Trend analyses for species of concern: Analysis of CPUE data for walleye, cisco, and smallmouth bass 1970-2008

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Gill net catch per unit effort (CPUE) data on walleye (2203 lakes), smallmouth bass (465), and cisco (701) from Minnesota lakes were examined for trends during the period 1970-2008. To account for repeated measures of lakes over time and correlated annual variation in CPUE among lakes, we used a linear mixed model (Venables & Ripley,2002) to estimate the temporal trend in ice out date using the *lmer* function from the lme4 package in version 2.8.1 of the R statistical program (R Development Core Team, 2008).

Methods: A mixed model has two components, a fixed effects portion and a random effects portion. In this case, the fixed effect portion was an ordinary linear regression of $\log_e$ CPUE+1 versus time:

$$CPUE_j = \beta_0 + \beta_1 * j + \varepsilon_j,$$

for j = (-19,…, 19) representing the years 1970-2008 centered by subtracting 1989, and for residual error $\varepsilon_j \sim N(0, \sigma)$. The β_1 parameter represents the intrinsic growth rate of the population (assuming CPUE is proportional to abundance); if the β_1 parameter is greater than zero, abundance is exponentially increasing, and conversely, if the β_1 parameter is less than zero, the abundance is declining over time. Because the year data were centered, the β_0 parameter represents the average $\log_e$ CPUE value over the group of lakes in 1989 (excluding year effects we discuss below).

The above regression would be a satisfactory model for a time series from a single population; however, our interest is not just in CPUE trends for a single lake, we also wanted to estimate the large scale, statewide trend in CPUE for each species. To analyze the data at that level, we use time series from many lakes (e.g., over 2200 lakes for walleye); however, the joint analysis of multiple time series introduces correlations among the observations that could potentially bias the trend estimate. We accounted for these correlations with random effects for year and lake-specific trends, giving the mixed effects model for the CPUE value in year j at lake i:

$$CPUE_{ij} = (\beta_0 + b_{0i}) + (\beta_1 + b_{1i}) * j + \psi_j + \varepsilon_{ij},$$

where b_{oi} and b_{1i} are random adjustments to the intercept and slope terms for lake i, and were assumed to be distributed as $N(0, \sigma_{L0})$ and $N(0, \sigma_{L1})$ respectively. The ψ_j term accounts for correlations in CPUE measurements within year j, and was assumed to be distributed as $N(0, \sigma_Y)$. Note that using the random effects adds 3 variance parameters to the model; an equivalent fixed effects-only model would use thousands of parameters for to account for individual lake and year effects. Though b_{0i}, b_{1i}, and ψ_j are not estimated parameters in the model, we can derive unique predictors of the individual lake regression coefficients and year effects. These predictors are denoted as BLUPs for 'best unbiased linear predictors', and can be used to determine annual deviations from the linear trend and to estimate CPUE trends in the individual lakes. For example, the terms ($\beta_0 + b_{0i}$) give the mean CPUE value for lake *i* in 1989 (excluding the random year effect), and the ($\beta_1 + b_{1i}$) terms give the trend in CPUE for lake *i*. We also used the lake BLUPs to evaluate differences in mean CPUE or trend over latitudinal, longitudinal, maximum lake depth, and lake geomorphic gradients.

Walleye (*Sander vitreus)* **results:** The overall trend estimate for walleye was slightly positive (0.0007), but was not statistically different from zero ($t = 0.52$; $p = 0.61$ on 37 df). The variation in mean $\log_e$(CPUE+1) among lakes had a standard deviation $\sigma_{L0} = 0.65$, and the standard deviation of individual lake trends was $\sigma_{L0} = 0.019$; BLUPs of individual lake trends varied from a 5% per year decline to a 5% per year increase. Of the 2203 lakes with walleye gillnet captures 10.1% (223 lakes) had per year declines greater than 1%, while only 12.9% (283 lakes) had per year increased greater than 1%; the remainder of the lakes (77%) had changes less than 1%, which could not be distinguished from no or flat trend. The annual variation about the fixed trend (i.e., random year effects) had a standard deviation $\sigma_Y = 0.074$ (see figure below for plot of fixed trend along with random year effects).

Random effects:			
Groups Name	Variance	Std.Dev.	Corr
DOWLKNUM (Intercept)	0.4248226	0.651784	
YR	0.00036685	0.019153	-0.013
YR (Intercept)	0.00546446	0.073922	
Residual	0.25718614	0.507135	
Number of obs: 9611, groups: DOWLKNUM, 2203; Yr, 39			

Fixed effects:			
	Estimate	Std. Error	t value
(Intercept)	1.380288	0.019778	69.79
YR	0.000708	0.001372	0.52

Figure XX. Average CPUE trend and annual deviations for walleye CPUE in 2203 MN lakes.

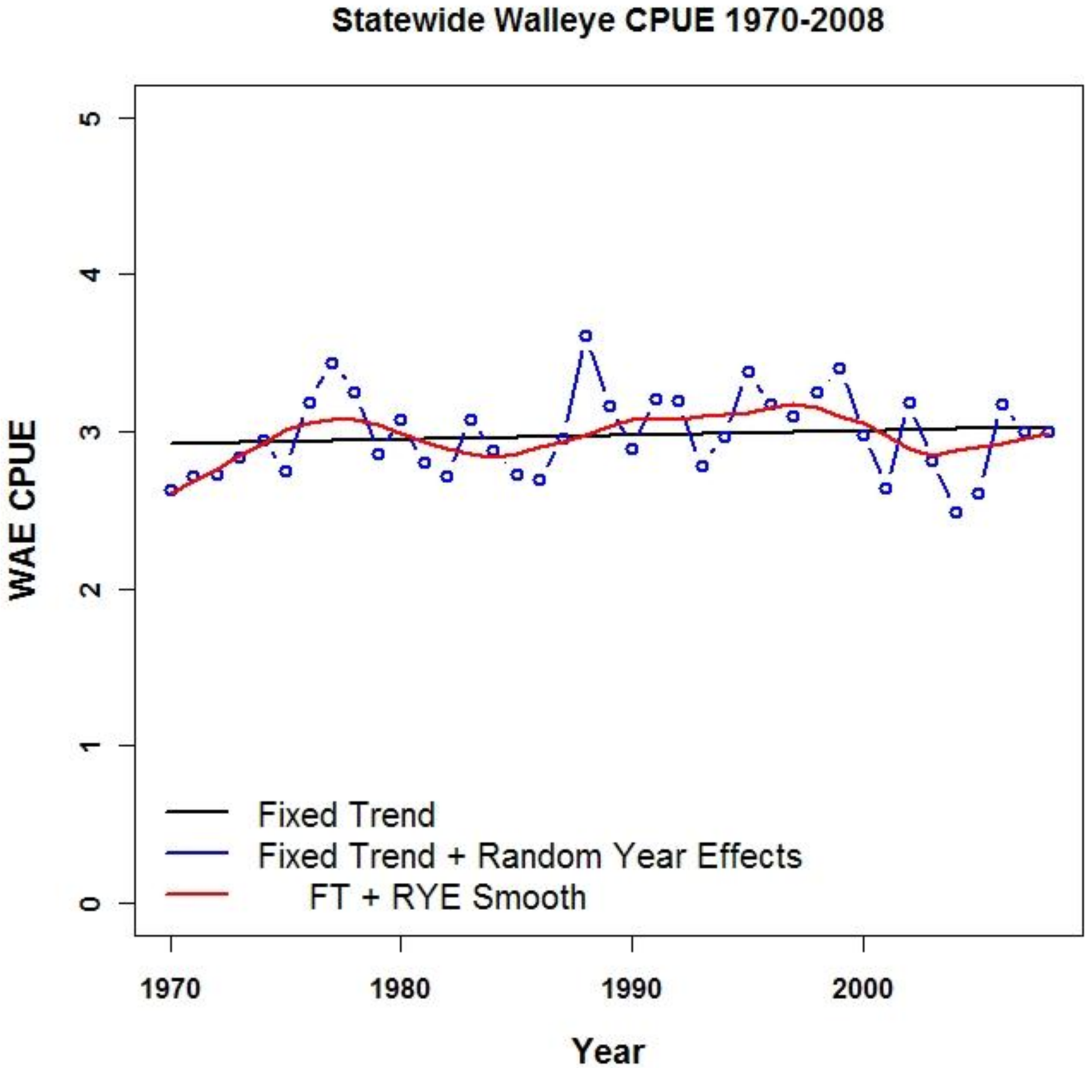
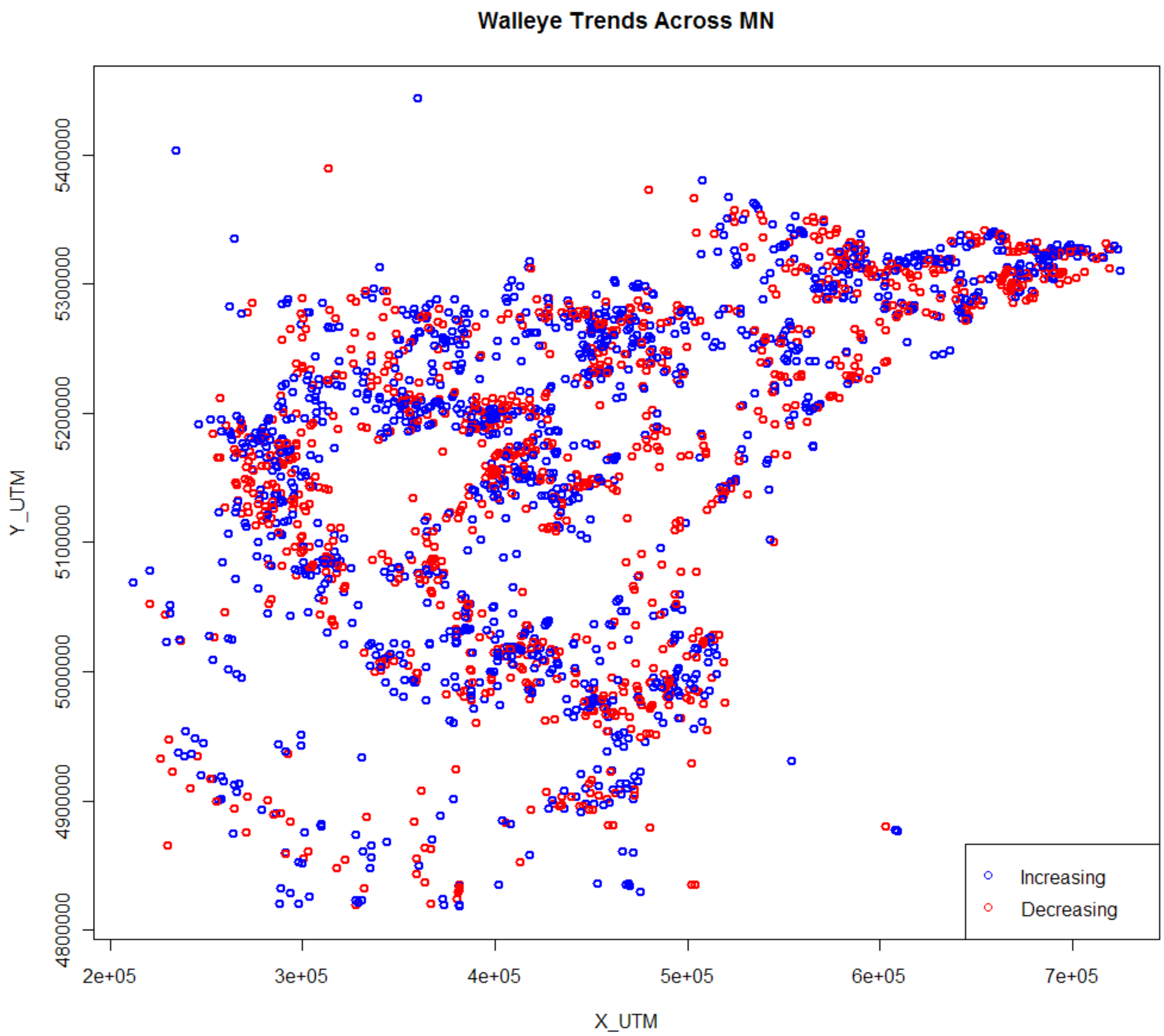


Figure XX. Spatial distribution of increasing and decreasing walleye lakes.



We did not detect a strong spatial pattern for increasing versus decreasing lakes.

Figure XXX. Lake specific BLUPs of intercept and slope versus UTM coordinates. These reflect individual lake differences in CPUE trends. Blue dashed lines are fixed intercept and trend values, red line is a non-parametric lowess smooth of the BLUP values. Intercept BLUPs reflect spatial differences in mean CPUE values. The slope BLUPs suggest that trends in walleye CPUE are similar across the state.

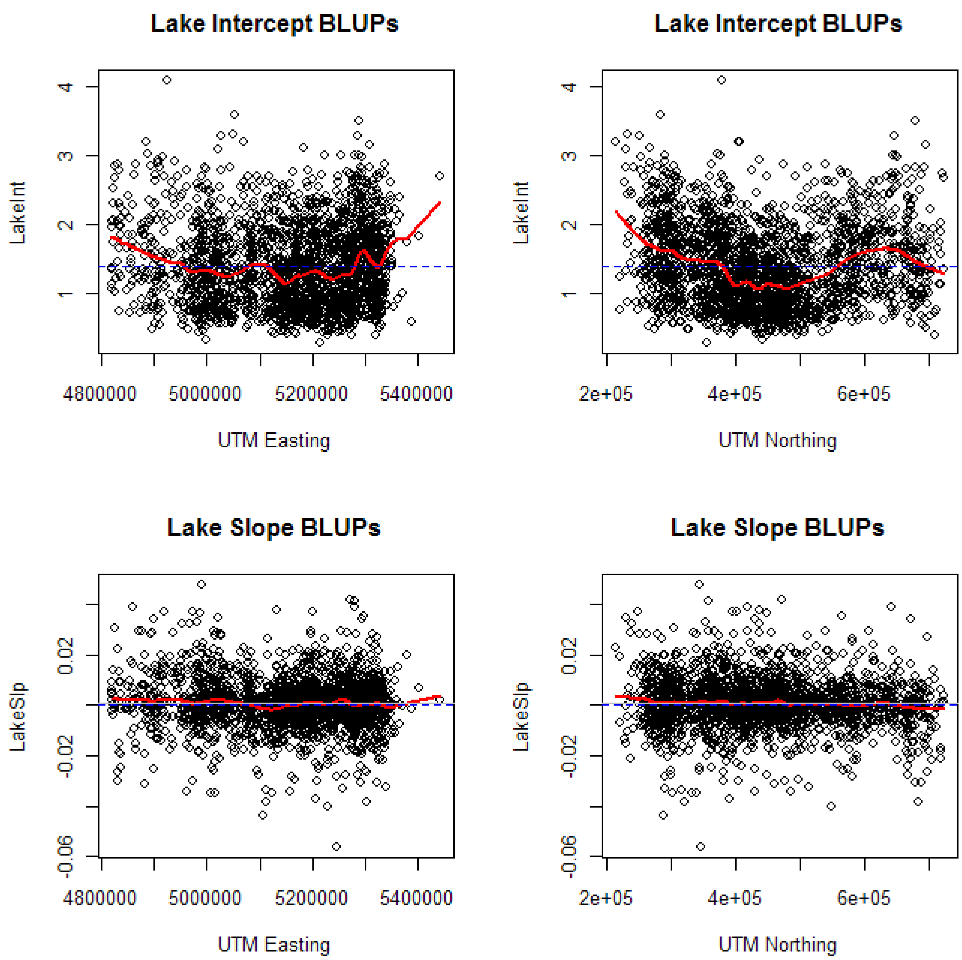
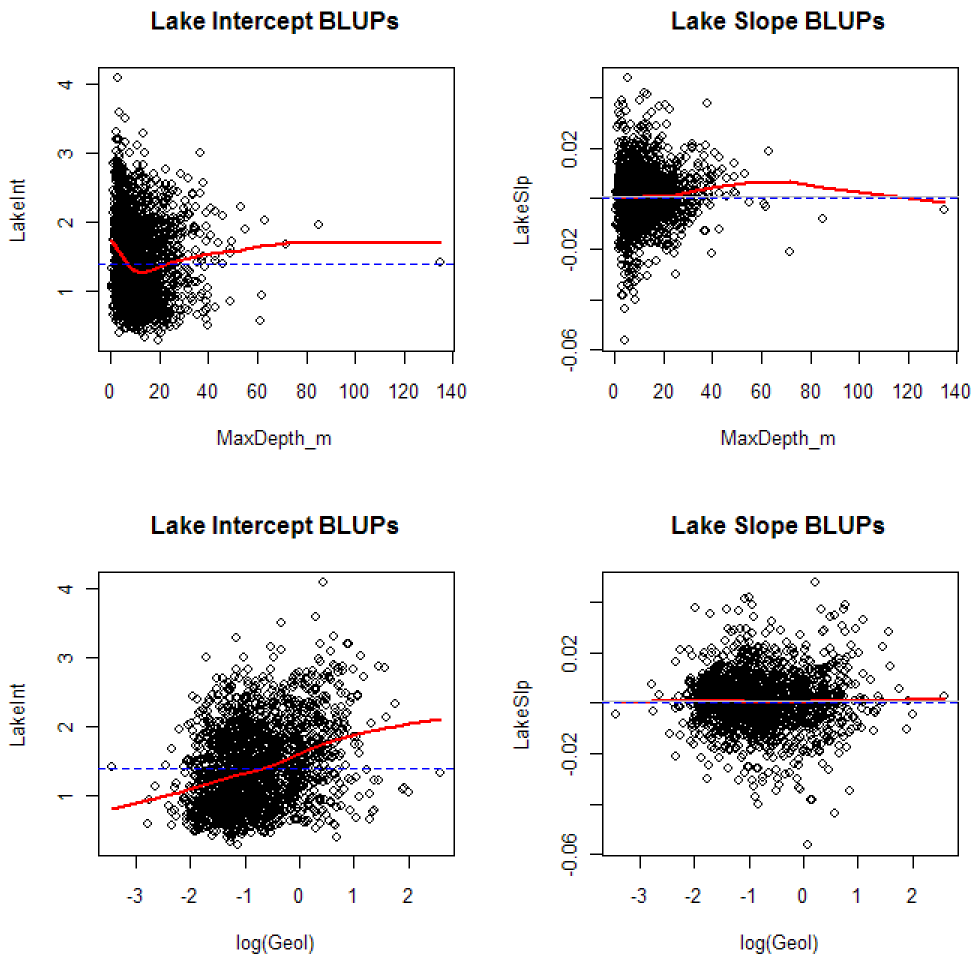


Figure XXX. Lake intercept and slope BLUPs versus geomorphic measurements. Walleye CPUE tended to be higher in shallower lakes and those with larger geomorphic index values (GeoI = area$^{.25}$/maximum depth). Temporal trends in walleye CPUE are relatively similar.



Cisco (*Corregonus species*) results: The overall trend estimate for cisco was significantly negative (-0.014, $t = -5.28$, $p < .0001$ on 37 df), indicating about a 1.5% per year decline since 1970. The variation in mean $\log_e$(CPUE+1) among lakes had a standard deviation $\sigma_{L0} = 0.73$, and the standard deviation of individual lake trends was $\sigma_{L0} = 0.025$; BLUPs of individual lake trends varied from a 5% per year decline to a 5% per year increase. Of the 701 lakes with cisco gillnet captures 63.9% (448 lakes) had per year declines greater than 1%, while only 4.4% (31 lakes) had per year increased greater than 1%. The annual variation about the fixed trend (i.e., random year effects) had a standard deviation σ_Y = 0.13 (see figure below for plot of fixed trend along with random year effects).

Random effects:			
Groups Name	Variance	Std.Dev.	Corr
DOWLKNUM (Intercept)	0.533142	0.73017	
YR	0.00063806	0.02526	-0.108
YR (Intercept)	0.01736128	0.13176	
Residual	0.37600301	0.61319	
Number of obs: 3119, groups: DOWLKNUM, 70; Yr, 39			

Fixed effects:		
Estimate	Std. Error	t value
(Intercept) 1.358317	0.038191	35.57
YR -0.013938	0.002641	-5.28

Figure XX. Average CPUE trend and annual deviations for cisco CPUE in 701 MN lakes.

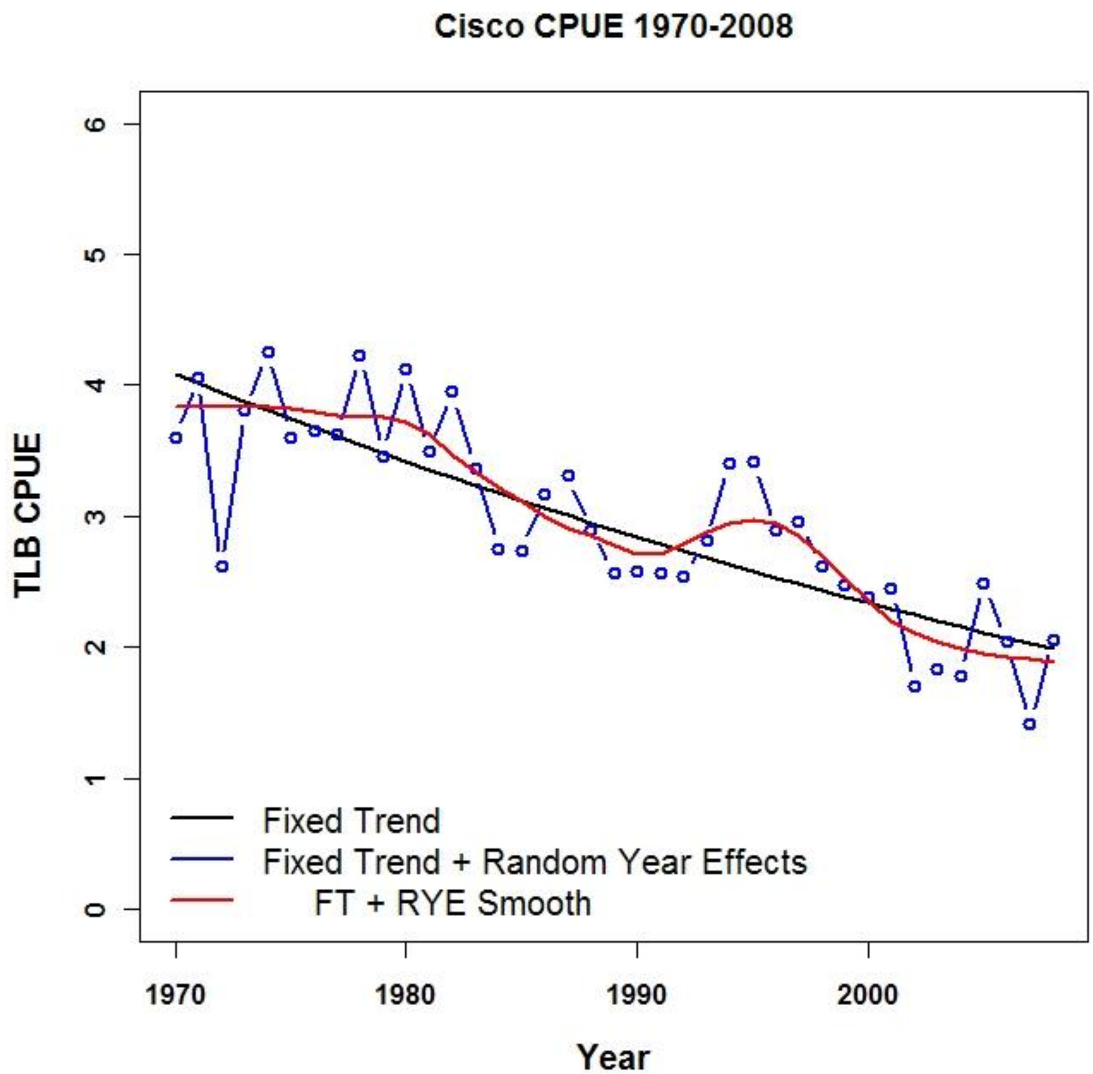
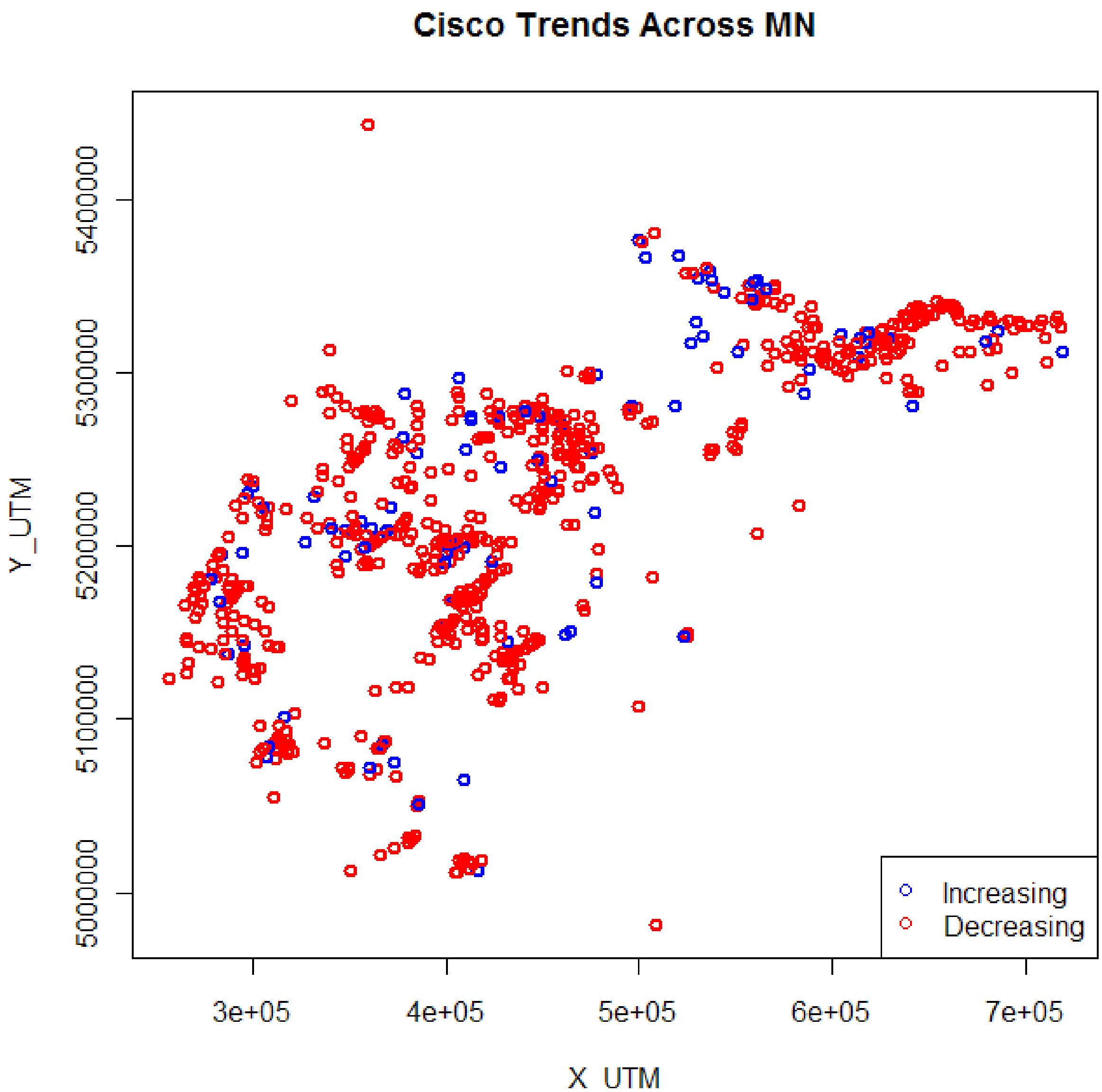


Figure XX. Spatial distribution of increasing and decreasing cisco lakes.



We did not detect a strong spatial pattern for increasing versus decreasing lakes. Nor did we detect any geomorphic relationship to increasing versus decreasing lakes or strength of decreasing trends.

Figure XXX. Lake specific BLUPs of intercept and slope versus UTM coordinates. These reflect individual lake differences in CPUE trends. Blue dashed lines are fixed intercept and trend values, red line is a non-parametric lowess smooth of the BLUP values. Intercept BLUPs reflect spatial differences in mean CPUE values (e.g., cisco CPUE tends to be higher in northeastern lakes). The slope BLUPs suggest that trends in cisco CPUE are similar across the state.

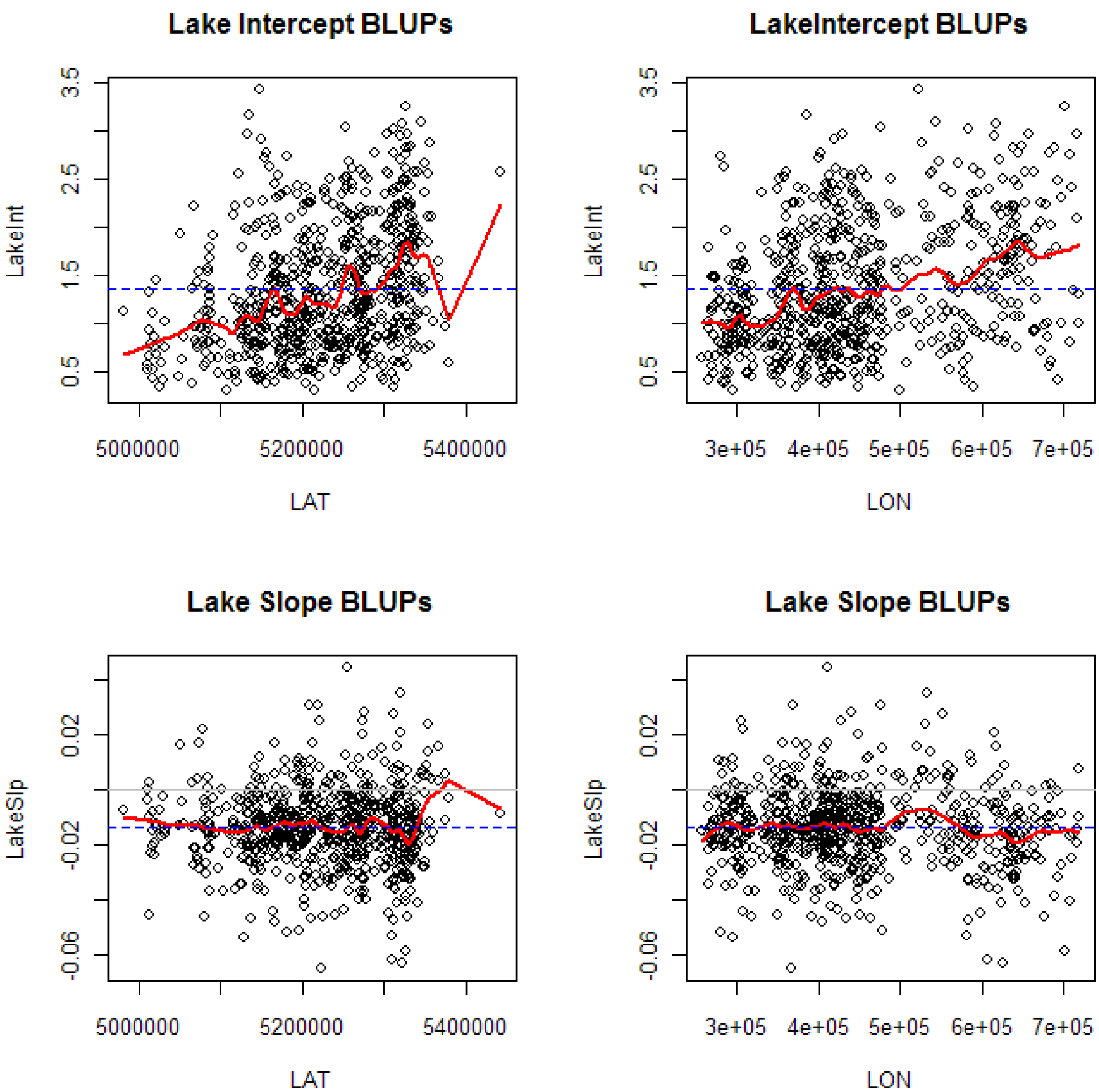
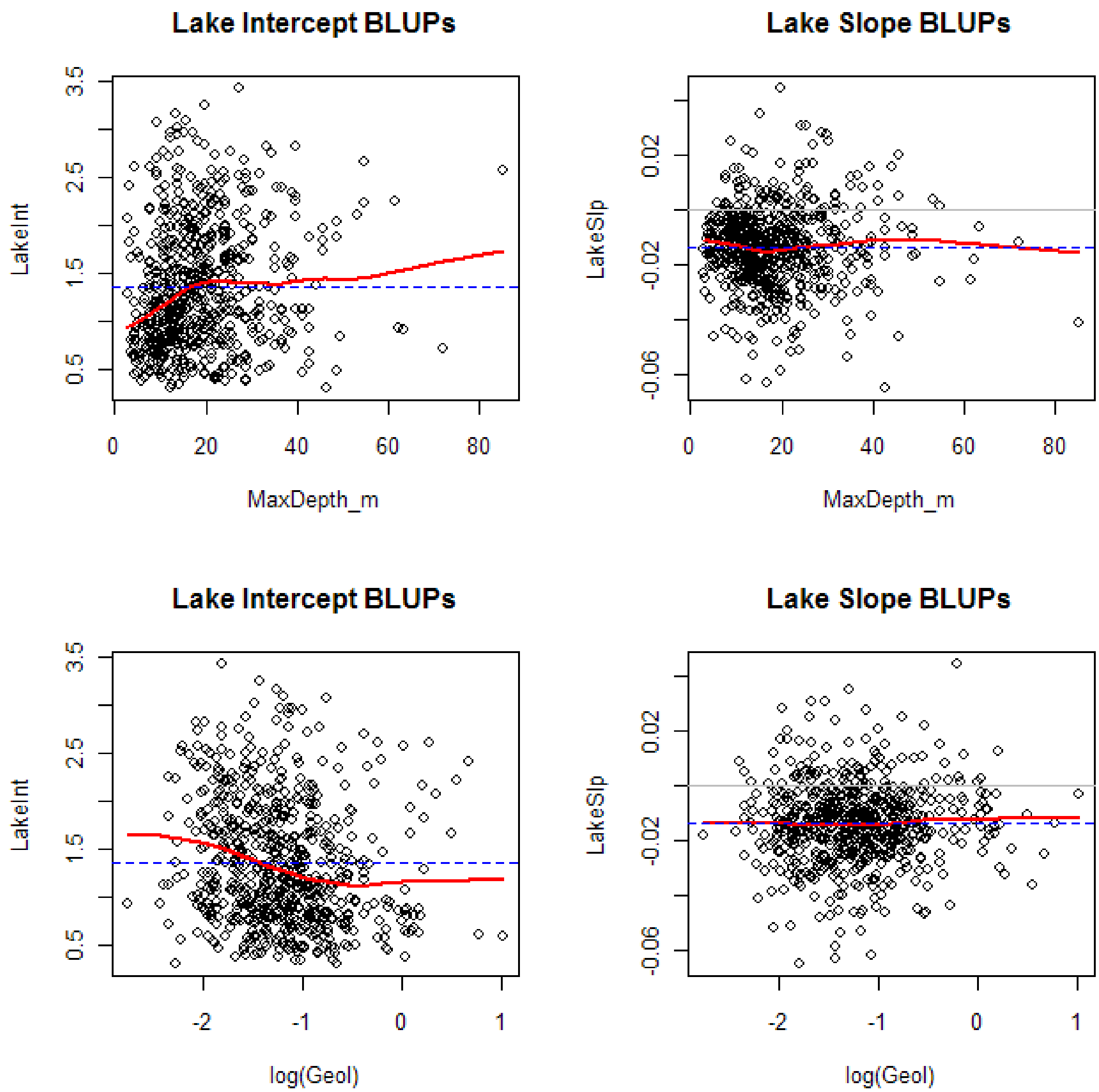


Figure XXX. Lake intercept and slope BLUPs versus geomorphic measurements. Cisco CPUE tended to be higher in deeper lakes and those with lower geomorphic index values (GeoI = area$^{.25}$/maximum depth). Temporal trends in cisco CPUE are relatively similar over the geomorphic gradients.



Smallmouth Bass (*Micropterus dolomieu*) results: The overall trend estimate for smallmouth bass was slightly positive (0.0006), but was not statistically different from zero (t = 0.35; p = 0.73 on 37 df). The variation in mean $\log_e$(CPUE+1) among lakes had a standard deviation σ_{L0} = 0.40, and the standard deviation of individual lake trends was σ_{L0} = 0.016; BLUPs of individual lake trends varied from a 4% per year decline to a 3.5% per year increase. Of the 465 lakes with smallmouth bass gillnet captures 6.7% (31 lakes) had per year declines greater than 1%, while 9.3% (43 lakes) had per year increased greater than 1%; the remainder of the lakes (84%) had changes less than 1%, which could not be distinguished from no or flat trend. The annual variation about the fixed trend (i.e., random year effects) had a standard deviation σ_Y = 0.067 (see figure below for plot of fixed trend along with random year effects).

Random effects:			
Groups Name	Variance	Std.Dev.	Corr
DOWLKNUM (Intercept)	0.158681	0.398348	
YR	0.000251	0.015834	-0.095
YR (Intercept)	0.004548	0.067437	
Residual	0.092956	0.304887	
Number of obs: 1727, groups: DOWLKNUM, 65; YR, 39			

Fixed effects:			
	Estimate	Std. Error	t value
(Intercept)	0.580761	0.024526	23.679
YR	0.000596	0.001699	0.351

Figure XX. Average CPUE trend and annual deviations for smallmouth CPUE in 465 MN lakes.

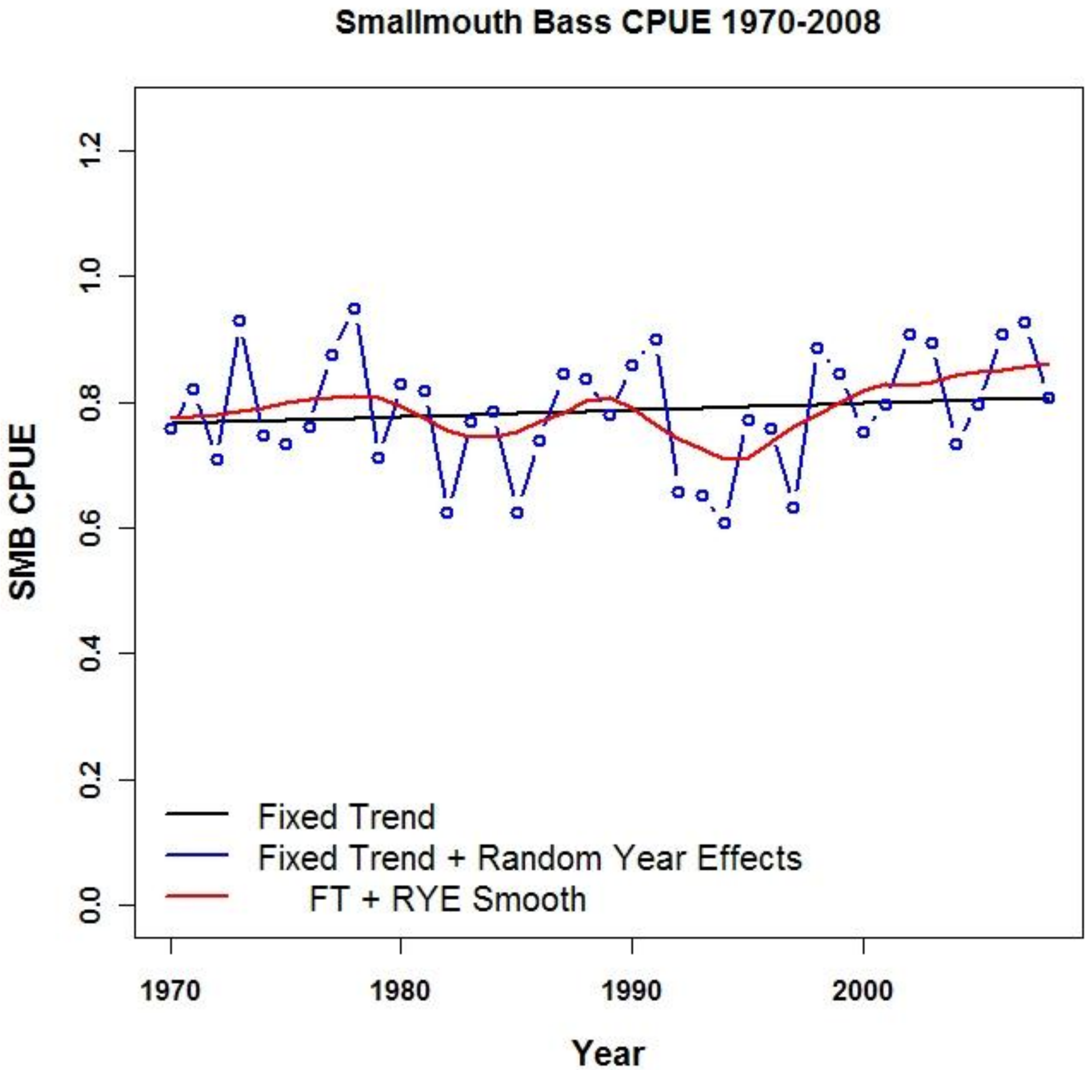


Figure XX. Spatial distribution of lakes with increasing and decreasing smallmouth bass CPUE.

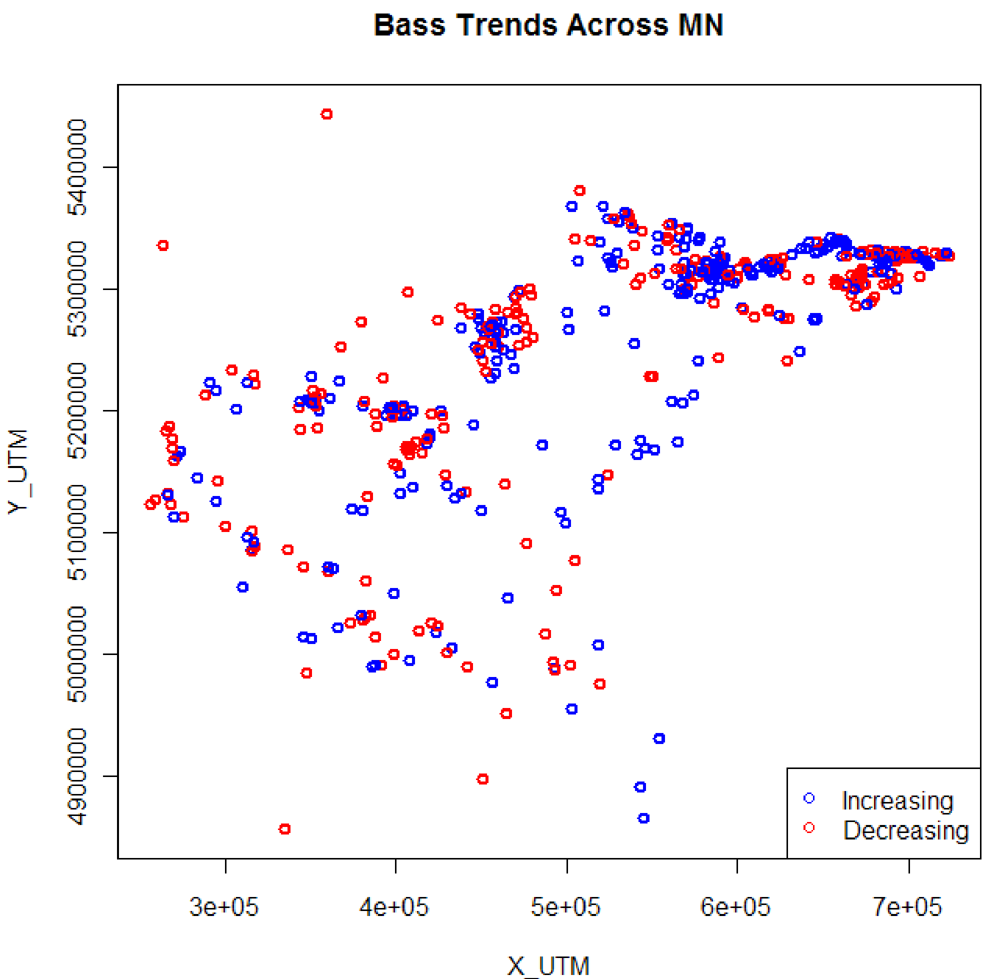


Figure XXX. Lake specific BLUPs of intercept and slope versus UTM coordinates. These reflect individual lake differences in smallmouth CPUE trends. Blue dashed lines are fixed intercept and trend values, red line is a non-parametric lowess smooth of the BLUP values. Intercept BLUPs reflect spatial differences in mean CPUE value. The slope BLUPs suggest that trends in smallmouth CPUE are similar across the state.

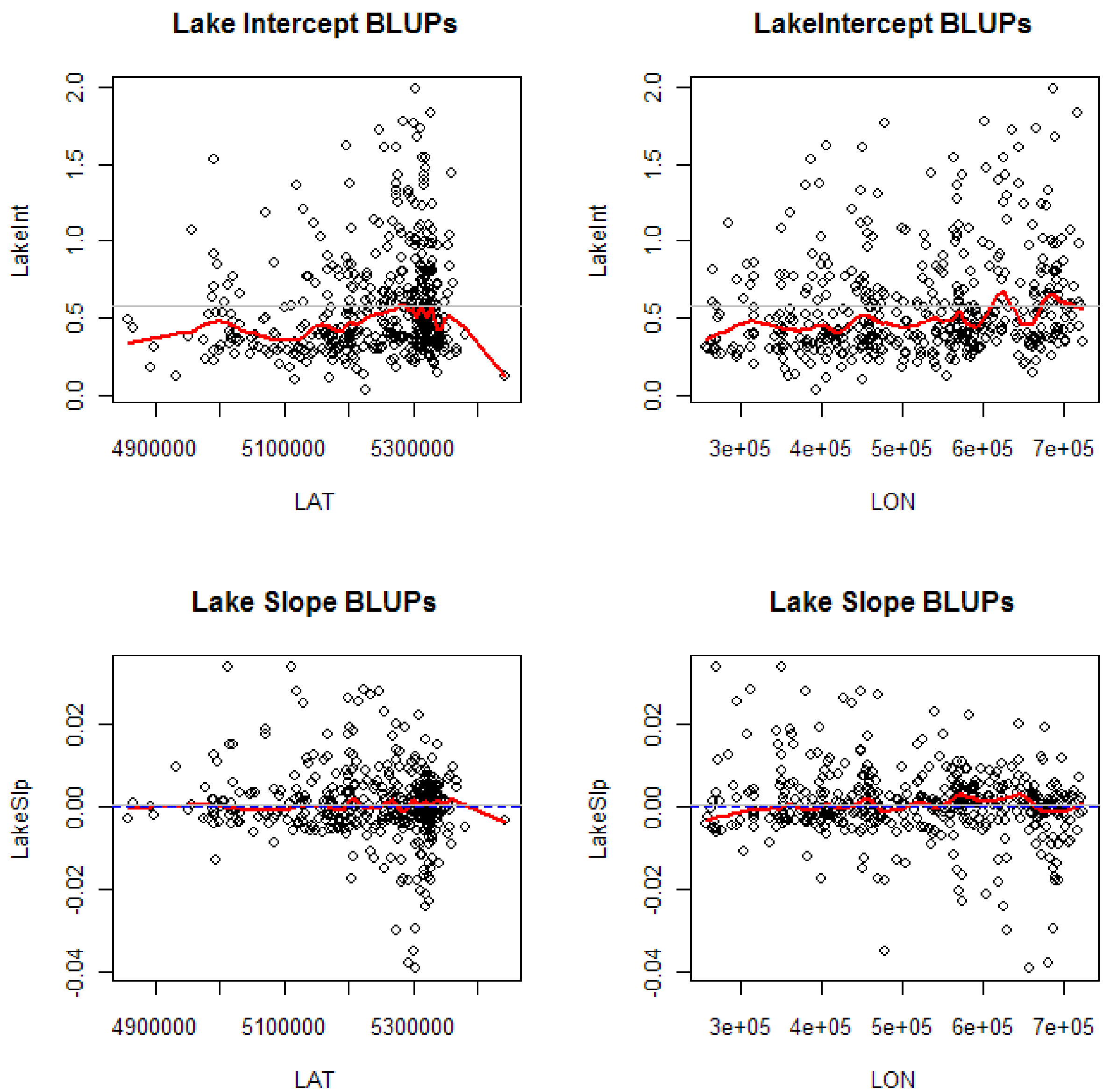


Figure XXX. Lake intercept and slope BLUPs versus geomorphic measurements. Smallmouth CPUE and its trend tended to be similar over the geomorphic gradients.