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Geographic and Hydrologic Patterns of Biological and Water-Quality Conditions in Streams of the Central United States

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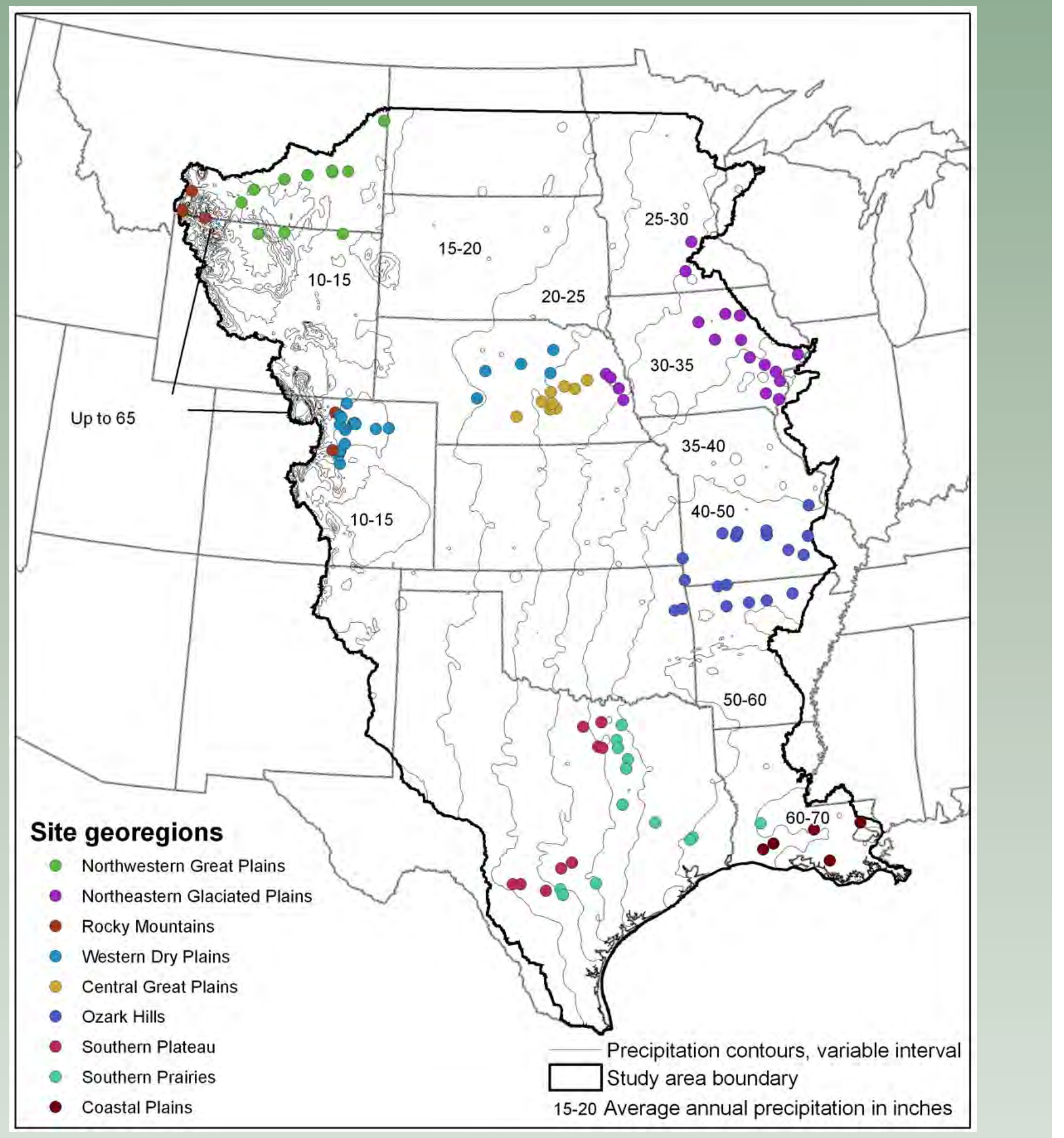
Introduction

Benthic macroinvertebrate and algal data from streams sampled by the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program were tested for response to hydrologic variation determined from streamflow record at gaging stations. Sites were grouped by a factor labeled "georegion" to determine if the ecological response to hydrology varied across the central United States. Hydrologic variables including measures of annual and seasonal magnitude and frequency of extreme events were calculated using the Index of Hydrologic Alteration software (Richter and others, 1996).

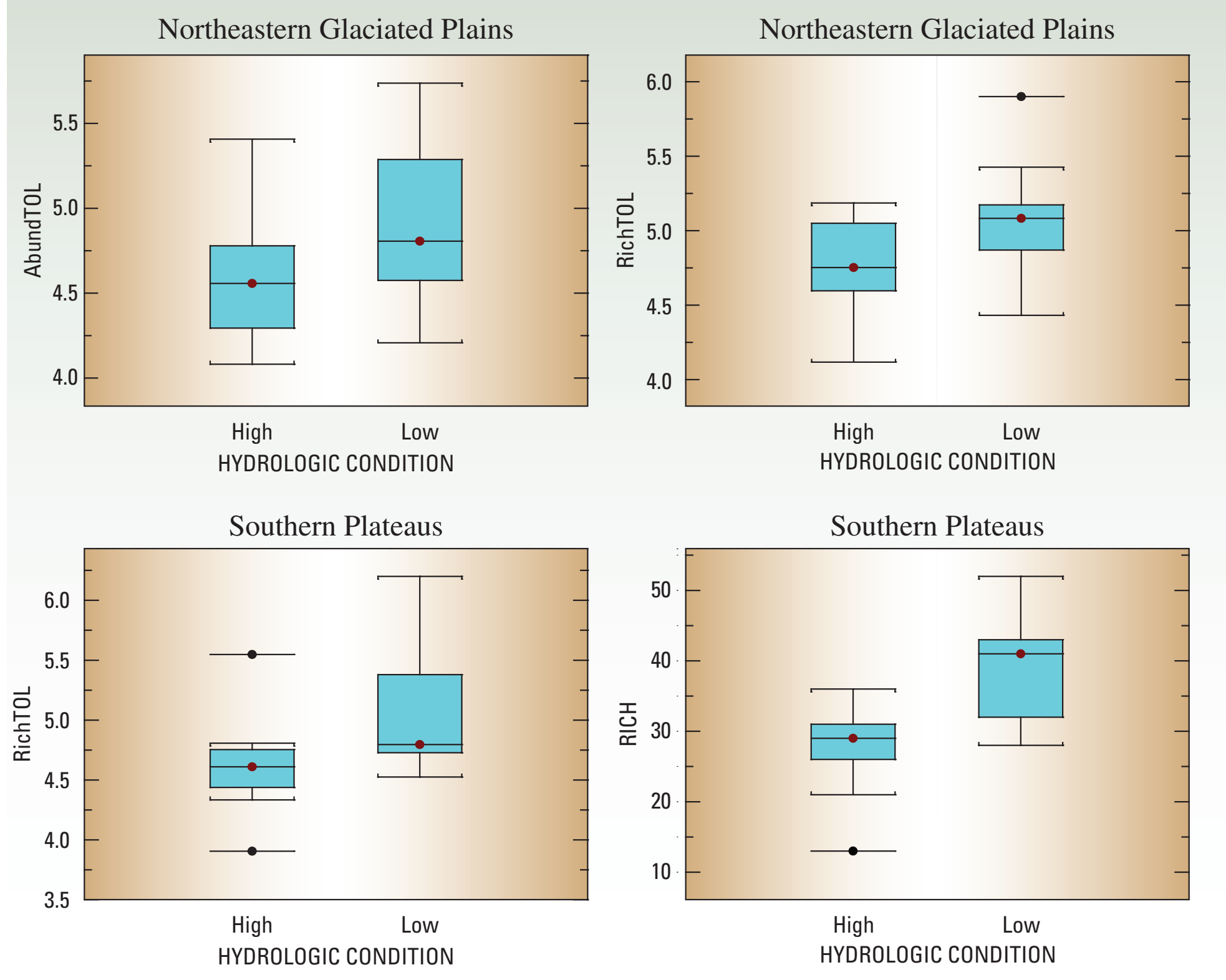


Georegions were aggregated from level III ecoregions (Omernik, 1987) on the basis of similar environmental setting.

Georegion code	Name	Level III Ecoregions
A	Northwestern Great Plains	43
B	Northeastern Glaciated Plains	40+46+47+51+72
C	Rocky Mountains	16+17+18+21
D	Western Dry Plains	25+26+44
E	Central Great Plains	27
F	Ozark Hills	38+39
G	Southern Plateaus	29+30+31
H	Southern Prairies	32+33+35
I	Coastal Plains	37+73

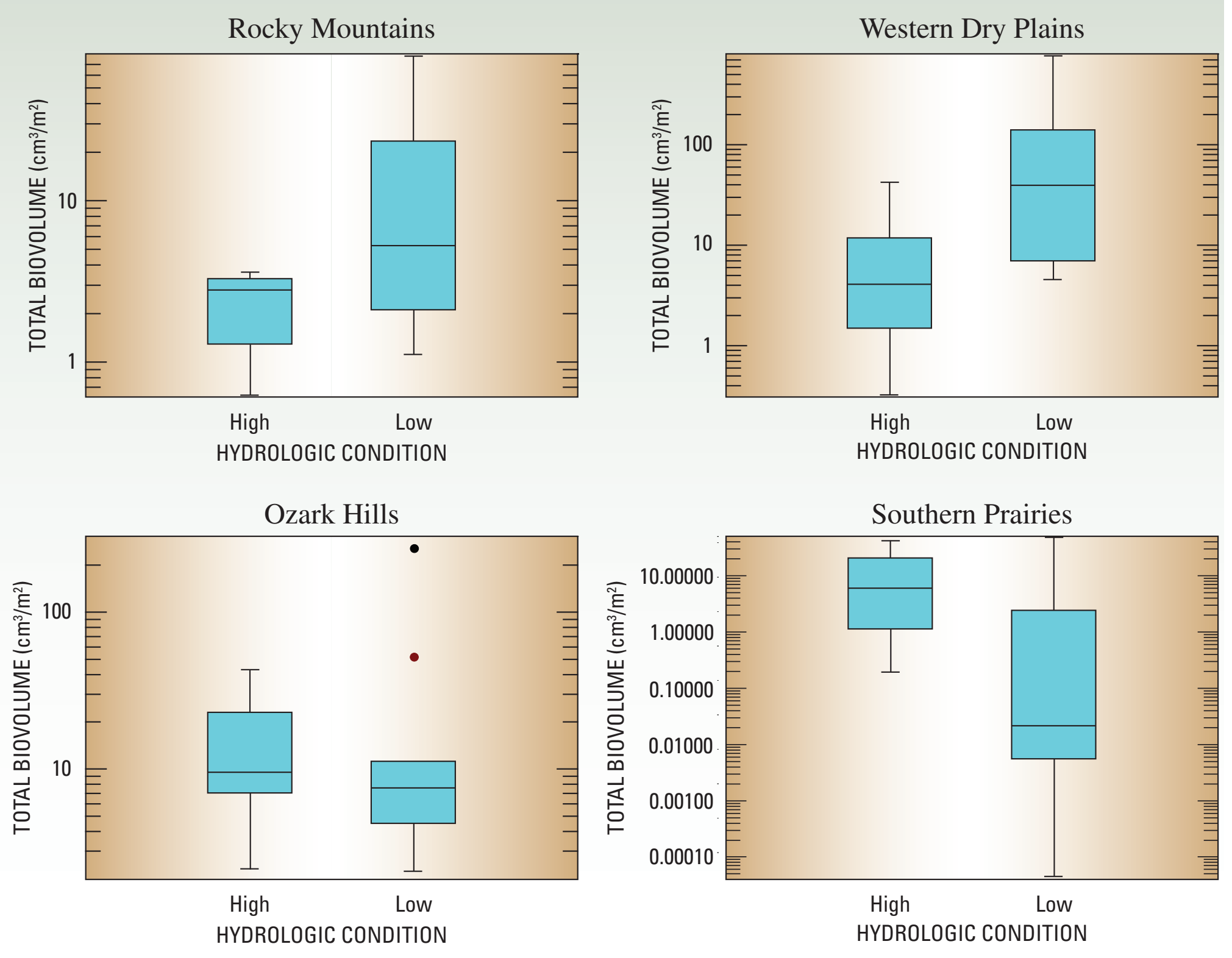
Macroinvertebrate Communities

Tolerance values of macroinvertebrate communities in most georegions showed a negative correlation with median annual streamflow and mean streamflow for the 45 days prior to the sampling event. The tolerance values, on the basis of both abundance and richness, indicated higher values and poorer water quality in low flow conditions than high-flow conditions. Richness tolerance values were significantly and positively correlated with the frequency of high flows in Georegions D and G, perhaps as a result of greater disruption of the macroinvertebrate community by spates. Taxa richness tended to be negatively correlated with annual median and 45-day streamflows, as well as frequency of high flows. The negative response of taxa richness to higher streamflow conditions was evident in most of the georegions, possibly as a result of greater disruption of the macroinvertebrate communities by the higher streamflows.



Algal Biomass

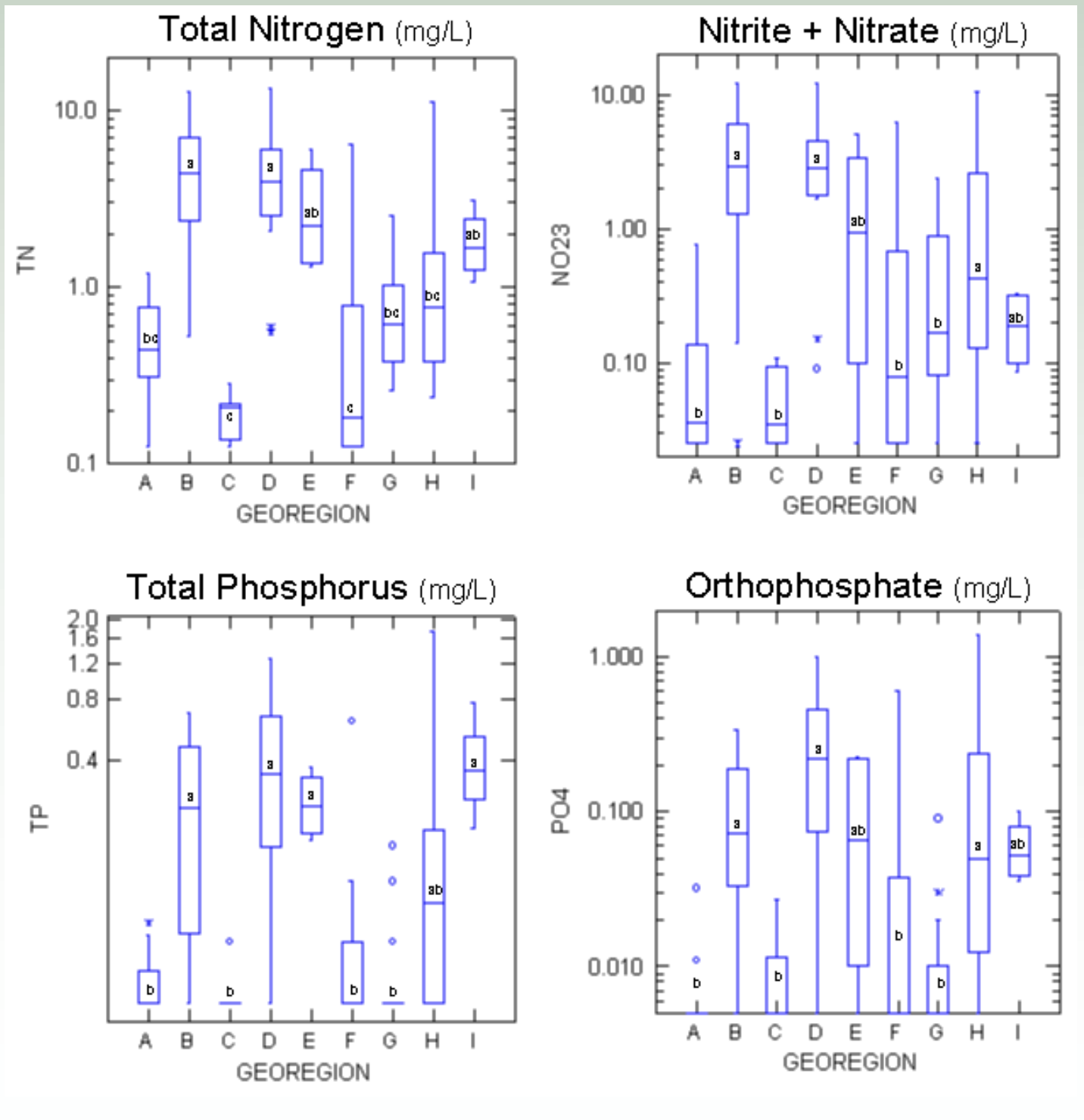
In most georegions, benthic-algal biomass (as biovolume, cm³/m²) was negatively correlated with seasonal streamflow (mean discharge 45-d prior to sample collection), the frequency of high-streamflow events (hydrologic disturbance), and the relative amount of rainfall received in stream basins during the year of sampling (i.e. wet or dry years). Algal biomass during low streamflow conditions (dry years) varied along a climate gradient ranging from the semi-arid northwest to the humid southeast. Median algal biomass was relatively larger during low than high streamflow conditions in northwestern streams (e.g. georegions C & D), where stream hydrology is controlled by snow melt and hydrologic diversions, and summer rainfall and runoff are relatively rare. By contrast, median biomass in southeastern streams, where stream hydrology often is influenced by patterns of summer rainfall and runoff (e.g. georegions F & H), was relatively larger during high than low streamflow conditions. Algal biomass in streams influenced by intensive row-crop agriculture (georegions B & E) did not differ appreciably between wet and dry years. Algal biomass increased significantly with concentrations of dissolved nitrogen in streams of the Ozark Hills (F) and Southern Plateau (G) georegions.

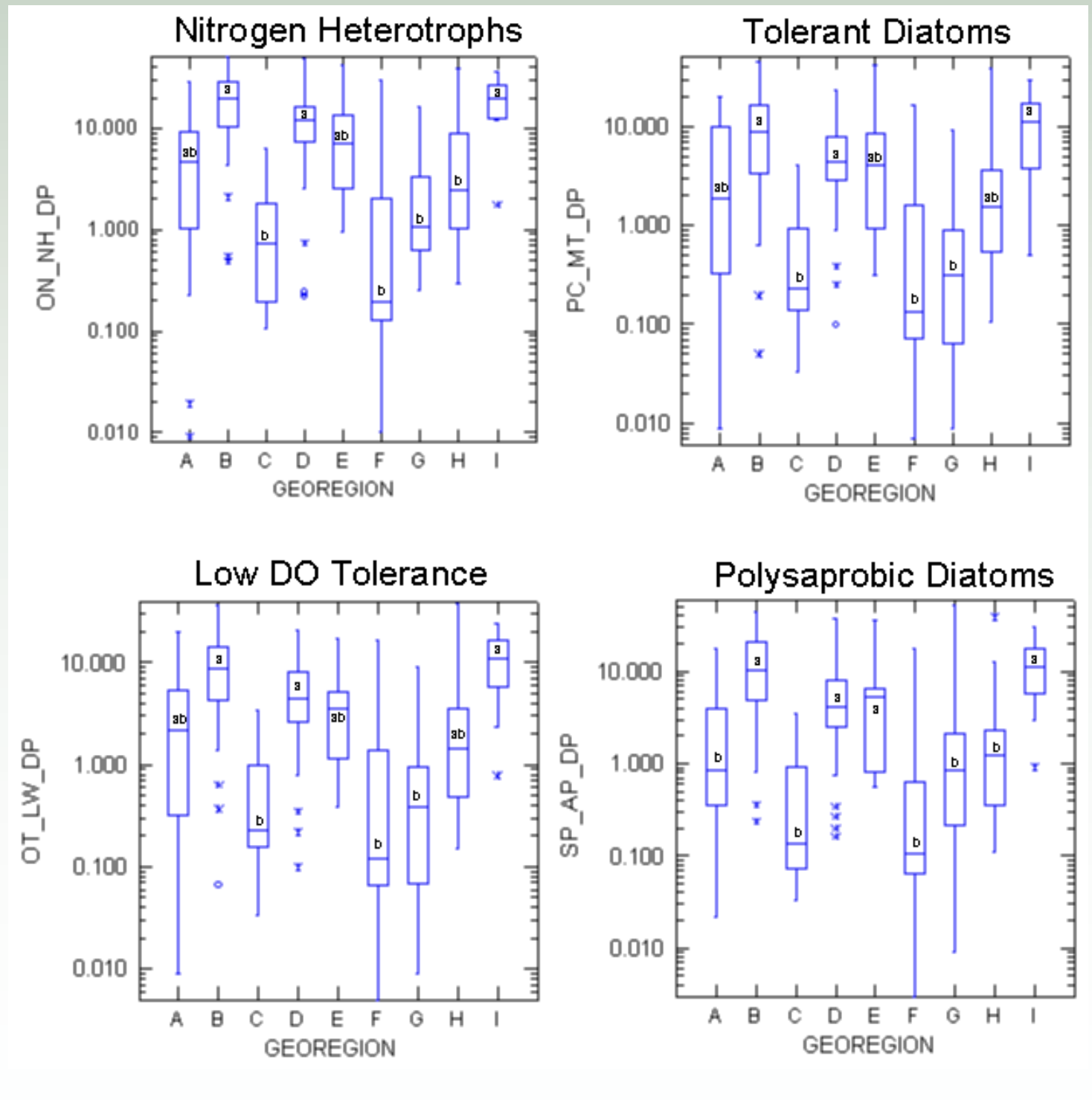


Algal Autecology

Algal metrics were most highly correlated with nutrient concentrations associated with agricultural and urban intensity that varies among georegions, however, differences in streamflow and climate conditions also influenced metric scores. Median algal-tolerance metric scores differed significantly among georegions, with largest values found in areas of intensive agricultural land use (georegions B and E) or mixed urban and agricultural uses (georegions D, H, and I). Metric scores were relatively lower in streams draining forested basins with relatively less agricultural and urban intensity (georegions A, C, F, and G). The geographic distribution of median nutrient concentrations parallels the results for the algal-tolerance metrics. Significant algal-metric interactions among georegion, land use, and hydrologic variables appear to be largely a function of algal-species responses to nutrient concentrations, however, spatial and temporal differences in climate and stream hydrology can influence metric scores similar to what is reported for algal biomass.

Algal-metric scores decreased with increases in median seasonal streamflow in the northwestern streams (georegions A, C, and D), whereas metric scores generally increased with median streamflow in the southeastern streams (georegions F, H, and I). Increases in the abundance of algal-metric indicators of nutrient and organic enrichment are commensurate with increases in algal biomass along a climate gradient. Algal-metric responses to hydrologic disturbance were variable among georegions. Metric values generally increased with the number of high-flow events in georegions C, E, and G, whereas values decreased with increasing hydrologic disturbance in georegion F.





General linear model, correlation coefficients (bold numbers indicate statistically significant correlation at $p < 0.05$)

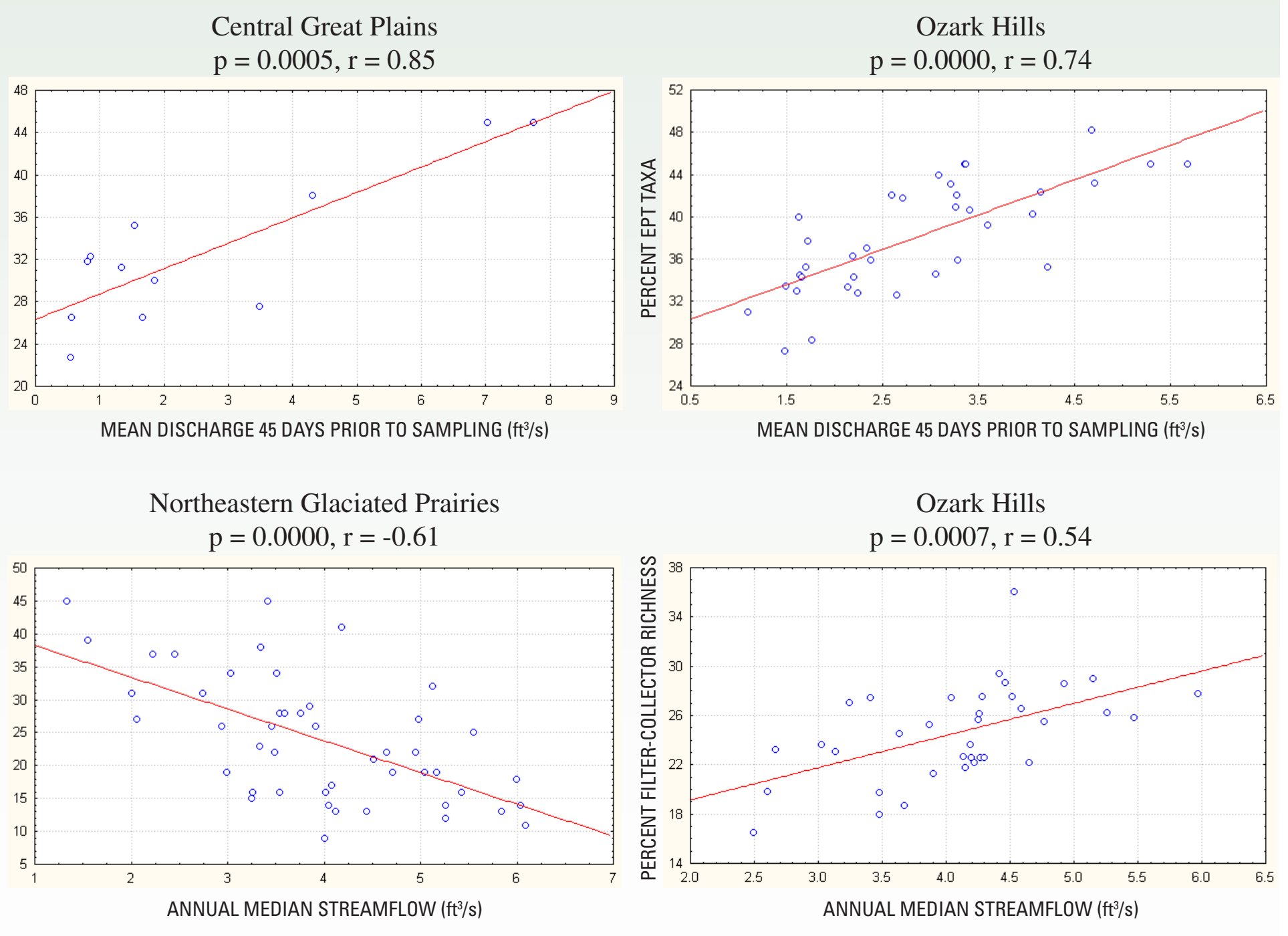
Invertebrate metric	A	B	C	D	E	F	G	H	I
Annual median streamflow									
Richness	-0.4	**-0.61**	-0.13	-0.16	-0.23	-0.06	-0.32	**-0.38**	**-0.64**
RichTol	**-.48**	-.28	.38	-.08	**-.82**	-.08	**-.52**	**-.49**	-.13
ShanDiv	-.39	**-.45**	-.21	-.16	.09	-.07	-.19	**-.36**	-.39
pGC_Rich	-.02	-.19	.21	.21	-.3	0	.01	-.02	**.65**
pFC_Rich	**.59**	**.39**	.2	-.1	**.73**	**.54**	.02	.27	.04
pEPTR	**.83**	.18	-.02	-.1	**.67**	**.58**	.42	**.51**	.24
pCHR	-.26	-.1	.22	-.02	.01	-.17	-.4	.01	.49
pNONINSR	**-.59**	-.02	-.26	.05	**-.79**	.07	**-.52**	**-.43**	.1
Mean discharge 45 days prior to sampling									
Richness	0.37	-0.13	-0.24	-0.05	-0.3	0.09	**-0.63**	0.04	-0.59
RichTol	**-.5**	**-.49**	**-.45**	**-.41**	**-.6**	-.2	-.1	-.29	.17
ShanDiv	.16	-.1	-.14	.04	-.04	.09	**-.63**	.16	-.56
pGC_Rich	.02	**-.26**	**-.6**	-.08	-.09	.05	.1	-.16	**.85**
pFC_Rich	-.03	-.21	-.16	.11	.31	.46	.3	.26	-.39
pEPTR	**.39**	**.41**	.3	**.36**	**.85**	**.74**	.03	.14	-.03
pCHR	-.05	**-.42**	-.31	**-.43**	**-.64**	-.19	-.19	.04	.32
pNONINSR	.09	**-.41**	-.04	-.06	**-.63**	-.35	-.12	-.02	.3
Frequency of high-flow events									
Richness	-0.14	-0.14	0.25	-0.06	0.41	-0.08	-0.21	-0.01	**-0.71**
RichTol	.22	-.24	-.08	**.46**	.27	-.04	**.62**	-.26	.44
ShanDiv	-.14	-.11	.11	-.14	.44	-.03	-.34	-.11	-.47
pGC_Rich	.02	-.12	.35	**.25**	-.29	-.24	-.51	-.32	**.76**
pFC_Rich	-.11	.07	-.23	**-.4**	-.16	-.12	.3	.16	-.42
pEPTR	**-.43**	.14	.05	**-.39**	-.16	-.04	-.39	.12	-.3
pCHR	.17	-.06	-.14	.16	.18	-.01	**.54**	-.21	.2
pNONINSR	-.16	-.04	-.15	**.4**	-.12	-.3	**.67**	-.1	**.58**

Invertebrate metric	Undeveloped	Large rivers	Partial (agricultural or urban)	Agricultural	Urban	Mixed
	Land use					
Richness	**-0.33**	-0.12	-0.21	**-0.54**	**-0.58**	-0.37
RichTol	-.01	-.15	-.22	-.13	.31	-.63
ShanDiv	**-.39**	-.13	-.25	**-.4**	**-.41**	.15
pGC_Rich	-.04	-.05	.03	-.06	**.56**	.52
pFC_Rich	**.46**	.1	-.11	.04	**-.43**	-.29
pEPTR	.25	.06	.04	.03	-.18	.48
pCHR	-.06	0	-.14	-.23	.4	.34
pNONINSR	-.08	.04	.2	.01	.25	-.43

Richness	Total number of discrete tax
RichTol	Average of the EPA tolerance values based on taxa richness
Abundtol	Average of the EPA tolerance values based on invertebrate abundance
ShanDiv	A meaure of community diversity based on distribution among the taxa
pGC_Rich	Percentage of total taxa richness based on the collector-gatherer functional feeding group
pFC_Rich	Percentage of total taxa richness based on the filterer-collector functional feeding group
pEPTR	Percentage of taxa richness attributable to Ephemeroptera, Plecoptera, and Trichoptera
pCHR	Percentage of taxa richness attributable to Chironomidae
pNONINSR	Percentage of taxa richness attributable to non-insects

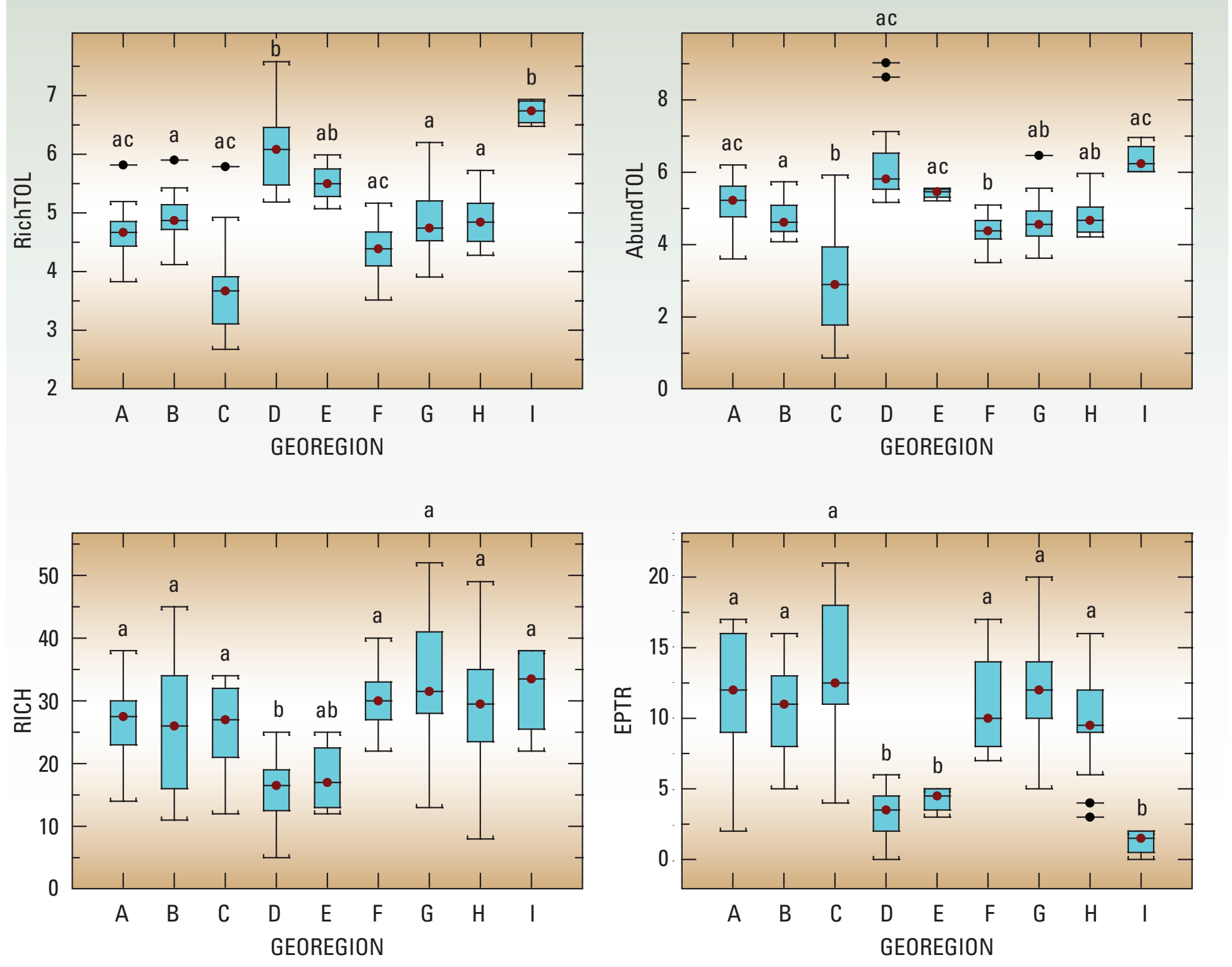
Algal metric	A	B	C	D	E	F	G	H	I
Mean discharge 45 days prior to sample collection									
Biovolume	0.23	**-0.37**	-0.19	**-0.38**	-0.21	0.13	0.16	-0.09	0.43
SP_AP_DP	**-.49**	.15	-.34	1.06	.28	.17	.25	**.40**	.14
ON_NH_DP	**-.53**	.12	-.47	1.16	.14	.17	1.09	.21	.27
TR_E_DP	-.05	.22	-.24	1.28	1.10	**.45**	.01	.24	.54
PC_MT_DP	**-.52**	.17	-.47	.08	.31	.15	1.02	.23	.08
SL_HB_DP	**-.53**	.07	**-.54**	**1.33**	1.33	.13	1.10	.06	**.68**
OT_AH_DP	.02	-.13	0.32	**1.40**	1.10	**.42**	**.49**	**.41**	.04
OT_LW_DP	-.38	.22	-.53	1.05	.24	.15	1.04	.27	.13
Frequency of high-flow events									
Biovolume	-0.15	-0.08	0.20	0.07	-0.50	-0.28	**-0.66**	-0.08	0.27
SP_AP_DP	.08	1.15	.49	.06	**.61**	**1.34**	1.03	.26	1.11
ON_NH_DP	.09	1.04	.49	.01	.40	**1.37**	**.41**	.23	1.28
TR_E_DP	1.11	1.14	.37	.22	.31	1.25	**.39**	.13	.14
PC_MT_DP	.17	1.02	.44	1.03	**.68**	**1.35**	**.41**	.22	1.10
SL_HB_DP	.09	1.04	.44	.17	1.09	1.12	**.39**	1.02	.41
OT_AH_DP	1.15	1.20	1.24	1.05	1.21	.24	**1.53**	.10	1.24
OT_LW_DP	.04	.10	.45	1.02	**.70**	**1.35**	**.40**	.17	1.06
Antecedent precipitation in relation to long-term mean values									
Biovolume	-0.02	-0.19	-0.41	**-0.44**	-0.06	-0.12	-0.23	-0.13	0.65
SP_AP_DP	-.19	.09	-.34	**-.34**	.19	.07	.17	.08	-.27
ON_NH_DP	-.16	.04	-.44	-.28	.28	.11	.02	.15	-.37
TR_E_DP	-.34	-.01	-.39	-.19	-.24	**.32**	.10	.11	-.53
PC_MT_DP	-.26	.26	-.43	-.21	.24	.06	.14	.07	-.23
SL_HB_DP	-.17	-.09	-.45	-.19	-.45	.15	.09	.10	-.46
OT_AH_DP	-.41	-.12	.09	-.00	.10	.29	.08	.16	-.03
OT_LW_DP	-.27	.19	-.43	**-.31**	.11	.06	.14	.09	-.33
Nitrite plus nitrate concentrations									
Biovolume	0.23	-0.08	0.28	0.18	-0.56	**0.60**	**0.42**	0.28	-0.24
SP_AP_DP	.26	**.31**	**.62**	**.52**	**.74**	**.60**	**.53**	-.13	**.87**
ON_NH_DP	.15	**.38**	**.81**	**.45**	**.65**	**.60**	.18	.19	.65
TR_E_DP	**.43**	**.36**	**.53**	**.38**	.58	**.39**	.22	.22	.52
PC_MT_DP	.23	**.46**	**.82**	**.43**	**.83**	**.60**	.22	.23	**.88**
SL_HB_DP	.08	-.11	**.84**	**.47**	.08	-.08	-.13	.30	-.40
OT_AH_DP	**.44**	.04	-.05	**-.33**	-.37	**-.35**	**.39**	-.22	**.77**
OT_LW_DP	.37	**.41**	**.86**	**.54**	**.81**	**.60**	.22	.18	**.85**

Biovolume	Total periphyton biovolume, cm³/m²
SP_AP_DP	Polysaprobic diatoms, relative abundance; van Dam et al. (1994) class 4
ON_NH_DP	Nitrogen heterotrophic diatoms, relative abundance; van Dam et al. (1994) classes 3+4
TR_E_DP	Eutrophic diatoms, relative abundance; van Dam et al. (1994) classes 4+5+6
PC_MT_DP	Pollution-tolerant diatoms, relative abundance; Bahls (1993) class 1
SL_HB_DP	Halobiontic diatoms, relative abundance; van Dam et al. (1994) classes 3+4
OT_AH_DP	Diatoms with requirements for high dissolved oxygen; van Dam et al. (1994) class 1
OT_LW_DP	Diatoms with tolerance for low dissolved oxygen; van Dam et al. (1994) class 4



Geographic Patterns of Invertebrate Communities

Invertebrate richness tolerance and abundance tolerance values tended to be highest in Georegion D (the Western Dry Plains in Colorado and Nebraska) and Georegion I (the Coastal Plains in Louisiana), indicating a higher proportion of pollution-tolerant organisms in those areas. Invertebrate communities of streams in Georegion C (the Rocky Mountains in Wyoming and Colorado) had significantly lower tolerance values than those in other georegions. The lower tolerance values and higher taxa richness of EPT in the Rocky Mountains are associated with better water quality in mountain streams than in streams in other areas. EPT richness was lowest in Georegions D, E, and I; total taxa richness also was lowest in Georegions D and E. The relatively low taxa richness and EPT richness in the Western Dry Plains (Geo D) and the Central Great Plains (Geo E) may well be a reflection of the high degree of streamflow diversion and hydrologic modification of streams in those areas.



Summary and Implications

Hydrologic measures, such as annual median streamflow, streamflow in the 45 days preceding sampling, and frequency of high flows, were strongly correlated with measures of macroinvertebrate and algal community structure. Water-quality assessments of stream trophic condition could differ between wet and dry years (relatively higher or lower antecedent streamflow conditions), as well as in relation to the frequency of high streamflow events prior to sampling. Understanding of how climate and stream hydrology influence chemical and biological indicators of trophic condition could benefit efforts towards establishing nutrient and ecological criteria and detecting trends or changes in stream quality over time.