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Project title: Phenolic compounds and black carbon feedback controls on peat decomposition and carbon accumulation in southeastern peatlands under regimes of seasonal drought, drainage and frequent fire

PI: Richardson, Curtis

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Distribution limitation notices: Protected data

ACCOMPLISHMENTS

Initial Scientific Questions and sub-Hypotheses

1. Why do southern (subtropical and tropical) peatlands (STPs) accumulate and store peat under warmer and mostly unsaturated conditions?
Ho: we postulate that high phenol/black carbon peats mainly derived from native fire-adapted high phenolic shrub/tree species generates a dual natural protection mechanism in STPs to enhance C sequestration and reduce C decomposition. The importance of the dual resistance mechanism increases in peatlands nearer the tropics.
2. Do STP peats having higher aromatic compounds (especially phenol) and black carbon demonstrate stronger resilience and resistance to climate change compared to boreal peatlands (the response and feedback to climate change)?
Ho: high phenol/black carbon can improve the natural resilience of peat, decreasing its sensitivity to drought, and global warming as well as drainage.
3. Is the phenol/black carbon resistance model of STP soils applicable to boreal shrub peatlands and will these mechanisms result in reduced decomposition of *Sphagnum/Carex* peat? This adaptive mechanism would be globally important, because many studies have shown that shrubs will further increase in the north with climate change induced drought and temperature increases, initially increasing decomposition and DOC release, i.e., availability of more labile C concentrations, and will potentially destroy existing older *Sphagnum* dominated peats.
Ho: increases in both shrub phenol and low-intensity fire black carbon can protect both old and fresh peat in boreal peatlands.

Major project objectives

I: Identify and compare the process-level mechanisms controlling peat decomposition along a latitudinal gradient of sites from the vast area of shrub dominated bogs in North Carolina, to the subtropical *Cladium* marshes of the Florida Everglades and on to the tropics as exemplified by the peat deposits of Peru. This gradient allowed us to test the interaction of phenolics in plants and litter, and fire regime production of black carbon aromatics as keystone controlling factors.
II: Assess the composition and origin of aromatic compounds in peat and porewater at the molecular level and the importance of fire derived aromatic compounds limiting peat decomposition using multiple advanced analytical techniques including Pyrolysis GC-MS, GC-

MS, LC-MS, NMR, FTIR, FT-ICR-MS and 3-Dimensional Excitation-Emission Matrix (EEM) fluorescence spectroscopy;
III: Experimentally (field to microcosm scale) determine peat decomposition, GHG fluxes and DOC loss integrated with soil C chemistry, soil bacterial/fungal composition, enzyme activities, and hydrologic properties to enhance our understanding of controls on C storage and fluxes.

Objective accomplishments

I and III: We compared composition and ecological traits of microbes, peat decomposition rate, physical and chemical parameters between boreal *Sphagnum* and subtropical shrub peatlands though a series of lab and field experiments. We also collected and analyzed soil respiration (>200 sites) in peatlands globally. We found previously unrecognized biotic constrains on carbon loss in low-latitude peatlands. Slow–growing microbes far more dominate in the subtropical peatlands, concomitant with plants–induced high recalcitrant carbon and phenolics. Phenolics likely acted as the overarching regulator, benefiting slow–growing fungi, while hampering fast–growing fungi. The slow-growing microbes including both bacteria and fungi from the subtropical sites decompose organic matter, even labile carbon, inherently slowly. However, the fast-growing microbes that dominated our *Sphagnum* sites and also most boreal *Sphagnum* peatlands, decomposed labile carbon over 30 times faster than the slow-growing microbes. Latitudinal soil-respiration analysis shows that decomposition does not increase exponentially from boreal to tropical peatlands as predicted by abiotic-factor controlling mechanisms alone, which indicate that biotic induced constrains as a natural defense gradually developed under long-term climate change and is applicable to a wide geographical range of peatlands. The biotic mechanism we found is at least as important as abiotic controls at regulating long–term carbon balance in peatlands, which needs to be explicitly considered in Earth system models (*Nature Geoscience*, under review).

We assessed the structural resistance and resilience of the soil fungi across a 30-year fire chronosequence in pocosins using high-throughput pyrosequencing of the internal transcribed spacer 2 (ITS2) region. Fungal diversity initially increased after fire events and then declined over time. Fungal community structures do not appear dissimilar among samples before fire, 15-d and 71-d post fire, and maintain nearly undisturbed communities that demonstrate resistance at least 71 days post fire. *Tremellomycetes, Eurotiomycetes, Dothideomycetes and Archaeorhizomycetes* were dominant microbes and significantly associated with fire history. Fire detrimentally affected symbiotrophic fungi, whereas saprotrophic fungi proportionally increased in soil soon after fire and declined over time. Fungal community assembly after fire was kept and was dominated by deterministic processes. However, at 30-y recovered sites, the fungal community was significantly less deterministic than other sites. These results suggest that fungi in some subtropical peatlands have an intrinsic capacity for reestablishment after fire and that domination of slow-growing fungi may be key in explaining their relatively stable assembly processes after fire (To be submitted to *The ISME Journal* in January, 2019).

II: We measured peat and plant chemistry, in particular the relative abundances of carbohydrates (i.e.,O-alkyl C or polysaccharides) and aromatics, across a latitudinal transect of major peatland regions (14 sites) from the Arctic to the tropics. The sites along the latitudinal transect included a permafrost plateau in Stordalen Mire, subarctic Sweden; boreal bogs and fens in northern Minnesota (MN); a boreal bog near Ottawa, Canada; temperate pocosin bogs in North Carolina(NC) with frequent low-intensity fires; subtropical peat marshes in the Loxahatchee National Wildlife Refuge, northern Everglades; and tropical peat swamp forest sites in the Ulu Mendaram Conservation Area in Brunei Darussalam, northwest Borneo. We used a newly developed approach for Fourier transform infrared spectroscopy (FTIR) analysis, which is based on area-normalized peak heights calibrated to wet chemistry analyses. Our results showed that near-surface peat in low-latitude peatlands contains lower carbohydrate and greater aromatic content than near-surface peat in high-latitude peatlands, which creates a reduced oxidation state and resulting recalcitrance. This chemical recalcitrance allows peat to persist in the low-latitude peatlands despite warm temperatures and seasonal drought. We suggest that high-latitude peat may be stabilized in the face of climate change by their lower carbohydrate and higher aromatic composition, similar to tropical peats (see details in *Nature Communications,* doi:10.1038/s41467-018-06050-2, 2018).

III: We observed the effects of low-intensity surface fires on the recalcitrance of SOM in peatlands across a latitudinal gradient from boreal to tropical regions. The timing and temperatures of low-intensity fires were measured in the field during prescribed burns and replicated in simulated fires. The effects of fire on the chemical structure of SOM were examined with FTIR, SEM and XPS. Burned and unburned peat replicates were incubated at three temperatures (5ºC, 15ºC, 25ºC) for more than six months. Burned replicates initially showed higher CO_2, CH_4 and NO_2 emissions. Yet within four weeks, emissions from the burned replicates dropped below those of unburned replicates and remained significantly lower (10-50%) for the duration of the experiment. In addition, thermal alteration significantly reduced the temperature sensitivity (Q_{10}) of thermally altered peat. Thermal alteration of SOM resulted in a net long-term reduction in carbon losses to microbial respiration. Such thermal alteration of SOM might be an underestimated factor influencing carbon accretion in frequently burned peatlands and could be globally relevant if climate change increases fire frequency in boreal peatlands.

PRODUCTS

Publications

1. Wang, H, J. Tian, H. Chen, M. Ho, R. Vilgalys, X. Liu and C.J. Richardson. How a natural course curbs carbon loss against climate change in peatlands. Nature Geoscience, under review.
2. Wang, H., M. River and C.J. Richardson, Does an 'iron gate' carbon preservation mechanism exist in organic-rich wetlands? Soil Biology &Biochemistry, under review.
3. Tian, J., H. Wang, R. Vilgalys, M. Ho, N. Flanagan, C. J. Richardson. Fungal resistance to fire in a low-latitude peatland. To be submitted to The ISME Journal in January, 2019.
4. Hodgkins, S.B., C.J. Richardson, R. Dommain, H. Wang, P.H. Glaser, B. Verbeke, B.R. Winkler, A.R.Cobb, V.I.Rich, M. Missilmani, N. Flanagan, M. Ho, A. M. Hoyt, C. F. Harvey, S. R. Vining, M. A. Hough, T.R. Moore, P.J.H. Richard, F. B. De La Cruz , J. Toufaily, R. Hamdan, W.T. Cooper, and J. P. Chanton, **2018**. Tropical peatland carbon storage linked to global latitudinal trends in peat recalcitrance, Nature Communications, 9, 3640, DOI:10.1038/s41467-018-06050-2.
5. Winton, R. S., Flanagan, N., Richardson, C. J. **2017**. Neotropical peatland methane emissions along a vegetation and biogeochemical gradient. PLOS ONE. 12(10), e0187019. DOI: 10.1371/journal.pone.0187019
6. Wang, H., Richardson, C. J., Ho, M., Flanagan, N. **2016**. Drained coastal peatlands: A potential nitrogen source to marine ecosystems under prolonged drought and heavy storm events--A microcosm experiment. Science of The Total Environment. 566-567, 621-626. DOI: 10.1016/j.scitotenv.2016.04.211
7. Wang, H., Richardson, C. J., Ho, M. **2015**. Dual controls on carbon loss during drought in peatlands. Nature Climate Change. 5(6), 584-587. DOI: 10.1038/nclimate2643

Manuscript in preparation

1. Wang, H., J. Tian, M. Ho, N. Flanagan and C. J. Richardson. Will climate change induced shrub expansion shut down methane emission by increasing humic substances as electron acceptor in peatlands?
2. Flanagan, N.E., Wang, H. and C. J. Richardson. Low-severity fire reduces heterotrophic carbon emission by altering the surface chemistry of organic matter, a process spanning global peatlands.

Presentations

1. Flanagan, N.E., Wang, H., Hodgkins, S. and C. J. Richardson. **2018** Thermal Alteration of

Peat Soil By Low-Severity Fire Reduces Net Carbon Loss to Microbial Respiration. 12th International Symposium on Biogeochemistry of Wetlands, April 23-26, 2018, Coral Springs, Florida, USA.

2. Richardson, N. Flanagan, C. J. Wang, M. Ho. **2018**. Peatland carbon farming in the Southeastern USA: A New ACR approved protocol based on long-term C sequestration and GHG flux measurements in coastal Pocosins. AGU Annual Meeting, Washington DC.
3. Richardson, C.J., H. Wang, S. Hodgkins, N. Flanagan, B. Cooper, J. Tian, M. Ho, J. Chanton, **2018**. Chemical Controls On Carbon Sequestration And GHG Flux Along A Boreal To Tropical Gradient. 12th International symposium on Biogeochemistry of Wetlands: Protecting the Future of Water. April 23-26, 2018, Coral Springs, Florida, USA.
4. Wang, H., M. River, C.J. Richardson. **2018**. Does an 'iron gate' regulate drought effects on peat decomposition? 12th International Symposium on Biogeochemistry of Wetlands, April 23-26, 2018, Coral Springs, Florida, USA.
5. Flanagan, N.E., Wang, H., Hodgkins, S. and C. J. Richardson. **2017**. The Role Low-Intensity Fire and Thermal Alteration of Soil Organic Matter and Carbon Preservation and GHG Flux from Peatlands. AGU Annual Meeting, New Orleans, LA.
6. Richardson, C.J., N. Flanagan H. Wang, M. Ho, S. Hodgkins, B. Cooper, J. Chanton, **2017**. Biogeochemical Controls on Peat Accumulation Along a Latitudinal Gradient from Minnesota to Peru. SWS Annual Meeting, June 5-8, Puerto Rico.
7. Wang, H., J. Tian, M. Ho, N. Flanagan, R. Vilgalys and C. J. Richardson. **2017**. Built-up resilience to climate change in peatlands. AGU Annual Meeting, New Orleans, LA.
8. Richardson, C.J., N. Flanagan, H. Wang, S. Hodgkins, J. Tian, M. Ho, B. Cooper, J. Chanton, **2017.** Decoding the secrets of carbon preservation in lower-latitude peatlands. AGU Annual Meeting, New Orleans, LA.
9. Richardson, C.J., H. Wang, S. Hodgkins, N. Flanagan, B. Cooper, J. Tian, M. Ho, J. Chanton, **2016**. The role of phenolic compounds, aromatics and black carbon controls on decomposition, GHG losses in peatlands along a latitudinal gradient from Minnesota to Panama. Environmental Systems Science Principal Investigator Meeting, Potomac, MD.
10. Richardson, C.J., H. Wang, N. Flanagan, M. Ho, B. Cooper, J. Chanton, **2016**. Fire Affects Phenolic Compounds, Black Carbon and Aromatic Controls on GHG Losses, Peat Decomposition and C Accumulation in Peatlands. SWS Annual Meeting May 31-June 4, Corpus Christi, Texas.
11. Richardson, C.J., H. Wang, N. Flanagan, M. Ho, B. Cooper, J. Chanton, **2016**.The Role of phenolic compounds, aromatics and black carbon controls on decomposition, GHG losses in peatlands along a latitudinal gradient from Minnesota to Panama." 10th INTECOL International Wetland Conference, Changshu, China. September 21, 2016.
12. Wang, H., J. Tian, M. Ho, N. Flanagan, R. Vilgalys and C. J. Richardson. **2016**. Climate change induced plant-microbe succession maintains carbon sinks in peatlands. ESA Annual Meeting. Fort Lauderdale, FL
13. Wang, H., M. Ho, J. Tian, N. Flanagan, C. J. Richardson. **2016**. Methane emissions from shrub bogs under different hydrological conditions. SWS Annual Meeting, Corpus Christi, TX.

14. Wang, H., C. J. Richardson, M. Ho, N. Flanagan, **2015**. Climate change induced plant succession holds the key to carbon sequestration in peatlands. SWS Annual Meeting, Providence, RI.
15. Richardson, C.J., H. Wang, N. Flanagan, M. Ho, B. Cooper, J. Chanton, **2015**. Phenolic Compounds and Black Carbon Feedback Controls on Peat Decomposition and Carbon Accumulation in Southeastern Peatlands. SWS Annual Meeting. September 22-25, Duluth Minnesota.
16. Richardson, C.J., H. Wang, N. Flanagan, M. Ho, B. Cooper, J. Chanton, **2014.** Phenolic Compounds and Black Carbon Feedback Controls on Peat Decomposition and Carbon Accumulation in Southeastern Peatlands." The Sixth International Workshop on Soil and Sedimentary Organic Matter Stabilization and Destabilization. Kiawah Island, SC. October 6, 2014.