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Effect of landscape position on the sediment chemistry of abandoned-channel wetlands

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Abstract

The nature of sediments in abandoned channels is an important component of their development as floodplain wetlands. The texture, organic matter, phosphorous, potassium, and nitrogen content of sediments were determined for abandoned channels along the Iowa and Cedar Rivers near their confluence in Iowa. Differences in the levels of these constituents were examined among categories of three landscape gradients: present connectivity to the river, time since abandonment, and proximity to agricultural land use. Local scale processes of ecological development are seen in the importance of time for increased organic matter and nitrogen. Basin scale processes of sediment transport and deposition are revealed by the importance of connectivity for decreases in these two elements, and by the counter-intuitive findings for nitrogen and especially phosphorous and potassium in relation to agricultural proximity. Location on a floodplain is important for differentiating development, but it cannot be reduced to univariate gradients.

1. Introduction

Channel dynamics create the topography of the riparian zone, and in turn are controlled by the topography; *e.g.* low areas are flooded more often and longer and still waters lead to the deposition of fine sediments, and these topographic depressions thus have very low infiltration rates, which increases surface storage and flood duration. Studies of the effects of channel dynamics on ecosystems are most common in alluvial rivers where channel position changes readily and where scars of earlier meanders leave a record of geographical instability (*e.g.*, Schumm and Meyer 1979). Many of the geomorphological features of the riparian zone are thus ephemeral. The spatially transgressive nature of this phenomenon may have important implications for landscape ecology (Kalliola and Puhakka 1988).

One particular result of channel dynamics is channel abandonment. This process typically provides a unique setting for an ecological development from river, to oxbow lake, to riparian wetland. Shankman and Drake (1990) and Shankman (1991) reported that *Taxodium distichum* may be dependent for regeneration on abandoned channels in the northern part of the Mississippi embayment. They found that it colonizes the shores of abandoned oxbow lakes and then the lake itself as it fills with sediment. Differences in the initial development of these features may lead to later distinction in major forest cover type, and has consequences for conservation of biodiversity (Shankman 1993).

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A channel may be abandoned by meander cutoff or chute development (Leopold *et al.* 1964). Each of these landforms is characterized by distinct alluvial deposits and in turn influences future sedimentation. Variation in sediment characteristics, particularly texture and chemical constituents may promote establishment and growth of some species at the expense of others. The importance of being able to distinguish the scale and origin of influence in riparian environments has been argued by Rostan *et al.* (1987), Baker (1989), Chauvet and Decamps (1989) and Malanson (1993). The objective of this study is to identify landscape factors (*cf.* Naiman and Decamps 1990) which are important influences on the depositional environment found in abandoned channels.

Landform developments in fluvial systems result from the interaction of complex geomorphic processes. Factors affecting the dynamics of abandoned channels are the flow of water across the floodplain and proximity of a site to the channel, vegetation on the floodplain, the relative width of the floodplain, and human activity in the drainage basin (*e.g.* James 1985; Bhowmik and Demissie 1989). Reineck and Singh (1973) described the specific process of sediment deposition in abandoned channels. These sites are slowly alluviated and sealed at both ends, isolating an oxbow lake. In the beginning, there is rapid sedimentation near the ends of the cut-off but this rate later slows. Suspended material is imported during overbank flows and deposits are mainly clayey sediments and organic matter. This process produces a sequence of clay plugs whose thicknesses are dependent on the depth of the abandoned channel. Reineck and Singh (1973) cite thicknesses of up to 40 m on the Mississippi River floodplain and lengths of 35 to 40 km. At the ends of the channel-fill deposits, sandy plugs are often present. However, these areas still have an abundance of silt and clay with only minor amounts of generally cross-bedded sands present. Mud layers are very thinly laminated and are found throughout such abandoned channels. Overall, these processes are largely a function of how connected the abandoned channel is to the active river (Rostan *et al.* 1987).

The chemical nature of floodplain sediments is influenced by allochthonous factors such as precipitation inputs, colluvial inputs, and alluvial inputs and exports (Rostan *et al.* 1987). Autochthonous nutrient cycling is also important in determining the chemical nature of the sediments. Because the riparian environment is an open ecosystem in terms of flow of energy and matter, an important factor influencing sediment chemistry is the large exchange due to flooding. Again, connectivity to the river is important, but other sources of inputs, such as agricultural fields on or adjacent to the floodplain, may have an effect. It has been suggested that riparian vegetation and wetlands can act as a sink for nutrients from directly upslope and from overbank flooding in different ways (*e.g., inter alia,* Nealson and Malanson 1994), and location is probably important.

The biological variety of abandoned channels is notable. The most complete body of work has been done along the Rhone and includes plant communities (*e.g.* Bravard *et al.* 1986; Castella and Amoros 1986), macroinvertebrates (*e.g.* Richardot-Goulet *et al.* 1987; Castella and Amoros 1988), soil fauna (*e.g.* Dole 1984), sediments (*e.g.* Bravard 1983; Rostan *et al.* 1987), and geochemistry (*e.g.* Carrel and Juget 1987). Abandoned channels are dynamic and the organisms present modify the environment and also change through time.

Abandoned channels now form most of the significant palustrine wetlands of the Midwestern USA. Because they are on floodplains some have not been drained and changed into agriculture; others that have been farmed, some behind levees, are now being reverted to natural systems under new land use policies (ISU Extension 1993). This habitat is also a central one in the reconstruction of paleoenvironmental response to climatic change (Chumbley *et al.* 1990). Understanding the landscape factors that determine the initial stages of the transition from a stream to a wetland ecosystem is necessary to guide the new land use policies and to interpret the relevance of past changes to the present.

1.1. Statement of problem

This study will investigate some of the variables which determine the characteristics of sediment in abandoned channels. These variables may represent processes operating at the local floodplain scale or the scale of the basin. The sediment characteristics should be influenced by the relative location of the site on the floodplain and in time; this is essentially a landscape ecology approach which has been advocated for wetland soils (Moorhead and Cook 1992) and for other benthic environments (Naiman *et al.* 1988; Butler and Malanson 1993). Three variables are hypothesized as controlling the textural, chemical and organic characteristics of the sediments in the abandoned channels: present connectivity to the river; time since channel abandonment; and proximity to agricultural activity.

First, present connectivity to the river dictates the importance of riverine, and thus basin scale, inputs to the abandoned channel. Sites that are best connected to the river will receive riverine inputs while the sites that are least connected should be more strongly influenced by autochthonous processes. Second, the characteristics of the sediment should reflect the position of the site on a temporal gradient; *e.g.*, older sites should contain sediments with higher organic contents. Third, proximity of the abandoned channel to agricultural field and pastures, at the local scale, should have an influence on the chemical nature of the sediments at the site; *e.g.*, those abandoned channels that are closest to agricultural activity should experience the highest concentrations of phosphorus, potassium and nitrogen.

2. Methods

2.1. Study sites

The processes of abandoned channel sedimentation and the succession of riverine sites to riparian ecosystems are exemplified on the floodplains of the Iowa and Cedar Rivers, Iowa, USA. These are meandering alluvial rivers flowing southeast through Iowa to the Mississippi River. The floodplain is separated from the rolling to flat uplands by bluffs, and itself has a slope of 0.05%, including our sites and nearby farmlands. Neither river has ever been channelized. Near their confluence in Louisa County, the Iowa and Cedar Rivers have left numerous abandoned channels in various stages of ecological development. The Iowa-Cedar Rivers basin is largely agricultural, and almost all of the agriculture is corn and soybeans; forested areas make up only 9% of the lands in eastern Iowa (Leatherberry *et al.* 1992). Some fields may be tiled to increase drainage, but we saw no evidence in the area of our field sites. Agricultural practices in the basin also include widespread use of chemicals. The natural vegetation of the floodplain is a hickory-hackberry (*Carya cordiformis* (Wang.) K. Koch-*Celtis occidentalis* L.) forest, with differences at cutbanks and point bars (Kupfer and Malanson 1993; Craig and Malanson 1993). The overall width of the forested riparian zone ranges from 0–1 km on either side of the river; at our study sites the forested zone was always > 100 m. Thirty sites were chosen to represent a range of the hypothesized explanatory variables. The sites are mapped as palustrine unconsolidated bottom or palustrine emergent in the National Wetlands Inventory.

2.2 Locational factors

2.2.1. River connectivity

Based on two criteria, relative position and hydrologic regime, we developed three categories of river connectivity. We defined as highly connected those sites having an open water connection to the river via less than 1000 m of channel or being within 1 m vertically and *500* m horizontally of the main channel. We assumed an intermediate level of connectivity to the river for those sites with open water to the river but through more than 1000 m of channel and those sites with intermittent stream flow but at a distance of more than *500* m from the river. We considered low connectivity to occur when there is no open water connection, no intermittent stream flow, and the site is more than 2 m above the main channel. We found 8, 12, and 10 sites in these **3** categories, respectively.

2.2.2. History

We determined the history of the rivers’ channel changes by evaluating aerial photographs dating to **1941** and plat maps dating back to **1872.** Based on this evidence, we developed three categories of site history: abandoned within the last **30** years, between **70** and 120 years ago, and prehistoric (none were found in the **31–69** yr period). We found **6, 15,** and **9** sites in these **3** categories, respectively.

2.2.3. Agricultural proximity
We considered agricultural proximity to be a function of distance from the field to the abandoned channel and drainage from the field into and through the abandoned channels. We identified closest sites when the site is close to (within **100** m) and directly drains a field. We assigned an intermediate influence for those sites which are in the direct drainage route from a field but are greater than **100** m from that field or which are very close to agricultural fields but do not have direct surface drainage (*e.g.* where a dike exists between the site and the field). The farthest category includes sites through which agricultural areas do not drain and are more than **1000** m from fields and pastures. We found **12, 9,** and **9** sites in these 3 categories, respectively. Because of the topography it was not possible to identify contributing drainage areas, and so additional characteristics of the agricultural land were not recorded.

2.3. Data collection and analysis

After sites were selected for study, sediments were collected and characteristics of the sites were documented in the field. The sediment characteristics were then determined in the laboratory. The data generated by field and laboratory were then subjected to statistical techniques to determine whether correlations exist and to test the hypotheses.

2.3.1. Sample collection
We collected samples in summer, **1989.** This was the second consecutive dry year and water levels and stream flow were low. Several sites had no standing water for the first time in recent memory, but surface sediments were close to saturation even in the driest cases. **A** single sample was collected from the deepest part of each abandoned channel. Only the top 5 cm of abandoned channel sediment deposits were collected and mixed to include the area of bioturbation and the vertical heterogeneity caused by seasonal and annual fluctuations in sediment deposition (*cf.* Petr **1976;** Hill and Sanmugadas **1985;** Rostan *et al.* **1987).** This sample represents recent depositional events, but does not include some potential variability.

Where the sites were subaerial, we removed any overlying vegetation and litter. At subaqueous sites, care was given to retaining the fine sediments which became suspended during the sampling procedure. At each site, we collected samples using a corer with a bore of 130 sq. cm. The samples were transferred to sealed plastic containers and frozen within **8** hours of collection to preserve their organic and chemical constituents. We also recorded the presence or absence of ponded water at each site.

2.3.2. Laboratory methods
We analyzed the samples for selected textural and chemical constituents. Clay percentage was determined using a mechanical analysis procedure described by Hallberg **(1978,** pp. **61–74).** We determined the organic matter content by loss on ignition. We then sent samples to the Minnesota Valley Testing Laboratories, Nevada, **IA,** for analyses of total nitrogen content (Kjeldahl method, ppm), Bray-1 phosphorus (kg/ha), and exchangeable potassium (kg/ha).

2.3.3. Statistical techniques
We calculated Pearson's coefficient of correlation to examine relations between pairs of the sediment variables and the two continuous variables of elevation and distance to river. Analysis of variance was performed to determine if the chemical characteristics varied significantly among the categories of each hypothetical gradient and between sites with and without ponded water. Kruskal-Wallis, the non-parametric ANOVA equivalent, was used when assumptions of ANOVA were not met. Levels within factors were compared by follow-up tests using the Bonferroni inequality for comparisons (Hays **1988).** We recognize that there is a potential

Table 1. Correlation matrix for the five sediment variables and the two continuous variables.

	Distance	Elevation	N	P	K	OM
Elevation	0.087	–				
N	0.414	0.195	–			
P	–.294	0.474	0.133	–		
K	–.278	0.692	0.087	0.356	–	
OM	0.319	0.212	0.919*	0.177	0.141	–
Clay	–.111	0.468	0.513*	0.284	0.712*	0.589*

* $p < .01$.

Table 2. Clay content (%) for the categorical variables.

	River Connectivity		
	high	intermediate	low
mean	32.0	37.0	44.3
standard dev.	16.6	7.7	14.3
	History		
	recent	historical	prehistoric
mean	28.5	40.7	40.2
standard dev.	17.7	9.75	13.77
	Agricultural Proximity		
	most	intermediate	least
mean	36.9[ab]	29.4[a]	48.4[b]
standard dev.	8.4	15.1	10.3
	Ponded Water		
	present	absent	
mean	35.2	42.2	
standard dev.	8.4	16.1	

[a,b] means with different superscript are significantly different in ANOVA, $p < .05$
[x,y] means with different superscript are significantly different in Kruskal-Wallis, $p < .05$.

for multivariate influence of the factors of river connectivity, site history, and agricultural proximity. Our sample shows no systematic relations between any of these three factors, based on analyses with missing data, but some confounding of effects may occur. It is not really surprising that they are independent, because the location of abandoned channel features depends on very unpredictable river dynamics. Missing combinations preclude an interpretable three-way ANOVA or a two-way ANOVA between History and Agricultural Proximity. Although other two-way tests show no significant interactions between any of the three factors, the significance of some relations in the one-way tests no longer appears, so we report both results.

3. Results

3.1. Correlations

Table 1 shows the Pearson correlation coefficients between the sediment variables, elevation, and distance. Clay content is significantly correlated with organic matter, potassium and nitrogen; additionally, nitrogen and organic matter are correlated. Elevation is significantly correlated with potassium. No other significant correlations, notably none with phosphorous, were found.

3.2. Clay content

Sediment textural characteristics were considered in terms of clay content. The clay content ranged from a minimum of 1.8% of the total inorganic weight to a maximum of 62.7%. The mean was 38.1 and the standard deviation was 13.27. The mean clay content of the groups of river connectivity and site age did not vary significantly.

The Kruskal-Wallis test found significantly different means between the groups of agricultural proximity (Table 2). Follow-up tests found the significance to exist between the intermediate and farthest sites, with the farthest sites having a higher percentage of clay in the sediments. The closest sites had an average clay percentage between the values of the intermediate and the farthest groups, though the result did not significantly differ from either. This finding appears to identify a controlling factor other than agricultural proximity. In two-way ANOVA with River Connectivity, neither groups showed a significant relation. When the average

Table 3. Organic matter content (%) for categorical variables.

	River Connectivity		
	high	intermediate	low
mean	7.3[a]	10.0[ab]	11.4[b]
standard dev.	3.0	3.4	2.8
	History		
	recent	historical	prehistoric
mean	6.3[x]	10.7[y]	10.4[y]
standard dev.	2.8	3.4	2.4
	Agricultural Proximity		
	most	intermediate	least
mean	10.4	7.7	10.9
standard dev.	4.1	2.9	1.9
	Ponded Water		
	present	absent	
mean	10.1	9.6	
standard dev.	3.6	3.1	

[a,b] means with different superscript are significantly different in ANOVA, $p < .05$

[x,y] means with different superscript are significantly different in Kruskal-Wallis, $p < .05$.

elevation for each of the agricultural proximity categories is calculated, the answer is apparent. Mean elevation of the closest channels is 3.75 m; the abandonments of intermediate proximity average an elevation of 1.67 m; and the elevation of the farthest abandoned channels is 7.11 m above the river. The difference found between means of the clay content in the agricultural proximity categories is more likely a result of the elevations of these groups rather than an influence of the proximity itself. Higher clay content at the higher elevations may also reflect less connectivity to the river. The clay content was not related to the presence of ponded water, however.

3.3. Organic matter

Organic matter content of the samples ranged from 1.52 to 20.27%. The mean was 9.74%. A significant difference of the means was found between groups of river connectivity. A significant difference was also found between the history groups. Agricultural proximity appears to have no influence on organic matter content, as no significant differences of means was found between levels of this variable (Table 3).

Follow-up tests to ANOVA showed the significance to exist between the most connected sites and the least connected sites – the highest organic content being found in the least connected channels. The history of the site also influences the amount of organics found in the abandoned channel sediments. Follow-ups to the Kruskal-Wallis test showed that the organic contents of the oldest and intermediate aged abandonments were significantly greater than that found in the most recently abandoned channels. The two way ANOVA between River Connectivity and Agricultural Proximity revealed no significant relation. Also, the organic matter was not related to the presence of ponded water.

3.4. Phosphorus

Phosphorus content ranged from 4.48 to 140.00 kg/ha with a mean of 29.87 kg/ha. When the phosphorus content is tested across levels of river connectivity and history categories, no significant difference is found (Table 4). A significant difference of phosphorus content was found between agricultural proximity groups (Table 4). Follow-up tests found significant phosphorus differences between the most and closest groups and the intermediate and farthest groups. Surprisingly however, the phosphorus content was found to increase with decreasing agricultural proximity. In the two way ANOVA between River Connectivity and Agricultural Proximity the latter is still significant. Phosphorous is negatively related to the presence of ponded water; even in two-way tests this relation remains significant.

3.5. Potassium

Potassium content ranged from 156.8 to 985.6 kg/ha. The mean was 468.9. No difference in con-

Table 4. Phosphorous content (ppm) for categorical variables.

	River Connectivity		
	high	intermediate	low
mean	17.4	30.0	39.8
standard dev.	14.7	20.4	38.2
	History		
	recent	historical	prehistoric
mean	16.1	31.4	36.6
standard dev.	10.9	18.2	42.8
	Agricultural Proximity		
	most	intermediate	least
mean	**19.7**[x]	**21.9**[x]	51.5[y]
standard dev.	12.0	14.9	38.8
	Ponded Water		
	present	absent	
mean	16.7[a]	45.0[b]	
standard dev.	10.4	32.7	

[a,b] means with different superscript are significantly different in ANOVA, $p < .05$
[x,y] means with different superscript are significantly different in Kruskal-Wallis, $p < .05$.

Table 5. Potassium content (ppm) for categorical variables.

	River Connectivity		
	high	intermediate	low
mean	364.0	458.3	565.6
standard dev.	136.3	208.9	264.4
	History		
	recent	historical	prehistoric
mean	349.1	514.5	472.9
standard dev.	155.4	261.6	167.8
	Agricultural Proximity		
	most	intermediate	least
mean	**397.6**[a]	**378.3**[a]	**654.6**[b]
standard dev.	199.8	128.6	225.1
	Ponded Water		
	present	absent	
mean	364.0[a]	590.7[b]	
standard dev.	109.1	256.4	

[a,b] means with different superscrip are significantly different in ANOVA, $p < .05$
[x,y] means with different superscript are significantly different in Kruskal-Wallis, $p < .05$.

tent was found between river connectivity categories (Table 5). The **USGS** sampled river water approximately 40 km downstream from these sites, and during the year of this study, concentrations of potassium ranged from 5.0 to 7.9 mg/l for their six samples (O'Connell *et al.* 1989). This concentration appears not to be great enough for riverine inputs of potassium to be important in this environment. Time since channel abandonment also does not influence the level of potassium in the sediments (Table 5).

The test across levels of agricultural proximity shows a significant difference in potassium content (Table 5). Follow-up tests showed this difference to be between the farthest sites and both the closest and intermediate sites. The farthest sites have a greater amount of potassium than either of the other proximity categories. In other words, inputs of potassium from agricultural runoff appears to have little importance relative to other mechanisms influencing sediment content. In the two way ANOVA between River Connectivity and Agricultural Proximity the latter is no longer significant ($p = .096$). Potassium, like phosphorous, is negatively related to the presence of ponded water, and in two-way tests it remains significant even though significant interaction occurs between ponded water and both agricultural proximity and river connectivity.

3.6. Nitrogen

Total Kjeldahl nitrogen content ranged from 625 ppm to 7406 ppm. The mean was 3501 ppm. A variation of means was found between groups for all

Table 6. Total nitrogen content (ppm) for categorical variables.

	River Connectivity		
	high	intermediate	low
mean	2531[a]	3521[ab]	4253[b]
standard dev.	994	1288	1445
	History		
	recent	historical	prehistoric
mean	2342[x]	3963[y]	3505[y]
standard dev.	1007	1629	611
	Agricultural Proximity		
	most	intermediate	least
mean	4069[x]	2495[y]	3750[y]
standard dev.	1801	837	450
	Ponded Water		
	present	absent	
mean	3703	3271	
standard dev.	1674	1001	

[a,b] means with different superscript are significantly different in **ANOVA, p** $<$ .05
[x,y] means with different superscript are significantly different in Kruskal-Wallis, p $<$ .05.

three variables – river connectivity, time since channel abandonment, and agricultural proximity (Table **6).** Nitrogen was not related to the presence of ponded water, however.

The sites which are the most connected to the river have a significantly lower level of nitrogen than the sites which are least connected to the river. It is evident that those sites which develop an ecosystem isolated from riverine influences have a greater amount of the nitrogen forms tested for being found in the sediments.

The importance of on-site ecosystem cycling of nitrogen is demonstrated by the difference found between the mean nitrogen content of the history categories. Follow-ups to the Kruskal-Wallis test showed that the most recently abandoned channels contained significantly lower amounts of nitrogen than the intermediate and the old sites. The sites which are of intermediate proximity have a significantly lower nitrogen content than either the sites least or most proximal to agricultural fields (Table *6).* While the nitrogen found in the closest sites is greater than that found in the farthest sites, the difference is not statistically significant. In the two way ANOVA between River Connectivity and Agricultural Proximity the latter is no longer significant. In this case the lack of correspondence among categories of proximity and history do not allow what might be a useful comparison.

4. Discussion

The characteristics of sediment deposited in abandoned alluvial channels on the floodplains of the Iowa and Cedar Rivers in southeast Iowa can be explained in part by: (a) current connectivity of the abandoned channel to the present active channel; (b) the history of the abandonment; and (c) the proximity of the abandoned channel to agricultural areas. It is important to note, however, that although these factors appeared to be significant in univariate statistical tests, two-way tests found fewer significant relations, although no interaction between any of these effects were found to be significant.

4.1. River connectivity

Connectivity to the main channel influences the level of organic matter and nitrogen found in the sediments. Those sites which are least connected to the river are best suited for a build-up of organics during soil development and lentic deposition. These least connected sites have a higher level of organic matter and total Kjeldahl nitrogen (of which organic nitrogen is a major part) than do the sites which are most connected to the river. Nitrogen content was also found to increase with distance from the main channel.

The connectivity of the site to the river could be important for two reasons. River connectivity reflects the likelihood of the site to be inundated and scoured during high flow events and saturated during normal flow. It also reflects the likelihood of receiving particulate organic matter during riverine deposition. Clearly, the more important factor in increasing the organic content in the sediments is the soil development of a terrestrial ecosystem, or deposition at the bottom of a lentic environment where anoxic conditions slow the mineralization of organics. Riverine deposition of particulate organics plays an insignificant role.

4.2. History

Organic matter and total Kjeldahl nitrogen are found in greater amounts in the sediments of both the intermediate and the older aged abandonments. The most recently abandoned sites have a lower level of organic matter and nitrogen content. Those sites which were categorized as of intermediate age and old age have been more strongly influenced by terrestrial ecosystem processes and soil development or the stabilization of a lentic ecosystem with accumulations of organics in the sediments. As with river connectivity, the importance of the soil development in a terrestrial ecosystem and organic build-up in lentic environments is evident. The youngest sites have not had time to increase organics in the sediments through these mechanisms while the intermediate and older sites have had sufficient time to increase the organic content of the sediment.

After abandonment, the ecosystem shifts from a lotic to a lentic or terrestrial ecosystem, depending on whether an oxbow lake or a dry channel bed results; age since abandonment is positively related to elevation. In either case, the ecosystem will build organic matter which will be deposited and decompose locally more readily than being exported downstream. The abandonment of the channel represents a degree of closure to the system in terms of flows of material, allowing soil development and nutrient cycling to proceed. As the sediments accumulate detritus, the content of nitrogen quickly increases. The rate of nitrogen increase slows with time so that the content found in the oldest abandonments is not significantly greater than that found in the channels of intermediate age.

These results for phosphorous and potassium suggest that cycling in this environment is dynamic enough that factors at work in the very recent past (*i.e.,* one or two growing seasons, flood events, etc.) have brought the phosphorus content to a steady state level faster than the coarse history categories of this study can detect. Site conditions having changed from five to 120 years previous to sampling has little if any importance.

4.3. Agricultural proximity

Differing levels of phosphorus, potassium, and nitrogen were found between groups categorized according to their proximity to agricultural areas. These results, attributed to agricultural proximity, are problematic and somewhat surprising.

This study did not confirm that the riparian ecosystem serves as a sink for agricultural inputs as they move from fields and pastures towards the stream. Demonstration of this function would have placed the highest levels of nutrients in the abandoned channels closest to the agricultural areas – those sites experiencing the highest concentration during runoff. However, each nutrient was significantly higher in the farthest sites than in at least one of the other proximity categories. This finding does not disprove the idea that riparian environments may serve as buffer strips, filtering agricultural runoff during certain hydrological conditions. Rather, the drought conditions during the period leading up to the time of the sampling for this study rendered the influence of agricultural proximity of lesser importance than other variables in determining surface sediment characteristics.

All sites classified as farthest are within riparian forest, although not forested themselves. In addition to being isolated from agricultural areas, these sites are fairly isolated from the river: six of the nine sites classified as farthest from agriculture are also classified as least connected to the river; and seven of the nine sites elevated more than two meters above the normal river stage are in the least proximal to agriculture category. It seems then that sites which are most removed from agricultural practices are also less likely to receive riverine inputs, and so precipitation inputs and autochthonous processing of phosphorus will be relatively more important here. The influence of agricultural proximity on phosphorus, potassium, and nitrogen appears to be a function of clay content, discussed below.

4.4. Other factors

Another source of the nutrients in sediment is from the atmosphere, especially precipitation, but inputs from precipitation are small in comparison to inputs from sediment deposition (*e.g.* Brinson *et al.* 1980). However, when considering a range of elevations on a floodplain, the higher sites can be expected to have a relatively higher proportion of chemical inputs from precipitation. O'Connell *et al.* (1989) reported that potassium in Iowa rainwater ranged from 0.003 to 3.420 mg/l with the majority (52 of 87 measurements) falling between 0.010 and 0.060 mg/l.

In addition to direct precipitation inputs, nutrients are also leached from the canopy. Brinson *et al.* (1980) doing research in an alluvial swamp on the North Carolina coastal plain, found a total potassium deposition of 11.96 kg/ha to the forest floor. Of this total, the authors report 8.9 kg/ha, or 74.4%, to have been leached from the canopy. This source of potassium may have increased the content in the sediments at several sites in this study. All of those sites with potassium levels greater than one standard deviation above the mean (of which there are five) were sampled under a canopy. It should be noted though, that several other sites were also sampled under a developed canopy and did not display unusually high potassium content. Additionally, of the fifteen sites with the most open canopy – those least likely to receive potassium from leaching – ten had below average levels of potassium.

Another important factor might be on site nutrient cycling related to the local hydrological regime. Higher elevations tended to be dry at the time the samples were collected: eight of the highest ten sites were dry, while nine of the twelve sites which were least elevated above the main channel contained water. Submerged sediments have an added pathway for phosphorus loss in that phosphorus is released to the overlying water, and the presence of exchangeable potassium in the soils is strongly influenced by the presence of standing water and saturated sediments. Sixteen sites were wet when sampled and these had significantly lower phosphorus and potassium levels than the dry sites.

Not considered in the categorization of river connectivity was whether water is retained at the site, and the duration of these ponding events. Retention of phosphorus in the sediments under ponding conditions appears to be short term. Nine of the ten sites with the highest phosphorus content were dry when sampled, while eight of the ten sites with the lowest phosphorus content had some ponded water overlying the sediments. Mitsch and Gosselink (1986) reported that the high clay content of riparian wetland sediments results in high concentrations of adsorbed phosphorus, but that during anoxic conditions during flooding the phosphorus will become mobilized. Forsberg (1989) stated that phosphorus release from lake sediments can occur when oxic water overlies the sediments. Bostrom *et al.* (1982) conclude that aerobic phosphorus release is important in shallow non-stratified lakes such as the oxbow ponds studied here. Reasons given include wind-induced turbulence transporting phosphorus from pore water, higher temperature at the sediment surface, and microbial activity reduces iron, freeing associated phosphorus.

Sampling the upper five cm of sediment during an extended dry period may have rendered agricultural proximity a non-explanatory variable. Eight of the nine sites least proximal to agriculture were dry at the time of sampling; four of the nine sites in the intermediate group were wet; and eleven of the twelve most proximal sites were saturated. It is unlikely there was any overland runoff of agricultural by-products or additives such as fertilizer for at least two years prior to sampling, and any movement of chemicals in subsurface flow would not be detected in the surface sediments at most of the sites. Therefore the influence of agricultural inputs may be diminished to the point where proximity to fields and pastures has little or no effect on the characteristics of the surface sediments in the abandoned channels during this study.

The presence of clay was found to be an important influence on the level of several of the chemical constituents. Differing environments conducive to clay deposition among the agricultural proximity categories must be considered a strong influence on potassium and nitrogen levels. Phosphorous, potassium, and ammonium readily adsorb to clay particles and a strong correlation is found between both potassium total nitrogen and clay content (Table 1). Phosphorus is also usually strongly correlated with clay content, and is not in this study because of one outlier. The difference in clay content found between the agricultural proximity categories probably led to the pattern in the levels of phosphorus, potassium and nitrogen found among those categories.

4.5. Conclusions

It has been shown that the location of the abandoned channel in the landscape has an influence on the sediments found at that site. The thirty abandonments studied and described here are all found in a riparian environment, with varying degrees of connectivity to the main river channel and proximity to agricultural activity. Because the riparian ecosystem is open to flows of energy and matter (specifically organics, sediment and nutrients), these landscape relationships influence the character of sediments found in this environment. This study demonstrates the importance of the interaction between the river and the riparian wetland in the finding that organics and nitrogen are in lesser quantity in the most connected sites – those sites which are least isolated from the effects of scouring and export during flood events. Basin scale processes thus seem to be important in determining the sediment quality of abandoned channel wetlands. This conclusion is supported equivocally because sediment chemistry had a relation to the proximity to agricultural areas nearly opposite of the hypothesized relation. Additionally, the ecology of a feature in a landscape must be considered in relation to multiple locational factors. This study indicates that the scale and connectivity concepts stressed by Baker (1989), Chauvet and Decamps (1989), and Malanson (1993) will have direct consequences on the ecological dynamics of the riparian zone.

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