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Missouri reservoirs in the Glacial Plains: evaluating small impoundments

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Introduction

Missouri reservoirs are located in a mid-continent ecotonal zone at the intersection of historic prairies and broad-leafed forests. Reservoir nutrients span the trophic state range and increase along a south-to-north axis across several distinct physiographic regions (Jones et al. 2008a). Empirical analyses show this pattern is largely accounted for by cropland cover in the catchments (a surrogate for nutrient loss from agriculture) as modified by morphology and hydrology (Jones et al. 2004, 2008b, 2009). These findings are consistent with limnological theory about the role of hydrology and morphology modifying external nutrient loads to lakes.

Most Missouri reservoirs were constructed within the past 50 years, but many are half that age. With few exceptions, land cover at the time of impoundment closely matched current conditions (Jones et al. 2004, 2009). As such, nutrient loads were in place prior to creating these artificial lakes on the landscape. Reservoir age does not influence cross-system patterns for nutrients, suggesting that trophic state is largely determined at impoundment (Jones et al. 2009). In this respect, these reservoirs differ from temperate lakes experiencing recent cultural eutrophication.

Missouri reservoir analyses are based on summer monitoring data from large- and moderate-size water bodies located throughout the state (Jones et al. 2008a). In summer 2006 we included 42 small reservoirs in the Glacial Plains physiographic section of north Missouri (north of latitude 38.7; Table 1, Fig. 1). Small impoundments are numerous in the region but largely unstudied. Small reservoirs were selected to represent a range in size/storage and land cover in their catchments and spatial distribution; about two-thirds were located in public conservation areas. The goal was to measure the trophic state of small artificial lakes in the Glacial Plains and determine if they fit within the empirical, cross-system pattern for pelagic nutrients found in larger reservoirs (Jones et al. 2008b, 2009).

Key words: empirical models, nitrogen, phosphorus, reservoirs, trophic state

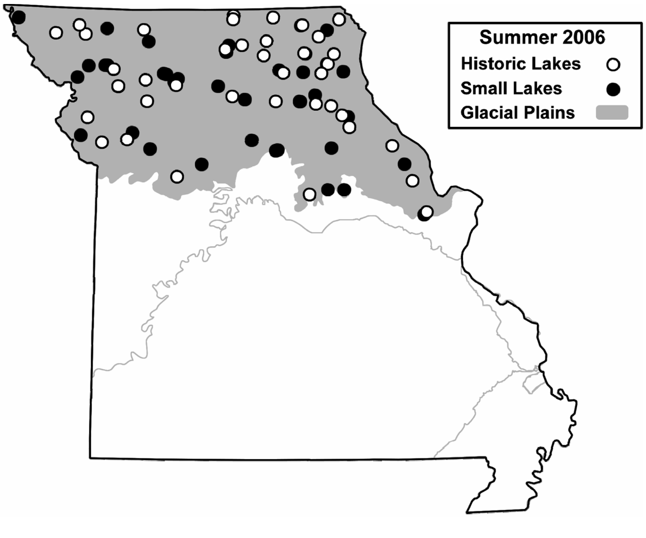

Fig. 1. Location of Historic (n = 39) and Small (n = 42) reservoirs in the Glacial Plains of Missouri.

Methods

Surface samples were collected from near-dam sites on 4 occasions during May–August 2006 from 39 Glacial Plains reservoirs included in the long-term inventory (Table 1; Jones et al. 2008a) and 42 small impoundments. Samples were processed by standard methodology (Jones et al. 2008a). Current land cover in the catchment of each reservoir (Table 1) was expressed as proportion in forest (%forest), grass (%grass), cropland (%crop) and presettlement prairie (%prairie, from survey records). Land cover data (Jones et al. 2009) were logit transformed prior to analyses, and water quality parameters were ln transformed. Reservoir morphology and catchment characteristics were explained with mean depth (as one-fourth of dam height) and an index of hydrologic flushing rate (a function of watershed area, runoff, and reservoir volume; Jones et al. 2008b).

For convenience, the 2 reservoir groups are referred to as "Historic" (n = 39) and "Small" (n = 42). An additional Small reservoir was sampled (Bowling Green # 2) but not included

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Table 1. Summary information on Historic and Small reservoirs sampled during summer 2006. Abbreviations are included in the text.

		Historic reservoirs (n = 39)				Small reservoirs (n = 42)			
Parameter	units	median	min	max	mean	median	min	max	mean
Area	ha	45	3.4	7 496	360	7.3	2.0	91	11.3
Flushing Rate	yr^{-1}	0.63	0.17	5.2	1.7	0.76	0.2	7.0	1.26
Storage	$m^3 * 10^6$	1.7	0.12	617	25.4	0.21	0.01	5.1	0.41
WS Area	$ha * 10^6$	0.8	0.16	608.6	19.0	0.11	0.02	2.1	0.20
Mean depth	m	3.3	1.5	8.5	3.7	2.3	1.2	4.6	2.4
Secchi	m	0.9	0.3	3.3	1.1	0.9	0.2	3.0	1.1
TP	µg/L	48	17	151	55	54	22	177	71
TN	µg/L	910	390	1 470	880	960	550	2 510	1 035
Chl	µg/L	25.1	4.1	102.8	32.8	29.8	5.9	151.6	43.4
NVSS	mg/L	3.1	0.6	16.3	4.2	2.3	0.5	30.3	3.6
VSS	mg/L	4.0	0.9	14.6	4.8	4.4	1.0	19.4	5.9
DOC	mg/L	6.4	4.2	8.9	6.4	7.3	4.3	10.2	7.5
Forest	%	11.2	0.6	79.4	16.4	10.0	0	81.4	16.1
Grass	%	38.0	8.7	81.8	43.1	38.7	6.7	73.9	38.2
Crop	%	27.0	1.4	70.3	26.6	21.7	0.3	70.3	26.7
Prairie	%	67.8	0	100	63.0	71.9	0	100	63.7
Chl/TP	µg/L / µg/L	0.53	0.23	1.08	0.56	0.56	0.18	1.38	0.57
Chl/TN	µg/L / mg/L	26.9	9.4	98.5	33.5	30.5	7.5	124.4	36.1
Tn/TP	µg/L / µg/L	20	9.5	35	19	16.6	6.5	35	18.4

in the analyses because the volume of this water supply impoundment was substantially reduced by withdrawal during summer 2006. Rainfall data were provided by the Missouri Climate Center. Statistical tests were performed with SPSS software and significance was set at 0.05.

Results and discussion

The median Small reservoir sampled in this study has about 15 % of the surface area, storage capacity, and watershed area and 1 m less mean depth than the median Historic reservoir (Table 1); these physical features were significantly different between the 2 groups (ANOVA, transformed data, n = 81). In contrast, there were no between-group differences in land cover type in their respective watersheds (% forest, grass, and crop), flushing index (FI), tropic state characteristics (total phosphorus (TP), chlorophyll (Chl), Secchi, and volatile suspended solids (VSS)), nonvolatile suspended solids (NVSS), yield of algal biomass per unit of plant nutrient (ratio of Chl/TP and Chl/TN) or ratio of the major plant nutrients (TP/TN; Table 1, ANOVA, transformed data). Slightly larger values of dissolved organic carbon (DOC) and TN in Small, relative to Historic reservoirs, however, were significant (transformed data, $p = 0.001$ and 0.04, respectively). Overall, this comparison suggests the suite of Small reservoirs was quite similar in land cover, hydrology, and limnological characteristics to the Historic group, which was a goal of the selection process.

Based on TP, some 60 % of both Small and Historic reservoirs would be classified eutrophic with others classified meso- or hypereutrophic (Table 1). This distribution generally agrees with trophic state assessments in Glacial Plains reservoirs based on long-term values (Jones et al. 2008a). Among the 39 Historic reservoirs, seasonal mean TP, TN and NVSS in 2006 averaged 92–97% of their long-term average (JONES et al. 2008a). Typically, nutrients and mineral suspended solids decline in Missouri reservoirs during summer (JONES & KNOWLTON 2005a, 2005b, and unpublished data), but this was not the rule among Glacial Plains reservoirs in 2006. In two-thirds of study reservoirs (n = 81) the August TP value was larger than the May measurement. The increase in TP was >25 % (maximum 247 %) of the initial value in over half of the reservoirs, and >30 % showed increases in TN of this magnitude. Nutrient increases in late summer were most extreme in Small reservoirs. Seasonal rainfall accounts for this pattern. During February–July 2006 rainfall in the Glacial Plains was about 14 cm (26 %) below the 30-year normal value, with May rainfall only 50 % of normal. In contrast, August rainfall was some 50 % above normal. Inter-annual variation of this magnitude has been documented and is the

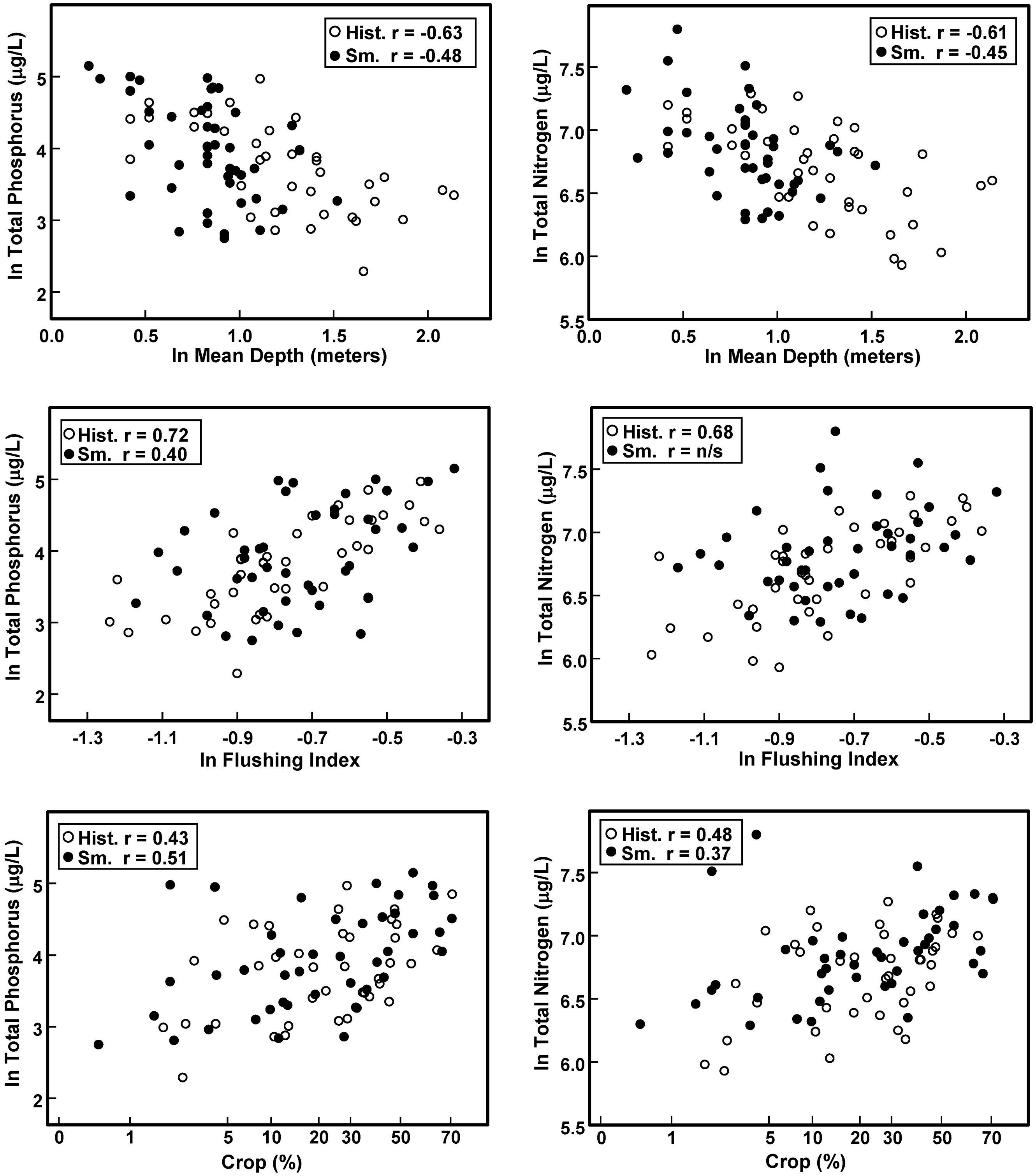

Fig. 2. Relations of seasonal mean TP and TN in Historic and Small reservoirs in the Glacial Plains during summer 2006 to mean depth, Flushing Index, and % cropland (logit-transformed).

primary reason we routinely sample reservoirs during at least 4 summers to estimate mean conditions (Knowlton & Jones 2006a, 2006b).

In Historic and Small reservoirs, seasonal mean TP and TN were significantly correlated with metrics representing hydrology, morphology, and land cover (Fig. 2).

Table 2. Multiple regressions of effects on seasonal mean TP and TN (ln-transformed, equations 1 and 2) in Historic reservoirs (n = 39) of Flushing Index, mean depth (Z), and % cropland (logit-transformed). Comparisons of predicted and observed TP and TN values in both Historic and Small reservoirs are based on equations 1 and 2. Bias was calculated as the mean difference between predicted and observed, and mean square error was calculated as the sum of the mean difference and the variance.

	Model	
	Equation 1	Equation 2
Historic, n = 39	TP_{ln}	TN_{ln}
Intercept	5.561	7.707
Slope for FI_{ln}	1.264	0.635
Slope for Z_{ln}	− 0.516	− 0.312
Slope for $\%C_{logit}$	0.141	0.102
r^2	0.66	0.65
Standard error	0.386	0.230
Comparisons of predicted and observed using eq 1 and 2		
Historic, n = 39		
Mean Difference (bias)	−3.1	−17.6
Median Difference	−1.04	29.3
Variance	394.8	33 663
Mean Square Error	15 104	504 218
Small, n = 42		
Mean Difference (bias)	−4	−32.5
Median Difference	5.0	−8.8
Variance	1 175	151 969
Mean Square Error	29 898	2 011 865

Data from these 2 groups show general overlap, but nutrient correlations with FI and mean depth were notably stronger among Historic reservoirs (Fig. 2). Using stepwise multiple regression, about two-thirds of cross-system variation in seasonal mean TP and TN among the 39 Historic reservoirs was accounted for by FI, mean depth, and %crop (Table 2, equations 1 and 2). The overall explained variation and coefficients for these deterministic variables from 2006 are similar to previous analyses based on long-term averages for plains reservoirs (Jones et al. 2008b). Regression of observed TP and TN on corresponding values predicted with these models resulted in slope coefficients near unity (1.02 and 0.95, respectively) with nonsignificant intercepts. In half of the Historic reservoirs predicted, TP values were within +25 % of observed, and among predicted TN values three-quarters were within this range.

When applied to the suite of Small reservoirs the mean difference between predicted and observed values for TP (bias; Table 2, equations 1 and 2) was slightly larger than for Historic reservoirs with nearly 3-times the variance and double the mean square error (Table 2). For TN, bias was about double that of Historic reservoirs with variance and mean square error values some 4-times larger. Among Small reservoirs the cases of under- and overprediction of observed nutrient values were more extreme than among Historic reservoirs (values not shown). Some of these extremes could be dampened by not including data from the August collection in the seasonal mean. Regardless, predicted TP values were within +25 % of observed in 45 % of Small reservoirs, and 60 % of predicted TN values were within this range.

This preliminary analysis suggests many Small reservoirs on the Glacial Plains broadly match the trophic state of larger impoundments in the region and fit the cross-system pattern describing pelagic nutrients. This information contributes to the growing body of information about impoundments in agricultural landscapes (Downing et al. 2008). Variation within and among these shallow reservoirs is expected as a consequence of seasonal climate patterns and other potential sources (Scheffer 1998). Most Small reservoirs in public conservation areas in Missouri have highly managed fisheries. Some include grass carp stocking to control macrophytes, which can result in dramatic increases in pelagic nutrients as determined by stocking practices and life span of the fish (Knowlton & Jones 2006b). Such management efforts differ within and among reservoirs over time and contribute to the backdrop of temporal variation. Long-term data sets are needed (Jones et al. 1998, Knowlton & Jones 2006b) to quantify the response of Small reservoirs to nutrient loading, morphology, and hydrology and to better determine how they compare with larger impoundments in the region.

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