Abstract No: A-253

THE UNITED STATES' NATIONAL WILDLIFE REFUGE SYSTEM: A NATURAL LABORATORY FOR STUDYING PEATLAND CARBON STORAGE, ECOSYSTEM SERVICES, AND IMPACTS OF MANAGEMENT

Kurt A. Johnson* and John Schmerfeld

U.S. Fish and Wildlife Service, 5275 Leesburg Pike, Falls Church, Virginia 22041 USA

**Corresponding author: kurt_johnson@fws.gov*

INTRODUCTION

The National Wildlife Refuge System (NWRS), administered by the U.S. Fish and Wildlife Service (FWS; an agency of the U.S. Department of the Interior), consists of over 560 national wildlife refuges (refuge or NWR) and 38 wetland management districts (WMDs) throughout the United States of America (USA) and its territories. Refuges and WMDs protect a wide variety of wetland habitats that are peat-forming, from pocosin wetlands in North Carolina to extensive peat bog systems in Alaska. In addition, the NWRS has over 180 coastal refuges, many of which sequester carbon underground in "blue-carbon" ecosystems—mangroves, seagrass beds and salt marshes. A large number of refuges occur on lands that were extensively modified in the past (e.g., drained and ditched), or that are intensively managed today (e.g., managed wetlands where water levels are manipulated).

The NWRS is a natural laboratory for studying peatland carbon storage, ecosystem services, and impacts of management and climate change. Indeed, peatland carbon research has been occurring on NWRS lands and waters for more than two decades, with studies in such ecosystems as tidal salt marshes in the northeast and along Chesapeake Bay, northern Michigan peatlands, coastal wetlands in north Florida, and Alaska peatlands. In recent years, FWS has undertaken collaborative pilot projects with the U.S. Geological Survey (USGS) to evaluate carbon sequestration and ecosystem services in key wetland ecosystem types in refuges around the USA.

This presentation summarizes carbon research in peatlands and blue carbon ecosystems managed by the NWRS. Lessons learned and their applicability to management of these ecosystem types are discussed. Specific refuges mentioned in the text are shown in Figure 1.

Keywords: *National Wildlife Refuge; carbon; peat; peatlands; blue carbon*

RESULTS

Peatlands

American peatlands occur in a varied array of wetland ecosystem types: freshwater marshes of many types; forested and shrub swamps; bogs; and freshwater fens. All of these peatland types occur on refuges and most have been studied to a greater or lesser degree to document basic ecology; peat paleohistory; carbon sequestration; and ecosystem services. Following is a regional overview of important peatland research on refuges. For each refuge, a brief summary of peatland type and research projects/results are given.

- Southeastern United States

  - **Okefenokee NWR** is a 402,000-acre refuge in southeastern Georgia. Peat deposits in Okefenokee have been studied extensively by Arthur Cohen and associates, who have mapped deposits and studied their petrology/petrography and palynology. The swamp has a more or less continuous layer of peat varying from 1 to 4.5 meters in thickness (Cohen *et al.* 1984). Extensive fires in 2007 affected peat thickness, petrography and chemistry (Cohen 2009). Preliminary results showed reductions in peat thickness of as much as two feet in some intensely burned areas, and evidence that severe deflation of domed peat surfaces occurred during the droughts prior to burning (Cohen 2009).
  - **Pocosin Lakes NWR** in northeast North Carolina protects over 60,000 acres (ac) (24,000 hectares, ha) of predominantly pocosin wetlands. Much of this landscape has been altered by past human land use, primarily ditching and drainage. Effects of fires and drought on peat have been investigated at the refuge. Wang *et al.* (2015) linked field and microcosm experiments to show how previously unrecognized mechanisms regulate the build-up of phenolics, which protect stored carbon directly during short-term drought and, indirectly after long-term moderate drought. Poulter *et al.* (2006) estimated carbon emissions from a peatland fire in the refuge

using remote sensing to reconstruct burn severity and topographic lidar to constrain peat burn depths. Total carbon emissions for the fire ranged from 1 to 3.8 Tg. *FWS is working with partners including USGS to implement a 1,325-acre peatland rewetting demonstration project at Pocosin Lakes. Carbon sequestration will be monitored—this project is discussed in another presentation in the special session.*

- **Alligator River NWR**, located on the Albemarle-Pamlico peninsula of North Carolina, inludes approximately 152,260 acres. The refuge has undertaken considerable habitat restoration work to restore hydrology and increase coastal resiliency to climate change and sea level rise. A detailed study of ecosystem carbon storage pools and transfers (fluxes) was begun in 2009 by King and associates of North Carolina State University, to characterize mechanisms controlling the rate of soil and ecosystem carbon sequestration and loss. To date, at least one research paper has resulted from this work. Miao *et al.* (2013) measured soil carbon dioxide efflux (Rs) continuously from 2009 to 2010 in a forested wetland in the refuge. The study indicated that Rs is highly linked to hydroperiod and microtopography in these forested wetlands and droughts will accelerate soil carbon loss therein.
- **Great Dismal Swamp NWR** occupies 111,203 acres in southeastern Virginia. The Great Dismal Swamp has a long history of human impact, primarily the construction of large canals to drain the swamp and convert it to farmland. In recent years, the refuge has endeavored to restore the natural hydrology of the refuge by constructing a series of water control structures. The refuge burned extensively in 2011. Reddy *et a*l. (2015) used multi-temporal lidar to obtain pre- and post-fire elevations and estimate soil carbon loss caused by this 2011 fire, called the Lateral West fire. *This project is discussed in another presentation in the special session.* FWS and USGS are collaborating on the Great Dismal Swamp Study, an application of USGS LandCarbon research results and protocols. The project is designed to produce local-scale carbon estimates (including fluxes, ecosystem balance, and long-term sequestration rate) to include in an ecosystem service assessment in support of refuge management activities. *This project is discussed in another presentation in the special session.*

- Appalachians and Northeast

a) **Canaan Valley NWR**, West Virginia encompasses the majority of West Virginia's largest wetland complex, including five mapped peatlands totaling 460 acres, the most voluminous central Appalachian peat deposits south of the glacial limit. Schaney (2015) conducted radiocarbon dating of histosols in refuge peatlands.

b) **Sunkhaze Meadows NWR**, Maine includes a large portion of the Sunkhaze peatland which encompass an area of approximately 3,301 acres. During 1983-84, numerous multilevel ground water monitoring wells and piezometers were drilled, stream discharge was measured, and precipitation and evaporation rates were monitored in order to characterize hydrogeologic conditions.

c) A multi-scale approach was used to reconstruct the landscape history in the **Great Swamp NWR,** a 7,800-acre refuge in New Jersey. The Great Swamp is the remnant of a lake bottom of a once-mighty glacial lake called Glacial Lake Passaic that about 15,000 to 11,000 years ago.

- Upper Midwest
  - **Seney NWR**, Michigan includes approximately 95,000 acres of wetland and forest habitats. Approximately 2/3 of the refuge is covered with peat often exceeding 1 m in depth. In the late 1800s, the greater Seney area was heavily logged, burned, ditched, and drained. Researchers have investigated the effect of long-term water table changes (approximately 80 years) on gaseous carbon fluxes in a peatland experiencing levee induced long-term water table drawdown and impoundment in relation to an unaltered site (Ballantyne *et al.* 2014).
  - **Necedah NWR** in Wisconsin and **Agassiz NWR** in Minnesota also have peat deposits that have been studied to a degree.

- Alaska
  - **Kenai NWR** is a nearly 2-million acre refuge on the Kenai Peninsula of south-central Alaska. Berg *et al.* (2009) investigated recent woody invasion of lowland wetlands in the refuge and determined through peat cores that these peatlands originated as wet Sphagnum–sedge fens with very little woody vegetation. Results suggest that wet Sphagnum–sedge fens began to dry in the 1850s and that this drying has greatly accelerated since the 1970s.
  - **Koyukuk NWR** is a 3.5-million-acre refuge in central Alaska, just north of the Yukon River. USGS researchers studied the effects of permafrost thaw on soil hydrologic, thermal, and carbon dynamics in collapse-scar bog chronosequence in the refuge (O'Donnell *et al.* 2012). They observed dramatic changes in the distribution of soil water associated with thawing of ice-rich frozen peat. The impoundment of warm water in collapse-scar bogs initiated talik formation and the lateral expansion of bogs over time. Their findings suggested that permafrost thaw and the subsequent release of organic carbon from thawed peat will likely reduce the strength of northern permafrost-affected peatlands as a carbon dioxide sink.

- **Innoko NWR** consists of two units in west-central Alaska, a northern unit of 750,000 acres and a larger southern unit of 3.85 million acres. To examine the effects of lowland permafrost thaw over millennial timescales, Johnston *et al.* (2014) measured carbon dioxide and methane exchange along sites that constitute a ~1000 yr thaw chronosequence of thermokarst collapse bogs and adjacent fen locations in the refuge. Their results provide evidence that methane emissions following lowland permafrost thaw are enhanced over decadal time scales, but limited over millennia.
- **Yukon Flats NWR** encompasses approximately 8.6-million acres of federal lands and 2.5-million acres of other lands in east-central, Alaska. Researchers examined charcoal records from 14 lakes in the Yukon Flats to infer causes and consequences of fire regime change over the past 10,000 years (Kelly *et al.*, 2013). They found that "the apparent limit to MCA burning has been surpassed by the regional fire regime of recent decades, which is characterized by exceptionally high fire frequency and biomass burning." USGS is collaborating with the refuge to develop a modeling framework that will help us improve our understanding of the impact of thermokarst disturbance on ecosystem structure and functions at the regional scale. The project is just getting underway.

Blue Carbon (Mangroves, Seagrasses, Saltmarshes)

The NWRS has over 180 coastal refuges, many of which sequester carbon underground in "blue-carbon" ecosystems—mangroves, seagrass beds and salt marshes. Blue carbon systems have the capacity to store tremendous amounts of carbon. Following is a regional overview of important peatland research on refuges. For each refuge, a brief summary of peatland type and research projects will be given.

- Mangroves

1. Coastal NWRs in Florida (**J.N. "Ding" Darling, Ten Thousand Islands, Merritt Island, Pelican Island NWRs**) have a variety of blue carbon systems, including mangroves, seagrasses and salt marshes. USGS and FWS have initiated a multi-component project in these four refuges to assess the vulnerability of mangroves, their carbon stocks, and key ecosystem service to climate change, sea level rise, and other stressors. Specific components of the project are: (1) mangrove remote-sense mapping and monitoring; (2) Surface Elevation Table (SET) network establishment; (3) carbon stock assessment; and (4) ecosystem services assessment. By assessing these components at the same time, researchers can assess changes in mangrove distribution and abundance due to climate change and concomitant sea level rise, and determine the impact on carbon storage and key ecosystem services.

- Seagrasses

2. **Izembek NWR**, located on the Alaska Peninsula, surrounds the Izembek Lagoon which is recognized as the largest contiguous eelgrass bed in the world. The Lagoon itself is a State of Alaska Game Refuge. Approximately 13,690 ha of Izembek Lagoon's 34,662 ha are covered with eelgrass. Tippery (2013) compared recent (2008) stable isotope (C and N) values and benthic community metrics to results from a similar study from the mid-1970's to gauge temporal food web and community structure differences. "An increase in reliance on seagrass carbon was detected in organisms involved in detrital and sediment processing. An increase in abundance of certain benthic organisms and a decrease in overall community evenness were also seen."

- Salt marshes (Eastern USA)

3. **St. Marks NWR** is located in the so-called panhandle of Florida on the Gulf of Mexico. Researchers studied the dynamics of carbon sequestration in St. Marks wetlands using radiocarbon measurements (Choi and Wang 2004).
4. **Sabine NWR** encompasses 126,000 acres of southwest Louisiana near the Gulf of Mexico. Researchers estimated vertical accretion of impounded salt marsh and adjacent natural salt marsh over three decades at four sites in southwestern Louisiana in 1994 by determining the depth of a stratum containing Cs137 deposited in 1963 (Bryant and Chabreck 1998).
5. **Cedar Island NWR** is a 14,500-acre refuge in east-central North Carolina on Pamlico Sound. Researchers measured soil carbon accumulation rates in salt marsh habitats (Chmura *et al.,* 2003).
6. **Blackwater NWR** is a 28,000-acre refuge on the eastern shore of Chesapeake Bay in Maryland.. Blackwater has a long history of carbon sequestration related research by scientists from regional universities and USGS. One key investigation sought to understand carbon sequestration and methane emissions in restored and natural tidal marshes at the refuge. In order to test and develop restoration methods using dredged material, a tidal marsh restoration project was undertaken in 2003. Collaborating scientists have been monitoring sites in these restored marshes as well as natural marshes for elevation changes and vegetation status to assess carbon sequestration and methane emissions (Wills *et al.,* 2008; Poffenbarger *et al.,* 2011). Kirwan and colleagues

have conducted several studies on the refuge (Kirwan *et al.*, 2013, Kirwan *et al.*, 2014, Kirwan and Guntenspergen 2015).

7. Four northeastern NWRs (**Forsythe (New Jersey); Wertheim (New York); Parker River (Massachusetts); Rachel Carson (Maine)**) occur along the Atlantic coast in the northeast USA. All four have natural and managed salt marsh systems. Researchers examined soil properties and carbon sequestration at one marsh managed with open marsh water management and one natural marsh in each of these four refuges (Drake *et al.*, 2015). They found that soil properties exhibited no consistent differences among managed and non-managed marshes. Soil organic carbon pools also did not differ.

- Salt marshes (Western USA)

1. California NWRs (**Tijuana Slough, San Pablo and Don Edwards**) have been sampled for carbon accumulation in salt marsh sediments.
2. **Billy Frank Jr Nisqually NWR** is a 2,900-acre refuge at the southern end of Puget Sound, Washington in the Nisqually River delta. In the past decade the refuge and the Nisqually Indian Tribe (Tribe) completed the largest wetland restoration project to date in the Pacific Northwest, removing an extensive dike system to restore tidal flow in a large portion of the estuary. USGS and FWS have undertaken the Nisqually River Delta Carbon project to document the carbon co-benefits of a restoring marsh compared to a natural marsh. Specific goals are to: (1) identify the relative importance of different carbon sources essential to support juvenile Chinook salmon prey resources and to contribute to current and historic peat accretion; (2) determine the net ecosystem carbon balance in a reference and restored marsh; and (3) model the sustainability of restored and reference marshes under projected sea-level rise and analyze historical vegetation change.

- Economic valuation of carbon in NWRs

1. Patton et al. (2015) attempted to quantify the economic value of carbon stored in wetlands ecosystems found in four NWRs: **Blackwater NWR (Maryland), Sevilleta and Bosque del Apache NWRs (New Mexico), Arrowwood NWR (North Dakota), Okefenokee NWR (Georgia)**. Results suggest that wetlands in NWRs provide substantial carbon storage benefits to the U.S. and world. For example, based on U.S. social costs of atmospheric carbon researchers "estimated the present value of carbon storage services supported by Okefenokee wetlands at approximately US $960 per hectare and US $146,000,000 in aggregate."

DISCUSSION

National Wildlife Refuges have provided a natural laboratory for studying the effects of fire and drought on peatland ecosystems. New methods have been tested for assessing peat loss through remote sensing (lidar). NWRs are also laboratories for assessing the impacts of peatland restoration activities on carbon storage and ecosystem services. Refuges have provided laboratories for evaluation of the impacts of wetland water management on carbon storage and carbon dynamics. Managed freshwater and salt marshes have been compared to their natural counterparts to assess differences and similarities and address causal mechanisms. Alaskan refuges are facing severe threats from global warming and have become natural laboratories for assessing the impact of warming on thawing permafrost, thermokarst development, and boreal forests. Refuges have provided a test case for the economic valuation of carbon in peatlands and other wetland systems and demonstrated the incredible value of carbon storage services in peatland systems

REFERENCES

1. Ballantyne, D.M., J.A. Hribljan, T.G. Pypker, and R.A. Chimner. 2014. Long-term water table manipulations alter peatland gaseous carbon fluxes in Northern Michigan. Wetlands Ecol. Manage. 22:35–47.
2. Berg, E.F., K. McDonnell Hillman, R. Dia and A. DeRuwe. 2009. Recent woody invasion of wetlands on the Kenai Peninsula Lowlands, south-central Alaska: a major regime shift after 18 000 years of wet Sphagnum–sedge peat recruitment. Canadian Journal of Forest Research 39(11): 2033-2046.
3. Bryant J.C. and R.H. Chabreck. 1998. Effects of impoundment on vertical accretion of coastal marsh. Estuaries 21:416–422
4. Choi, Y. and Y. Wang. 2004. Dynamics of carbon sequestration in a coastal wetland using radiocarbon measurements. Global Biogeochemical Cycles 18: GB4016.
5. Chmura, G.L., S.C. Anisfeld, D.R. Cahoon and J. C. Lynch. 2003. Global carbon sequestration in tidal, saline wetland soils. Global Biogeochemical. Cycles 17(4): 1111
6. Cohen, A.D. 2009. Comparisons of pre-fire and post-fire peat thicknesses, petrography, and chemistry in the Okefenokee Swamp of Georgia following the fires of 2007. Paper Presentation to Southeastern Section GSA - 58th Annual Meeting.

7. Cohen, A.D., M.J. Andreiko, W. Spackman and D. Corvinus. 1984. Peat deposits of the Okefenokee Swamp. Pp. 493-524 in A.D. Cohen et a1. (eds.), Okefenokee Swamp: Nat. Hist. GeoI. & Geochem., Wetland Surveys, Los Alamos, N. Mexico.
8. Drake, K., H. Halifax, S.C. Adamowicz and C. Craft. 2015. Carbon sequestration in tidal salt marshes of the Northeast United States. Environmental Management DOI 10.1007/s00267-015-0568-z
9. Johnston, C.E., S.A. Ewing, J.W. Harden, R.K. Varner, K.P. Wickland, J.C. Koch, C.C. Fuller, K. Manies and M T. Jorgenson. 2014. Effect of permafrost thaw on CO2 and CH4 exchange in a western Alaska peatland chronosequence. Environmental Research Letters 9(8).
10. Kelly, R., M.L. Chipman, P.E. Higuera, I. Stefanova, L.B. Brubaker, and F.S.Hu. Recent burning of boreal forests exceeds fire regime limits of the past 10,000 years. Proceedings national Academy of Science 110(32): 13055–13060.
11. Kirwan, M.L. and Guntenspergen, G.R., 2015. Response of plant productivity to experimental flooding in a stable and a submerging marsh. Ecosystems 18, 903-913.
12. Kirwan, M.L., Guntenspergen, G.R., and Langley, J.A., 2014. Temperature sensitivity of organic-matter decay in tidal marshes. Biogeosciences 11, 4801-4808.
13. Kirwan, M.L., Langley, J.A., Guntenspergen, G.R., and Megonigal, J.P., 2013. The impact of sea-level rise on organic matter decay rates in Chesapeake Bay brackish tidal marshes. Biogeosciences 10, 1869-1876.
14. Miao, G., A. Noormets, J.-C. Domec, C.C. Trettin, S.G. McNulty, G. Sun, and J.S. King. 2013. The effect of water table fluctuation on soil respiration in a lower coastal plain forested wetland in the southeastern U.S., J. Geophys. Res. Biogeosci., 118, 1748–1762.
15. O'Donnell J.A., M.T. Jorgenson, J.W. Harden, A.D. McGuire, M.Z. Kanevskiy and K.P. Wickland. 2012. The effects of permafrost thaw on soil hydrologic, thermal, and carbon dynamics in an Alaskan peatland. Ecosystems 15: 213–29.
16. Patton, D., J.C Bergstrom, R. Moore, and A.P. Covich. 2015. Economic value of carbon storage in U.S. National Wildlife Refuge wetland ecosystems. Ecosystem Service 16: 94-104.
17. Poffenbarger H.B., B. Needleman and P.J. Megonigal. 2011. Salinity influence on methane emissions from tidal marshes. Wetlands 31:831–842.
18. Poulter, B., N.L. Christensen and P.N. Halpin. 2006. Carbon emissions from a temperate peat fire and its relevance to interannual variability of trace atmospheric greenhouse gases. Journal of Geophysical Research: Atmospheres, 111 (D6) (2006), Article D06301.
19. Pypker, T.G., P.A. Moore, J.M. Waddington , J.A. Hribljan and R. C. Chimner. 2013. Shifting environmental controls on CH4 fluxes in a sub-boreal peatland. Biogeosciences, 10, 7971–7981.
20. Reddy, A.D., T..J. Hawbaker, F. Wurster, Z. Zhu, S. Ward, D. Newcomb, R. Murray. 2015. Quantifying soil carbon loss and uncertainty from a peatland wildfire using multi-temporal LiDAR Remote Sensing of Environment 170 (2015) 306–316.
21. Schaney. M.L. 2015. Radiocarbon dating histosols in the peatlands of Canaan Valley National Wildlife Refuge, West Virginia. 2015 GSA Annual Meeting in Baltimore, Maryland, USA.
22. Wang, H., C.J. Richardson and M. Ho. 2015. Dual controls on carbon loss during drought
23. in peatlands. Nature Climate Change (5), DOI: 10.1038/NCLIMATE2643
24. Wills, S.A., B.A. Needelman and RR. Weil. 2008. Carbon distribution in restored and reference marshes at Blackwater National Wildlife Refuge. Archives of Agronomy and Soil Science 54(3): 239-248