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Chapter 3

Characterization of the Kootenai River Aquatic Macroinvertebrate Community before and after Experimental Nutrient Addition, 2003 - 2006

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ABSTRACT

The Kootenai River ecosystem has experienced numerous ecological changes since the early 1900s. Some of the largest impacts to habitat, biological communities, and ecological function resulted from levee construction along the 120 km of river upstream from Kootenay Lake, completed by the 1950s, and the construction and operation of Libby Dam, completed in 1972 on the river near Libby Montana. Levee construction isolated tens of thousands of hectares of historic functioning floodplain habitat from the river channel, eliminating nutrient production and habitat diversity crucial to the functioning of a large river-floodplain ecosystem. Libby Dam continues to create large changes in the timing, duration, and magnitude of river flows, and greatly reduces sediment and nutrient transport to downstream river reaches. These changes have contributed to the ecological collapse of the post-development Kootenai River ecosystem and its native biological communities.

In response to this artificial loss of nutrients, experimental nutrient addition was initiated in the Kootenay Lake's North Arm in 1992, the South Arm in 2004, and in the Kootenai River at the Idaho-Montana border during 2005. This report characterizes the macroinvertebrate community in the Kootenai River and its response to experimental nutrient addition during 2005 and 2006. This report also provides an initial evaluation of cascading trophic interactions in response to nutrient addition.

Macroinvertebrates were sampled at 12 sites along a 325 km section of the Kootenai River, representing an upriver unimpounded reference reach, treatment and control canyon reach sites, and braided and meandering reach sites, all downstream from Libby Dam. Principle component analysis revealed that richness explained the greatest amount of variability in response to nutrient addition as did taxa from Acari, Coleoptera, Ephemeroptera, Plecoptera, and Trichoptera. Analysis of variance revealed that nutrient addition had a significant effect ($p<0.0001$) on invertebrate abundance, biomass, and richness at sites KR-9 and KR-9.1 combined (the zone of maximum biological response). Richness, a valuable ecological metric, increased more than abundance and biomass, which were subject to greater sampling bias. Cascading trophic interactions were observed as increased algal accrual, increased in-river invertebrate abundance, and increased invertebrate counts in mountain whitefish (*Prosopium williamsonii*) guts samples, but were not quantitatively tested. Sampling and analyses across trophic levels are currently ongoing and are expected to better characterize ecological responses to experimental nutrient addition in the Kootenai River.

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INTRODUCTION

Evaluation of aquatic macroinvertebrate community attributes and dynamics provides a valuable approach to characterizing natural and altered large river ecosystems (Allan and Castillo 2007). In the overall context of this project, the macroinvertebrate community serves as the critical trophic level energetically linking primary producers in the lower trophic level with fish, avian, and mammal (predator and omnivore) communities in the higher trophic level(s). Evaluating and understanding the array of functional linkages, food web dynamics, and potential trophic cascading effects among macroinvertebrates and other biological communities in the altered Kootenai River ecosystem, with and without experimental nutrient addition treatments, is crucial to evaluating the success Kootenai River ecosystem restoration.

In addition to characterizing the macroinvertebrate community upstream and downstream from, and before and after experimental nutrient addition, we provide results from taxonomic analyses across trophic levels to assess ecological linkage and potential cascading trophic effects. These analyses include algal accrual rate comparisons upstream and downstream from, and before and after nutrient addition, and frequency comparisons between invertebrate taxa groups in the river with analogous invertebrate taxa frequency data from stomach content samples of mountain whitefish (*Propospium williamsonii*), often a very responsive indicator to ecological change, and a native fish species in the Kootenai River.

Study area

The Kootenai River Subbasin is situated between 48° and 51° north latitude and 115° and 118° west longitude and includes parts of southeastern British Columbia, northern Idaho, and northwestern Montana. It measures approximately 238 miles by 153 miles and has an area 16,180 sq miles (Figure 1). Nearly two-thirds of the Kootenai River's 485-mile-long channel and almost 70 percent of its watershed area are located in British Columbia. An additional 23 percent of the watershed is in Montana, while the Idaho portion is about 6.5 percent (Knudson 1994).

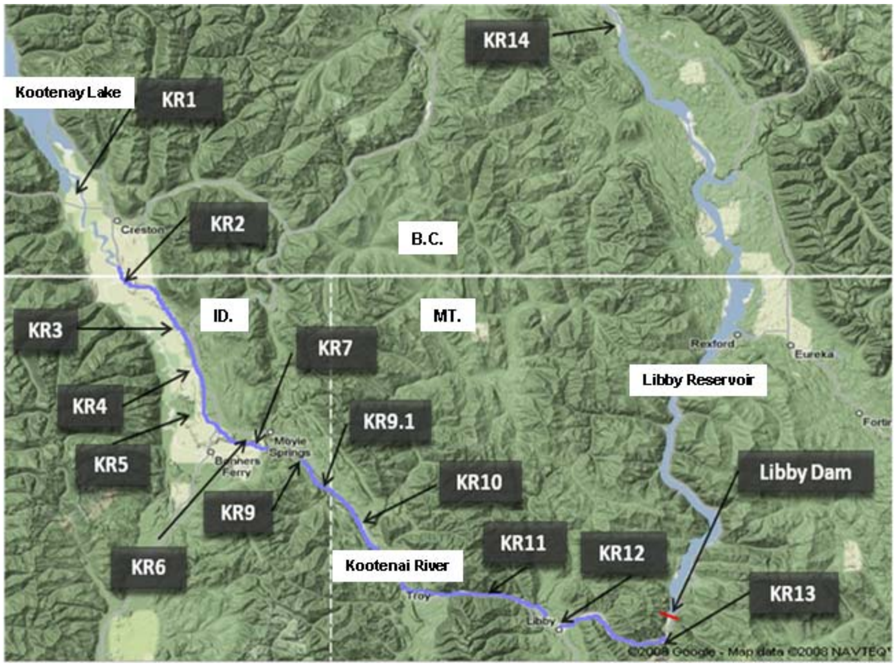


Figure 1. Study area and macroinvertebrate sampling sites (2003–2006) (Figure provided by SCS). Additional reach and site information is provided in Table 1.

Sampling reaches and sites

The aquatic macroinvertebrate study area encompassed a 325 km reach from the upper Kootenay River at Wardner B.C. (rkm 445) downstream through Montana and Idaho to Kootenay Lake in B.C. (rkm 120) (Figure 1). Sampling reaches included an unimpounded reach furthest upstream and four reaches downstream from Libby Dam affected by impoundment: two in canyon habitat (one with and one without nutrient addition), a braided reach, and a meandering reach (Table 1).

The Kootenai River has three major geomorphically distinct reaches in downstream orientation: the canyon, braided, and meandering reaches. The canyon reach (rkm 352–258) extends from Libby Dam downstream to the mouth of the Moyie River in Idaho. This reach is characterized by relatively high gradient and hydraulic energy. Substrates in the canyon reach range from exposed bedrock to boulders, cobble, and gravels.

Immediately downstream from the canyon reach, the short braided reach (rkm 258–246) extends from the mouth of the Moyie River to the Highway 95 Bridge at Bonners Ferry, Idaho. The braided reach is characterized by a series of braided channels with reduced slope and hydraulic energy compared to the upstream canyon reach. Braided reach substrates are typically gravels to sand and fine sediments in the off channel habitats.

Further downstream, the meander reach extends from Bonners Ferry downstream to the river delta at Kootenay Lake (rkm 246-120). The meander reach lies entirely within the historic floodplain within the Purcell Trench, a glacial valley that runs north from Bonners Ferry into British Columbia, forming the basin for Kootenay Lake (Figure 1). The meander reach is characterized by very low gradient, low hydraulic energy, and fine substrates, mainly silt and sand.

Table 1. Aquatic macroinvertebrate sampling reach and site attributes.

Orientation	Upstream……				……Downstream
Reach	Unimpounded Reach	Montana Canyon (Control)	Idaho Canyon (Treatment)	Braided Reach (Treatment)	Meander Reach (Treatment)
Locations	BC upstream of Libby Res.	Libby Dam downstream to ID/MT state line	ID/MT state line to Moyie River	Moyie River to Bonners Ferry	Bonners Ferry to Kootenay Lake
Reach (rkm) boundaries		357-276	276-258	258-246	246-120
Sampling Sites (rkm)	KR-14 (445.0)	KR-10 (285.6) KR-11 (310.7) KR-12 (325.0) KR-13 (347.4)	KR-9 (262.2) KR-9.1 (276.1)	KR-6 (250.0) KR-7 (255.4)	KR-1 (123.5) KR-2 (170.0) KR-3 (203.6) KR-4 (231.4)
Features	Natural river conditions; upstream reference site	Canyon habitat with hydropower effects	Canyon habitat with hydropower and fertilization effects	Braided channel reach with hydropower and fertilization effects	Leveed meander habitat with hydropower and fertilization effects
Trophic status[a]	Autotrophic	Autotrophic	Autotrophic	Autotrophic	Heterotrophic

a: Autotrophic: Photosynthesis > respiration Heterotrophic: Photosynthesis < respiration;

METHODS

Experimental nutrient addition treatment

Experimental nutrient addition treatments began in the Kootenai River at the Idaho-Montana border (KR-9.1, rkm 276.1; Figure 1) in July of 2005 in response to a series of previous studies that documented the nutrient poor (ultraoligotrophic) conditions in the Kootenai River following loss of the historic floodplain and impoundment (Daley et al. 1981; Woods 1982; Snyder and Minshall 1994, 1995, 1996; Snyder 2001, 2005). Target in-river phosphorus concentrations were 1.5 µg/L during 2005 and 3.0 µg/L during 2006 and 2007 (KTOI 2005, 2006, 2007). No nitrogen was added during these years because no nitrogen limitation (< 60 µg/L) was observed based on weekly water sampling upstream and downstream of the nutrient addition site. (Hoyle 2005 2006, 2007)

Data availability

With the exception of three sampling sites (KR-3.1, KR-5.1 and KR-8) most sites have data for most years from 2000 through 2006 (Table 2). Alternatively, sites KR-6, KR-9, and KR-9.1 were established part way into the study (Table 2). Analyses in this report used only data from 2003 through 2006.

Table 2. Macroinvertebrate data availability matrix by year and by site.

	Year						
Site	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
KR1	▨	▨	▨	▨	▨	☐	▨
KR2	▨	▨	▨	▨	▨	☐	▨
KR3	▨	▨	▨	▨	▨	▨	▨
KR3.1	☐	☐	☐	▨	☐	☐	☐
KR4	▨	▨	▨	▨	▨	▨	▨
KR5.1	▨	▨	☐	☐	☐	☐	☐
KR6	☐	☐	☐	▨	▨	▨	▨
KR7	▨	▨	▨	▨	▨	▨	▨
KR8	☐	▨	☐	☐	☐	☐	☐
KR9	☐	▨	▨	▨	▨	▨	▨
KR9.1	☐	☐	☐	☐	▨	▨	▨
KR10	▨	▨	▨	▨	▨	▨	▨
KR11	▨	▨	▨	▨	▨	▨	▨
KR12	▨	▨	▨	▨	▨	▨	▨
KR13	▨	▨	▨	▨	▨	▨	▨
KR14	▨	▨	▨	▨	▨	▨	▨

▨ - Data Available
☐ - Data not Available

Field sampling protocols

Field sampling was designed to represent and characterize aquatic macroinvertebrate community attributes along a longitudinal gradient of environmental conditions in the Kootenai River: (1) upstream and downstream from Libby Dam; (2) before and after experimental nutrient addition; and (3) upstream and downstream from nutrient addition.

Macroinvertebrate samples were collected monthly at up to 13 sites (KR-1 through KR-14; excluding KR-8) from Wardner B.C. downstream into Montana and through Idaho to Kootenay Lake, B.C. (Figure 1) from April to October, 2002 through 2006, as flow conditions permitted. Six macroinvertebrate samples were taken at each site, three representing near-shore or shallower habitat conditions (depth 1-5 m) and three representing mid-channel habitat conditions (depth 6-18m) within the meander reach (KR1-4), and within shallow riffle habitats (0.25-0.75 m) at sites KR-5.1 to KR-14. Quantitative sampling gear (Ponar, Hess, and modified slack sampler) was used at all sites.

Various benthic macroinvertebrate sampling gear was used because substrate type and particle size varied within and among the study reaches. A slack sampler (modified Surber Sampler) was used at sites KR-6 through KR-13 given the riverine habitat conditions at these sites (e.g. gravel/cobble and higher current velocities). A Hess sampler was used at KR-14, and a boat-mounted Ponar dredge was used within the meander reach (sites KR-1 through KR-4) to effectively sample macroinvertebrates in fine sediments or sand substrates.

A 500 mm mesh size was used for all samplers and sorting screens according to EPA standards (Barbour et al. 1999). Insect samples were preserved in 70% ethanol until they were sorted and identified. Whole samples were sorted in the lab using a 2X viewing lens. Invertebrate specimens were shipped to EcoAnalysts, Inc. in Moscow, Idaho for taxonomic analysis, enumeration, and analyses of community attributes. Biomass of individual invertebrate samples was determined at the University of Idaho Holm Research Center in Moscow, Idaho.

Summary statistics

Biological and ecological response variables.—Nineteen biological and ecological response variables were evaluated and reported as bar charts by site and by year for all sites and periods of data availability (Table 2). Response variables included: abundance, biomass, total richness (# of species), richness by taxonomic order (for EPT), numerical and percent richness by feeding ecology functional group (e.g. filterer, gatherer, predator and scraper (Table 3).

Abundance, Biomass, and Species Richness.—Bar charts and line plots of total invertebrate abundance (number/m^2) biomass (g/m^2), and species richness (richness) were produced for all available samples by site and by year from 2003 through 2006.

EPT Richness. —Line plots for richness (number of taxa) for Ephemeroptera, Plecoptera, and Trichoptera (EPT) combined and separately were produced for all available samples by site and by year from 2003 through 2006. Bar charts depicting changes in response variables listed in Table 3 from 2003 through 2006 were also generated.

Table 3. Aquatic macroinvertebrate response variables evaluated from 2003 through 2006.

Response variable	Units
Abundance	Numbers/m^2
Biomass	g/m^2
Richness	Overall number of species sampled
EPT_Richness	Number of species in the Orders Ephemeroptera, Plecoptera and Trichoptera
E_richness	Number of species in the Order Ephemeroptera
P_richness	Number of species in the Order Plecoptera
T_richness	Number of species in the Order Trichoptera
Filterer_richness	Number of species in “Filterer” functional group
Gatherer_richness	Number of species in “Gatherer” functional group
Predator_ richness	Number of species in “Predator” functional group
Scraper_richness	Number of species in “Scraper” functional group
p_ Ephemeroptera	% of Order Ephemeroptera
p_ Plecoptera	% of Order Plecoptera
p_ Trichoptera	% of Order Trichoptera
p_ Filterers	% of “Filterer” functional group
p_ Gatherers	% of “Gatherer” functional group
p_ Predator	% of “Predator” functional group
p_ Scraper	% of “Scraper” functional group

Shannon	Shannon's index of diversity

Richness by Functional Feeding Guilds.—Richness for invertebrates grouped by functional feeding guild (filterers, gatherers, predators, and scrapers; Table 3) were plotted by site and by year for all sites from 2003 through 2006.

Order composition.—Mean abundance (number/m^2) by taxonomic order, by site (KR-1 through KR-14), and by year (2003 through 2006) were calculated for all sites and years for which data were available. Bar charts depicting abundance of available orders were also produced for each site and year (2003 through 2006).

EPT Species composition.—Pie charts indicating species composition for invertebrate specimens within Ephemeroptera, Plecoptera, and Trichoptera (EPT) at sites KR-9 and KR-9.1 were produced for 2003 through 2006. No data were collected from KR-9.1 during 2003 because site KR-9.1 was not established until 2004.

Taxonomic analyses across trophic level: Invertebrates and algal accrual rate.—Total chlorophyll accrual rate (mg/m2/30d) were calculated and compared over sites and years. Algal accrual rates were compared with chironomid abundance at site KR-9.1 and presented as a bar and line chart.

Taxonomic analyses across trophic level: Invertebrate and fish.—A series of taxonomic trend analyses were performed to investigate ecological linkage and possible responses across trophic levels (trophic cascading effects) during pre-treatment and treatment years (2004 through 2006). Analyses included in-river data from a series of separate invertebrate taxa groups individually compared with analogous taxonomic data in fish (mountain whitefish, *Propospium williamsonii*) stomach content samples at the nutrient addition and ecological response sites of KR-9 and KR-9.1. Fish stomach content samples were only collected at KR-9 during all years.

Individual analyses included comparisons of:

1. Taxa composition and dynamics among Chironomidae in the river and in mountain whitefish stomach contents;
2. Taxa composition and dynamics among Coleoptera in the river and in mountain whitefish stomach contents;
3. Taxa composition and dynamics among Diptera in the river and in mountain whitefish stomach contents; and
4. Taxa composition and dynamics among Ephemeroptera in the river and in mountain whitefish stomach contents;

Site comparisons across years (2004 through 2006) were also performed for the above analyses. All results were presented as pie, line, and bar charts.

Quantitative methods

Principal Components Analysis (PCA).—Data for all PCA runs were selected to represent taxonomic orders and metrics that were common in samples from all dates at those sites or site combinations. Principle components analysis was performed to reduce the dimension of macroinvertebrate data and to determine which taxonomic groups or metrics were contributing significantly to the observed variation. Results of the PCA analyses were tabulated to indicate eigenvalues, proportion, and cumulative percent variation, as well as eigenvectors (loadings) for each of the components. Biplot graphic displays (Shafii 1993; Shafii and Price 1998) were also generated to investigate the pattern and structure of the underlying variation.

Additional analyses were presented for pre- and post-fertilization treatment at the KR9 and KR9.1 combination of sites and at KR-10. Principal Components Analysis of response variables were conducted for sites KR-9.1, KR-10 and KR-14 separately and sites KR-9 and KR-9.1 combined for all sites and years for which data were available. All principle components analyses were performed using SAS (2004).

Analysis of variance (ANOVA).—ANOVA was performed using data from 2003 through 2006 to investigate the average macroinvertebrate abundance, biomass, and richness responses to the nutrient addition treatment (Table 4), and to test for site effects on these metrics. Abundance and biomass responses were logarithmically transformed to meet statistical requirements of the analyses. Analysis of variance tables, least squares means tables, and a table of predetermined contrasts for reach effects were provided as output. All ANOVA procedures were performed using SAS (2004).

Invertebrate response to nutrient addition.—Experimental nutrient addition in the Kootenai River began in 2005 with target in-river phosphorus concentrations of 1.5 μg/L during 2005 and 3.0 μg/L during subsequent years. ANOVA was used to assess the average aggregated invertebrate abundance, biomass, richness responses. Taxonomic order composition was also evaluated in the zone of maximum expected response (sites KR-9.1 and KR-9 combined) with analogous testing at KR-10 (the control site upriver from nutrient addition).

Table 4. Objectives tested with ANOVA to assess effects of experimental nutrient addition on invertebrate abundance, biomass, richness, and taxonomic order composition in the Kootenai River at sites KR-9 and KR-9.1 for all years sampled.

Response Metric	Objectives
Abundance	Determine if experimental nutrient addition had a significant effect on average aggregated macroinvertebrate abundance at sites KR-9 and KR-9.1 combined.
Biomass	Determine if experimental nutrient addition had a significant effect on average aggregated macroinvertebrate biomass at sites KR-9 and KR-9.1 combined.
Richness	Determine if experimental nutrient addition had a significant effect on average macroinvertebrate richness at sites KR-9 and KR-9.1combined.
Order composition	Determine if experimental nutrient addition had a significant effect on average macroinvertebrate order composition at sites KR-9 and KR-9.1 combined.

Trophic Level Interactions

We also investigated potential cascading trophic interactions in the Kootenai River using empirical primary production (algal accrual), invertebrate measures, and fish stomach content data, from the perspective of the invertebrate community. This investigation included data from the zone of maximum biological response (KR-9 and KR-9.1) and the immediate upriver control site (KR-10) only to best characterize potential responses to nutrient addition across trophic levels. Algal accrual before and after nutrient addition was presented in bar charts by site and by year. Total algal accrual and corresponding chironomid counts before and after nutrient addition were presented in a line and bar chart. A stack bar chart was used to present taxa composition of chironomid taxa in mountain whitefish (*Prosopium williamsonii*) gut content samples. A bar chart was used to present a site comparison of chironomid frequency at KR-9 in river and fish gut samples because no fish stomach data have been collected to date at KR-9.1.

RESULTS

Summary statistics

Field sampling from 2003 through 2006 at all sites produced a total of 179,180 metric observations covering 27 invertebrate taxa collected in the Kootenai River (Table 5 and Table 6). More detailed taxonomic frequency data are presented in Appendix A.

Table 5. Annual and total number of observations for invertebrate metrics in the Kootenai River at all sites sampled from 2003 through 2006.

Year	Number of observations
2003	51,576
2004	78,368
2005	31,062
2006	18,174
Total, all yrs.	179,180

Table 6. Higher level taxonomic groups represented by aquatic macroinvertebrate sampling in the Kootenai River at all sites from 2003 through 2006.

Acari	Heterostropha
Amphipoda	Hydroida
Annelida	Lepidoptera
Arachnida	Lumbricina
Arhynchobdellida	Nematoda
Basommatophora	Odonata
Bivalvia	Oligocheata
Chironomidae	Plecoptera
Coleoptera	Rhynchobdellida
Crustacea	Trichoptera
Diptera	Turbellaria
Ephemeroptera	Unionoida
Gastropoda	Veneroida
Hemiptera	

Abundance.—Aggregated invertebrate abundance was more spatially variable during the post-treatment years (2005, 2006) than during 2003 and 2004 (Figure 2). The data exhibited a general trend in a downstream direction from the highest values of nearly 14,000 organisms/m^2 at sites KR-11 and KR-13 during 2005 and 2006 to less than 2,000 at the furthest downstream sites, KR-1 through KR-4 during all years (Figure 2). Aggregated abundance was greatest in the canyon reach, followed by abundance at braided and meander reach sites (Figure 2).

The unimpounded upstream reference site (KR-14) had lower invertebrate abundance values than all canyon reach sites downstream from Libby Dam, and had comparable values with the braided and meander sites during pre-treatment years. The highest abundance values were observed during 2006 both upstream and downstream from the nutrient addition site. Abundance typically increased during each of the four consecutive years, with the largest response at the nutrient addition site (KR-9.1), which had the greatest abundance during treatment years and was positively correlated with in-stream nutrient targets among years (Figure 2).

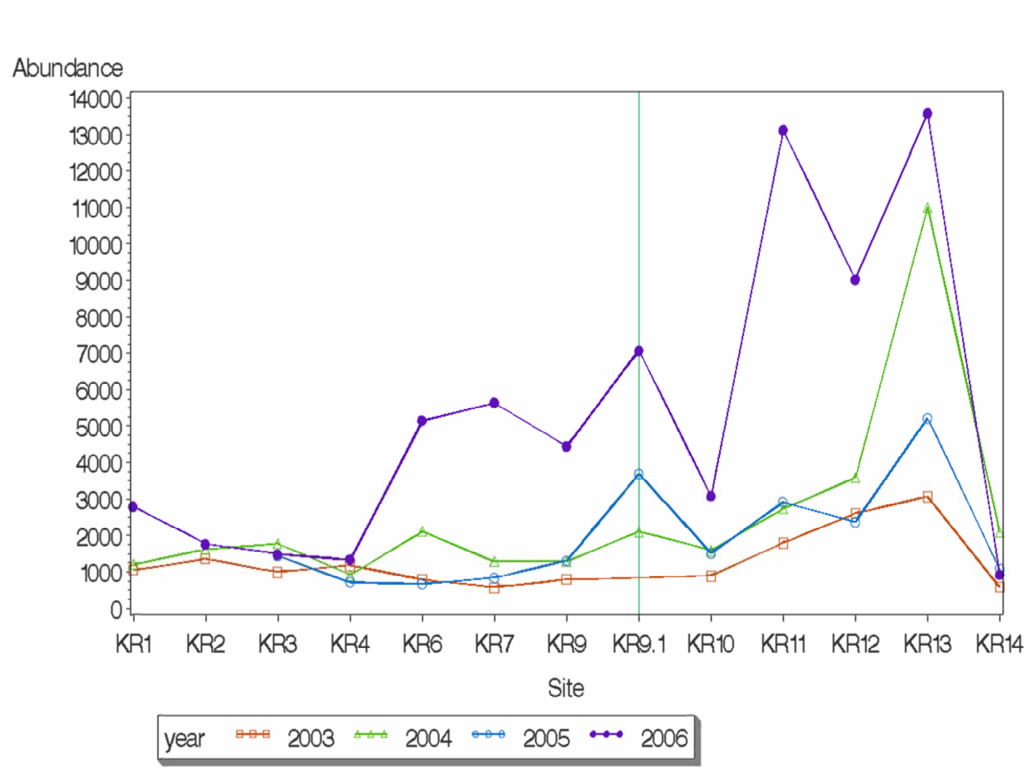


Figure 2. Aggregate abundance (numbers/m^2) of aquatic benthic macroinvertebrates sampled in the Kootenai River, Idaho, Montana, and British Columbia, from 2003 through 2006. The vertical line at KR-9.1 represents the nutrient addition site; downstream orientation is from right to left.

Biomass.—Aggregated invertebrate biomass exhibited a decreasing downstream trend over the study area during all years (Figure 3) similar to that of aggregated abundance (Figure 2). Aggregated invertebrate biomass during all years in the meander reach was very low ($\leq$ 1 g/m^2) compared to upriver meander and canyon sites, which ranged from < 1 to about 2.5 g/m^2 (Figure 3). Biomass was much greater and more variable (1.5–4.5 g/m^2) at sites from KR-7 through KR-13 during 2006 than during any other years.

However, higher biomass values and associated variability extended farther downstream compared to the aggregated abundance trend (Figure 2 and Figure 3).

As with aggregated abundance, the highest biomass values occurred during 2006 in all locations except the meander reach (KR-1 through KR-4), while biomass values at the nutrient addition site increased every year (Figure 3). However, unlike abundance, peak biomass values occurred both upstream and downstream from the nutrient addition site (Figure 3). Aggregated biomass values, like aggregated abundance values at the upriver reference site (KR-14) were lower than all corresponding values at the downstream canyon and braided reach sites (KR 6 through KR-13), and were similar in magnitude to the less productive (heterotrophic) meander reach sites during most study years (Figure 3).

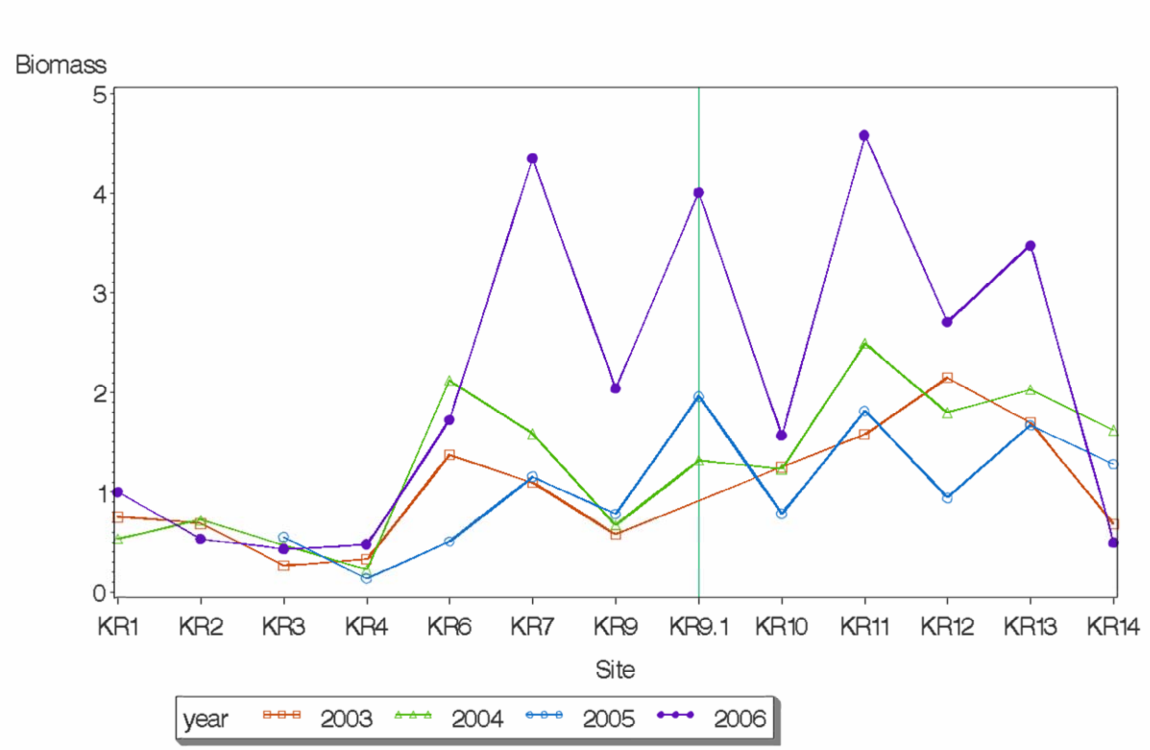


Figure 3. Aggregated biomass (g/m^2) of aquatic benthic macroinvertebrates sampled in the Kootenai River, Idaho, Montana, and British Columbia, from 2003 through 2006. The vertical line at KR-9.1 represents the nutrient addition site; downstream orientation is from right to left.

Richness.—Aggregated invertebrate richness (number of species) showed a decreasing downstream trend (Figure 4) similar to aggregated abundance and biomass (Figure 2 and Figure 3). Richness values ranged from 3 to 13 in the meander reach and the upstream reference site (KR-14), and from 15 to 30 in the braided and canyon reach sites (Figure 4). Similarly, but less distinctly than observed for aggregated abundance and biomass, richness values in the canyon and meander reaches were elevated relative to the upriver reference and downstream meander reach sites (KR-14 and KR-1 through KR-4; Figure 4).

However, unlike aggregated abundance and biomass, richness: (1) exhibited a marked single peak at the nutrient addition site and the adjacent downstream site (KR-9.1 and

KR-9.1) during 2006; and (2) exhibited a consistent drop of > 50% between canyon and braided reach sites and the downstream meander reach sites during all years (Figure 4).

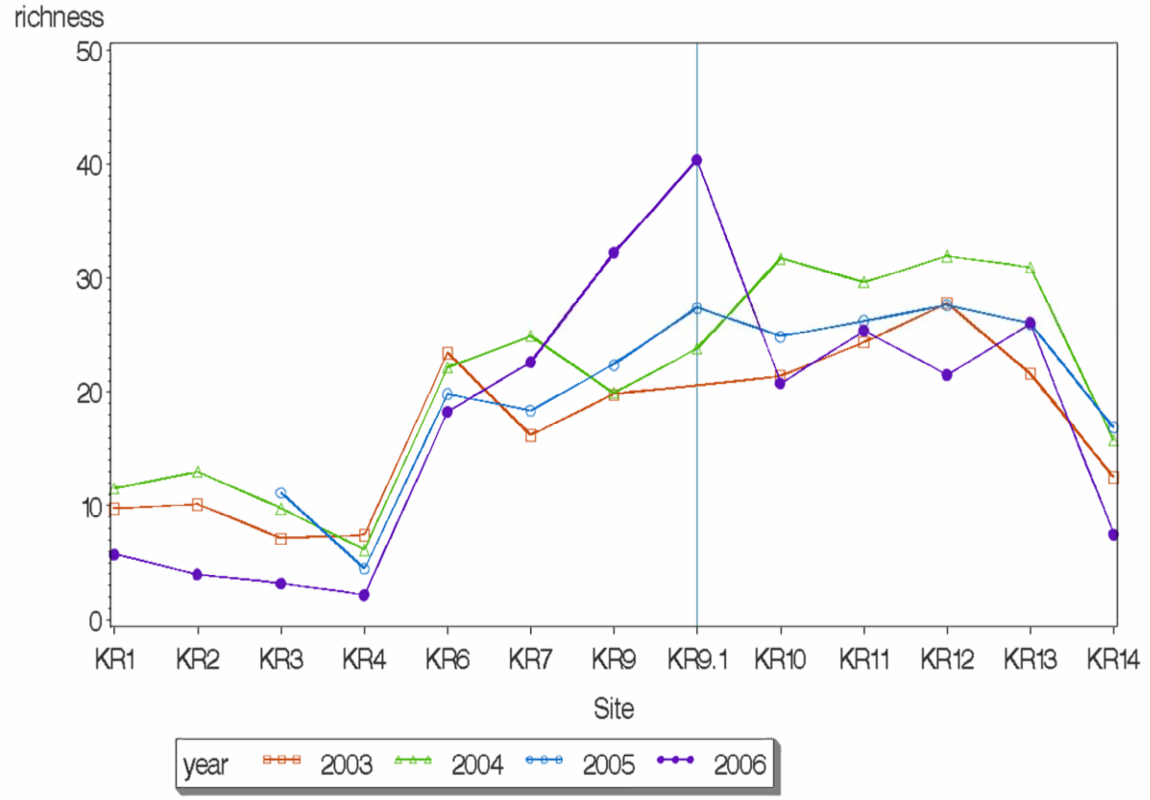


Figure 4. Aggregated species richness (number of taxa) of aquatic benthic macroinvertebrates sampled in the Kootenai River, Idaho, Montana, and British Columbia, from 2003 through 2006. The vertical line at KR-9.1 represents the nutrient addition site; downstream orientation is from right to left.

EPT richness.—Richness among taxa of Ephemeroptera, Plecoptera, and Trichoptera (EPT) collectively was relatively stable across most of the canyon and braided reach sites (KR-6 through KR-12) during all years, with elevated values during 2006 both downstream and upstream from the nutrient addition site (Figure 5). EPT richness was consistently at least 4 times greater at nearly all canyon and braided reach sites (range 8-17, KR-6 through KR 12) than in the meander sites during all years (range 0-2; KR-1 through KR-4; Figure 5). EPT richness was also lower at the upstream reference site (KR-14) and the Libby Dam tailwater site (KR-13) than at the canyon reach sites, ranging from about 6 to 10 upstream, with the exception of KR-13 during 2006, where EPT richness peaked above 14 taxa (Figure 5).

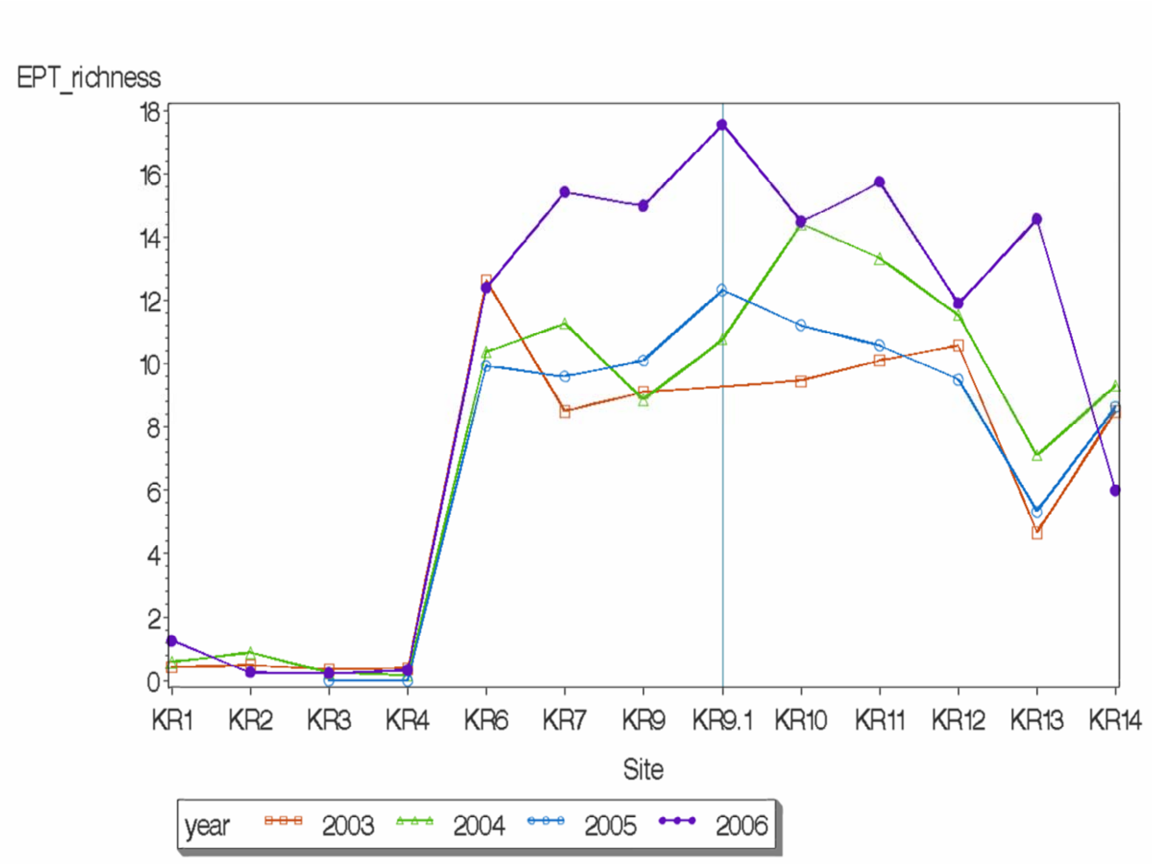


Figure 5. EPT richness in the Kootenai River, Idaho, Montana, and British Columbia, from 2003 through 2006. The vertical line at KR-9.1 represents the nutrient addition site; downstream orientation is from right to left.

EPT richness by individual taxonomic order.—Richness for invertebrates within Ephemeroptera (Figure 6) had a similar distribution to the combined EPT richness plots (Figure 5). Richness for all three orders (EPT) also dropped dramatically in the downstream meander reach (Figure 6). Ephemeroptera in samples from the braided and canyon reaches revealed increasingly elevated richness during 2005 and 2006 (post-treatment years) compared with pre-treatment years of 2003 and 2004.

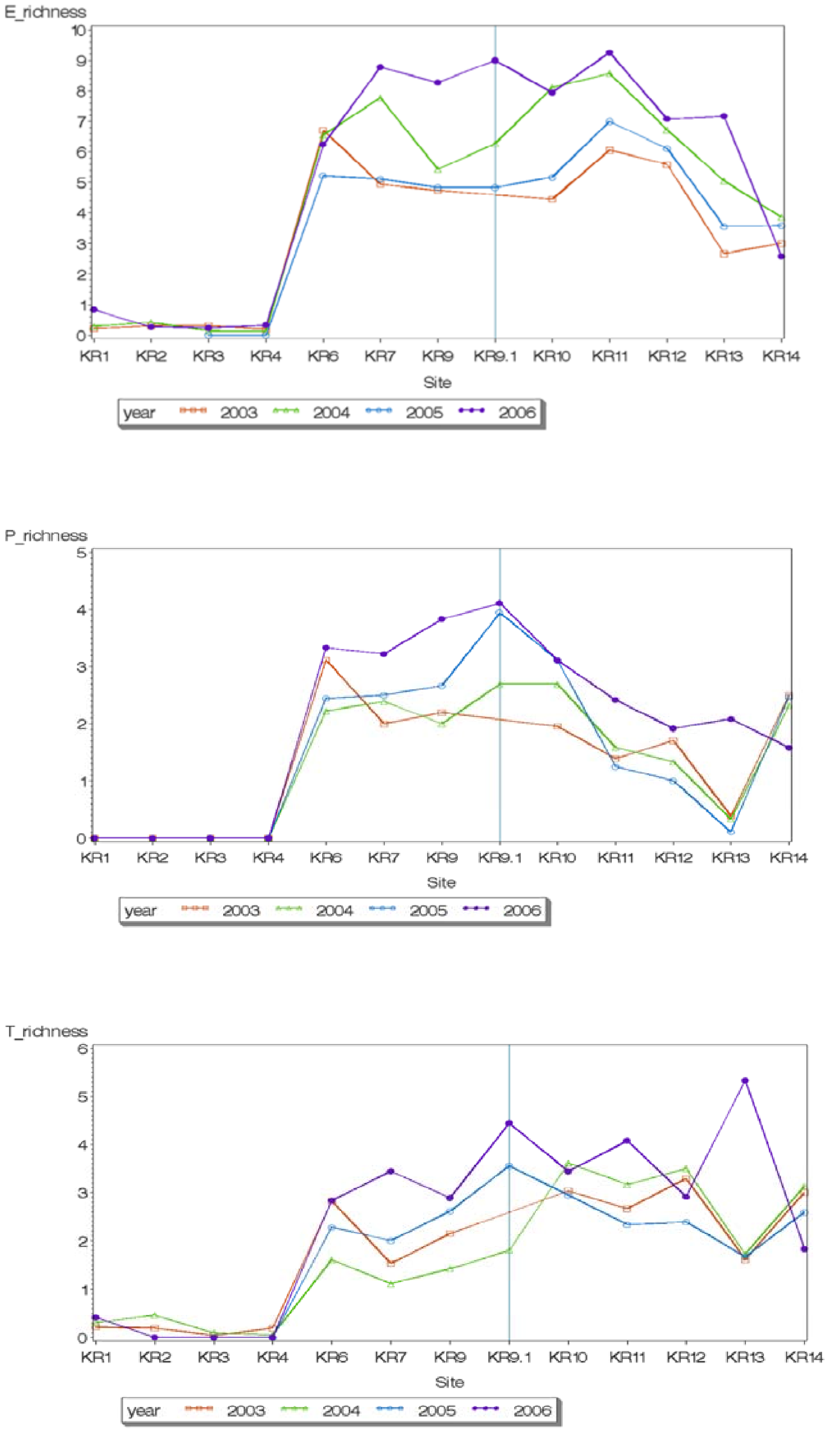


Figure 6. Ephemeroptera, Trichoptera, and Plecoptera (EPT) richness in the Kootenai River, Idaho, Montana, and British Columbia, from 2003 through 2006. The vertical line at KR-9.1 represents the nutrient addition site; downstream orientation is from right to left.

Order composition.—Invertebrate taxonomic composition at the order level exhibited a predominant longitudinal feature across years, delineated by the boundary between the heterotrophic meander reach and the autotrophic upstream sites. Upstream from this boundary the river habitat is typically characterized by higher gradient, higher hydraulic energy, and larger particle size (Table 1). Invertebrate orders sampled at the canyon, braided and upstream reference sites (KR-6 through KR-14) were typically dominated by Ephemeroptera, Diptera, Plecoptera, and Trichoptera (Figure 7), whereas the heterotrophic, low energy meander reach sites, characterized by fine sediment and sand substrates were dominated by annelids, chironomids, and oligochaetes. A graphical representation of invertebrate taxonomic (order) composition at KR-9, KR-9.1, and KR-10 for years sampled is provided in Appendix B. Contact KTOI for additional information regarding the remaining sites.

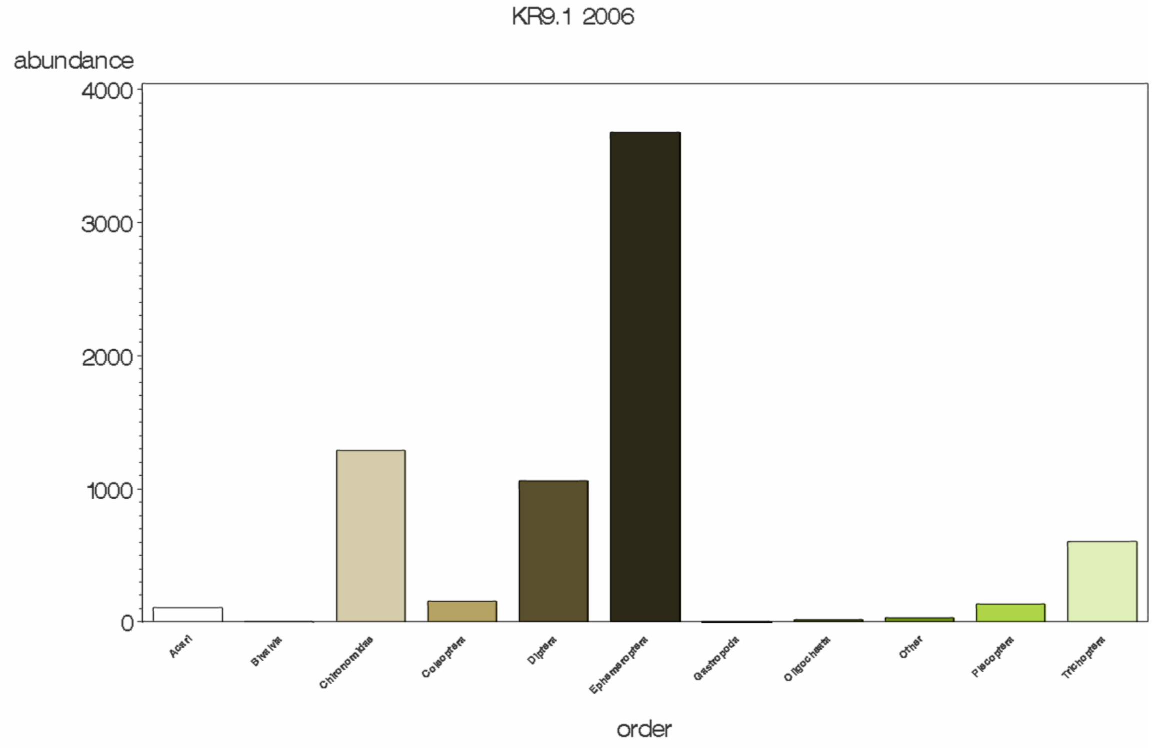


Figure 7. Abundance of invertebrate taxa representative of the canyon reach.

Taxa composition.—A complete characterization of species composition for Ephemeroptera, Plecoptera, and Trichoptera sampled at KR-9 and KR-9.1 is presented in Appendix C.

Sites KR-9, KR-9.1 and KR-10, Chironomidae: Comparisons of frequency counts of Chironomidae sampled at KR-9, KR-9.1, and KR-10 indicated a general increase at KR-9 and KR-9.1 over time, with the largest increase at KR-9.1 between pre-treatment and treatment years (Figure 8). Chironomidae at KR-10 was relatively stable among years (Figure 8). A large increase in frequency was observed during 2006, represented by a large increase in *Orthoclades spp*. at KR-9, with a larger increase during 2006 (Figure 9).

Sites KR-9, KR-9.1 and KR-10, Ephemeroptera: Comparisons of frequency counts of Ephemeroptera sampled at KR-9, KR-9.1, and KR-10 indicated a general increase at KR-9 and KR-9.1 over time, with the largest increase at KR-9.1 between pre-treatment and treatment years (Figure 8). Ephemeroptera at KR-10 was also stable or decreasing, with the 4 dominant taxa observed during 2004 and 2005 not present in 2006. Relatively proportional increases in frequency were observed for dominant Ephemeroptera taxa *Ephemerella* and *Rhithrogena* at KR-9 in 2006 compared to previous years, whereas a much larger increase was seen at KR-9.1 in 2006, due to a larger increase in *Ephemerella spp.* (Figure 10).

At sites KR-9, KR-9.1 and KR-10 Coleoptera species showed a similar but lower magnitude response across years, with highest frequencies observed during 2006 relative to previous years, with the exception of Site KR-9 (Figure 8). A systematic decrease in abundance over time was observed for Coleoptera among years at KR-9, with *Zaitzevia spp.* specifically decreasing in abundance (Figure 11). Alternatively, a systematic increase in abundance over time was observed at KR-9.1, with *Zaitzevia* and *Optioservus spp.* increasing in abundance (Figure 11).

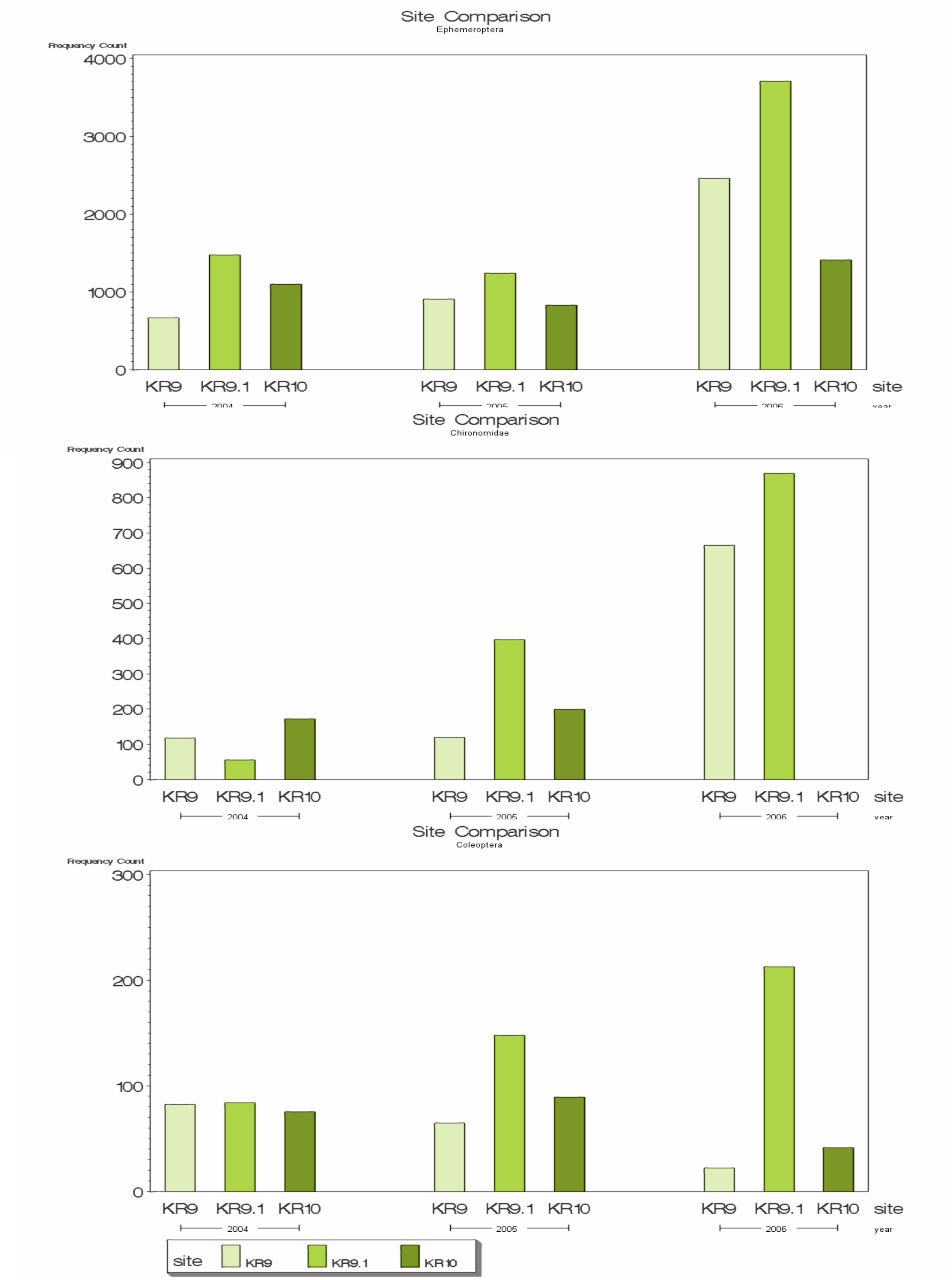


Figure 8. Frequency comparisons among Ephemeroptera, Chironomidae, and Coleoptera by site and by year at KR-9, KR-9.1, and KR-10 before and during initial two years of nutrient addition.

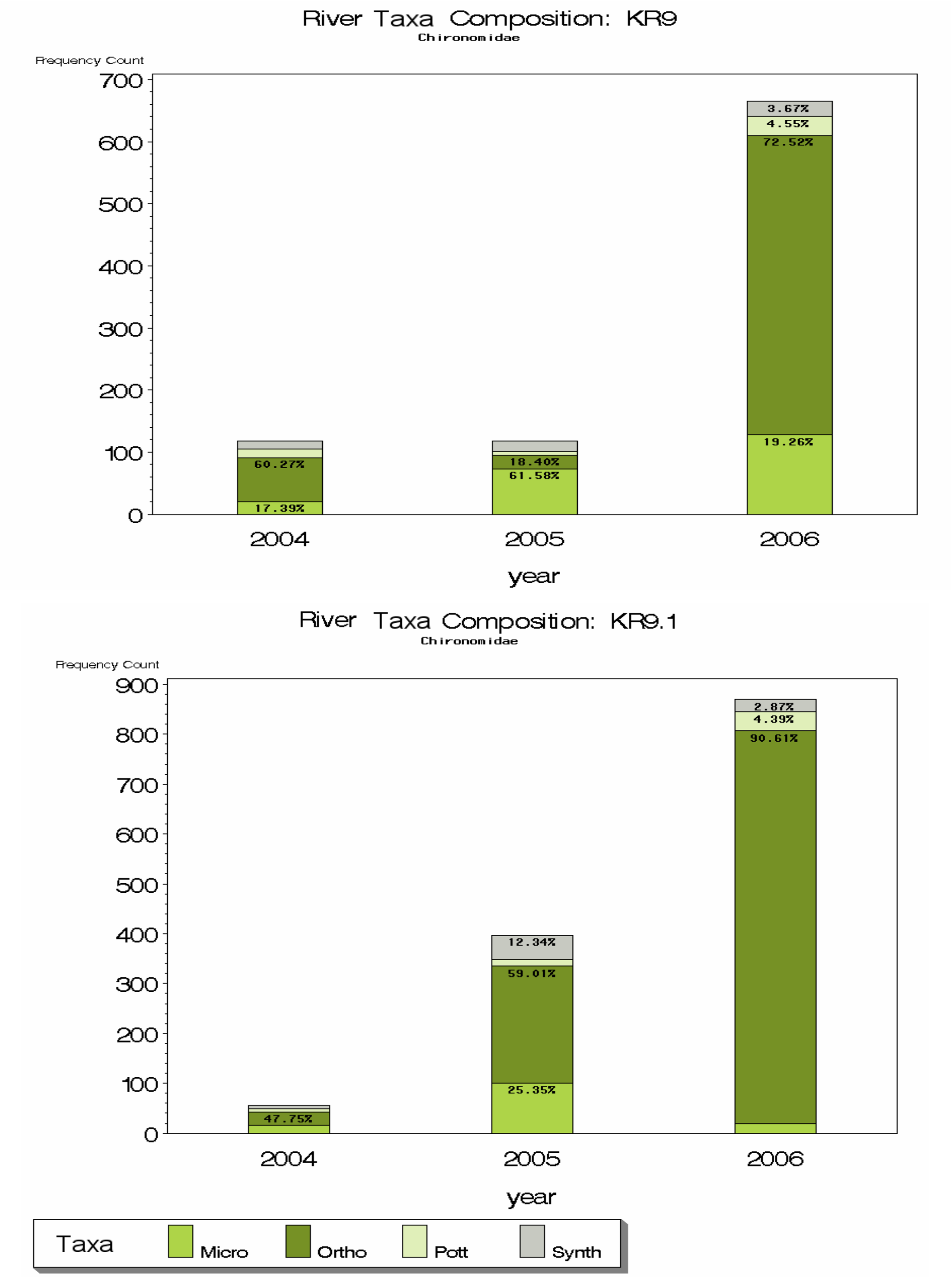


Figure 9. Frequency of chironomid taxa at KR-9 and KR-9.1 before and after initial experimental nutrient addition.

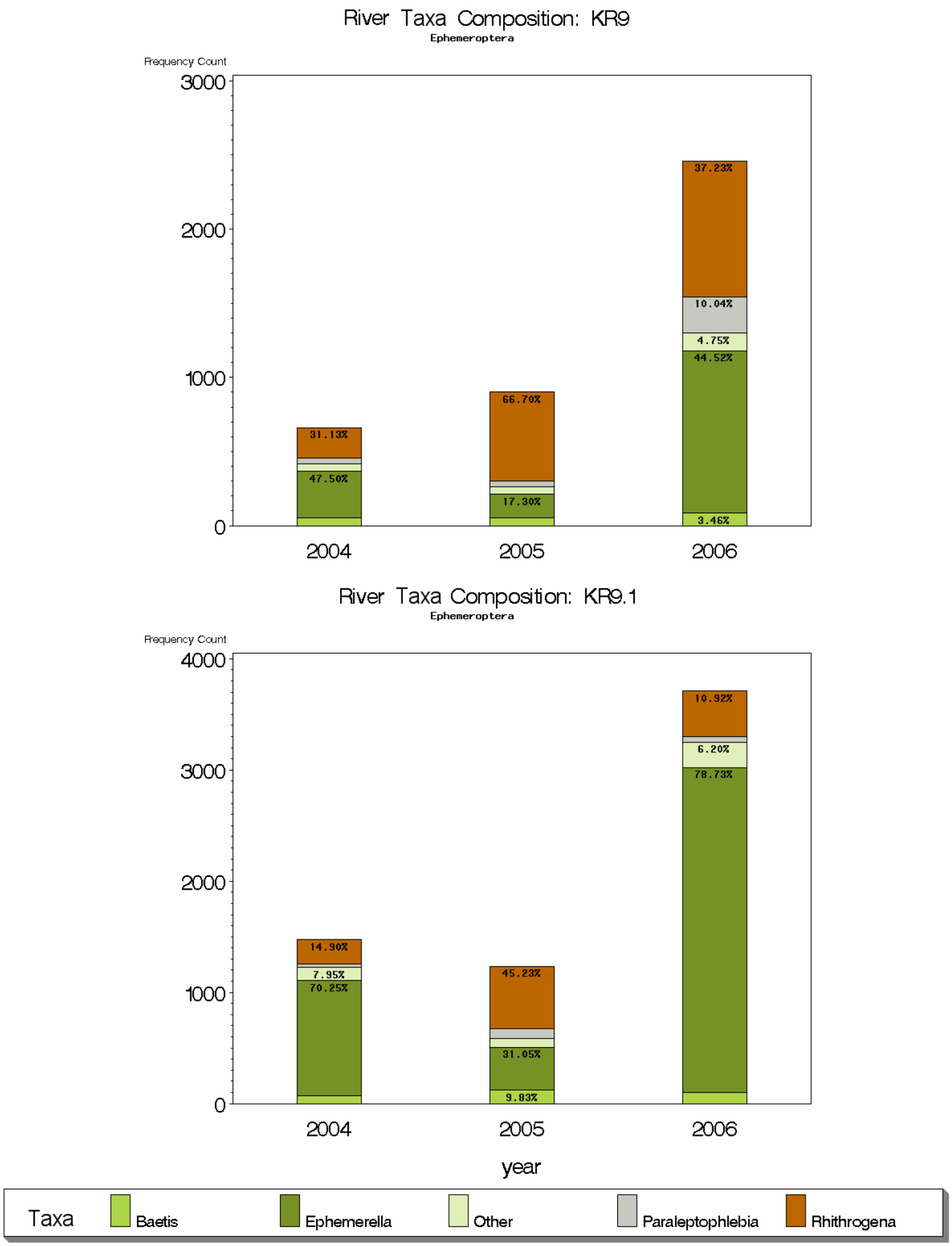


Figure 10. Frequency of Ephemeroptera taxa at KR-9 and KR-9.1 before and after initial experimental nutrient addition.

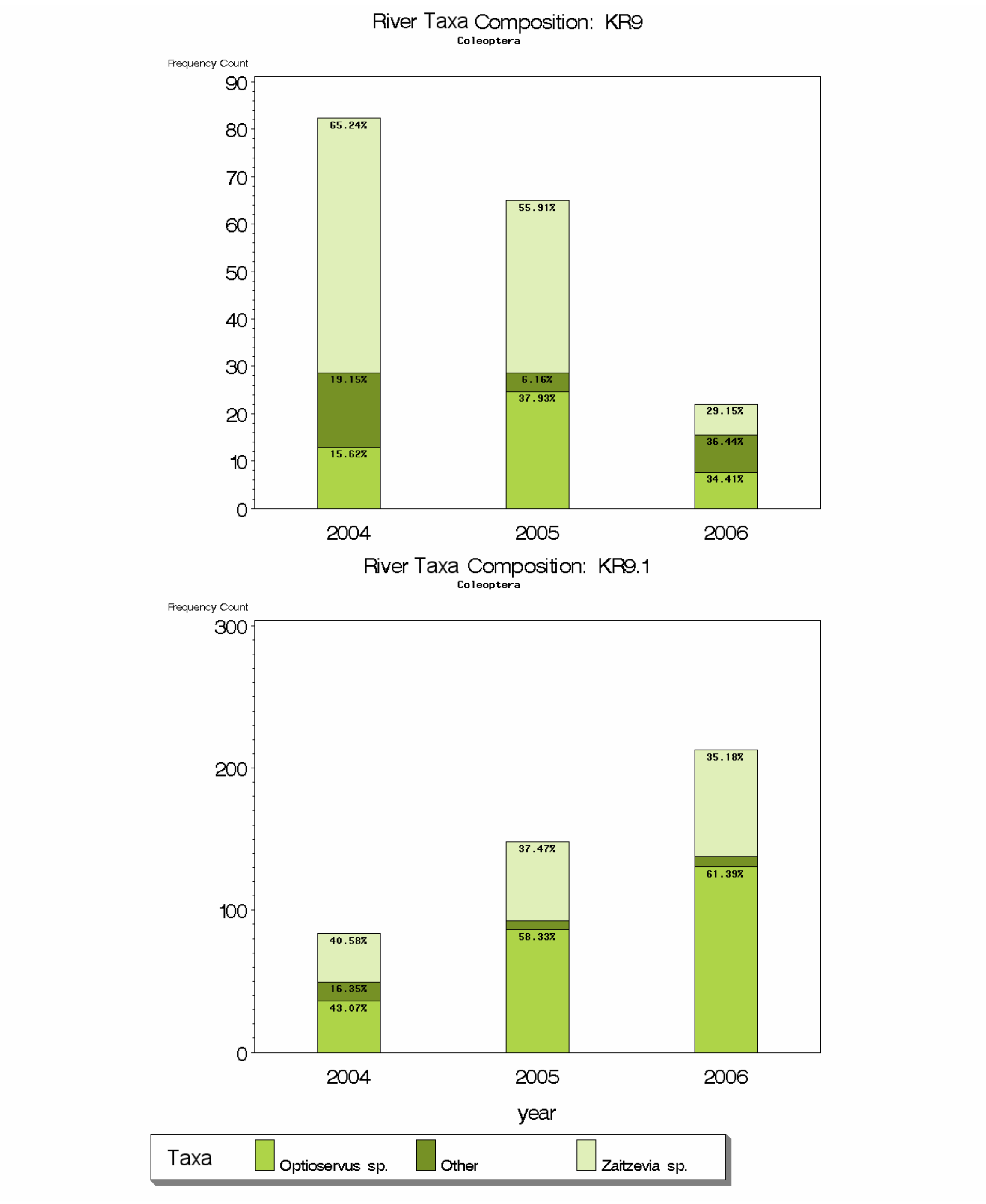


Figure 11. Frequency of Coleoptera taxa at KR-9 and KR-9.1 before and after initial experimental nutrient addition.

Total invertebrate richness and richness by taxa (EPT) were also evaluated by site, year, and month (Table 7). The largest response across all metrics was typically observed at KR-9 and KR-9.1, the nutrient addition response zone. A complete graphical representation of all metrics at KR-9, KR-9.1 and KR-10 is provided in Appendix D. Contact the KTOI for additional detail from additional sample sites.

Table 7. Summarized total invertebrate and Ephemeroptera (E), Plecoptera (P), Trichoptera (T), and Coleoptera (C) richness trends by reach. See Appendix D for all corresponding plots.

Reach	Total Richness (all taxa)	E -Richness	P-Richness	T-Richness	C-Richness
Unimpounded Reference (KR-14)	Lower than autotrophic downstream sites (higher than meander sites), high temporal variability within years, decreasing trend across years and within seasons	Lower than autotrophic downstream sites, high temporal variability within years; no real trend across yrs.	Decreasing seasonal trends during 04 and 05; 06 very low in comparison to 2004 and 2005.	Lower than autotrophic downstream sites, high temporal variability within years; decreasing trend within and across years	Big drop in 2006 at KR-14 like seen at KR-6 and 7 (downstream control canyon sites); high temporal variability within years during 2004 and 2005
Montana Canyon (Control) (KR10-13)	Richness higher, typically decreasing over years and within seasons at KR-12 and KR-13	High temporal variability w/i years and sites; Decreasing temporal trend in 2006	Consistently mid-summer lows; limited within-season increase, High spike at KR-13 in April 06 (hydro/Fisher?); KR-13 otherwise very low during all years	High temporal variation within years and sites; increasing trend in 04 across sites; highest richness at KR-13 in April 2006	Consistent big drop in 2006 at all control sites; 04 and 05 had high temporal variability within years and sites
Idaho Canyon (Treatment) (KR6-9.1)	KR 9.1 then 9 highest during 2006 and 2005; high seasonal variability; 05 and 06 not significantly higher than 04 in lower two sites	Considerably higher richness across treatment sites, high temporal variability within years and sites; highest response at 9 and 9.1 in 06	No distinct trends during 2004 thru 2006; seasonal increase at each site within 2005, notable drops mid summer at most trt. Sites; consistent seasonal increases at KR-9.1, including trt and non-trt yrs.	Increased richness relative to mender reach, high temporal variation within years and sites	Increased richness relative to mender reach, high temporal variation within years and sites; highest values in 2006 at KR-9 and 9.1 with temporal decline within 2006. “Positive trt effect didn’t make it to KR 6 and KR-7 during 2006”
Meander Reach (KR1-4)	Generally low spp. Richness. Reduced richness in 2005 and 2006.	Low in 04/No E richness during 2005-2006	No P richness during 2004-2006	No T richness in 05 and 06; only (low) richness in late season 2004, KR-1 and KR-2	Big drop in 2005 and 2006 vs. 2004, with exception of April and May 05 at KR-3

Table 8. Summarized invertebrate richness trends by functional feeding guild by reach and by year. See Appendix D for all corresponding plots. Contact the KTOI for additional detail from additional sample sites.

Reach	Predator Richness	Scraper Richness	Gatherer Richness	Filterer Richness
Unimpounded Reference (KR-14)	Low richness all years; 2006 lower than 04 and 05, peaks in 04 and 05, 2-3 spp; high temporal variability within seasons (yrs)	Lower than control canyon sites; highest during April 04, downward trend over time	Lower than control canyon sites; highest during April 04, downward trend over time; lowest (0) from April through June 2006	Lower than control canyon sites ≤3 spp; highest peaks in 04 and 05; 2006 richness lower, most 0s during 06; high temporal variability within seasons and years.
Montana Canyon (Control) (KR10-13)	Relatively stable across years all control canyon sites, peaks 4-6 spp, typical mid-summer dips	Similar to treatment reach with generally increased richness, peaks 5-6 spp; big peak (10) in April 2006 at KR 13; mid summer dips in richness common	Similar or higher ranges as treatment sites but general decreasing trend over years, from richness peaks about 18-24 down to 5 spp	Considerable temporal variation within years, typically mid-season toughs among years; richness lowest at all control canyon sites during 2006
Idaho Canyon (Treatment) (KR6-9.1)	General trend increasing richness in upstream orientation all years most notable increases during October 2006 at KR 9 and KR 9.1; peaks 4-8+ spp, @ 9.1	Higher richness than meander; standard mid-summer dip; high temporal variability. Values peak at 4-6 spp	Higher richness than meander; standard dip during mid season 2005 at all treatment canyon sites; values at KR-9 and 9.1 highest in treatment years and during 2004	High temporal variability across sites and years (July data missing)
Meander Reach (KR1-4)	Downstream and temporal increase among 4 meander sites during 2004; low to no richness in other years; peaks 2-5 spp, <1 spp at KR-4 all years	Richness in 05 and 06 typically reduced from 04; little seasonality; decreasing upstream direction to nil during 2005 and 2006; Peaks typically ≤ 1 spp	KR 3 and 4 similar, but reduced richness at KR-4; increasing numbers from KR1-2-3, reduced at KR4 upstream 2005; lower 2006 lowest; peaks April May 2005 at KR-3	No richness at KR-4 all sampled months during 05 and 06; decreasing magnitude and frequency in upstream direction and across years.

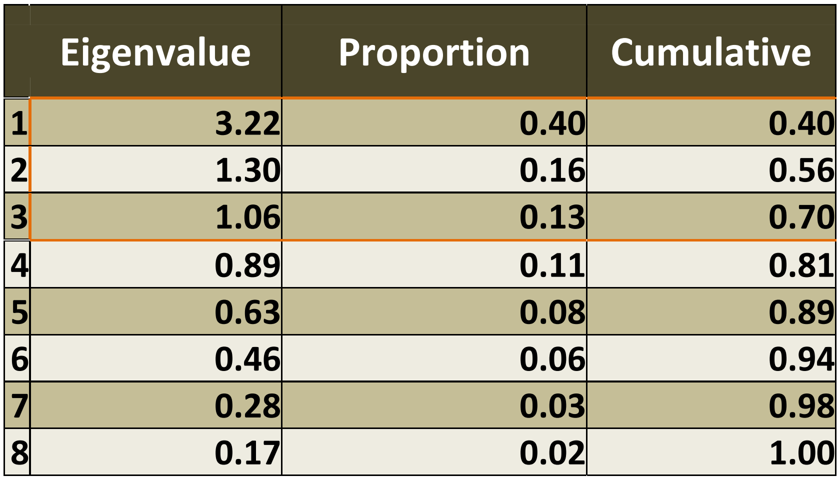
Principle Component Analysis

Principle components analysis was performed to determine which taxonomic groups or metrics were contributing significantly to the observed structure and patterns of variation. PCA output for taxonomic groups is presented below followed by output for the specified metrics (Tables 9-16).

Taxonomic Orders, Sites KR-9 and KR-9.1

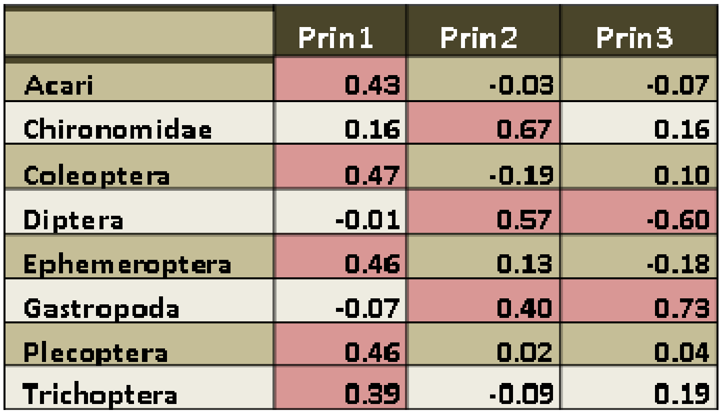
The first three components of the PCA for taxonomic orders at sites KR-9 and KR-9.1 collectively explained 70% of the taxonomic variability at these sites (Table 9). The first component or axis was composed of Acarii, Coleoptera, and EPT, whereas the Chironomidae, Diptera, and Gastropoda comprised the second axis (Table 10). The biplot for this analysis revealed a rightward shift of the data cloud on the first axis (Prin1) in response to nutrient addition, indicating an increase in prevalence of Acari, Coleoptera, and EPT in response to nutrient addition at sites KR-9 and KR-9.1 (Figure 132).

Table 9. Eigenvalue, proportion, and cumulative percentage for the PCA of taxonomic orders sampled at KR-9 and KR-9.1 during all years.



	Eigenvalue	Proportion	Cumulative
1	3.22	0.40	0.40
2	1.30	0.16	0.56
3	1.06	0.13	0.70
4	0.89	0.11	0.81
5	0.63	0.08	0.89
6	0.46	0.06	0.94
7	0.28	0.03	0.98
8	0.17	0.02	1.00

Table 10. Principle component loadings by taxonomic order for three significant principle components generated by the PCA of invertebrate taxonomic orders sampled at KR-9 and KR-9.1 during all years.



	Prin1	Prin2	Prin3
Acari	0.43	-0.03	-0.07
Chironomidae	0.16	0.67	0.16
Coleoptera	0.47	-0.19	0.10
Diptera	-0.01	0.57	-0.60
Ephemeroptera	0.46	0.13	-0.18
Gastropoda	-0.07	0.40	0.73
Plecoptera	0.46	0.02	0.04
Trichoptera	0.39	-0.09	0.19

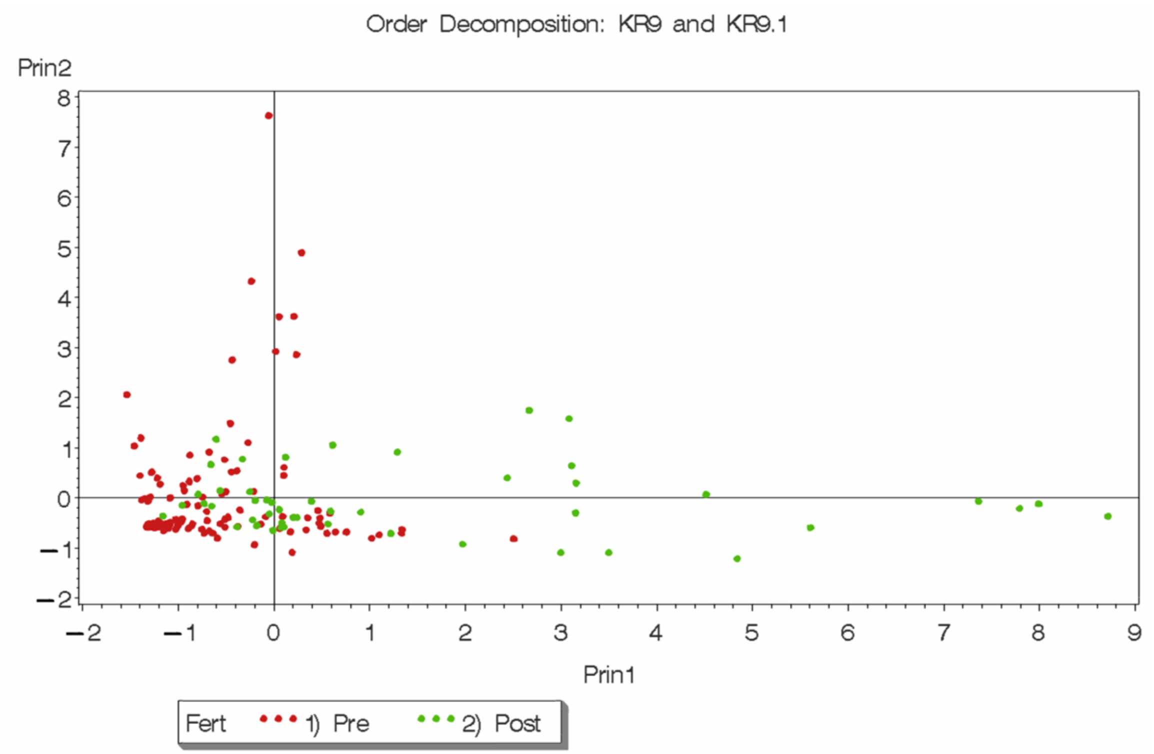


Figure 12. Biplot showing taxonomic order decomposition from Principle Component Analysis for sites KR-9 and KR-9.1 during all years.

Metrics, Sites KR-9 and KR-9.1

The first three components of the PCA for metrics at sites KR-9 and KR-9.1 collectively explained 65% of the taxonomic variability at these sites (Table 11). The first and second components were composed of richness and diversity measures, respectively (Table 12). The biplot for this analysis revealed a split of the first axis by nutrient treatment indicating an increase in richness measures due to nutrient addition (Figure 12).

Table 11. Eigenvalue, proportion, and cumulative percentage for the PCA of metrics sampled at KR-9 and KR-9.1 during all years sampled.

	Eigenvalue	Proportion	Cumulative
1	8.24	0.37	0.37
2	3.14	0.14	0.52
3	2.94	0.13	0.65
4	2.05	0.09	0.74
5	1.12	0.05	0.79
6	0.90	0.04	0.84
7	0.66	0.03	0.87
8	0.54	0.02	0.89

Table 12. Principle component loadings by metrics for three significant principle components generated by the PCA of invertebrate taxonomic orders sampled at KR-9 and KR-9.1 during all years sampled.

	Prin1	Prin2	Prin3
richness	0.33	0.07	-0.16
EPT_richness	0.33	-0.03	-0.09
E_richness	0.24	-0.08	-0.31
% richness	0.29	-0.01	0.13
T_richness	0.28	0.05	0.08
C_Richness	0.26	0.09	-0.31
% Ephemeroptera	0.12	-0.43	0.09
% Plecoptera	0.12	0.07	0.42
% Trichoptera	0.17	0.16	0.25
% Coleoptera	-0.04	0.25	0.12
% Filterers	0.01	0.03	-0.02
% Gatherers	-0.15	0.35	-0.15
% Predators	0.07	0.20	0.38
% Scrapers	0.15	-0.20	0.30
Shannon	0.20	0.34	0.09
Simpson	0.12	0.32	0.18
Hilsenhoff	-0.16	0.41	-0.18
% Tolerant_taxa	-0.12	0.25	-0.06
Filterer_richness	0.26	0.15	-0.02
Gatherer_richness	0.25	0.12	-0.33
Predator_richness	0.28	0.06	0.15
Scraper_richness	0.28	-0.11	-0.17

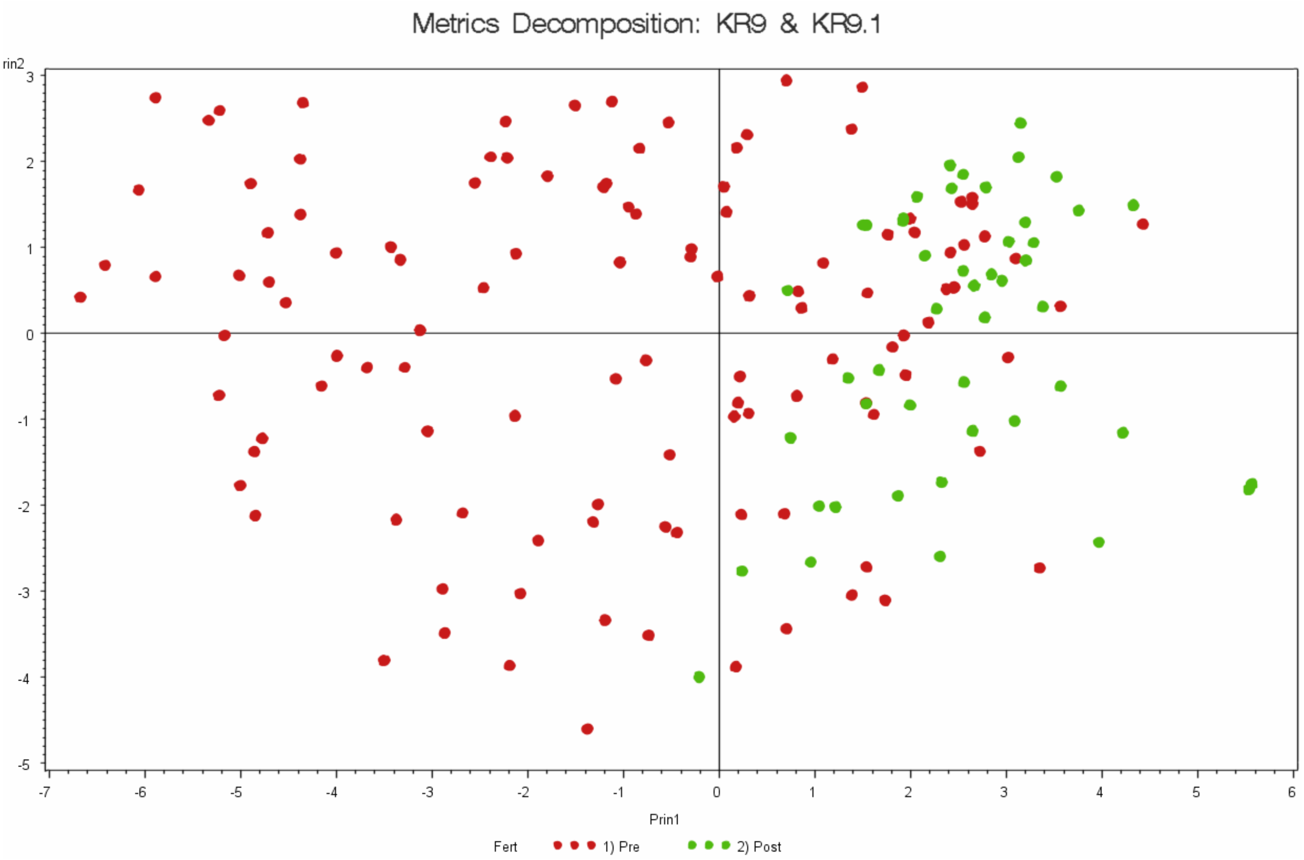


Figure 13. Biplot showing metric decomposition from Principle Component Analysis for sites KR-9 and KR-9.1 during all years sampled.

Taxonomic Orders, Site KR-10

The first two components of the PCA of taxonomic orders at site KR-10 collectively explained only 51% of the taxonomic variability at these sites (Table 13). The first component was composed of Acarii, Coleoptera, and EPT, whereas taxa of Chironomidae, Diptera, and Gastropoda comprised the second axis (Table 14). The biplot for this analysis revealed no distinct pattern of taxonomic changes in response to nutrient addition (as expected, being the control site; Figure 14). This lack of background variation in taxonomic orders confirmed the value of KR-10 as a legitimate control site.

Table 13. Eigenvalue, proportion, and cumulative percentage for the PCA for taxonomic orders sampled at KR-10.

	Eigenvalue	Proportion	Cumulative
1	2.73	0.34	0.34
2	1.38	0.17	0.51
3	0.92	0.11	0.63
4	0.86	0.11	0.74
5	0.69	0.09	0.82
6	0.63	0.08	0.90
7	0.47	0.06	0.96
8	0.31	0.04	1.00

Table 14. Principle component loadings by taxonomic order for three significant principle components generated by PCA of invertebrate taxonomic orders sampled at KR-10 during all years.

	Prin1	Prin2	Prin3
Acari	0.40	-0.04	-0.04
Chironomidae	-0.10	0.67	0.13
Coleoptera	0.38	-0.03	0.28
Diptera	-0.07	0.65	0.27
Ephemeroptera	0.40	0.17	-0.14
Gastropoda	-0.17	-0.29	0.87
Plecoptera	0.47	0.12	0.21
Trichoptera	0.52	-0.05	0.10

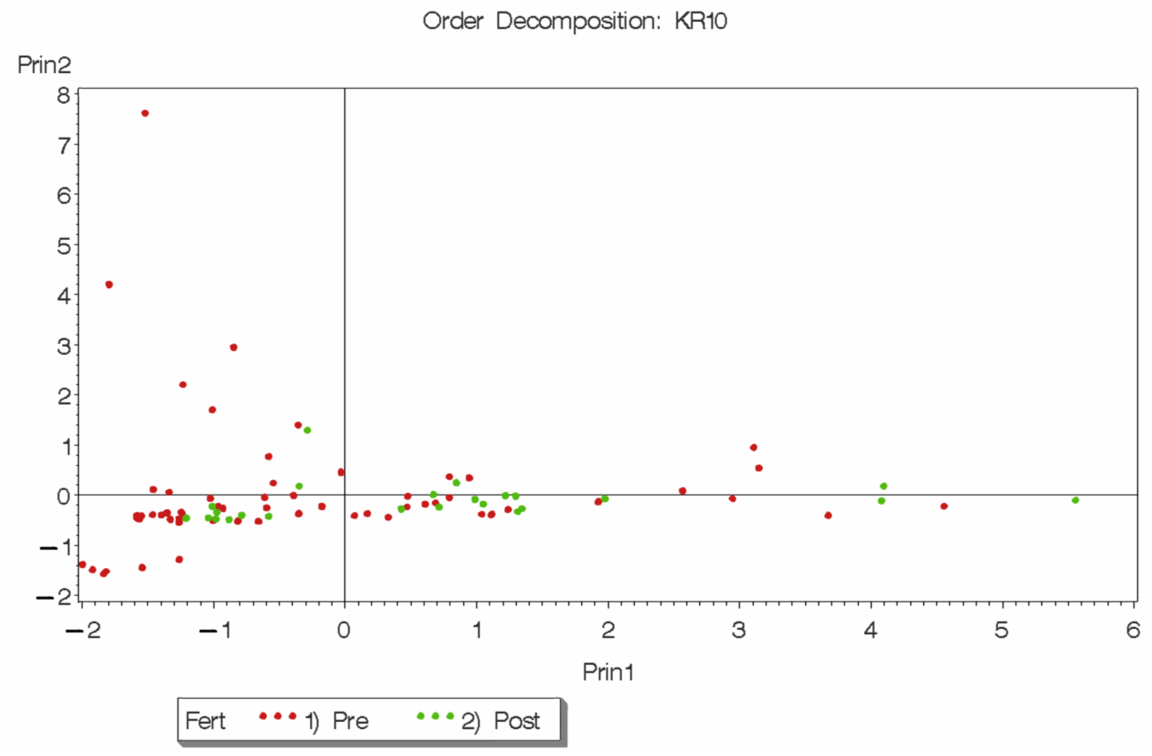


Figure 14. Biplot showing taxonomic order decomposition from Principle Component Analysis for site KR-10.

Metrics, Site KR-10

The first three components of the PCA of metrics at sites KR-10 collectively explained 63% of the taxonomic variability at these sites during all years sampled (Table 15). The first and second components or axes were composed of richness and diversity measures respectively (Table 16). No clear patterns relating to nutrient addition and no clear patterns due to background variation were exhibited in the biplot for this analysis (Figure 15).

Table 15. Eigenvalue, proportion, and cumulative percentage for the PCA for metrics at KR-10 during all years sampled.

	Eigenvalue	Proportion	Cumulative
1	6.41	0.29	0.29
2	4.36	0.20	0.49
3	3.08	0.14	0.63
4	1.86	0.08	0.71
5	1.32	0.06	0.77
6	0.91	0.04	0.82
7	0.85	0.04	0.85
8	0.70	0.03	0.89

Table 16. Principle component loadings by metrics for three significant principle components generated by PCA of invertebrate taxonomic orders sampled at KR-10 during all years.

	Prin1	Prin2	Prin3
richness	0.36	0.10	-0.16
EPT_richness	0.35	-0.13	-0.09
E_richness	0.23	-0.07	-0.32
% richness	0.26	-0.18	0.08
T_richness	0.31	-0.08	0.15
C_Richness	0.20	0.28	-0.19
% Ephemeroptera	0.13	-0.36	-0.06
% Plecoptera	0.11	0.17	0.35
% Trichoptera	0.15	0.11	0.42
% Coleoptera	0.04	0.21	0.16
% Filterers	0.03	0.14	0.31
% Gatherers	-0.12	0.14	-0.33
% Predators	0.03	0.17	0.20
% Scrapers	0.20	-0.25	0.20
Shannon	0.16	0.37	0.01
Simpson	0.08	0.35	0.08
Hilsenhoff	-0.12	0.33	-0.03
% Tolerant_taxa	0.05	0.19	-0.23
Filterer_richness	0.29	0.13	0.02
Gatherer_richness	0.25	0.24	-0.29
Predator_richness	0.29	-0.02	0.17
Scraper_richness	0.31	-0.14	-0.14

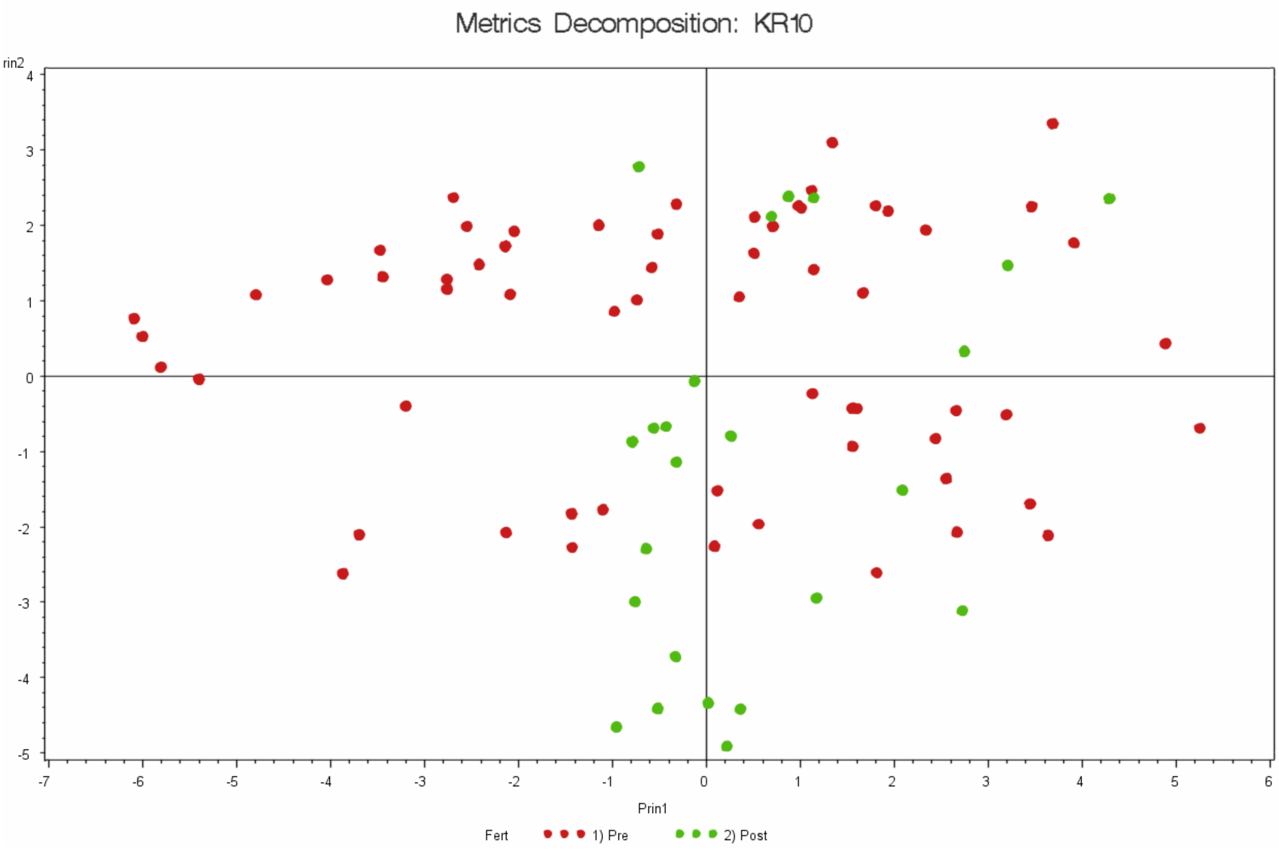


Figure 15. Biplot showing metric decomposition from Principal Component Analysis for site KR-10, all years sampled.

Analysis of Variance

Nutrient addition had a significant effect (*p<0.0001*) on invertebrate abundance, biomass, and richness at KR-9 and KR-9.1 combined (Table 17). Mean abundance and biomass both increased following nutrient addition, whereas mean richness nearly doubled from 20 to 35 taxa (Table 18).

Table 17. ANOVA results for pre and post-addition aggregated average abundance, biomass, and richness at sites KR-9 and KR-9.1 combined for all years sampled.

Response	Source	DF	Type III SS	Mean Square	F Value	Pr > F
Log(Abundance)	Nutrient Addition	1	54.69	54.69	37.30	<.0001
Log(Biomass)	Nutrient Addition	1	41.14	41.14	27.27	<.0001
Richness	Nutrient Addition	1	7794.25	7794.25	110.75	<.0001

Table 18. Least square means and standard error values for response variables (abundance, biomass and richness) in analysis of variance for pre- and post-fertilization years.

Response	Fert	LSMEAN	S.E.
Log(Abundance)	Pre	6.90	0.12
	Post	8.33	0.20
Log(Biomass)	Pre	-0.52	0.12
	Post	0.72	0.20
Richness	Pre	20.05	0.91
	Post	34.93	1.08

Site effects on Abundance.—A trend of increasing significance for aggregated invertebrate abundance by year was observed (Table 19). Three of 14 (21%) of the abundance contrasts by site or site groupings were significant prior to nutrient addition (2003 and 2004) compared to 11 of 14 (79%) being significant during the post-fertilization years (2005 and 2006; Table 19). Aggregated invertebrate abundance was significantly higher ($p<0.0001$) for the hydro-affected sites (KR-10 and KR-13, representing tailwater and upper canyon habitats) than for the natural upstream site (KR-14; Table 19). Mean abundance at most sites was higher during 2006 than during 2004 (Table 20).

Table 19. Grouped site contrasts for aggregated invertebrate abundance by year. Shaded cells indicate significance at α=0.05.

Site Contrast for Abundance	2003	2004	2005	2006
Meander (KR1-KR4) vs ID Canyon (KR9, KR9.1)*			■	■
Control (KR10) vs Treated (KR9, KR9.1)*				■
Natural (KR14) vs Hydro (Kr10-KR13)	■	■	■	■
Braided (KR6, KR7) vs Canyon (KR9, KR9.1)*			■	
Braided (KR6, KR7) vs Meander (KR1-KR4)		■		■
Braided (KR6, KR7) vs Control (KR10)			■	■
Braided (KR6, KR7) vs Natural (KR14)			■	■

Table 20. Mean log abundance values from analysis of variance for all years.

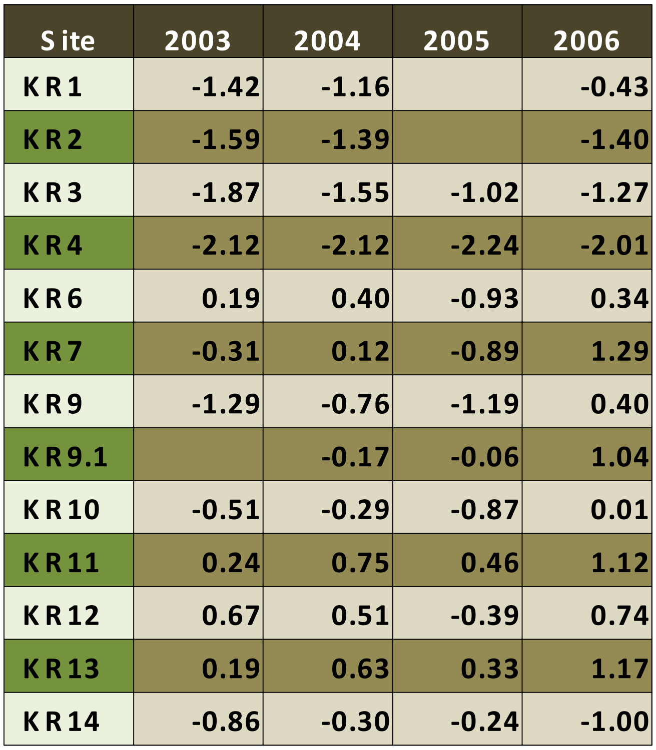
Site	2003	2004	2005	2006
KR1	6.09	6.70		7.58
KR2	6.41	6.80		7.04
KR3	6.15	6.50	6.68	6.74
KR4	6.11	6.08	5.82	6.10
KR6	6.44	7.37	6.23	8.21
KR7	5.83	6.98	5.94	8.30
KR9	5.91	6.65	6.62	8.03
KR9.1		7.07	7.33	8.63
KR10	6.45	7.06	6.91	7.67
KR11	7.34	7.85	7.75	9.39
KR12	7.59	8.09	7.69	8.99
KR13	7.65	9.12	8.46	9.31
KR14	6.05	7.08	6.83	6.50

Site effects on Biomass.—Unlike abundance, few site effect trends in biomass were evident across years or between pre- and post-fertilization years (Table 21). However, braided reach sites exhibited significantly greater invertebrate biomass than meander reach sites during all years, whereas canyon sites exhibited significantly greater invertebrate biomass during 3 of 4 years, including the two nutrient addition years (Table 21). Mean biomass was more variable among years than abundance, but typically increased during 2006 relative to previous years (Table 22).

Table 21. Grouped site contrasts for aggregated invertebrate biomass by year. Shaded cells indicate significance at α=0.05.

Site Contrast for Biomass	2003	2004	2005	2006
Meander (KR1-KR4) vs ID Canyon (KR9, KR9.1)*		🟦	🟦	🟦
Control (KR10) vs Treated (KR9, KR9.1)*	🟦			
Natural (KR14) vs Hydro (Kr10-KR13)	🟦	🟦		🟦
Braided (KR6, KR7) vs Canyon (KR9, KR9.1)*	🟦	🟦		
Braided (KR6, KR7) vs Meander (KR1-KR4)	🟦	🟦	🟦	🟦
Braided (KR6, KR7) vs Control (KR10)				🟦
Braided (KR6, KR7) vs Natural (KR14)	🟦		🟦	🟦

Table 22. Mean biomass values from analysis of variance for all years and all sites.



Site	2003	2004	2005	2006
KR1	-1.42	-1.16		-0.43
KR2	-1.59	-1.39		-1.40
KR3	-1.87	-1.55	-1.02	-1.27
KR4	-2.12	-2.12	-2.24	-2.01
KR6	0.19	0.40	-0.93	0.34
KR7	-0.31	0.12	-0.89	1.29
KR9	-1.29	-0.76	-1.19	0.40
KR9.1		-0.17	-0.06	1.04
KR10	-0.51	-0.29	-0.87	0.01
KR11	0.24	0.75	0.46	1.12
KR12	0.67	0.51	-0.39	0.74
KR13	0.19	0.63	0.33	1.17
KR14	-0.86	-0.30	-0.24	-1.00

Site effects on Richness.—A slight increase in the number of significant site effect contrasts of invertebrate richness was observed between pre-treatment and treatment years. Nine of the 14 (64%) of site effect contrasts for richness were significant during treatment years, compared to 11 of 14 (79%) during post-treatment years (Table 23).

Several trends of richness contrasts by site or site groupings were significant during all years: (1) The canyon reach sites had significantly greater invertebrate richness than the meander reach sites; (2) the braided reach had significantly greater richness than the meander reach sites; and (3) lower river sites (< KR-14, downstream from Libby Dam) had significantly greater richness than the upstream unimpounded site KR-14 (Table 23). Overall, nutrient addition had the greatest impact on richness measures, compared to treatment effects on abundance and biomass.

Table 23. Grouped site contrasts for invertebrate richness by year. Shaded cells indicate significance at α=0.05.

Site Contrast for Richness	2003	2004	2005	2006
Meander (KR1-KR4) vs ID Canyon (KR9, KR9.1)*	🟦	🟦	🟦	🟦
Control (KR10) vs Treated (KR9, KR9.1)*		🟦		🟦
Natural (KR14) vs Hydro (Kr10-KR13)	🟦	🟦	🟦	🟦
Braided (KR6, KR7) vs Canyon (KR9, KR9.1)*			🟦	🟦
Braided (KR6, KR7) vs Meander (KR1-KR4)	🟦	🟦	🟦	🟦
Braided (KR6, KR7) vs Control (KR10)		🟦	🟦	
Braided (KR6, KR7) vs Natural (KR14)		🟦		🟦

Compared to average abundance and average biomass, average richness exhibited the largest response to nutrient addition, both temporally and longitudinally. Richness was highest during 2006 at the fertilization site (KR-9.1) and declined in a downstream direction as a function of distance from the nutrient addition site (Table 24). Mean richness at the nutrient addition site increased from 23 in 2004 to 40 in 2006, and from 20 in 2004 to 32 in 2006 (Table 24).

Table 24. Mean richness values from analysis of variance for all years and all sites.

Site	2003	2004	2005	2006
KR1	9.86	11.83		5.47
KR2	8.68	13.18		4.08
KR3	7.29	9.74	11.00	3.25
KR4	7.12	6.12	4.50	2.42
KR6	23.61	22.17	19.83	18.25
KR7	16.21	24.94	18.39	22.61
KR9	19.65	19.96	22.39	32.22
KR9.1		23.83	27.39	40.39
KR10	21.42	31.64	24.89	20.78
KR11	24.39	29.67	26.25	25.42
KR12	27.64	31.94	27.61	21.50
KR13	21.61	30.94	26.00	26.08
KR14	12.50	15.93	17.29	7.50

Trophic Interactions

In addition to increases in invertebrate abundance, a large response in primary productivity also occurred within the nutrient addition zone (measured as mg chlorophyll *a, b*/m^2/30d). A order of several magnitudes increase was observed at KR-9 and KR-9.1 between pre-treatment and treatment years (Appendix D). The comparatively large increase in algae production at KR-9.1 was partly due to KR-9.1 being located near (about 1 km downstream) the nutrient addition outlet. This is within the zone of incomplete nutrient mixing which likely causes higher phosphorus (P) concentrations than occurs several kilometers downstream where complete nutrient mixing of P occurs (Ward and Associates 2006). The higher site-specific nutrient availability at KR 9.1 likely caused the large increase in productivity and algal accrual. However, large increases in primary productivity, throughout the treatment reach, likely resulted in increased food availability for the invertebrate community, and caused a bottom-up energy cascade. The result of this cascade from primary productivity to secondary productivity is observed as an increase in abundance, biomass, and species richness within the macroinvertebrate community in the Kootenai River.

Initial review of empirical responses across trophic levels, including primary production and fish stomach content data provided evidence of positive upward trophic cascades in the Kootenai River downstream from the nutrient addition site during years of nutrient addition. Chironomid taxa are algal consumers, and the simultaneous increase in algal accrual rates and chironomid frequency may reflect increased food availability in response to experimental nutrient addition.

One example of potential trophic cascading interactions involved total algal accrual rates at KR-9 and KR-9.1 that increased markedly from 2004 to 2006 (Figure 15). Lesser algal accrual rate increases were observed at KR-10 (a non-treatment location) compared to the changes observed at KR-9 and KR-9.1. Comparisons of chironomid frequency or relative abundance at KR-9.1 showed a similar, dramatic increase from 2004 through 2006, with larger changes in both metrics between 2005 and 2006 (Figure 16). Frequency of chironomids in the KR-9.1 samples increased by nearly two orders of magnitude from around 50 to nearly 900 between 2004 and 2006. Total algal accrual at KR-9.1 was more than ten times higher in 2006 than in 2004 at KR-9.1 (Figure 17). Simultaneous increases in chironomid frequency in the river and in fish stomach contents were also observed at KR-9 across years (Figure 18).

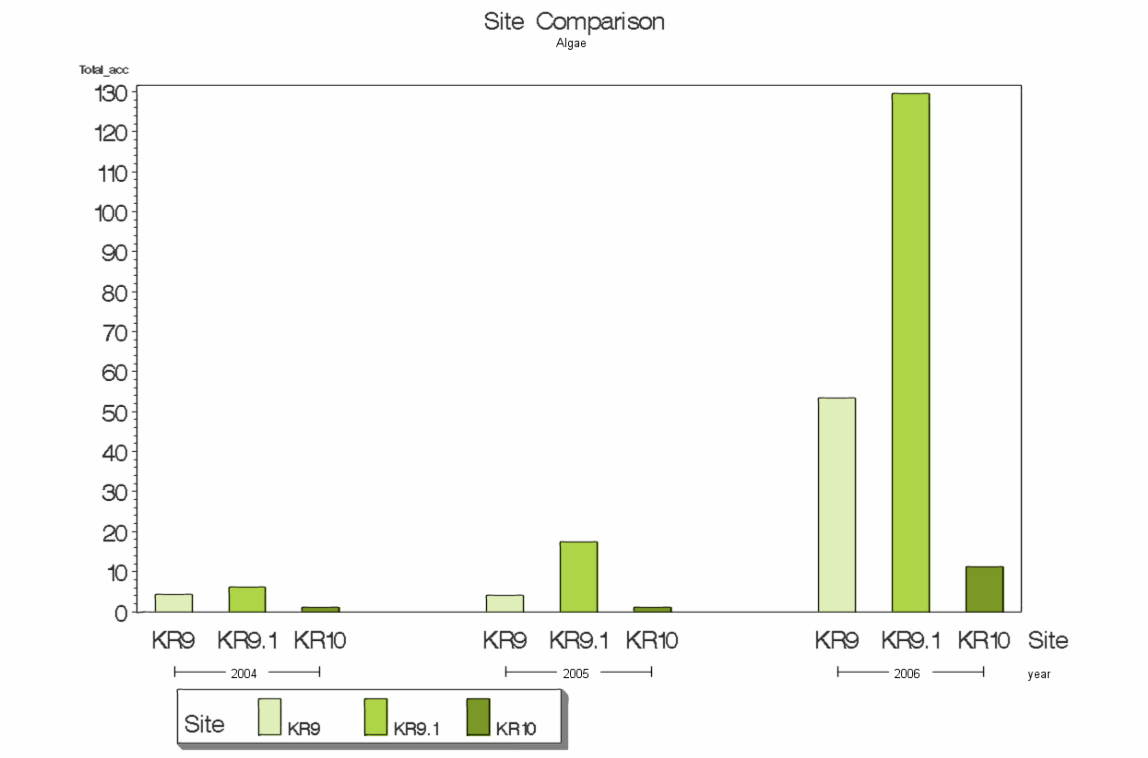
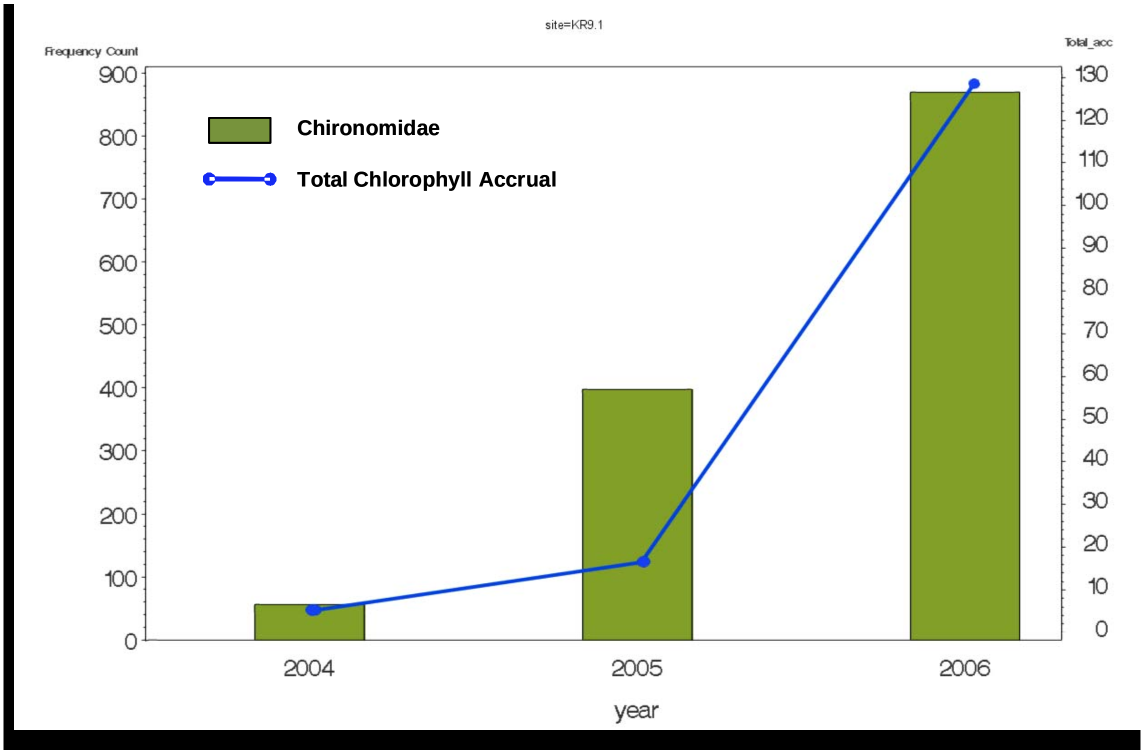


Figure 16. Total chlorophyll accrual[1] at KR-9, KR-9.1, and KR-10 from 2004 through 2006.



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[1] Chlorophyll *a* + *b* expressed in mg·m^{-2} over a 30 day period.

Figure 17. *Chironomidae* abundance and total chlorophyll accrual at site KR9.1.

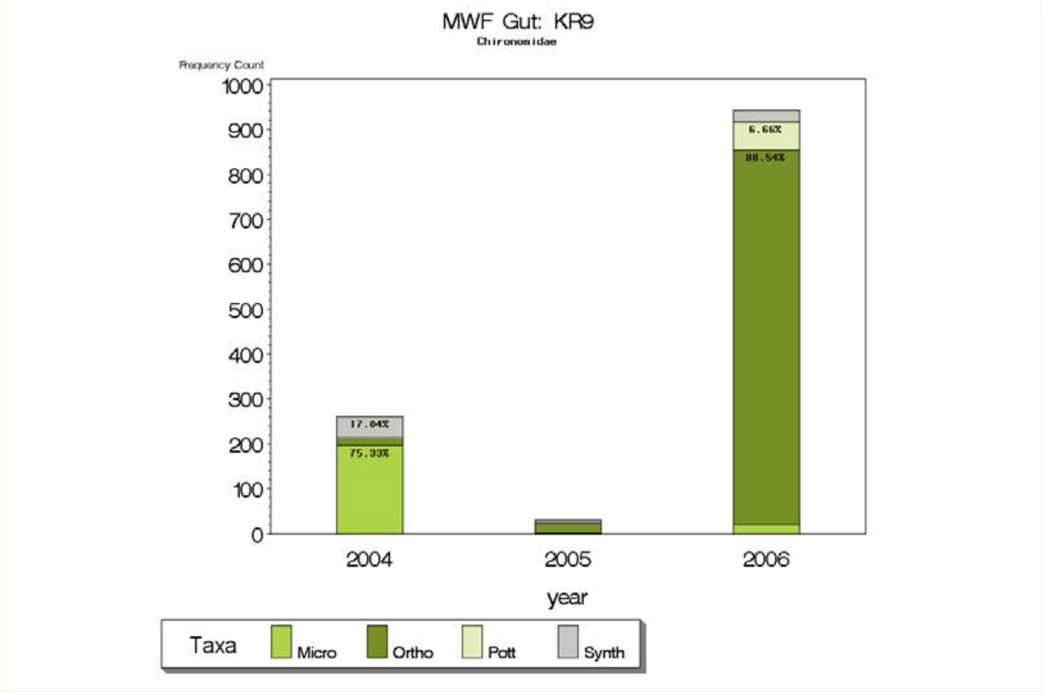

Figure 18. Composition of major chironomid taxa in mountain whitefish stomach content samples at KR-9, 2004 through 2006.

Site comparison across years—*Chironomidae*

Chironomids exhibited similar relative abundance patterns both in the river and within fish stomach content samples across years at KR-9, suggesting that as a collective taxonomic group they were consumed in proportion to their abundance (Figure 19).

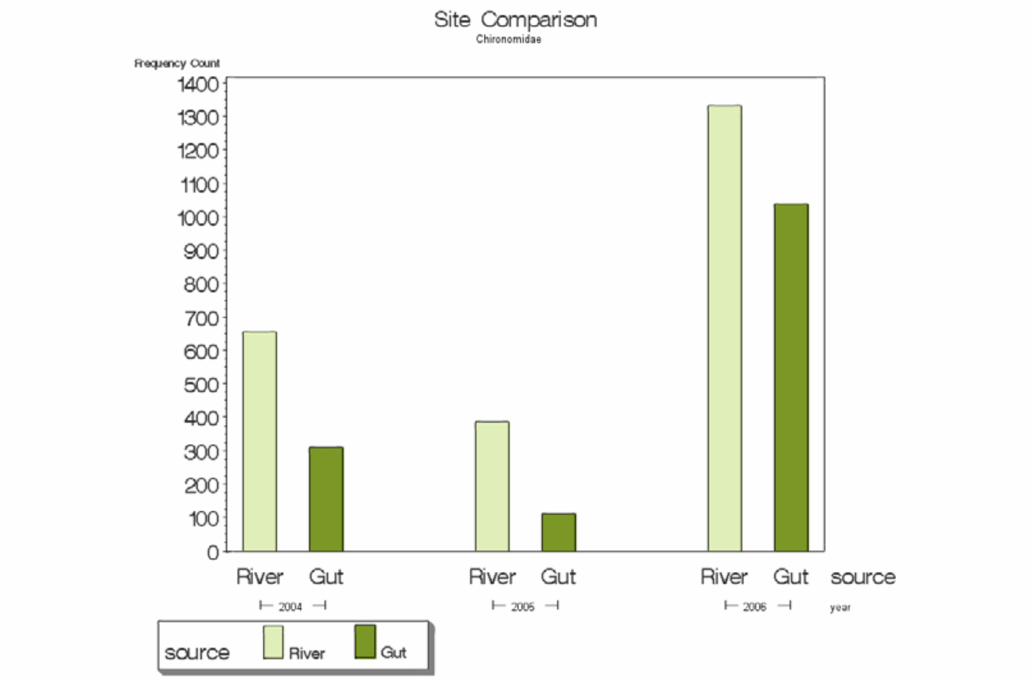

Figure 19. Site comparison of chironomid frequency between KR-9 and in mountain whitefish stomach content samples from 2004 through 2006.

DISCUSSION

The observed invertebrate metric and taxonomic responses and trends presented in this report may have resulted from or been affected to varying degrees by many factors, including: background (ambient) variability, nutrient availability and addition, ecosystem metabolism, hydrologic (water year) conditions, Libby Dam operations, the spatial and temporal distribution of habitat structure and diversity, and cascading trophic interactions. In this section we discuss factors affecting responses and trends in the series of summary and quantitative statistics reported.

Summary statistics

Line plots of aggregated abundance, biomass, richness, and various taxa, taxa group and functional feeding groups collectively revealed considerable longitudinal (upstream-downstream) variability within and among years. Taxa-specific slopes of the invertebrate abundance, biomass, and richness plots revealed differences in tolerance and suitability for existing ecological and physical habitat conditions by taxa, whereas differences in the magnitude (height) of the same curves for the same taxa between treatment and control years in some cases revealed effects of the nutrient addition. In other cases, ambient or background variability may have contributed to changes observed during treatment years.

Abundance and Biomass~ **A** decreasing downstream trend in aggregate macroinvertebrate abundance and biomass is reversed from what is predicted in unaltered large rivers by the river continuum concept (Vannote et al. 1980). Aquatic insect density and biomass typically increase with river order in unregulated rivers, as tributary inputs increase nutrient and organic food levels.

Thus, observations from this study (i.e. decreasing longitudinal trends in insect abundance and biomass) are more indicative of serial disequilibrium theory (SDT) conditions commonly observed for post-dam large rivers (Ward and Stanford 1983). SDT predicts that dams act as an ecological, chemical and physical parameter reset mechanism, essentially shifting the functionality of the river towards headwater conditions (e.g. low nutrients and primary productivity). In addition to productivity lost to river impoundment, wetland development for agriculture in the meander reach also has negatively affected invertebrate abundance due to the loss of habitat, nutrients, and organic matter inputs.

An increase in abundance and biomass values in the tailwater and canyon reaches (most notably at the sites closest to and downstream from Libby Dam), relative to the upstream reference site (KR-14), and sites further downstream in Idaho, likely reflect an artificially enhanced tailwater ecological condition common to post-impoundment large river ecosystems (Campbell 1989). River productivity in these reaches may be aided by primary productivity (phytoplankton) occurring in Libby Reservoir which is passed downstream by various water operations. The aquatic insect community in the tail-water reach is dominated by a collector-filterer feeding guild. These insects can filter plankton from the current as a food source and are probably benefiting from entrained reservoir plankton and organic matter, as opposed to feeding on in situ primary productivity.

Increased macroinvertebrate biomass farther downstream (i.e. MT-ID border area) during 2006 as opposed to 2005 and earlier (non-treatment) years is likely a response to nutrient additions. In terms of abundance and biomass responses to increased nutrient availability (from experimental nutrient addition), abundance increases would have to occur either through immigration, likely by drifting, to sampling sites following nutrient addition, or from increased fecundity, which is taxa dependent. Alternatively, increases in biomass that could occur in response to increased food availability (e.g. algae) during time periods shorter than the generation time. In other words, more invertebrates are required for increases in abundance, whereas biomass increases can be detected with no increase in numbers of individuals (abundance). In this sense, biomass may be a slightly more informative variable. Similarly, empirical abundance estimation, like biomass estimation is also confounded by substrate-specific patchy distribution of benthic invertebrates. However sample size analyses indicated that insect populations should be well represented with the current sampling scheme (see sample size analysis chapter of this report volume for further information).

Species Richness.—The prominent longitudinal feature of aggregated richness was a large decrease in richness downstream from the braided reach, relative to upstream reaches. This gradient reflects the large reduction in habitat diversity or complexity and reduced nutrient availability of the meander reach. Due to levee construction and isolation of the floodplain for the lower 240 km upstream from Kootenay, the meander reach may be artificially heterotrophic (photosynthesis < respiration), whereas the upstream braided and canyon reaches remain naturally autotrophic (photosynthesis > respiration). Thus, the post-development meander reach may currently support fewer, more tolerant taxa relative to the upstream reaches. These factors may in part explain the consistently reduced richness values for the meander reach sites.

Unlike abundance and biomass, the single peak in richness at the nutrient addition site during 2006, with a smaller increase during 2005, suggests possible response to increased nutrient availability from nutrient addition. Mechanisms for increased richness could have included immigration at various time scales, and increased production from increased individual and population level fecundity and nutrient availability. Increased invertebrate richness at the nutrient addition site during 2006 and the slight increase during 2005 could also reflect a temporal lag period involved with a larger response or a threshold response scenario.

EPT richness.—Consistently elevated EPT richness values at the canyon and braided reach sites compared to the meander reach sites (generally 4 to 8 times higher) may have resulted in part because these aquatic invertebrate taxa (EPT) select and are well adapted to higher gradient, higher energy, riverine conditions found in these reaches (KR6 through KR-14), and are absent in the meander reach (KR-1 through KR 4), where reach scale and microhabitat conditions are unsuitable. The observation of elevated EPT richness at KR9.1 appeared to be in part a response to nutrient addition, proportional with increasing annual nutrient addition targets. However, EPT richness was also highest in the upstream control reach (KR10 through KR-13) during 2006, suggesting that natural background variation may have explained some of the downstream response during 2006. No increase in EPT richness was seen downstream from KR-9.1 at the lower in-river nutrient target during 2005

An additional prominent feature of EPT richness among sites and years was consistently reduced EPT richness at KR-14 compared to downstream canyon reach sites (KR-6 through KR-13). This pattern of increased diversity and richness in a downstream orientation is consistent with ecological theory (Vannote et al. 1980). The large drop in EPT richness during all years except 2006 at most canyon sites, compared to upstream sites (KR-13 and KR-14), may be partially explained by nutrient trapping effects of Libby Dam and the upstream reservoir.

EPT Richness by individual taxonomic order.—Spatial and temporal richness patterns of Ephemeroptera, Plecoptera, and Trichoptera taxonomic groups closely resembled the general longitudinal trends exhibited by combined EPT richness among years. This suggested relatively similar contributions to combined richness among these taxa. One exception was Trichoptera richness at KR-13 during 2006, which was much higher than during other years and higher than other taxa contributions. This spike in Trichoptera richness at KR-13 may have resulted from the 2006 flood, with the greatest responses showing at closest proximity to Libby Dam downstream.

Taxa composition.—Invertebrates within Ephemeroptera, Chironomidae, and Coleoptera responded favorably to nutrient addition, most strongly during 2006, at the highest in-river nutrient concentrations, and at the sites closest to nutrient addition. Invertebrates within the orders Ephemeroptera, Chironomidae, and Coleoptera, had frequency counts up to eight times greater in 2006 than in 2004. Greatest responses were seen at the nutrient addition site (KR-9.1), followed by the adjacent downriver site (KR-9) about 5 km downstream. Increased frequencies in the samples of these taxa were also observed in the same patterns but at lower magnitudes during 2005, suggesting possible dose-dependent responses to nutrient addition.

Quantitative methods

Principal component analysis.—Principal component analysis in the maximum biological response zone (KR-9 and KR-9.1) successfully reduced the dimension of invertebrate data and identified which taxonomic groups and metrics contributed significantly to the observed variation. PCA revealed significant responses to nutrient addition among the taxa Ephemeroptera, Plecoptera, Trichoptera, Acarii, and Coleoptera at these sites. By contrast, analogous PCA at the upstream control site (KR-10) accounted for only 51% of the taxonomic variability. Results of PCA with KR-10 data suggested no changes in taxonomic composition as seen in the downstream treatment reach. This lack of response at the upstream control site lends credibility to downstream taxonomic responses observed at KR-9 and KR-9.1, further supporting a valid biological response to nutrient addition reflected in taxonomic composition changes. PCA of metrics also indicated significant structural changes in richness and diversity measures at KR-9 and KR-9.1, but not at KR-10.

Invertebrate responses identified by PCA are consistent with invertebrate community structure characteristic of riverine environments found in the Kootenai River, with these taxa providing potential increases in food availability for the fish community. Future efforts to statistically test and link individual invertebrate taxa increases to increased algal and primary productivity (i.e. increased food availability for benthic macroinvertebrates) and to fish diet selection will more informatively characterize the important ecological responses and linkages among trophic levels needed to evaluate this project and the roles of nutrient addition in restorative large river ecology.

Analysis of variance.—Analysis of variance indicated that nutrient addition had significant effects on average invertebrate abundance, biomass, and richness at KR-9 and KR-9.1. However, significant effects were not distributed uniformly, spatially, and temporally. Site contrasts for abundance exhibited the greatest significant response frequency during 2005 and 2006 (fertilization years) compared to analogous site contrasts for biomass and richness.

Analysis of variance also identified a significant ecological or biological effect of impoundment. In all but one of 12 site contrasts for invertebrate abundance, biomass, and richness (biomass 2005) these metrics were always significantly different between the natural, unimpounded site (KR-14) and all other sites located downstream and affected by the construction and operation of Libby Dam. This finding emphasizes the magnitude of the ecological disruption from the construction and operation of Libby Dam, and the need to fulfill ecological restoration as mitigation for Libby Dam.

This study has shown empirical benefits of nutrient addition within the invertebrate community, and has provided some empirical evidence for positive cascading trophic interactions. Although early in the project cycle, results of this study are encouraging as they suggest experimental nutrient addition as a potentially feasible option for restoration of altered large river floodplain ecosystems. However, at this time such initial findings should be limited to rivers that share the suite of artificially nutrient-limited conditions as seen in the Kootenai River. Additional years of data, not only in the invertebrate community, but from all trophic levels are required to more informatively evaluate the success of this project and the value and feasibility of nutrient addition as a restorative ecology tool for large altered rivers.

CONCLUDING REMARKS

The macroinvertebrate communities in rivers and streams are important ecologically, both in terms of potential top-down and bottom-up regulation of ecological function, as well as trophic structure, and taxonomic composition. In this study the macroinvertebrate community provided a good starting point for the exploration of ecological responses to experimental nutrient addition and for the assessment of inter-trophic relationships in a large altered river-floodplain ecosystem. Nutrient addition at KR-9.1 produced relatively strong macroinvertebrate responses that highlighted potential cascading interactions across trophic levels. The upstream control sites (KR-10 through KR-14) provided meaningfully partitioned background variability to better assess treatment effects.

Future macroinvertebrate sampling should be coordinated with ongoing annual fish condition and community sampling to better assess trophic linkages and interactions between the two communities. Future fish sampling should also be expanded to at least provide comparable fish consumption and invertebrate community data at KR-9.1. Implementing these actions will provide a more accurate assessment of the potential role of nutrient addition in restorative large river ecology.

Finally, this project represents the first large-scale experimental approach on the Kootenai River, and the largest experimental nutrient treatment in any river to the best of the authors' knowledge. The project is aimed at one of the critical sources of biological limitation among the entire array of communities and populations in the Kootenai River: hydrologic, energetic, and nutrient delivery alterations caused by the construction and operation of Libby Dam, in addition to floodplain loss from levee construction.

Results of this study showed clear, positive signs of ecological response. The authors intend to expand statistical analyses presented in this report to other trophic levels, to include nutrient availability, primary production, and fish community attributes. This expanded approach will: (1) more rigorously characterize ecological responses to nutrient addition in the Kootenai River, (2) further develop and evaluate successful mitigation actions for the hydropower system in general and the construction and operation of Libby Dam more specifically, and (3) better evaluate the feasibility of nutrient addition as a direct mitigation tool for broader applications in restorative river ecology.

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APPENDIX A: COMPLETE LIST OF INVERTEBRATE TAXA SAMPLED IN THE KOOTENAI RIVER, 2003 THROUGH 2006

Taxa	Species
Acarii	Acari
Acari	Arrenurus sp.
Acari	Atractides sp.
Acari	Hygrobates sp.
Acari	Lebertia sp.
Acari	Limnesia sp.
Acari	Limnesiidae
Acari	Oribatei
Acari	Pionidae
Acari	Sperchon sp.
Acari	Sperchonopsis sp.
Acari	Torrenticola sp.
Acari	Torrenticolidae
Amphipoda	Crangonyx sp.
Amphipoda	Hyalella sp.
Annelida	Erpobdellidae
Annelida	Glossiphoniidae
Annelida	Helobdella stagnalis
Annelida	Lumbricina
Annelida	Oligochaeta
Annelida	Piscicola salmositica
Annelida	Piscicola sp.
Arachnida	Acari
Arhynchobdellida	Erpobdella sp.
Basommatophora	Acari (=Acarina)
Basommatophora	Gyraulus sp.
Basommatophora	Lymnaeidae
Basommatophora	Physa (Physella) sp.
Basommatophora	Physa sp.
Basommatophora	Physella sp.
Basommatophora	Planorbidae
Basommatophora	Stagnicola sp.
Bivalvia	Anodonta sp.
Bivalvia	Bivalvia
Bivalvia	Pisidium sp.
Bivalvia	Sphaeriidae
Bivalvia	Unionidae
Chironomidae	Ablabesmyia sp.
Chironomidae	Acricotopus sp.
Chironomidae	Alotanypus sp.
Chironomidae	Apedilum sp.
Chironomidae	Brillia sp.
Chironomidae	Cardiocladius albiplumus
Chironomidae	Cardiocladius sp.
Chironomidae	Chaetocladius sp.
Chironomidae	Chironomidae
Chironomidae	Chironominae
Chironomidae	Chironomini
Chironomidae	Chironomus sp.
Chironomidae	Cladopelma sp.
Chironomidae	Cladotanytarsus sp.
Chironomidae	Corynoneura sp.
Chironomidae	Cricotopus bicinctus gr.
Chironomidae	Cricotopus sp.
Chironomidae	Cricotopus trifascia gr.
Chironomidae	Cryptochironomus sp.
Chironomidae	Cryptotendipes sp.
Chironomidae	Demicryptochironomus sp.
Chironomidae	Diamesa sp.
Chironomidae	Dicrotendipes sp.
Chironomidae	Diplocladius sp.
Chironomidae	Endochironomus sp.
Chironomidae	Endochironomus subtendens
Chironomidae	Eukiefferiella brehmi gr.
Chironomidae	Eukiefferiella brevicalcar gr.
Chironomidae	Eukiefferiella claripennis gr.
Chironomidae	Eukiefferiella coerulescens gr.
Chironomidae	Eukiefferiella devonica gr.
Chironomidae	Eukiefferiella gracei gr.
Chironomidae	Eukiefferiella pseudomontana gr.
Chironomidae	Eukiefferiella sp.
Chironomidae	Euryhapsis sp.
Chironomidae	Glyptotendipes sp.
Chironomidae	Harnischia sp.
Chironomidae	Heleniella sp.
Chironomidae	Heterotrissocladius marcidus gr.
Chironomidae	Hydrobaenus sp.
Chironomidae	Kloosia sp.
Chironomidae	Larsia sp.
Chironomidae	Lauterborniella sp.
Chironomidae	Limnophyes sp.
Chironomidae	Lipiniella sp.
Chironomidae	Lopescladius sp.
Chironomidae	Macropelopia sp.
Chironomidae	Macropelopiini
Chironomidae	Micropsectra sp.
Chironomidae	Micropsectra/Tanytarsus sp.
Chironomidae	Microtendipes pedellus gr.
Chironomidae	Microtendipes rydalensis gr.
Chironomidae	Microtendipes sp.

Taxa	Species
Chironomidae	Monodiamesa sp.
Chironomidae	Nanocladius sp.
Chironomidae	near Heleniella sp.
Chironomidae	Odontomesa sp.
Chironomidae	Orthocladiinae
Chironomidae	Orthocladius (Euortho.) rivicola
Chironomidae	Orthocladius (Euortho.) rivicola gr.
Chironomidae	Orthocladius (Euortho.) rivulorum
Chironomidae	Orthocladius (Euortho.) rivulorum gr
Chironomidae	Orthocladius (Euortho.) rivulorum gr.
Chironomidae	Orthocladius (Euorthocladius) sp.
Chironomidae	Orthocladius annectens
Chironomidae	Orthocladius Complex
Chironomidae	Orthocladius sp.
Chironomidae	Pagastia sp.
Chironomidae	Pagastiella sp.
Chironomidae	Parachaetocladius sp.
Chironomidae	Parachironomus sp.
Chironomidae	Paracladius sp.
Chironomidae	Paracladopelma sp.
Chironomidae	Parakiefferiella sp.
Chironomidae	Paralauterborniella nigrohalteralis
Chironomidae	Paralauterborniella nigrohalteris
Chironomidae	Paramerina sp.
Chironomidae	Parametriocnemus sp.
Chironomidae	Paraphaenocladius sp.
Chironomidae	Paratanytarsus sp.
Chironomidae	Paratendipes sp.
Chironomidae	Parorthocladius sp.
Chironomidae	Phaenopsectra sp.
Chironomidae	Polypedilum sp.
Chironomidae	Potthastia gaedii gr.
Chironomidae	Potthastia longimana gr.
Chironomidae	Potthastia sp.
Chironomidae	Procladius sp.
Chironomidae	Psectrocladius sp.
Chironomidae	Pseudochironomus sp.
Chironomidae	Pseudodiamesa sp.
Chironomidae	Psilometriocnemus sp.
Chironomidae	Radotanypus sp.
Chironomidae	Rheocricotopus sp.
Chironomidae	Rheotanytarsus sp.
Chironomidae	Robackia demeijerei
Chironomidae	Robackia sp.
Chironomidae	Sergentia sp.
Chironomidae	Smittia sp.
Chironomidae	Stempellina sp.
Chironomidae	Stempellinella sp.
Chironomidae	Stenochironomus sp.
Chironomidae	Stictochironomus sp.
Chironomidae	Sublettea sp.
Chironomidae	Sympotthastia sp.
Chironomidae	Synorthocladius sp.
Chironomidae	Tanypodinae
Chironomidae	Tanypus sp.
Chironomidae	Tanytarsini
Chironomidae	Tanytarsus sp.
Chironomidae	Thienemanniella sp.
Chironomidae	Thienemannimyia gr. sp.
Chironomidae	Tribelos jucundum
Chironomidae	Tribelos sp.
Chironomidae	Tvetenia bavarica gr.
Chironomidae	Tvetenia discoloripes gr.
Chironomidae	Tvetenia sp.
Chironomidae	Tvetenia vitracies gr.
Coleoptera	Amphizoa sp.
Coleoptera	Brychius sp.
Coleoptera	Cleptelmis addenda
Coleoptera	Cleptelmis sp.
Coleoptera	Dubiraphia sp.
Coleoptera	Dytiscidae
Coleoptera	Elmidae
Coleoptera	Gyrinus sp.
Coleoptera	Haliplus sp.
Coleoptera	Heterlimnius sp.
Coleoptera	Hydroporinae
Coleoptera	Laccophilus sp.
Coleoptera	Lara sp.
Coleoptera	Narpus sp.
Coleoptera	Ochthebius sp.
Coleoptera	Optioservus sp.
Coleoptera	Ordobrevia nubifera
Coleoptera	Oreodytes sp.
Coleoptera	Stictotarsus sp.
Coleoptera	Zaitzevia sp.
Crustacea	Crangonyx sp.
Crustacea	Gammarus sp.
Crustacea	Hyalella sp.
Crustacea	Ostracoda
Diptera	Antocha sp.

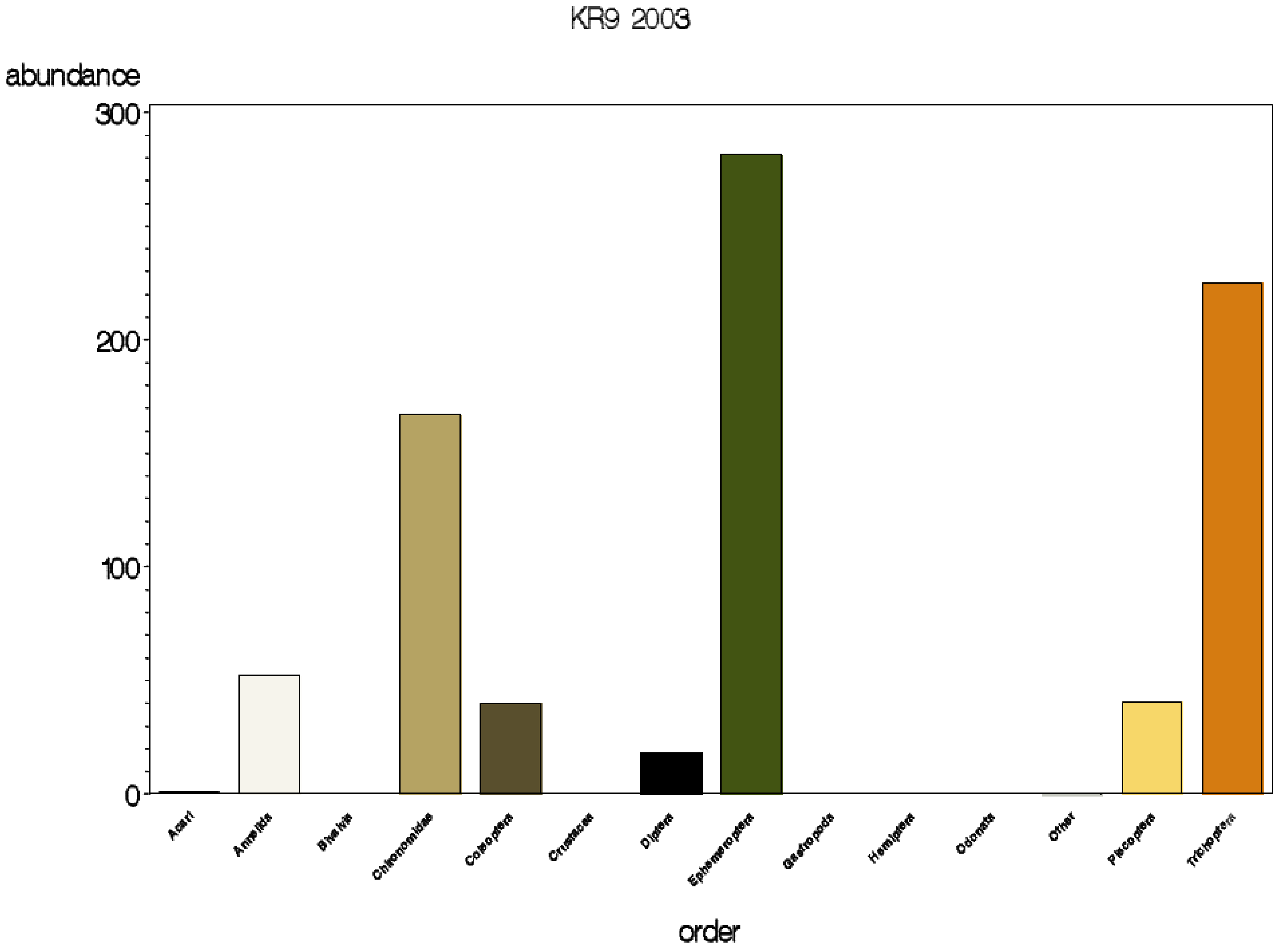
Taxa	Species
Diptera	Atherix sp.
Diptera	Bezzia/Palpomyia sp.
Diptera	Ceratopogoninae
Diptera	Chaoborus sp.
Diptera	Chelifera sp.
Diptera	Chelifera/Metachela sp.
Diptera	Chrysops sp.
Diptera	Clinocera sp.
Diptera	Cryptolabis sp.
Diptera	Culicoides sp.
Diptera	Dicranota sp.
Diptera	Diptera
Diptera	Dolichopodidae
Diptera	Empididae
Diptera	Ephydridae
Diptera	Forcipomyia sp.
Diptera	Glutops sp.
Diptera	Hemerodromia sp.
Diptera	Hesperoconopa sp.
Diptera	Hexatoma sp.
Diptera	Limnophila sp.
Diptera	Limonia sp.
Diptera	Muscidae
Diptera	Neoplasta sp.
Diptera	Oreogeton sp.
Diptera	Pericoma/Telmatoscopus sp.
Diptera	Probezzia sp.
Diptera	Prosimulium sp.
Diptera	Protanyderus sp.
Diptera	Ptychoptera sp.
Diptera	Rhabdomastix fascigera gr.
Diptera	Rhabdomastix sp.
Diptera	Rhabdomastix tricophora gr.
Diptera	Sciomyzidae
Diptera	Simuliidae
Diptera	Simulium sp.
Diptera	Stratiomyidae
Diptera	Tabanidae
Diptera	Tabanus sp.
Diptera	Tipula sp.
Diptera	Tipulidae
Diptera	Trichoclinocera sp.
Diptera	Wiedemannia sp.
Ephemeroptera	Acentrella insignificans
Ephemeroptera	Acentrella sp.
Ephemeroptera	Acentrella turbida
Ephemeroptera	Ameletus sp.
Ephemeroptera	Attenella attenuata
Ephemeroptera	Attenella margarita
Ephemeroptera	Attenella sp.
Ephemeroptera	Baetidae
Ephemeroptera	Baetis alius
Ephemeroptera	Baetis flavistriga
Ephemeroptera	Baetis sp.
Ephemeroptera	Baetis tricaudatus
Ephemeroptera	Brachycercus sp.
Ephemeroptera	Caenis sp.
Ephemeroptera	Callibaetis sp.
Ephemeroptera	Caudatella edmundsi
Ephemeroptera	Caudatella heterocaudata
Ephemeroptera	Caudatella hystrix
Ephemeroptera	Caudatella sp.
Ephemeroptera	Centroptilum sp.
Ephemeroptera	Cinygma sp.
Ephemeroptera	Cinygmula sp.
Ephemeroptera	Diphetor hageni
Ephemeroptera	Drunella coloradensis/flavilinea
Ephemeroptera	Drunella doddsi
Ephemeroptera	Drunella flavilinea
Ephemeroptera	Drunella grandis
Ephemeroptera	Drunella sp.
Ephemeroptera	Drunella spinifera
Ephemeroptera	Epeorus albertae
Ephemeroptera	Epeorus deceptivus
Ephemeroptera	Epeorus grandis
Ephemeroptera	Epeorus longimanus
Ephemeroptera	Epeorus sp.
Ephemeroptera	Ephemerella inermis/infrequens
Ephemeroptera	Ephemerella sp.
Ephemeroptera	Ephemerellidae
Ephemeroptera	Heptagenia sp.
Ephemeroptera	Heptageniidae
Ephemeroptera	Hexagenia sp.
Ephemeroptera	Ironodes sp.
Ephemeroptera	Leptophlebiidae
Ephemeroptera	Maccaffertium terminatum
Ephemeroptera	Nixe sp.
Ephemeroptera	Paraleptophlebia sp.
Ephemeroptera	Plauditus sp.
Ephemeroptera	Rhithrogena sp.
Ephemeroptera	Serratella sp.
Ephemeroptera	Serratella teresa
Ephemeroptera	Serratella tibialis
Ephemeroptera	Siphlonurus sp.
Ephemeroptera	Stenonema sp.
Ephemeroptera	Timpanoga hecuba

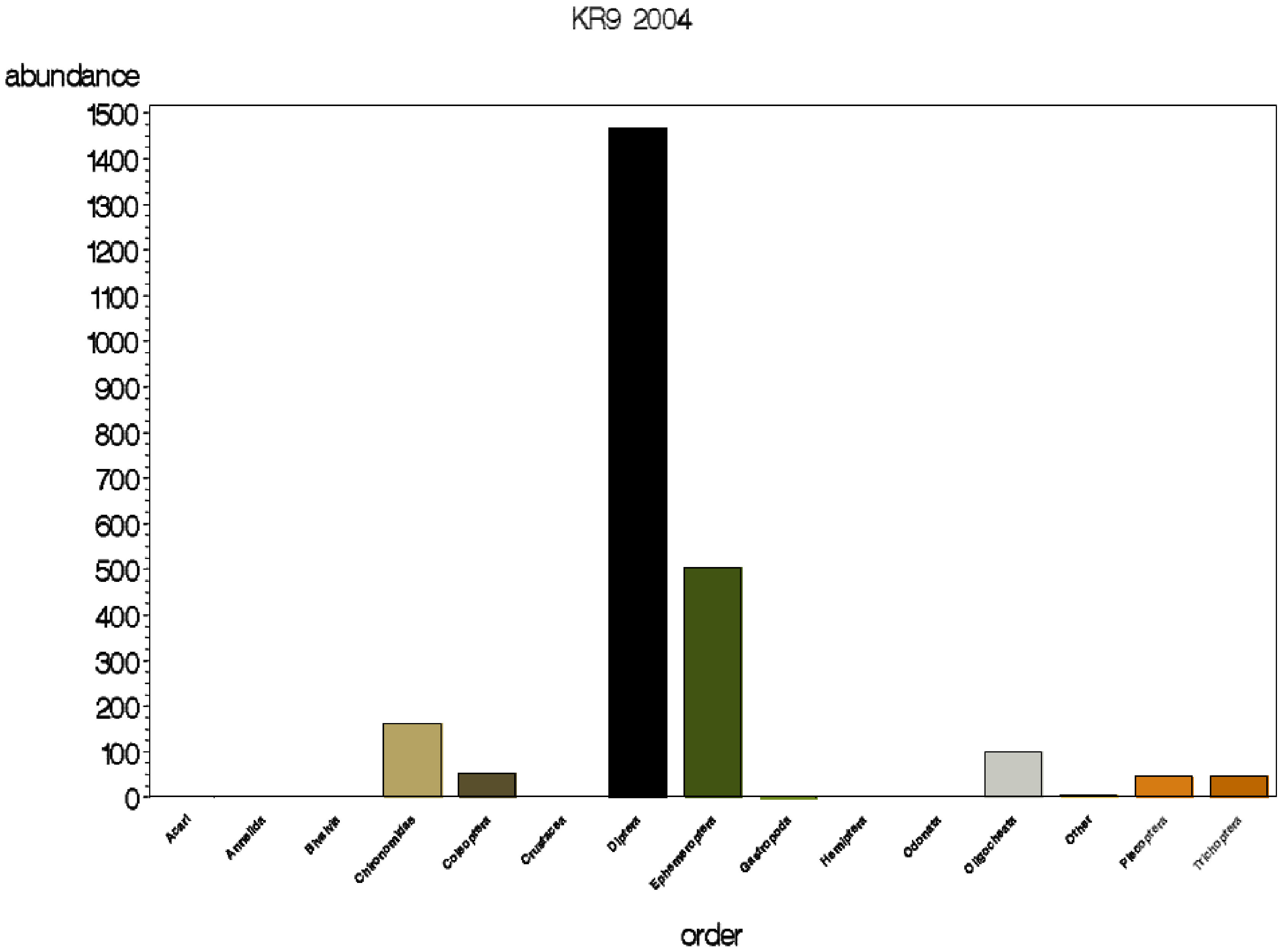
Taxa	Species
Ephemeroptera	Tricorythodes sp.
Gastropoda	Fossaria sp.
Gastropoda	Gastropoda
Gastropoda	Gyraulus sp.
Gastropoda	Lymnaeidae
Gastropoda	Physa (Physella) sp.
Gastropoda	Physa sp.
Gastropoda	Planorbella sp.
Gastropoda	Planorbidae
Gastropoda	Radix auricularia
Gastropoda	Stagnicola sp.
Gastropoda	Valvata sp.
Gastropoda	Valvata tricarinata
Hemiptera	Corixidae
Heterostropha	Valvata tricarinata
Hydroida	Acari (=Acarina)
Hydroida	Hydra sp.
Lepidoptera	Petrophila sp.
Lumbricina	Lumbricina
Nematoda	Nematoda
Odonata	Coenagrion/Enallagma sp.
Odonata	Coenagrionidae
Odonata	Enallagma sp.
Odonata	Gomphidae
Odonata	Ophiogomphus severus
Odonata	Ophiogomphus sp.
Oligochaeta	Lumbriculidae
Oligochaeta	Oligochaeta
Oligocheata	Erpobdellidae
Oligocheata	Glossiphoniidae
Oligocheata	Helobdella sp.
Oligocheata	Helobdella stagnalis
Oligocheata	Oligochaeta
Oligocheata	Piscicola salmositica
Oligocheata	Piscicola sp.
Oligocheata	Piscicolidae
Other	Coenagrion/Enallagma sp.
Other	Coenagrionidae
Other	Corixidae
Other	Gomphidae
Other	Hydra sp.
Other	Nematoda
Other	Nematomorpha
Other	Polycelis sp.
Other	Prostoma sp.
Other	Sigara sp.
Other	Turbellaria
Plecoptera	Calineuria californica
Plecoptera	Capniidae

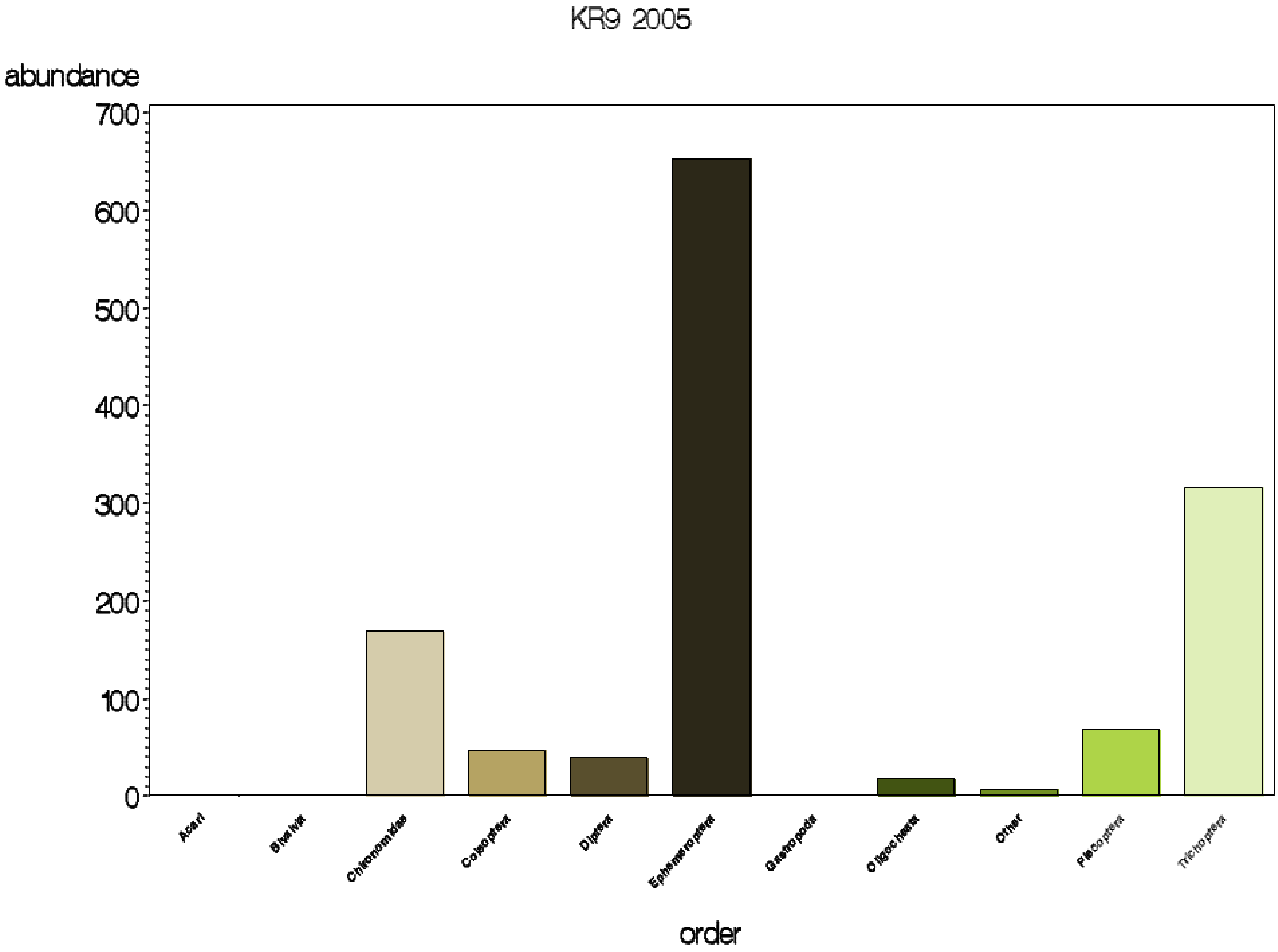
Taxa	Species
Plecoptera	Capnura sp.
Plecoptera	Chloroperlidae
Plecoptera	Claassenia sabulosa
Plecoptera	Cultus sp.
Plecoptera	Despaxia augusta
Plecoptera	Doroneuria sp.
Plecoptera	Eucapnopsis brevicauda
Plecoptera	Hesperoperla pacifica
Plecoptera	Hesperoperla sp.
Plecoptera	Isogenoides sp.
Plecoptera	Isoperla sp.
Plecoptera	Leuctridae
Plecoptera	Megarcys sp.
Plecoptera	Nemouridae
Plecoptera	Paraleuctra sp.
Plecoptera	Paraperla sp.
Plecoptera	Perlidae
Plecoptera	Perlodidae
Plecoptera	Perlomyia sp.
Plecoptera	Plecoptera
Plecoptera	Plumiperla sp.
Plecoptera	Podmosta sp.
Plecoptera	Prostoia sp.
Plecoptera	Pteronarcella sp.
Plecoptera	Pteronarcyidae
Plecoptera	Pteronarcys californica
Plecoptera	Pteronarcys sp.
Plecoptera	Skwala sp.
Plecoptera	Suwallia sp.
Plecoptera	Sweltsa sp.
Plecoptera	Taenionema pacificum
Plecoptera	Taenionema sp.
Plecoptera	Taeniopterygidae
Plecoptera	Triznaka sp.
Plecoptera	Visoka cataractae
Plecoptera	Zapada cinctipes
Plecoptera	Zapada columbiana
Plecoptera	Zapada frigida
Plecoptera	Zapada sp.
Rhynchobdellida	Glossiphoniidae
Rhynchobdellida	Helobdella stagnalis
Rhynchobdellida	Placobdella sp.
Trichoptera	Agraylea sp.
Trichoptera	Amiocentrus aspilus
Trichoptera	Amiocentrus sp.
Trichoptera	Amphicosmoecus canax
Trichoptera	Apatania sp.
Trichoptera	Arctopsyche californica
Trichoptera	Arctopsyche grandis

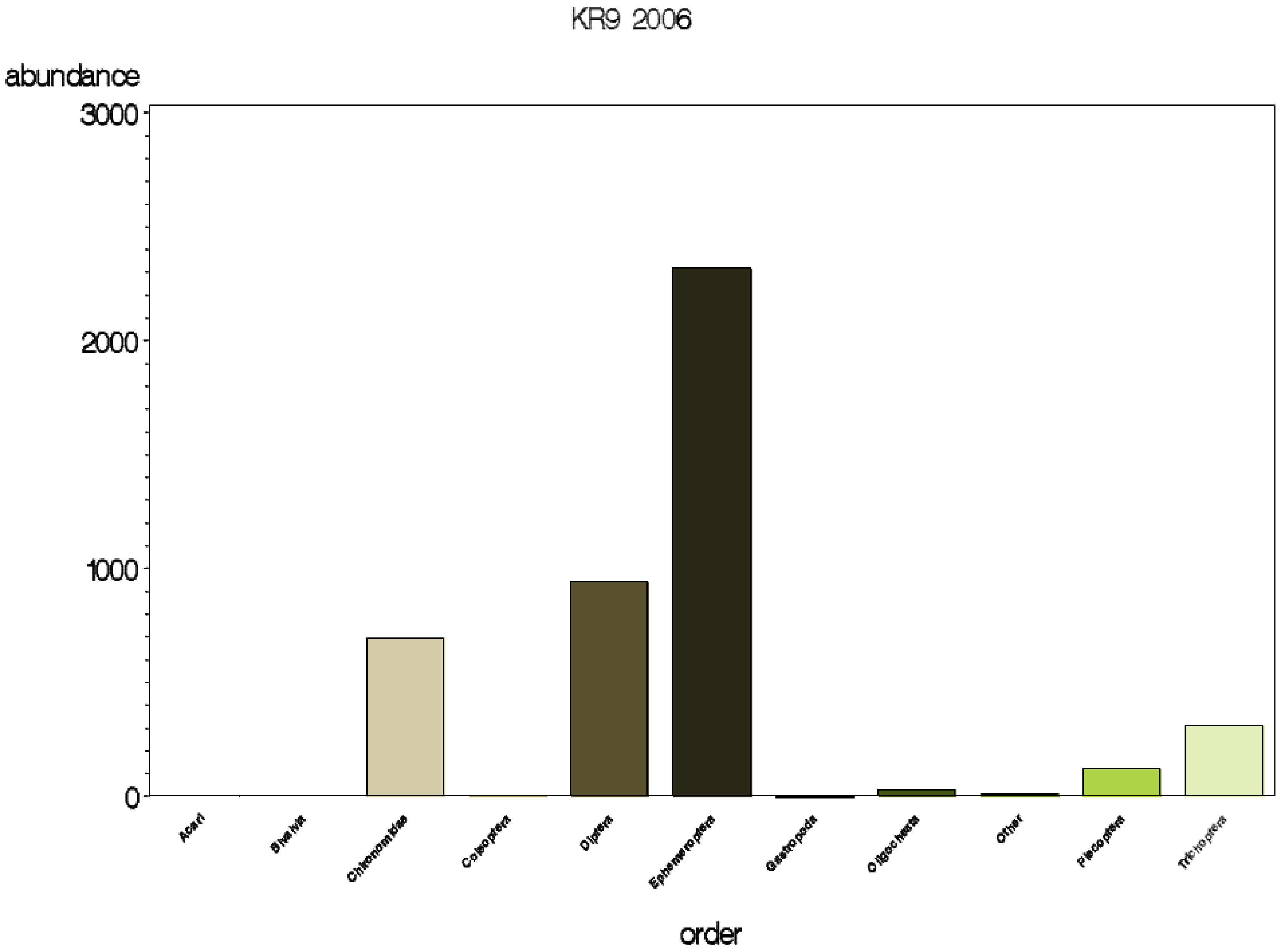
Taxa	Species
Trichoptera	Arctopsyche sp.
Trichoptera	Brachycentridae
Trichoptera	Brachycentrus americanus
Trichoptera	Brachycentrus occidentalis
Trichoptera	Brachycentrus sp.
Trichoptera	Ceraclea sp.
Trichoptera	Cheumatopsyche sp.
Trichoptera	Chyranda centralis
Trichoptera	Desmona sp.
Trichoptera	Dicosmoecus gilvipes
Trichoptera	Dicosmoecus sp.
Trichoptera	Dolophilodes sp.
Trichoptera	Ecclisomyia sp.
Trichoptera	Glossosoma sp.
Trichoptera	Glossosomatidae
Trichoptera	Hydropsyche morosa gr.
Trichoptera	Hydropsyche sp.
Trichoptera	Hydropsychidae
Trichoptera	Hydroptila sp.
Trichoptera	Hydroptilidae
Trichoptera	Lepidostoma sp.
Trichoptera	Leptoceridae
Trichoptera	Limnephilidae
Trichoptera	Micrasema sp.
Trichoptera	Mystacides alafimbriata
Trichoptera	Mystacides sp.
Trichoptera	Neophylax rickeri
Trichoptera	Neophylax sp.
Trichoptera	Ochrotrichia sp.
Trichoptera	Oecetis avara
Trichoptera	Oecetis sp.
Trichoptera	Onocosmoecus sp.
Trichoptera	Phryganea cinerea
Trichoptera	Phryganea sp.
Trichoptera	Polycentropodidae
Trichoptera	Polycentropus sp.
Trichoptera	Protoptila sp.
Trichoptera	Psychoglypha sp.
Trichoptera	Psychomyia lumina
Trichoptera	Psychomyia sp.
Trichoptera	Rhyacophila angelita gr.
Trichoptera	Rhyacophila arnaudi
Trichoptera	Rhyacophila betteni gr.
Trichoptera	Rhyacophila brunnea gr.
Trichoptera	Rhyacophila coloradensis
Trichoptera	Rhyacophila coloradensis gr.
Trichoptera	Rhyacophila hyalinata gr.
Trichoptera	Rhyacophila narvae
Trichoptera	Rhyacophila pellisa/valuma
Trichoptera	Rhyacophila sp.
Trichoptera	Rhyacophila verrula
Trichoptera	Triaenodes sp.
Trichoptera	Trichoptera
Trichoptera	Wormaldia sp.
Turbellaria	Turbellaria
Unionoida	Anodonta sp.
Unionoida	Gonidea angulata
Unionoida	Margaritifera falcata
Veneroida	Pisidium sp.
Veneroida	Sphaeriidae

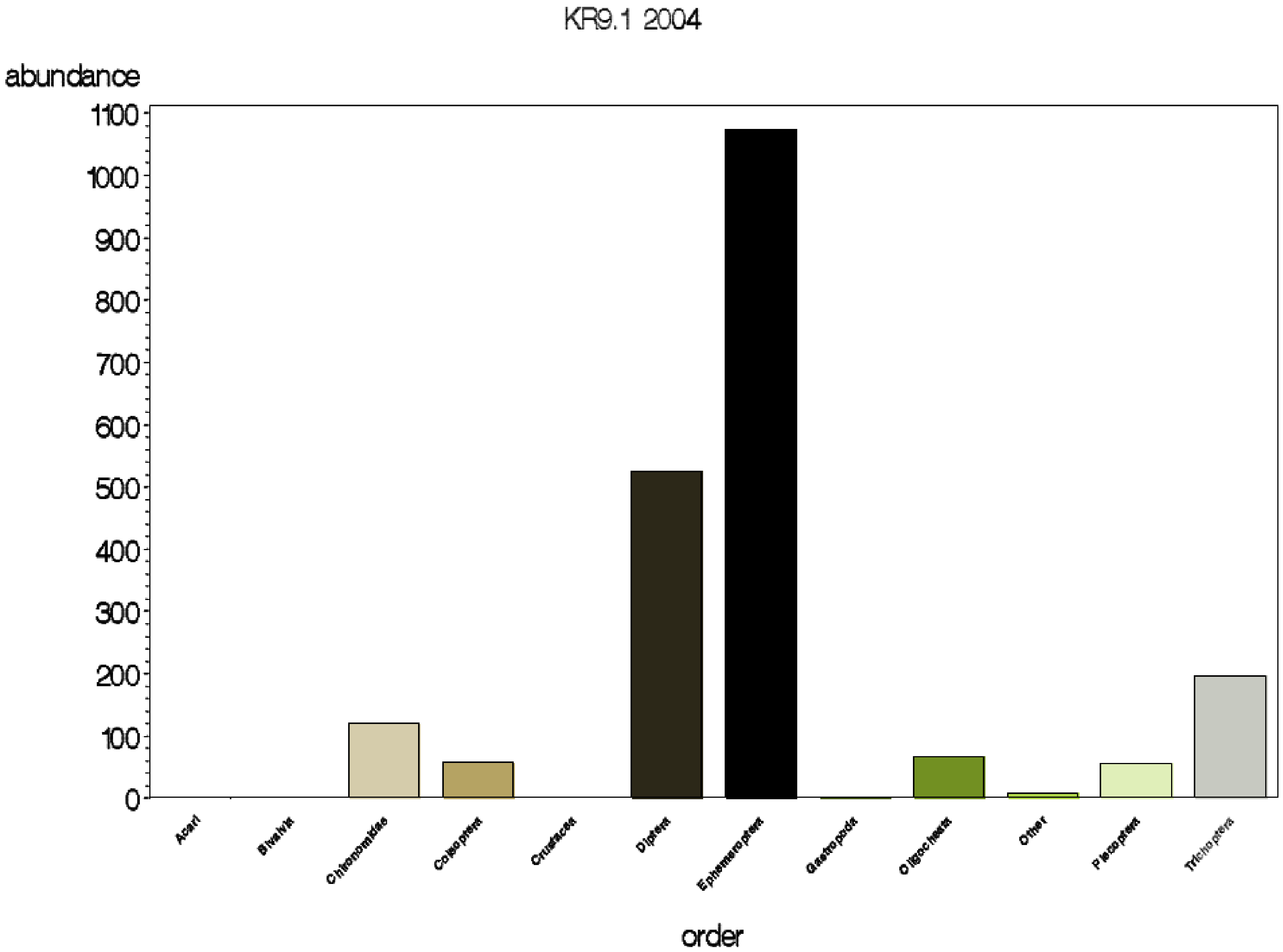
APPENDIX B: SELECTED INVERTEBRATE TAXONOMIC (ORDER) COMPOSITION CHARTS FOR KR-9, KR-9.1, AND KR-10.

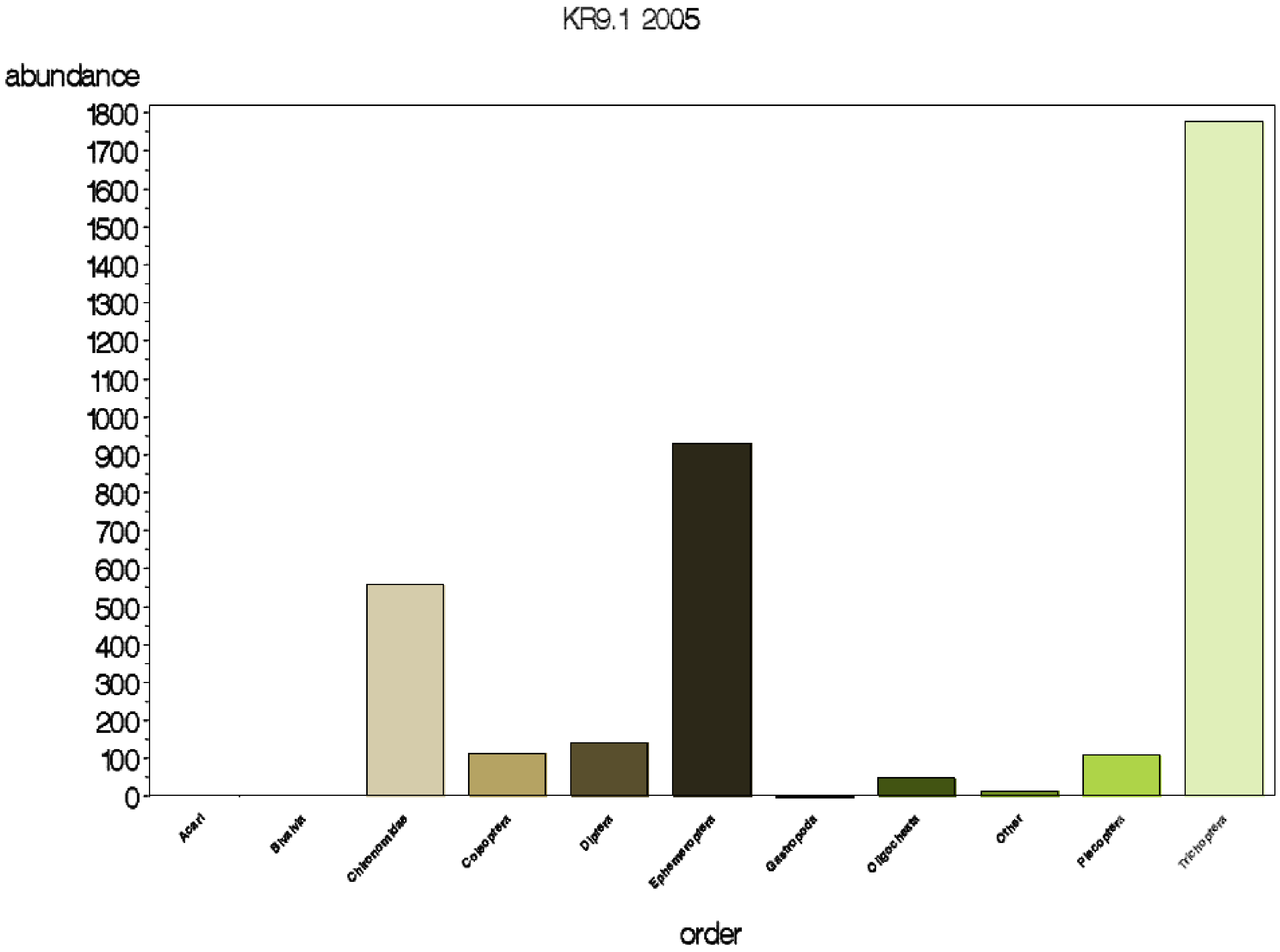


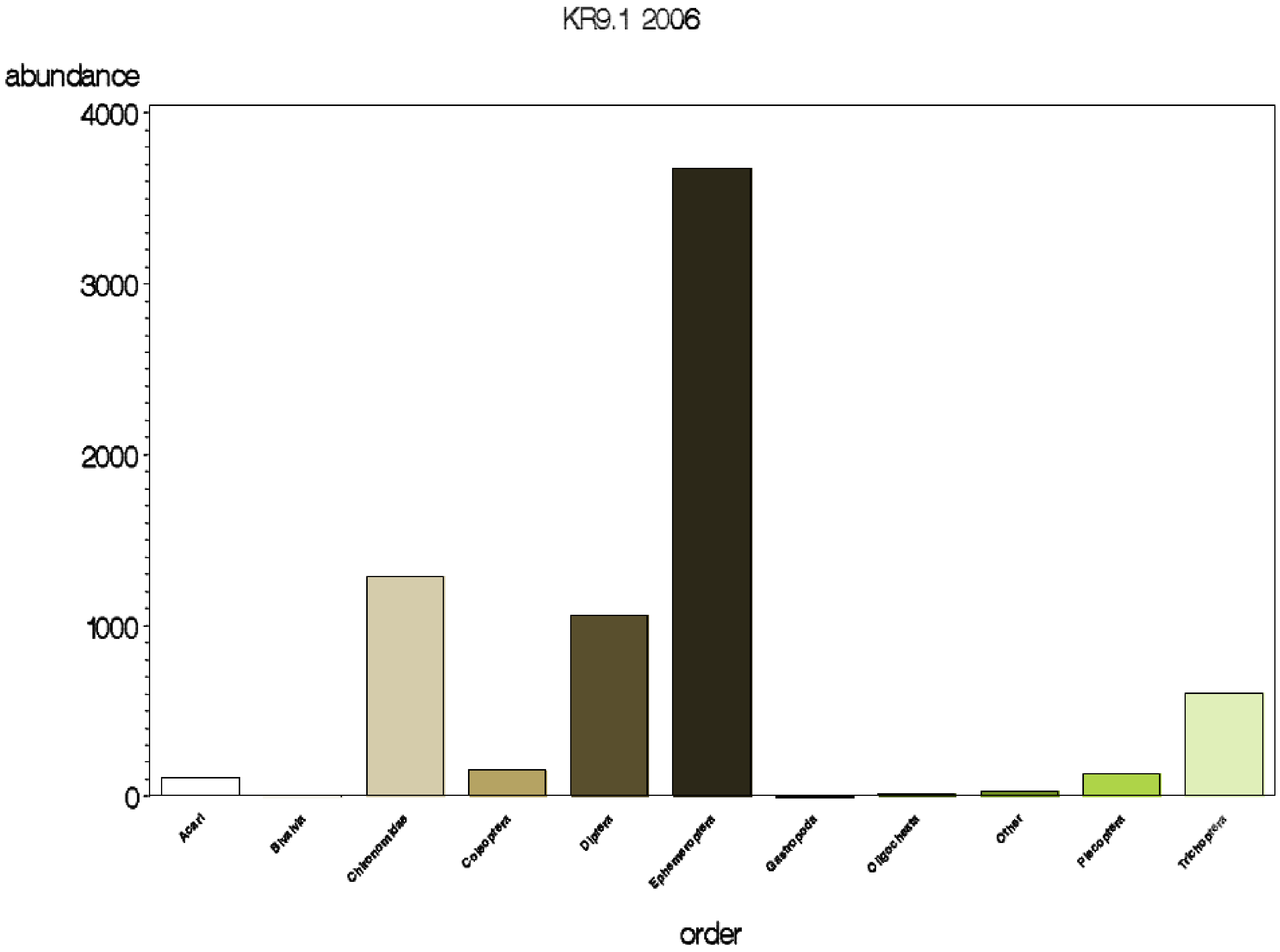

KR9 2004
abundance
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Acari
Annelida
Bivalvia
Chironomidae
Coleoptera
Crustacea
Diptera
Ephemeroptera
Gastropoda
Hemiptera
Odonata
Oligochaeta
Other
Plecoptera
Trichoptera
order

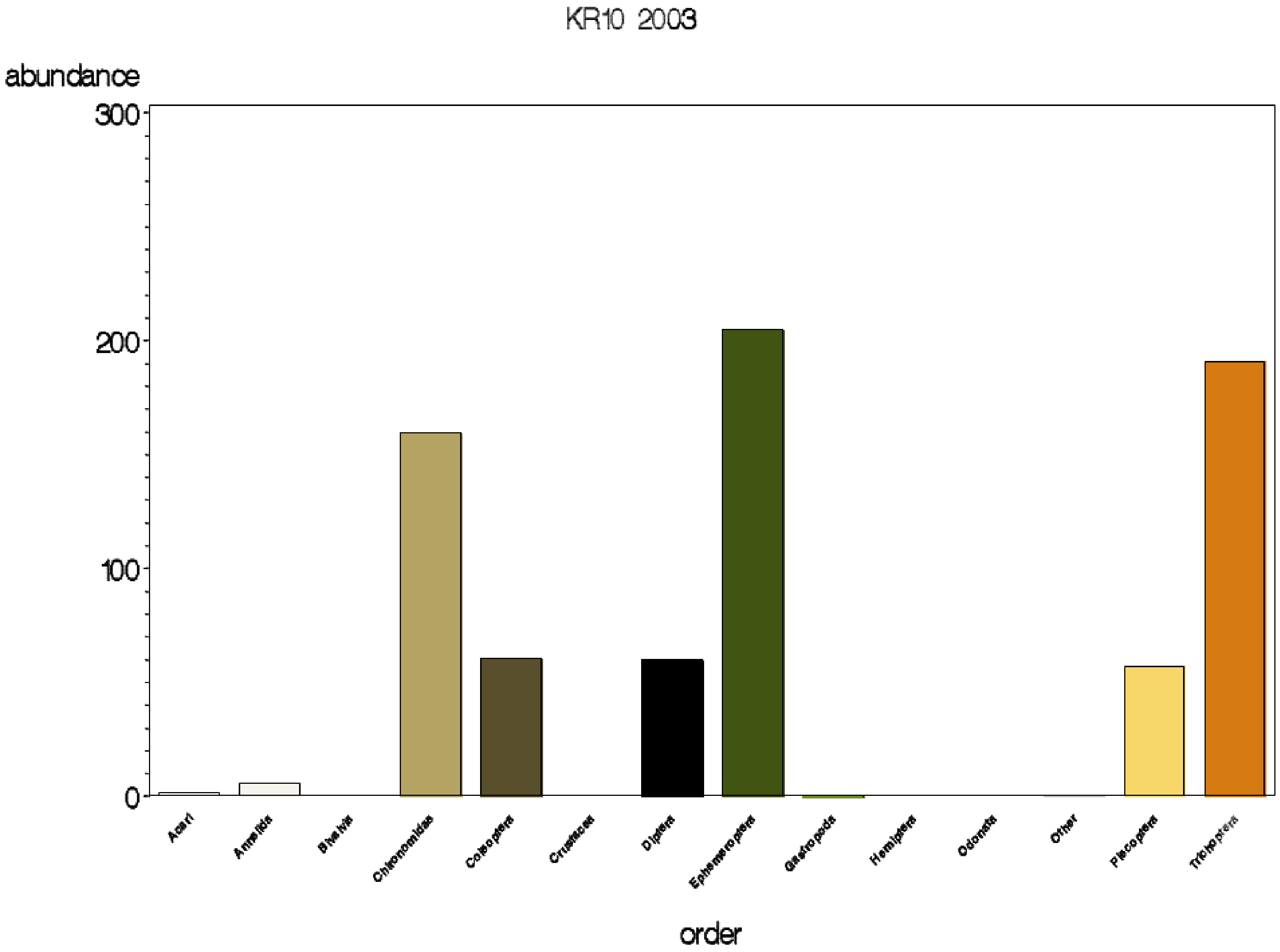

KR9 2005
abundance
700
600
500
400
300
200
100
0
Acari
Bivalvia
Chironomidae
Coleoptera
Diptera
Ephemeroptera
Gastropoda
Oligochaeta
Other
Plecoptera
Trichoptera
order

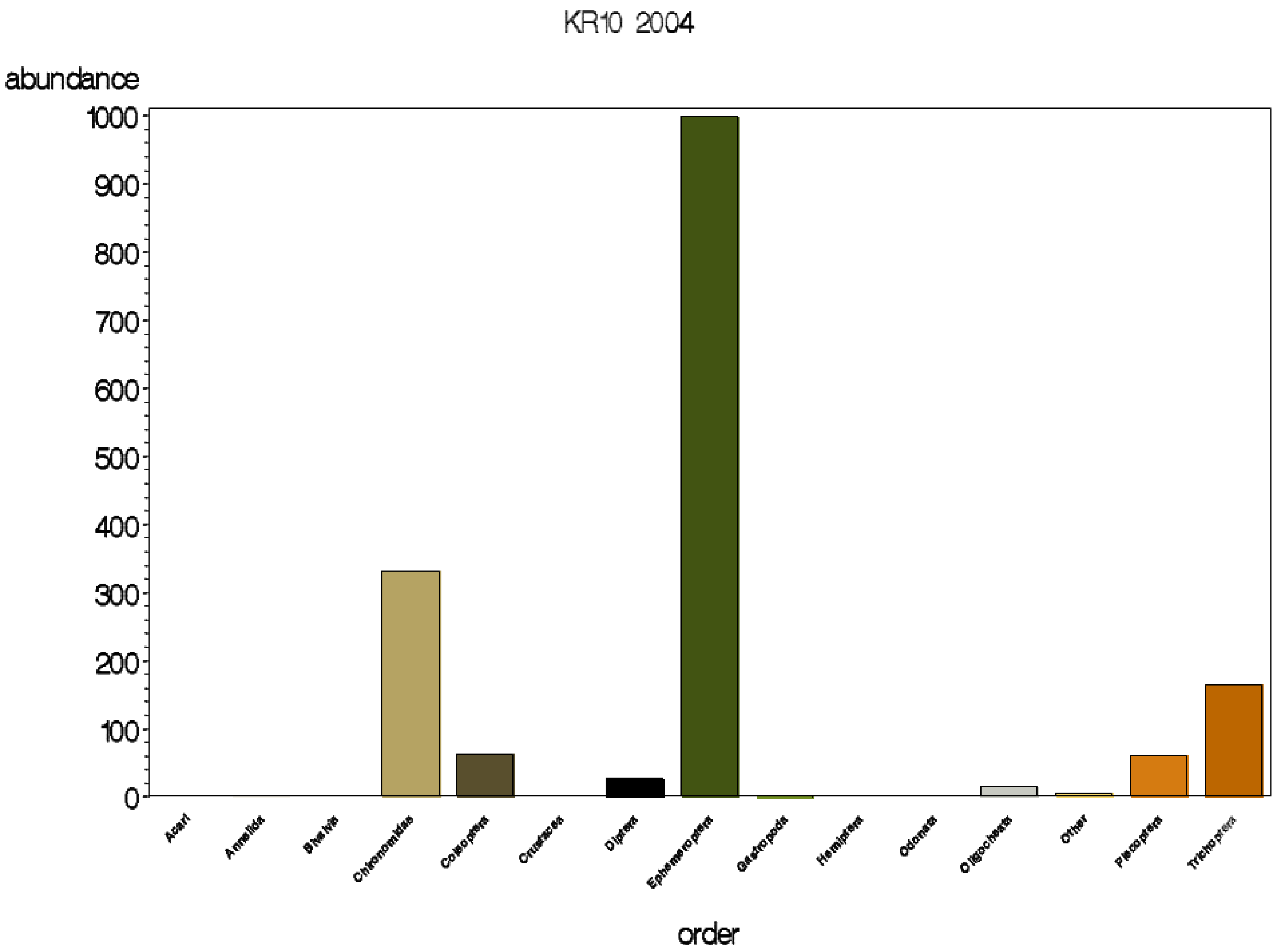

KR9 2006
abundance
3000
2000
1000
0
Acari
Bivalvia
Chironomidae
Coleoptera
Diptera
Ephemeroptera
Gastropoda
Oligochaeta
Other
Plecoptera
Trichoptera
order

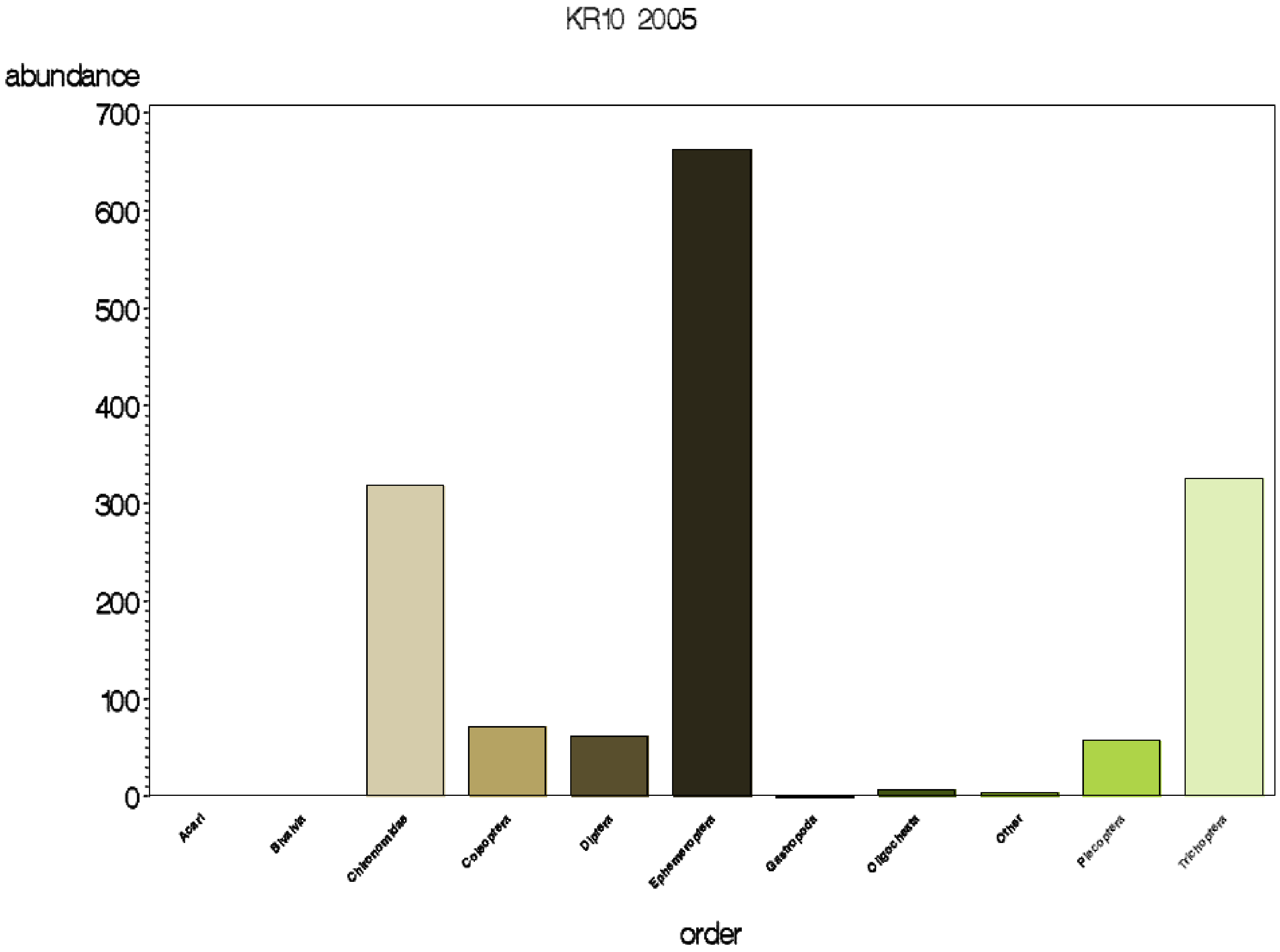

KR9.1 2004
abundance
1100
1000
900
800
700
600
500
400
300
200
100
0
Acari
Bivalvia
Chironomidae
Coleoptera
Crustacea
Diptera
Ephemeroptera
Gastropoda
Oligochaeta
Other
Plecoptera
Trichoptera
order

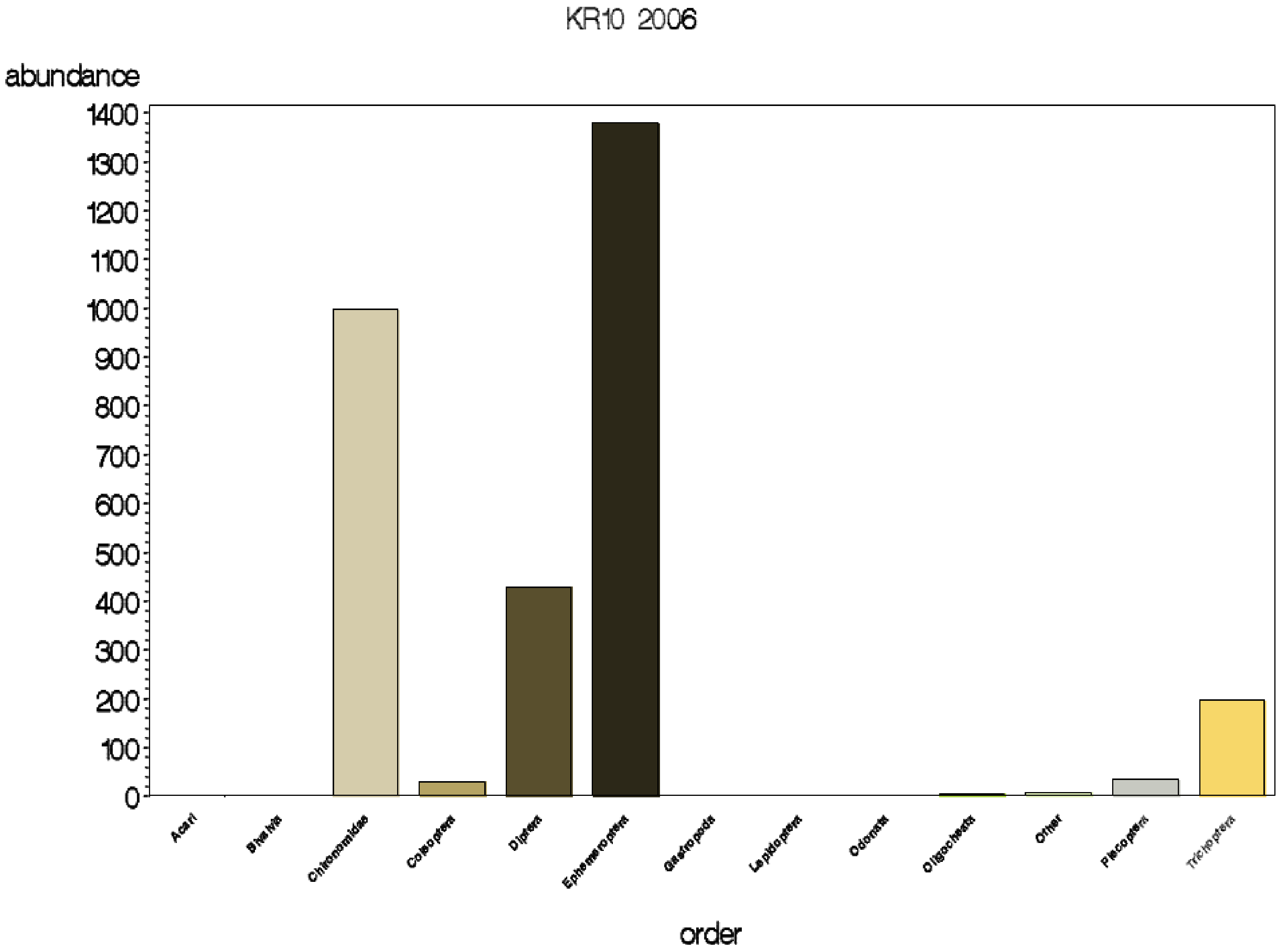

KR9.1 2005
abundance
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Acari
Bivalvia
Chironomidae
Coleoptera
Diptera
Ephemeroptera
Gastropoda
Oligochaeta
Other
Plecoptera
Trichoptera
order


KR9.1 2006
abundance
4000
3000
2000
1000
0
Acari
Bivalvia
Chironomidae
Coleoptera
Diptera
Ephemeroptera
Gastropoda
Oligochaeta
Other
Plecoptera
Trichoptera
order


KR10 2003
abundance
300
200
100
0
Acari
Annelida
Bivalvia
Chironomidae
Coleoptera
Crustacea
Diptera
Ephemeroptera
Gastropoda
Hemiptera
Odonata
Other
Plecoptera
Trichoptera
order


KR10 2004
abundance
1000
900
800
700
600
500
400
300
200
100
0
Acari
Annelida
Bivalvia
Chironomidae
Coleoptera
Crustacea
Diptera
Ephemeroptera
Gastropoda
Hemiptera
Odonata
Oligochaeta
Other
Plecoptera
Trichoptera
order


KR10 2005
abundance
700
600
500
400
300
200
100
0
Acari
Bivalvia
Chironomidae
Coleoptera
Diptera
Ephemeroptera
Gastropoda
Oligochaeta
Other
Plecoptera
Trichoptera
order


KR10 2006
abundance
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Acari
Bivalvia
Chironomidae
Coleoptera
Diptera
Ephemeroptera
Gastropoda
Lepidoptera
Odonata
Oligochaeta
Other
Plecoptera
Trichoptera
order

APPENDIX C: EPT COMPOSITION AT KR-9 AND KR-9.1

Appendix Table C-1. Ephemeroptera species composition at KR-9 and KR-9.1, 2003 through 2006.

Order	Site	Year	Species	%	Abundance
Ephemeroptera	KR9	2003	Rhithrogena sp.	52.6	2964
Ephemeroptera	KR9	2003	Ephemerella inermis/infrequens	25.6	1440
Ephemeroptera	KR9	2003	Other	8.5	480
Ephemeroptera	KR9	2003	Serratella tibialis	7.2	404
Ephemeroptera	KR9	2003	Paraleptophlebia sp.	6.1	344
Ephemeroptera	KR9	2004	Ephemerella inermis/infrequens	47.3	8812
Ephemeroptera	KR9	2004	Rhithrogena sp.	29.8	5560
Ephemeroptera	KR9	2004	Other	12.8	2388
Ephemeroptera	KR9	2004	Paraleptophlebia sp.	5.6	1052
Ephemeroptera	KR9	2004	Baetis tricaudatus	4.4	824
Ephemeroptera	KR9	2005	Rhithrogena sp.	61.4	7216
Ephemeroptera	KR9	2005	Ephemerella sp.	16.9	1984
Ephemeroptera	KR9	2005	Baetis tricaudatus	7.5	880
Ephemeroptera	KR9	2005	Acentrella turbida	5.5	644
Ephemeroptera	KR9	2005	Paraleptophlebia sp.	4.0	472
Ephemeroptera	KR9	2005	Ephemerella inermis/infrequens	3.0	356
Ephemeroptera	KR9	2005	Other	1.7	204
Ephemeroptera	KR9	2006	Ephemerella inermis/infrequens	41.5	17328
Ephemeroptera	KR9	2006	Rhithrogena sp.	39.5	16488
Ephemeroptera	KR9	2006	Ephemerella sp.	5.7	2392
Ephemeroptera	KR9	2006	Other	5.0	2104
Ephemeroptera	KR9	2006	Paraleptophlebia sp.	4.7	1976
Ephemeroptera	KR9	2006	Baetis tricaudatus	3.5	1448
Ephemeroptera	KR9.1	2004	Ephemerella inermis/infrequens	69.3	26816
Ephemeroptera	KR9.1	2004	Rhithrogena sp.	14.8	5708
Ephemeroptera	KR9.1	2004	Other	8.4	3232
Ephemeroptera	KR9.1	2004	Baetis tricaudatus	4.2	1620
Ephemeroptera	KR9.1	2004	Drunella coloradensis/flavilinea	3.4	1312
Ephemeroptera	KR9.1	2005	Rhithrogena sp.	40.0	6708
Ephemeroptera	KR9.1	2005	Ephemerella inermis/infrequens	34.1	5708
Ephemeroptera	KR9.1	2005	Baetis tricaudatus	10.1	1700
Ephemeroptera	KR9.1	2005	Paraleptophlebia sp.	4.8	800
Ephemeroptera	KR9.1	2005	Acentrella turbida	4.2	708
Ephemeroptera	KR9.1	2005	Other	3.6	596
Ephemeroptera	KR9.1	2005	Drunella grandis	3.2	536
Ephemeroptera	KR9.1	2006	Ephemerella inermis/infrequens	65.6	43396
Ephemeroptera	KR9.1	2006	Ephemerella sp.	13.8	9156
Ephemeroptera	KR9.1	2006	Rhithrogena sp.	11.0	7288
Ephemeroptera	KR9.1	2006	Other	9.6	6344

A complete graphical depiction of EPT taxa metrics at KR-9 and KR-9.1 are provided in Appendix D.*Metric Charts* on the following pages.

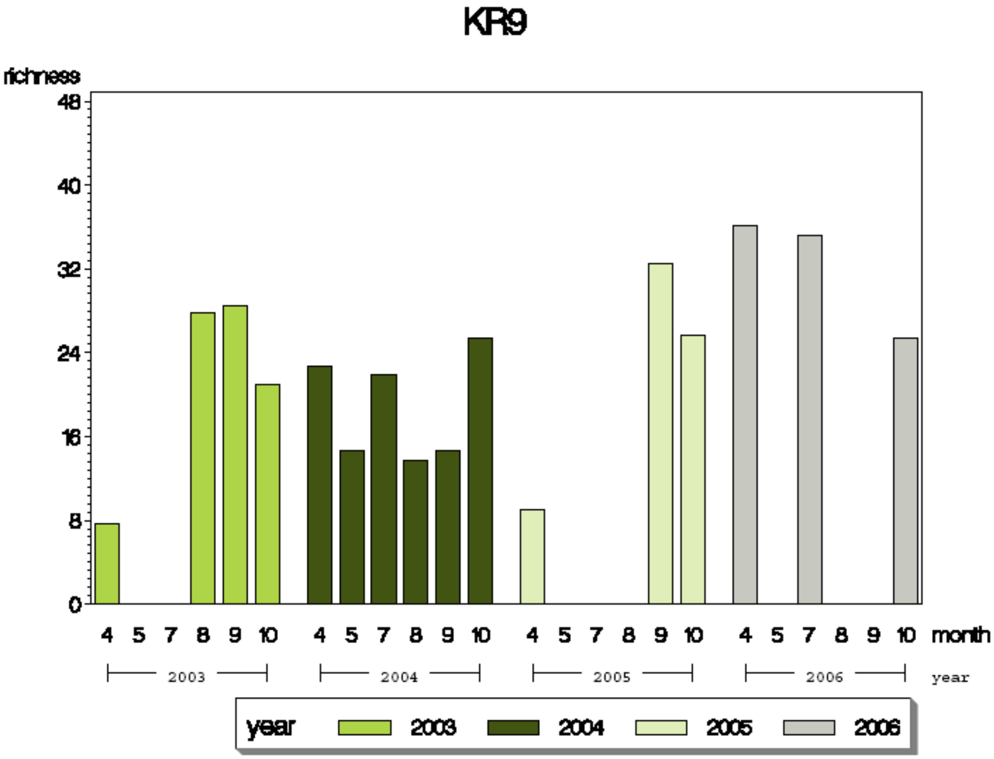
Appendix Table C-2. Plecoptera species composition at KR-9 and KR-9.1, 2003 through 2006.

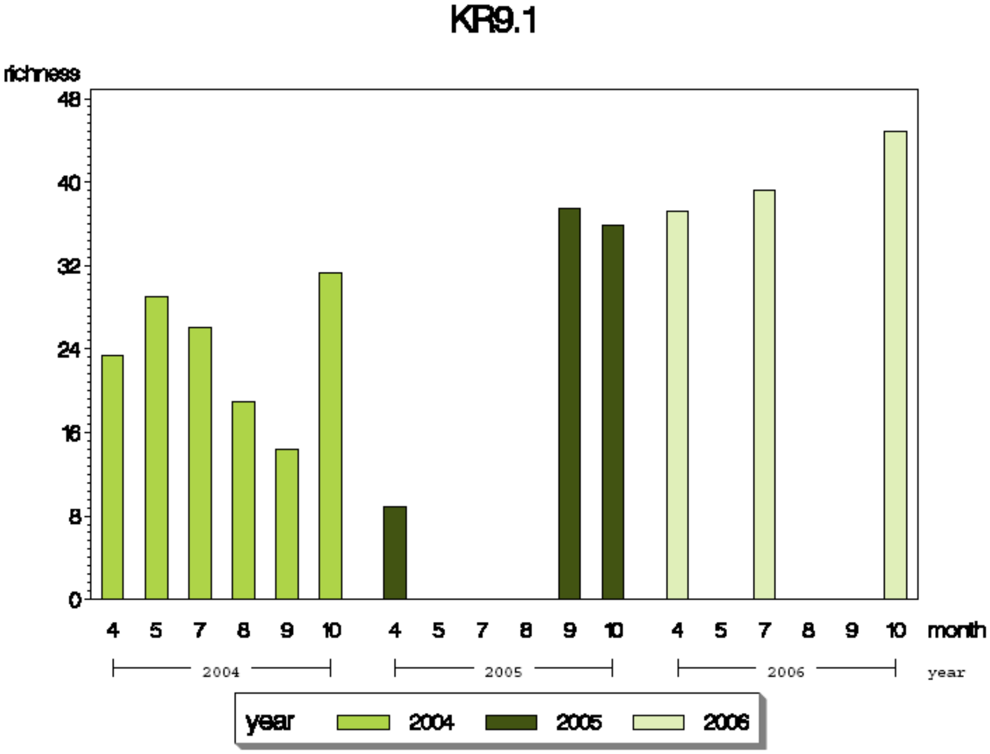
Order	Site	Year	Species	%	Abundance
Plecoptera	KR9	2003	Claassenia sabulosa	69.3	560
Plecoptera	KR9	2003	Pteronarcys californica	14.4	116
Plecoptera	KR9	2003	Sweltsa sp.	6.9	56
Plecoptera	KR9	2003	Other	5.9	48
Plecoptera	KR9	2003	Pteronarcys sp.	3.5	28
Plecoptera	KR9	2004	Claassenia sabulosa	28.8	472
Plecoptera	KR9	2004	Pteronarcys californica	22.2	364
Plecoptera	KR9	2004	Taeniopterygidae	17.3	284
Plecoptera	KR9	2004	Perlidae	9.0	148
Plecoptera	KR9	2004	Podmosta sp.	7.1	116
Plecoptera	KR9	2004	Sweltsa sp.	6.8	112
Plecoptera	KR9	2004	Other	5.1	84
Plecoptera	KR9	2004	Pteronarcys sp.	3.7	60
Plecoptera	KR9	2005	Claassenia sabulosa	71.2	872
Plecoptera	KR9	2005	Pteronarcys californica	11.1	136
Plecoptera	KR9	2005	Sweltsa sp.	7.2	88
Plecoptera	KR9	2005	Other	6.5	80
Plecoptera	KR9	2005	Taeniopterygidae	3.9	48
Plecoptera	KR9	2006	Claassenia sabulosa	63.3	1372
Plecoptera	KR9	2006	Prostoia sp.	13.8	300
Plecoptera	KR9	2006	Pteronarcys sp.	8.1	176
Plecoptera	KR9	2006	Other	5.0	108
Plecoptera	KR9	2006	Sweltsa sp.	3.5	76
Plecoptera	KR9	2006	Pteronarcys californica	3.1	68
Plecoptera	KR9	2006	Taeniopterygidae	3.1	68
Plecoptera	KR9.1	2004	Claassenia sabulosa	29.8	600
Plecoptera	KR9.1	2004	Pteronarcys californica	21.2	428
Plecoptera	KR9.1	2004	Pteronarcys sp.	11.7	236
Plecoptera	KR9.1	2004	Other	10.7	216
Plecoptera	KR9.1	2004	Perlidae	8.3	168
Plecoptera	KR9.1	2004	Taenionema sp.	6.3	128
Plecoptera	KR9.1	2004	Hesperoperla pacifica	4.8	96
Plecoptera	KR9.1	2004	Sweltsa sp.	3.8	76
Plecoptera	KR9.1	2004	Taeniopterygidae	3.4	68
Plecoptera	KR9.1	2005	Claassenia sabulosa	35.0	672
Plecoptera	KR9.1	2005	Pteronarcys californica	27.1	520
Plecoptera	KR9.1	2005	Taeniopterygidae	10.4	200
Plecoptera	KR9.1	2005	Other	9.6	184
Plecoptera	KR9.1	2005	Sweltsa sp.	9.2	176
Plecoptera	KR9.1	2005	Hesperoperla pacifica	8.8	168
Plecoptera	KR9.1	2006	Pteronarcys californica	21.4	520
Plecoptera	KR9.1	2006	Claassenia sabulosa	19.1	464
Plecoptera	KR9.1	2006	Taeniopterygidae	17.3	420
Plecoptera	KR9.1	2006	Prostoia sp.	16.6	404
Plecoptera	KR9.1	2006	Taenionema sp.	7.6	184
Plecoptera	KR9.1	2006	Hesperoperla pacifica	5.1	124
Plecoptera	KR9.1	2006	Sweltsa sp.	4.8	116
Plecoptera	KR9.1	2006	Other	4.6	112
Plecoptera	KR9.1	2006	Pteronarcys sp.	3.6	88

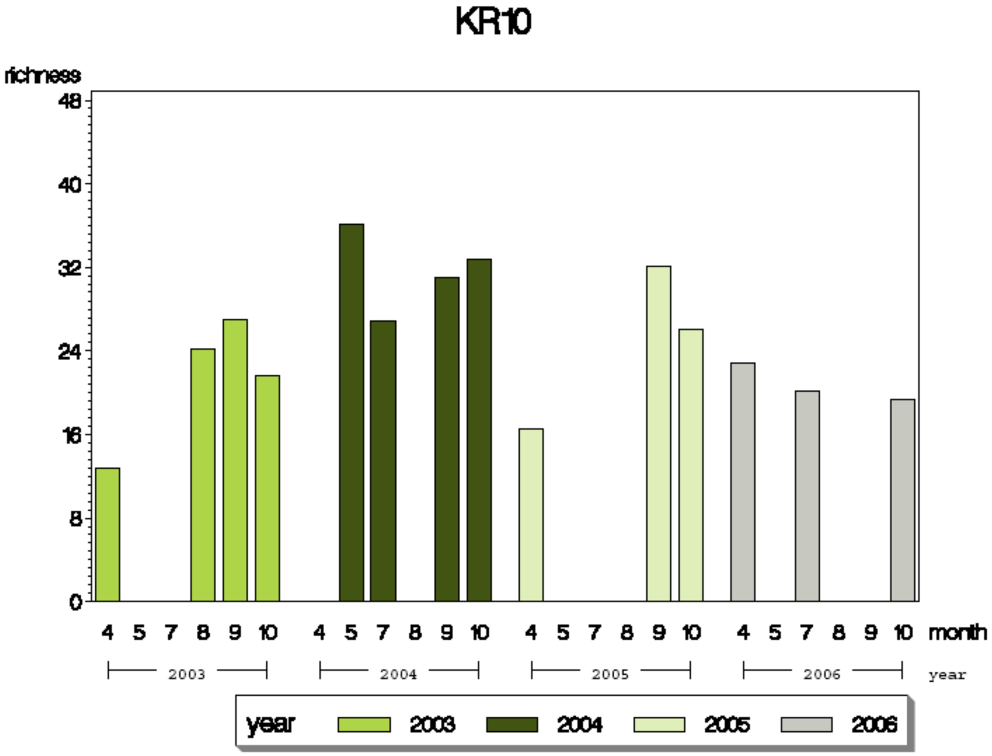
Appendix Table C-3. Trichoptera species composition at KR-9 and KR-9.1, 2003 through 2006.

Order	Site	Year	Species	%	Abundance
Trichoptera	KR9	2003	Hydropsyche sp.	83.5	3760
Trichoptera	KR9	2003	Cheumatopsyche sp.	15.0	676
Trichoptera	KR9	2003	Other	1.5	68
Trichoptera	KR9	2004	Hydropsyche sp.	60.1	1072
Trichoptera	KR9	2004	Cheumatopsyche sp.	30.9	552
Trichoptera	KR9	2004	Glossosoma sp.	3.4	60
Trichoptera	KR9	2004	Hydropsychidae	3.4	60
Trichoptera	KR9	2004	Other	2.2	40
Trichoptera	KR9	2005	Hydropsyche sp.	64.3	3660
Trichoptera	KR9	2005	Cheumatopsyche sp.	29.1	1656
Trichoptera	KR9	2005	Glossosoma sp.	4.8	272
Trichoptera	KR9	2005	Other	1.9	108
Trichoptera	KR9	2006	Hydropsyche sp.	73.4	4128
Trichoptera	KR9	2006	Cheumatopsyche sp.	22.4	1260
Trichoptera	KR9	2006	Glossosoma sp.	3.1	176
Trichoptera	KR9	2006	Other	1.1	60
Trichoptera	KR9.1	2004	Cheumatopsyche sp.	55.9	3964
Trichoptera	KR9.1	2004	Hydropsyche sp.	41.0	2908
Trichoptera	KR9.1	2004	Other	3.2	224
Trichoptera	KR9.1	2005	Hydropsyche sp.	53.5	17092
Trichoptera	KR9.1	2005	Cheumatopsyche sp.	42.4	13544
Trichoptera	KR9.1	2005	Glossosoma sp.	3.6	1136
Trichoptera	KR9.1	2005	Other	0.6	188
Trichoptera	KR9.1	2006	Hydropsyche sp.	78.4	8516
Trichoptera	KR9.1	2006	Cheumatopsyche sp.	15.9	1724
Trichoptera	KR9.1	2006	Glossosoma sp.	3.6	388
Trichoptera	KR9.1	2006	Other	2.2	236

APPENDIX D: SELECTED METRIC CHARTS FROM KR-9, KR-9.1, AND KR-10



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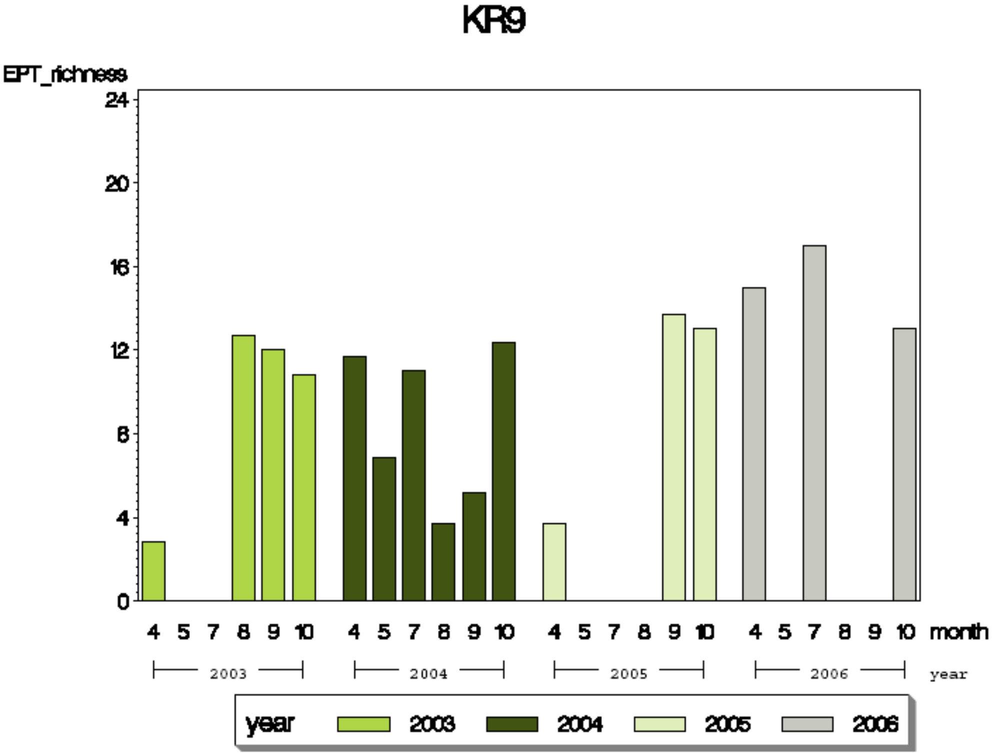
year 2003 2004 2005 2006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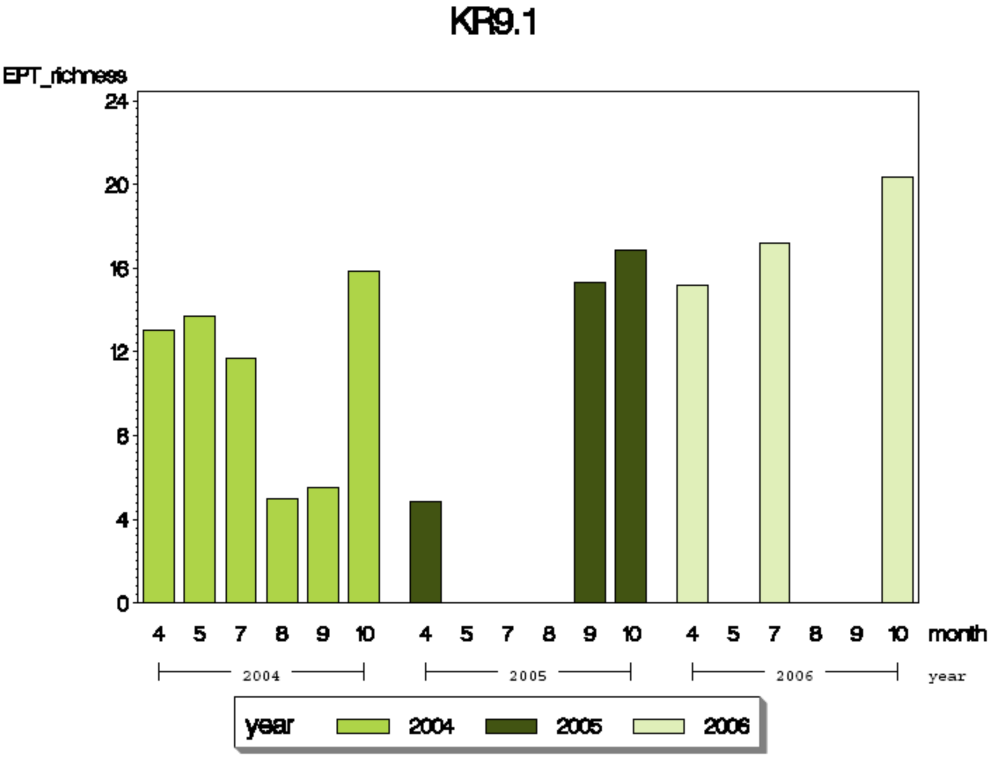
year 2003 2004 2005 2006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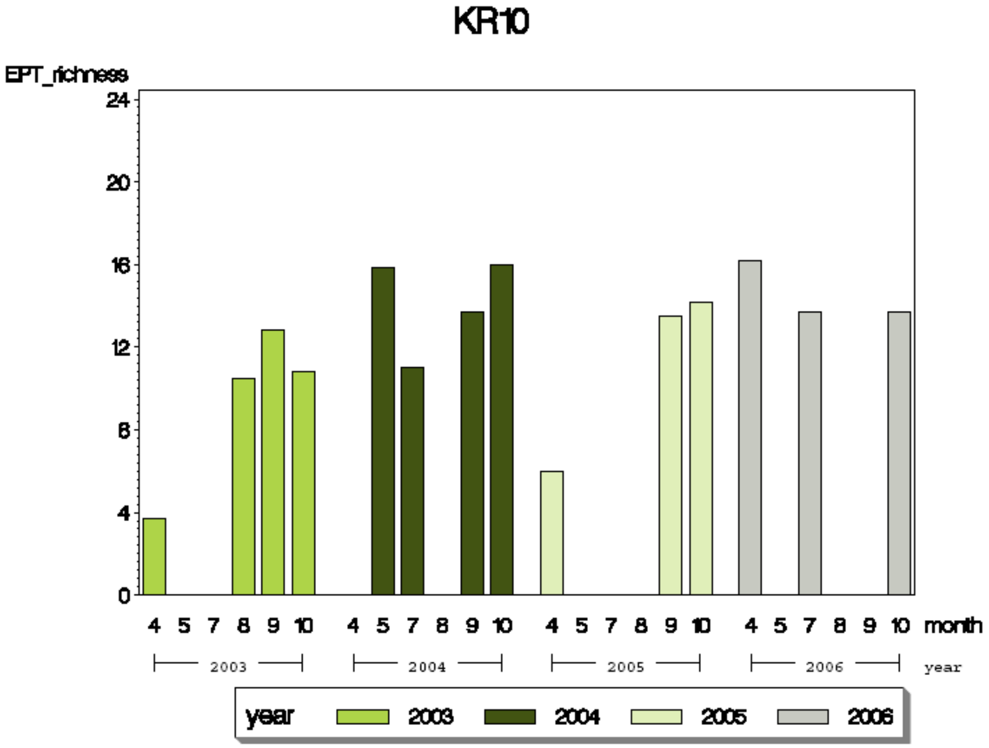
2005
2006
year
year 2004 2005 2006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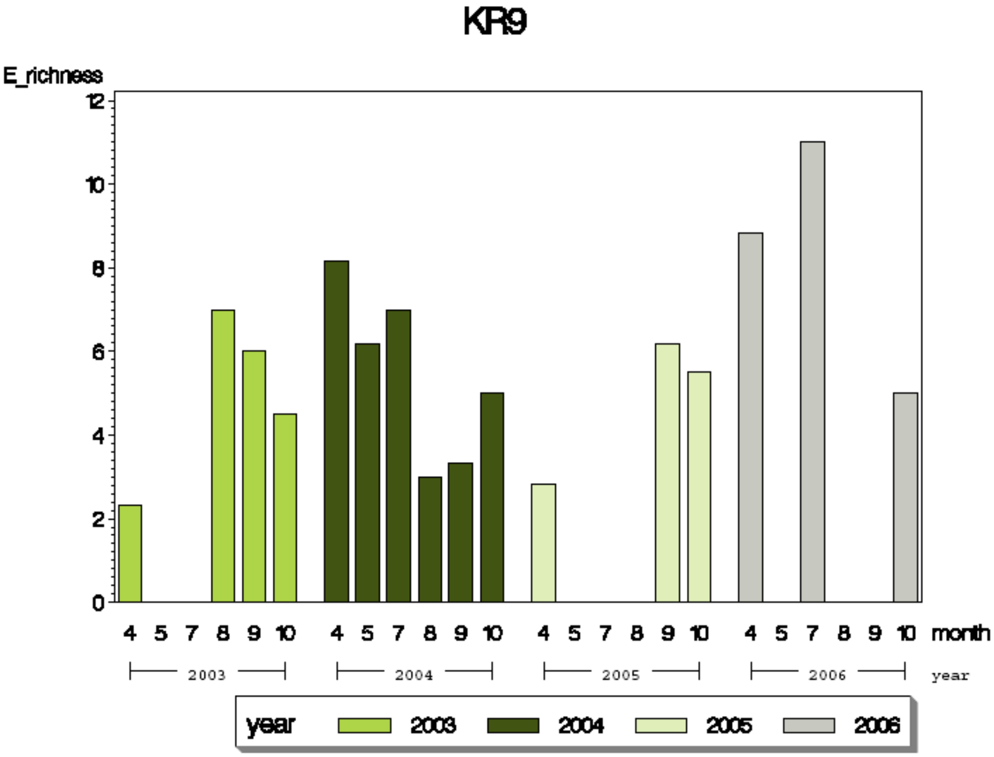
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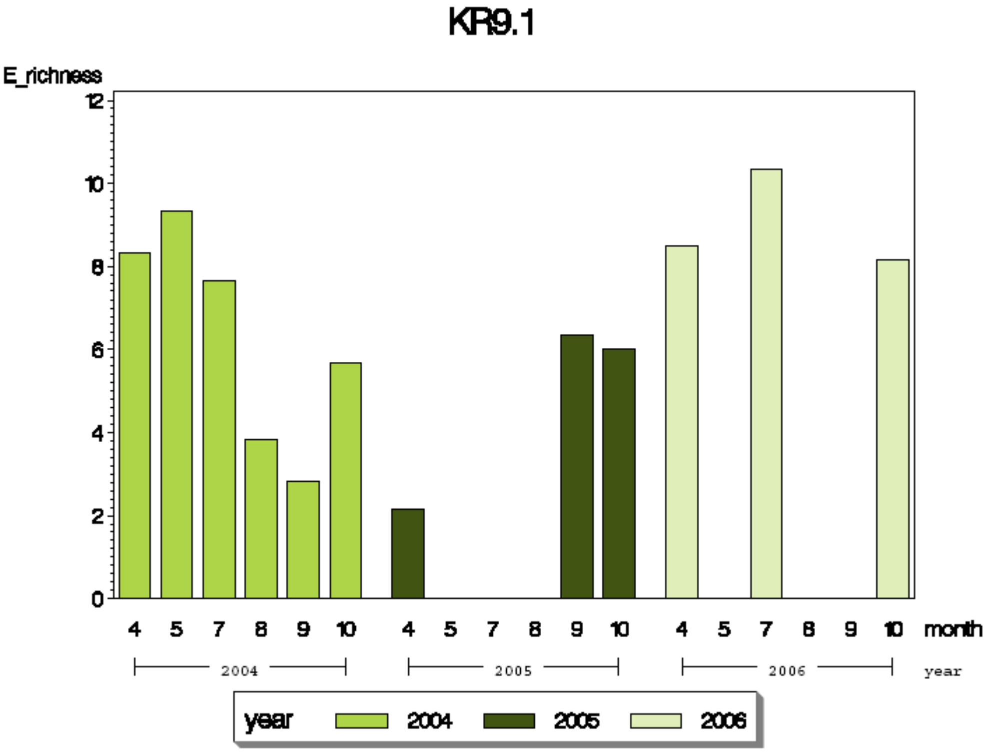
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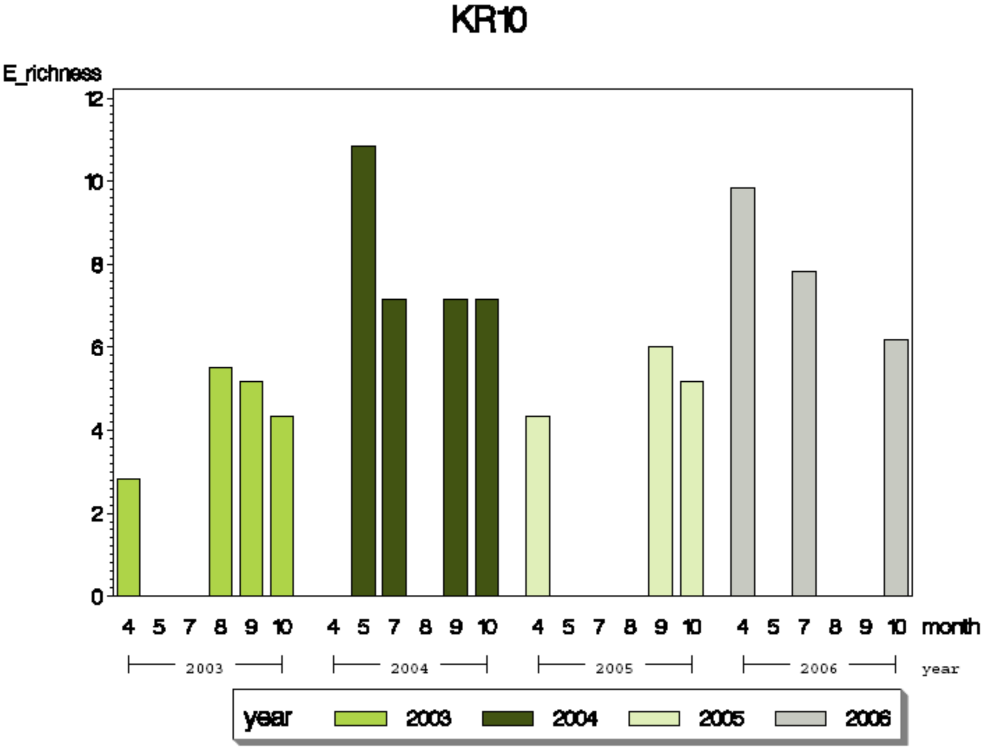
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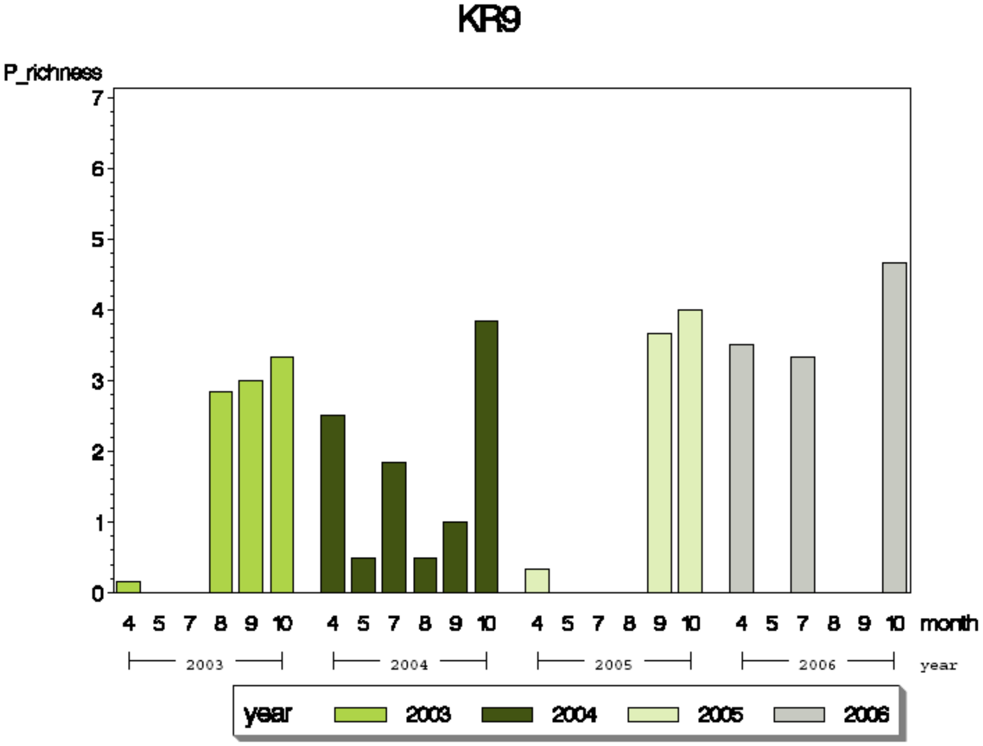
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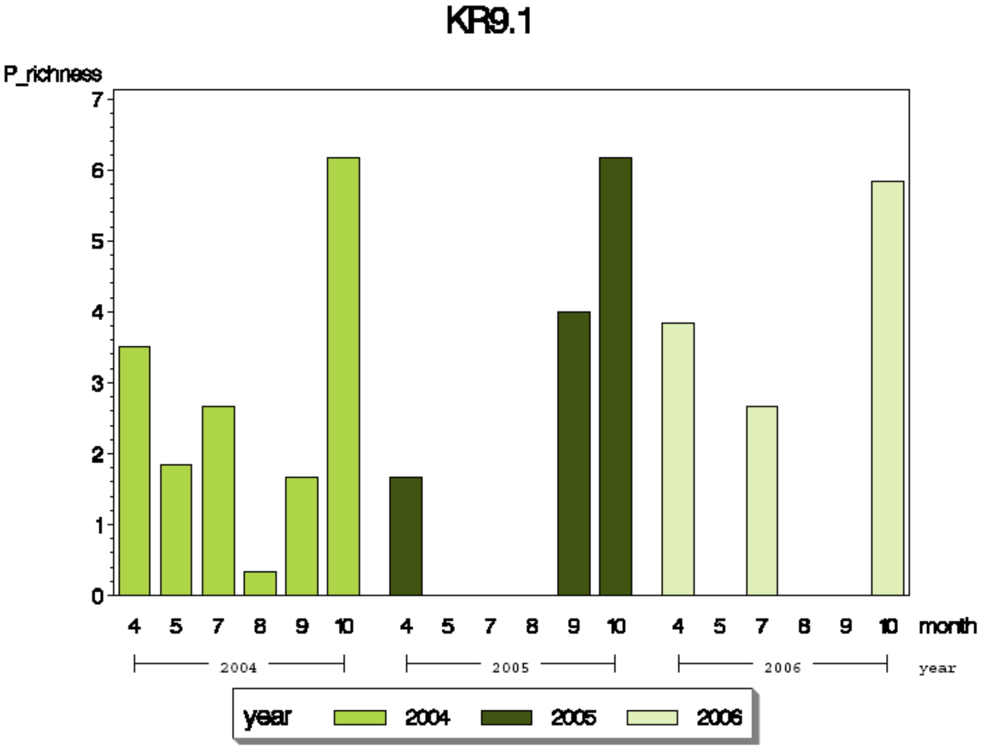
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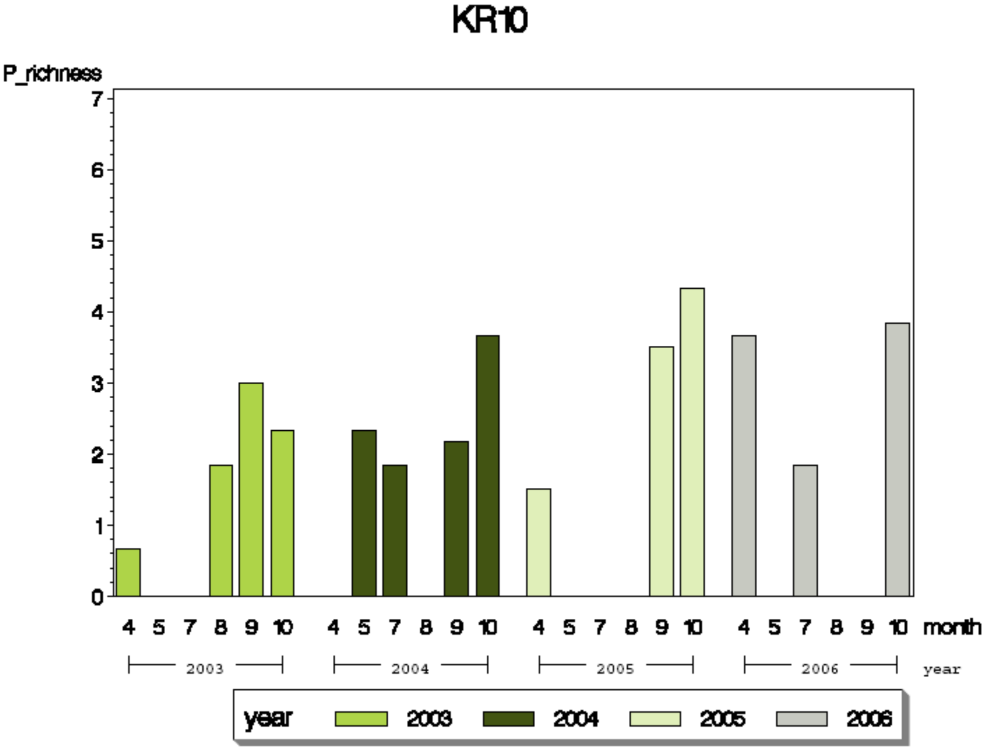
year 2004 2005 2006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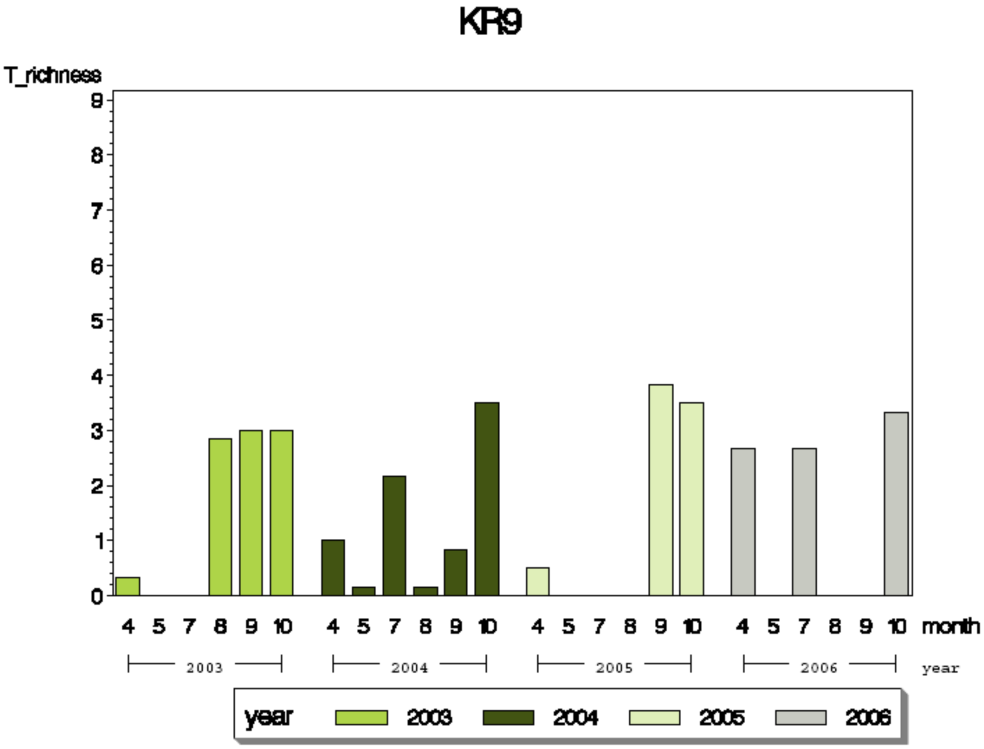
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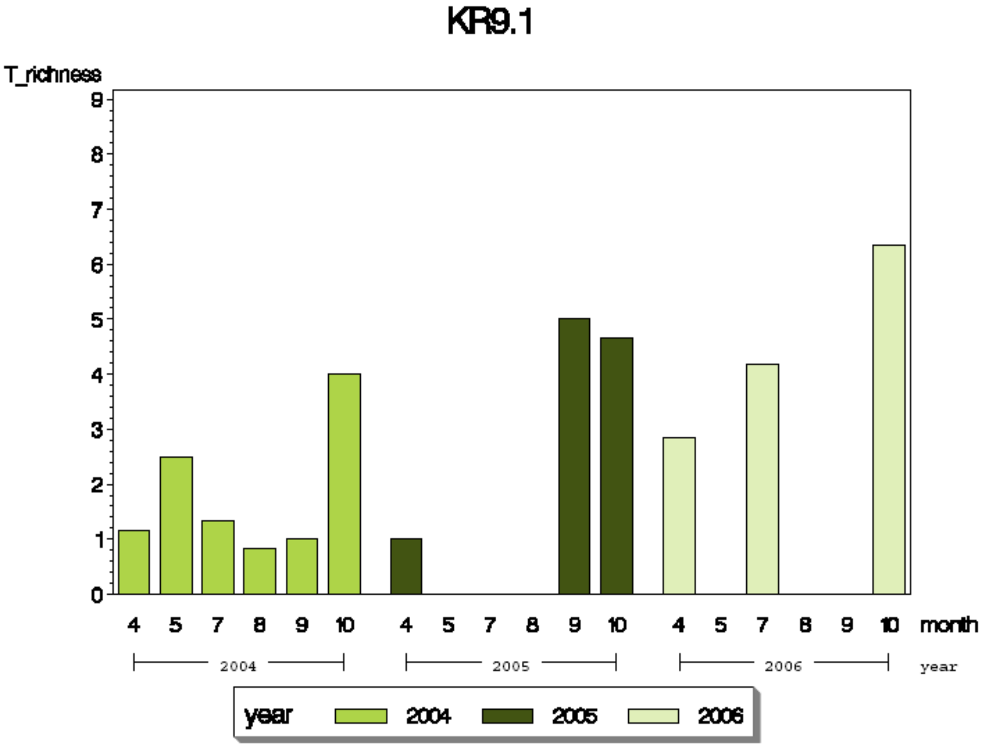
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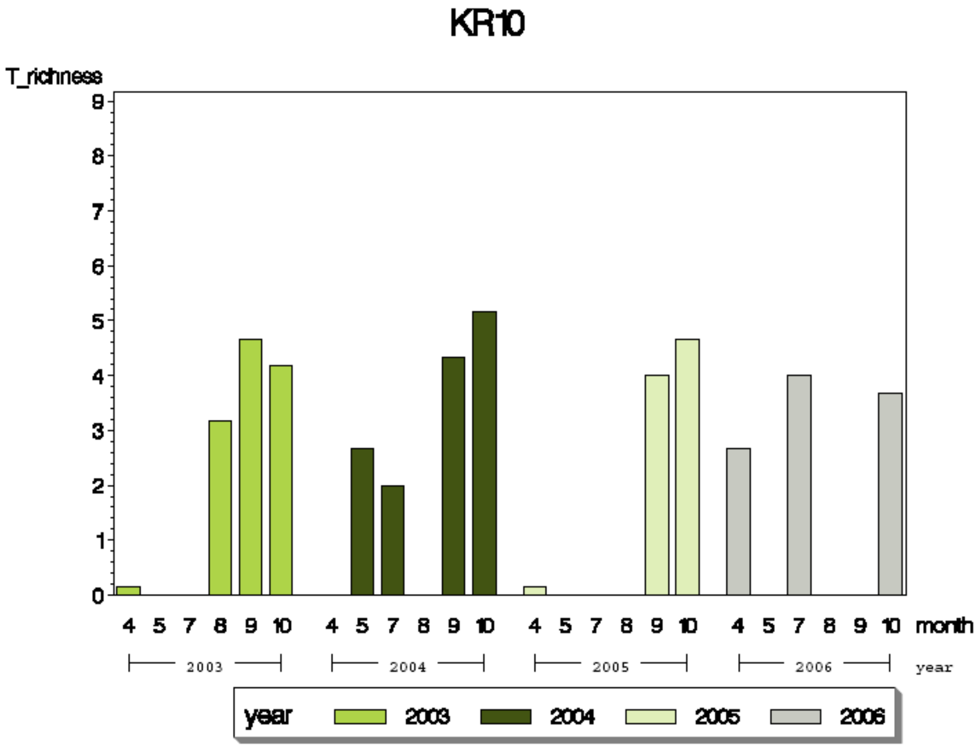
year 2004 2005 2006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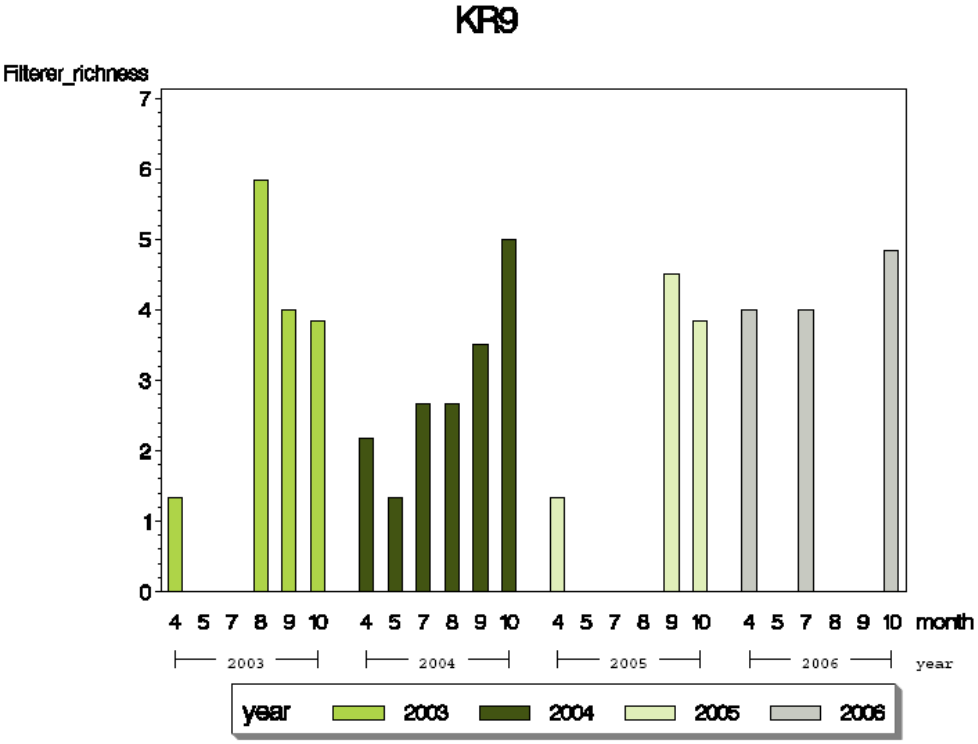
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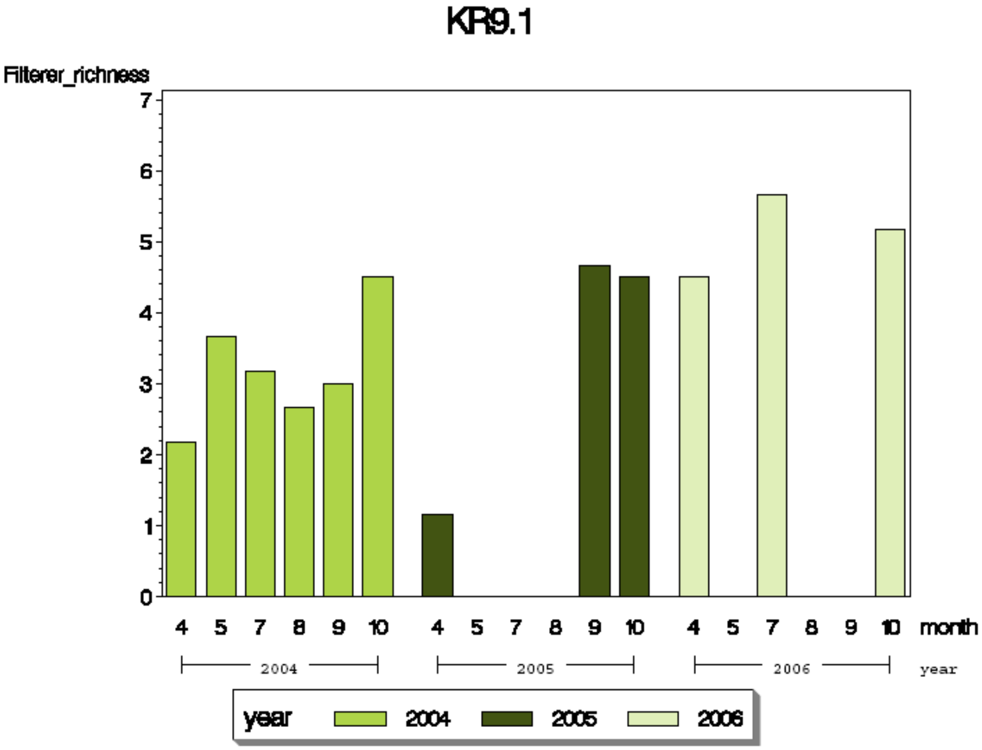
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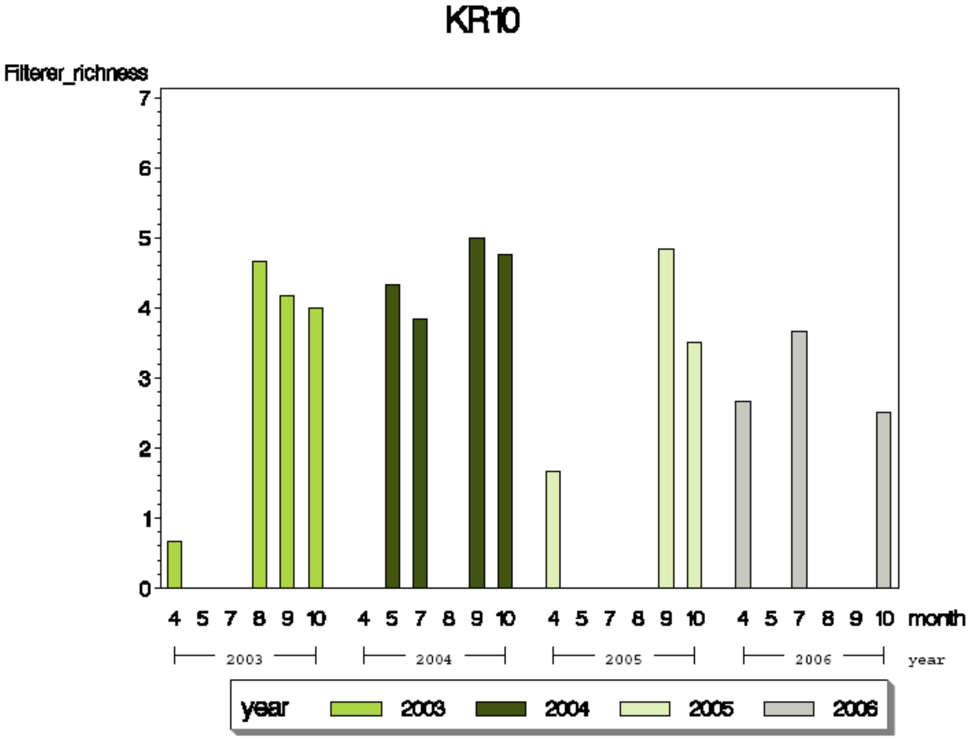
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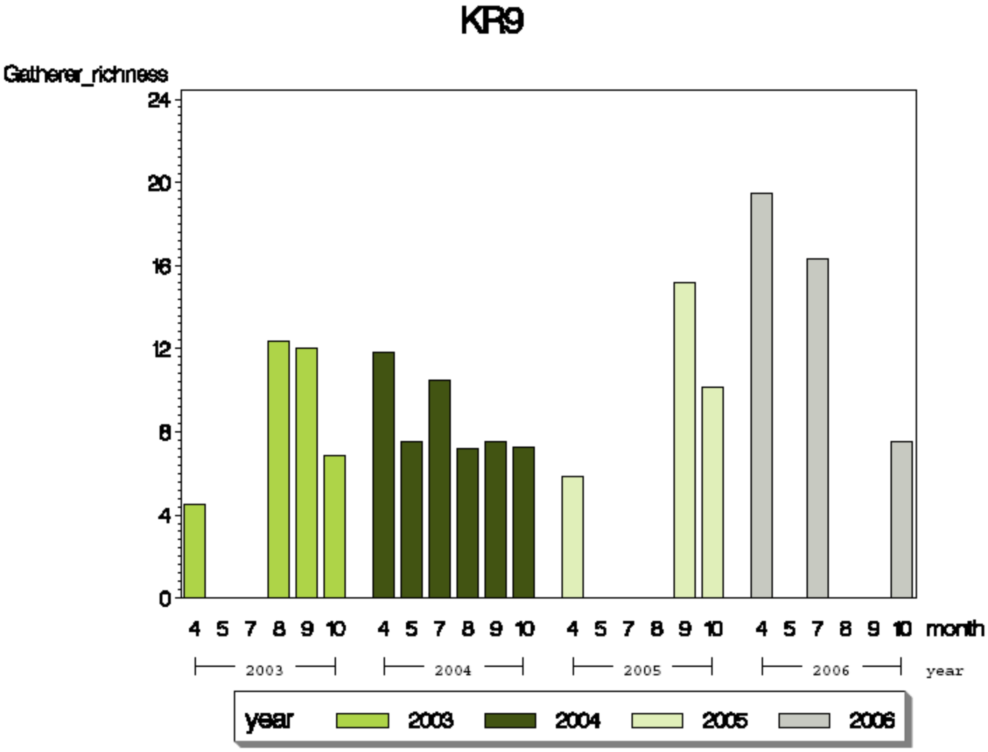
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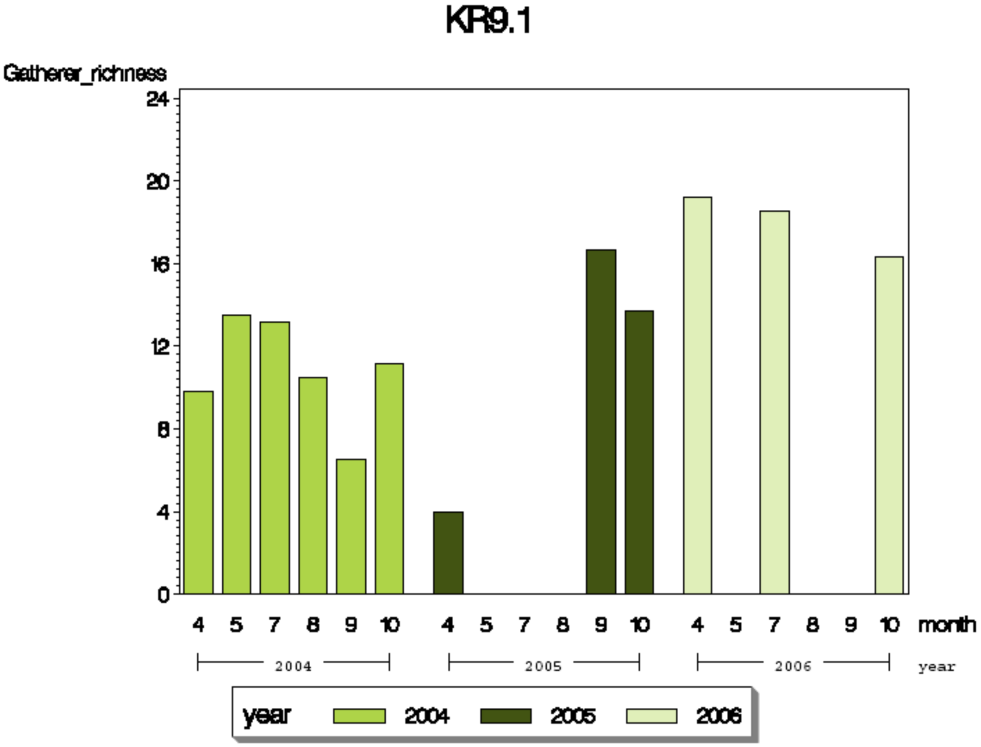
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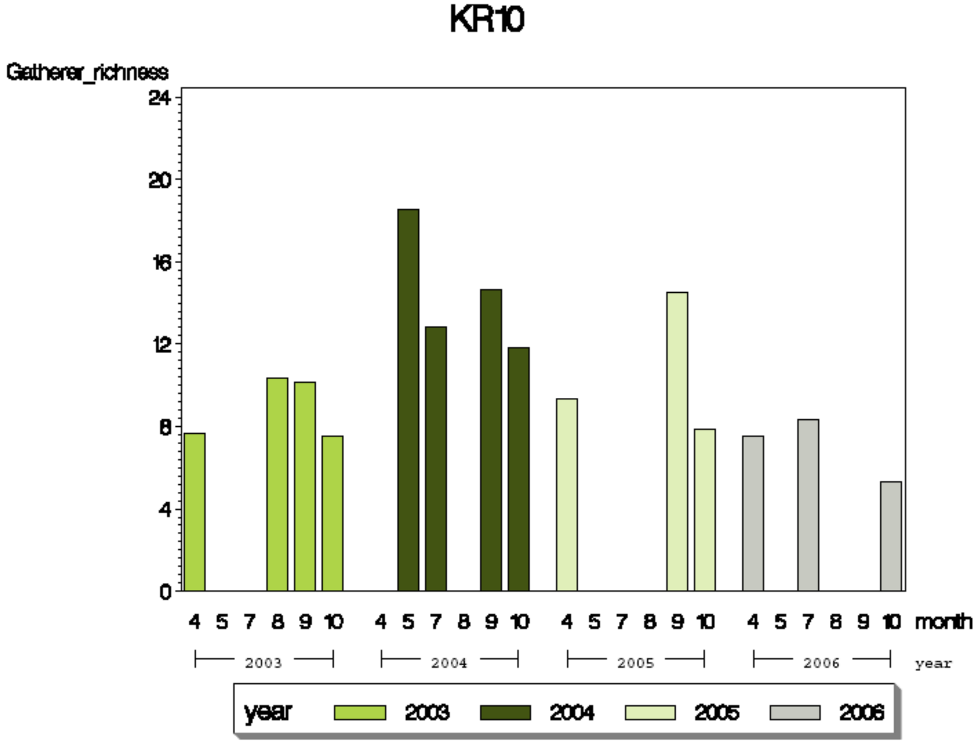
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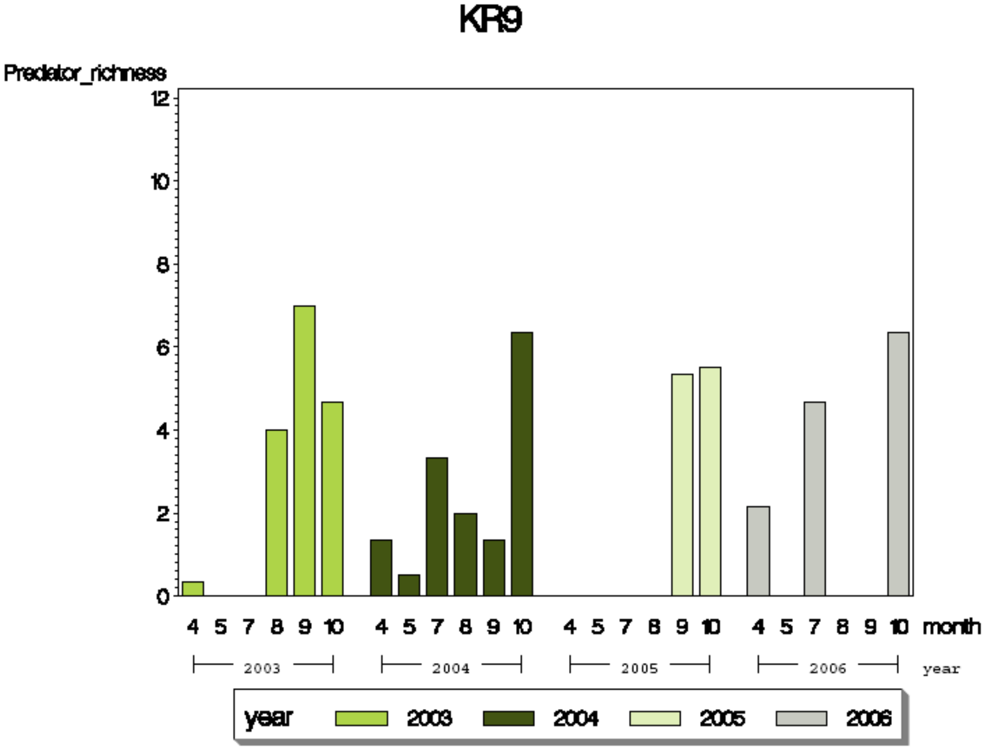
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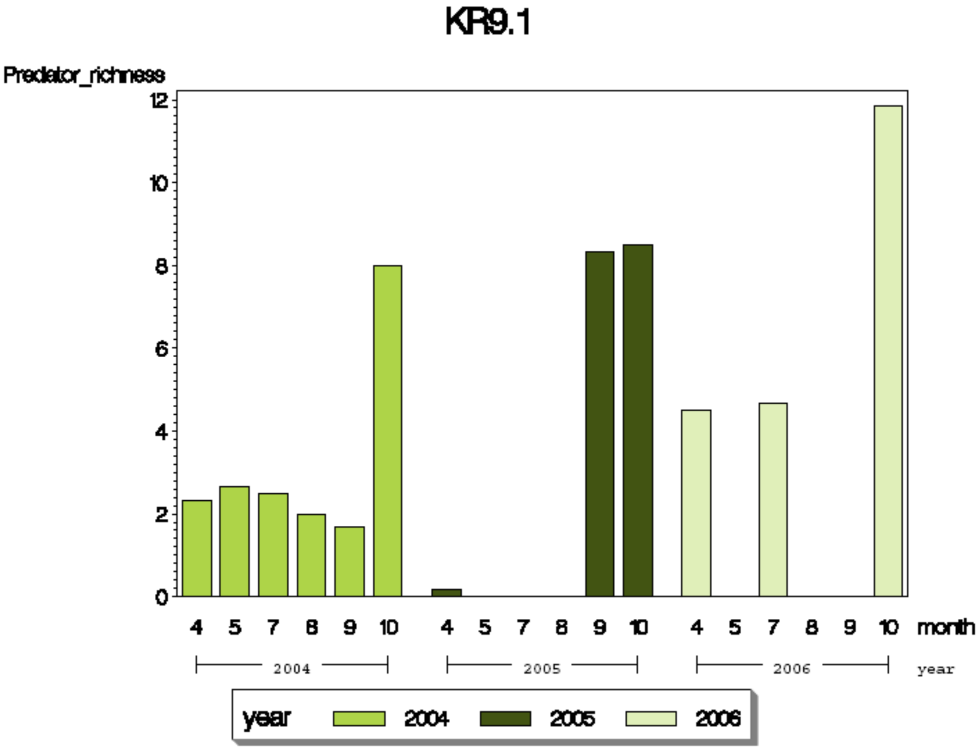
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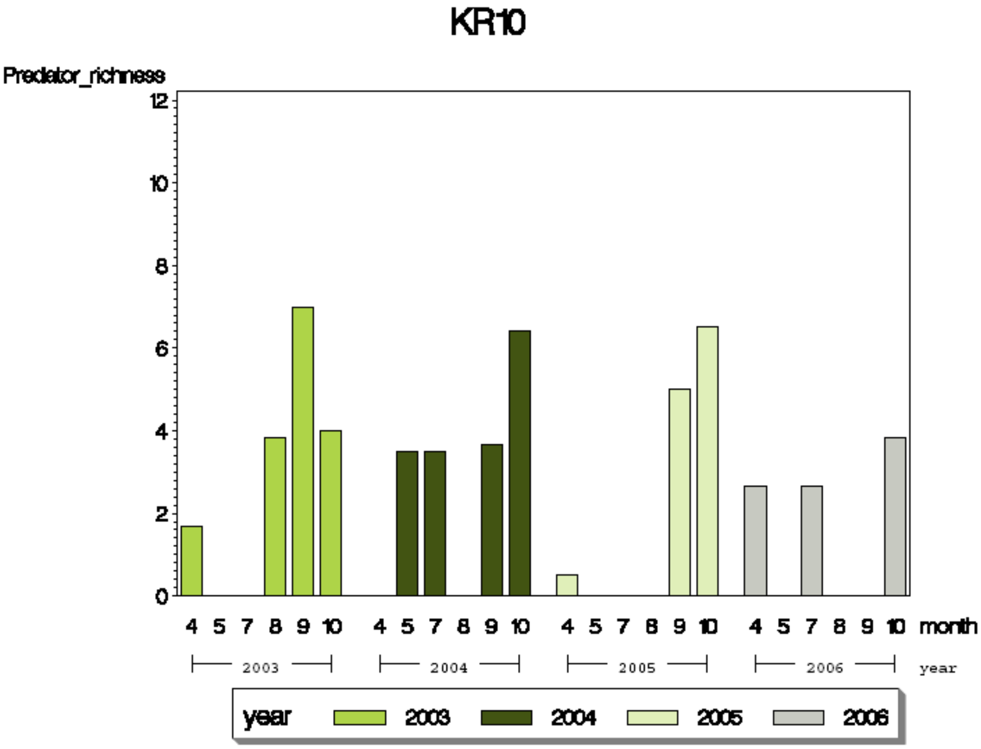
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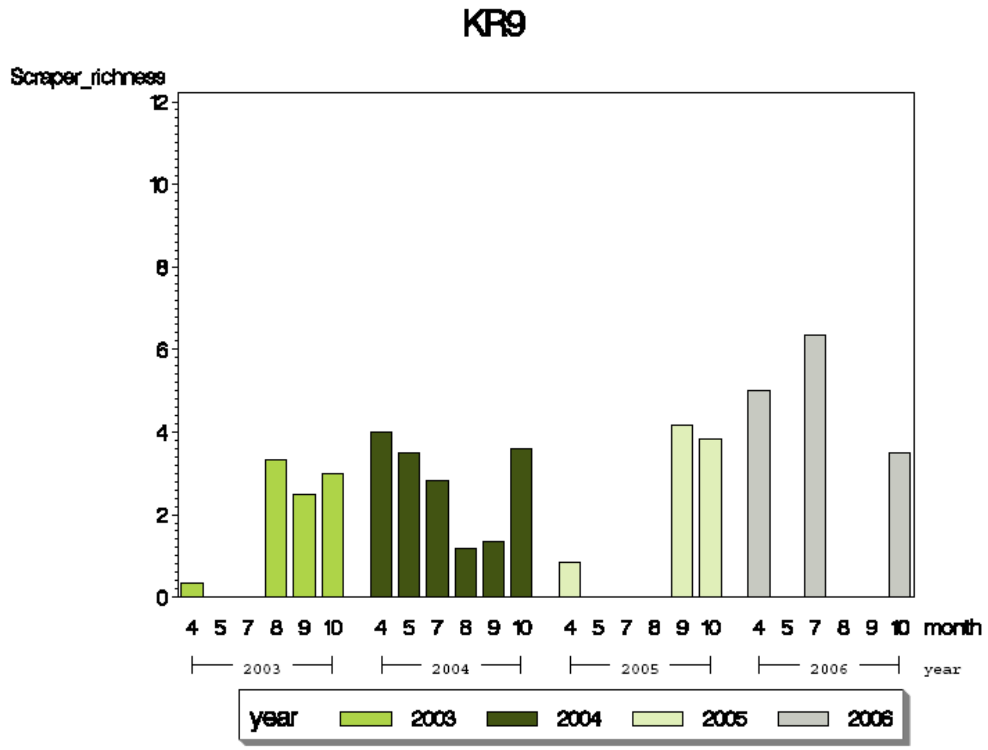
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Scraper_richness
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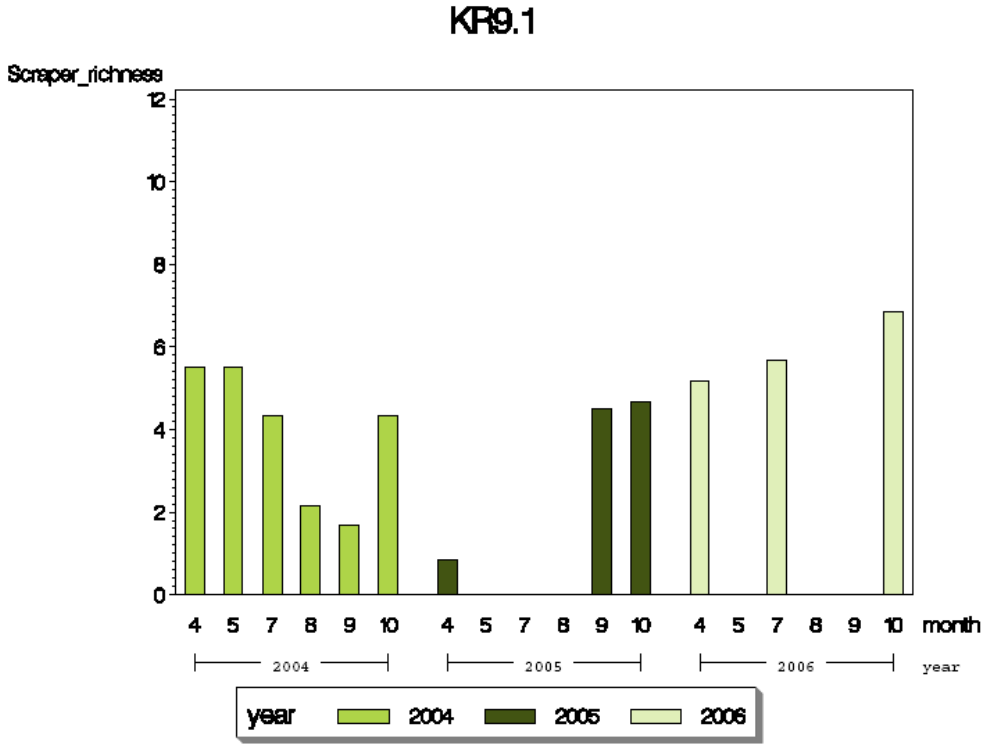
year 2003 2004 2005 2006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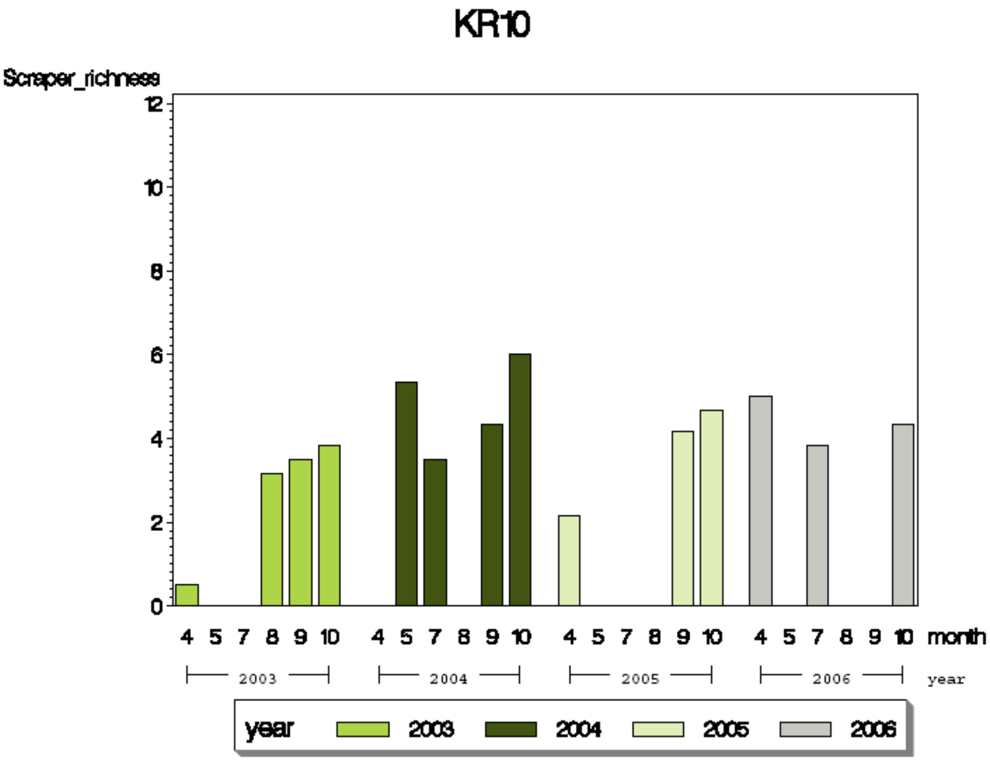
year 2004 2005 2006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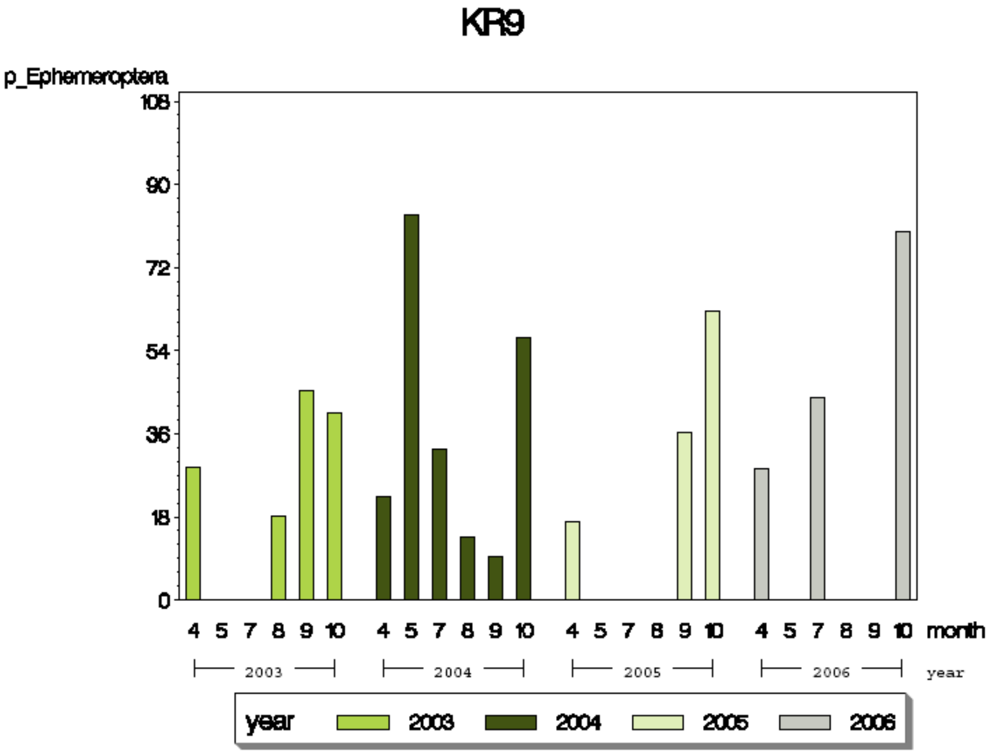
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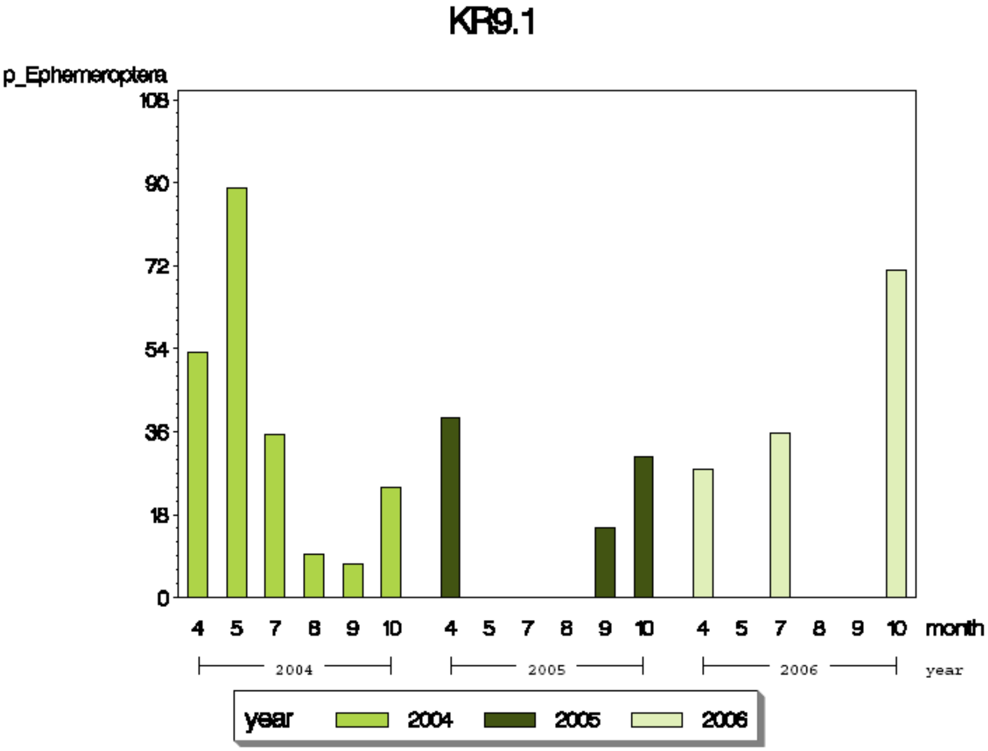
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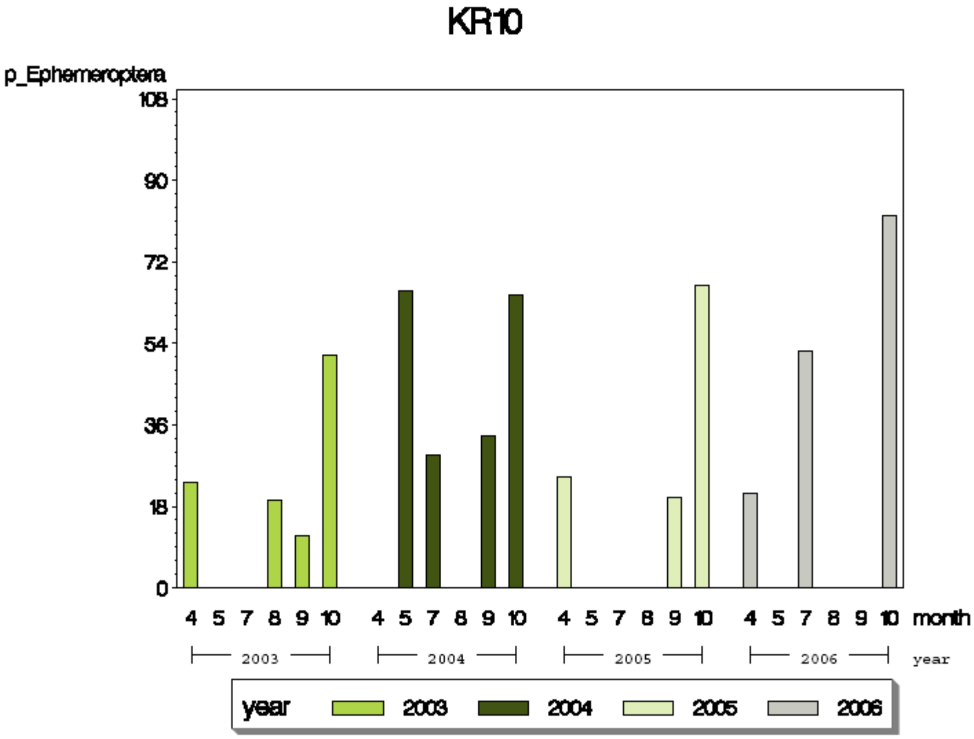
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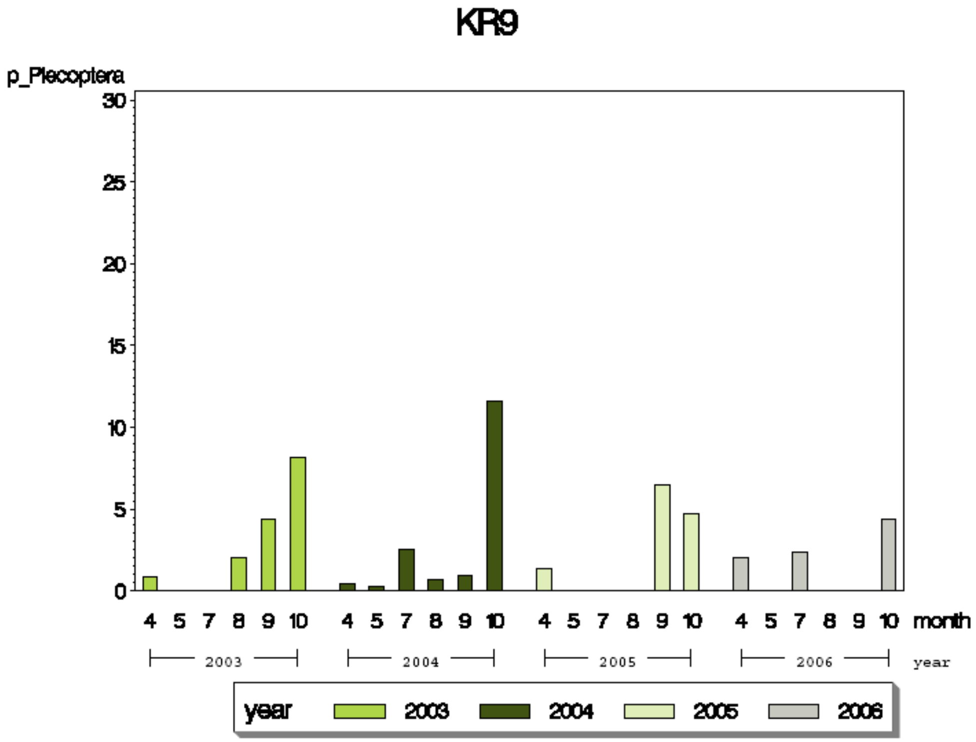
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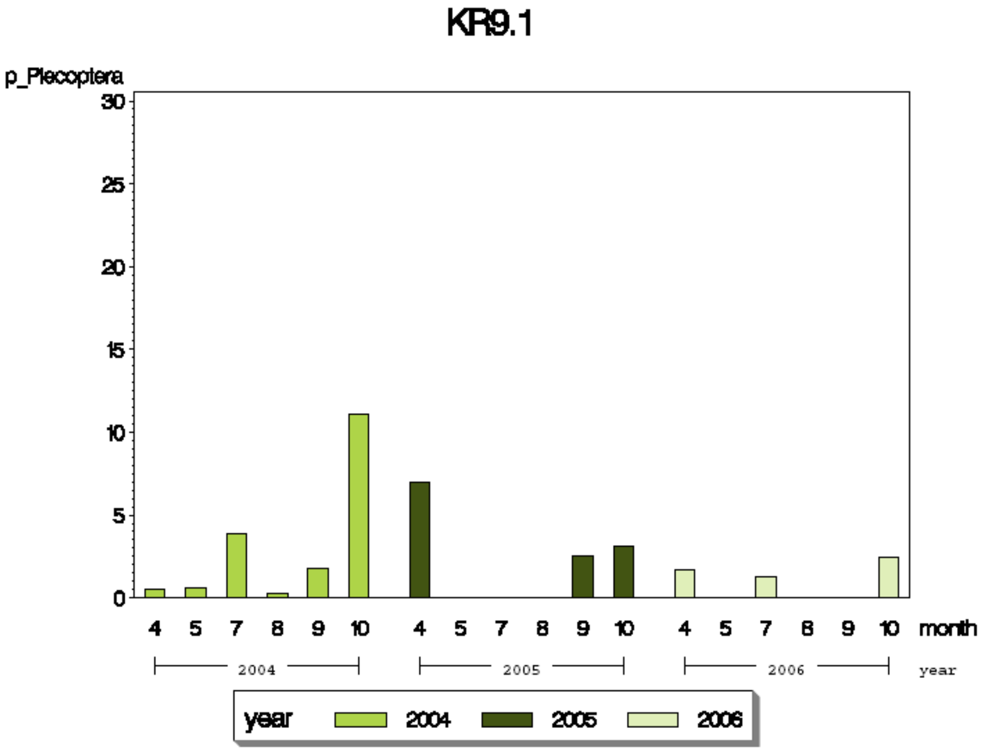
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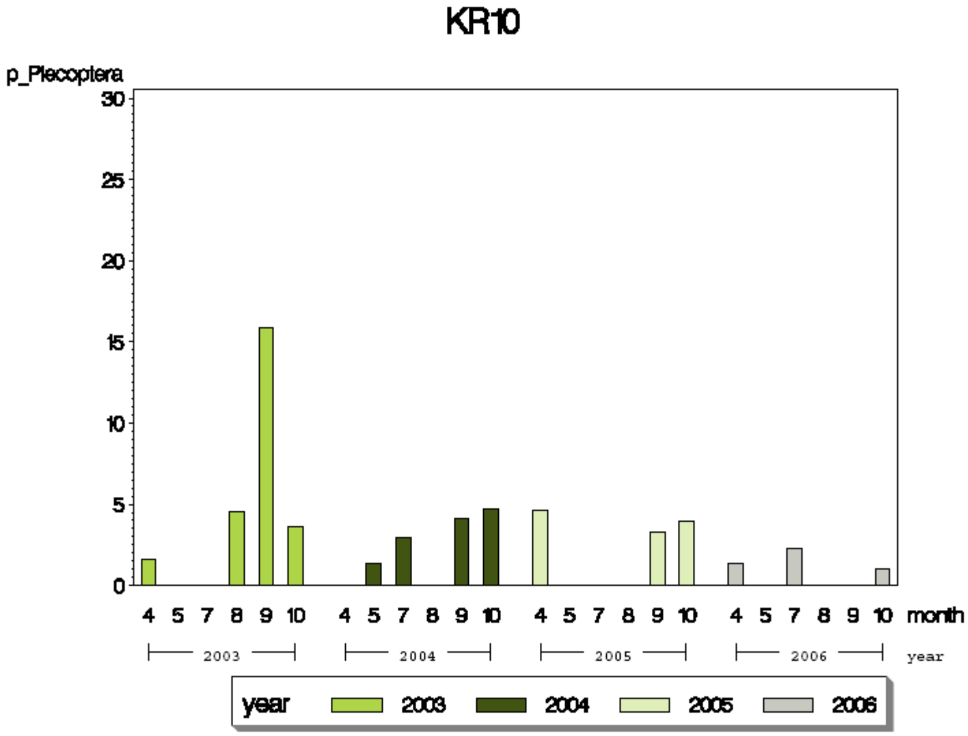
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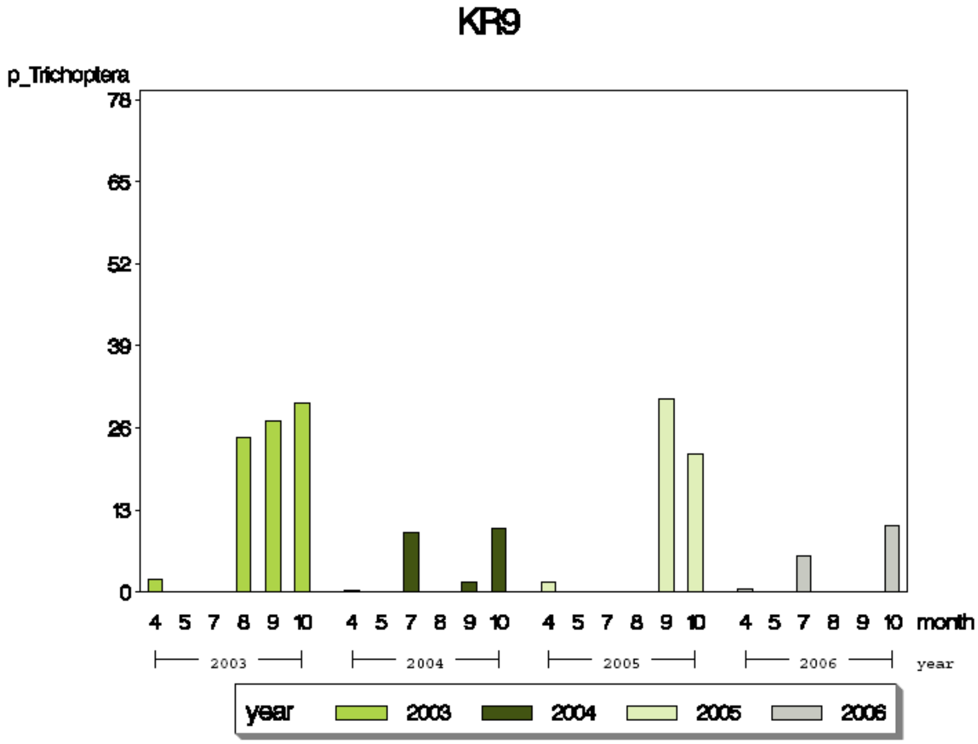
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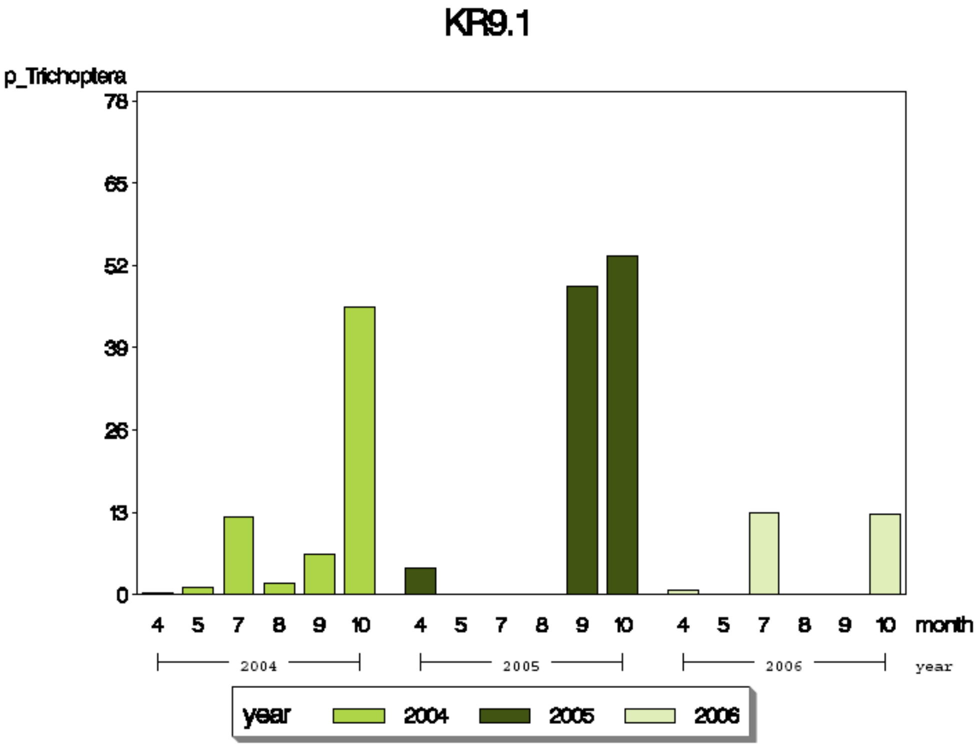
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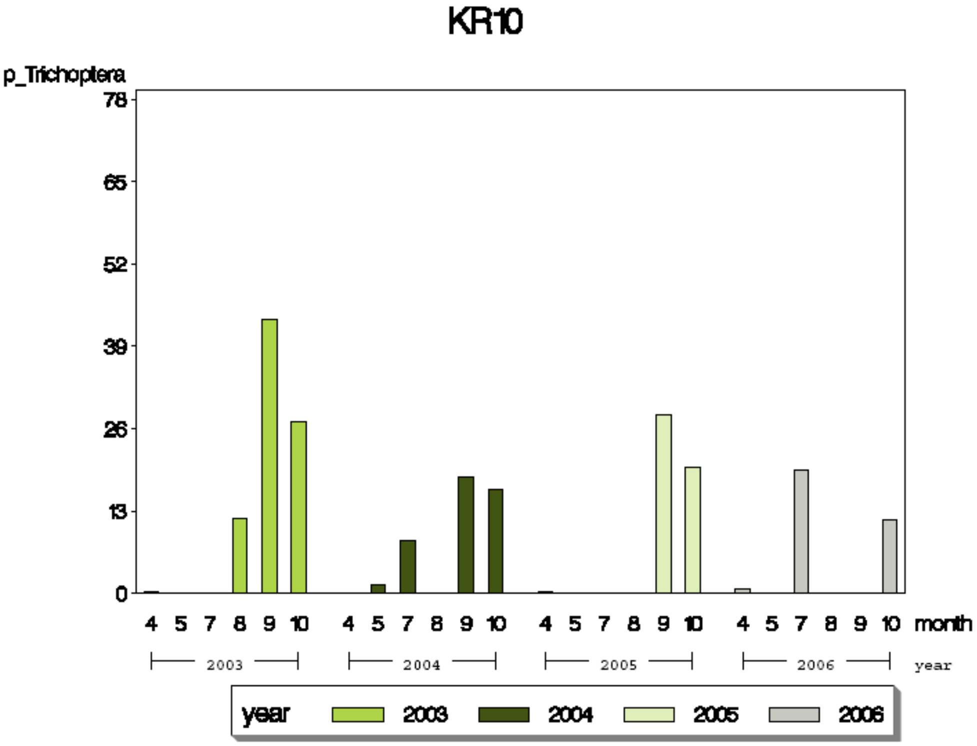
year 2004 2005 2006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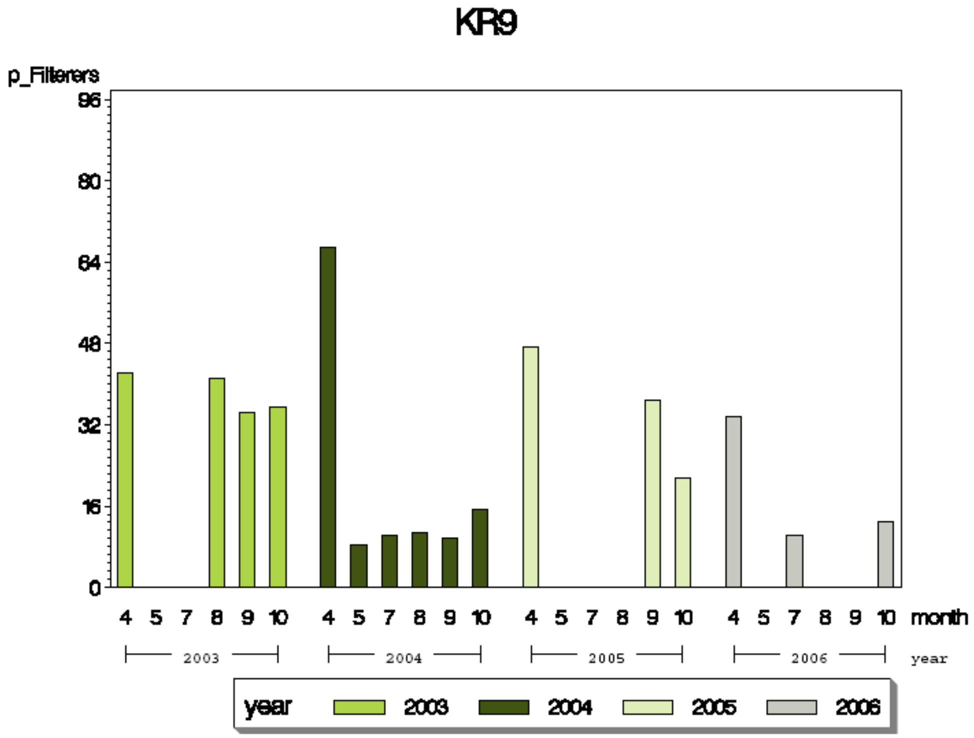
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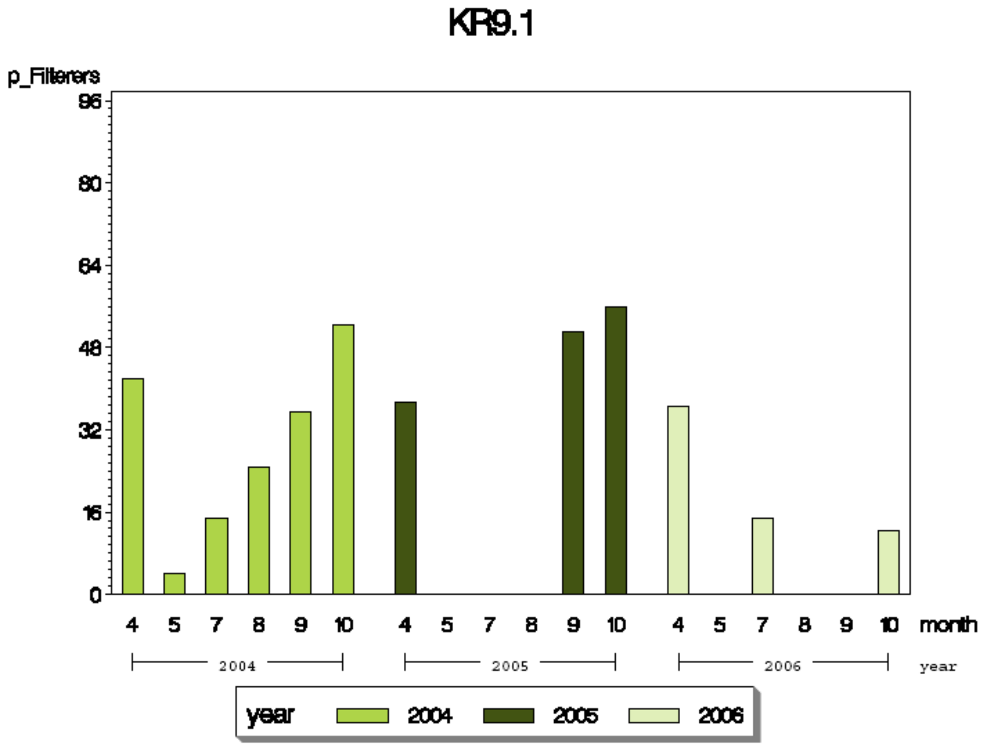
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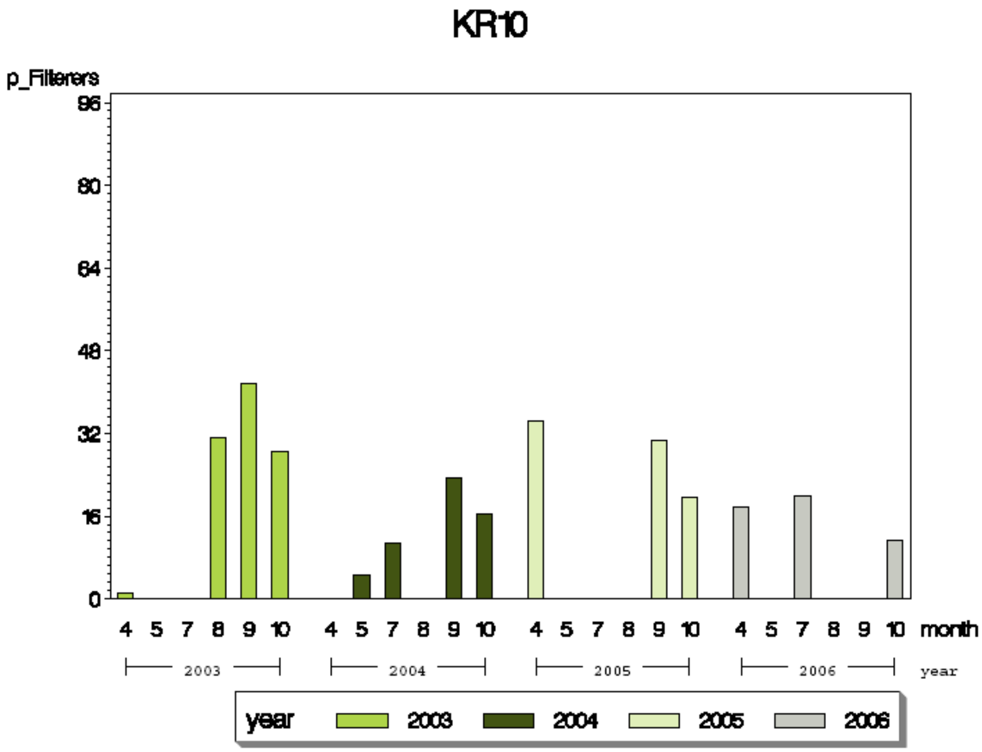
year
year 2004 2005 2006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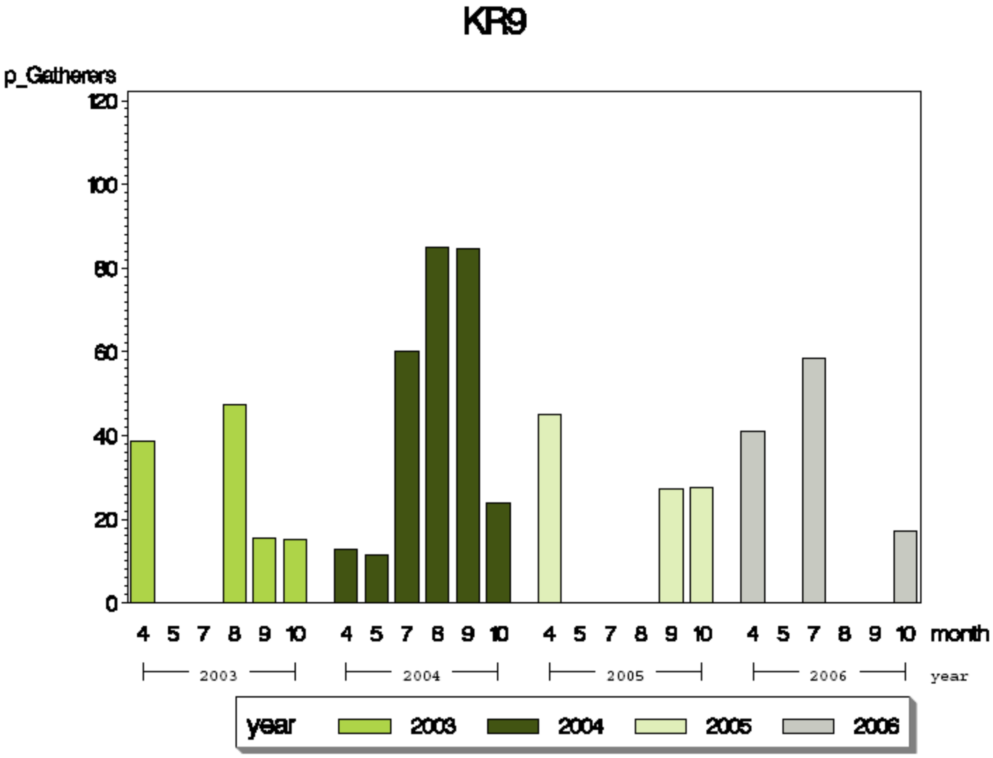
2003 2004 2005 2006 year
year 2003 2004 2005 2006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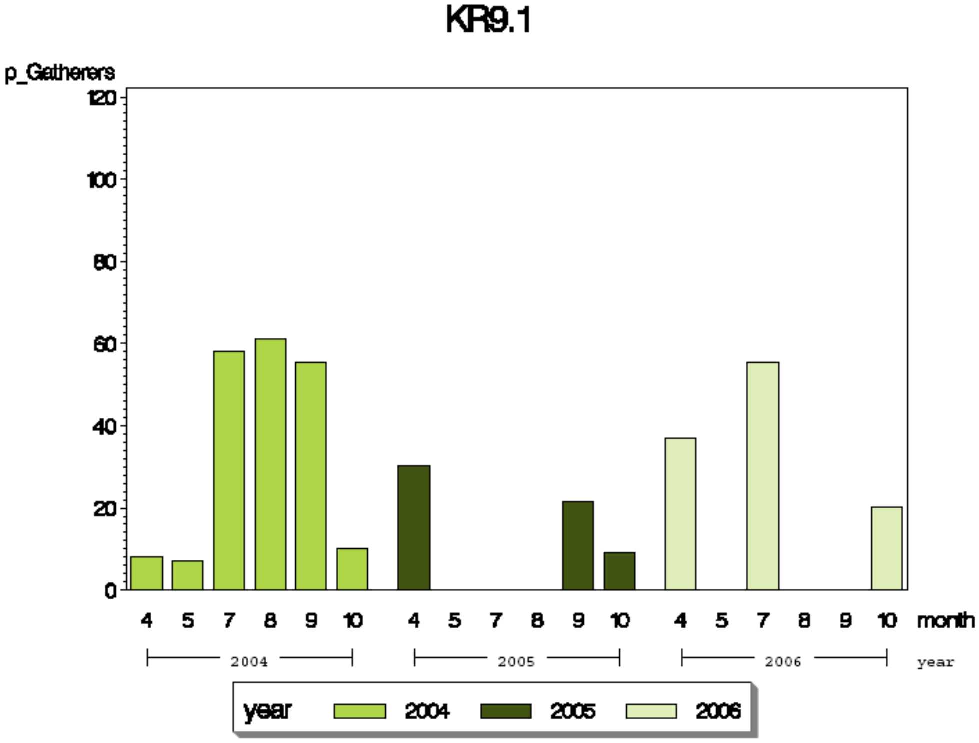
2003 2004 2005 2006 year
year 2003 2004 2005 2006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year
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2005
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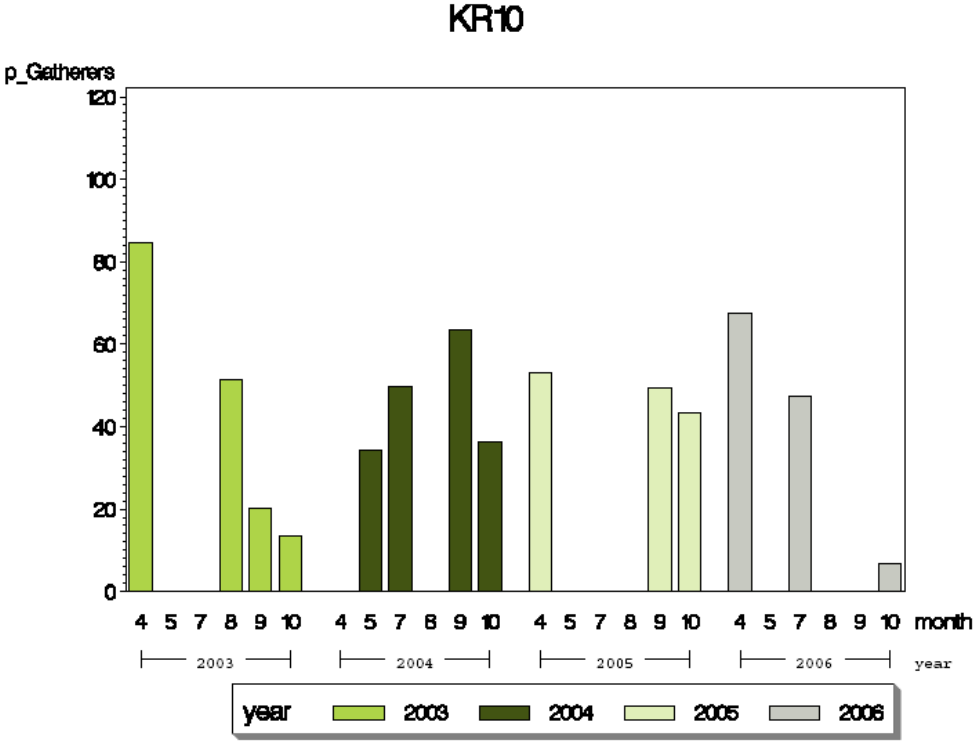
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4
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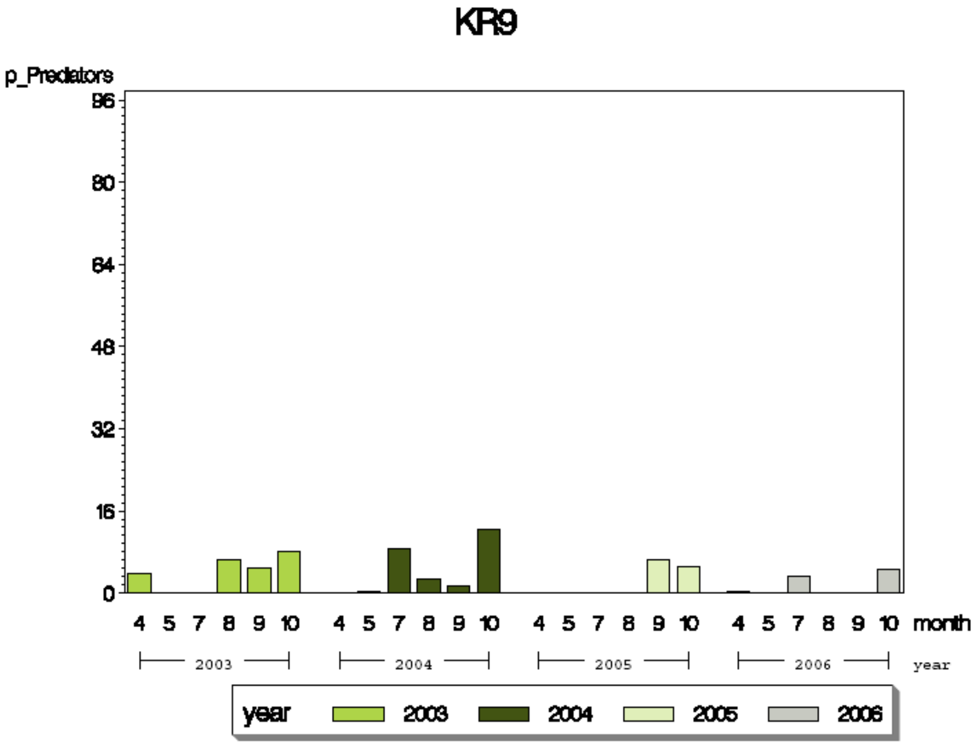
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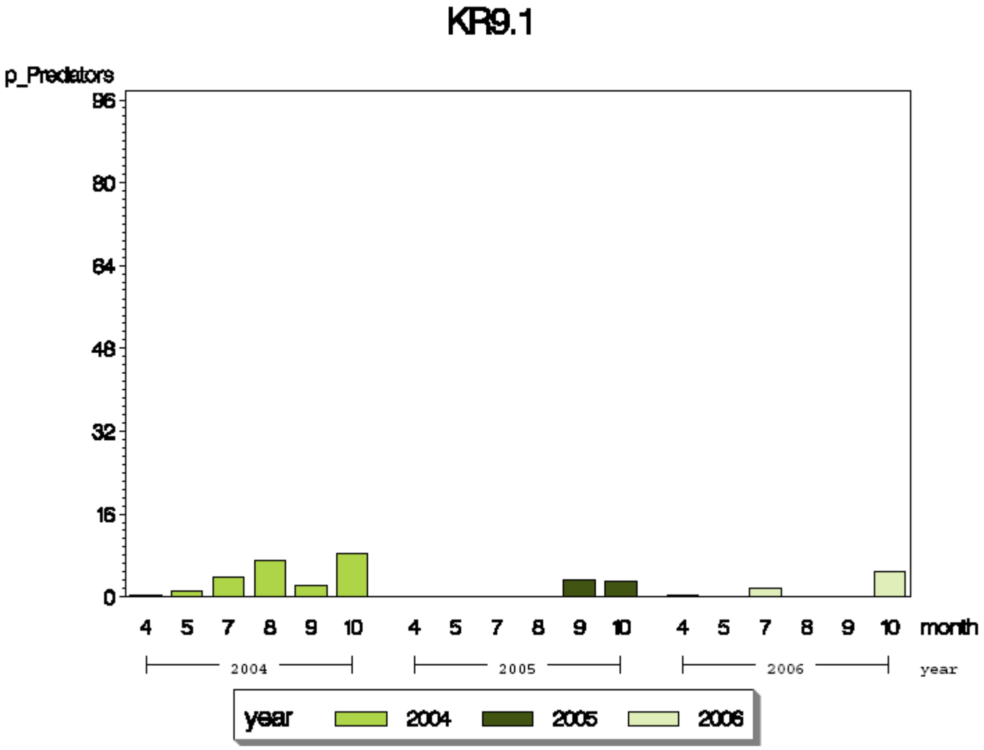
year 2003 2004 2005 2006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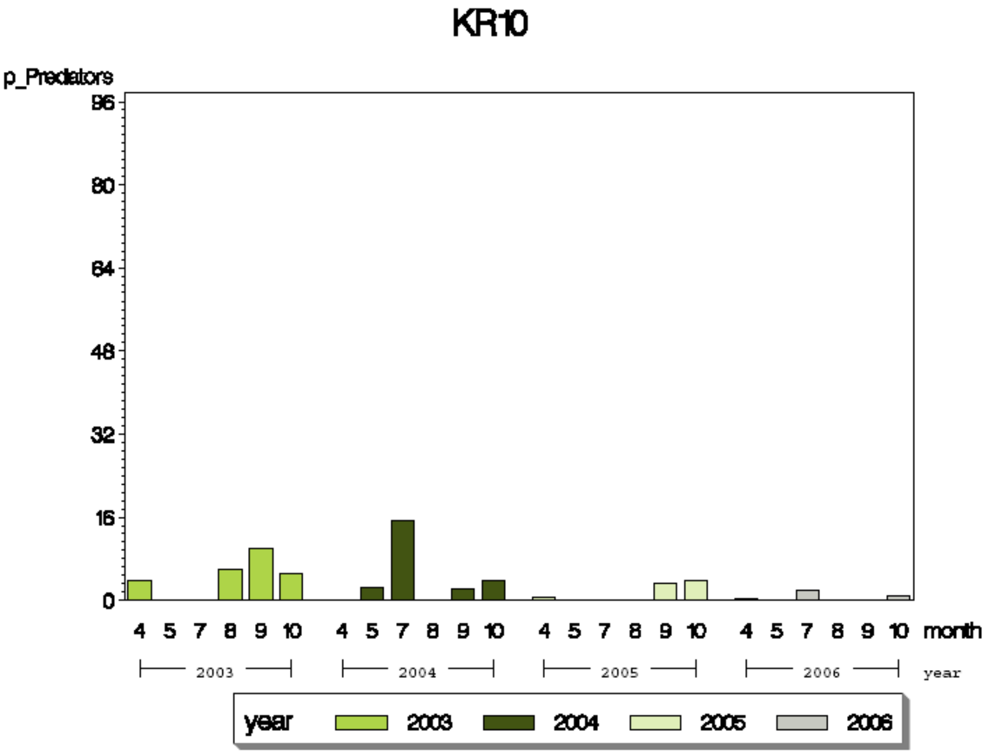
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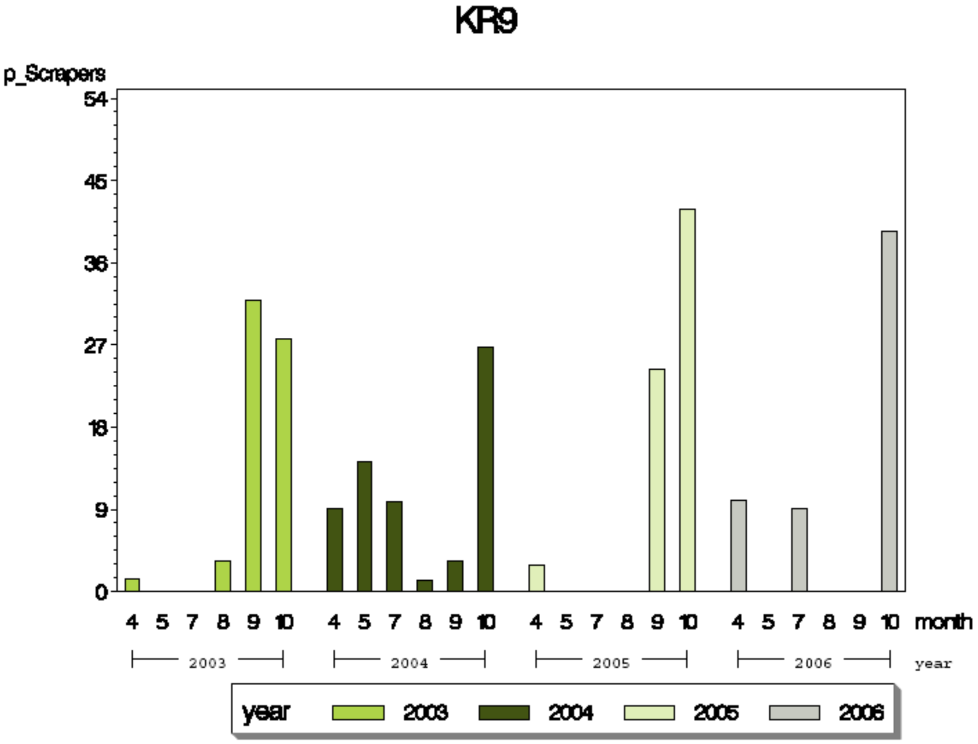
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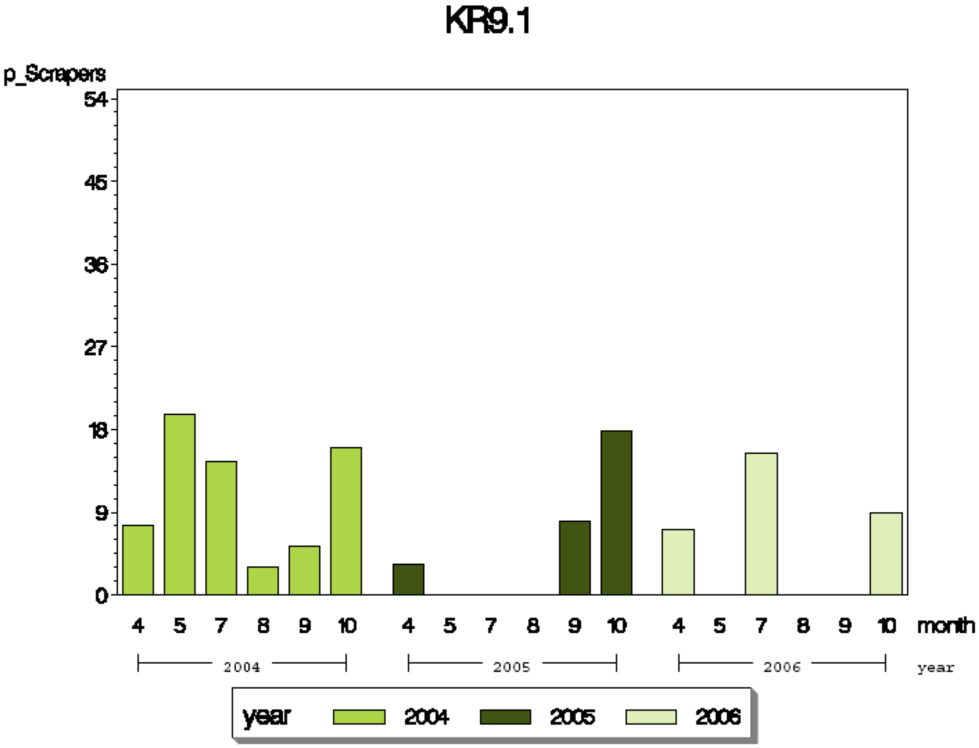
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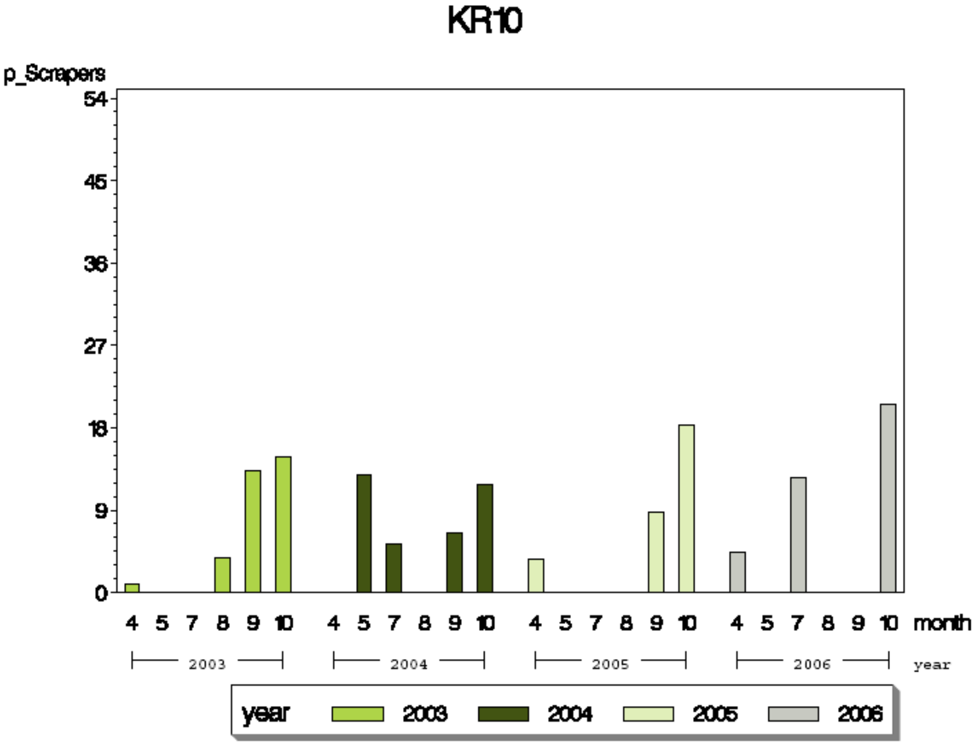
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