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Carbon sequestration and nutrient accumulation in floodplain and depressional wetlands

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ABSTRACT

We measured soil organic carbon (C) sequestration and nutrient (nitrogen-N, phosphorus- P) burial in Czech and Midwest U.S. freshwater floodplain and depressional wetlands to evaluate how landscape position and agricultural land use intensity affects C, N, and P retention. Land use in the South Bohemia of the Czech Republic is dominated by forest and pasture, whereas in the Midwest U.S., land use is dominated by row crop agriculture. Cs-137 and ^{210}Pb dating of soil cores revealed comparable rates of soil accretion among wetland types, ranging from 0.5 mm/yr in a Czech floodplain wetland to 2.3 mm/yr in a U.S. depressional wetland. Carbon sequestration and N & P burial did not differ among floodplain (47 + 14 g C/m^2/yr, 3.7 + 1 g N/m^2/yr, 0.47 + 0.16 g P/m^2/yr) and depressional wetlands (50 + 19 g/m^2/yr, 3.6 + 1.3 g N/m^2/yr, 0.51 + 0.14 g P/m^2/yr). However, sediment deposition in Czech floodplain and depressional wetlands was only 10–50% (150–340 g/m^2/yr) of rates measured in U.S. wetlands (650–1460 g/m^2/yr). Our results suggest that, in agricultural landscapes, land use intensity rather than landscape position – floodplain versus depression – drives wetland C sequestration and nutrient retention through increased sediment deposition.

1. Introduction

Freshwater wetlands are agents of materials exchange and nutrient transformations between terrestrial and aquatic ecosystems and often serve as sinks for sediment and nutrients (Hopkinson 1992; Craft and Casey 2000; Dunne et al., 2007; Bernal and Mitsch 2012; Wolf et al., 2013; Marton et al., 2015). Their ability to retain these materials depends on their position in the landscape, and hence their opportunity to intercept materials from terrestrial lands adjacent to and upstream. Floodplains often trap large amounts of sediment and phosphorus (P) (Craft and Casey 2000; Noe and Hupp 2005). Considerable nitrogen (N) also is buried in floodplain soils (Bannister et al., 2015). Depressional wetlands receive less overland flow than floodplains and may be expected to sequester C and bury N & P at lower rates than floodplain wetlands.

In addition to landscape position, wetland C sequestration and nutrient retention also is affected by land use. In Europe, the history of human alteration of wetlands by ditching and drainage is a long one, extending for hundreds to a thousand years. Wetlands of central Europe have been exposed to a long history of hydrologic alteration with many flooded and converted to fish ponds 400–600 years ago while others were drained (Šusta, 1995). Nutrient enrichment of European freshwaters and wetlands also has a long history where the application of manure to enhance soil fertility and fertilize fish ponds has occurred for hundreds of years (IUCN, 1996) though at lower intensity than occurs today. Low intensity agriculture such as hay cutting and fertilizer application using manure was employed for most of this time with more intensive row crop agriculture becoming common following the decline and fall of the Soviet Union.

In the Midwest U.S., also known as the *Corn Belt*, land conversion to agriculture is more recent but much more intense. In this region, nearly 90% of the wetlands were drained during the past 150–200 years (Dahl 1990). Today, the land is farmed for nutrient intensive row crops that require large and frequent fertilizer (N, P) applications.

We compared C sequestration and N & P burial by floodplain and depressional wetlands in the Czech Republic and in the Midwest U.S. Corn Belt. We hypothesize that landscape position determines

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the rate of C sequestration and N & P burial with floodplain wetlands having the highest C sequestration and N & P burial. We further hypothesize that the intensity of agricultural land use has a secondary effect on nutrient accumulation and C sequestration. In the Corn Belt region of the U.S., floodplain and depressional wetlands will exhibit greater rates of sedimentation and P burial than wetlands in the south Bohemian region of the Czech Republic.

2. Methods

2.1. Site description

We collected soil cores from freshwater wetlands of the Czech Republic and the midwestern (Indiana, Illinois) U.S. Two types of wetlands were sampled: floodplains and depressional wetlands.

In the Czech Republic, soils were collected from depressional (n = 1) and floodplain wetlands (n = 3) in South Bohemia in the UNESCO MAB Třeboň Biosphere Reserve. The Třeboň basin is a low-lying region that consists of extensive fish ponds and natural wetlands. Beginning in the 13th century, fish ponds were constructed from existing wetlands facilitated by channelization of several rivers and construction of the Golden Canal that moved water from ponds in the upper basin to its lower reaches (IUCN, 1996). Today, the ponds continue to be used to produce common carp (*Cyprinus carpio*) and other fish for food. The climate of South Bohemia is temperate continental with mean annual temperature of 7.1 °C and annual precipitation of 66 cm (1961–2008), which includes 70 cm of snow (8 cm liquid) (Czech Hydrometeorological Institute, 2017).

In the U.S., floodplains (n = 2) and depressions (n = 3) were sampled in the Corn Belt of the Midwest, in northern Indiana and Illinois. Floodplain wetlands were located along the Kankakee River (Newton County), Indiana. Depressional wetlands were located in the Willow Slough Wildlife Management Area (Newton County) and the Iroquois County Conservation Area (Iroquois County) across the state line in Illinois. The landscape of the Midwest consists of flat topography dominated by high-intensity row crop agriculture, mostly corn and soybeans. Extensive draining and ditching in the 1800′s was followed in the mid 20th century by widespread application of inorganic fertilizers, especially N. Today, it is estimated that 85–90% of wetlands that were present in the region 200 years ago have been drained for agriculture (Dahl 1990). Like the Czech Republic, the climate of the Midwest U.S. is temperate continental, with slightly warmer temperature (11.5 °C), more precipitation (91) cm and comparable snowfall (84 cm, 9 cm liquid) (U.S. National Weather Service, Chicago IL).

The Czech and U.S. wetlands dramatically differ in the land use and intensity of fertilizer use (Appendix A Table A1). In the U.S., agricultural land use (73%) is double that of the south Bohemia region of the Czech Republic (30%). Of the agricultural land in the U.S., 93% is cultivated (Northwest Indiana Regional Planning Commission, 2012) where most agricultural land in the south Bohemia region of the Czech Republic is in pasture (Pokorný et al., 2000). Agricultural intensity in the Midwest U.S. watershed also is greater than in the Czech Republic with much greater rates of N and P fertilization for corn relative to Czech pastures (Table 1).

In both countries, depressional wetlands were dominated by grasses and sedges whereas floodplain wetlands were dominated by forest (U.S.) or grasses (Czech Republic).

2.2. Soil sampling and lab analysis

Soil cores, one to two per site, each 8.5 cm (U.S.) or 5 cm (Czech Republic) in diameter, were collected for a total of 13 cores, five from the Czech Republic and eight from the U.S. (Table 2). Core length ranged from 35 cm to 50 cm. Cores were sectioned into 2 cm increments in the field, then transported to the lab where they were air dried and weighed for bulk density. Once dried, increments were ground, passed through a 2 mm mesh sieve, and analyzed for ^{137}Cs, ^{210}Pb, total C, N and P.

Bulk density of each depth increment was calculated from the dry weight per unit volume after correcting for moisture content of an oven-dried (70 °C) soil sample (Blake and Hartje 1986). Samples containing carbonates were treated with 0.1 mol L^{-1} HCl to remove carbonates prior to C analysis so measured values represent organic C. Carbon and N were analyzed using a Perkin-Elmer 2400 CHN analyzer (Perkin-Elmer, Waltham MA USA). Total P was determined colorimetrically after digestion in nitric-perchloric acid (Sommers and Nelson 1972). Recovery of NIST standard #1646a (estuarine sediment, 270 μg/g) yielded 92% for total P (n = 23 samples). For C and N, recovery of NIST standard 1632b (bituminous coal, 76.9% C, 1.56% N) yielded 90% for C and 92% N (n = 20). Analysis of in-house soil standard (6.1% C, 0.37% N) recovered 102% for C and 103% for N (n = 20). All analyses were expressed on a dry weight basis by correcting for the moisture content of the soil, determined by weighing 1 g of subsoil before and after drying at 70 °C for 24 h.

Ground soils were packed into 50 mm diameter by 9 mm petri dishes and analyzed by gamma spectrometry for Cs-137 (661.6 keV photopeak) andPb-210 (46.5 keV photopeak). Cesium-137 (half life 30 years) is an impulse marker produced as fallout by above-ground nuclear bomb blast tests (Ritchie and McHenry 1990). We used the increment with maximum ^{137}Cs activity to represent the year 1964, the year of greatest atmospheric fallout. Lead-210 (half life 22 years) is a naturally occurring radioisotope produced by decay of ^{235}Uranium and is used to estimate soil accretion during the past 100–150 years. We used the constant activity model to calculate accretion using the exponential decrease of excess ^{210}Pb with depth as it undergoes radioactive decay (Oldfield and Appleby, 1984). Excess ^{210}Pb was calculated by subtracting background ^{210}Pb, determined from uniform low level ^{210}Pb activity that occurred at depth in each core.

Rates of C sequestration and N & P burial were calculated using ^{137}Cs and ^{210}Pb-derived accretion rates, bulk density (BD), and C, N, and P concentration in depth increments above and including the ^{137}Cs maxima, and within increments containing excess ^{210}Pb. The rate of C accumulation (g/m^2/yr), for example, is calculated as cm^2/m^2

$$C(g/m^2/yr) = Accretion(cm/yr) \times BD(g/cm^3) \times C(g/g) \times 10000$$

3. Results and discussion

3.1. Bulk soil properties

Floodplain and depressional wetlands of the Czech Republic contained much higher percent C and N than comparable wetlands in the U.S. (Table 1). In the U.S., floodplain and depressional wetlands were underlain by mineral soils with high bulk density (0.87–0.94 g/cm^3) and low organic C (4–5%). Phosphorus concentrations also were greater in wetlands of the Czech Republic and they were twice as high (>1000 μg/g) as comparable wetlands in the U.S. (400–450 μg/g).

Soil C:N of depressions and floodplains was less than or equal to 20 (Table 1) suggesting that sufficient N is available to meet microbial needs. Carbon:N of depressions of the southeastern U.S. (12–18; Craft and Chiang 2002) were similar to our measurements in depressions (Table 1). Soil N:P of floodplain and depressional wetlands ranged from 18 to 26, suggesting that N is more limiting in these wetlands (Koerselman and Mueleman 1996). Nitrogen:P of our depressions and floodplain soils are low relative to depres-

Table 1
Soil bulk density, organic carbon, total nitrogen and total phosphorus (mean + SE, 0–30 cm) in floodplain and depressional wetlands of the Czech Republic and the eastern U.S. Values in *italics* are expressed on a volume (mg/per cm^3 for C and N, μg per cm^3 for P) basis.

Site (# sites, # cores)	Bulk density (g/cm^3)	Organic C (%)	Nitrogen (%)	Phosphorus (μg/g)	C:N	N:P
Czech Republic						
Floodplain (3,1)	0.33 + 0.06	22.0 ± 7.0	1.28 ± 0.25	1070 ± 50	20 + 2	26 + 3
		72 ± 23	*4.2 ± 0.8*	*353 ± 16*		
Depression (1,2)	0.29	22	1.32	1150	19	25
		64	*3.8*	*333*		
Eastern U.S.						
Floodplain (2,2)	0.94 + 0.30	5 ± 3	0.37 ± 0.24	410 ± 50	16 + 6	20 + 4
		47 ± 28	*3.5 ± 2.3*	*385 ± 47*		
Depression (3,1–2)	0.87 + 12	4.5 ± 2.2	0.37 ± 0.18	450 ± 20	14 + 5	18 + 3
		39 ± 19	*3.2 ± 1.6*	*391 ± 17*		

Table 2
Published studies of C sequestration, N & P burial, and sediment deposition (all in $g/m^2/yr$) in floodplain and depressional wetlands. Values from this study are based on ^{137}Cs and ^{210}Pb.

	Method	Organic C	Nitrogen	Phosphorus	Sediment
Floodplain					
Georgia (US)[a]	^{137}Cs and ^{210}Pb dating	63	4.7	0.44	710
Georgia (US)[b]	^{137}Cs and ^{210}Pb dating	50	4.0	0.70	1470
North Carolina (US)[c]	Sediment pads	–	–	0.17	–
Maryland (US)[d]	^{137}Cs dating	6–114	–	–	180–240
Mid-Atlantic coastal plain (US)[e]	Sediment pads	143	8.8	2.58	2550
Mid-Atlantic coastal plain (US)[f]	Sediment pads	93	5.5	0.79	976
Virginia (US)[g]	Sediment pads	–	13.2	–	2530
Virginia (US)[h]	Sediment pads	55–295	–	–	950–26100
Virginia (US)[i]	Sediment pads	11	–	–	–
Illinois (US)[j]	Sediment pads	–	–	3.6	5600
Wisconsin (US)[k]	^{137}Cs dating	–	12.8	2.6	2000
Ohio (US)[l]	^{137}Cs and ^{210}Pb dating	105	–	–	–
Ohio[m]	Mass balance	181–193	16.2–16.6	3.3–3.5	–
Ohio[n]	Mass balance	219–267	38.8	2.4	–
Arkansas (US)[o]	^{137}Cs dating, dendrogeomorphic approach and clay pads	–	–	–	800
Okavango delta (Botswana)[p]	^{137}Cs and ^{210}Pb dating	33–80	–	–	–
Danube floodplain Austria[q]	^{137}Cs dating	180	–	–	–
Mean (Published studies)	–	125 ± 23	16 ± 4.8	2.2 ± 0.48	3034 ± 1260
Mean (This study)	–	47 ± 14	3.7 ± 1.0	0.47 ± 0.16	1110 ± 600
Depression					
Georgia (US)[a]	^{137}Cs and ^{210}Pb dating	45	3.4	0.16	530
Florida (US)[r]	Mass balance approach	–	1.8	0.01	–
Virginia (US)[g]	Sediment pads	–	1.7	–	230
South Dakota (US)[s]	Mass balance approach	–	1.4	0.30	–
North Dakota (US)[t]	^{137}Cs dating and mass balance approach	–	–	–	1730
Ohio (US)[l]	^{137}Cs and ^{210}Pb dating	202–473	–	–	–
Costa Rica[p]	^{137}Cs and ^{210}Pb dating	61–131	–	–	–
Netherlands[u]	Net ecosystem exchange	280	–	–	–
Mean (Published studies)	–	190 ± 70	2.1 ± 0.4	0.16 ± 0.08	830 ± 460
Mean (This study)	–	50 ± 19	3.6 ± 1.3	0.51 ± 0.14	780 ± 300

[a] Craft and Casey (2000).
[b] Bannister et al. (2015).
[c] Yarbro (1983).
[d] Kroes and Hupp (2010), Natural floodplain.
[e] Organic C, N and P from Noe and Hupp (2005) for rivers in Virginia, Maryland, Delaware. Sediment from Wolf et al. (2013) for rivers in Virginia.
[f] Noe and Hupp (2009), Seven rivers.
[g] Wolf et al. (2013).
[h] Hupp et al. (2013), 5th order Virginia piedmont stream.
[i] Batson et al. (2015), 5th order Virginia piedmont stream.
[j] Mitsch et al. (1979).
[k] Johnston et al. (1984).
[l] Bernal and Mitsch (2012).
[m] Anderson and Mitsch (2006), Created wetlands.
[n] Mitsch et al. (2014), Created wetlands.
[o] Kleiss (1996).
[p] Bernal and Mitsch (2013).
[q] Zehetner et al. (2009).
[r] Dierberg and Brezonik (1983).
[s] Johnston (1991).
[t] Freeland et al. (1999).
[u] Hendriks et al. (2007), Former agricultural land in a drained natural lake.

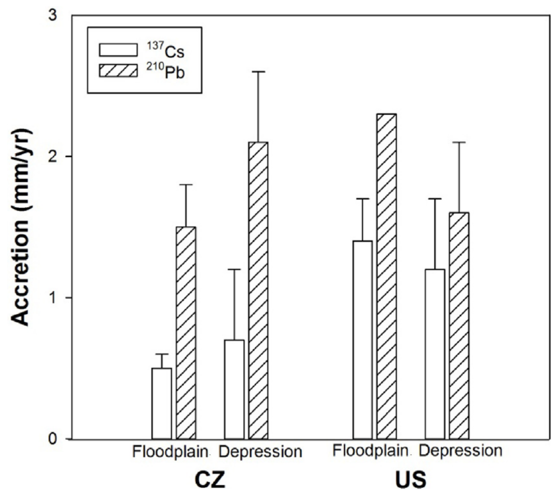

Fig. 1. ^{137}Cs and ^{210}Pb accretion rates (mean + SE) in floodplain and depressional wetlands of the Czech Republic and U.S.

sions in the southeastern U.S (40–80) where soil P is much less (20–80 μg/g; Craft and Chiang 2002) than in our soils.

In spite of large differences in (mass) concentrations of C and nutrients, when expressed on a volume basis, floodplain and depressional wetlands had relatively uniform C "density", ranging from 39 to 72 mg C/cm^3 (Table 1). For N and P, floodplain and depressional wetlands also were surprisingly uniform ranging from 3.2-4.2 mg N/cm^3 and 330–390 μg P/cm^3 (Table 1).

3.2. ^{137}Cs and ^{210}Pb accretion rates

All thirteen soil cores exhibited an interpretable ^{137}Cs profile with the maxima occurring within 10 cm of the surface (see Figs. A1–A3). There was no clear difference in ^{137}Cs-based accretion rates among floodplain and depressional wetland soils. Accretion rates based on ^{137}Cs ranged from 0.5 mm/yr in a Czech floodplain to 1.7 mm/yr in a U.S. depressional wetland. Cs-137-based accretion in U.S. floodplain and depressional wetlands (1.0–1.4 mm/yr) was nearly double those of comparable Czech wetlands (0.5–0.7 mm/yr; Fig. 1).

Pb-210 decreased exponentially with depth in four of five cores from the Czech Republic and in six of eight cores from the U.S. (see Appendix A). The goodness of fit of the regression of excess ^{210}Pb versus depth for these interpretable cores ranged from 0.75 (U.S. depression) to 0.89 (Czech floodplain). As with ^{137}Cs, ^{210}Pb accretion exhibited no clear differences among wetland types (Fig. 1), ranging from 1.2 mm/yr in a Czech floodplain wetland to 3.5 mm/yr in a U.S. depressional wetland. When averaged across wetland types, soil accretion measured using ^{210}Pb was two times greater (2.0 + 0.3 mm/yr) than measurements based on ^{137}Cs (1.0 + 0.3 mm/yr) and it was evident in both Czech and U.S. wetland soils (Fig. 1). It is unclear why longer-term accretion based on ^{210}Pb (100-year timescale) is greater than that of ^{137}Cs (50-year timescale) though it may be related to soil conservation practices (contour plowing, no-till agriculture, cover crops) in use today.

Another factor may be differences in the reliability of the two radiometric dating methods. ^{137}Cs is effectively sorbed onto clay particles, adsorption is rapid, and it is essentially non-exchangeable (Ritchie and McHenry 1990). ^{210}Pb, which is polyvalent, is tightly held (chelated) by soil organic matter. Both methods require relatively uniform sediment grain size such that lithologic discontinuities (sand lenses and bioturbation) – that were not evident in our cores – can confound interpretation of their profiles (Kirchner and Ehlers 1998; Appleby 2001). The two methods are considered reliable means to date soils and sediment in depositional environments and, in fact, are considered to be complementary to each other (Robbins and Edgington 1975; Appleby 2001).

Wetland accretion, especially sediment accretion, is measured using a variety of techniques that vary in their timescales. Methods include long-term (50–100 yr) radiometric techniques, medium- to long-term dendrogeomorphology, where the bases of trees are used to estimate sedimentation since the time of seedling establishment (Hupp and Bazemore 1993), and short-term (months to years) clay pads and ceramic tiles. Comparison of long term measurements of sediment accretion using ^{137}Cs and dendrogeomorphology techniques generally yield similar results whereas short-term measurements using clay pads or tiles yield higher rates. Kleiss (1996) reported comparable rates of sedimentation using ^{137}Cs (1.8 + 0.2 mm/yr) and dendrogeomorphology (1.6 + 0.4 mm/yr) in the floodplain of the Cache River, Arkansas. These rates were considerably less than measurements using sediment disks (8.1 + 1.8 mm/yr). In the floodplain of the Roanoke River, North Carolina, sediment accretion ranged from 0.5-3.4 mm/yr using the dendrogeomorphic technique versus 0.3–5.9 mm/yr using clay pads (Hupp et al., 2015). Our measured rates of accretion in floodplain wetlands (^{137}Cs: 1.4–1.6 mm/yr, ^{210}Pb: 1.5–2.3 mm/yr) are comparable to long-term measurements of accretion by Kleiss (1996) and Hupp et al. (2015).

3.3. Cs-137 sedimentation and organic C, N, P accumulation

Contrary to our hypothesis of greater C sequestration and N & P burial with increasing connectivity, we observed no difference in C, N & P burial and sediment deposition among floodplain and depressional wetlands (Fig. 2). There were, however, pronounced differences in sediment deposition among wetlands of the Czech Republic and U.S, with four times greater sedimentation rates in U.S. floodplain and depressional wetlands (Fig. 2) that support our second hypothesis regarding agricultural land use intensity. Phosphorus burial also was substantially greater in U.S. floodplain wetlands than in Czech floodplain wetlands (Fig. 2). Carbon sequestration and N burial also were much lower in U.S. wetlands, likely the result of dilution by sediment deposition. Intensive row crop agriculture (73% of land use) predominates in the Midwestern U.S. whereas low-intensity agriculture (30%) and forestry (45%) are the major land uses in the south Bohemia (Table A1). Another factor may be the intense drainage (i.e., subsurface tiles) of Corn Belt wetlands that, over time, have oxidized existing C stores with resultant lower concentrations (see Table 1) and stocks of soil organic C in wetlands of the U.S. Midwest (11.7-14.1 kg C/m^2, 0–30 cm) than in comparable Czech wetlands (19.2-21.6 kg C/m^2, 0–30 cm).

3.4. Pb-210 sedimentation and organic C, N, P accumulation

Patterns of ^{210}Pb sediment and P accumulation generally were similar to ^{137}Cs-basedmeasurements, but were greater because of higher accretion rates. There were no clear differences in C sequestration, N & P burial among floodplain and depressional wetlands. However, wetlands of the Midwest U.S. exhibited much higher rates of sediment deposition than Czech wetlands as it was four to nearly ten times greater in U.S. depressions (1450 g/m^2/yr) and floodplains (2700 g/m^2/yr) than in Czech depressions (340 g/m^2/yr) and floodplains (190 g/m^2/yr) (Fig. 2). In contrast, C sequestration and N burial in Czech wetlands was greater (110 + 16 g C/m^2/yr, 5.9 + 1.0 g N/m^2/yr) relative to U.S. wetlands (39 + 3 g C/m^2/yr, 2.6 + 0.9 g N/m^2/yr). The higher rates were driven by greater percent soil organic C and N of floodplains and depressions (Table 1), not by differences in accretion (Fig. 1).

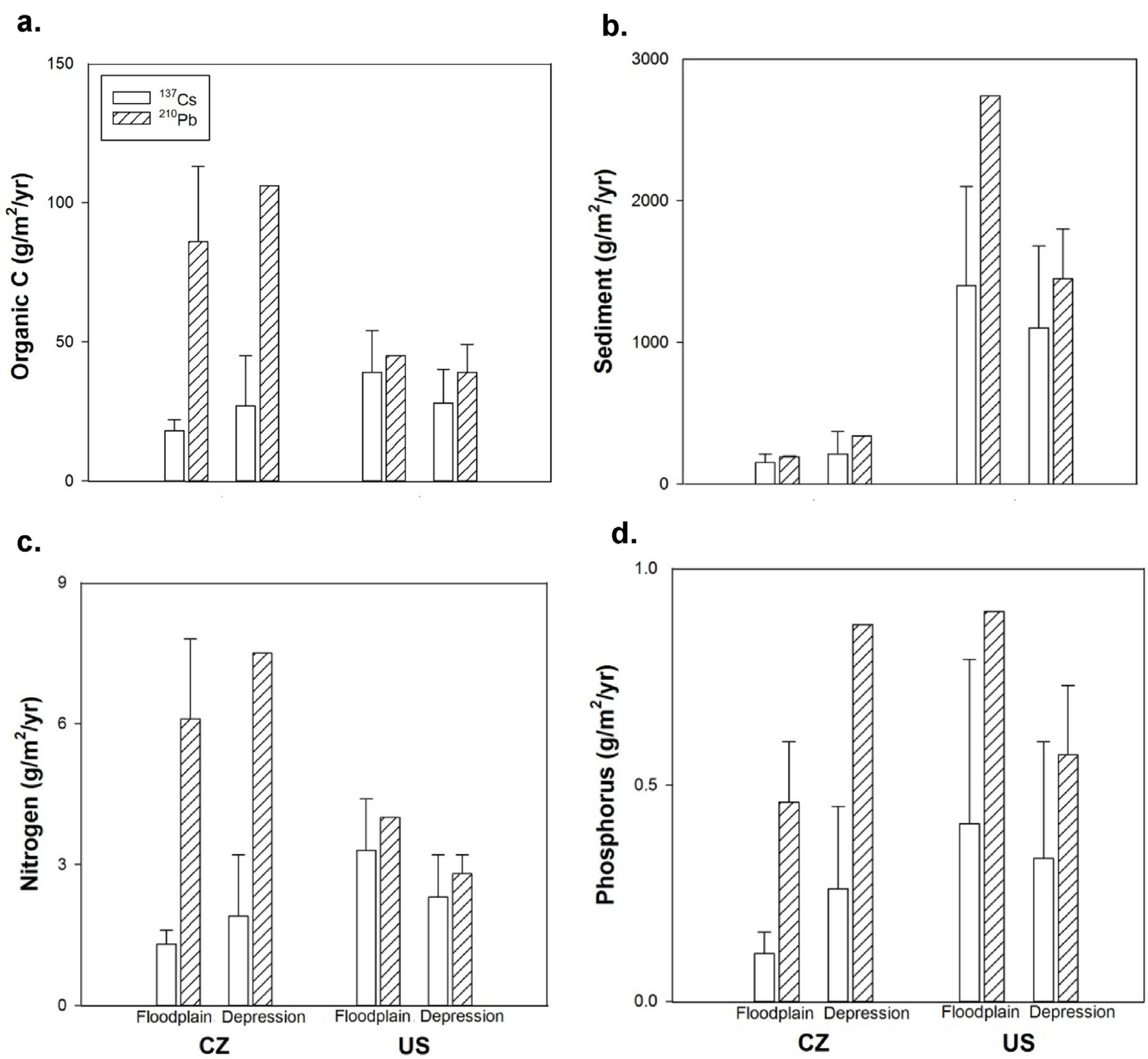

Fig. 2. ^{137}Cs- and ^{210}Pb-based rates (mean + SE) of C, N, P, and sedimentation accumulation in floodplain and depressional wetlands of the Czech Republic and U.S.

3.5. Comparison with published studies

We compared our measurements of C sequestration, nutrient retention and sedimentation with published studies from floodplains and depressional wetlands of the U.S. and Europe (Table 2). Our measurements of C sequestration, N & P burial and sedimentation are at the low end of the range published for floodplains and depressional wetlands. Similar to our findings, C sequestration based on published studies was comparable in depressions and floodplains (Table 2). In contrast to our findings, floodplain wetlands exhibited higher rates of N & P burial than depressional wetlands.

In conclusion, our findings suggest that agricultural land use intensity is a major determinant of wetland C sequestration and N & P burial through increased sediment deposition that enhances P burial and excessive drainage that may accelerate decomposition of soil organic matter and deplete soil C (and N) pools. Our results are tempered by the low replication of sites and number of cores collected from each site. In spite of these constraints, our findings are supported by a *meta*-analysis of other published studies showing that landscape position – floodplain versus depressional – interacts with land use intensity to determine retention of sediment, carbon, and nutrients on the landscape.

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Appendix A.

Table A1
Land use and fertilizer intensity of Czech versus U.S. wetland catchments.

	Land use				Fertilizer Intensity[c]
	Agriculture	Forest	Urban	Other[d]	
Czech Republic[a]	30	45	8	17	70 kg N/ha/yr 5 kg P/ha/yr
U.S.[b]	73	9	7	11	172 kg N/ha/yr 68 kg P/ha/yr

[a] From Pokorn& et al. (2000).
[b] From Northwest Indiana Regional Planning Commission (2012).
[c] From USDA National Agricultural Statistics Service, Pokorn& et al. (2000).
[d] Water and wetlands.

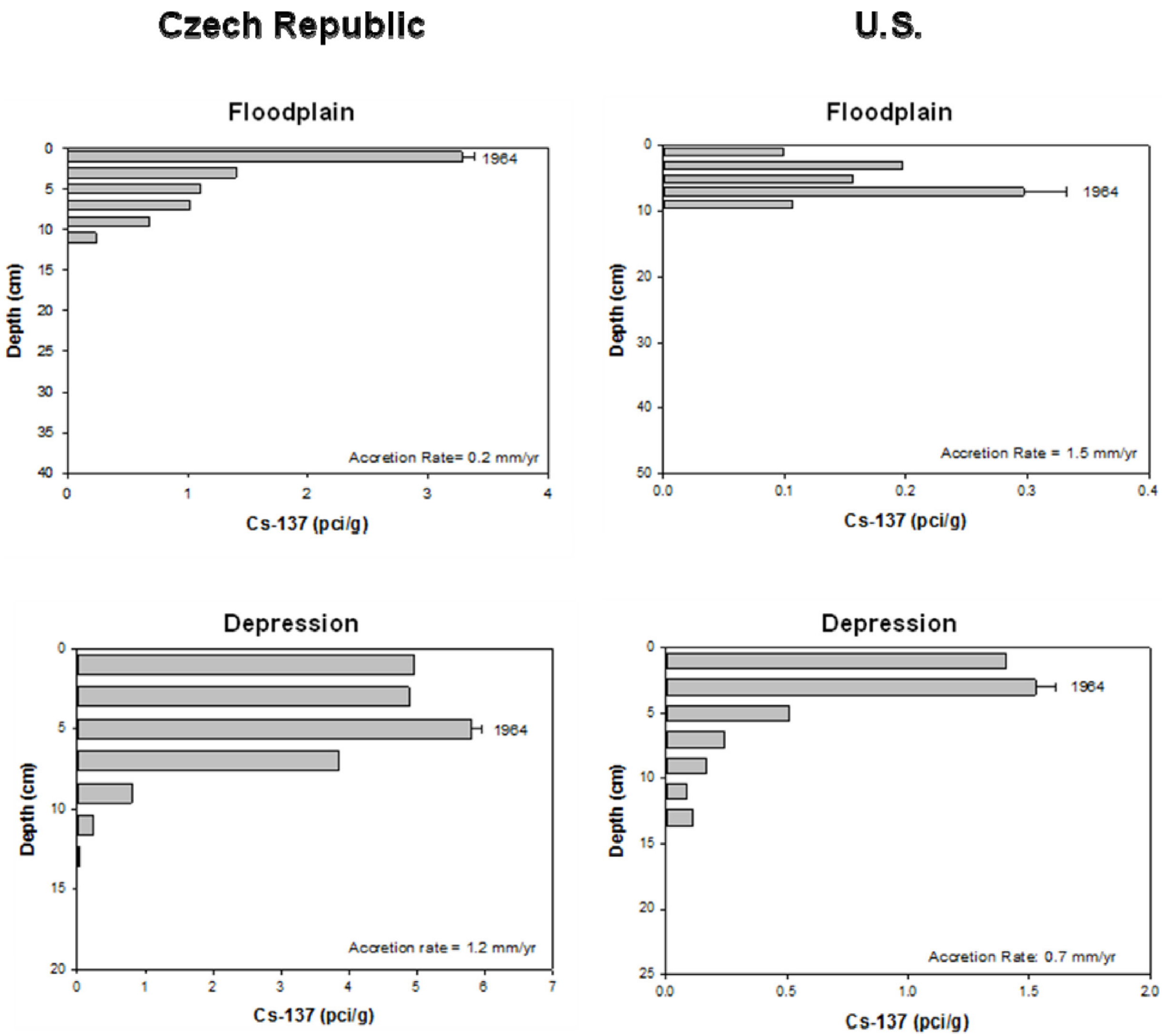

Fig. A1. Representative ^{137}Cs profiles in soil cores collected from Czech Republic and U.S. floodplains and depressions. Accretion is calculated as the depth of soil (in cm) above and including the ^{137}Cs maxima divided by the time between year of sampling and 1964, the year of maximum ^{137}Cs deposition.

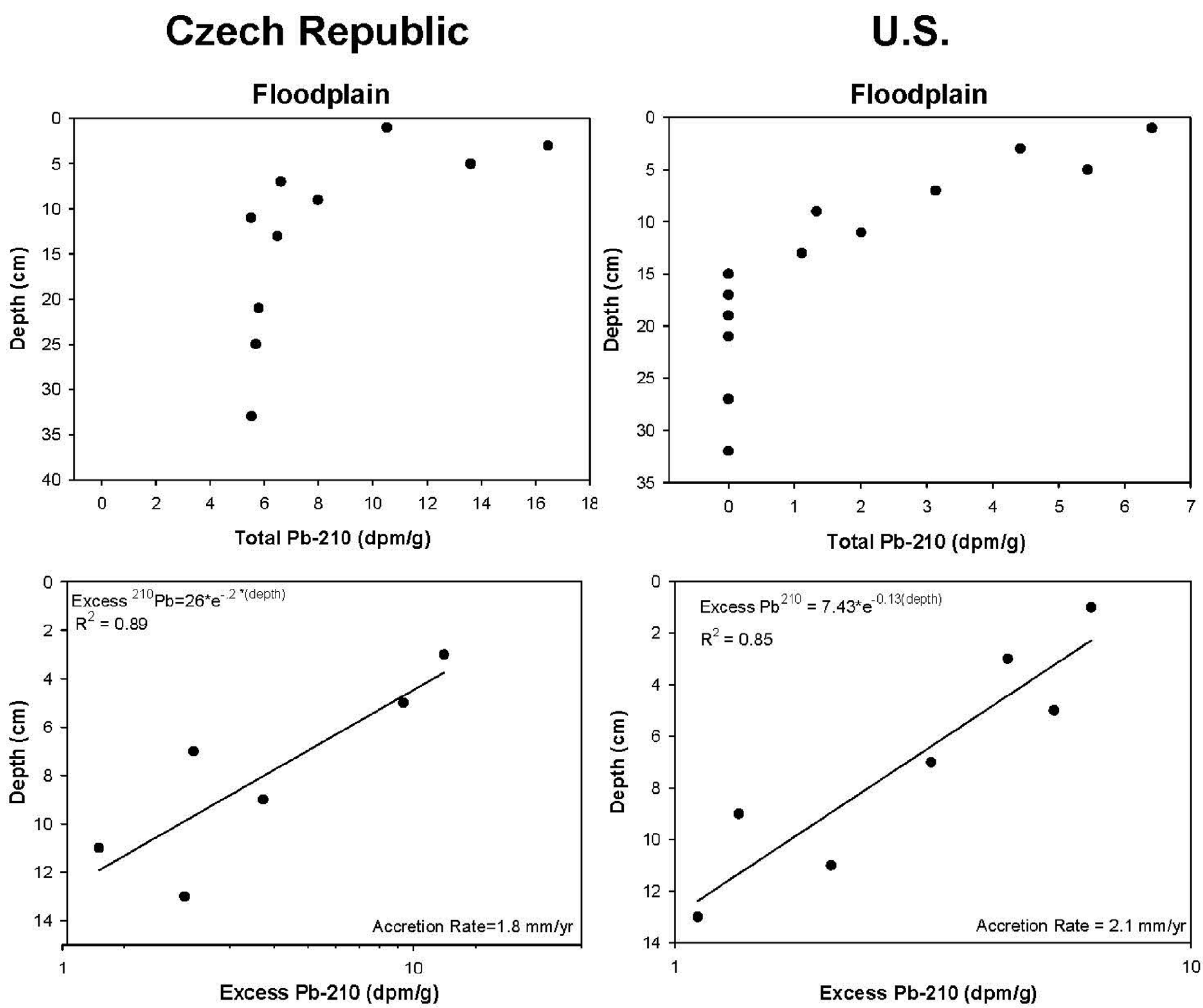

Fig. A2. Total and excess ^{210}Pb as a function of depth in representative floodplain soil cores collected from Czech Republic and the eastern U.S. Excess ^{210}Pb represents the atmospheric deposition of ^{210}Pb whose exponential decay is used to calculate accretion.

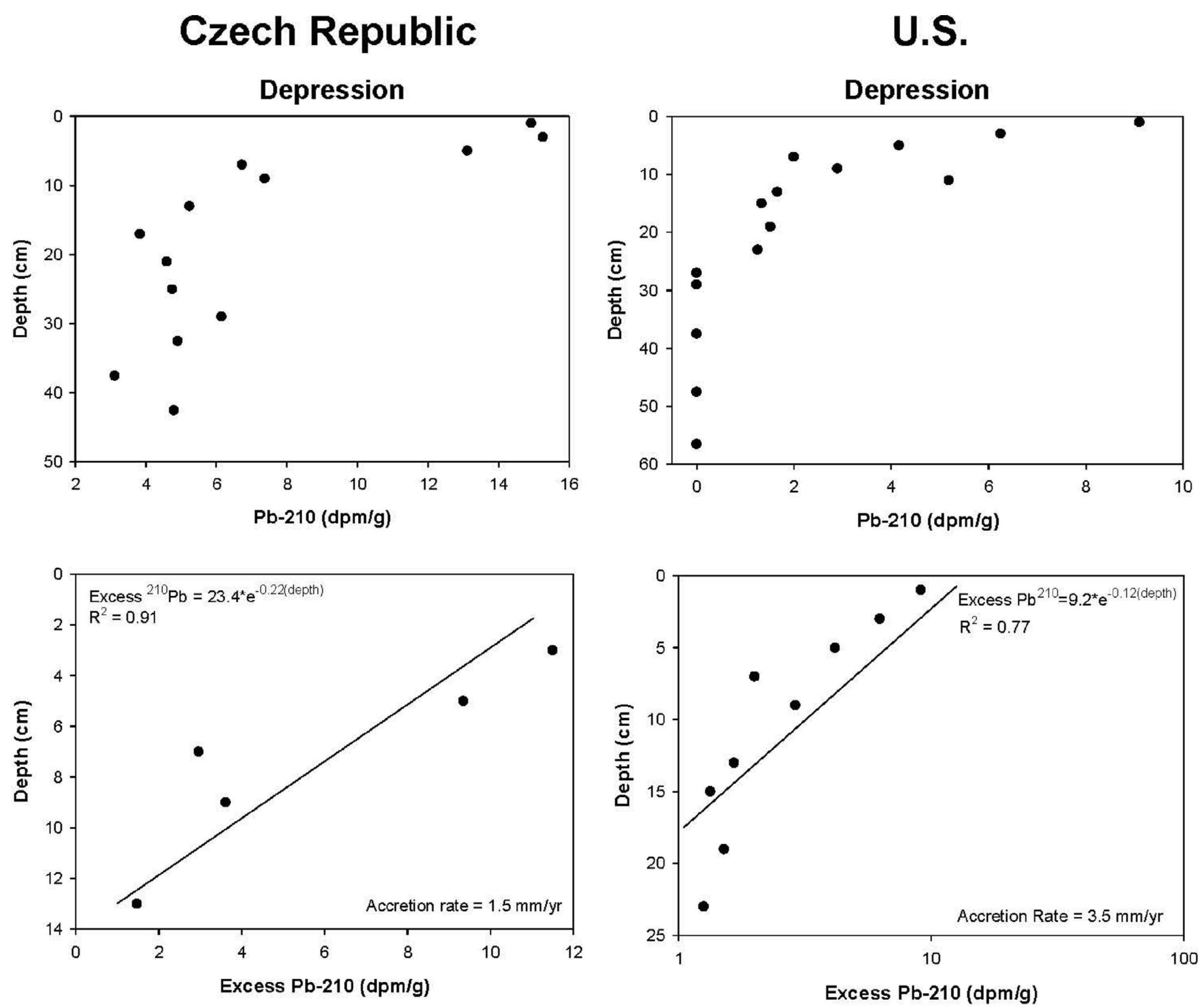

Fig. A3. Total and excess ^{210}Pb as a function of depth in representative depressional wetland soil cores collected from the Czech Republic and the eastern U.S.

References

Šusta, J. (1995) Five centuries of fishpond management in Třeboň. Carpio, Třeboň, Czech Republic.

Anderson, C.J., Mitsch, C.J., 2006. Sediment, carbon, and nutrient accumulation at two 10 year-old created riverine marshes. Wetlands 26, 779–792.

Appleby, P.B., 2001. Chronostratographic techniques in recent sediments. In: Last, W.M., Smol, J.P. (Eds.), Tracking Environmental Change Using Lake Sediments. Vol. 1, Basin Analysis, Coring, and Chronological Techniques. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 171–203.

Bannister, J.M., Herbert, E.R., Craft, C.B., 2015. Spatial variability in sedimentation, carbon sequestration, and nutrient accumulation in an alluvial floodplain forest. In: Vymazal, J. (Ed.), The Role of Natural and Constructed Wetlands in Nutrient Cycling and Retention on the Landscape. Springer, New York, pp. 41–56.

Batson, J., Noe, G.B., Hupp, C.R., Krauss, K.W., Rybicki, N.B., Schenck, E.R., 2015. Soil greenhouse gas emissions and carbon budgeting in a short-hydroperiod floodplain wetland. J. Geophys. Res. 120, 77–95.

Bernal, B., Mitsch, W.J., 2012. Comparing carbon sequestration in temperate freshwater wetland communities. Global Change Biol. 18, 1636–1647.

Bernal, B., Mitsch, W.J., 2013. Carbon sequestration in freshwater wetlands in Costa Rica and Botswana. Biogeochemistry 115, 77–93.

Blake, G.R., Hartje, K.H., 1986. Bulk density. In: Klute, A. (Ed.), Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. , 92nd ed. ASA and SSSA, Madison, pp. 363–375 (Agronomy monograph).

Craft, C.B., Casey, W.P., 2000. Sediment and nutrient accumulation in floodplain and depressional freshwater wetlands of Georgia, USA. Wetlands 20, 323–332.

Craft, C.B., Chiang, C., 2002. Forms and amounts of soil nitrogen and phosphorus across a longleaf pine-depressional wetland landscape. Soil Sci. Soc. Am. J. 66, 1713–1721.

Czech Hydrometeorological Institute Historical data -Meteorology and Climatology. http://portal.chmi.cz/historicka-data/pocasi/zakladni-informace (Accessed 04.19.17).

Dahl, T.E., 1990. Wetland losses in the United States 1780's to 1980's. In: U.S. Department of the Interior, Fish and Wildlife Service Washington, D.C. (21 pp).

Dierberg, F.E., Brezonik, P.L., 1983. Nitrogen and phosphorus mass balances in natural and sewage-enriched cypress domes. J. Appl. Ecol. 20, 323–337.

Dunne, E.J., Smith, J., Perkins, D.B., Clark, M.W., Jawitz, J.W., Reddy, K.R., 2007. Phosphorus storages in historically isolated wetland ecosystems and surrounding pasture uplands. Ecol. Eng. 31, 16–28.

Freeland, J.A., Richardson, J.L., Foss, L.A., 1999. Soil indicators of agricultural impacts on northern prairie wetlands: cottonwood lake research area, North Dakota, USA. Wetlands 19, 56–64.

Hendriks, D.M.D., van Huissteden, J., Dolman, A.J., van der Molen, M.K., 2007. The full greenhouse gas balance of an abandoned peat meadow. Biogeosci. Discuss. Eur. Geosci. Union 4, 277–316.

Hopkinson, C.S., 1992. A comparison of ecosystem dynamics in fresh-water wetlands. Estuaries 15, 549–562.

Hupp, C.R., Bazemore, D.E., 1993. Temporal and spatial patterns of wetland sedimentation, West Tennessee. J. Hydrol. 141, 179–196.

Hupp, C.R., Noe, G.B., Schenck, E.R., Benthem, A.J., 2013. Recent and historic sediment dynamics along Difficult Run, a suburban Virginia piedmont stream. Geomorphology 180–181, 156–169.

Hupp, C.R., Schenk, E.R., Kroes, D.E., Willard, D.A., Townsend, P.A., Peet, R.K., 2015. Patterns of floodplain sediment deposition along the regulated lower Roanoke River, North Carolina : Annual, decadal, centennial scales. Geomorphology 228, 666–680.

IUCN (1996) The importance of fishponds for central European landscape. Sustainable use of fishponds in the Protected Nature Reserve and Biospheric Reservation Třeboňsko. Czech Coordination Center IUCN Prague, Czech Republic, IUCN Gland, Switzerland and IUCN Cambridge, UK. (in Czech with English summary).

Johnston, C.A., Bubenzer, G.D., Lee, G.B., Madison, F.W., McHenry, J.R., 1984. Nutrient trapping by sediment deposition in a seasonally flooded lakeside wetland. J. Environ. Qual. 13, 283–290.

Johnston, C.A., 1991. Sediment and nutrient retention by freshwater wetlands: effects on surface water quality. Crit. Rev. Environ. Control 21, 491–565.

Kirchner, G., Ehlers, H., 1998. Sediment geochronology in changing coastal environments: potentials and limitations of the ^{137}Cs and ^{210}Pb methods. J. Coast. Res. 14, 483–492.
Kleiss, B.A., 1996. Sediment retention in a bottomland hardwood wetland in eastern Arkansas. Wetlands 16, 321–333.
Koerselman, W., Mueleman, A.M.F., 1996. The vegetation N:P ratio: a new tool to detect the nature of nutrient limitation. J. Appl. Ecol. 33, 1441–1450.
Kroes, D.E., Hupp, C.R., 2010. The effect of channelization in floodplain sediment deposition and subsidence along the Pocomoke River, Maryland. J. Am. Water Resour. Assoc. 46, 686–699.
Marton, J., Creed, I., Lewis, D., Lane, C., Basu, N., Cohen, M., Craft, C., 2015. Geographically isolated wetlands are important biogeochemical reactors on the landscape. Bioscience 65, 408–418.
Mitsch, W.J., Dorge, C.L., Weimhoff, J.R., 1979. Ecosystem dynamics and a phosphorus budget of an alluvial cypress swamp in southern Illinois. Ecology 60, 1116–1124.
Mitsch, W.J., Zhang, L., Waletzko, E., Bernal, B., 2014. Validation of the ecosystem services of created wetlands: two decades of plant succession, nutrient retention, and carbon sequestration in experimental riverine marshes. Ecol. Eng. 72, 11–24.
Noe, G.B., Hupp, C.R., 2005. Carbon, nitrogen, and phosphorus accumulation in floodplains of Atlantic coastal plain rivers, USA. Ecol. Appl. 18, 1178–1190.
Noe, G.B., Hupp, C.R., 2009. Retention of riverine sediment and nutrient loads by coastal plain floodplains. Ecosystems 12, 728–746.
Northwest Indiana Regional Planning Commission, 2012. Northwest Indiana Watershed Management Framework: Chapter 3 Kankakee Sub-Basin, http://www.nirpc.org/2040-plan/environment-green-infrastructure/water-resources/watershed-management/northwest-indiana-watershed-management-framework/ (Accessed 04.19.17).
Oldfield, F., Appleby, P.G., 1984. Empirical testing of ^{210}Pb models for dating lake sediments. In: Haworth, E.Y., Lund, J.W.G. (Eds.), Lake Sediments and Environmental History. University of Minnesota Press, Minneapolis, pp. 93–124.
Pokorný, J., Šulcová, J., Hátle, M., Hlásek, J. (2000). Třeboňsko 2000. Ekologie a aekonomika Třeboňska po dvaceti letech. (Třeboň region 2000. Ecology and economy of Třeboň region after twenty years). ENKI, o.p.s., Třeboň. ISBN 80–238-6370-3.
Ritchie, J.C., McHenry, J.R., 1990. Application of radioactive fallout cesium-137 for measuring soil erosion and sediment accumulation rates and patterns: a review. J. Environ. Qual. 19, 215–233.
Robbins, J.A., Edgington, D.N., 1975. Determination of recent sedimentation rates in Lake Michigan using Pb-210 and Cs-137. Geochim. Cosmochim. Acta 39, 286–304.
Sommers, L.E., Nelson, D.W., 1972. Determination of total phosphorus in soils: a rapid perchloric acid digestion procedure. Soil Sci. Soc. Am. J. 36, 902–904.
U.S. National Weather Service, Chicago IL. Local data/records. http://w2.weather.gov/climate/index.php?wfo=lot (Accessed 04.19.17).
Wolf, K.L., Noe, G.B., Ahn, C., 2013. Hydrologic connectivity to streams increases nitrogen and phosphorus inputs and cycling in soils of created and natural floodplain wetlands. J. Environ. Qual. 42, 1245–1255.
Yarbro, L.A., 1983. Influence of hydrologic variations on phosphorus cycling and retention in a swamp stream ecosystem. In: Dynamics of Lotic Ecosystems. Ann Arbor Science, Ann Arbor, Michigan, pp. 223–245.
Zehetner, F., Lair, G.J., Gerzabek, M.H., 2009. Rapid carbon accretion and organic matter pool stabilization in riverine floodplain soils. Global Biogeochem. Cycles 23 (4), http://dx.doi.org/10.1029/2009gb003481.