



The use of aquatic macroinvertebrates as water quality indicators in mountain streams in Montana  
by David C Richards

A thesis submitted in partial fulfillment of the requirements for the degree Master of Science in  
Entomology

Montana State University

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**Abstract:**

The use of aquatic macroinvertebrates for monitoring water quality has become popular. This paper assessed the ability of rapid assessment using a one minute riffle kick net method to detect natural within-stream and seasonal macroinvertebrate variability in the mountain stream ecoregion of Montana. It also assessed the ability of these methods to detect water quality impairment. Results suggest that the methods used are able to reflect natural variability and that some indices or 'metrics' are potentially more useful than others for detecting water quality impairment in heavily 'impaired' streams. It is unknown how useful these methods are for detecting water quality impairment in less severely impaired streams. Suggestions are also made on how to increase the sensitivity of these methods.

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INDICATORS IN MOUNTAIN STREAMS OF MONTANA

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in

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APPROVAL

of a thesis submitted by

David C. Richards

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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## TABLE OF CONTENTS

INTRODUCTION .....	1
HYPOTHESES TESTED .....	4
LITERATURE REVIEW .....	5
Water Quality Problems in the U.S. ....	5
Water Quality Problems in Montana .....	6
Biomonitoring Approaches .....	7
Rapid Assessment .....	11
Problems with Rapid Assessments .....	13
Rapid Assessment in Montana .....	14
Macroinvertebrate Variability in Mountain Streams .....	15
MATERIALS AND METHODS .....	19
Within-site Variability Collection Sites .....	19
Within-stream Variability Collection Sites .....	25
Seasonal variability Collection Sites .....	27
Macroinvertebrate Collection .....	27
Physical and Chemical Data .....	28
Metrics and Statistical Analysis .....	30
RESULTS .....	31
Within-site Variability .....	31
Within- stream Variability .....	32
Seasonal Variability .....	61
Bozeman Creek .....	61
The Three Bear Creeks 1994 and 1995. ....	91
Impaired vs. Unimpaired (Reference) Streams .....	96
Divide Creek .....	97
Soda Butte Creek .....	97
Reference streams, Cottonwood Creek, Hyalite Creek, and Squaw Creek .....	118
DISCUSSION .....	143

Multivariate Analysis vs. a Multi-metric Approach . . . . .	143
Within-site Variability . . . . .	144
Within-stream Variability . . . . .	144
Seasonal Variability . . . . .	146
Impaired vs. Least -impaired (Reference) Streams . . . . .	148
Squaw vs. Cottonwood Creek . . . . .	149
Soda Butte Creek . . . . .	150
CONCLUSION . . . . .	154
LITERATURE CITED . . . . .	157
APPENDICES . . . . .	166
Table 38. Species list for Bozeman Creek seasonal samples . . . . .	167
Table 39. Species list for Soda Butte Creek . . . . .	173
Table 40. Species list for Pebble Creek, 1995 . . . . .	179
Table 41. Species list for N. F. Bear Creek, M. F. Bear Creek, and Bear Creek 1994 and 1995 . . . . .	185
Table 42. Species list for Divide Creek 1995 and 1994, Cottonwood Creek 1995 and Squaw Creek 1995 . . . . .	189

## LIST OF TABLES

Table	Page
1. Metrics used in this study . . . . .	2
2. Descriptions of the 10 mountain streams sampled in this study, including mountain range, drainage, longitude, latitude, township, range, 1/4 section, stream order, link magnitude, elevation, direction of stream flow, pH, conductivity, Rosgen stream type, estimated discharge, and date of collection . . . . .	21
3. Number of road kilometers per square kilometer (km/km <sup>2</sup> ), number of clear-cut hectares per square kilometer (hect/km <sup>2</sup> ), and the number of cubic meters of woody debris per stream kilometer (m <sup>3</sup> /km) in the Bozeman, Hyalite, Cottonwood, and Squaw Creek drainages . . . . .	25
4. Mean and CV of CV's for reference stream sites (N = 34 samples; except Metals Tolerance Index, N = 17 samples). . . . .	32
5. Eigenvectors defining the first three principal components from 16 samples from Pebble Creek, 1995. . . . .	33
6. Mean ( $\pm$ 95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Pebble Creek, 1995 site Km 2 . . . . .	35
7. Mean ( $\pm$ 95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Pebble Creek, 1995 site Km 6.5. . . . .	36
8. Mean ( $\pm$ 95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Pebble Creek, 1995 site Km 9. . . . .	37
9. Mean ( $\pm$ 95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Pebble Creek, 1995 site Km 13. . . . .	38

10. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Pebble Creek, 1995 site Km 16. . . . . 39
11. Eigenvectors defining the first three principal components from thirteen riffle samples from Bozeman Creek for four seasons using raw species abundance data from each sample as a sampling unit. . . . . 61
12. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Bozeman Creek, August 9, 1994 (N = 4). . . . . 63
13. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Bozeman Creek, October 21, 1994 (N = 3). . . . . 64
14. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Bozeman Creek, February 5, 1995 (N = 3). . . . . 65
15. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Bozeman Creek, May 5, 1995 (N = 3). . . . . 66
16. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Bozeman Creek, September 20, 1995 (N = 3). . . . . 67
17. Species diversity indices for sixteen samples from five sampling periods in Bozeman Creek, Spring 1995, Summer 1994 (Smr1, Smr2, Smr3, and Smr4), Fall 1994, Winter 1995, and Summer 1995 (Smr1, Smr2, and Smr3). . . . . 69
18. Mean, variance, standard deviation (s.d.), and coefficient of variation (CV) for Shannon diversity index for four seasons (including two summer seasons) from Bozeman Creek, 1994 and 1995. . . . . 71
19. Quantitative Similarity Index values between the three samples for each season, Summer 1994, Winter 1995, Spring 1995, and Summer 1995 including mean ( $\pm$  95% CI), variance (var.), s.d., and CV. . . . . 72

20. Quantitative Similarity Index values for four combinations of three samples (1,2,3,4) from Bozeman Creek 1994 including mean ( $\pm$  95% CI) variance, s.d., and CV. . . . . 72
21. Quantitative Similarity Index (QSI) comparisons between mean % relative abundances for Summer 1994, Autumn 1994, Winter 1995, and Spring 1995 from Bozeman Creek macroinvertebrate samples. . . . . 73
22. Eigenvectors defining the first three principal components between sampling units for N. F. Bear Cr., M. F. Bear Cr., and Bear Creek, 1994 and 1995. . . . . 91
23. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for N. F. Bear Creek, 1995. . . . . 93
24. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for M. F. Bear Creek, 1995. . . . . 94
25. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Bear Creek, 1995. . . . . 95
26. Metric values for macroinvertebrate samples collected from N. F. Bear Creek, M.F. Bear Creek, and Bear Creek in 1994. One sample was collected from each creek. . . . . 96
27. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Divide Creek, 1995. . . . . 116
28. Metric scores from Divide Creek, July 16, 1994 (one sample). . . . . 117
29. Eigenvectors defining the first three principal components between 18 sampling units from Soda Butte Creek, 1995. . . . . 118
30. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Soda Butte Creek, km 1, 1995. . . . . 120
31. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Soda Butte Creek, km 2, 1995. . . . . 121
32. Metrics calculated for Soda Butte Creek sites km 1 and km 2, 1994. . . . . 122

33. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for seven reference streams (N = 34, except Metals Tolerance Index N = 17). . . . .139
34. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Hyalite Creek, 1995 (N = 3). . . . . 140
35. Mean, variance, standard deviation (s.d.), coefficient of variation (CV) and 95% confidence interval (CI) for metrics calculated for Squaw Creek, 1994 (N = 4). . . . . 141
36. Mean, variance, standard deviation (s.d.), coefficient of variation (CV) and 95% confidence interval (CI) for metrics calculated for Cottonwood Creek, 1995 (N = 4). . . . .142
37. Comparison of metrics from the seven reference and three impaired streams: including direction of metric values due to impairment, overlap in 25th to 75th percentile, longitudinal and seasonal trends, and potential of metric for continued use in assessment of water quality in mountain streams. . . . .151

## LIST OF FIGURES

Figure	Page
1. Map of study sites.....	20
2. Principal Components Analysis for Pebble Creek.....	34
3. Mean ( $\pm$ 95% CI) number of organisms for six sites from Pebble Creek . . .	42
4. Mean ( $\pm$ 95% CI) number of taxa for six sites from Pebble Creek . . . . .	43
5. Mean ( $\pm$ 95% CI) number of EPT taxa for six sites from Pebble Creek . . .	44
6. Mean ( $\pm$ 95% CI) number of Ephemeroptera taxa for six sites from Pebble Creek . . . . .	45
7. Mean ( $\pm$ 95% CI) number of Plecoptera taxa for six sites from Pebble Creek . . . . .	46
8. Mean ( $\pm$ 95% CI) number of Trichoptera taxa for six sites from Pebble Creek . . . . .	47
9. Mean ( $\pm$ 95% CI) number of shredder taxa for six sites from Pebble Creek . . . . .	48
10. Mean ( $\pm$ 95% CI) number of scraper taxa for six sites from Pebble Creek . . . . .	49
11. Mean ( $\pm$ 95% CI) number of collector-gatherer and filter-gatherer taxa for six sites from Pebble Creek . . . . .	50
12. Mean ( $\pm$ 95% CI) number of predator taxa for six sites from Pebble Creek . . . . .	51
13. Mean ( $\pm$ 95% CI) % shredder taxa for six sites from Pebble Creek . . . . .	52
14. Mean ( $\pm$ 95% CI) % scraper taxa for six sites from Pebble Creek . . . . .	53
15. Mean ( $\pm$ 95% CI) % collector-gatherer and filterer-gatherer taxa for six sites from Pebble Creek . . . . .	54

16. Mean ( $\pm$ 95% CI) % predator taxa for six sites from Pebble Creek . . . . .	55
17. Mean ( $\pm$ 95% CI) % dominant taxa for six sites from Pebble Creek . . . . .	56
18. Mean ( $\pm$ 95% CI) % Chironomidae organisms for six sites from Pebble Creek . . . . .	57
19. Mean ( $\pm$ 95% CI) % EPT taxa for six sites from Pebble Creek . . . . .	58
20. Mean ( $\pm$ 95% CI) Shannon Diversity Index values for six sites from Pebble Creek . . . . .	59
21. Mean ( $\pm$ 95% CI) HBI values for six sites from Pebble Creek . . . . .	60
22. Principal components analysis for Bozeman Creek. . . . .	62
23. Mean ( $\pm$ 95% CI) number of organisms for Bozeman Creek. . . . .	74
24. Mean ( $\pm$ 95% CI) number of taxa for Bozeman Creek. . . . .	75
25. Mean ( $\pm$ 95% CI) number of EPT taxa for Bozeman Creek. . . . .	76
26. Mean ( $\pm$ 95% CI) number of Ephemeroptera taxa for Bozeman Creek. . . . .	77
27. Mean ( $\pm$ 95% CI) number of Plecoptera taxa for Bozeman Creek. . . . .	78
28. Mean ( $\pm$ 95% CI) number of Trichoptera taxa for Bozeman Creek. . . . .	79
29. Mean ( $\pm$ 95% CI) number of shredder taxa for Bozeman Creek. . . . .	80
30. Mean ( $\pm$ 95% CI) number of scraper taxa for Bozeman Creek. . . . .	81
31. Mean ( $\pm$ 95% CI) number of collector-gatherer and filter-gatherer taxa for Bozeman Creek. . . . .	82
32. Mean ( $\pm$ 95% CI) number of predator taxa for Bozeman Creek. . . . .	83
33. Mean ( $\pm$ 95% CI) % shredder taxa for Bozeman Creek. . . . .	84
34. Mean ( $\pm$ 95% CI) % scraper taxa for Bozeman Creek. . . . .	85
35. Mean ( $\pm$ 95% CI) % collector-gatherer and filter-gatherer taxa for Bozeman Creek. . . . .	86

36. Mean ( $\pm$ 95% CI) % predator taxa for Bozeman Creek. . . . .	87
37. Mean ( $\pm$ 95% CI) % dominant taxa for Bozeman Creek. . . . .	88
38. Mean ( $\pm$ 95% CI) HBI values for Bozeman Creek. . . . .	89
39. Mean ( $\pm$ 95% CI) Shannon Diversity Index values for Bozeman Creek . . . . .	90
40. Principal components analysis for the Three Bear Creeks. . . . .	92
41. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for number of organisms. . . . .	98
42. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for number of taxa. . . . .	99
43. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for number of EPT taxa. . . . .	100
44. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for number of Ephemeroptera taxa. . . . .	101
45. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for number of Plecoptera taxa. . . . .	102
46. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for number of Trichoptera taxa. . . . .	103
47. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for number of shredder taxa. . . . .	104
48. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for number of scraper taxa. . . . .	105

49. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for number of collector-gatherer and filter-gatherer taxa. . . . .	106
50. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for number of predator taxa . . . . .	107
51. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for % shredder taxa. . . . .	108
52. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for % scraper taxa. . . . .	109
53. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for % collector-gatherer and filter-gatherer taxa. . . . .	110
54. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for % predator taxa. . . . .	111
55. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for % dominant taxa. . . . .	112
56. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for % EPT taxa. . . . .	113
57. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for % Chironomidae organisms . . . . .	114
58. Impaired vs. unimpaired (reference) stream box and whisker plots showing median, minimum, maximum, and 25th to 75th percentile values for HBI values. . . . .	115
60. Principal Components Analysis for Soda Butte Creek, 1995. . . . .	119

61. Mean ( $\pm$  95% CI) number of organisms for Soda Butte Creek, 1995. . . . 123

62. Mean ( $\pm$  95% CI) number of taxa for Soda Butte Creek, 1995.. . . .124

63. Mean ( $\pm$  95% CI) number of EPT taxa for Soda Butte Creek, 1995. . . . 125

64. Mean ( $\pm$  95% CI) number of Ephemeroptera taxa for  
Soda Butte Creek, 1995. . . . . 126

65. Mean ( $\pm$  95% CI) number of Plecoptera taxa for  
Soda Butte Creek, 1995. . . . . 127

66. Mean ( $\pm$  95% CI) number of Trichoptera taxa for  
Soda Butte Creek, 1995. . . . .128

67. Mean ( $\pm$  95% CI) number of shredder taxa for  
Soda Butte Creek, 1995. . . . . 129

68. Mean ( $\pm$  95% CI) number of scraper taxa for  
Soda Butte Creek, 1995. . . . . 130

69. Mean ( $\pm$  95% CI) number of collector-gatherer and filter-gatherer taxa  
for Soda Butte Creek, 1995. . . . .131

70. Mean ( $\pm$  95% CI) number of predator taxa for  
Soda Butte Creek, 1995. . . . . 132

71. Mean ( $\pm$  95% CI) % shredder taxa for Soda Butte Creek, 1995. . . . .133

72. Mean ( $\pm$  95% CI) % scraper taxa for Soda Butte Creek, 1995. . . . . 134

73. Mean ( $\pm$  95% CI) % collector-gatherer and filter-gatherer taxa for  
Soda Butte Creek, 1995. . . . . 135

74. Mean ( $\pm$  95% CI) % predator taxa for Soda Butte Creek, 1995. . . . .136

75. Mean ( $\pm$  95% CI) % dominant taxa for Soda Butte Creek, 1995 . . . . . 137

76. Mean ( $\pm$ 95% CI) % EPT taxa for Soda Butte Creek, 1995 . . . . . 138

## ABSTRACT

The use of aquatic macroinvertebrates for monitoring water quality has become popular. This paper assessed the ability of rapid assessment using a one minute riffle kick net method to detect natural within-stream and seasonal macroinvertebrate variability in the mountain stream ecoregion of Montana. It also assessed the ability of these methods to detect water quality impairment. Results suggest that the methods used are able to reflect natural variability and that some indices or 'metrics' are potentially more useful than others for detecting water quality impairment in heavily 'impaired' streams. It is unknown how useful these methods are for detecting water quality impairment in less severely impaired streams. Suggestions are also made on how to increase the sensitivity of these methods.

## INTRODUCTION

Freshwater is one of the most important resources in the world, however, within the last two hundred years, technology and human population growth have caused tremendous impacts on freshwater ecosystems (Bau 1995; Karr 1991). For example, Benke (1990) reported that 98% of the 3.2 million miles of rivers in the U. S. were not healthy enough to be considered high quality and worthy of federal protection.

The U.S. Clean Water Act of 1972 (CWA) reflects the concerns of the people of the United States regarding clean water and healthy aquatic ecosystems and mandates, as its goal, "...to improve and maintain the physical, chemical, and biological integrity of our nation's waters". Biological integrity can be defined as "...the ability of an aquatic ecosystem, to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitats of a region" (Karr and Dudley 1981).

The U. S. Environmental Protection Agency (U.S. EPA) is the federal regulatory agency responsible for the enforcement of the Clean Water Act of 1972. The U.S. EPA has encouraged individual states to develop their own regionalized methods of assessing the biological integrity of their (states) surface waters based on a model proposed in the U.S. EPA's Rapid Bioassessment Protocols (RBP's)(U.S. EPA 1989).

Most RBP's rely on a multi-metric approach using reference conditions from a regional framework (Davis and Simon 1995). A metric is simply a numeric index which estimates some attribute of a community, for example, the number of taxa present in a sample or the number of individual organisms in a sample. Metrics that were used in this study are in Table 1.

Table 1. Metrics used in this study.

Taxa richness <sup>1</sup>	EPT Richness <sup>2</sup>	% dominant taxa
# of organisms/ sample	% EPT individuals	modified HBI <sup>5</sup>
# of Ephemeroptera taxa	QSI for taxa <sup>3</sup>	Shannon Index <sup>6</sup>
# of Plecoptera taxa	# of cg and fg taxa <sup>4</sup>	% predator taxa
# of Trichoptera taxa	# of shredder taxa	% shredder taxa
% semivoltine taxa	# of scraper taxa	% scraper taxa
% multivoltine taxa	# of predator taxa	% cg and fg taxa
% univoltine taxa	MTI <sup>7</sup>	

<sup>1</sup>Taxa richness is the number of different taxa

<sup>2</sup> EPT richness is the number of Ephemeroptera, Plecoptera, and Trichoptera taxa

<sup>3</sup> QSI for taxa is the Quantitative Similarity Index based on percent relative abundances of taxa between samples

<sup>4</sup> # of cg and fg taxa is the number of collector-gatherer and filterer-gatherer taxa based on Merritt and Cummins (1984)

<sup>5</sup> HBI is the Hilsenhoff Biotic Index based on organic pollution tolerance values (Hilsenhoff 1987 and Bukantis 1995b)

<sup>6</sup> Shannon Index is a biotic diversity index

<sup>7</sup> MTI is a metals tolerance index (Bukantis 1995b)

Reference biological and habitat conditions are obtained from "least impaired" sites in an ecoregion or sub-ecoregion (regional framework) as defined by Omernik (1987). A biological assessment is then made for the site that is thought to be impaired within the reference ecoregion using this multi-metric approach. RBP's are used by many state and federal agencies for monitoring water quality. Regionalized RBP's are designed to be efficient, economical, easily interpretable, and accurate in assessing water quality impairment, at least on a gross level (Resh and Jackson 1993). Results of

many RBP's can be implemented in less than 5 days (Lenat and Barbour 1994) although, often this may not be true for agencies that do not have the resources available (Bukantis 1995). RBP's can be used for both point and non-point sources of impairment (Resh and Jackson 1993). Aquatic macroinvertebrates are the most frequently used organism in RBP assessments (Rosenberg and Resh 1993).

The State of Montana is presently developing its own modified RBP's for wadeable rivers and streams in Montana and has delineated the state into three ecoregions: 1) the plains, 2) foothills and intermountain valleys, and 3) mountain ecoregions based on Omernik (1987) and from preliminary findings of macroinvertebrate communities in Montana using Detrended Correspondence Analysis (DECORANA) (Wisseman 1990). Water quality impairment in these three ecoregions in Montana is mostly due to non-point sources (Montana 305b Report 1994). The majority of non-point impairment in Montana to rivers and streams is from agriculture, logging and mining (particularly in the mountain ecoregion), road building, sedimentation, irrigation, and habitat loss (Montana 305b Report 1994). Of the 176,750 miles of streams in Montana, only 10% have been assessed for water quality (Montana 305b Report 1994). The State of Montana Water Quality Division of the Department of Environmental Quality has been developing RBP's since 1989 (Wisseman 1990) and is increasing its data base annually (McGuire 1994, 1995). Bollman (1995) is presently completing an extensive study in the foothill and intermountain ecoregion in Montana. Very little data exists using macroinvertebrates to assess water quality impairment in the mountain streams ecoregion of Montana.

## HYPOTHESES TESTED

I tested four hypotheses:

- 1) within-site variation exists in the abundance and distribution of macroinvertebrate taxa in mountain streams of Montana and can be detected with methods used in this study.
- 2) within-stream variation exists in the abundance and distribution of macroinvertebrate taxa in mountain streams of Montana and can be detected with methods used in this study.
- 3) seasonal variation exists in the abundance and distribution of macroinvertebrate taxa in mountain streams of Montana and can be detected with methods used in this study.
- 4) water quality impairment affects the abundance and distribution of macroinvertebrate taxa in mountain streams of Montana and can be detected with methods used in this study.

## LITERATURE REVIEW

### Water Quality Problems in the U.S.

Human caused degradation of river ecosystems worldwide has reached unprecedented levels. "Not one riverine system in America has been spared" (Doppelt et al. 1993). Doppelt et al. (1993) report that 50% of our nations' waters fail to meet federal water quality standards. Also, less than 2% of our nations's rivers even qualify for Wild and Scenic designation. From one-third to three-fourths of aquatic species nationwide are rare to extinct. Aquatic species are disappearing at a faster rate than terrestrial species (Doppelt et al. 1993) with twenty percent of native fishes in the western U.S. extinct or endangered (Miller et al. 1989). Two hundred and fourteen stocks of native Pacific salmon and steelhead are facing extinction (Nehlsen et al. 1991) and commercial fish harvests in major rivers throughout the U.S. have declined from 80% to 100% (Karr et al. 1985; Ebel et al. 1989; and Patrick 1992). Karr (1991) asked 'what would our country think if U. S. agricultural productivity decreased by 80%?'

It is estimated that 60% to 80% of natural riparian vegetation has already been lost or is degraded due to human activities in the U.S. (Swift 1984), while seventy percent of our nations' rivers and streams have been impaired by flow alteration (Doppelt et al. 1993). Over 600,000 miles of rivers have already been dammed in the U. S., with the Yellowstone River being the only remaining free-flowing large river

(longer than 600 miles) left in the U.S., outside of Alaska (Karr 1995).

The only attempt at quantifying river channelization in the U.S. was conducted over 20 years ago in 1972 by the Council of Environmental Quality which estimated that 235,000 miles of streams and rivers in the U.S. have been channelized (Doppelt et al. 1993). The United States Environmental Protection Agency (U.S. EPA) reports that nonpoint sources affect 65% of impaired streams (Karr 1991).

#### Water Quality Problems in Montana

Assessments of water quality in Montana have been completed in only 10% of its stream miles ( Montana Water Quality Division 1994). The State of Montana classifies its streams as fully supporting, partially supporting, or non-supporting of their designated uses. Non-supporting stream miles total 925 (about 5% of those assessed) and partially supporting streams total 75% of those assessed. It is unknown how many unassessed stream miles (159,070 miles) are fully supporting their designated uses. Agriculture has impaired 75% of the stream miles that have been assessed and 90% of stream mileage impairment in Montana comes from non-point sources (Montana Water Quality Division 1994). Nutrients, siltation, suspended solids, salinity, flow and habitat alterations, and metals are the major causes of stream impairment in Montana ( Montana Water Quality Division 1994).

### Biomonitoring Approaches

The idea of biological indicator organisms is not new. A king's use of winetasters and the use of canaries by miners to detect dangerous gases are familiar examples of biological indicators (Cairns and Pratt 1993). Even the relative abundance of rats in our cities is a biological indication of environmental conditions.

The use of freshwater aquatic organisms as bioindicators of water quality appears to have its origins in Europe with the work of Kolenati in 1848. Kolenati (1848) reported that city effluents caused the disappearance of caddisflies downstream. Kolkwitz and Marsson (1908) related the degree of pollution in a river as a measure of sewage organic matter. Other researchers then began developing lists of pollution 'indicator organisms' in rivers and streams (Richardson 1925, 1929; Gauvin 1958; Cairns and Pratt 1993). Cairns and Pratt (1993) suggest that presently, "biological surveillance of communities - with special emphasis on characterizing taxonomic richness and composition - is perhaps the most sensitive tool now available for quickly and accurately detecting alterations in aquatic ecosystems".

Aquatic macroinvertebrates are the most commonly used indicator organisms for water quality assessment (Rosenberg and Resh 1993), although other aquatic organisms are routinely used, including fishes (Simon and Lyons 1995) and periphyton (Bahls 1993). Some of the reasons for using aquatic macroinvertebrates as indicators of water quality include: 1) macroinvertebrates occur in all types of freshwater environments (Merritt and Cummins 1984), 2) the many different kinds of

macroinvertebrate species found in freshwater habitats allows for a wide range of responses to different sources of impairment (Hellowell 1986, Abel 1989), 3) aquatic macroinvertebrates are less mobile than fishes which allows for spatial analysis of impairment (Slack et al. 1973, Hellowell 1986) and 4) macroinvertebrates have longer life cycles compared with microorganisms and periphyton, which allows for analysis of disturbance over time (Gaufin 1973, Abel 1989). Aquatic macroinvertebrates are "on site monitoring the water, regardless of the presence or absence of the investigating biologist" (Nehrig 1976).

Many types of biomonitoring of freshwater ecosystems are in use (Johnson et al. 1993). The use of individual organisms for toxicity testing for various pollutants in the laboratory, in artificial streams, and in field studies is common (Gaufin 1973, Rahel and Kolar 1990, Dunkel and Richards, submitted). These studies typically measure physiological, biochemical, behavioral, and life history changes of the individual test organisms to various types of pollutants (Marten and Zwick 1989, Nardi and Watson 1990, Johnson et al. 1993).

Population and community structure studies are also used to measure the effects of different pollutants on aquatic macroinvertebrates both in the laboratory and more commonly in field studies. These studies may use a univariate or multivariate approach or a combination of the two (Johnson et al. 1993).

Univariate studies of populations and communities can be used to develop biotic indices and scoring systems. An example of such an index is the Hilsenhoff Biotic Index which scores the sensitivities of many aquatic macroinvertebrates to organic

pollution and is widely used in monitoring programs (Hilsenhoff 1987, Resh and Jackson 1993). A prerequisite to the use of biotic indices is a thorough knowledge of how the type of pollution used for each index affects the biota (Johnson et al 1993).

Often graphical analysis of macroinvertebrate data can provide more insight into biology than a simple p-value (Fore et al. 1995). For example, Fore et al. (1995) were interested in whether scores (metrics) for best and worst sites clumped together tightly or were spread more evenly. Graphs allowed them to examine each metric's range and evaluate where along the continuum of degradation the metric was most sensitive. Fore et al. (1995) suggest that the main problem with statistical correlation is that no single variable can summarize all the human activities that degrade streams. Different data may be appropriate for different types of degradation. Fore et al. (1995) doubt that any single land-use or chemical variable can reliably rank sites. Fore et al. (1995) suggest that this is a primary reason for evaluating the river condition according to the resident biota. In most cases, sites that appear to a human observer to be heavily used and visibly damaged usually are more degraded than those that appear pristine (Fore et al. 1995).

Multivariate approaches including regression analysis can be used to ordinate populations or communities along environmental gradients (Digby and Kempton 1994). Johnson et al. (1993) suggested that direct gradient analysis (regression) could be used to predict species assemblages along a known environmental gradient. This information can then later be used to infer water quality from species assemblages found in a study site.

Principal Components Analysis (PCA) is an example of indirect gradient analyses which measure species assemblages gradients regardless of any environmental gradient (Johnsen et al. 1993). For example, in Principal Components Analysis, Principal Component 1 (or eigenvector 1) contains the largest individual differences in a species assemblage. The second Principal Component (eigenvector) accounts for the largest proportion of remaining individual differences not correlated to (or orthogonal to) Principal Component 1 (Williams and Feltmate 1992). PCA calculates the line, or component, that extracts the maximum amount of statistical variance from a cloud of points (Tabachnick and Fidell 1989). For stream macroinvertebrate analysis, each point then will represent a stream site. The number of dimensions through which the line passes would equal the number of taxa collected (Fore et al. 1995). Usually, PCA data uses species lists and abundances to interpret differences between stream sites (Norris and Georges 1993). If land use data are not sufficient to perform canonical correspondence analysis, then PCA may be used and site characteristics can later be identified on the principal components plots (Fore et al. 1995). Hannaford and Resh (1995) used PCA to analyze the correlation matrix of six RBP metrics used in their study of variability in rapid-bioassessment surveys. In an intensive ecological study, Gustafson (1990) was able to use principal components analysis to identify the velocity preferences of aquatic insects in the Gallatin River, MT and identify the insect species distribution to three distinct sections of the river. Gustafson (1990) also used a faunal and physical component PCA analysis to easily identify headwater insect species, lower Gallatin River species, and widespread species within the drainage.

With the many types of data analysis available, it should be pointed out that ... "Too often biological patterns in complex data sets are reported in terms of complicated, high level statistics such as principal components analysis" (Fore et al. 1995). While many times it is easier to compare sites and search for patterns in the raw data by simply noticing which taxa were present or absent in similar sites (Fore et al. 1995). All of these quantitative methods mentioned above require many replicates with detailed statistical analysis, which may be cost prohibitive given the thousands of miles of rivers and streams potentially impaired in the U. S. (Resh and Jackson 1993).

#### Rapid Assessment

With the high cost associated with quantitative methods, limited budgets and limited personnel in management agencies responsible for water quality, and given the increasing deterioration of water quality throughout the world, the most recent approach in biomonitoring has been "rapid assessment". Rapid assessment is a qualitative method (sometimes semi-quantitative) designed to measure water quality and can also be used to measure long-term regional changes (Resh and Jackson 1993).

63% of the 123 U.S.D.A. National Forest Districts and 61% of the 56 Department of Interior, Bureau of Land Management Districts surveyed by Angradi and Vinson 1995, reported conducting some type of aquatic macroinvertebrate monitoring. Mining, timber harvest, and grazing management were the most often cited reasons for using aquatic macroinvertebrate monitoring. Protocol III is the most rigorous tier level approach for the RBP's suggested by the U.S. EPA and is used by

over 20 states (Resh et al. 1995). Protocol III identifies macroinvertebrates to the genus or species level and incorporates a habitat assessment for each site.

Many of the assessment methods used throughout the U.S. rely on a multimetric approach, while in Europe a multivariate approach is more common. Norris (1995) discussed the use of multivariate methods in Europe and suggested that multivariate methods are seriously under used in the U.S. Gerritsen (1995) on the other hand, argues that multimetric methods used in the U.S. function well and that multivariate methods "...are more complex, require additional specialization by practitioners, and are more difficult to convey to managers and the public". Fore et al. (1995) state that, "multimetric indices formalize what any good biologist familiar with local biota, knows about the biological condition of a stream". Indices, thus, become important tools for communication with non specialists. A multimetric approach can be compared to familiar economic indexes such as the consumer price index which has been widely used for over 50 years (Fore et al. 1995).

Rapid bioassessments are frequently compared to the use of thermometers in assessing human health (Karr 1995; Resh and Jackson 1993). Results are easily obtained and can be compared to the "normal" condition. Resh and Jackson (1993) point out that the key questions then become: what populations and community measures are biologically relevant (the thermometers)?, what are the thresholds against which they are being compared (the normal body temperature)? and, how much of a deviation from the threshold is a sign of "ill health"? They suggest that a critical and often controversial decision is the selection of the most appropriate measures for use in

multimetric rapid assessment approaches.

Many metrics or indices are presently being tested and used in rapid assessment programs throughout the U.S. including the Pacific Northwest (Fore et al. 1995). Resh and Jackson (1993) gave an excellent overview of the many metrics that have been proposed for use, as well as the various collection methods, sampling strategies and taxonomic resolution used by various researchers and agencies.

#### Problems with Rapid Assessments

Even though rapid assessments are becoming very popular, their ability to detect water quality impairment is often questioned (Norris 1995, Southerland and Stribling 1995, Resh and Jackson 1993). Although rapid bioassessments were designed to be cost effective, several Forest Service Districts and Bureau of Land Management Districts surveyed by Angradi and Vinson (1995) reported that they could not afford to conduct assessments properly. Several districts also reported that natural variability is so great in aquatic macroinvertebrate communities that current methods are unreliable or insensitive to land management impacts.

Another problem using RBP's concerning natural within-site variability is that most RBP's, including Protocol III of the U.S. EPA, suggest collection of only one sample per site (Resh and Rosenberg 1989). Research has shown variability in the replication of many RBP metrics (Resh et al. 1990, Steven and Szczytko 1990, Barbour et al. 1992, Hannaford and Resh 1995, and Resh 1994).

The choice of sampling methods and the choice of the most appropriate habitat

to be sampled may influence results (Rosenberg and Resh 1993). Even the choice of the portion of a riffle to be sampled may be biased due to the distribution of benthic organisms within the riffle. Brown and Brown (1984) showed a strong upstream biased distribution of insects within riffles. With all of the problems seemingly associated with rapid assessment, many researchers and managers feel that these problems can be addressed and eventually overcome with an increased understanding of macroinvertebrate community responses to water quality impairment.

#### Rapid Assessment in Montana

The Water Quality Division (WQD) of the Montana Department of Environmental Quality (DEQ) is presently assessing the applicability of its modified version of the U. S. Environmental Protection Agencies (EPA) Rapid Bioassessment Protocols (RBP's) using macroinvertebrates for monitoring water quality in mountain streams of Montana. These methods use a multi-metric approach based on reference conditions within a regional framework (Davis and Simon 1995). The Montana Water Quality Division recommends the collection of macroinvertebrate samples during the summer season (June 21 to September 21), following runoff. This is because the Montana WQD has the most reference data from this season and because stream flows and weather conditions are most suitable for field work. The Montana WQD also recommends that for monitoring trends at a particular site over time, sampling as close as possible on the same date will produce the best results (Bukantis 1995).

Numerous researchers have suggested that within-site, within-stream,

seasonal, and yearly variability of stream macroinvertebrate communities may affect rapid assessment metrics enough to make them unreliable for assessing water quality impairment (Resh and Jackson 1993; Bode and Novak 1995; Angradi and Vinson 1995). To be effective, rapid assessment metrics must be able to discriminate between impairment and natural variability (Bode and Novak 1995; Barbour et al. 1995). Very little analyzed data exists concerning metric variability using rapid assessment in mountain streams of Montana.

#### Macroinvertebrate Variability in Mountain Streams

There has been much documentation of within-stream and seasonal variability of macroinvertebrates in mountain streams and these types of variability are well understood concepts (Ward and Kondratieff 1992; Resh and Rosenberg 1989; Yoder and Rankin 1995). For example, longitudinal macroinvertebrate community changes within a stream from headwaters downstream have fostered many classification and zonation schemes including the River Continuum Concept (Vanote et al. 1980) and Illies' and Botosaneanu's (1963) zonation system.

Seasonal and yearly variability studies are numerous. Richards et al. (1995) reported a 3 to 4- fold increase in abundance of adult *Pteronarcys californica* (Plecoptera) in the Madison River in SW Montana between 1994 and 1995. Gustafson (1990) conducted an intensive study of the ecology of aquatic insects in the Gallatin River drainage in SW Montana. From his work on the mainstem of the Gallatin River, Gustafson (1990) reported that total macroinvertebrate density was very low the first

summer but was at an all time high during the following summer, which he attributed to an early spring run-off before the second summer. Gustafson (1990) also reported that in autumn, the species numbers peak due to the appearance of species with winter life cycles. A winter depression of species numbers occurred due to winter mortality or downward migration from the top layer of the benthos. The peak in species number during the spring was associated with the appearance of species with summer life cycles, which occurs before all species with winter cycles have emerged. Gustafson (1990) stated that spring peaks in species numbers occurred during a depression in total invertebrate density. A decline in the average number of species after the spring peak was associated with an increased total density because many of the species with winter life cycles were absent from the benthos and the species with summer life cycles became very abundant (Gustafson 1990). Gustafson's (1990) conclusion was that there were low macroinvertebrate densities in summer, then an increase during autumn, a decline in winter, a brief increase in the spring, followed by a decline to the summer low.

The State of Ohio suggested that fundamental decisions need to be made early in the development of biocriteria, including accounting for seasonal variability (Yoder and Rankin 1995). The State of Ohio confines their collection times to June through September and is presently analyzing temporal variability from a special Ohio EPA methods study conducted in 1981 (DeShon 1995). Bode and Novak (1995) tested seasonal variability by sampling two streams monthly for a year. They suggested that between-month comparisons should not be done. Reash (1995) reported that seasonal

and yearly variability must be accounted for when deriving biocriteria. Reash (1995) based this by monitoring fish populations in the Ohio River, where 50% of the electrofishing and gill net samples showed significant (5% level) temporal variability in catch per unit effort or in total biomass. Resh and Jackson (1995) reported that in their study of the accuracy of macroinvertebrate rapid assessment measures, 16 of the 22 measures tested found significant (5% level) seasonal differences. A detailed knowledge of life histories, especially voltinism and phenology, of macroinvertebrates encountered in biomonitoring samples should help alleviate many problems associated with seasonal variability (Rosenberg and Resh 1995; Johnson et al. 1995).

Functional feeding groups are also known to follow seasonal patterns of abundance (Cummins 1974). The functional feeding group classification system "distinguishes macroinvertebrate taxa that perform different functions within aquatic ecosystems with respect to processing of nutritional resource categories" (Merritt and Cummins 1984). Functional feeding groups are analogous to "guilds". Many stoneflies that are in the functional feeding group 'shredders' have short life cycles and may be present or absent from samples collected at certain times of the year (Gustafson 1990). Gustafson (1990) reported that predators, shredders, and collectors generally increased in density as stream order increased, while the density of scrapers peaked in the mid-order streams in the Gallatin River drainage. Scrapers had a high variance at all stream orders and headwater streams had more species of shredders than streams of intermediate size (Gustafson 1990).

At present, the Montana WQD RBP's for the mountain stream ecoregion do

not fully address within-site, within-stream, seasonal, and yearly variability of macroinvertebrate communities, although variability is taken into account by setting wide confidence limits on impairment (Bukantis 1996). The Montana WQD RBP's also do not incorporate the potential beneficial uses of seasonal variability into their assessments. For example, the higher abundance of certain taxa at different seasons, other than summer, that may be more sensitive to various sources of impairment.

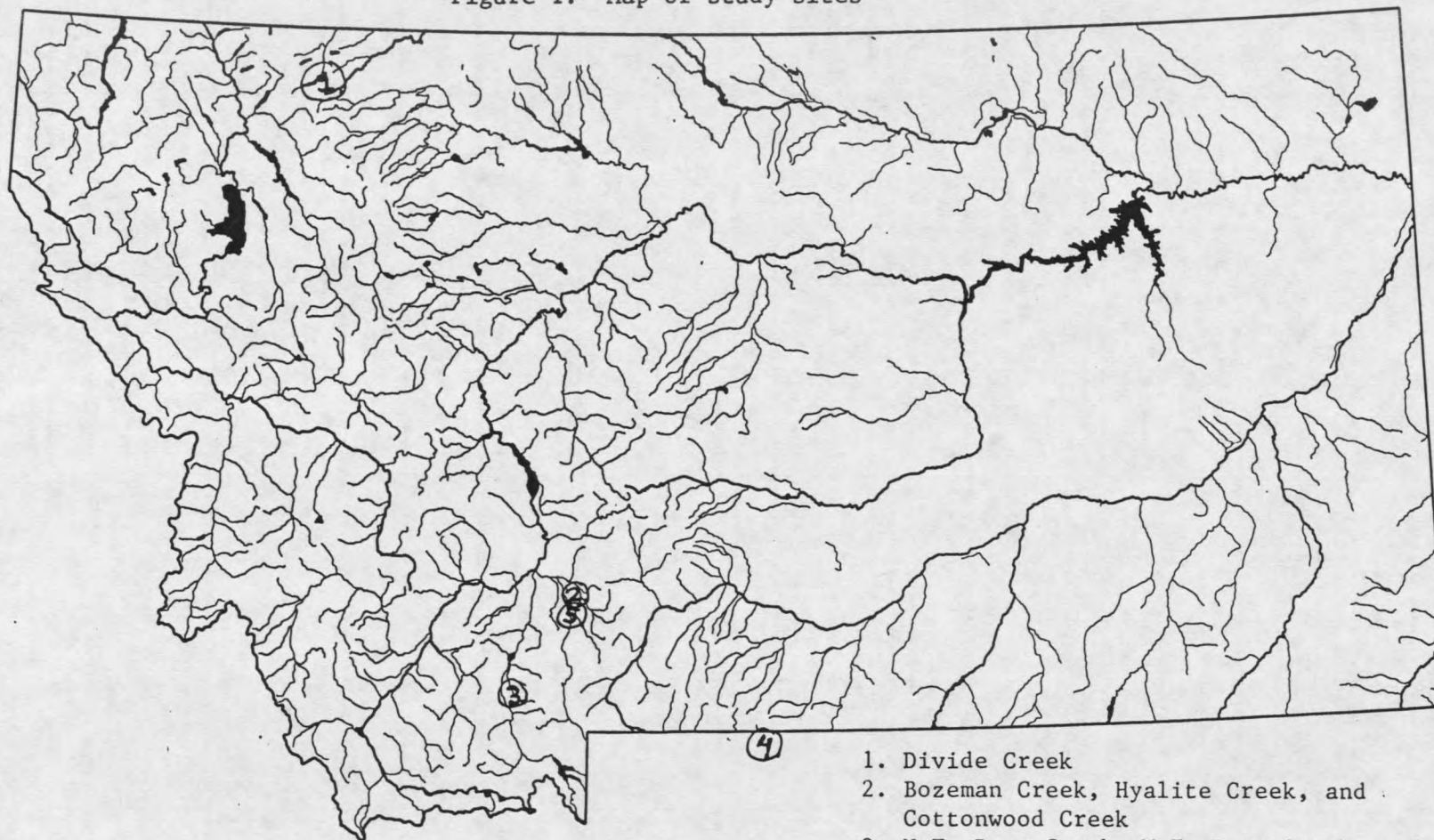
## MATERIALS AND METHODS

### Within-site Variability Collection Sites

Twenty six sites from ten mountain streams in western Montana and NW Wyoming were used to test within-site variability. The ten mountain streams were Bozeman Creek, Hyalite Creek, Cottonwood Creek, Squaw Creek, Pebble Creek, Soda Butte Creek, North Fork Bear Creek, Middle Fork Bear Creek, Bear Creek, and Divide Creek (Figure 1). A riffle sequence was defined as a series of consecutive riffles and pools. Three macroinvertebrate samples were collected from each riffle sequence (site), one sample per riffle, in 1995. Hyalite Creek, 1994 and Bozeman Creek, August, 9, 1994 had four samples collected from a riffle sequence (1 sample per riffle). Collection dates, physical and chemical data, and descriptions of the streams are presented in Table 2.

Of these 26 sites ( riffle sequence), 14 were from 7 'least impaired' reference mountain streams. The seven reference streams included 5 sites (riffle sequences) from Pebble Creek, (1995) and 1 site from each of the following streams, Cottonwood Creek (1995), N. F. Bear Creek (1995), M. F. Bear Creek (1995), Bear Creek (1995), Soda Butte Creek (km 1, 1995), Bozeman Creek (summer 1994) and Bozeman Creek (summer 1995)(Table 2). Mean, variance, standard deviation (s.d.), coefficient of variation (CV) and 95% confidence intervals (CI) were derived for each metric used.

Figure 1. Map of study sites



1. Divide Creek
2. Bozeman Creek, Hyalite Creek, and Cottonwood Creek
3. N.F. Bear Creek, M.F. Bear Creek, and Bear Creek
4. Pebble Creek and Soda Butte Creek
5. Squaw Creek

Table 2. Descriptions of the 10 mountain streams sampled in this study including, mountain range, drainage, longitude, latitude, township, range 1/4 section, stream order, link magnitude, elevation direction of stream flow, pH, conductivity, Rosgen stream type, estimated discharge, and date of collection.

	Bozeman Creek	N. F. Bear Creek	M. F. Bear Creek	Bear Creek	Divide Creek	Soda Butte Creek	Cottonwood Creek	Squaw Creek	Hyalite Creek
<b>Mountain range</b>	Gallatin range	Madison range	Madison range	Madison range	Lewis range	Absaroka range	Gallatin range	Gallatin range	Gallatin range
<b>drainage</b>	Gallatin River	Madison River	Madison River	Madison River	St. Mary River	Lamar River (Yellowstone River)	Gallatin River	Gallatin River	Gallatin River
<b>longitude</b>	111° 1' W	111° 33' W	111° 33' W	111° 33' W	113° 25' W	110° 00' W	111° 05'	111° 13'	111° 02'
<b>latitude</b>	45° 35' N	45° 10' N	45° 10' N	45° 09' N	48° 45' N	45° 00' N	45° 34'	45° 25'	45° 33'
<b>township range 1/4 section</b>	T3S/R6E Sec.18 NE	T7S/R1E sec. 36 SW	T8S/R1E sec. 1 NW	T8S/R1E sec. 12 NW	T35N/R14 W sec. 34 SW	T9S/R15E sec 29	T3S/R5E sec 35	T4S/R4E sec 35	T3S/R5E sec 32
<b>stream order</b>	3	3	3	3	3	2, 3	3rd	3rd	3rd
<b>link magnitude</b>	34	14	17	9	18	2, 8	9	32	32
<b>elevation (meters)</b>	1627	1948	1887	1932	1380	2370, 2332	1744	1634	1990
<b>direction of stream flow</b>	NW	WSW	WSW	W	NW	W	NW	WNW	N
<b>pH</b>	8.5	8.4	8.4	8.4	8.6	8.6, 7.3	8.6	8.4	8.4
<b>conductivity</b>	160	110	140	210	180	210, 300	170	180	120

Table 2. Continued.

	Bozeman Creek	N. F. Bear Creek	M. F. Bear Creek	Bear Creek	Divide Creek	Soda Butte Creek	Cotton- wood Creek	Squaw Creek	Hyalite Creek
Rosgen stream type	C4b	A2/A3b	B3c	B3/B4	B3/B4	B3, B3	C4	C4	B2c
estimated discharge (m <sup>3</sup> /s)	na	2.84	1.48	0.35	na	na	na	na	na
date sampled	Sept 20, 1995	July 5, 1995	July 5, 1995	July 5, 1995	August 30, 1995	August 16, 1995	July 15, 1995	July 12, 1995	June 27, 1994

**Table 2. continued. Descriptions of Pebble Creek sites sampled in this study including, mountain range, drainage, longitude, latitude, township, range 1/4 section, stream order, link magnitude, elevation direction of stream flow, pH, conductivity, Rosgen stream type, estimated discharge, and date of collection.**

measure	Km 2	Km 4	Km 6.5	Km 9	Km 13	Km 16
Mountain range	Absaroka range	Absaroka range	Absaroka range	Absaroka range	Absaroka range	Absaroka range
drainage	Lamar River (Yellowstone River)	Lamar River	Lamar River	Lamar River	Lamar River	Lamar River
longitude	110° 02'	na	na	na	na	110° 10'
latitude	45° 01'	na	na	na	na	44° 13'
township range 1/4 section	T9S/R14E sec 19	na	na	na	na	T57N/R11 0W sec 13
stream order	2	2	3	3	3	3
link magnitude	5	6	8	10	17	23
elevation (meters)	2733	2667	2600	2533	2483	2300
direction of stream flow	SW	SW	S	S	S	S
pH	8.8	8.6	8.6	8.0	8.2	8.5
conductivity (micro siemens)	170	190	200	170	170	160
Rosgen stream type	B3c	B3c	C3/C4	C3/C4	B2/B3	B2/B3
estimated discharge (m <sup>3</sup> /s)	1.08	na	2.64	2.73	na	na
date sampled	August 16, 1995	August 16, 1996	August 15, 1995	August 15, 1995	August 15, 1995	August 16, 1995

Three samples collected from N. F. Bear Creek, M. F. Bear Creek, and Bear Creek (collectively referred to as the Three Bear Creeks in this study) were collected on July 5, 1995, while one sample was collected from the same riffle on June 24, 1994 from each stream. The three Bear Creeks originate in the Madison range of SW Montana within the Lee Metcalf Wilderness (Table 2 and Figure 1). Sample sites were within the wilderness area and were assumed to be 'least impaired' sites.

Divide Creek is a third order stream near St. Mary, MT and forms part of the eastern border between Glacier National Park and the Blackfeet Indian Reservation in NW Montana (Figure 1. and Table 2 ). Divide Creek has been drastically channelized in an attempt to prevent flooding of private businesses in St. Mary and to prevent a historic bridge (operated by the National Park Service) from being washed out (Rosgen 1994b). Divide Creek is usually channelized by bulldozers yearly (Rosgen 1994b). Therefore, Divide Creek was used as an 'impaired' site.

One sample was also collected on October 20, 1994 from Squaw Creek. Squaw Creek has had extensive logging associated activities in its drainage including the removal of most of the large woody debris in the lower mainstem where the samples were collected (Table 3) and was considered 'impaired'.

One sample from two sites (km 1 and km 2) was also collected on August 13, 1994 from Soda Butte Creek. Soda Butte Creek is located near Cooke City, SW Montana (Table 2 and Figure 1). Soda Butte Creek receives mine leachate from the McLaren tailings in Cooke City before it flows into Yellowstone National Park. One collection site was located above the McLaren tailings (km 1) and considered 'least

impaired' and one site was located directly below the McLaren tailings (km 2) and was obviously 'impaired'. The amount of logging associated activity in Bozeman Creek, Hyalite Creek, Squaw Creek, and Cottonwood Creek are in Table 3.

Table 3. Number of road kilometers per square kilometer (km/km<sup>2</sup>), number of clear-cut hectares per square kilometer (hect/km<sup>2</sup>), and the number of cubic meters of woody debris per stream kilometer (m<sup>3</sup>/km) in the Bozeman, Hyalite, Cottonwood, and Squaw Creek drainages.

	Bozeman Creek	Hyalite Creek	Cottonwood Creek	Squaw Creek
roads (km/km <sup>2</sup> )	0.86	1.15	0.24	1.26
clear-cuts <sup>a</sup> (hect./ km <sup>2</sup> )	7.71	12.52	4.96	23.28
woody debris <sup>b</sup> (m <sup>3</sup> /km)	152.01	66.52	191.03	46.18

<sup>a</sup> data was not available on the age of the clear-cuts or how close to the stream the clear-cuts occurred.

<sup>b</sup> woody debris was measured along a 3.2 km (2 mile) similar section of each stream.

#### Within-stream Variability Collection Sites

Six collection sites (3 samples per site) in Pebble Creek (Yellowstone National Park, Wyoming and Montana) were used to test within-stream variability (Figure 1 and Table 2). These sites were also used to test within-site variability. Pebble Creek was considered to be a 'least impaired' mountain stream. Any changes in the metrics calculated for Pebble Creek were assumed due to natural causes. Collection sites in Pebble Creek were at approximately 2 km, 4 km, 6.5 km, 9 km, 13 km, and 16 km

from its headwaters. Pebble Creek sites were labelled site 2 km, site 4 km, site 6.5 km and so forth for future reference. Principal Components Analysis using raw species abundances from each sample (3 per site) was used to explore longitudinal relationships between each site. Mean, variance, standard deviation (s.d.), coefficient of variation (CV), and 95% confidence intervals (CI) for twenty metrics were calculated for each site.

Six collection sites in Soda Butte Creek (Montana and Yellowstone National Park, Wyoming) were also used to test within-stream variability (Figure 1) using PCA of raw species abundance data for each sample as a sampling unit. Soda Butte Creek is an 'impaired' stream, therefore, within-stream variability analysis was complicated by its impairment. Sites were labelled for their distance from Soda Butte Creek's origin at 1km, 2 km, 4 km, 8 km, 11 km and 16 km.

### Seasonal Variability Collection Sites

Samples used to test for seasonal variability were collected from the same riffle sequence (site) from Bozeman Creek (Gallatin River drainage, SW Montana) at five different times; four samples on August 9, 1994, three samples on October 21, 1994, three samples from February 5, 1995, three samples on May 5, 1995, and three samples on September 20, 1995.

Bozeman Creek, also known as Sourdough Creek, near Bozeman, MT (Figure 1 and Table 2) is part of the city of Bozeman's water supply. There is an unimproved road along Bozeman Creek for much of its length which is used by recreationalists. Bozeman Creek is closed to unauthorized vehicles. Only limited logging activity has occurred in the Bozeman Creek drainage (Table 3). The stream corridor receives limited use and is protected from logging associated activities. Because it is a city water supply, Bozeman Creek was used as a reference or 'least impaired' stream.

### Macroinvertebrate Collection

Macroinvertebrate samples were collected, sorted, and taxonomically identified using the Water Quality Division (WQD), State of Montana, Standard Operating Procedures, except that no sub-sampling was done (State of Montana recommends a 300 organism sub-sample). A one-minute traveling kick using a standard D-frame net with a 1 mm mesh size was used in riffle habitats for all samples collected (Bukantis 1995). Riffle samples were collected by vigorously kicking the substrate and moving

diagonally downstream and across the riffle in an effort to sample all of the riffle sub-habitats at an approximate rate of 0.3 meters (1 foot) per second. Timing of the sample collection for one minute provided for a semi-quantitative analysis used in the computation of various metrics.

Samples were then either placed in a shallow pan and all macroinvertebrates hand-picked and placed in 95% ethanol at the collection site or all of the contents collected in the net, including debris, were directly placed in 95% ethanol and sorted at a later time. For the purpose of this study all of the organisms collected in the samples were sorted and identified regardless of their numbers. Macroinvertebrates were identified to the taxonomic level suggested by the State of Montana, usually genus or species, by using taxonomic keys from Merrit and Cummins 1983, Stewart and Stark 1993, Pennak 1989, Wiggins 1977, and Gustafson 1994. More difficult identifications were verified by Dr. Dan Gustafson at Montana State University. Voucher specimens were placed in the Montana Entomology Collection at Montana State University.

#### Physical and Chemical Data

Physical and chemical stream data were collected at the time of the macroinvertebrate collections at each site and included: 1) temperature, 2) pH, 3) conductivity, 4) gradient, 5) velocity, 6) width, 7) depth, and 8) substrate composition. Water temperature was measured with a calibrated mercury bulb thermometer. pH was measured with a Cole-Parmer pH Tester 2<sup>TM</sup>. Conductivity was measured with a Cole-Parmer TDS Tester<sup>TM</sup>. Stream gradient at the riffle site was estimated using a 60 meter

line and line level. Velocity was estimated by floating a stick for a distance of 60 meters centered on the riffle section and timed on a watch to the nearest second. Five passes were made and then averaged. A correction factor of 0.85 was used to adjust for average velocity within the water column (Harrelson et al. 1994). Stream width was measured at estimated bank full stage to the nearest tenth of a meter and stream depth was measured at estimated bank full stage to the nearest centimeter at ten intervals and then averaged. Velocity, width, and average depth were used to roughly estimate discharge at sites where no gaging stations are established. Substrate composition was measured using a Wolman 100 pebble count (Wolman 1954; Kondolf and Li 1992). Measurements of gradient and substrate size composition along with an estimate of sinuosity and entrenchment were used to classify each study site using the Rosgen stream classification system (Rosgen 1994a).

Stream order, link magnitude, elevation, longitude, latitude, township, range, 1/4 section, mountain range, major river drainage, and flow direction were made from U.S.G.S. 15- minute topographic maps and U.S.D.A. Forest Service maps. Stream order was classified using the following method; a first order stream is the headwater stream, a second order stream is formed where two first order streams join, a third order stream is formed when two second order streams join and a fourth order stream is formed when two third order streams join (Strahler 1957). Link magnitude is the total number of first order streams entering within the drainage upstream of the study section.

### Metrics and Statistical Analysis

Metrics calculated and used in this study are listed in Table 1. Mean, 95% confidence interval (CI), variance, standard deviation (s.d.) and coefficient of variation (CV) were calculated for sites with more than one sample per site using QuatroPro (Borland 1993). All ( $\pm$ ) intervals reported in this study are 95% confidence intervals (CI). Richness, evenness, and diversity indices were computed for most samples using Statistical Ecology (Ludwig and Reynolds 1988). Principal Components Analysis (PCA) was used to explore variability in the macroinvertebrate community in Bozeman Creek, Pebble Creek, Soda Butte Creek, and the three Bear Creeks by using the raw species abundance data for each sample as a sampling unit using Statistical Ecology (Ludwig and Reynolds 1988) and QuatroPro (Borland 1993). Typically the first three eigenvectors describe most of the variability (Ludwig and Reynolds 1988), therefore, only the first three eigenvector values were computed.

## RESULTS

### Within-site Variability

Mean within-site CV's ranged from a low of 0.05 for % EPT taxa to a high of 0.43 for % Chironomidae (Table 4). The second highest mean CV value was the number of organisms metric at 0.23. The other 19 metrics CV values were less than 0.23.

Longitudinal comparisons of mean and 95% CI's for 15 metrics from Pebble Creek also showing within-site variability are in the within-stream portion of the Results section. Seasonal mean and 95% CI's showing within-site variability for 17 metrics from Bozeman Creek are in the seasonal portion of the Results section.

Voltinism metrics were not used for further analysis because the range in variability calculated for within-sites in Bozeman Creek was considered too large (range of 0.00 CV to 1.73 CV) and also because present knowledge of voltinism in mountain stream macroinvertebrates in Montana is limited.

Table 4. Mean of CV's for reference stream sites (n = 34 samples, except Metals Tolerance Index: n = 17 samples).

metric	mean CV
# of organisms	0.23
taxa richness <sup>1</sup>	0.09
EPT richness <sup>2</sup>	0.08
# of Plecoptera taxa	0.18
# of Ephemeroptera taxa	0.07
# of Trichoptera taxa	0.12
# of shredder taxa	0.12
# of scraper taxa	0.09
# of cg and fg taxa <sup>3</sup>	0.09
# of predator taxa	0.22
% shredder taxa	0.17
% scraper taxa	0.11
%cg and fg taxa	0.11
% predator taxa	0.19
% dominant	0.18
HBI <sup>4</sup>	0.15
Shannon Diversity Index	0.07
%EPT richness	0.05
%EPT organisms	0.06
% Chironomidae	0.43
Metals Tolerance Index	0.15

<sup>1</sup>Taxa richness is the number of taxa per sample.

<sup>2</sup>EPT richness is the number of Ephemeroptera, Plecoptera, and Trichoptera taxa in a sample.

<sup>3</sup>cg and fg is the number of collector-gatherer and filter-gatherer taxa

<sup>4</sup>HBI is Hilsenhoff Biotic Index

### Within-stream Variability

#### Pebble Creek

Principal Components Analysis of the 6 sites from Pebble Creek using raw species abundance data showed that macroinvertebrate samples from km 2 (N = 3), the most upstream headwater site (2nd order stream segment), clustered together and were distinct from the other sites. Site km 4 (N = 1) also a 2nd order stream segment, clustered separately from the rest of the sites. Macroinvertebrate samples from sites

km 6.5, km 9, km 13, and km 16 ( $N = 3$ ) formed a loose cluster with sites km 13 and km 16 clustering more tightly than the other sites (Table 5 and Figure 2).

Table 5. Eigenvectors defining the first three principal components from 16 samples from Pebble Creek, 1995.

Sample Unit		I	II	III
Km 2	1	-0.16	-1.22	0.37
	2	0.07	-0.95	-0.3
	3	-0.07	-1.14	0.05
Km 4	4	-0.7	-0.67	1.68
Km 6.5	5	-0.11	0.54	0.16
	6	0.57	1.29	0.34
	7	-0.66	1.29	0.57
Km 9	8	-0.82	0.31	0.08
	9	-0.52	0.5	0.05
	10	2.69	0.02	0.55
Km 13	11	0	0.14	-0.27
	12	-0.23	0.05	-0.63
	13	-0.11	0.05	-0.48
Km 16	14	0.52	0.06	-0.56
	15	0.04	-0.21	-0.85
	16	0.11	-0.03	-0.75

The mean, variance, standard deviation, CI, and CV values for the six Pebble Creek sites are in Tables 6 through 10.

Figure 2. Principal Components Analysis for Pebble Creek.

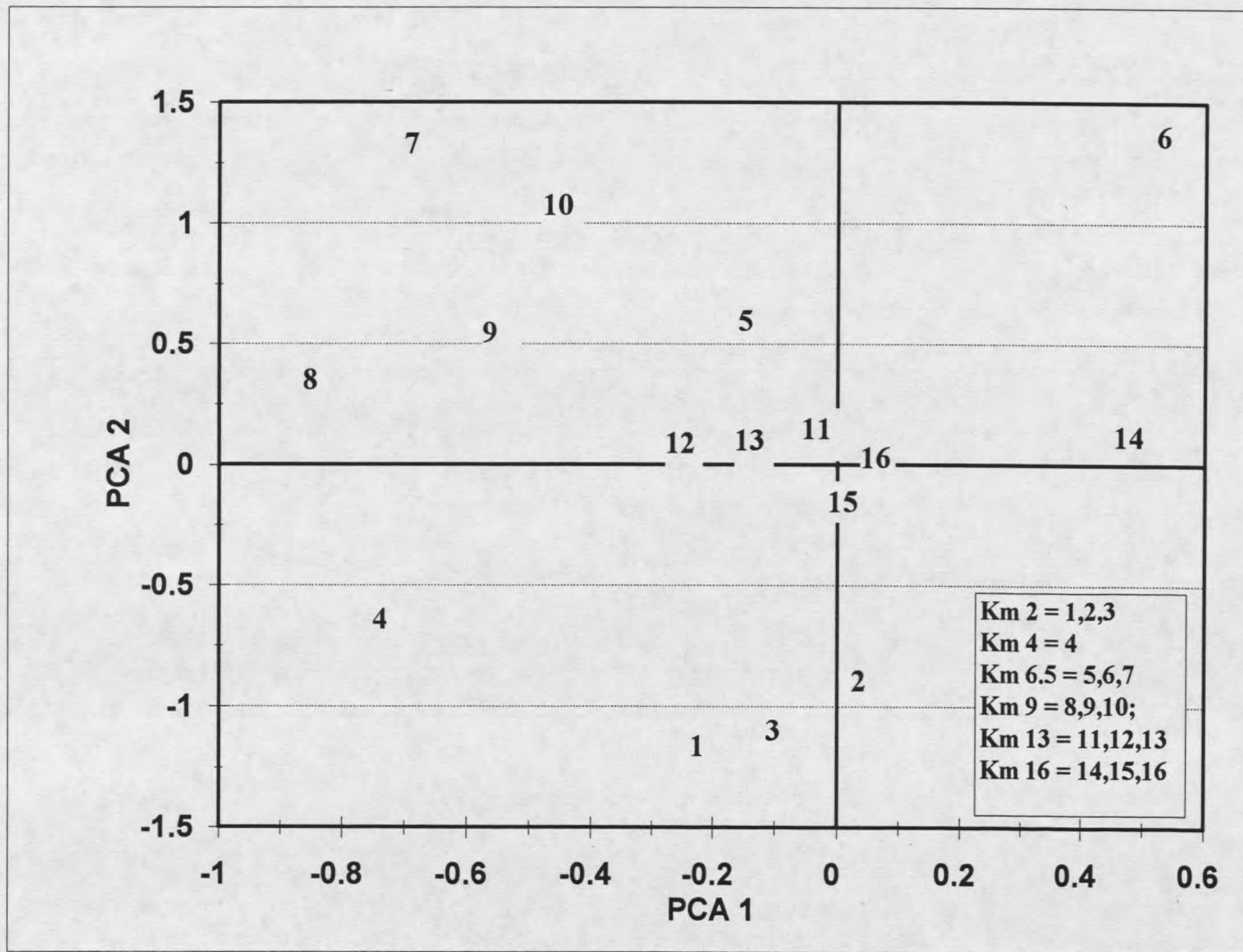


Table 6. Mean ( $\pm$  95% CI), variance, standard deviation (s. d.), and coefficient of variation (CV) for metrics calculated for Pebble Creek 1995 site km 2 (N=3).

metric	mean ( $\pm$ 95% C.I.)	variance	s.d.	CV
# of organisms	588.33 ( $\pm$ 243.73)	46386.00	215.37	0.38
taxa richness <sup>1</sup>	25.33 ( $\pm$ 3.46)	9.33	3.06	0.12
EPT richness <sup>2</sup>	17.67 ( $\pm$ 2.85)	6.33	2.52	0.14
# of Plecoptera taxa	3.33 ( $\pm$ 1.30)	1.33	1.15	0.35
# of Ephemeroptera taxa	7.67 ( $\pm$ 1.30)	1.33	1.15	0.15
# of Trichoptera taxa	6.67 ( $\pm$ 0.66)	0.33	0.58	0.09
# of shredder taxa	1.00 ( $\pm$ 0.00)	0.00	0.00	0.00
# of scraper taxa	3.33 ( $\pm$ 0.65)	0.33	0.58	0.17
# of cg and fg taxa <sup>3</sup>	5.67 ( $\pm$ 1.31)	1.33	1.15	0.20
# of predator taxa	7.67 ( $\pm$ 1.73)	2.33	1.53	0.20
% shredder taxa	4.00 ( $\pm$ 1.00)	0.00	0.00	0.12
% scraper taxa	13.00 ( $\pm$ 2.00)	0.00	1.00	0.11
% cg + fg taxa	21.00 ( $\pm$ 3.00)	0.00	3.00	0.03
% predator taxa	29.00 ( $\pm$ 4.00)	0.00	4.00	0.13
% dominant	26.38 ( $\pm$ 11.08)	95.95	9.80	0.37
HBI <sup>4</sup>	4.89 ( $\pm$ 0.89)	0.62	0.79	0.16
Shannon Diversity Index	2.48 ( $\pm$ 0.19)	0.03	0.17	0.07
%EPT richness	67.11	na	na	na
MTI	2.20 ( $\pm$ 0.25)	0.05	0.22	0.10
EPT taxa	17.67 ( $\pm$ 2.85)	6.33	2.52	0.14
%EPT organisms	39.00 ( $\pm$ 13.00)	1.00	11.00	0.28
% Chironomidae	54.00 ( $\pm$ 14.00)	2.00	12.00	0.23

<sup>1</sup>Taxa richness is the number of taxa per sample.

<sup>2</sup>EPT richness is the number of Ephemeroptera, Plecoptera, and Trichoptera taxa in a sample.

<sup>3</sup>cg and fg is the number of collector-gatherer and filter-gatherer taxa; <sup>4</sup> HBI is Hilsenhoff Biotic Index

Table 7. Mean ( $\pm$  95% C.I.), variance, standard deviation (s. d.), and coefficient of variation (CV) for metrics calculated for Pebble Creek, 1995 site km 6.5 (N=3).

metric	mean ( $\pm$ 95% C.I.)	variance	s. d.	CV
# of organisms	429.00 ( $\pm$ 137.49)	14763.00	121.50	0.28
taxa richness <sup>1</sup>	28.33 ( $\pm$ 2.85)	6.33	2.52	0.09
EPT richness <sup>2</sup>	21.00 ( $\pm$ 1.13)	1.00	1.00	0.05
# of Plecoptera taxa	4.67 ( $\pm$ 0.66)	0.33	0.58	0.12
# of Ephemeroptera taxa	10.33 ( $\pm$ 0.66)	0.33	0.58	0.06
# of Trichoptera taxa	6.00 ( $\pm$ 0.00)	0.00	0.00	0.00
# of shredder taxa	1.00 ( $\pm$ 0.00)	0.00	0.00	0.00
# of scraper taxa	5.67 ( $\pm$ 0.65)	0.33	0.58	0.10
# of cg and fg taxa <sup>3</sup>	7.67 ( $\pm$ 1.73)	2.33	1.53	0.20
# of predator taxa	7.67 ( $\pm$ 1.31)	1.33	1.15	0.15
% shredder taxa	4.00 ( $\pm$ 0.00)	0.00	0.00	0.09
% scraper taxa	20.00 ( $\pm$ 3.00)	0.00	3.00	0.13
%cg and fg taxa	28.00 ( $\pm$ 9.00)	1.00	8.00	0.28
% predator taxa	27.00 ( $\pm$ 5.00)	0.00	5.00	0.18
% dominant taxa	13.50 ( $\pm$ 1.47)	1.69	1.30	0.10
HBI <sup>4</sup>	0.78 ( $\pm$ 0.03)	0.00	0.03	0.04
Shannon Diversity Index	2.74 ( $\pm$ 0.02)	0.00	0.02	0.01
%EPT richness	74.30 ( $\pm$ 3.43)	0.09	3.03	0.04
% EPT organisms	93.00 ( $\pm$ 3.00)	0.00	3.00	0.03
% Chironomidae	4.00 ( $\pm$ 2.00)	0.00	2.00	0.44

<sup>1</sup>Taxa richness is the number of taxa per sample.

<sup>2</sup>EPT richness is the number of Ephemeroptera, Plecoptera, and Trichoptera taxa in a sample.

<sup>3</sup>cg and fg is the number of collector-gatherer and filter-gatherer taxa

<sup>4</sup> HBI is Hilsenhoff Biotic Index

Table 8. Mean ( $\pm$  95% CI), variance, standard deviation (s. d.), and coefficient of variation (CV) for metrics calculated for Pebble Creek, site km 9 (N=3).

metric	mean ( $\pm$ 95% C.I.)	variance	s.d.	CV
# of organisms	483.67 ( $\pm$ 63.26)	3124.33	55.90	0.12
taxa richness <sup>1</sup>	28.33 ( $\pm$ 3.64)	10.33	3.21	0.11
EPT richness <sup>2</sup>	22.67 ( $\pm$ 1.31)	1.33	1.15	0.05
# of Plecoptera taxa	5.00 ( $\pm$ 1.13)	1.00	1.00	0.20
# of Ephemeroptera taxa	11.00 ( $\pm$ 1.13)	1.00	1.00	0.09
# of Trichoptera taxa	6.67 ( $\pm$ 1.73)	2.33	1.53	0.23
# of shredder taxa	1.33 ( $\pm$ 0.65)	0.33	0.58	0.43
# of scraper taxa	5.00 ( $\pm$ 0.00)	0.00	0.00	0.00
# of cg and fg taxa <sup>3</sup>	8.33 ( $\pm$ 0.65)	0.33	0.58	0.07
# of predator taxa	7.33 ( $\pm$ 1.31)	1.33	1.15	0.16
% shredder taxa	5.00 ( $\pm$ 2.00)	0.00	0.01	0.31
% scraper taxa	18.00 ( $\pm$ 2.00)	0.00	2.00	0.11
% cg and fg taxa	30.00 ( $\pm$ 5.00)	0.00	4.00	0.14
% predator taxa	26.00 ( $\pm$ 4.00)	0.00	3.00	0.13
% dominant taxa	27.40 ( $\pm$ 6.89)	37.03	6.08	0.22
HBI <sup>4</sup>	1.65 ( $\pm$ 0.06)	0.00	0.05	0.15
Shannon Diversity Index	2.56 ( $\pm$ 0.09)	0.01	0.08	0.03
%EPT richness	80.37 ( $\pm$ 5.55)	0.24	4.90	0.06
%EPT organisms	89.00 ( $\pm$ 2.00)	0.00	2.00	0.02
% Chironimidae	9.00 ( $\pm$ 2.00)	0.00	2.00	0.22

<sup>1</sup>Taxa richness is the number of taxa per sample.

<sup>2</sup>EPT richness is the number of Ephemeroptera, Plecoptera, and Trichoptera taxa in a sample.

<sup>3</sup>cg and fg is the number of collector-gatherer and filter-gatherer taxa

<sup>4</sup>HBI is Hilsenhoff Biotic Index

Table 9. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Pebble Creek, site km 13 (N=3).

metric	mean ( $\pm$ 95% C.I.)	variance	s.d.	CV
# of organisms	241.67 ( $\pm$ 39.14)	1196.33	34.59	0.14
taxa richness <sup>1</sup>	23.67 ( $\pm$ 2.61)	5.33	2.31	0.10
EPT richness <sup>2</sup>	18.33 ( $\pm$ 1.31)	1.33	1.15	0.06
# of Plecoptera taxa	2.33 ( $\pm$ 0.66)	0.33	0.58	0.25
# of Ephemeroptera taxa	9.67 ( $\pm$ 1.30)	1.33	1.15	0.12
# of Trichoptera taxa	6.33 ( $\pm$ 0.66)	0.33	0.58	0.09
# of shredder taxa	1.00 ( $\pm$ 0.00)	0.00	0.00	0.00
# of scraper taxa	5.33 ( $\pm$ 0.65)	0.33	0.58	0.11
# of cg and fg taxa <sup>3</sup>	6.67 ( $\pm$ 0.65)	0.33	0.58	0.09
# of predator taxa	5.00 ( $\pm$ 1.13)	1.00	1.00	0.20
% shredder taxa	4.00 ( $\pm$ 0.00)	0.00	0.00	0.00
% scraper taxa	23.00 ( $\pm$ 3.00)	0.00	2.00	0.10
% cg + fg taxa	28.00 ( $\pm$ 0.00)	0.00	0.00	0.01
% predator taxa	21.00 ( $\pm$ 5.00)	0.00	5.00	0.21
% dominant taxa	18.73 ( $\pm$ 2.36)	4.36	2.09	0.11
HBI <sup>4</sup>	1.04 ( $\pm$ 0.28)	0.06	0.25	0.24
Shannon Diversity Index	2.61 ( $\pm$ 0.10)	0.01	0.09	0.03
% EPT taxa	77.44 ( $\pm$ 6.10)	0.25	4.81	0.08
% EPT organisms	89.00 ( $\pm$ 3.00)	0.00	3.00	0.03
% Chironimidae	5.00 ( $\pm$ 3.00)	0.00	3.00	0.54

<sup>1</sup>Taxa richness is the number of taxa per sample.

<sup>2</sup>EPT richness is the number of Ephemeroptera, Plecoptera, and Trichoptera taxa in a sample.

<sup>3</sup>cg and fg is the number of collector-gatherer and filter-gatherer taxa

<sup>4</sup>HBI is Hilsenhoff Biotic Index

Table 10. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Pebble Creek, site km 16 (N=3).

metric	mean ( $\pm$ 95% C.I.)	variance	s.d.	CV
# of organisms	156.33 ( $\pm$ 51.32)	2056.33	45.35	0.29
taxa richness <sup>1</sup>	24.67 ( $\pm$ 1.73)	2.33	1.53	0.06
EPT richness <sup>2</sup>	21.67 ( $\pm$ 1.73)	2.33	1.53	0.07
# of Plecoptera taxa	4.67 ( $\pm$ 0.66)	0.33	0.58	0.12
# of Ephemeroptera taxa	11.00 ( $\pm$ 1.13)	1.00	1.00	0.09
# of Trichoptera taxa	6.00 ( $\pm$ 1.13)	1.00	1.00	0.17
# of shredder taxa	1.00 ( $\pm$ 0.00)	0.00	0.00	0.00
# of scraper taxa	3.67 ( $\pm$ 0.65)	0.33	0.58	0.16
# of cg and fg taxa <sup>3</sup>	9.67 ( $\pm$ 0.65)	0.33	0.58	0.06
# of predator taxa	7.00 ( $\pm$ 0.00)	0.00	0.00	0.00
% shredder taxa	4.00 ( $\pm$ 0.00)	0.00	0.00	0.06
% scraper taxa	15.00 ( $\pm$ 2.00)	0.00	2.00	0.11
%cg and fg taxa	39.00 ( $\pm$ 4.00)	0.00	4.00	0.10
% predator taxa	28.00 ( $\pm$ 2.00)	0.00	2.00	0.06
% dominant taxa	11.70 ( $\pm$ 1.46)	1.66	1.29	0.11
HBI <sup>4</sup>	1.11 ( $\pm$ 0.42)	14.00	37.00	0.33
Shannon Diversity Index	2.89 ( $\pm$ 0.08)	0.00	0.07	0.02
% EPT richness	87.84 ( $\pm$ 3.67)	1.39	2.43	0.08
%EPT organisms	82.00 ( $\pm$ 3.00)	0.00	2.00	0.03
% Chironimidae	11.00 ( $\pm$ 2.00)	0.00	0.02	0.15

<sup>1</sup>Taxa richness is the number of taxa per sample.

<sup>2</sup>EPT richness is the number of Ephemeroptera, Plecoptera, and Trichoptera taxa in a sample.

<sup>3</sup>cg and fg is the number of collector-gatherer and filter-gatherer taxa

<sup>4</sup>HBI is Hilsenhoff Biotic Index

Using the mean and 95% CI for within-stream metric comparison, the number of organisms per sample in Pebble Creek decreased from headwaters downstream, with km 2 being most variable (Figure 3). Taxa richness was highest in the mid-reach C-type channels (Rosgen method), km 6.5, and km 9 (Figure 4). Number of EPT (Figure 5) taxa increased downstream. Number of Ephemeroptera taxa increased in a downstream direction (Figure 6). Number of Plecoptera taxa was highest in the mid-reach C-type channels, km 6.5 and km 9 (Figure 7). Number of Trichoptera taxa was fairly constant throughout Pebble Creek, with km 4 having the highest value of 9 taxa (Figure 8). The number of shredder taxa was consistent at one taxon with little variability (Figure 9). Number of scraper taxa was highest in the mid-reaches of Pebble Creek (sites km 6.5 and km 9)(Figure 10). Number of collector-gatherer and filter-gatherer taxa increased from the upstream to downstream sites (Figure 11). Number of predator taxa did not show any trend for the sites (Figure 12). Percent shredder taxa was 3% to 7% (95% CI) throughout Pebble Creek (Figure 13). Percent scraper taxa increased downstream except for a decrease at km 16 (Figure 14). Percent collector-gatherer and filterer-gatherer taxa increased downstream (Figure 15). Percent predator taxa was fairly constant throughout (Figure 16). Percent dominant taxa was highly variable within-sites and between sites (Figure 17). Percent Chironomidae organisms was highest and most variable at km 2 and decreased markedly downstream (Figure 18). Percent EPT taxa increased sharply from km 2 downstream (Figure 19). Shannon Diversity index also tended to increase downstream (Figure 20). HBI was highest at

km 2 and decreased rapidly downstream with little within-site variability (Figure 21).

The large values of HBI and MTI in site Km 2 and Km 4 were due to the high relative abundance of Chironomidae larvae that were identified to genus and sub-family levels. HBI values for Chironomidae larvae at the genus and sub-family level are based on data from pollution tolerant species and may not reflect pollution tolerances of mountain stream species of Chironomidae larvae within these genera and sub-families.

Figure 3. Mean ( $\pm$  95% CI) number of organisms for six sites from Pebble Creek.

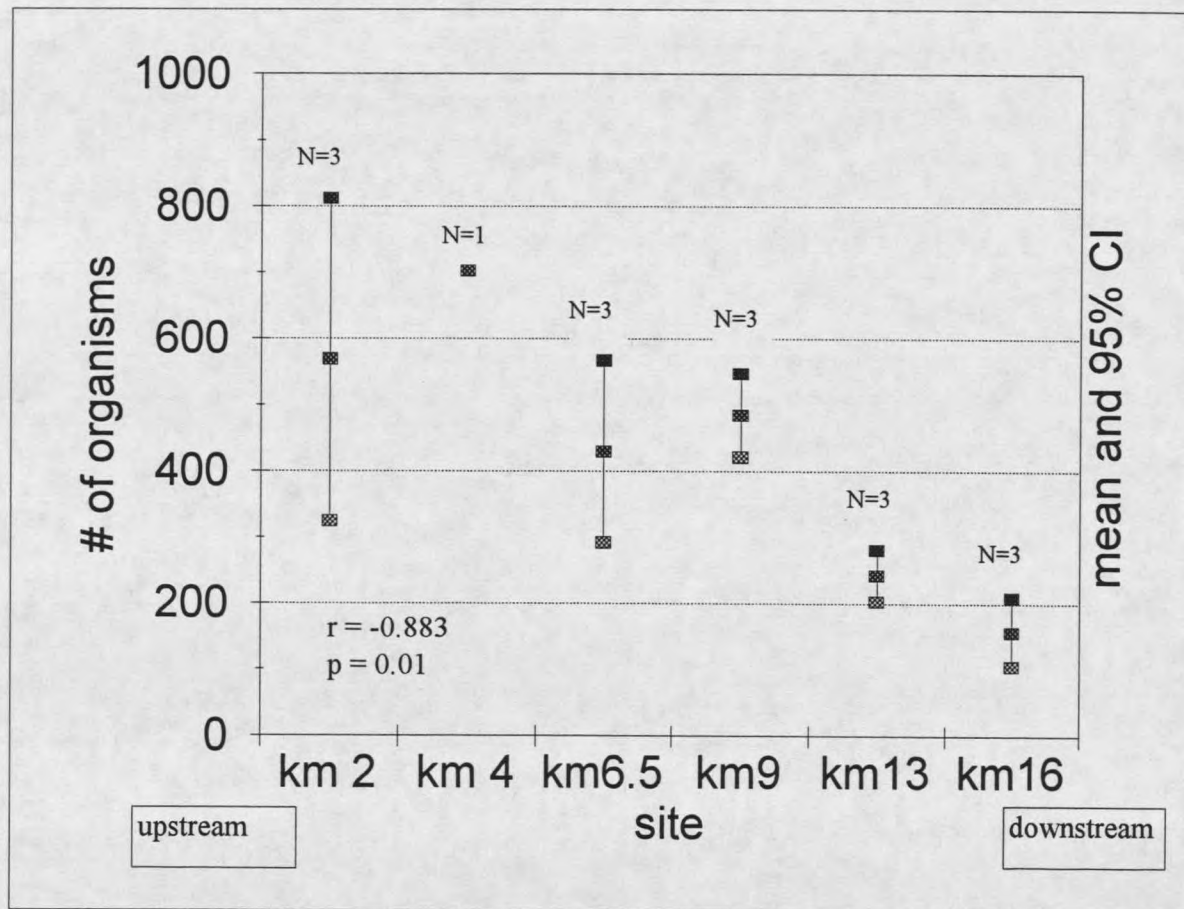


Figure 4. Mean ( $\pm$  95% CI) number of taxa for six sites from Pebble Creek.

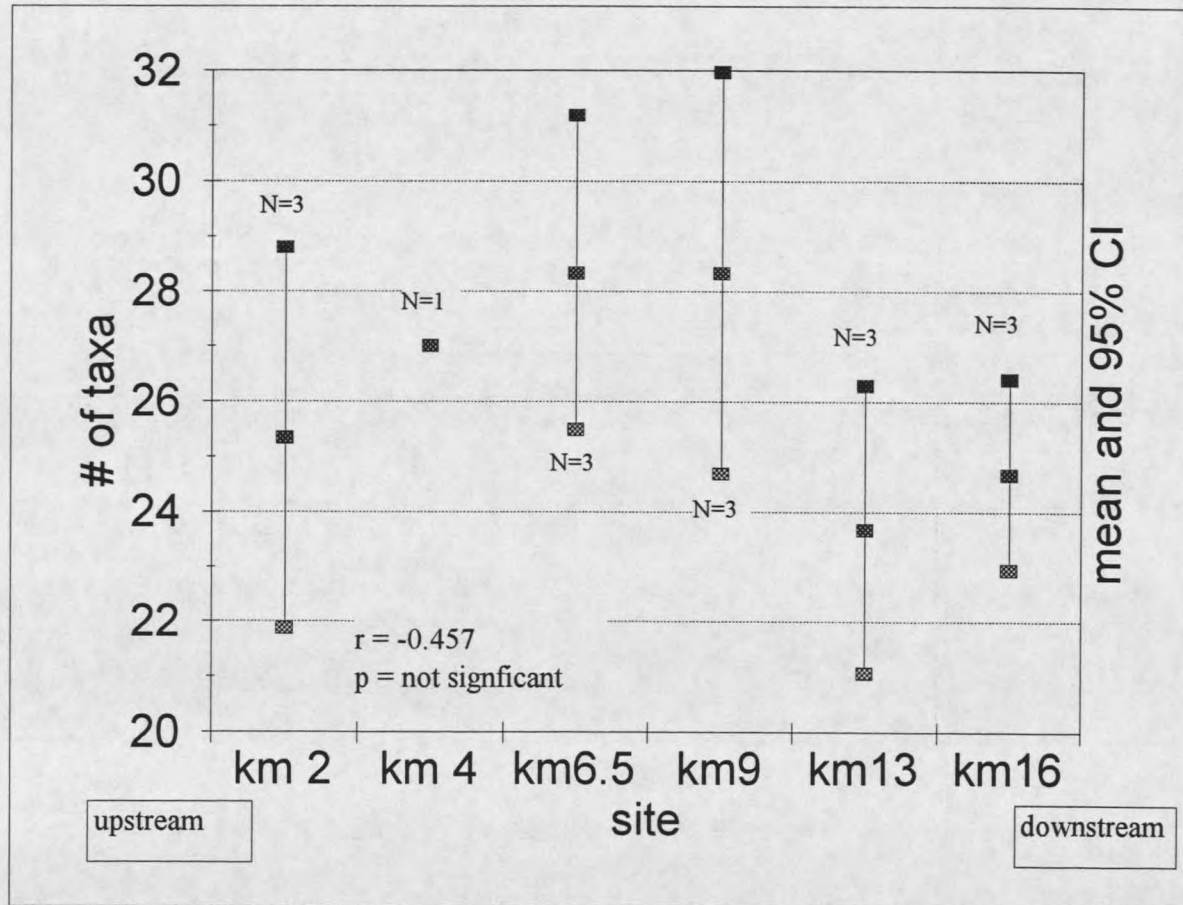


Figure 5. Mean ( $\pm$  95% CI) number of EPT taxa for six sites from Pebble Creek.

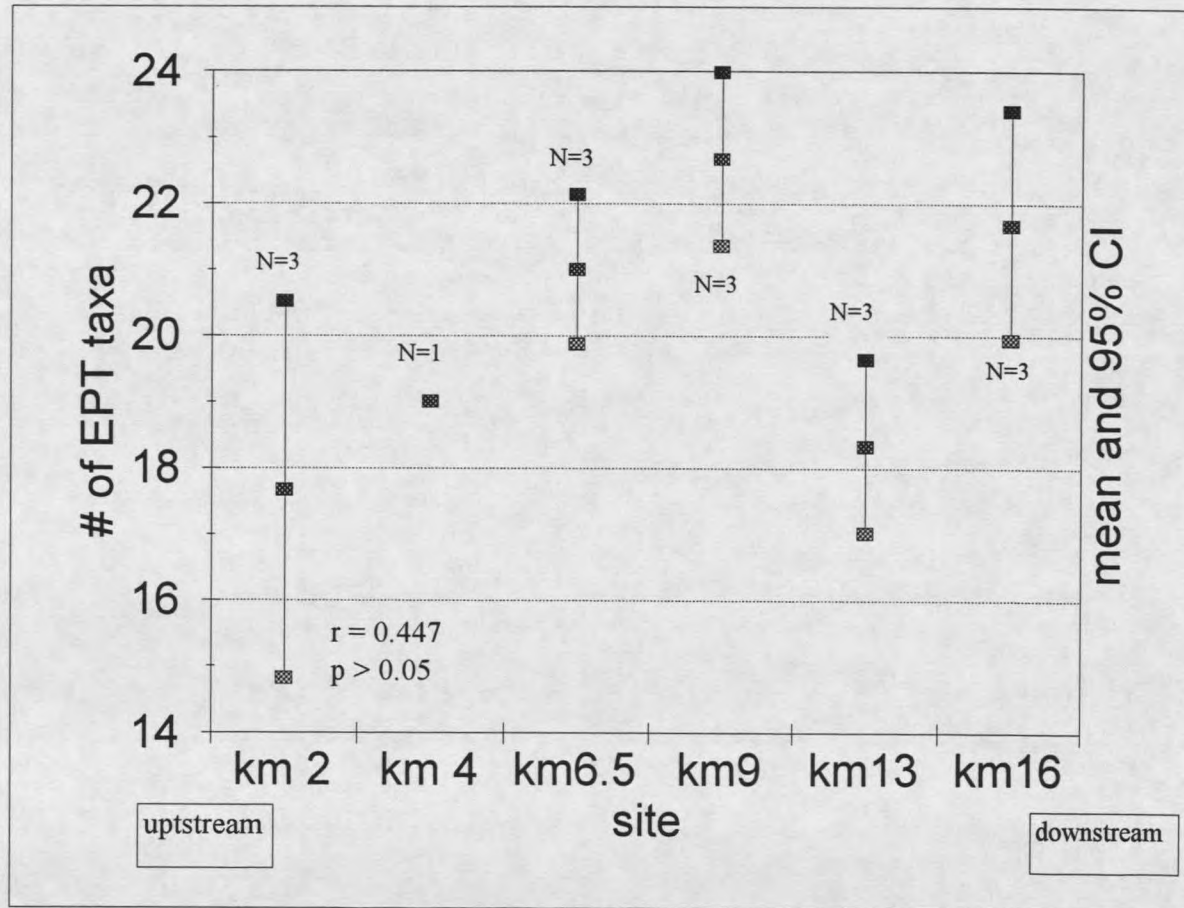


Figure 6. Mean ( $\pm 95\%$  CI) number of Ephemeroptera taxa for six sites from Pebble Creek.

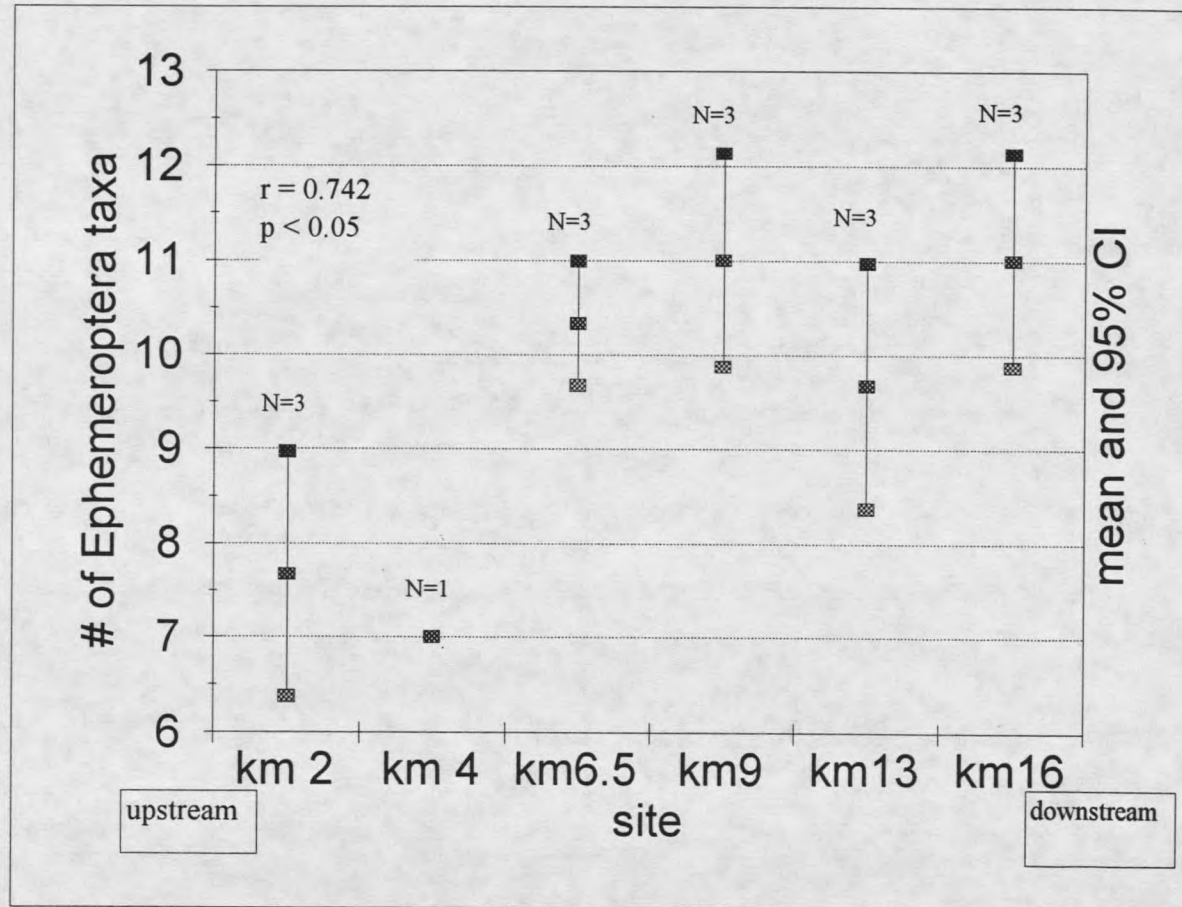


Figure 7. Mean ( $\pm$  95% CI) number of Plecoptera taxa for six sites from Pebble Creek.

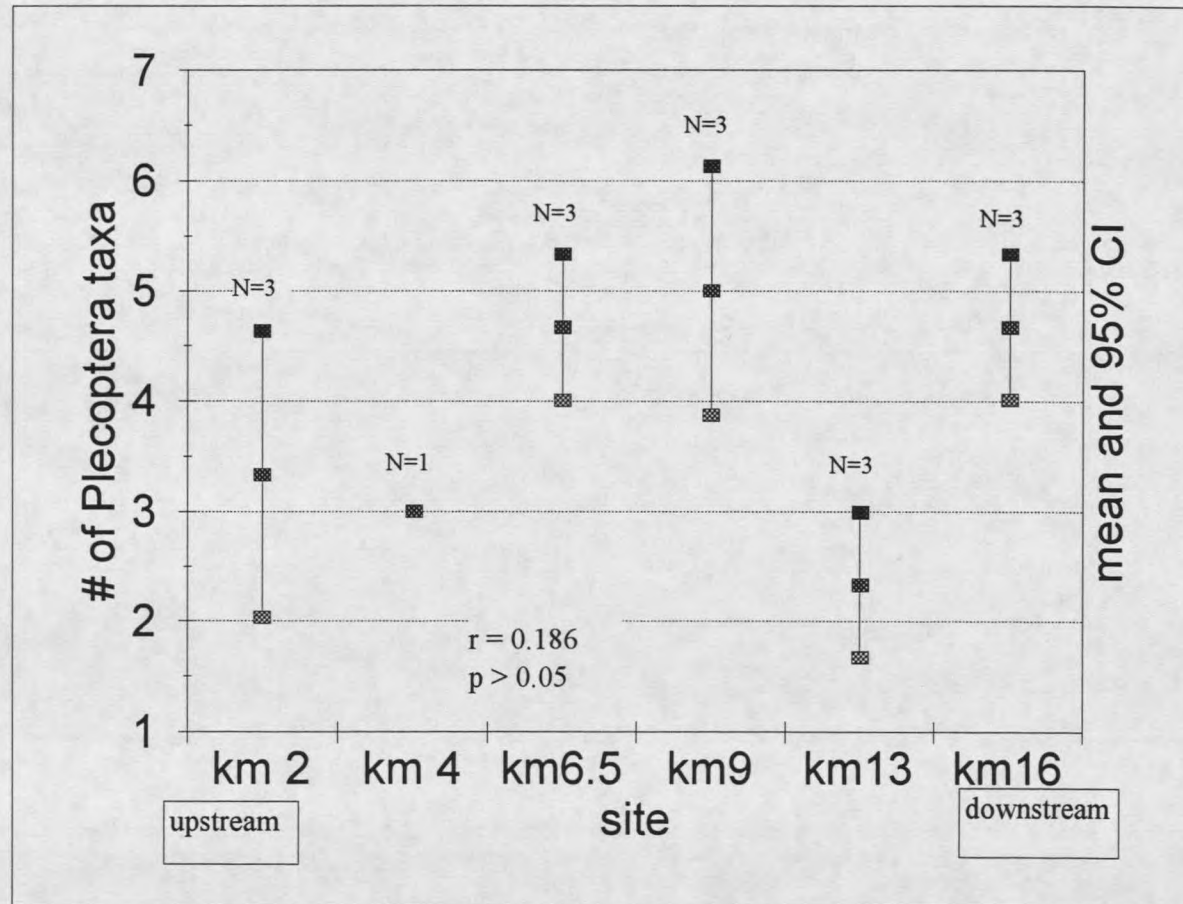


Figure 8. Mean ( $\pm$  95% CI) number of Trichoptera taxa for six sites from Pebble Creek.

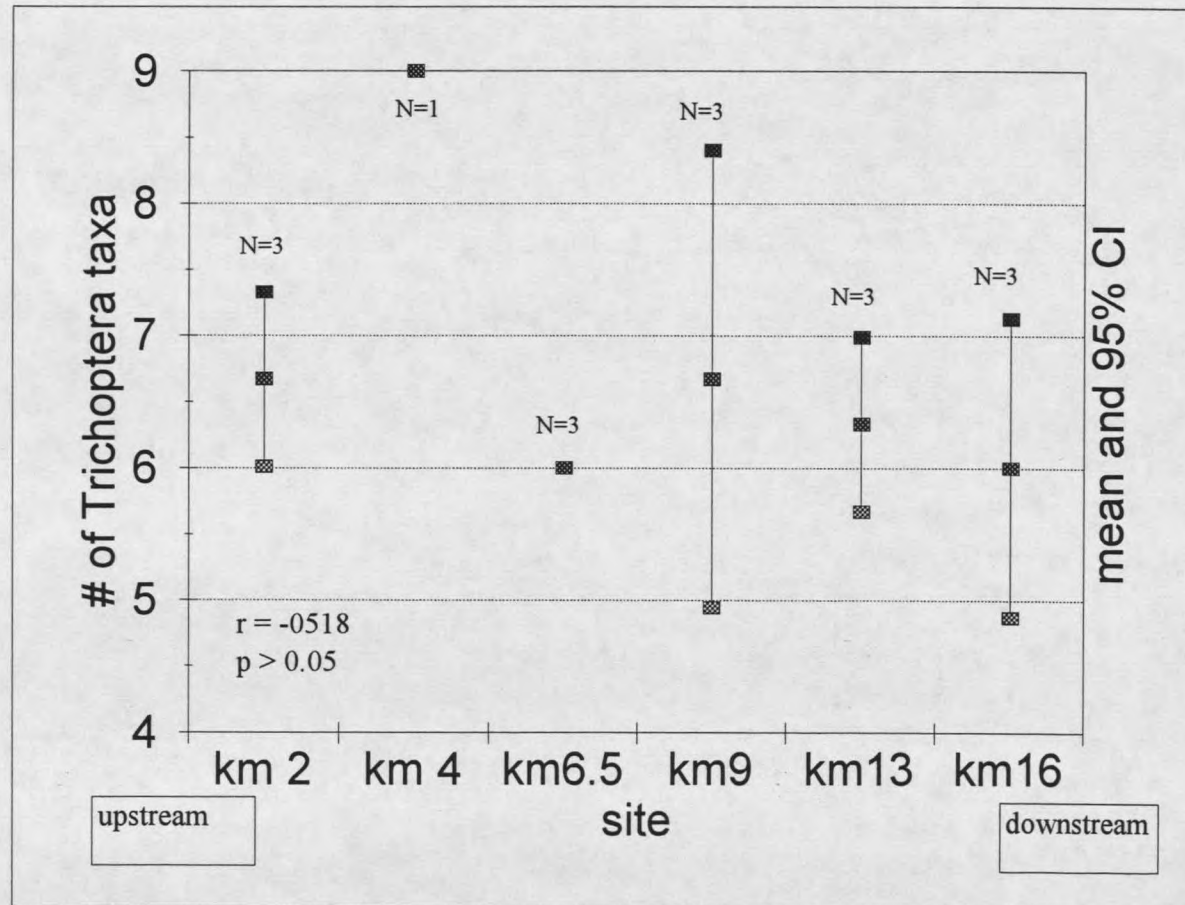


Figure 9. Mean ( $\pm$  95% CI) number of shredder taxa for six sites from Pebble Creek.

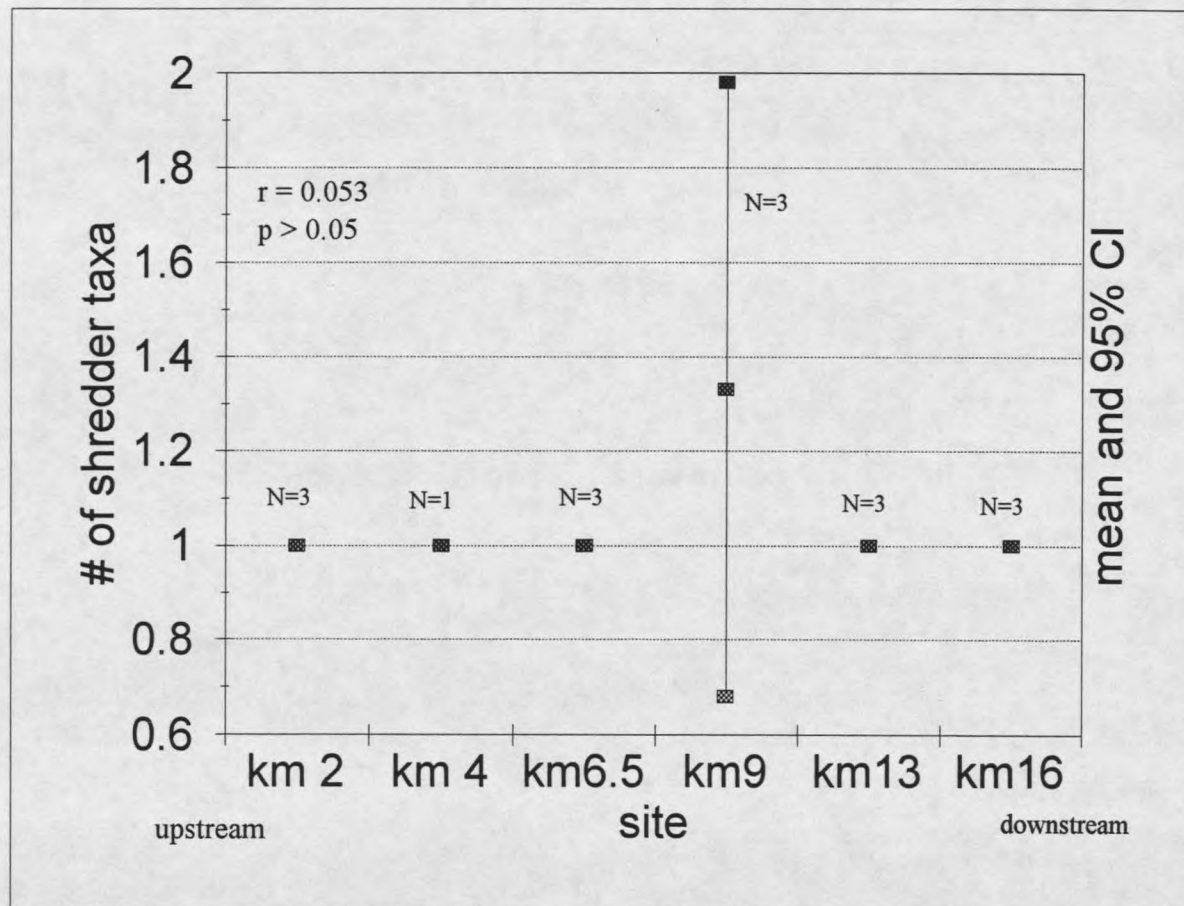


Figure 10. Mean ( $\pm$  95% CI) number of scraper taxa for six sites from Pebble Creek.

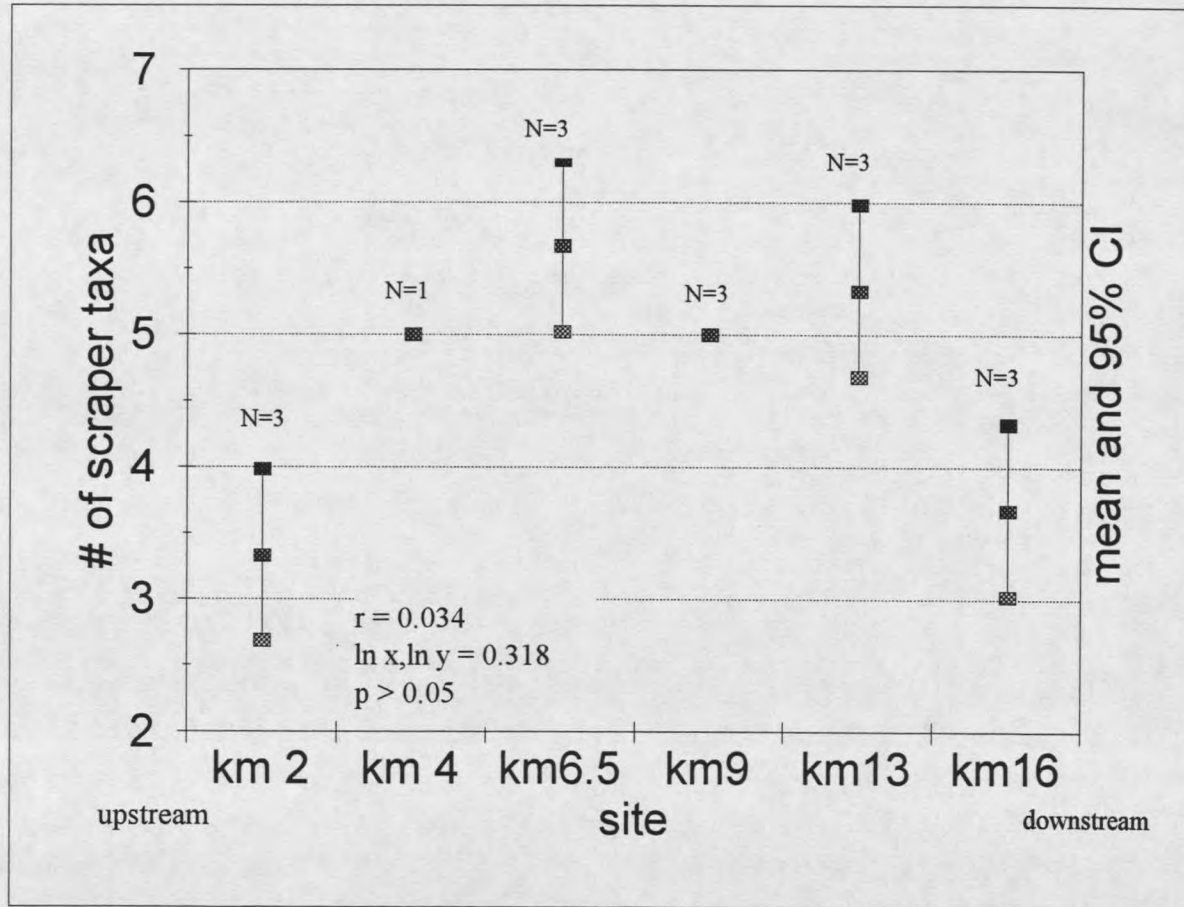


Figure 11. Mean ( $\pm$  95% CI) number of collector-gatherer and filter-gatherer taxa for six sites from Pebble Creek.

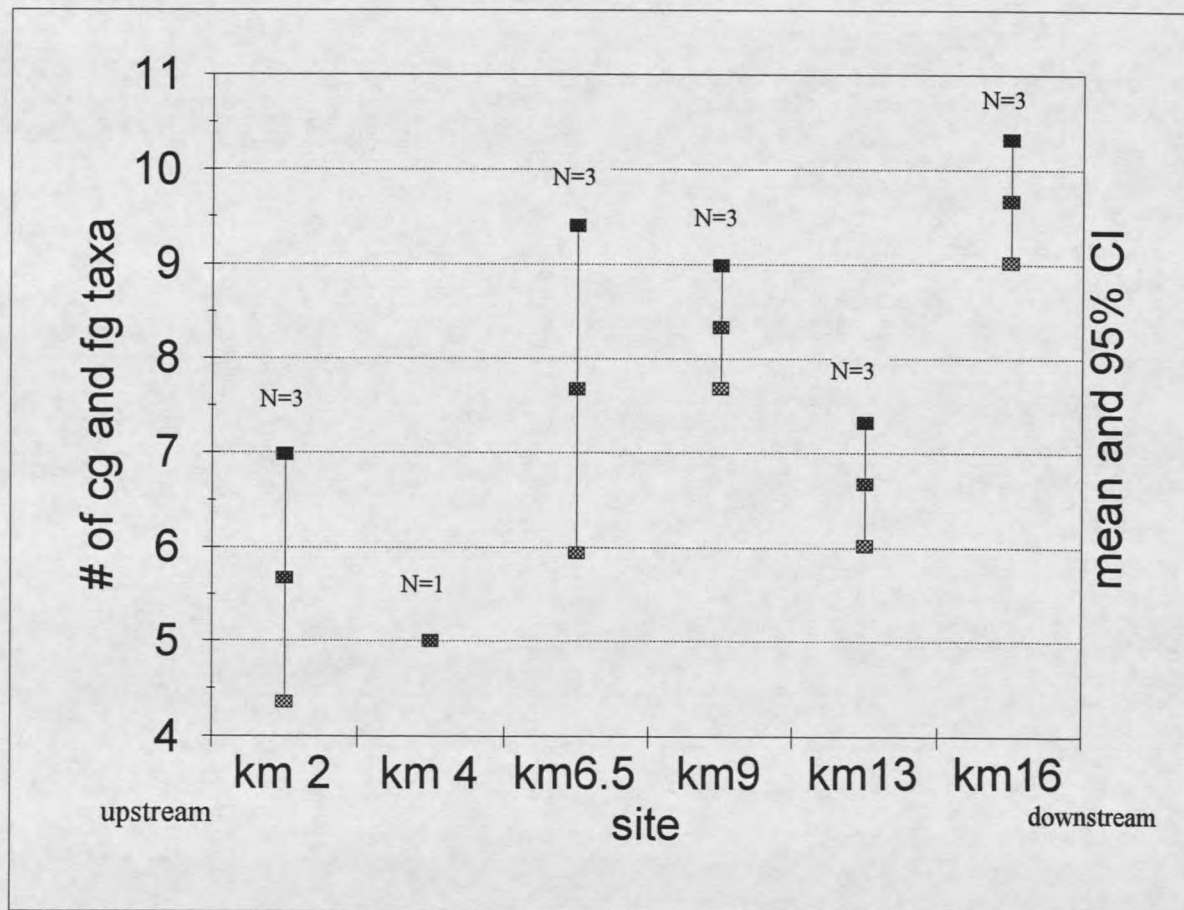


Figure 12. Mean ( $\pm$  95% CI) number of predator taxa for six sites from Pebble Creek.

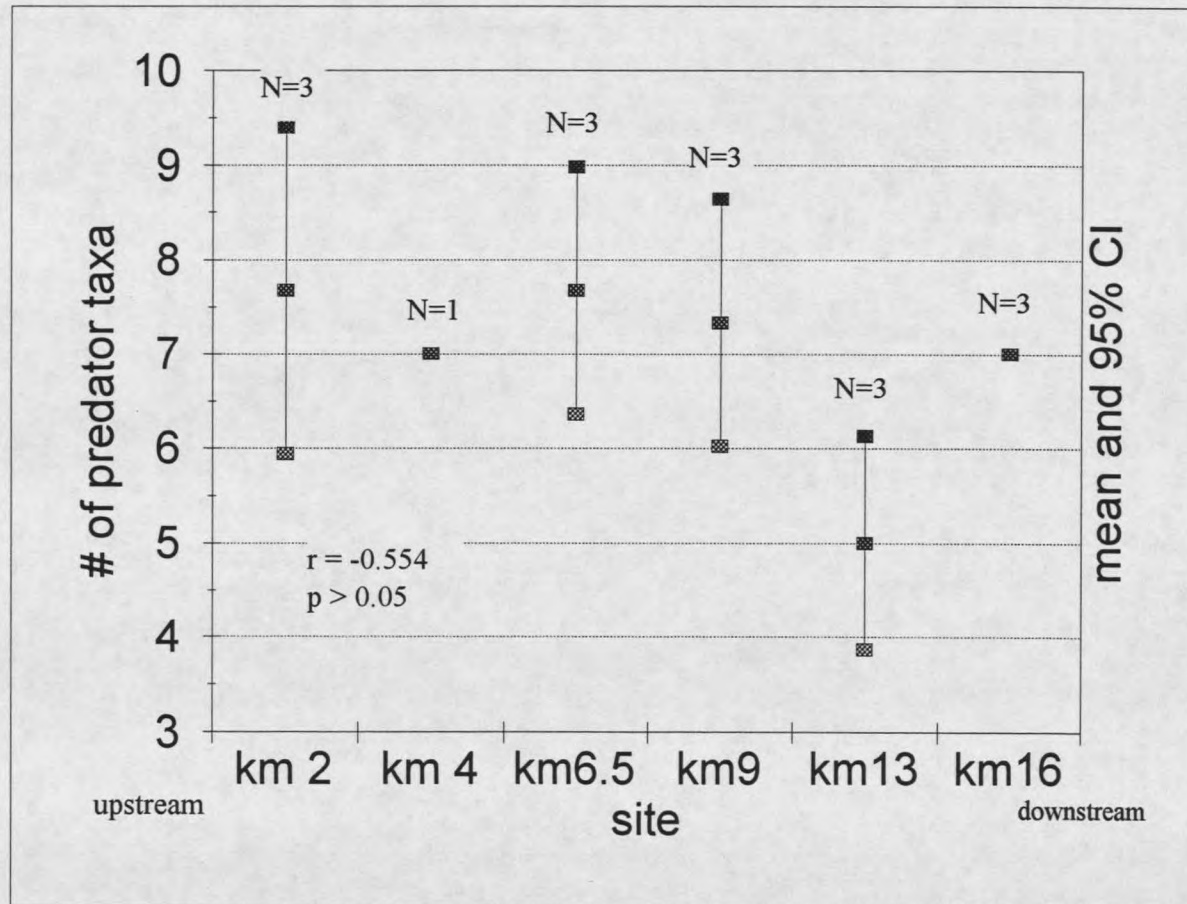


Figure 13. Mean ( $\pm$  95% CI) % shredder taxa for six sites from Pebble Creek.

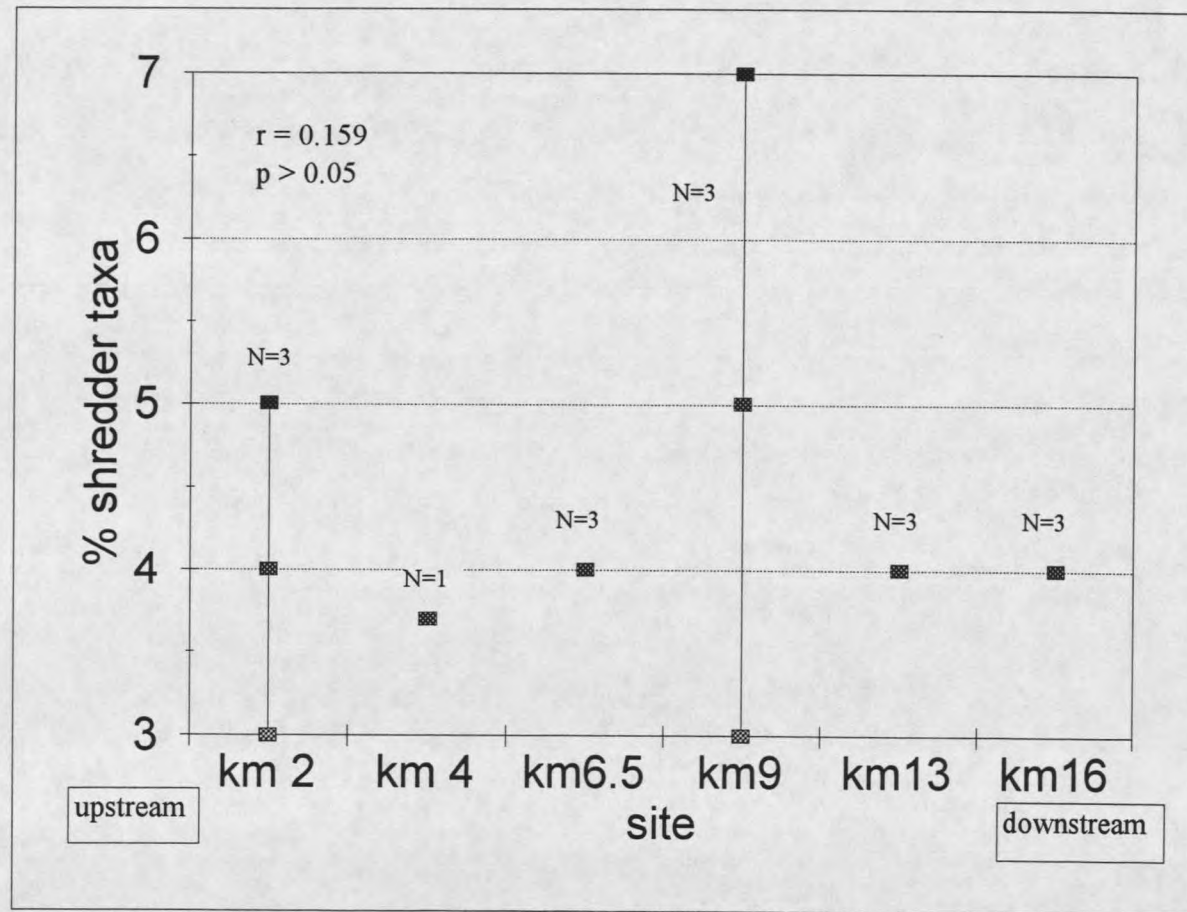


Figure 14. Mean ( $\pm$  95% CI) % scraper taxa for six sites from Pebble Creek.

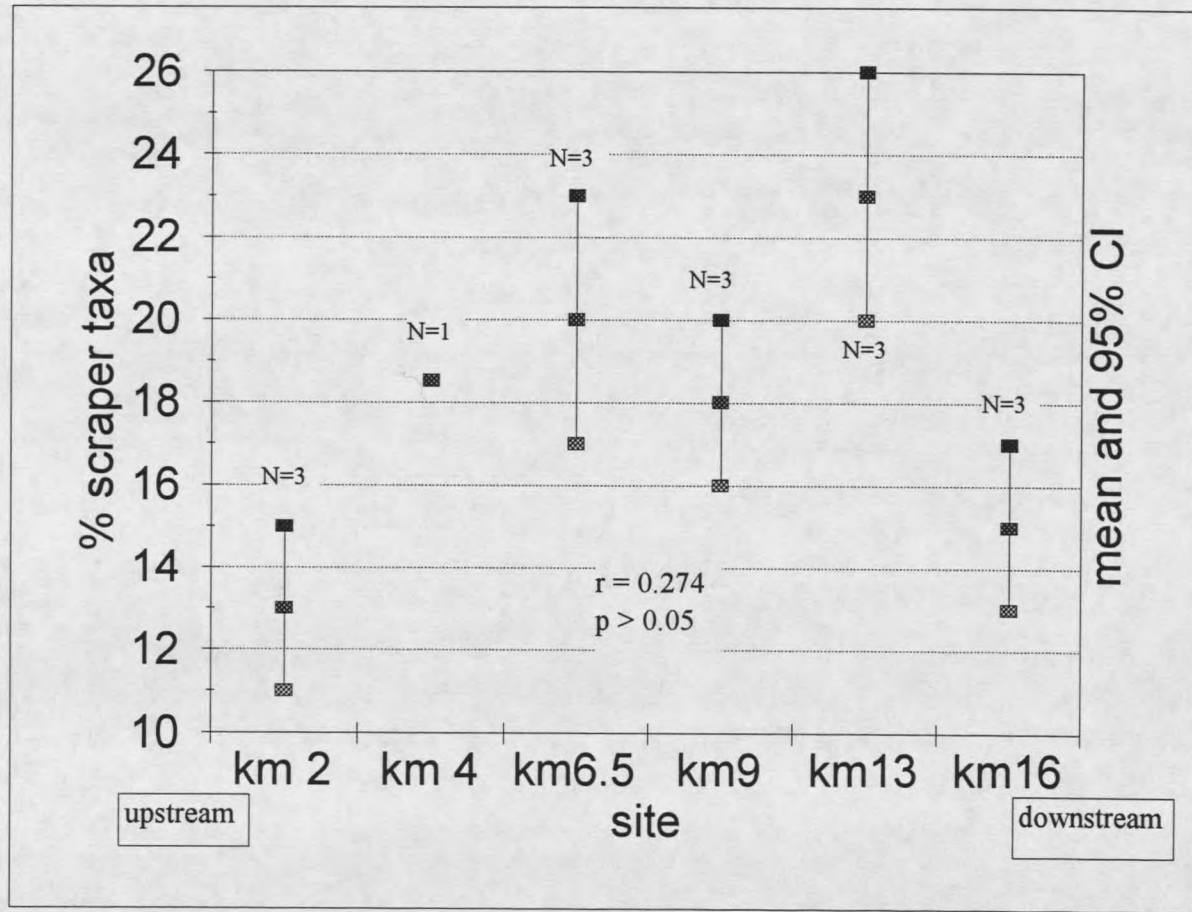


Figure 15. Mean ( $\pm$  95% CI) % collector-gatherer and filter-gatherer taxa for six sites from Pebble Creek.

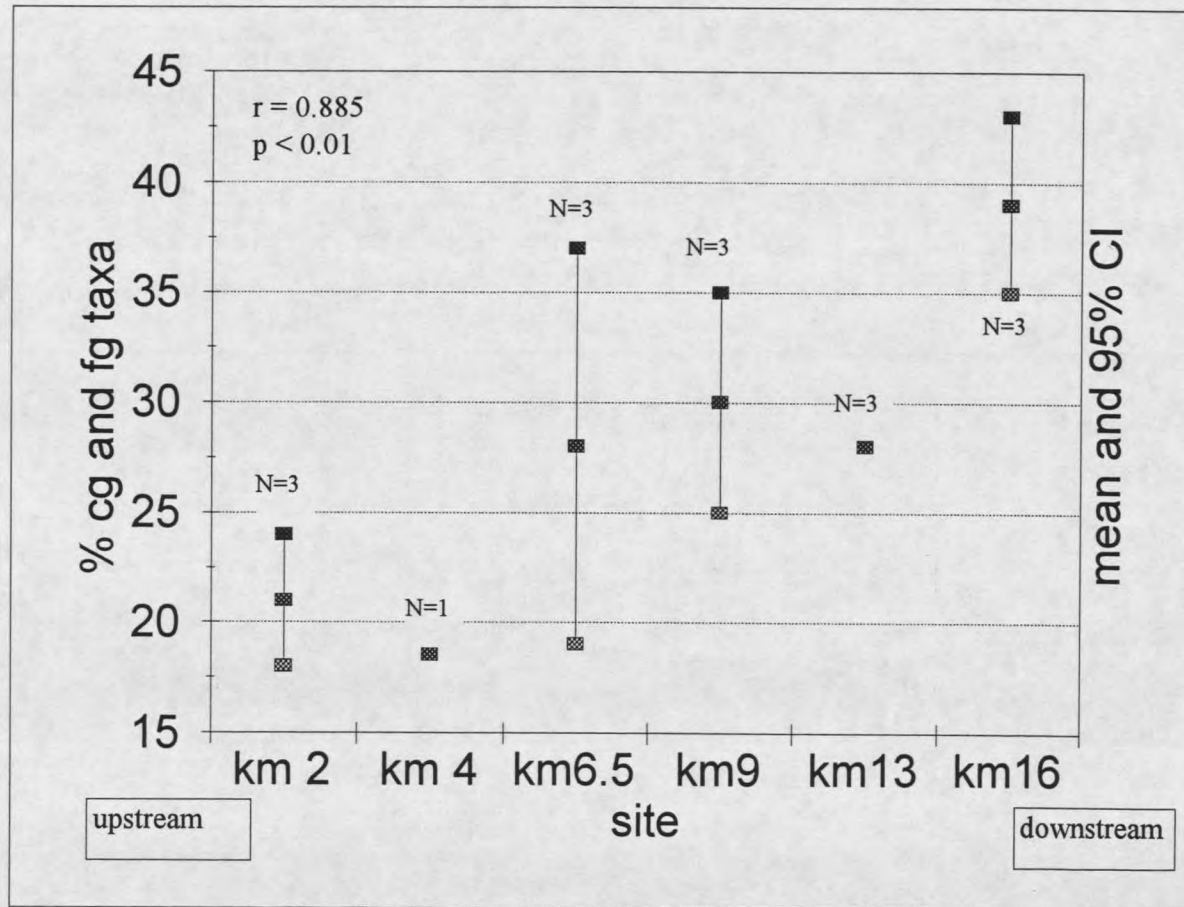


Figure 16. Mean ( $\pm$  95% CI) % predator taxa for six sites from Pebble Creek.

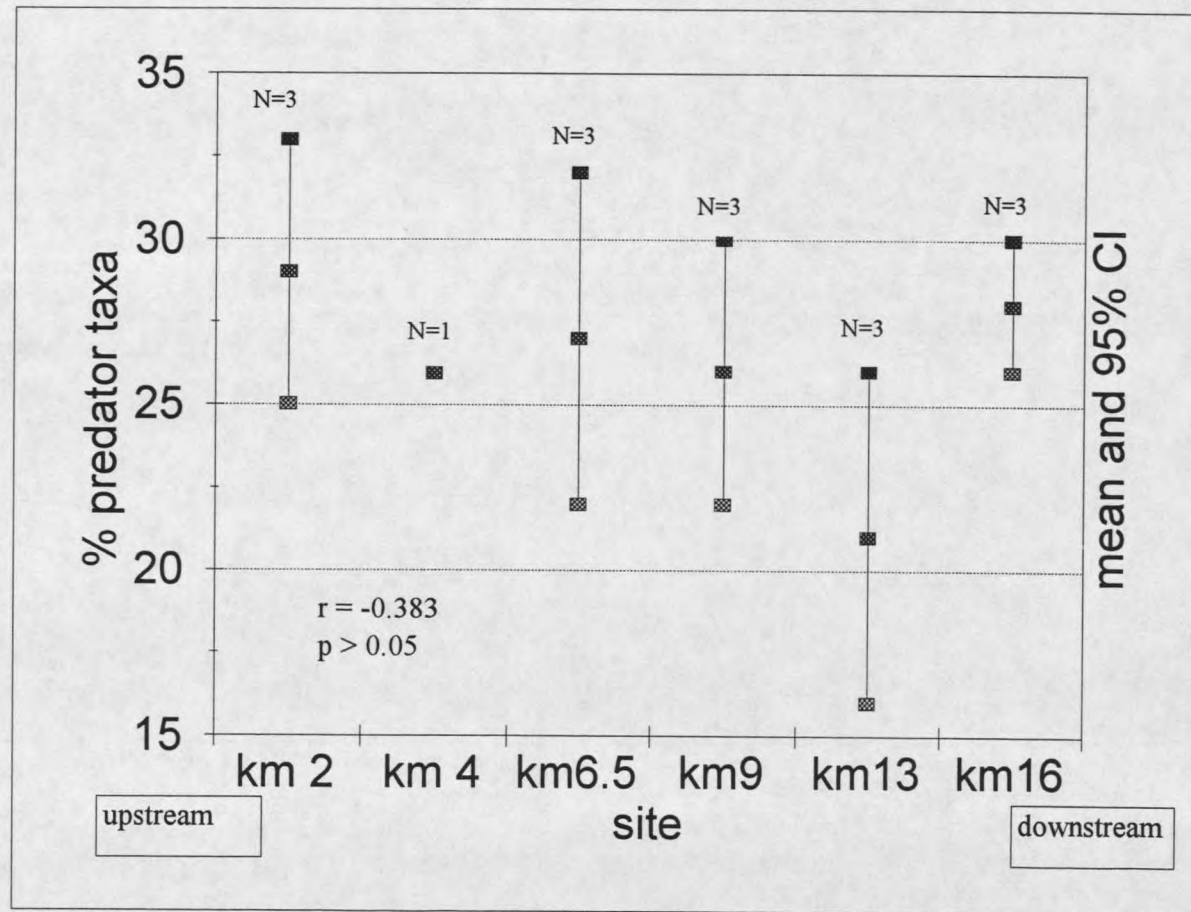


Figure 17. Mean ( $\pm$  95% CI) % dominant taxa for six sites from Pebble Creek.

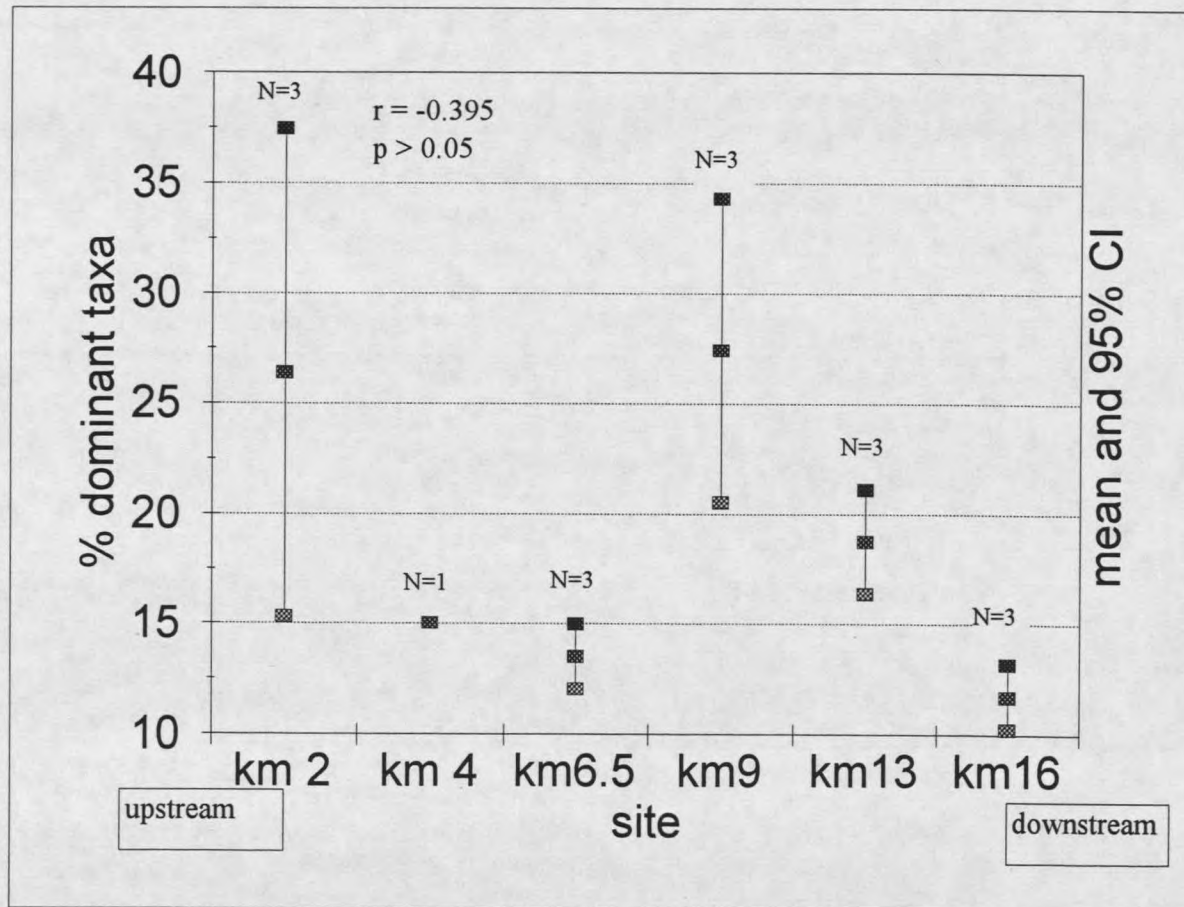


Figure 18. Mean ( $\pm$  95% CI) % Chironomidae organisms for six sites from Pebble Creek.

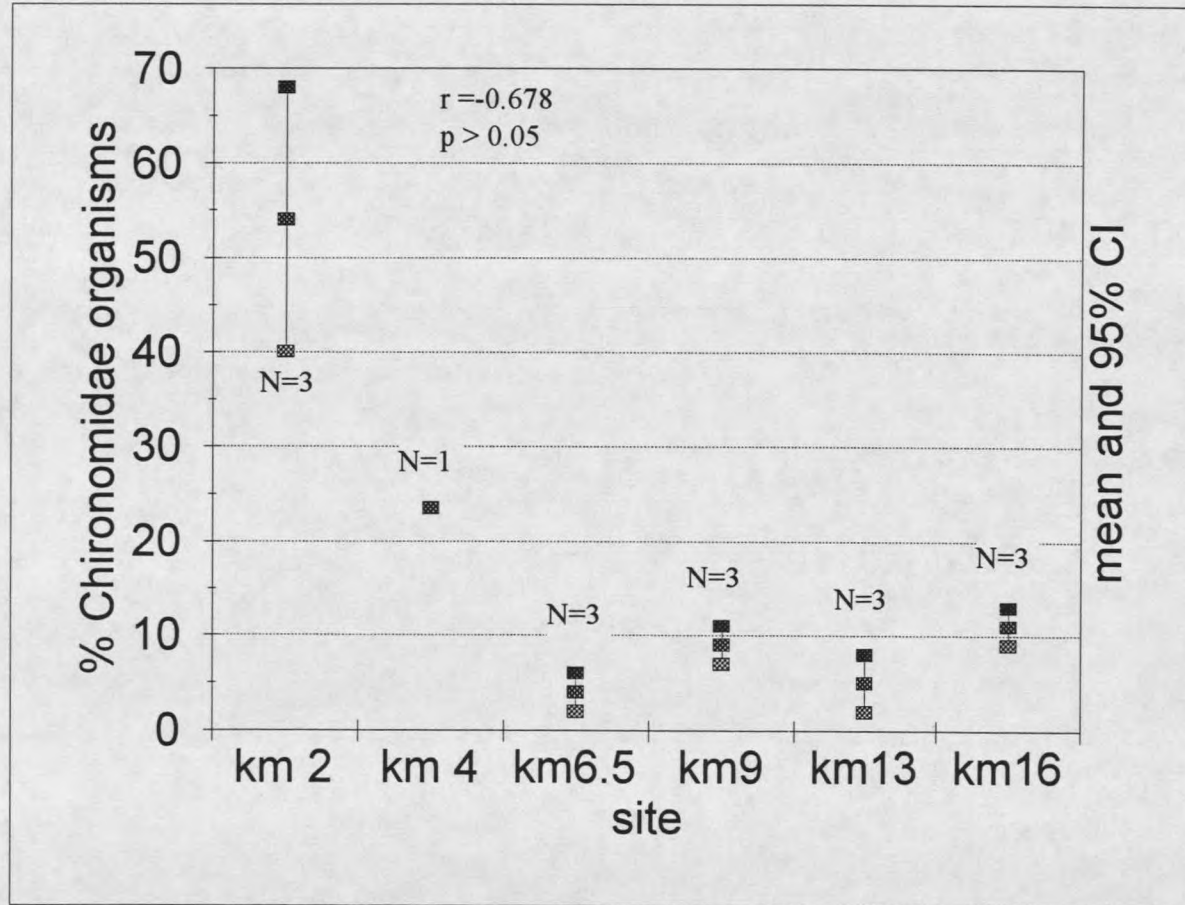


Figure 19. Mean ( $\pm$  95% CI) % EPT taxa for six sites from Pebble Creek.

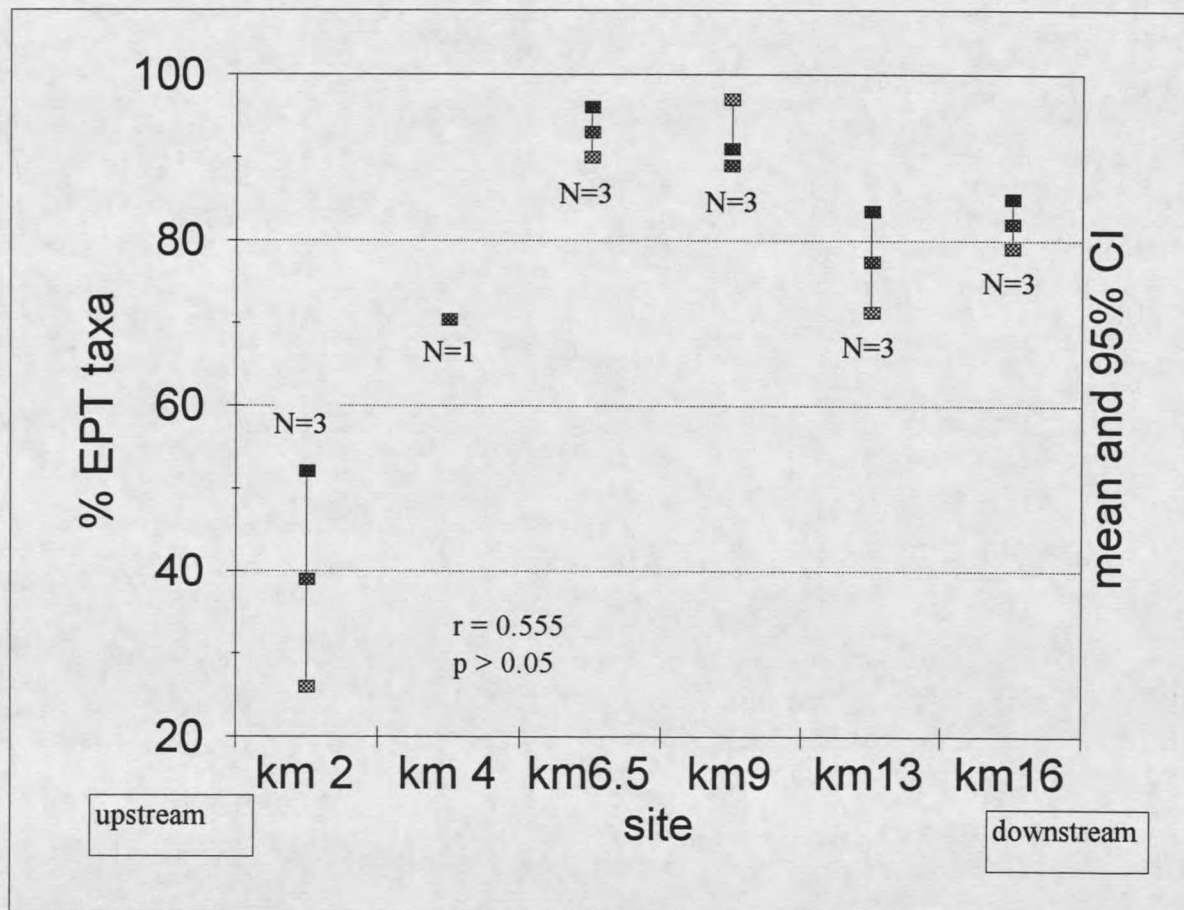


Figure 20. Mean ( $\pm$  95% CI) Shannon Diversity Index values for six sites from Pebble Creek.

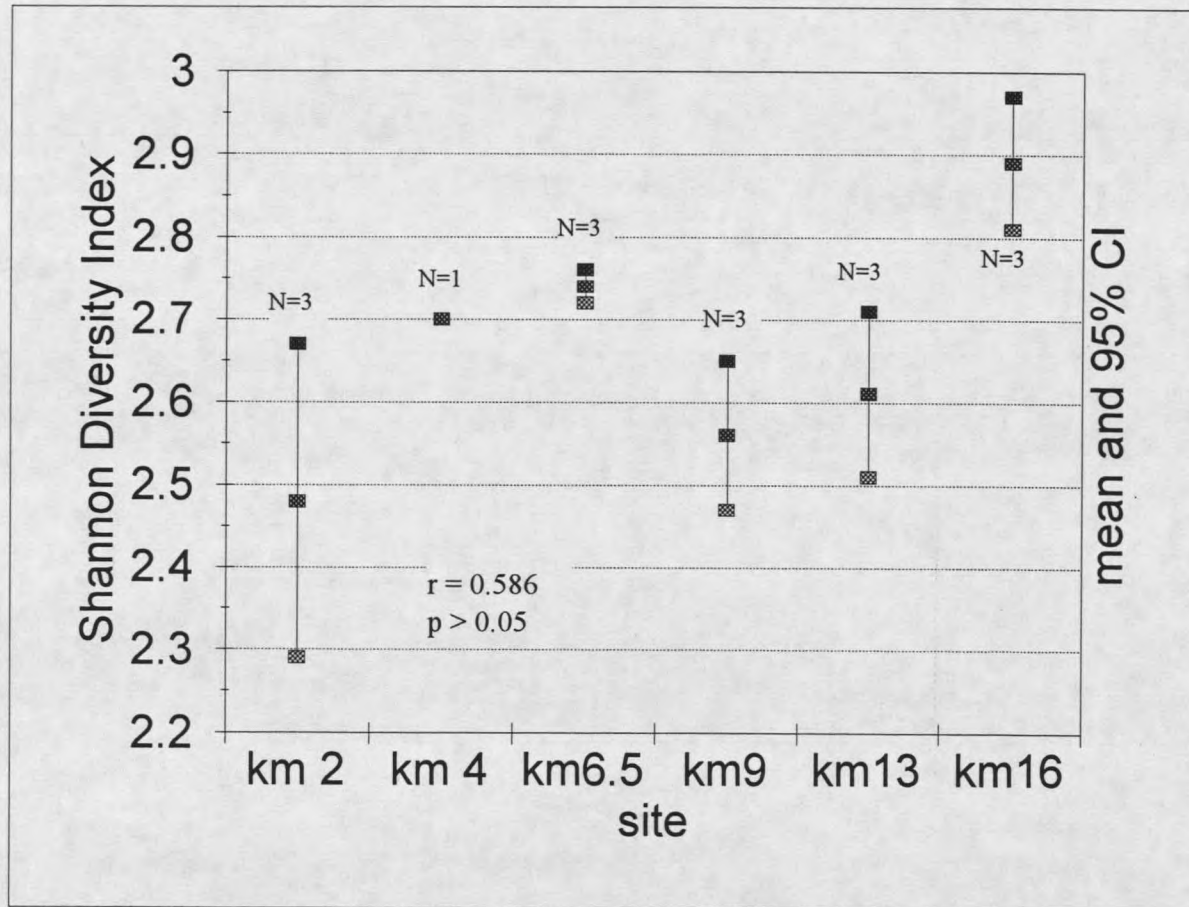
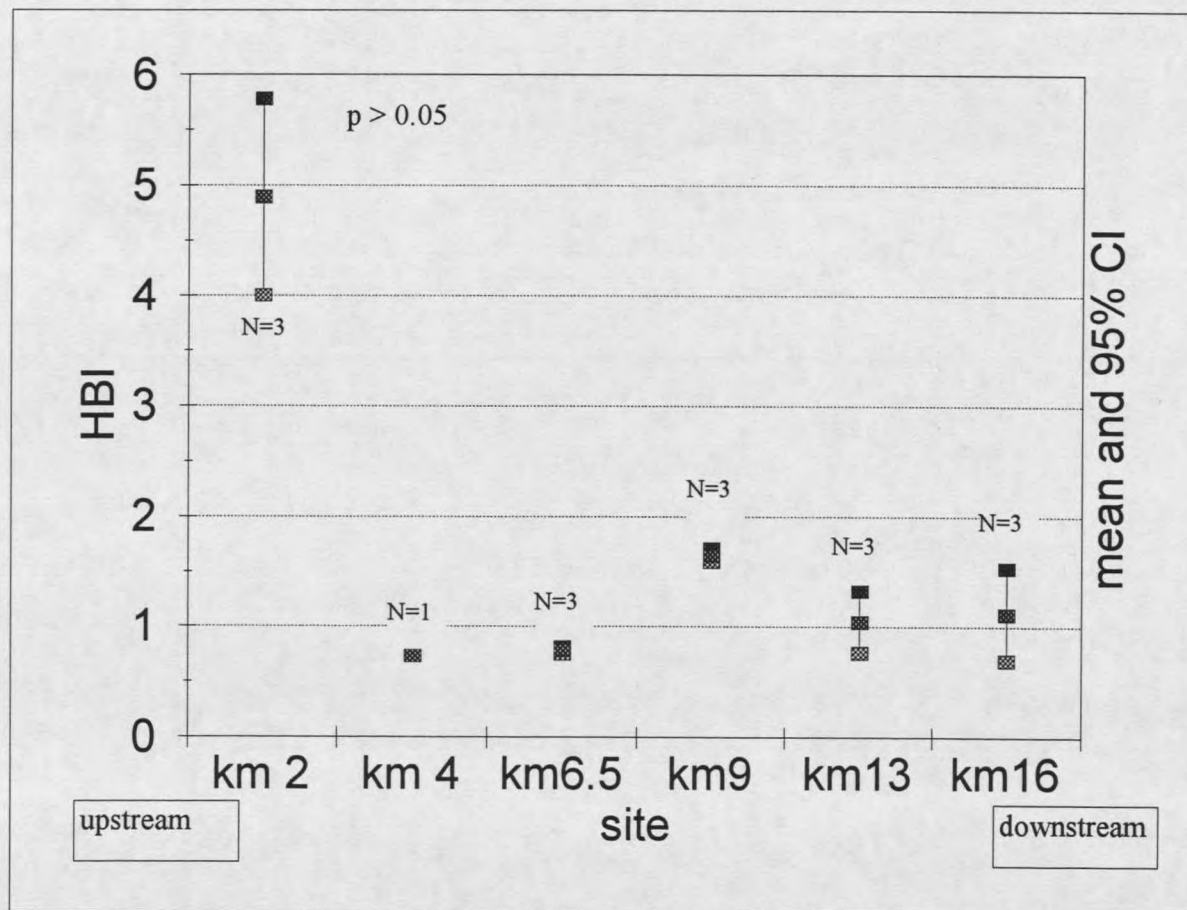


Figure 21. Mean ( $\pm$  95% CI) HBI values for six sites from Pebble Creek.



Seasonal Variability

Bozeman Creek

Results of Principal Components Analysis using raw species abundance data from each sample as a sampling unit from each of four seasons for Bozeman Creek are in Table 11. Graphical analysis using the first two principal component eigenvalues as axis' show that Winter 1995 and Spring 1995 were most similar (Figure 22).

Table 11. Eigenvectors defining the first three principal components from thirteen riffle samples from Bozeman Creek for four seasons using raw species abundance data from each sample as a sampling unit.

Sample Unit		I	II	III
Summer	1	-1.451	-1.05	-0.558
	2	-0.714	-0.399	-0.013
	3	-1.368	-0.814	-0.85
	4	-0.986	-0.877	-0.321
Autumn	5	-0.7	1.988	0.522
	6	-0.325	0.924	0.091
	7	-0.155	1.776	-0.061
Winter	8	0.855	-0.148	-0.047
	9	0.76	-0.04	-1.7
	10	0.523	-0.08	-0.725
Spring	11	0.595	-0.445	-0.523
	12	1.773	-0.614	1.501
	13	1.193	-0.222	0.342

The mean ( $\pm$  95% C.I.), variance, standard deviation (s. d.) and coefficient of variation (CV) for 21 metrics calculated for the different season samples from Bozeman Creek are presented in Tables 12 through 16.

Figure 22. Principal components analysis for Bozeman Creek

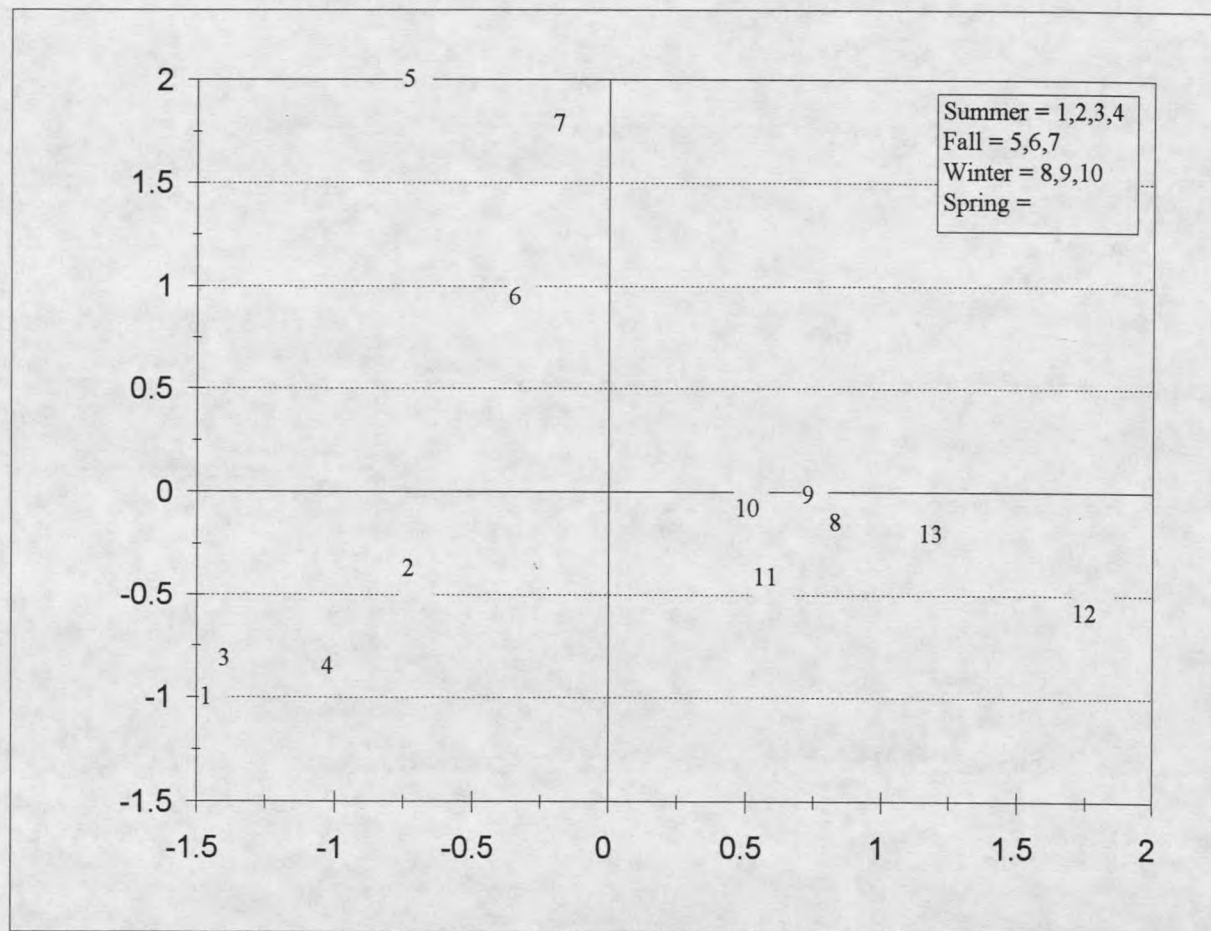


Table 12. Mean ( $\pm$  95% CI), variance, standard deviation (s. d.), and coefficient of variation (CV) for metrics calculated for Bozeman Creek, August 9, 1994 (N=4).

metric	mean ( $\pm$ 95% C.I.)	variance	s. d.	CV
# of organisms	315.75 ( $\pm$ 63.56)	4206.90	64.86	0.21
taxa richness <sup>1</sup>	27.75 ( $\pm$ 1.24)	1.58	1.26	0.05
EPT richness <sup>2</sup>	19.75 ( $\pm$ 1.47)	2.25	1.50	0.08
# of Plecoptera taxa	2.00 ( $\pm$ 0.00)	0.00	0.00	0.00
# of Ephemeroptera taxa	9.25 ( $\pm$ 0.94)	0.92	0.96	0.10
# of Trichoptera taxa	8.5 ( $\pm$ 0.57)	0.33	0.58	0.07
# of shredder taxa	2.25 ( $\pm$ 0.96)	0.92	0.98	0.44
# of scraper taxa	4.00 ( $\pm$ 0.80)	0.67	0.82	0.21
# of cg and fg taxa	10.5 ( $\pm$ 0.57)	0.33	0.58	0.06
# of predator taxa	5.00 ( $\pm$ 1.38)	2.00	1.41	0.28
% shredder taxa	8.11 ( $\pm$ 3.63)	13.71	3.70	0.45
% scraper taxa	14.41 ( $\pm$ 2.69)	7.55	2.75	0.19
% cg and fg taxa	37.88 ( $\pm$ 2.25)	5.27	2.30	0.06
% predator taxa	18.09 ( $\pm$ 5.25)	28.73	5.36	0.30
% dominant taxa	15.71 ( $\pm$ 3.55)	13.11	3.62	0.23
HBI <sup>4</sup>	1.63 ( $\pm$ 0.26)	0.07	0.27	0.17
% asynchronous <sup>5</sup>	0.06 ( $\pm$ 0.02)	0.00	0.02	0.30
% semi-voltine <sup>5</sup>	0.06 ( $\pm$ 0.02)	0.00	0.02	0.26
% uni-voltine <sup>5</sup>	0.57 ( $\pm$ 0.04)	0.00	0.04	0.06
Shannon Diversity Index	2.80 ( $\pm$ )	0.01	0.05	0.18
% EPT richness	71.26 ( $\pm$ 5.69)	0.34	5.81	0.08

<sup>1</sup>Taxa richness is the number of taxa per sample; <sup>2</sup>EPT richness is the number of Ephemeroptera, Plecoptera, and Trichoptera taxa in a sample; <sup>3</sup>cg and fg is the number of collector-gatherer and filter-gatherer taxa; <sup>4</sup>HBI is Hilsenhoff Biotic Index; <sup>5</sup>% voltinism metrics were determined to be too variable for further consideration.

Table 13. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Bozeman Creek, October 21, 1994 (N=3).

metric	mean ( $\pm$ 95% C.I.)	variance	s. d.	CV
# of organisms	649.00 ( $\pm$ 387.43)	11721.10	342.36	0.53
taxa richness <sup>1</sup>	20.67 ( $\pm$ )	8.33	2.89	0.14
EPT richness <sup>2</sup>	15.67 ( $\pm$ 2.35)	4.33	2.08	0.13
# of Plecoptera taxa	4.00 ( $\pm$ 0.00)	0.00	0.00	0.00
# of Ephemeroptera taxa	6.00 ( $\pm$ 1.13)	1.00	1.00	0.17
# of Trichoptera taxa	5.67 ( $\pm$ 1.30)	1.33	1.15	0.20
# of shredder taxa	4.00 ( $\pm$ 1.13)	1.00	1.00	0.25
# of scraper taxa	4.00 ( $\pm$ 1.13)	1.00	1.00	0.25
# of cg + fg taxa <sup>3</sup>	4.33 ( $\pm$ 1.79)	2.33	1.58	0.36
# of predator taxa	4.00 ( $\pm$ 1.13)	1.00	1.00	0.25
% shredder taxa	19.22 ( $\pm$ 3.37)	8.85	2.98	0.16
% scraper taxa	19.22 ( $\pm$ 3.37)	8.85	2.98	0.16
% cg + fg taxa	20.61 ( $\pm$ 5.23)	21.35	4.62	0.22
% predator taxa	19.22 ( $\pm$ 3.37)	8.85	2.98	0.16
% dominant taxa	20.75 ( $\pm$ 3.04)	7.22	2.69	0.13
HBI <sup>4</sup>	1.31 ( $\pm$ 0.29)	0.11	0.34	0.26
% asynchronous <sup>5</sup>	0.01 ( $\pm$ 0.03)	0.00	0.02	1.73
% semi-voltine <sup>5</sup>	0.01 ( $\pm$ 0.03)	0.00	0.02	1.73
% univoltine <sup>5</sup>	0.067 ( $\pm$ 0.14)	0.02	0.12	0.19
Shannon Diversity Index	2.31 ( $\pm$ 0.2)	0.01	0.86	0.37
%EPT Richness	75.88 ( $\pm$ 3.10)	0.08	2.74	0.04

<sup>1</sup>Taxa richness: number of taxa per sample; <sup>2</sup>EPT richness: number of Ephemeroptera, Plecoptera, and Trichoptera taxa; <sup>3</sup>cg and fg: number of collector-gatherer and filter-gatherer taxa; <sup>4</sup>HBI:Hilsenhoff Biotic Index; <sup>5</sup> % voltinism metrics were determined to be to variable for further consideration

Table 14. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Bozeman Creek, February 5, 1995 (N=3).

metric	mean (+ 95% C.I.)	variance	s. d.	CV
# of organisms	259.67 ( $\pm$ 44.48)	1545.30	39.31	0.15
taxa richness <sup>1</sup>	26.33 ( $\pm$ 1.73)	2.33	1.53	0.06
EPT richness <sup>2</sup>	19.00 ( $\pm$ 1.13)	1.00	1.00	0.05
# of Plecoptera taxa	6.33 ( $\pm$ 1.73)	2.33	1.53	0.24
# of Ephemeroptera taxa	6.67 ( $\pm$ 1.73)	2.33	1.53	0.23
# of Trichoptera taxa	6.00 ( $\pm$ 0.00)	0.00	0.00	0.00
# of shredder taxa	4.67 ( $\pm$ 0.66)	0.33	0.58	0.12
# of scraper taxa	4.00 ( $\pm$ 1.13)	1.00	1.00	0.25
# of cg + fg taxa <sup>3</sup>	5.33 ( $\pm$ 0.66)	0.33	0.58	0.11
# of predator taxa	6.67 ( $\pm$ 1.73)	2.33	1.53	0.23
% shredder taxa	17.84 ( $\pm$ 3.51)	9.60	3.10	0.17
% scraper taxa	15.31 ( $\pm$ 4.87)	18.50	4.30	0.28
% cg + fg taxa <sup>3</sup>	20.22 ( $\pm$ 1.26)	1.23	1.11	0.05
% predator taxa	25.26 ( $\pm$ 6.10)	29.05	5.39	0.21
% dominant taxa	19.45 ( $\pm$ 5.98)	27.93	5.28	0.27
HBI <sup>4</sup>	0.72 ( $\pm$ 0.14)	0.33	0.12	0.17
% asynchronous <sup>5</sup>	0.00 ( $\pm$ 0)	0.00	0.00	0.00
% semi-voltine <sup>5</sup>	0.05 ( $\pm$ 0.02)	0.00	0.02	0.37
% univoltine <sup>5</sup>	0.54 ( $\pm$ 0.033)	0.00	0.03	0.05
Shannon Diversity Index	2.69 ( $\pm$ 0.20)	0.15	0.12	0.05

<sup>1</sup>Taxa richness is the number of taxa per sample.

<sup>2</sup>EPT richness is the number of Ephemeroptera, Plecoptera, and Trichoptera taxa in a sample.

<sup>3</sup>cg and fg is the number of collector-gatherer and filter-gatherer taxa

<sup>4</sup> HBI is Hilsenhoff Biotic Index

<sup>5</sup> % voltinism metrics were determined to be too variable for further consideration

Table 15. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Bozeman Creek, May 5, 1995 (N=3).

<b>métric</b>	<b>mean (<math>\pm</math> 95% C.I.)</b>	<b>variance</b>	<b>s. d.</b>	<b>CV</b>
# of organisms	396.67 ( $\pm$ 102.30)	8176.33	90.40	0.23
taxa richness <sup>1</sup>	32.67 ( $\pm$ 3.97)	12.33	3.51	0.11
EPT richness <sup>2</sup>	25.00 ( $\pm$ 3.92)	12.00	3.46	0.14
# of Plecoptera taxa	6.67 ( $\pm$ 0.66)	0.33	0.58	0.09
# of Ephemeroptera taxa	9.67 ( $\pm$ 2.61)	2.33	2.00	0.11
# of Trichoptera taxa	8.33 ( $\pm$ 0.66)	4.33	0.58	0.07
# of shredder taxa	3.33 ( $\pm$ 0.66)	0.33	0.58	0.17
# of scraper taxa	3.33 ( $\pm$ 1.30)	1.33	1.15	0.35
# of cg and fg taxa <sup>3</sup>	8.33 ( $\pm$ 1.73)	2.33	1.53	0.18
# of predator taxa	8.67 ( $\pm$ 3.27)	8.33	2.89	0.33
% shredder taxa	10.27 ( $\pm$ 2.15)	3.60	1.90	0.19
% scraper taxa	10.04 ( $\pm$ 3.13)	7.67	2.77	0.28
% cg + fg taxa <sup>3</sup>	26.05 ( $\pm$ 8.69)	59.01	7.68	0.29
% predator taxa	26.23 ( $\pm$ 7.16)	39.99	6.32	0.24
% dominant taxa	6.67 ( $\pm$ 1.73)	2.33	1.53	0.23
<b>HBI</b> <sup>4</sup>	1.52 ( $\pm$ 0.63)	0.31	0.56	0.37
% asynchronous <sup>5</sup>	0.05 ( $\pm$ 0.02)	0.00	0.01	0.28
% semi-voltine <sup>5</sup>	0.06 ( $\pm$ 0.06)	0.00	0.05	0.85
% univoltine <sup>5</sup>	0.50 ( $\pm$ 0.05)	0.00	0.04	0.09
<b>Shannon Diversity Index</b>	2.78 ( $\pm$ 0.3)	0.19	0.14	0.05

<sup>1</sup>Taxa richness is the number of taxa per sample.

<sup>2</sup>EPT richness is the number of Ephemeroptera, Plecoptera, and Trichoptera taxa in a sample.

<sup>3</sup>cg and fg is the number of collector-gatherer and filter-gatherer taxa

<sup>4</sup>HBI is Hilsenhoff Biotic Index

<sup>5</sup>% voltinism metrics were determined to be too variable for further consideration

Table 16. Mean ( $\pm$  95% CI), variance, standard deviation (s.d.), and coefficient of variation (CV) for metrics calculated for Bozeman Creek, September 20, 1995 (N=3).

metric	mean	var.	s. d.	CV
# of organisms	673 ( $\pm$ 257.45)	51753.00	227.50	0.34
taxa richness <sup>1</sup>	32.00 ( $\pm$ 1.13)	1.00	1.00	0.03
EPT richness <sup>2</sup>	24.33 ( $\pm$ 0.66)	0.33	0.58	0.02
# of Plecoptera taxa	5.33 ( $\pm$ 0.66)	0.33	0.58	0.11
# of Ephemeroptera taxa	9.33 ( $\pm$ 0.66)	0.33	0.58	0.06
# of Trichoptera taxa	9.67 ( $\pm$ 1.73)	2.33	1.53	0.16
# of shredder taxa	4.33 ( $\pm$ 1.30)	1.33	1.15	0.27
# of scraper taxa	4.00 ( $\pm$ 1.00)	1.00	1.00	0.25
# of cg+fg taxa <sup>3</sup>	5.33 ( $\pm$ 0.66)	0.33	0.58	0.11
# of predator taxa	6.67 ( $\pm$ 1.73)	2.33	1.53	0.23
% shredder taxa	13.49 ( $\pm$ 3.74)	10.93	3.31	0.25
% scraper taxa	12.48 ( $\pm$ 3.29)	8.46	2.91	0.23
% cg+fg taxa <sup>3</sup>	16.68 ( $\pm$ 2.11)	3.46	1.86	0.11
% predator taxa	20.75 ( $\pm$ 4.72)	17.4	4.17	0.20
% dominant taxa	12.67 ( $\pm$ 1.05)	0.87	0.93	0.07
HBI <sup>4</sup>	1.61 ( $\pm$ 0.24)	0.04	0.21	0.13
Shannon diversity index	3.00 ( $\pm$ 0.30)	0.00	0.07	0.00

<sup>1</sup>Taxa richness is the number of taxa per sample.

<sup>2</sup>EPT richness is the number of Ephemeroptera, Plecoptera, and Trichoptera taxa in a sample.

<sup>3</sup>cg and fg is the number of collector-gatherer and filter-gatherer taxa

<sup>4</sup>HBI is Hilsenhoff Biotic Index

Two richness indices, four diversity indices, and five evenness indices were computed for the five sample times from Bozeman Creek. Results are presented in Table 16. Shannon diversity index is the most commonly used diversity index by 1) ecologists (Ludwig and Reynolds 1988), 2) most rapid assessment programs (Barbour et al. 1995), and 3) is recommended for use by the Water Quality Division of Montana (Bukantis 1995b). Further analysis of Shannon diversity index was made for seasonal variability in Bozeman Creek.

The mean, variance, s.d. and CV of the Shannon diversity index values are presented in Table 18. Results of this analysis suggested that there was little variability in species diversity between each riffle sample within each season and between each season as shown by the small CV values.

To a limited extent, the percent dominant taxa metric can also be used to analyze species diversity (evenness). The % dominant taxa as measured by relative abundance, comprised only 6.67% ( $\pm 1.73\%$ ) of the organisms in the Spring 1995 samples (Appendix 21). On the other hand, 20.61% ( $\pm 3.04\%$ ) and 19.45% ( $\pm 5.98\%$ ) of the organisms in the Autumn 1994 and Winter 1995 samples were from one taxon, the Plecopteran shredder *Zapada* spp. Summer 1994 and Summer 1995, % dominant taxon accounted for 15.71% ( $\pm 3.55\%$ ) and 12.67% ( $\pm 1.05\%$ ) of the total number of organisms, respectively.

Table 17. Species diversity indices for sixteen samples from five sampling periods in Bozeman Creek, Spring 1995, Summer 1994 (Sm1, Smr2, Smr3, and Smr4), Fall 1994, Winter 1995, and Summer 1995 (Smr1, Smr2, and Smr3).

Spr 1	Spr 2	Spr 3	Smr 1	Smr 2	Smr 3	Smr 4	Fall 1	Fall 2	Fall 3	Wntr 1	Wntr 2	Wnt 3	Smr 1	Smr 2	Smr 3
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**Richness**

No	29.0	36.0	33.0	28.0	26.0	28.0	29.0	24.0	19.0	19.0	26.0	25.0	28.0	31.0	33.0	32.00
R1	4.92	5.67	5.29	4.80	4.64	4.62	4.71	3.31	2.98	2.91	4.48	4.18	4.87	4.87	4.69	4.82
R2	1.68	1.66	1.61	1.68	1.76	1.51	1.49	0.74	0.93	0.86	1.60	1.41	1.75	1.43	1.09	1.28

**Diversity**

S	0.10	0.08	0.07	0.08	0.07	0.09	0.08	0.14	0.11	0.14	0.11	0.08	0.08	0.07	0.06	0.06
H'	2.63	2.89	2.83	2.75	2.79	2.80	2.87	2.29	2.40	2.23	2.56	2.72	2.80	2.93	3.06	3.01
N <sub>1</sub>	13.8	17.9	16.9	15.6	16.3	16.4	17.6	9.87	11.0	9.26	12.8	15.2	16.5	18.8	21.4	20.31
N <sub>2</sub>	9.57	12.7	13.4	12.2	14.3	11.6	13.2	7.32	8.83	7.39	9.08	12.2	12.5	15.0	16.4	16.29

Table 17. continued

Evenness

E1	0.78	0.81	0.81	0.83	0.86	0.84	0.85	0.72	0.82	0.76	0.78	0.85	0.84	0.85	0.88	0.87
E2	0.48	0.50	0.51	0.56	0.63	0.59	0.61	0.41	0.58	0.49	0.50	0.61	0.59	0.61	0.65	0.63
E3	0.46	0.49	0.50	0.54	0.61	0.57	0.59	0.39	0.56	0.46	0.48	0.59	0.57	0.59	0.64	0.62
E4	0.69	0.71	0.70	0.78	0.87	0.71	0.75	0.07	0.80	0.80	0.70	0.81	0.76	0.80	0.76	0.80
E5	0.67	0.69	0.78	0.76	0.87	0.69	0.75	0.71	0.78	0.77	0.68	0.79	0.74	0.79	0.75	0.79

No=number of taxa; R1=Margalef richness index; R2= Menhinick index; S=Simpson diversity index; H' = Shannon's diversity index; N1= Hill's diversity number using Shannons's index; N2= Hill's diversity number using Simpson's index; E1= Pielou's evenness index; E2= Sheldon's evenness index; E3= Heip's evenness index; E4= Hill's evenness index; E5= the modified Hill evenness index (Ludwig and Reynolds 1988)

Table 18. Mean, variance, standard deviation (s.d.), and coefficient of variation (CV) for Shannon diversity index for four seasons (including two summer seasons) from Bozeman Creek, 1994 and 1995.

	Summer 1994 (N=4)	Fall 1994 (N=3)	Winter 1994 (N=3)	Spring 1995 (N=3)	Summer 1995 (N = 3)
mean	2.80	2.31	2.69	2.78	3.00
variance	0.00	0.01	0.02	0.02	0.00
s.d.	0.05	0.09	0.12	0.14	0.07
CV	0.02	0.04	0.05	0.05	0.0

Samples collected in late summer 1995 from Bozeman Creek probably reflect the transition between early summer macroinvertebrate community composition (summer 1994 samples) and between the autumn macroinvertebrate community composition (autumn 1994 samples). The number of organisms collected in late summer 1995 was 673.00 ( $\pm$  257.45) which was closer to the autumn 1994 number of organisms mean of 649.00 ( $\pm$  387.43), while the mean number of organisms collected in early summer 1994 was 315.75 ( $\pm$  63.56). Number of taxa (taxa richness) for late summer 1995 was 32.0 ( $\pm$  1.13) which is more similar to the mean number of taxa for the early summer 1994 collections at 27.75 ( $\pm$  1.24). The autumn 1994 mean number of taxa was only 20.67 ( $\pm$  3.27).

A quantitative similarity index (QSI) for taxa was used to quantify the similarities between samples within each season and between seasons (Table 19). The

QSI used % relative abundances of each species from each sample and compared this percentage between all three samples to give a total % similarity between samples for each season. For Bozeman Creek, all three samples were used from each season to determine a QSI value, except for Summer 1994. Since Summer 1994 had four samples, a mean value of the four combinations of three samples collected in Summer 1994 was used (Table 20).

Table 19. Quantitative Similarity Index values between the three samples for each season, Summer 1994, Autumn 1994, Winter 1995, Spring 1995, and Summer 1995 including mean ( $\pm$  95% C. I.), variance (var.), s. d. and CV.

	smmr 94 <sup>1</sup>	atmn 94	wntr 95	spring 95	smmr 95	mean	var.	s.d.	CV
QSI	43.05	45.37	52.48	58.82	69.92	53.93 $\pm$ 9.53	10.76	10.87	0.3

<sup>1</sup>Summer 1994 QSI was from the mean value from four combinations of three samples used to standardize each season at three samples (Table 20).

Table 20. Quantitative Similarity Index (QSI) values for four combinations of three samples (1,2,3,4) from Bozeman Creek summer 1994 including mean ( $\pm$  95% C.I.), variance, s. d., and CV.

	1,2,3	1,3,4	2,3,4	1,2,4	mean	variance	s.d.	CV
QSI	48.32	41.19	44.69	37.99	43.05 ( $\pm$ 4.36)	19.84	4.45	0.10

QSI values used for Bozeman Creek seasonal variability showed that Summer 1994 and Spring 1995 samples were least similar (Table 21). The QSI value was 0.334 or 33.4% similarity. The most similar seasons using QSI were Winter 1995 and

Spring 1995 with a value of 0.82 (82% similar). The only other seasons greater than 50% similarity were Fall 1994 and Winter 1995 with a QSI value of 0.516 (Table 21).

Table 21. Quantitative Similarity Index (QSI) comparisons between mean % relative abundances for Summer 1994, Autumn 1994, Winter 1995, and Spring 1995 from Bozeman Creek macroinvertebrate samples.

Season	QSI
Summer 94/Spring 95	33.40
Autumn 94/Spring 95	34.50
Summer 94/Autumn 94	35.13
Winter 95/Summer 94	38.67
Autumn 94/Winter 95	51.61
Winter 95/Spring 95	82.00

The modified Hilsenhoff Biotic Index (HBI) is a measure of a taxons' sensitivity to organic pollution. HBI values range from 0 for least tolerant taxa to 10 for most tolerant taxa. HBI values were lowest for Winter 1995 samples with a mean of 0.72, indicating that the most sensitive taxa to organic pollution occurred in the benthos during winter season.

Mean and 95% CI's for seventeen metrics for the five seasons sampled in Bozeman Creek are in Figures 23 through 39.

Figure 23. Mean ( $\pm$  95% CI) number of organisms for Bozeman Creek.

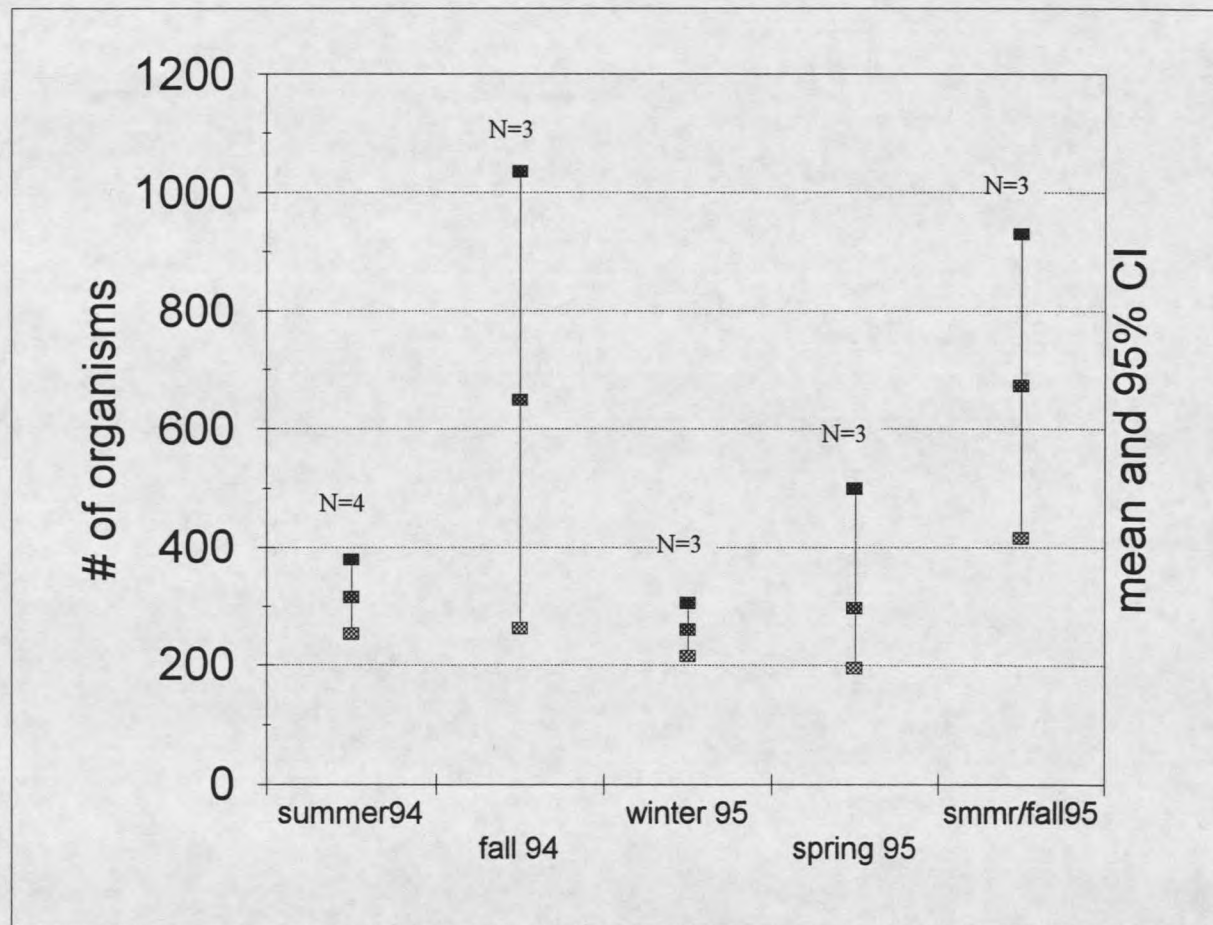


Figure 24. Mean ( $\pm$  95% CI) number of taxa (taxa richness) for Bozeman Creek.

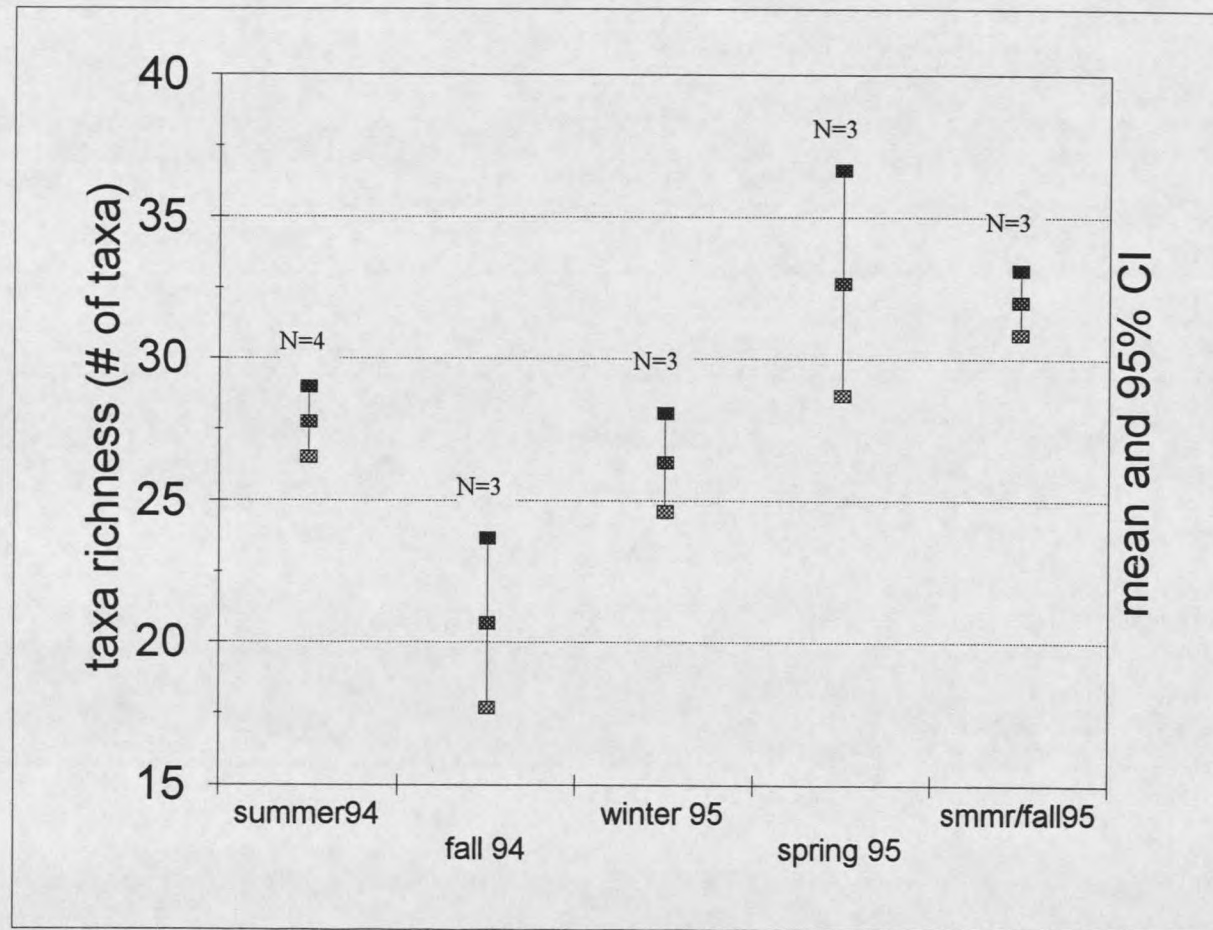


Figure 25. Mean ( $\pm$  95% CI) number of EPT taxa for Bozeman Creek.

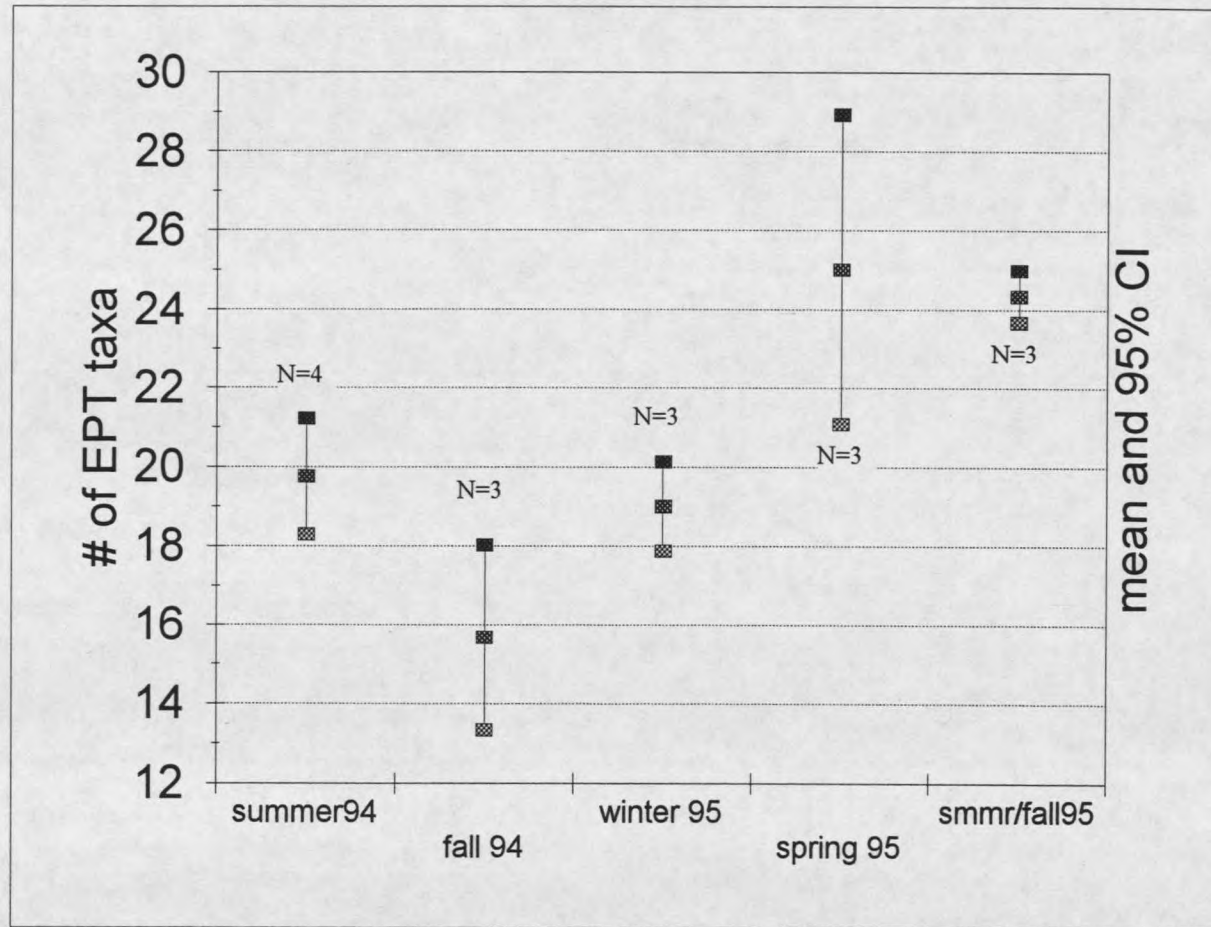


Figure 26. Mean ( $\pm$  95% CI) number of Ephemeroptera taxa for Bozeman Creek.

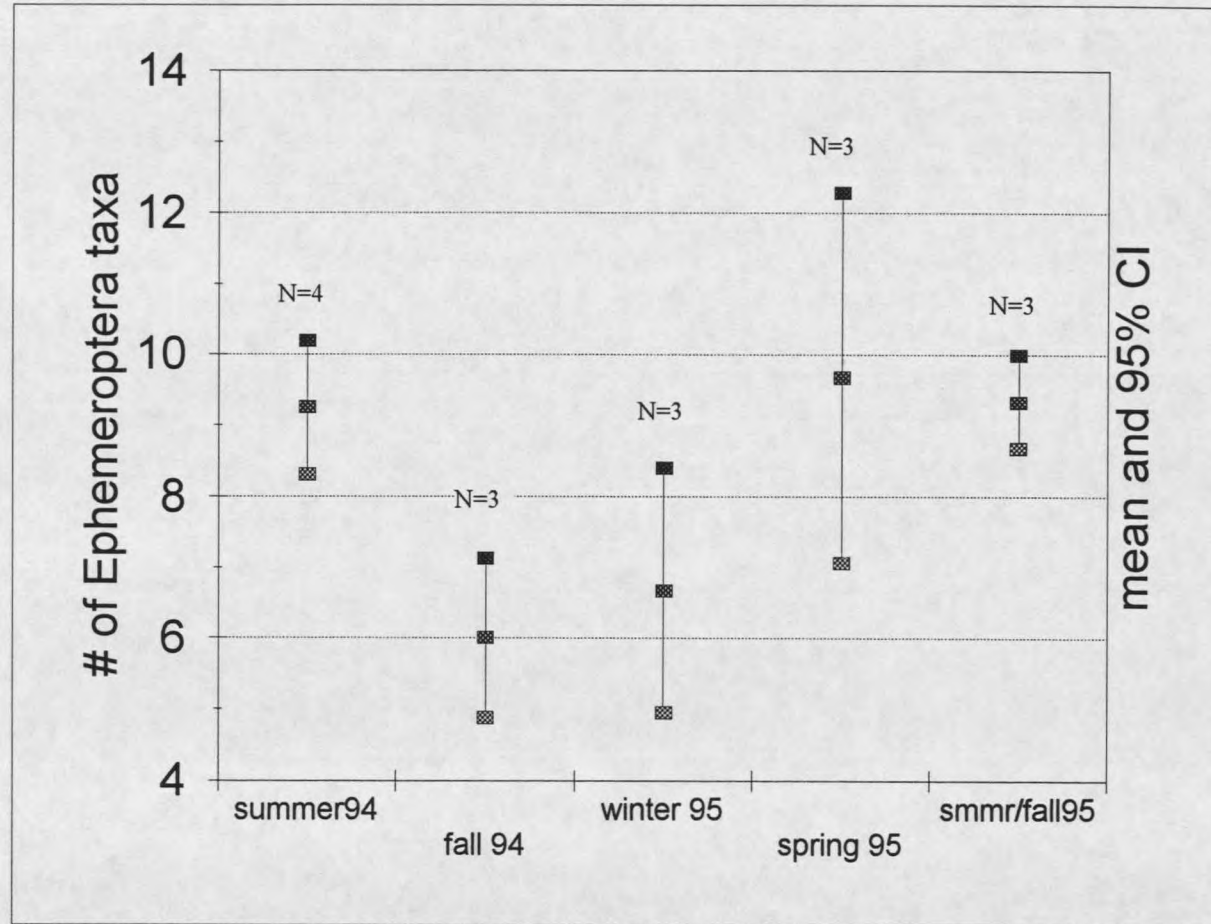


Figure 27. Mean ( $\pm$  95% CI) number of Plecoptera taxa for Bozeman Creek.

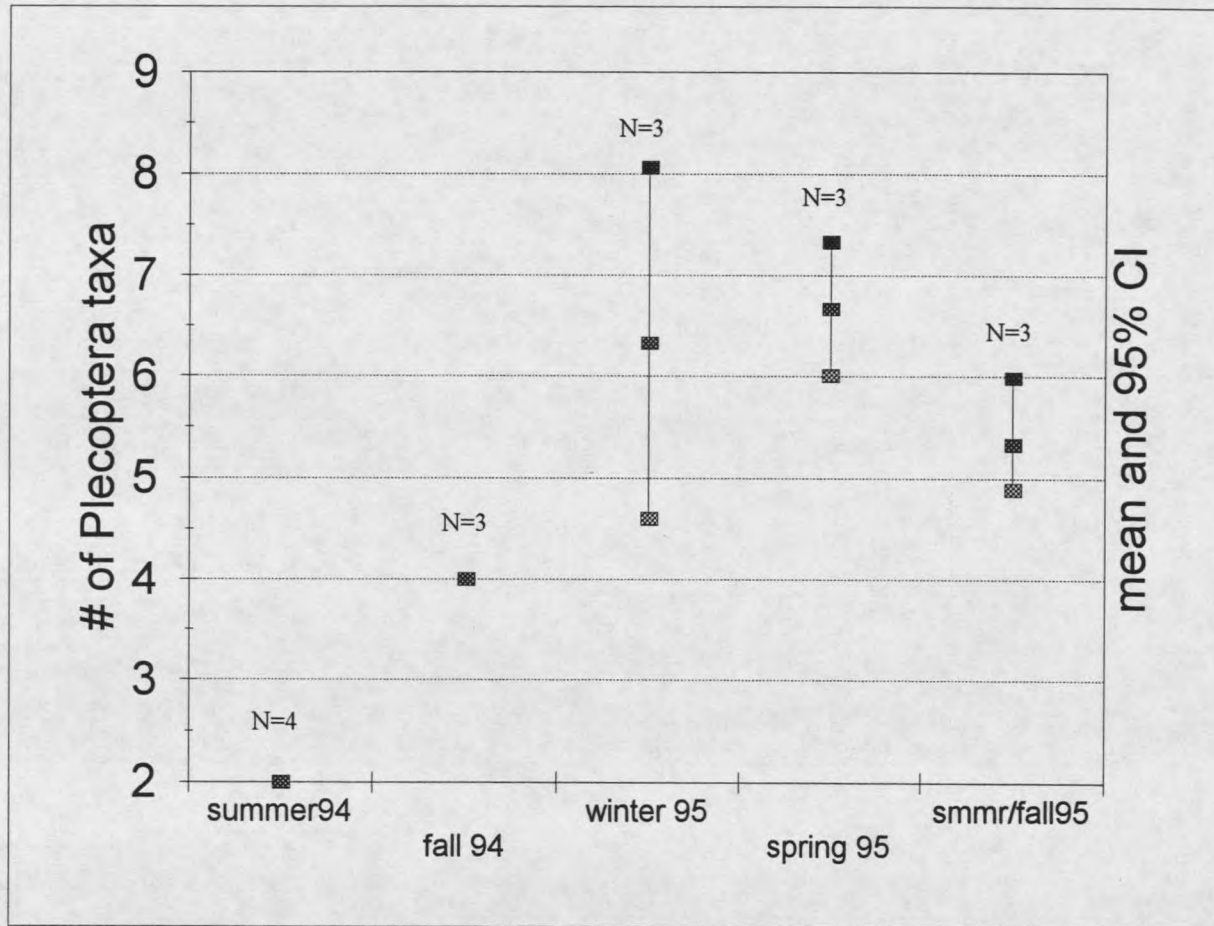


Figure 28. Mean ( $\pm$  95% CI) number of Trichoptera taxa for Bozeman Creek.

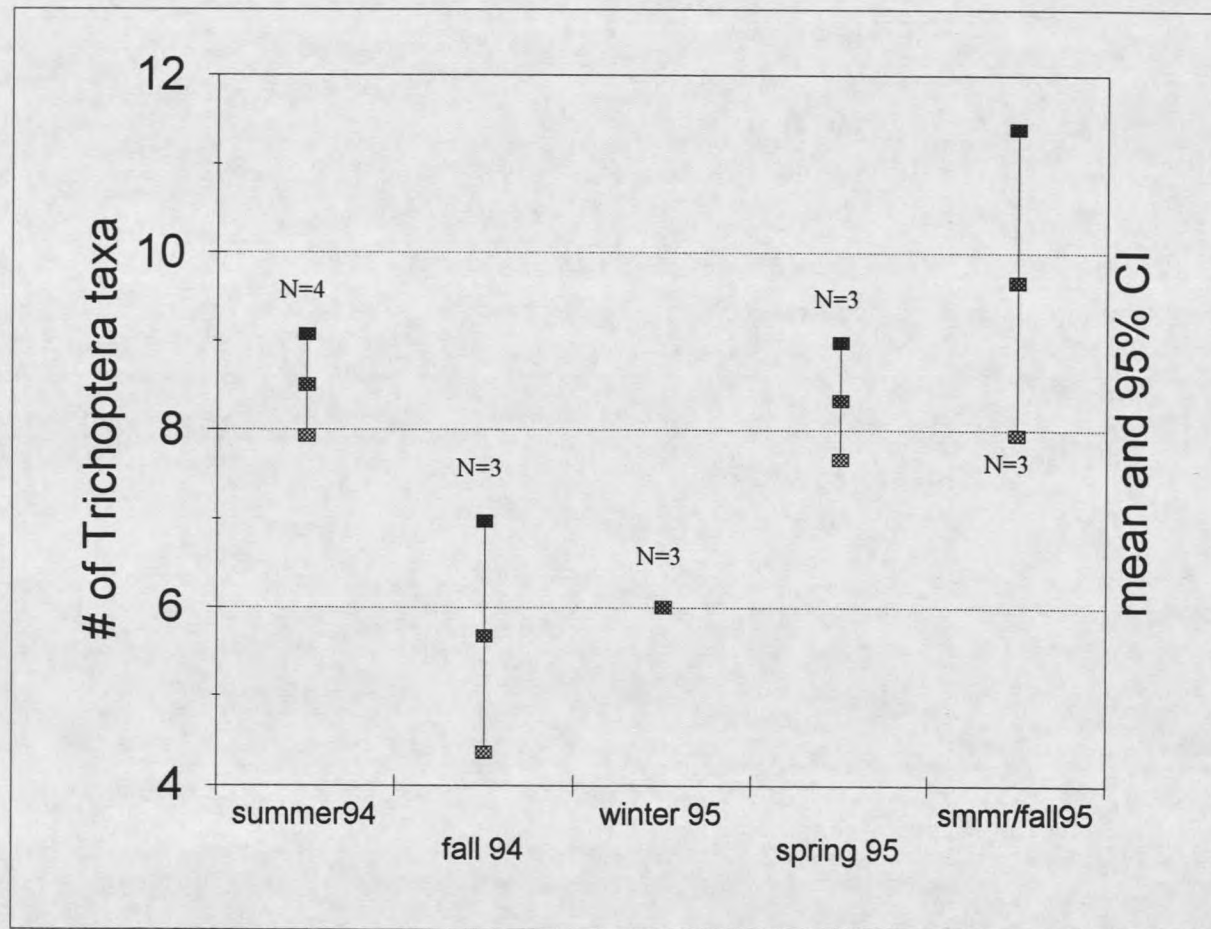


Figure 29. Mean ( $\pm$  95% CI) number of shredder taxa for Bozeman Creek.

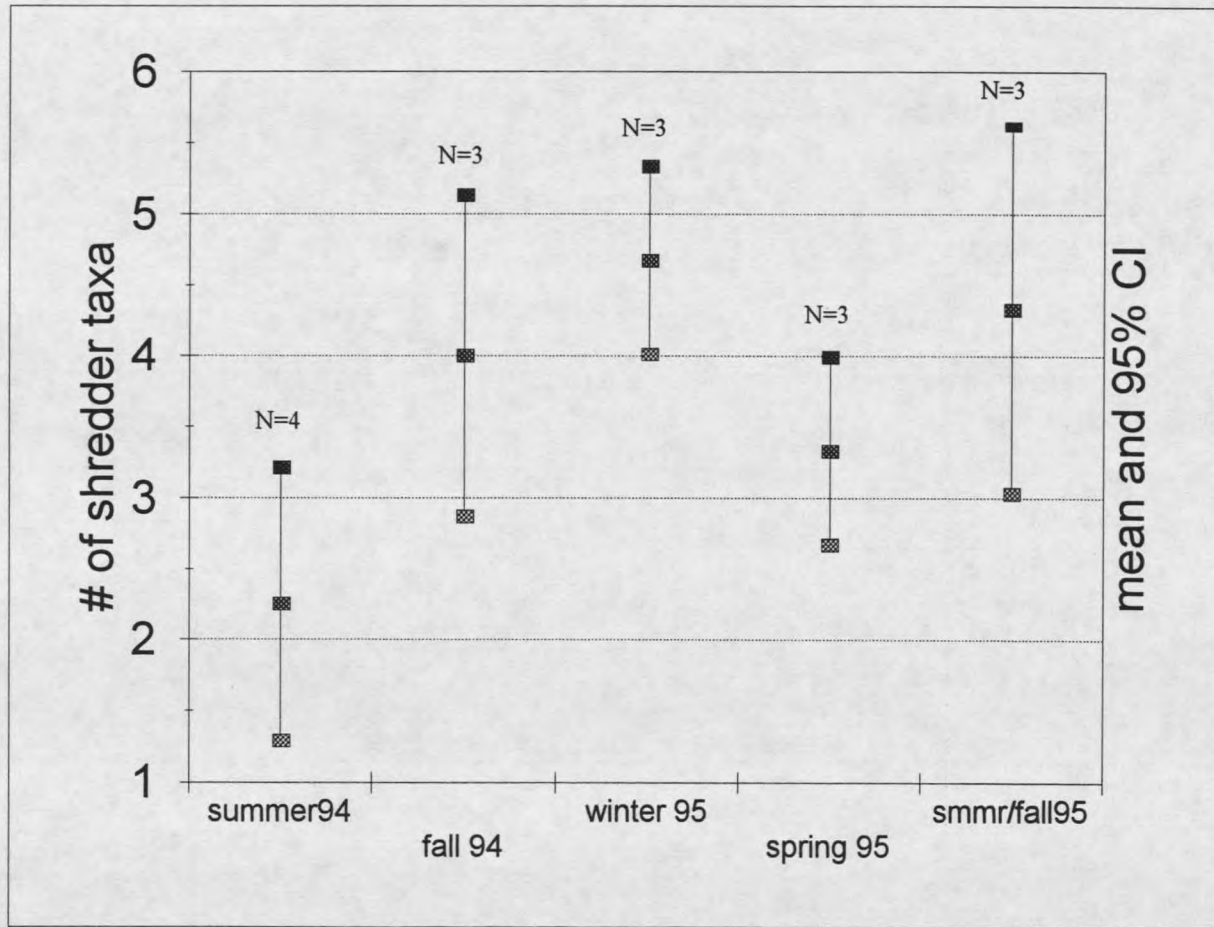


Figure 30. Mean ( $\pm$  95% CI) number of scraper taxa for Bozeman Creek.

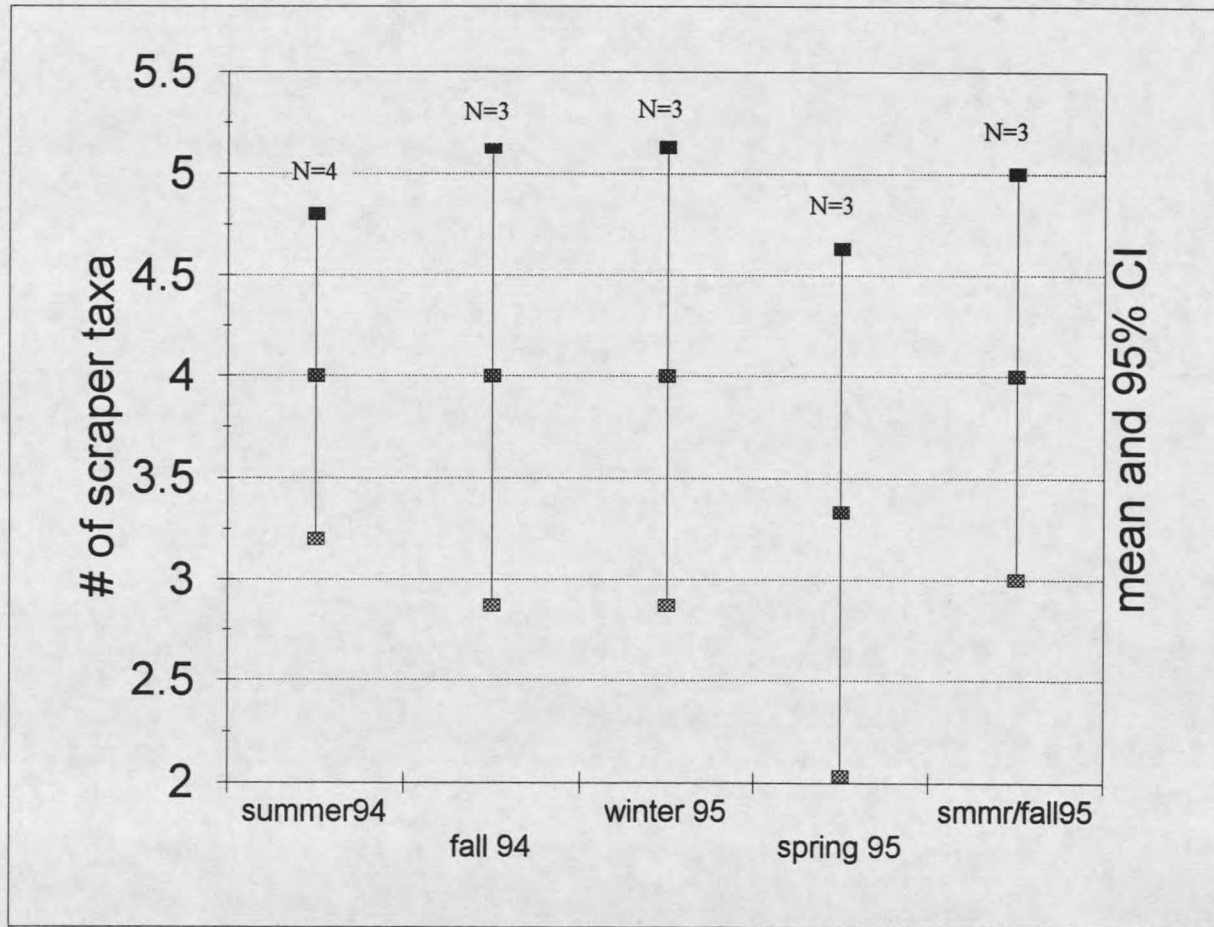


Figure 31. Mean ( $\pm$  95% CI) number of collector-gatherer and filter-gatherer taxa for Bozeman Creek.

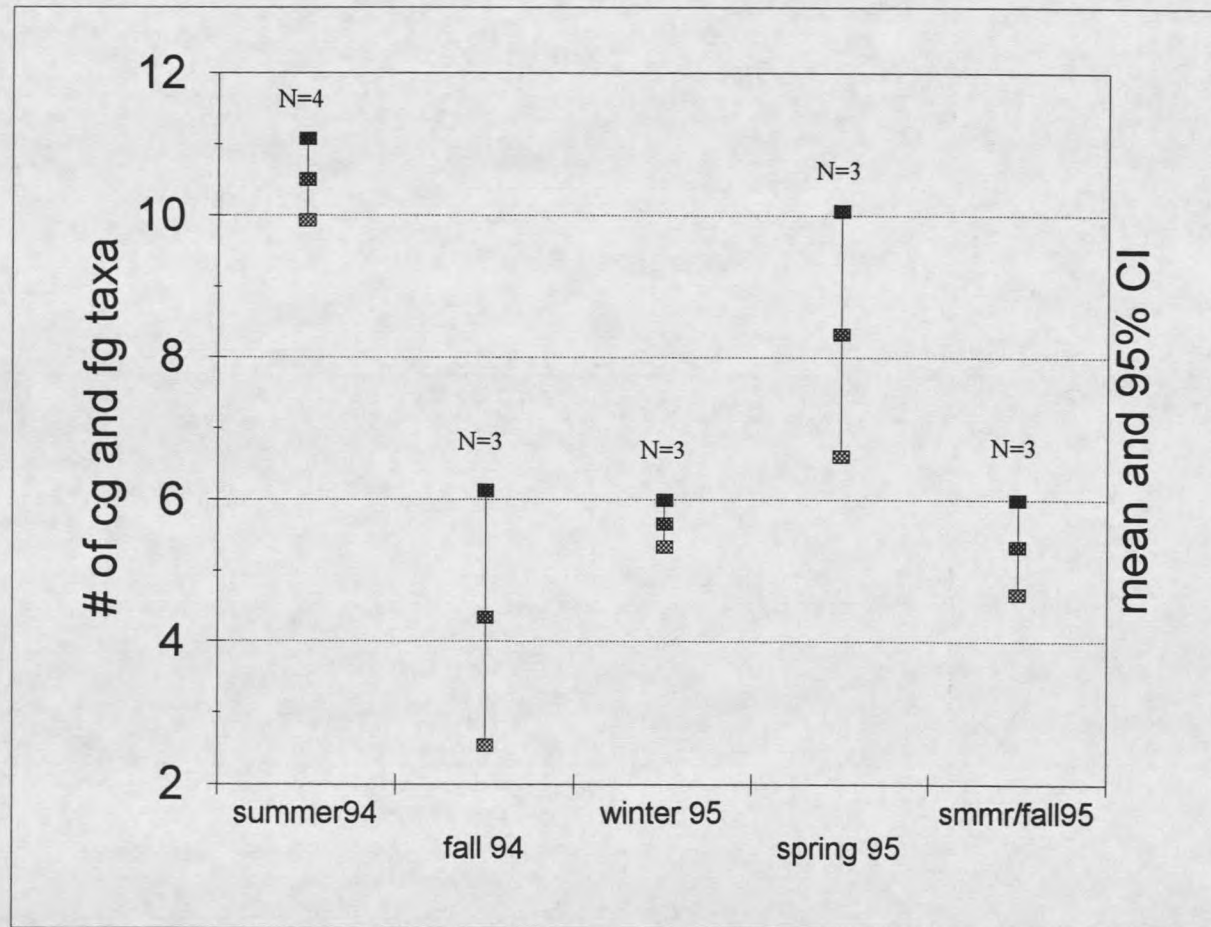


Figure 32. Mean ( $\pm$  95% CI) number of predator taxa for Bozeman Creek.

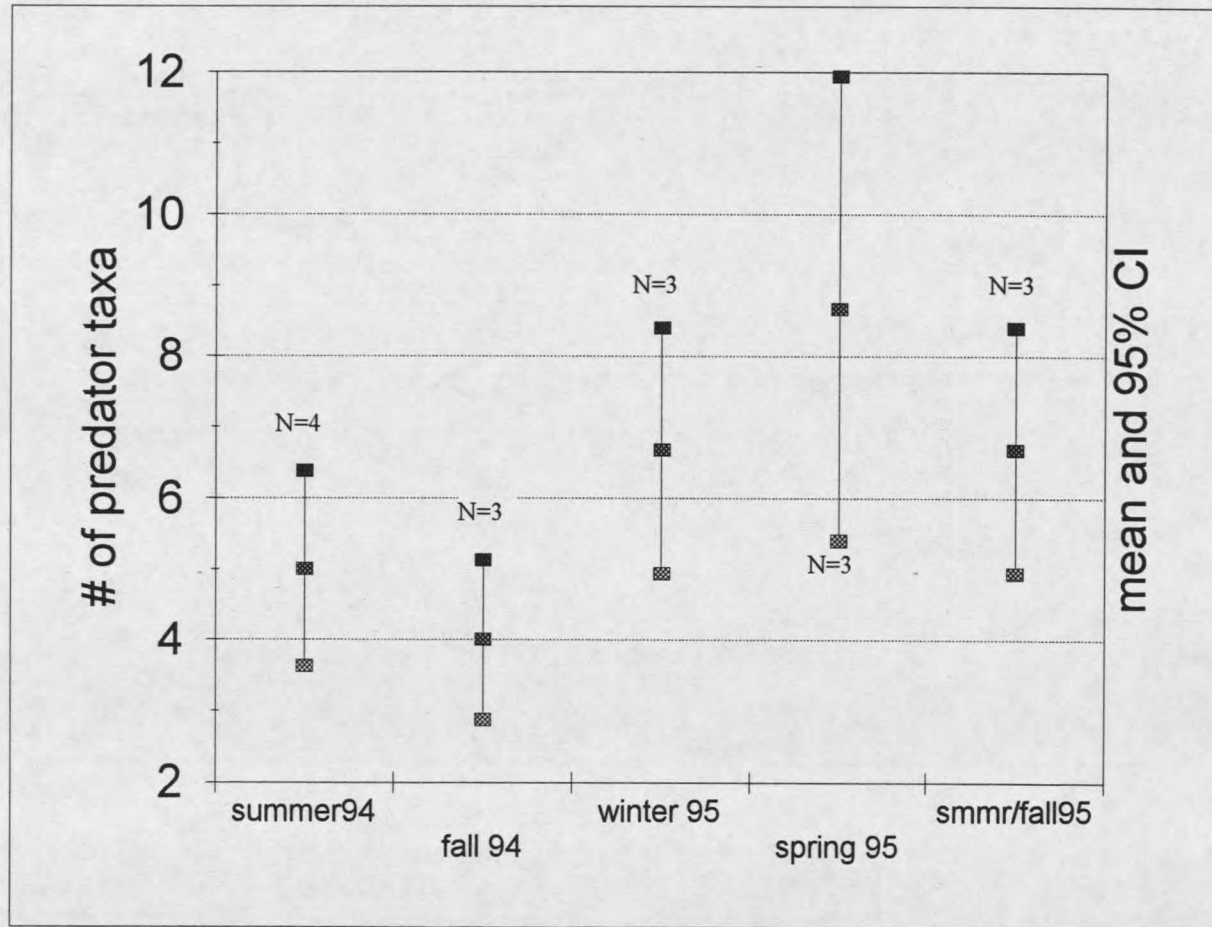


Figure 33. Mean ( $\pm$  95% CI) % shredder taxa for Bozeman Creek.

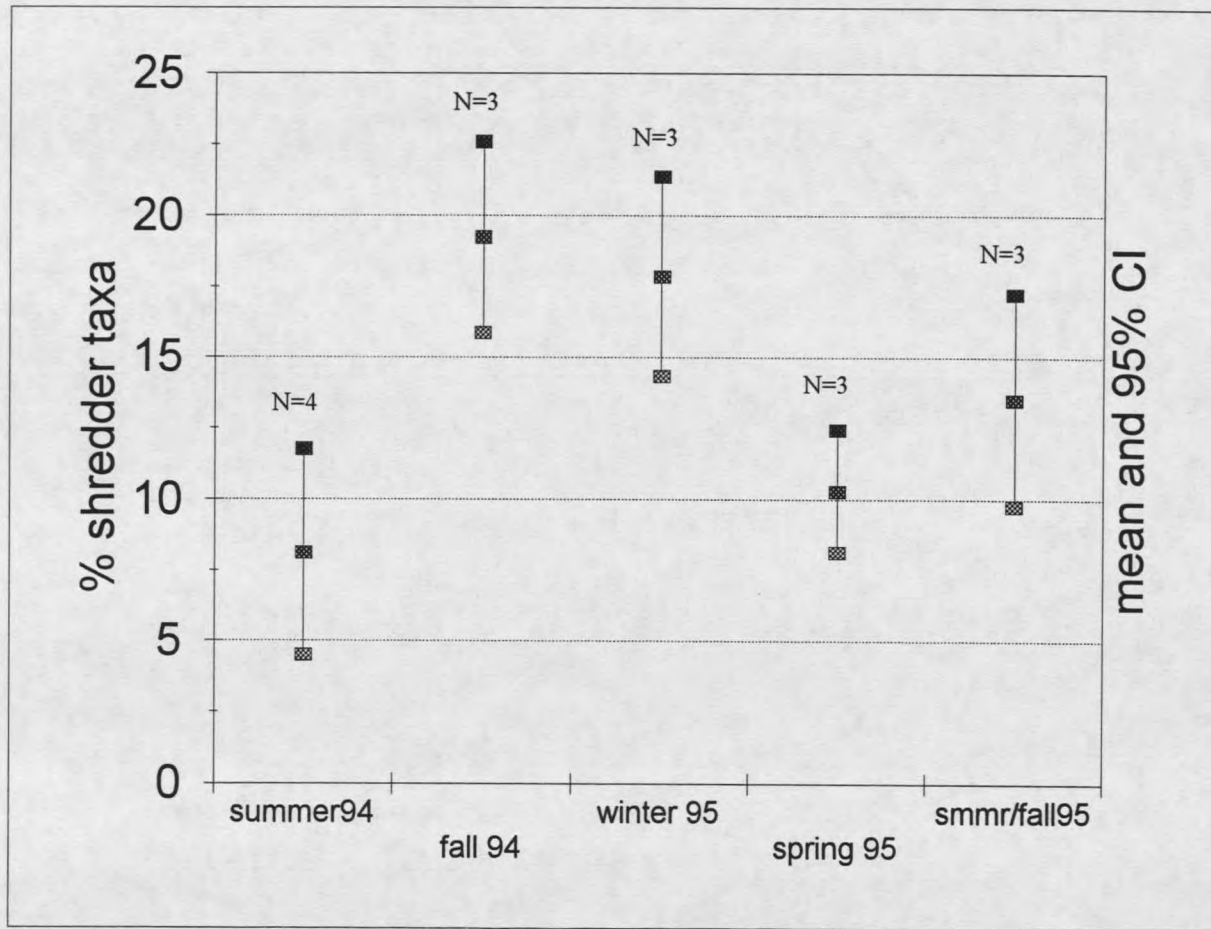


Figure 34. Mean ( $\pm$  95% CI) % scraper taxa for Bozeman Creek.

