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Short-term changes in soil nutrients during wetland creation

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Abstract

This study examined changes in pH and extractable nutrients in soils inundated eight months following wetland creation. Sample plots were established in two areas: (1) an old-field with parts that were flooded during wetland creation, and (2) a native wetland in a floodplain of the Ohio River called Green Bottom Swamp. Soils were sampled before inundation and eight months afterwards. Compared to old-field soils in the pre-inundation period, swamp soils exhibited: (1) higher acidity, (2) lower NO_3 and higher NH_4 concentrations, (3) higher extractable P, Fe, and Mn, and (4) lower Ca, Mg, and Zn concentrations. Eight months after inundation, the old-field soil redox decreased from + 210 mV in the old field − 290 mV, and extractable NO_3 and Ca decreased and extractable NH_4 and Fe increased, but pH and extractable P, Mn, Mg, and Zn changed either slightly or not at all. These results suggest that eight months is an insufficient period of time for a complete change toward hydromorphic soils. Other results suggest that the response of nitrogen during the wetland creation processes may be extremely rapid.

Introduction

The United States Army Corps of Engineers constructed a series of dikes in 1992 in an old-field within the Green Bottom Wildlife Management Area, located 27 km northeast of Huntington, West Virginia. This activity was to compensate for the loss of wetland habitat by the Gallipolis (Ohio) Locks and Dam Replacement project, which required the draining of nearly 30 ha of native wetlands along the Ohio River (Evans and Allen, 1995). The construction of the wetland site offered the opportunity to study changes in some of the soil processes that occur during transformation from a terrestrial to a wetland ecosystem.

The most immediate soil change following inundation is the rapid depletion of O_2 and the establishment of reducing conditions, a process that may take as little as several hours or as much as several days (Mitsch and Gosselink, 1993). Cogger et al. (1992), for example, found a change in soil oxidation-reduction (redox) potential from + 600 mV to − 300 mV in < 35 d following experimental flooding of soils in the Puget Lowland of western Washington.

Nitrate reduction follows soon after O_2 depletion when soils become inundated. Nitrate present in the soil can either become reduced to NH_4 or reduced to N_2O or N_2 (denitrification) (Reddy and Graetz, 1988; Mitsch and Gosselink, 1993). Mn and then Fe reduction follows NO_3 at approximately − 250, − 225, and − 120 mV, respectively (O'Neill, 1985).

Phosphorus (P) availability generally increases following flooding under reducing conditions. The PO_4 bound as $FePO_4$ can be released when Fe^{3+} is reduced to Fe^{2+} under low redox conditions (Hossner and Baker, 1988). Thus, for soils high in Fe, post-inundation phosphorus dynamics should follow closely those of Fe. Changes in availability of macronutrient cations (e.g., Ca, Mg, and K) and other micronutrient cations (e.g., Zn and Cu) in flooded soils have been less well-studied (Gilmour and Gale, 1988).

The U.S. Army Corps of Engineers provided funding for a one-year study on soil changes during wetland creation at the Green Bottom Wildlife Management Area, West Virginia (USA). The purpose of this study was to examine short-term changes in several soil chemical components during the creation of a mitigation wetland.

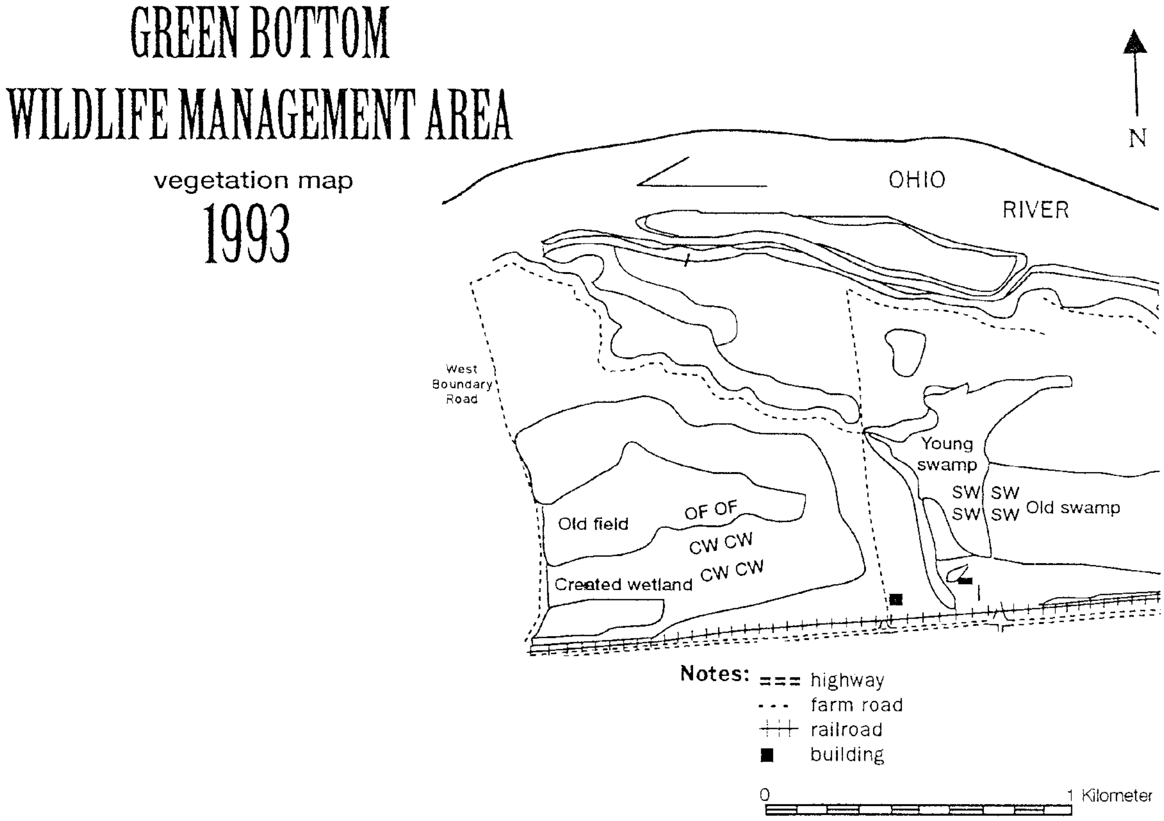

Figure 1. Location of sample sites at Green Bottom Wildlife Management Area. Sites are indicated as follows: OF = old-field, CW = created wetland, and SW = swamp. Note: CW plots were old-field sites prior to inundation.

Methods

Study site

The Green Bottom Wildlife Management Area (GBWMA) is a 338 ha area of riparian floodplain supporting terrestrial and wetland habitats along the Ohio River in Cabell County, West Virginia. The most predominant habitat feature of GBWMA is the Green Bottom Swamp (GBS), which consists of approximately 60 ha of native freshwater wetland that has experienced several changes related to past land-use practices. Beaver dams have expanded wetland habitat in recent years. Abandoned fields in various stages of old-field succession are next to GBS (Stark, 1993).

The climate of this area is temperate continental. Mean annual precipitation is 1040 mm, with a maximum and minimum monthly mean of 120 and 66 mm in July and February, respectively (Cole, 1989). Two major soils are within the study area. Non-hydric old-field soils are fine-silty, mixed, mesic Fluvaquentic Eutrochrepts of the Lindside series. The hydric swamp soils are fine-silty, mixed, nonacid, mesic Typic Fluvaquents of the Melvin series (Cole, 1989).

Sampling and analysis

Ten sample plots were located in three different areas within GBWMA (Figure 1). Six sample plots (two parallel transects of three plots each) were established in the pre-inundation old-field to span an elevation gradient from approximately 168 m to 165 m above mean sea level over a surface distance of about 100 m. The uppermost plot of each transect was high enough ($\sim$168 m) to avoid inundation during the wetland creation process; these plots will be referred to as ‘old-field’ plots. The lower two plots of each transect were inundated during wetland formation, and will be referred to as the ‘created wetland’ plots. The four remaining sample plots were located in adjacent GBS. These consisted of two of each of two swamp types: a ‘young’ swamp, approximately 8-yr-old following dam construction by beaver activity; and an ‘old’ swamp, GBS. Because there were no significant differences between young versus old swamps for any analyzed variable (Gilliam, 1995), these sites will be combined in this paper and will be collectively referred to as ‘swamp’ plots. Thus, old-field and swamp plots represent controls in this experimental design, because their hydrologic status remained unchanged throughout the experiment.

Pre-inundation sampling occurred 9 September 1992, concurrent with the dike construction by U.S. Army Corps of Engineers. Post-inundation sampling took place 16 September 1993. Standing water had been present for eight months by the time of post-inundation sampling.

Oxidation-reduction (redox) potential was measured in situ by inserting an Orion platinum redox electrode (Model 96-78) 10 and 20 cm directly into the soil. The electrode was attached to an Orion portable pH/ISE meter, Model 250A. Because of great spatial variability in redox conditions, three measurements were taken at each depth in each plot. These three values were averaged for one mean redox value per plot at each soil depth.

Soils were sampled at 0–10 cm and 10–20 cm depth. Three cores were taken with a 2-cm diameter soil probe at each plot. Each core was then divided into the two depths, after which all three cores were combined to yield a single composite soil sample per depth at each plot.

Soil pH was measured with glass electrode following H_2O-extraction (1:10, weight:volume). Subsamples of soil were sent to the University of Maine Soil Testing Service and Analytical Laboratory for analysis. Extractable P, Ca, Mg, K, Fe, Mn, Cu, and Zn were determined with plasma emission following extraction with ammonium acetate (pH 4.8). NO_3-N and NH_4-N were measured with auto-colorimetry following 1:10 (weight:volume) extraction with 1 N KCl.

Pre- versus post-inundation means of all measured variables, separated by depth and site, were compared using Student’s t-test (Proc TTEST, SAS, 1982; Zar, 1994). Old-field versus swamp means of all measured variables, separated by depth, were compared using Student’s t-test for the pre-incubation period only.

Results and discussion

Results of this study will be examined and discussed in two ways. First, we will compare extractable nutrients and pH of old-field and swamp soils and generate predictions concerning possible change in soils of the created wetland in response to inundation. In other words, we will predict that the pattern of changes through time in the created wetland soils will resemble the pattern of differences between old-field and swamp soils. We will then examine the actual changes taking place in the created wetland soils during the period of inundation for their similarities to, and differences from, the predicted patterns.

Comparisons between old-field and swamp soils

Differences between old-field and swamp soils were consistent with what would be predicted for changes in soil processes under flooded conditions (see pre-inundation upper case versus SW means, Table 1). Mitsch and Gosselink (1993) described a pattern of such change over time as a sequence of reduction reactions involving a variety of soil constituents in the following order: (a) O_2 reduction, (b) NO_3 reduction (to NH_4, N_2O, or N_2), (c) gradual increases in NH_4 and PO_4, (d) reduction of relatively insoluble Mn^{3+} (resulting in increases in more soluble Mn^{2+}), and (e) reduction of relatively insoluble Fe^{3+} (increases in Fe^{2+}). Gilmour and Gale (1988) found either slight decreases or no appreciable change for Cu and Zn in flooded soils. Calcium, Mg, and K exhibited patterns similar to those for Cu and Zn (Gilmour and Gale, 1988).

Our data confirm that many ionic constituents of soils are sensitive to redox conditions. Because hydrogen ions (H^+) dominate the soil system under reducing conditions, pH was approximately one-half a pH unit lower in swamp soils than in old-field soils (Table 1). Old-field soils at the GBWMA were under oxidizing conditions with a redox potential of + 410 mV, whereas swamp soils were decidedly reducing at around − 200 mV. Cations such as Ca, Mg, and Zn become less soluble under reducing conditions and were thus lower in swamp soils (Table 1), whereas relatively insoluble Mn^{3+} and Fe^{3+} are reduced to more soluble Mn^{2+} and Fe^{2+}, respectively, under these conditions and were higher in swamp soils compared to old-field soils (Table 1).

The response of extractable nitrogen to flooding is somewhat more complex than the responses of metals. Inorganic forms of nitrogen were somewhat equally extractable as NO_3 and NH_4 in the old-field soils (Table 1). The anaerobic conditions of the swamp soils, however, prevent nitrification; consequently, there was little nitrogen in the form of NO_3 in the swamp soils

Table 1. T-test comparisons of pre- versus post-inundation period means of pH and extractable macro- and micronutrients in soils from old-field (OF), created wetland (CW), and swamp (SW) sites. Pre-inundation means are also compared between OF versus SW sites. Values in parentheses are standard errors of means. All values, except pH, are in units of mg kg^{-1} soil.

Site	OF	OF	CW	CW	SW	SW
Depth (cm)	0–10	10–20	0–10	10–20	0–10	10–20
Parameter						
pH						
Before	5.50[1]	5.60	5.75	5.90	5.18	5.40
	(0.20)	(0.10)	(0.13)	(0.08)	(0.10)	(0.14)
After	5.60	5.65	5.68	5.95	5.10	5.40
	(0.30)	(0.10)	(0.10)	(0.03)	(0.08)	(0.09)
NO_3						
Before	6.7[1]	1.9[1]	6.8**	5.9	0.7**	0.7
	(2.1)	(0.7)	(1.6)	(0.2)	(0.2)	(0.1)
After	0.8	1.0	1.8	5.8	0.1	0.4
	(0.2)	(0.3)	(0.5)	(0.8)	(0.1)	(0.1)
NH_4						
Before	5.2[1,*]	3.4[1,*]	4.6**	3.4**	67.5	45.3
	(1.6)	(0.0)	(0.2)	(0.2)	(4.0)	(3.4)
After	2.5	1.8	62.7	20.8	62.5	39.0
	(0.0)	(0.1)	(15)	(4.4)	(1.7)	(3.4)
P						
Before	3.0[1]	2.1[1]	3.9*	2.8	6.2**	4.7*
	(0.1)	(0.1)	(0.1)	(0.7)	(0.4)	(0.3)
After	3.7	2.3	3.0	2.6	3.8	2.9
	(0.3)	(0.1)	(0.4)	(0.3)	(0.6)	(0.4)
Ca						
Before	1346[1]	1315[1]	1675*	1651	866	874
	(54)	(80)	(71)	(27)	(60)	(13)
After	1410	1323	1406	1614	816	942
	(148)	(85)	(88)	(42)	(22)	(29)
K						
Before	142	76	120	86	134	97
	(4)	(2)	(12)	(9)	(10)	(4)
After	145	94	118	88	120	99
	(3)	(6)	(10)	(5)	(10)	(7)
Mg						
Before	242[1]	213[1]	266	260	121	132**
	(11)	(11)	(13)	(11)	(10)	(1)
After	263	218	226	265	121	155
	(37)	(18)	(18)	(4)	(3)	(7)

and $>98\%$ of extractable nitrogen was in the form of NH_4. It should be noted that nitrogen data in this study represent pools of available N, and not nitrogen fluxes (total availability) (Gilliam et al., 1996). Therefore, what appeared to be seven-fold higher available nitrogen for swamp soils (~ 70 mg N/kg swamp soil vs. ~ 10 mg N/kg old-field soil) was most likely a result of lower uptake of nitrogen by swamp vegetation, resulting in an accumulation (greater pool) of nitrogen as NH_4 in swamp soils (Fisher, 1996).

Pre- versus post-inundation period comparisons

There were few significant changes during the 1-yr period in soil chemical characteristics in either of the

Table 1. (Continued)

Site Depth (cm)	OF 0–10	OF 10–20	CW 0–10	CW 10–20	SW 0–10	SW 10–20
Fe						
before	12[1]	13[1]	37*	20*	256**	207**
	(1)	(1)	(10)	(2)	(30)	(6)
after	13	13	112	36	176	103
	(4)	(1)	(30)	(7)	(47)	(15)
Mn						
before	23[1]	16[1]	42	26	156	220
	(3)	(1)	(3)	(1)	(52)	(58)
after	21	13	46	36	189	237
	(3)	(1)	(15)	(11)	(74)	(72)
Cu						
before	1.6**	2.0*	2.5**	2.7***	2.6*	2.9
	(0.1)	(0.1)	(0.3)	(0.2)	(0.5)	(0.7)
after	0.9	1.1	1.6	1.5	1.8	1.4
	(0.1)	(0.0)	(0.2)	(0.1)	(0.4)	(0.2)
Zn						
before	10.7[1]	8.3[1]	12.2	9.7	5.1	2.9
	(0.1)	(0.0)	(0.9)	(0.8)	(1.7)	(0.9)
after	10.7	8.8	10.3	8.5	6.2	3.2
	(1.1)	(0.6)	(1.3)	(0.5)	(1.9)	(0.8)

* Indicates significant difference between pre- and post-inundation period means at $p < 0.10$.
** Indicates significant difference between pre- and post-inundation period means at $p < 0.05$.
*** Indicates significant difference between pre- and post-inundation period means at $p < 0.01$.
[1] Indicates significant difference between pre-treatment OF versus SW means at $p < 0.05$.

control site types, as expected. The observed changes were probably related to normal seasonal fluctuations in ambient conditions for the old-field and swamp sites (Table 1).

The results of pre- versus post-inundation comparisons of the created wetland plots were mixed with respect to what was predicted based on old-field versus swamp comparisons in Table 1. Several pre- to post-inundation changes in these plots were consistent with what was predicted. For example, soil redox potential decreased from + 210 mV before inundation, to − 290 mV following eight months of inundation, indicating the anticipated shift from oxidizing to reducing soil conditions.

The temporal changes in extractable nitrogen for the created wetland plots were also consistent with predictions. There were significant decreases in NO_3 coupled with increases in NH_4 in the newly created wetlands (Table 1). Although differences in the extractable nitrogen from pre- to post-inundation period were also significant for old-field and swamp soils (Table 1), much of this difference may be related to the annual variation in plant uptake of nitrogen. These changes were likely the result of two additional changes caused by flooding. First, anaerobic conditions would inhibit nitrification, which is otherwise pronounced in these old-field soils (Gilliam and Fisher, 1995). Second, the uptake of available nitrogen would have been decreased substantially due to extensive mortality of old-field plant species under water-logged soil conditions. As a result, there were decreases in the soil NO_3 pool accompanied by substantial accumulations in the NH_4 pool.

Other changes in created wetland soils that were consistent with old-field versus swamp comparisons involved Ca and Fe. Ca decreased significantly after eight months (Table 1), whereas Fe increased significantly (Table 1). Although little is known about the changes in soil Ca availability following flooding (Gilmour and Gale, 1988), our results support the idea that Ca solubility is greater under oxidizing conditions.

In contrast to Ca, much is known about the response of Fe to inundation (Mitsch and Gosselink, 1993). Following shortly after nitrogen and Mn reduction, Fe reduction begins at 120 mV. Because Fe solubility is directly proportional to Fe reduction, the increases in Fe during inundation in the created wetland soils (and higher Fe in swamp soils than old-field soils) likely are related to increased Fe solubility under reducing conditions (Ponnamperuma, 1972).

Several other measured variables exhibited responses to inundation which were not consistent with what was expected from old-field versus swamp site comparisons. For example, the anticipated changes in Mg, pH, Mn, and Zn were not observed (Table 1). Also, the extractable P decreased rather than increased under inundated conditions (Table 1).

Conclusions

Although the mitigation wetland soils in this study lacked some of the characteristics of hydromorphic swamp soils of GBWMA (e.g., lower extractable Mn and P than was expected in the mitigation wetland soils), other data indicate that these soils were behaving as true wetland (hydromorphic) soils during the eight months of inundation. Conditions in these soils were distinctly reducing, causing a significant change in the dynamics of several nutrients (e.g., N, Ca, and Fe) which are typical of hydromorphic soils. The change in nitrogen dynamics was particularly substantial and rapid.

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References

Cogger, C.G., Kennedy, P.E. and Carlson, D. 1992. Seasonally saturated soils in the Puget Lowland II. Measuring and interpreting redox potentials. Soil Science 154: 50–58.

Cole, C.P. 1989. Soil survey of Cabell County, West Virginia. Soil Conservation Service, United States Department of Agriculture.

Evans, D.K. and Allen, H.A. (eds). 1995. Mitigation wetland restoration: environmental effects at Green Bottom Wildlife Management Area, West Virginia. U.S. Army Corps of Engineers, Waterways Experiment Station. Wetlands Research Program Technical Report WRP-RE-10. 229 pp.

Fisher, M.A. 1996. Nitrogen transformations in a mitigated wetland in the Green Bottom Wildlife Management Area. M.S. Thesis, Marshall University, Huntington, W.Va.

Gilliam, F.S. 1995. Changes in soil physical and chemical characteristics. *In:* Evans, D.K. and H.A. Allen (eds), Mitigation Wetland Restoration: Environmental Effects at Green Bottom Wildlife Management Area, West Virginia. pp. 55–69. U.S. Army Corps of Engineers, Waterways Experiment Station. Wetlands Research Program Technical Report WRP-RE-10.

Gilliam, F.S. and Fisher, M.A. 1995. Nitrogen transformations. *In:* Evans, D.K. and H.A. Allen (eds), Mitigation Wetland Restoration: Environmental Effects at Green Bottom Wildlife Management Area, West Virginia. pp. 70–76. U.S. Army Corps of Engineers, Waterways Experiment Station. Wetlands Research Program Technical Report WRP-RE-10.

Gilliam, F.S., Adams, M.B. and Yurish, B.M. 1996. Ecosystem nutrient responses to chronic nitrogen inputs at Fernow Experimental Forest, West Virginia. Can. J. For. Res. 26: 196–205.

Gilmour, J.T. and Gale, P.M. 1988. Chemistry of metals and trace elements in a submerged soil. *In:* Hook, D.D. et al. (eds), Vol. 1: The Ecology of Wetlands. pp. 279–292. Timber Press, Portland, OR.

Hossner, L.R. and Baker, W.H. 1988. Phosphorus transformations in flooded soils. *In:* Hook, D.D. et al. (eds), Vol. 1: The Ecology of Wetlands. pp. 293–306. Timber Press, Portland, OR.

Mitsch, W.J. and Gosselink, J.G. 1993. Wetlands. 2nd edn. Van Nostrand Reinhold, New York.

O'Neill, P. 1985. Environmental chemistry. George Allen and Unwin, London.

Ponnamperuma, F.N. 1972. The chemistry of submerged soils. Adv. Agron. 24: 29-96.

Reddy, K.R. and Graetz, D.A. 1988. Carbon and nitrogen dynamics in wetland soils. *In:* Hook, D.D. et al. (eds), Vol. 1: The Ecology of Wetlands. pp. 307–318. Timber Press, Portland, OR.

SAS Institute, Inc. 1982. SAS user's guide: Statistics, 1982 Edition. SAS Institute, Inc. Cary, NC.

Stark, T.J. 1993. The flora and vegetation of the Green Bottom Wildlife Management Area. M.S. Thesis, Marshall University, Huntington, WV.

Zar, J.H. 1994. Biostatistical Analysis. 3rd edn. Prentice-Hall, Englewood Cliffs, NJ.