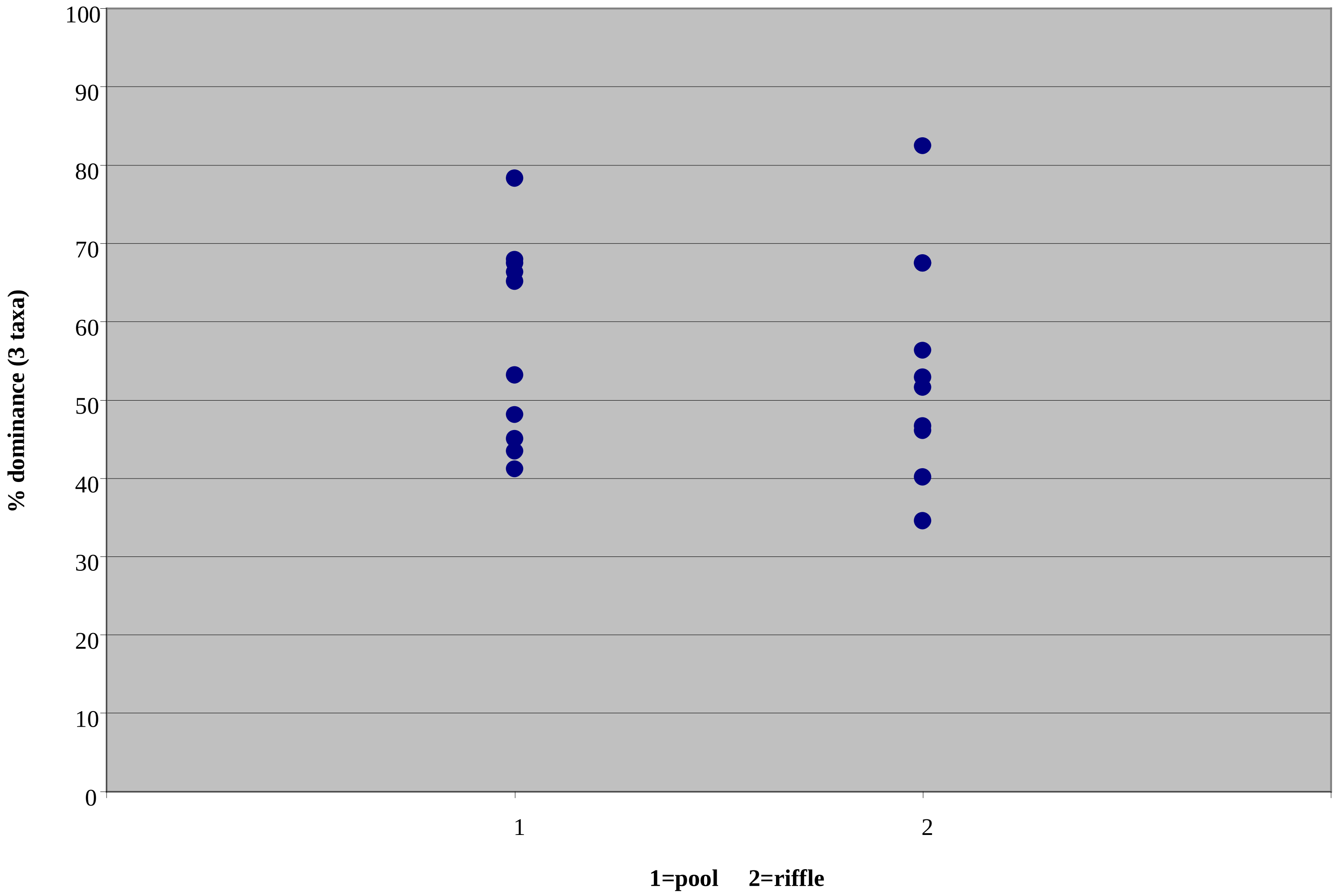


Number of long-lived taxa
0
1
2
3
4
5
6
7
1
2
1=pool 2=riffle


Number of intolerant taxa
0
1
2
3
4
5
6
7
8
9
10
1
2
1=pool 2=riffle


35
30
25
20
15
10
5
0
% of individuals in tolerant taxa
1
2
1=pool 2=riffle


35
30
25
20
15
10
5
0
% of predator individuals
1
2
1=pool 2=riffle


% dominance (3 taxa)
100
90
80
70
60
50
40
30
20
10
0
1
2
1=pool 2=riffle

Appendix D

Biometrics Data for Each Site

(BACK-OF-PAGE PLACEHOLDER FOR DUPLEX PRINTING)

Habitat	Name	Taxa #	Eph_Taxa	Ple_Taxa	Tri_Taxa	LL_Taxa	Intol_Taxa	%Tol_Taxa	%Pred	%Dom_3	B-IBI
riffle	Allen Cr (68I)	30	3	4	4	2	1	0.81	11.11	56.36	33
pool	Allen Cr (68I)	46	3	2	2	0	1	23.73	7.24	43.44	25
riffle	Edgecomb Cr (60D)	54	6	9	11	5	8	2.62	25.27	34.55	45
pool	Edgecomb Cr (60D)	30	4	5	5	1	4	10.63	32.53	48.14	39
riffle	Munson Cr (73C)	24	3	0	3	3	1	1.66	0.66	67.45	29
pool	Munson Cr (73C)	29	4	0	1	1	2	13.41	7.68	67.94	27
riffle	Munson Cr (73B)	19	1	0	0	1	0	7.25	1.98	82.45	17
pool	Munson Cr (73B)	13	0	1	0	2	0	8.33	13.34	78.33	21
riffle	Munson Cr (73D)	38	5	5	6	2	2	2.68	5.91	51.61	33
pool	Munson Cr (73D)	39	3	0	3	6	2	19.94	3.98	66.29	29
riffle	Quilceda Cr (44H)	26	5	3	2	2	1	19.09	3.36	46.06	33
pool	Quilceda Cr (44H)	26	0	2	0	0	0	28.03	17.59	45.06	23
riffle	Quilceda Cr (44N)	39	5	6	9	2	2	6.18	17.35	40.15	39
pool	Quilceda Cr (44N)	45	1	3	6	2	1	8.57	11.97	53.2	33
riffle	M.F. Quilceda Cr (58B)	51	5	3	1	3	1	6.92	7.05	46.65	33
pool	M.F. Quilceda Cr (58B)	42	4	0	0	2	1	30.21	4.34	41.18	25
riffle	M.F. Quilceda Cr (58F)	49	8	10	11	4	4	0.08	18.74	52.89	43
pool	M.F. Quilceda Cr (58F)	46	7	5	11	3	2	1.73	26.58	67.48	39
riffle	Quilceda Cr (49B)	32	2	2	3	2	1	0.97	5.37	67.48	27
pool	Quilceda Cr (49B)	20	1	0	0	0	0	10.46	10.46	65.12	21

Abbreviations:

Taxa # - number of taxa at a site
Eph_Taxa - number of mayfly (Ephemeroptera) taxa
Ple_Taxa - number of stonefly (Plecoptera) taxa
Tri_Taxa - number of caddisfly (Trichoptera) taxa
LL_Taxa - number of long-lived taxa
Intol_Taxa - number of intolerant taxa
%Tol_Taxa - percent of tolerant taxa
%Pred - percent of predator taxa
%Dom_3 - percent of top three dominant taxa
B-IBI (Benthic Index of Biotic Integrity)