APPLICATION OF THE SOIL PERTURBATION INDEX TO EVALUATE CREATED AND RESTORED WETLANDS

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Abstract—Biogeochemical properties of wetlands have recently been investigated to assess recovery of wetland ecosystems following human alteration. Analyses of soil samples have shown that the natural regeneration of timber-harvested wetlands exhibits predictable trends for soil organic matter, total organic carbon, total Kjeldahl nitrogen, and total phosphorus. Incorporating these four nutrients, a Soil Perturbation Index (SPI) was previously developed to aid in biogeochemical comparisons of altered wetlands at different successional stages to mature reference wetlands. The current study explores whether reforested sites previously in agriculture exhibit similar biogeochemical trends to forested wetlands previously timber harvested. Results indicate that reforested sites previously in agriculture exhibit biogeochemical trends similar to timber-harvested wetlands, although perhaps at slower rates. Trends for the SPI developed from the agriculturally based sites were very similar to that of the original SPI developed from naturally regenerated sites.

INTRODUCTION

The Nature Conservancy (1992) estimates that about 4.9 million ha of forested wetlands remain in the Lower Mississippi River Alluvial Valley. In fact, between 1883 and 1991, 77 percent of southern bottomland hardwood forests are estimated to have been lost due to timber harvesting, conversion to agriculture, and other human uses (Gosselink and Lee 1987, King and Keeland 1999, Mitsch and Gosselink 2000, The Nature Conservancy 1992). The combined efforts of the Wetlands Reserve Program (WRP) and the Conservation Reserve Program (CRP) within the U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) and other Federal programs have led to the planting and contracts for planting of about 126 000 ha of bottomland hardwoods in the Southern United States since 1985 (Deavers 2000). We need sound methods to evaluate these and various other wetland creation and restoration efforts.

It has been shown that the natural regeneration of timbered wetlands exhibits similar trends for soil organic matter (SOM), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), and total phosphorus (TP) (Smith 1997). The Soil Perturbation Index (SPI) evaluates how the different successional stages compare to mature reference wetlands from a biogeochemical standpoint. The SPI uses the means of SOM, TOC, TKN, and TP data collectively for each wetland to compare with the biogeochemical reference, which is established from mature wetlands of the same type and ecoregion. The SPI consists of data that were transformed to percentage data by the following equation using the parameter TP as an example:

$$[(u - c)/ u] \times 100 = \text{perturbation number},$$

where

u = TP mean value for the 0 (mature) successional stage wetlands, and
c = TP mean for the cut wetland in question.

Percentages are calculated for all four parameters and then plotted according to successional stage (fig. 1). Our assumption is that the greater the change from the reference conditions, the lower the ecological integrity of the system (Maul and others 1999, Smith 1997). The SPI (Smith 1997) indicates a shift in biogeochemical conditions after timber harvest, with the greatest change from reference conditions reached at approximately 8 to 9 years after alteration (fig. 1). As calculated previously, this index predicts that it would take 16 to 17 years for concentrations of the SPI components (SOM, TOC, TKN, and TP) to return to preharvest conditions (Maul and others 1999). We suggest that the SPI be one component of an index of biotic integrity for freshwater wetlands.

Our hypothesis was that if agriculturally based sites exhibit a 2[d] order polynomial curve as do logged and naturally regenerated wetlands, one could use the SPI to evaluate how the created and restored sites are developing. Thus, the objectives of this study are to determine if reforested sites previously in agriculture exhibit biogeochemical trends similar to forested wetlands previously timber harvested (Smith 1997), and, if so, to determine if the SPI is useful in evaluating the restoration of created wetlands and restored wetlands or both previously in agriculture. Soils from WRP, CRP, and cottonwood sites within Mississippi, U.S.A., (fig. 2) were analyzed to determine if reforested sites previously in agriculture exhibit biogeochemical trends similar to those exhibited by forested wetlands previously timber harvested

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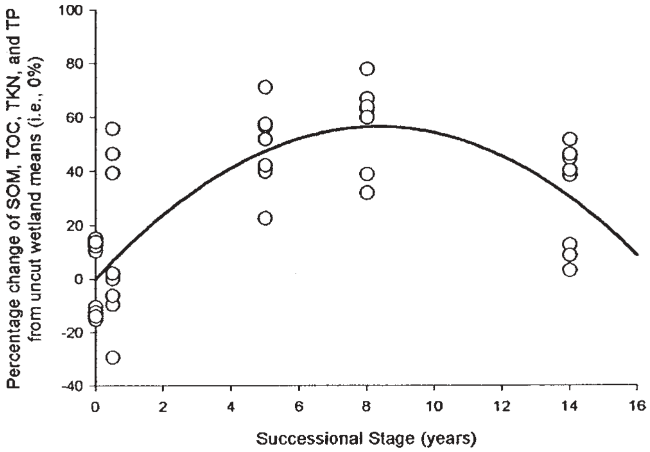

Figure 1—The Soil Perturbation Index (SPI = percentage change of SOM, TOC, TKN, and TP from uncut wetland means) from Maul and others (1999) shows percent change from a biogeochemical reference determined from mature wetlands prior to harvest (0 years = highest ecological integrity exhibited in mature reference wetlands, and 100 percent indicates greatest change from reference condition). The SPI shows a decrease in biogeochemical function (55 percent) that is greatest 8 to 9 years after timber harvesting. This index predicts that it would take 16 to 17 years for the SOM, TOC, TKN, and TP to return to preharvest conditions.

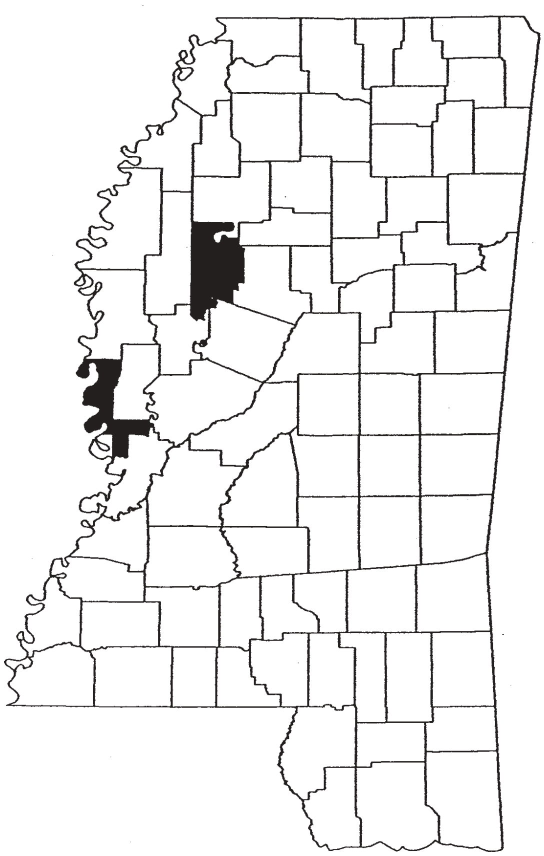

Figure 2—Map of Mississippi, U.S.A., showing Leflore County (uppermost designated county) and Issaquena County. Mature and WRP sites in Leflore County were sampled by Balducci (1998) during 1997. CRP and all cottonwood sites in Issaquena County were sampled during 1998. Map created by William A. Tedesco, Department of Geology and Geological Engineering, The University of Mississippi.

(as described by Smith 1997 and Smith and others 1996). Because NRCS was interested in differences between WRP and CRP, data are reported separately throughout our paper. However, we were interested in overall SPI trends, so we have shown WRP and CRP results on a single AG-SPI curve (see fig. 6).

SITE DESCRIPTIONS

WRP sites with stands 3 and 5 years old and mature natural forested wetlands with stands greater than 60 years old were sampled in August and September of 1997 by Balducci (1998) (table 1). Hereafter, the mature sites are referred to as 0 successional stage because no creation or restoration procedures were performed on those sites. These sites are located in Leflore County, MS (fig. 2). In 1998, we focused on sites reforested on agricultural land of various successional stages ranging from 1 to 22 years since cultivation. To encompass this range of successional stages, CRP and cottonwood sites in Issaquena County, MS (fig. 2) were sampled in August 1998 (table 1). The cottonwood sites consist of two types: the term cottonwood refers to sites that were planted on previous agricultural land and have not yet been harvested; and coppice cottonwoods have been through one harvest and resprouting cycle. The created sites of table 1 include all WRP and CRP sites.

METHODS

Soil

Ten soil cores were randomly sampled within each site. While in the field, cores were placed on ice and, once in the lab, were frozen until processed. The top 5 cm were chosen to represent the most recent influx of nutrients into the soil (Smith 1997). The SOM was measured by loss on ignition at 550 ^{o}C for 5 hours (Craft and others 1991). The TOC was analyzed by a Leco CN 2000 Carbon and Nitrogen Analyzer (Leco Corporation 1996). The TKN and TP were measured by a TRAACS 800 Autoanalyzer (Technicon Industrial Systems Corporation 1987). Soil particle size analyses were performed on a Horiba LA-910 Particle Size Analyzer (Horiba Ltd. 1997).

Statistical Analyses

Individual parameter response—Each individual parameter was analyzed separately using a one-way analysis of variance (ANOVA) for each site. In the first analysis, responses of SOM, TOC, TKN, and TP of the cottonwood sites and mature sites (0 successional stage) were observed. The treatment was successional stage consisting of five groups: 0, 5, 8, 16, and 22 years (n = 3, 2, 2, 2, and 1, respectively). The second analysis compared SOM, TOC, TKN, and TP among the WRP, CRP, and mature sites. The treatment was successional stage consisting of four groups: 0, 3, 5, and 9 years (n = 3, 3, 2, and 2, respectively). The third analysis compared SOM, TOC, TKN, and TP between 9-year coppice cottonwood sites and 9-year CRP sites (n = 2). All variables were normally distributed based on Shapiro-Wilk statistic for normality (SAS Institute, Inc. 1988). All ANOVAs and Student-Newman-Kuels (SNK) tests ($p < 0.05$) were performed with PC/SAS software (SAS Institute, Inc. 1988).

Table 1—Study sites, successional stage (years since alteration), treatment (coppice, cottonwood, created, or natural), and soil nutrient parameters

Site	Stage	Treatment	SOM	TOC	TKN	TP
	Year		- - - - - - - - - - - - *mg/g*	- - - - - - - - - - - -		
WRP3A	3	Created[a]	66.4	20.88	3.150	1.653
WRP3B	3	Created[a]	86.5	27.55	3.637	1.029
WRP3C	3	Created[a]	40.0	12.53	2.175	.475
5A	5	Cottonwood[b]	88.8	29.01	3.380	1.206
5B	5	Cottonwood[b]	52.1	14.40	1.863	.996
WRP5A	5	Created[a]	82.9	35.22	4.792	.745
WRP5B	5	Created[a]	30.6	5.24	1.213	.369
8A	8	Cottonwood[b]	48.8	20.09	2.168	1.053
8B	8	Cottonwood[b]	40.9	15.83	1.949	.845
C9A	9	Coppice[c]	101.6	36.71	4.972	1.339
C9B	9	Coppice[c]	95.3	32.79	4.216	1.171
CRPA	9	Created[d]	76.2	20.22	2.535	.805
CRPB	9	Created[d]	91.6	27.34	3.252	1.245
16A	16	Cottonwood[b]	105.9	39.67	5.323	1.205
16B	16	Cottonwood[b]	77.8	29.98	3.919	1.133
22A	22	Cottonwood[b]	88.4	34.35	5.175	1.300
Mature	> 60	Natural[a]	189.3	86.85	13.400	1.200
Mature	> 60	Natural[a]	170.9	72.96	15.380	1.760
Mature	> 60	Natural[a]	172.7	80.27	11.260	1.520

SOM = soil organic matter; TOC = total organic carbon; TKN = total Kjeldahl nitrogen; TP = total phosphorus.
[a] Sites sampled by Balducci in August and September 1997.
[b] Cottonwood sites were planted on land previously used for agriculture and have not been harvested (sampled August 1998).
[c] Coppice sites were allowed to sprout from trunks after harvesting (sampled August 1998).
[d] Conservation Reserve Program sites sampled in August 1998.

Soil Perturbation Index—The SPI (Maul and others 1999, Smith 1997) uses the means of SOM, TOC, TKN, and TP data for each wetland to calculate the percent change from the biogeochemical reference determined from the mature wetland soils. Because there are replicate wetlands per successional stage (n) and four parameters analyzed per wetland, 4 by (n) replicate points for each successional stage are plotted. The cottonwood and mature sites were used to develop a single agriculturally based SPI (AG-SPI) for reforested sites previously in agriculture. As in Maul and others (1999), the perturbation numbers were plotted for each parameter (TP, SOM, TOC, and TKN) and for the different successional stages. A 2[d] order polynomial equation for AG-SPI [(Y = M0 + M1(x) + M2(x)) where M0 = 5.424, M1 = 10.660, M2 = -0.434, and x = successional stage (years)] provided the best fit line for the index with r = 0.77.

RESULTS

Individual Parameter Response

The majority of all the sites were classified as having soil textural classes of silt or silt loam (table 2). The cottonwood sites exhibited similar observable trends for all four parameters (TP, SOM, TOC, and TKN). Concentrations of soil parameters changed until the 8-year stage, then moved back toward mature conditions (fig. 3). The SOM, TOC, TKN,

Table 2—Soil particle size analysis and textural class data of Balducci (1998) and this study

Site	Sand	Silt	Clay	Textural class
	- - - - - *Percent* - - - - - -			
WRP3A	1.7	88.1	10.2	Silt
WRP3B	2.5	84.9	12.6	Silt loam
WRP3C	22.6	69.9	7.4	Silt loam
5A	14.8	80.1	5.1	Silt loam
5B	9.1	85.5	5.4	Silt
WRP5A	1.9	91.5	6.7	Silt
WRP5B	48.2	46.2	5.6	Sandy loam
8A	40.6	58.1	1.3	Silt loam
8B	39.0	59.6	1.4	Silt loam
C9A	7.1	87.6	5.3	Silt
C9B	8.0	87.1	4.9	Silt
CRPA	4.0	88.7	7.3	Silt
CRPB	8.1	83.7	8.2	Silt
16A	20.6	75.0	4.4	Silt loam
16B	29.7	67.0	3.3	Silt loam
22A	18.6	77.7	3.6	Silt loam
Mature	5.0	86.6	8.4	Silt
Mature	25.7	65.9	8.4	Silt loam
Mature	16.6	79.1	4.3	Silt

and TP trends exhibited in this study (fig. 4) are similar to trends found in the timber-harvested wetland study sites of Maul and others (1999). Coppice sites contained higher concentrations of SOM, TOC, TKN, or TP than the created sites (fig. 5).

Soil Perturbation Index

The AG-SPI combines data from the cottonwood and mature sites (fig. 6). According to this study, reforested sites previously in agriculture exhibit similar biogeochemical trends as natural forested sites previously timber harvested. The best-fit curve for both SPIs is a 2[d] order polynomial curve. The AG-SPI indicates that reforested sites previously in agriculture take longer to recover biogeochemically than timber-harvested wetlands. The point indicating greatest change from reference conditions for the AG-SPI is about 12 years whereas the original SPI indicates the greatest change at 8 to 9 years after alteration. The AG-SPI predicts it would take 24 years for SOM, TOC, TKN, and TP to return to mature conditions compared to the 16 to 17 years suggested by the original SPI. The AG-SPI biogeochemical levels deviate approximately 70 percent from the mature sites where the original SPI only changes about 55 percent from the mature sites.

The WRP and CRP sites were plotted on the AG-SPI to provide a biogeochemical comparison (fig. 6). The AG-SPI indicates that WRP sites may exhibit a greater change from mature biogeochemical conditions compared to other wetlands of similar age and background. According to index calculations run for the current study, the 9-year CRP sites

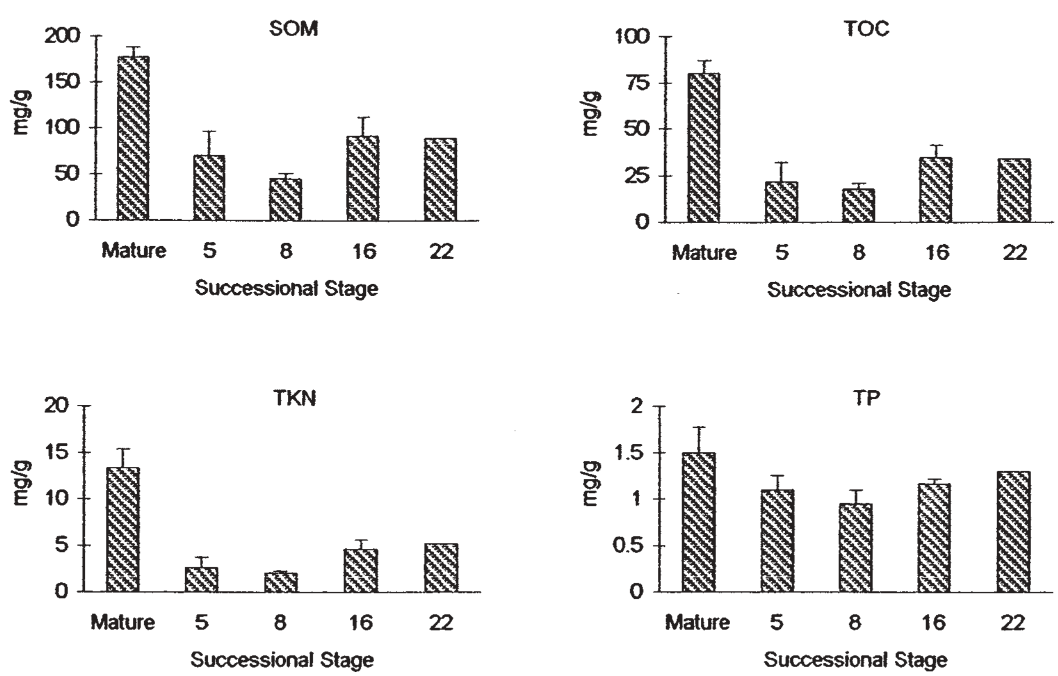

Figure 3—Trends of soil organic matter (SOM), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), and total phosphorus (TP) among cottonwood sites of different successional stages and mature sites. Error bars represent one standard error. Data for mature sites are from Balducci (1998). Cottonwood sites were sampled in August 1998.

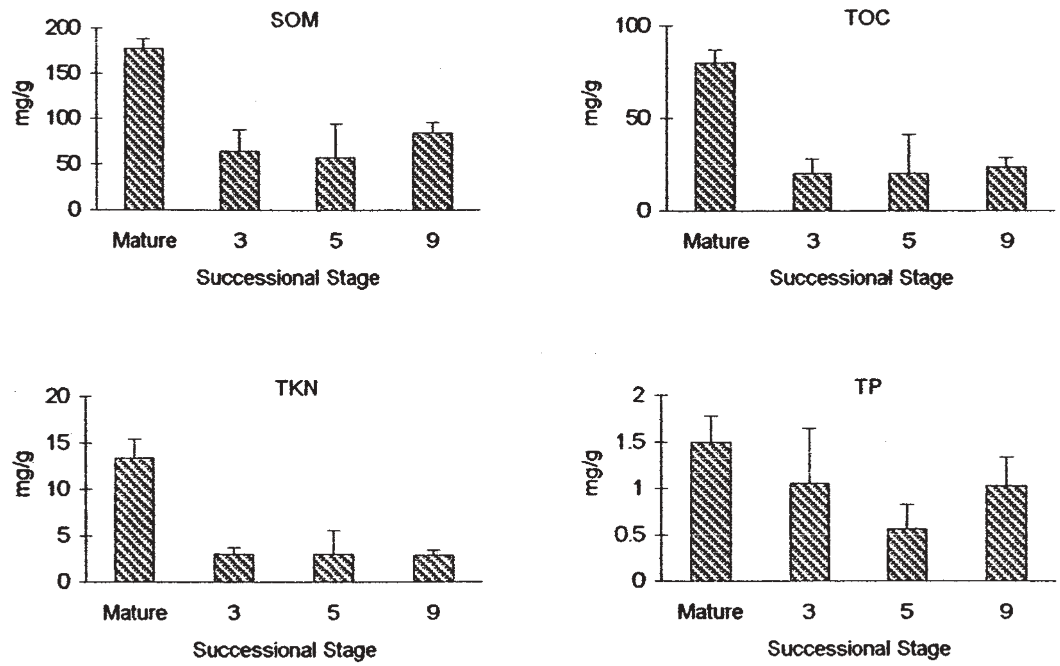

Figure 4—Trends of soil organic matter (SOM), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), and total phosphorus (TP) among different successional stages of WRP (3 and 5 year), CRP (9 year) and mature sites. Error bars represent one standard error. Mature and WRP sites were sampled in August and September 1997 (Balducci 1998). The CRP sites were sampled in August 1998.

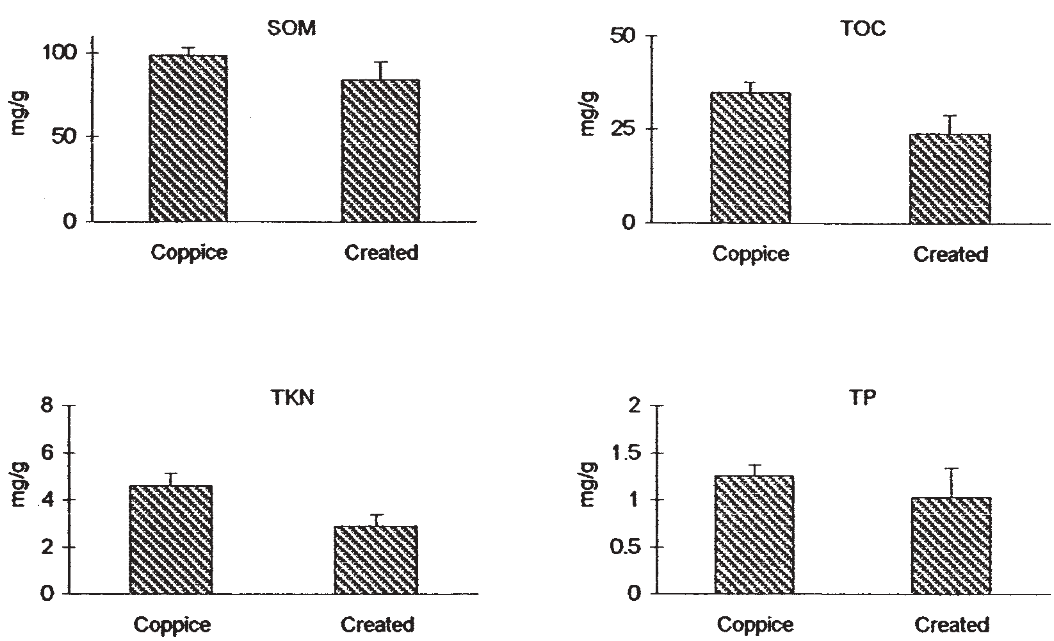

Figure 5—Comparisons of soil organic matter (SOM), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), and total phosphorus (TP) between 9-year coppice and 9-year CRP sites. Error bars represent one standard error. Sites sampled in August 1998.

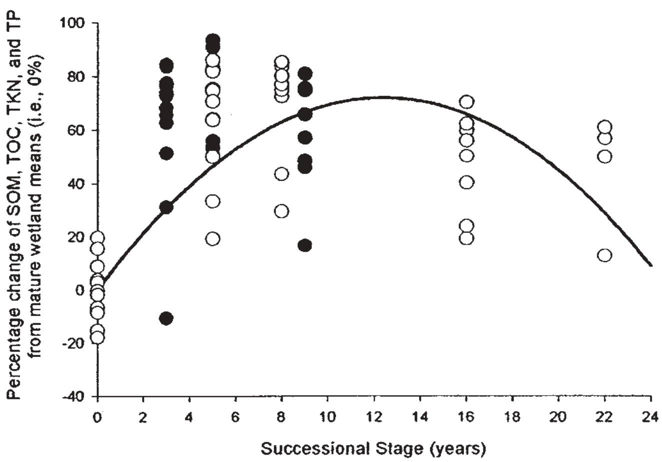

Figure 6—The agriculturally based Soil Perturbation Index (AG-SPI) shows percent change from a biogeochemical reference determined from mature wetlands (0 years before alteration). The AG-SPI shows a change in biogeochemical function (70 percent) that is greatest 12 years after planting. This index predicts that it would take 24 years for the SOM, TOC, TKN, and TP to return to mature condition. The white circles represent mature and cottonwood sites and the black circles represent WRP- and CRP-created sites. The WRP and CRP sites were plotted for comparison. Mature and WRP sites were sampled by Balducci (1998). Cottonwood and CRP sites were sampled in August 1998.

are functioning in the same range as other sites (cottonwood) previously in agriculture.

DISCUSSION

Individual Parameter Response

It is indicated in this study that reforested sites (cottonwood) previously in agriculture exhibit similar biogeochemical trends, although at lower levels, as wetlands allowed to naturally regenerate following timber harvest. The SOM, TOC, TKN, and TP concentrations decrease until the 8-year stage then increase toward mature conditions. The pattern observed in the current study is the same as that exhibited by timber-harvested wetlands found in the Maul and others (1999) study. Several factors promote such a change from the biogeochemical parameters of mature wetlands and subsequent rebound of soil nutrient concentrations. Young aggrading stands have higher rates of nutrient uptake than mature systems (Lockaby and Walbridge 1998). The young successional stages produce less foliage and other organic components contributing to organic matter than mature systems. As the sites mature, the vegetation produces more leaf litter, which upon recycling of nutrients, increases the productivity of the wetland (Smith and others 1996). Changes in the SOM concentrations or in rates of carbon cycling may have important effects on nutrient cycling, vegetative composition, and productivity (Trettin and others 1996). Thus, time is required in order for the system to reach the biogeochemical conditions of mature reference wetlands.

Soil Perturbation Index

The SPI can aid as one component in evaluating created or restored forested wetlands, or both, previously in agriculture. The agriculturally based cottonwood sites produce an AG-SPI very similar to that of the Maul and others (1999) SPI developed from previously timber-harvested wetlands. The recovery time of the AG-SPI is longer, and there is a greater change in biogeochemical conditions than seen in the SPI reported by Maul and others (1999). This longer recovery time is expected due to the lack of organic matter accumulation in the soil resulting from agricultural practices. The disturbance of the soil and drier conditions of these sites may contribute to the lower concentrations of SOM, TOC, TKN, and TP retained within soils of the current study.

The WRP and CRP sites were plotted on the AG-SPI to provide a biogeochemical comparison of how the created wetlands are progressing. From a biogeochemical standpoint, the 3- and 5-year WRP sites are functioning at lower biogeochemical levels than other wetlands of the same stage and background. Visual observation (nonquantitative) indicated very few tree saplings were present in any of the WRP sites. The 9-year CRP sites were functioning within the range of other agriculturally based sites (cottonwood) of the same stage. Visual observation indicated trees were present and hardy in both CRP sites. The SPI should be combined with other quantitative data such as for vegetation and hydrology to provide a more comprehensive evaluation of these created or restored wetlands, or both. Further studies should focus on other human alterations as well as natural disturbances. Wetlands created for mitigation purposes might also be studied to determine if the SPI is useful as one component in the evaluation of these wetlands.

CONCLUSION

The SPI is a useful component and tool to evaluate created or restored wetlands, or both, previously in agriculture. The SPI is applicable to reforested wetland systems previously in agriculture and can be one useful component of an index of biotic integrity for wetland ecosystems. This study and that of Maul and others (1999) indicate that wetlands previously altered by human activity (agriculture and timber harvesting) exhibit similar biogeochemical trends following alterations. The SPI can be used to evaluate the biogeochemical trends of created or restored wetlands, or both, (WRP and CRP) compared to other wetlands of similar land use history, type, and ecoregion.

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