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Peatlands In a Changing Climate: Vulnerability and Resilience

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This is the second of a series of articles that considers the projected climate mediated impacts on wetlands in the Northeast, for which NH Wetland Scientists and policymakers should take note.

The first in this series introduced projected climate mediated changes in temperature and hydrology that drive wetland ecosystem response. It ended with a discussion of how best to monitor and evaluate change over the short and midterm. This article will expand on the general discussion of a changing climate on wetlands, to a more focused discussion of climate change parameters in the context of *Sphagnum* dominated peatlands and possible responses that may occur to these relatively unique systems into the future.

In this context, peatland will refer to systems with an accumulation of peat at least at least 30 cm depth (53, 36), which is the approximate minimal depth of a *histic epipedon* hydric soil. These systems range from oligotrophic systems (rain-fed) to rheotrophic/mineraltrophic (flow-fed) systems. Both can be dominated by non-woody vegetation (bogs and fens) or by woody vegetation as shrub/tree peat swamps (35, 51).

There may be no true bogs in New Hampshire, where the sole source of water input is from precipitation-mediated, micro-shed runoff (51). There are many isolated minerotrophic fens in New Hampshire, which have bog-like characteristic (poor-fens), including, low vegetation diversity, low pH waters and are nutrient poor (12, 17, 58, 36, 5). Such communities are dominated by *Sphagnum* mosses, ericaceous shrubs and black spruce (57)and examples ofsuch poor-fen systems in New Hampshire may include: Airport Bog in Keene, Bradford Bog in Bradford, Cranberry Bog in Madison, Mud Pond Bog in Hillsborough, Philbrick-Cricenti Bog in New London, Ponemah Bog in Amherst, Quincy Bog in Rumney.

With a changing climate, we are seeing an increased in atmospheric CO_2 and a related increase in average global temperatures, with a disproportionate temperature increase in the higher latitudes (8, 31). Due to this increase in both atmospheric and ocean temperatures, there is a concurrent increase in water evaporation, which has driven a higher frequency of more extreme precipitation events in different parts of the country, including the Northeast (23). All of these factors should be considered when projecting future response by peatlands to a changing climate.

Peat accumulation is the result of a balance between plant productivity and decomposition. The productivity of peatland vegetation is not excessive compared to other wetland systems. Through experimental treatments, it has been demonstrated that such productivity can be curtailed by CO_2 when light and temperature are not limiting (41). However, in temperate peatlands, the decomposition rate is depressed, which is the prime reason for peat accumulation. Major factors affecting decomposition rate are temperature, saturation, pH and dominant vegetation. The dynamic is complex because each of these variables can influence the others (36).

Globally, peatland formation is concentrated in the higher northern latitudes of the globe, where the length of the growing season is short, and soil microbial processes are curtailed due to cooler temperatures. As such, with a drop in soil temperature, there is a corresponding drop in microbial activity responsible for nutrient cycling within such systems (24). With depressed nutrient cycling, organic materials will accumulate over time.

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A great deal of research indicates that decomposition rates in peatlands are influenced by the distance of the water table from the surface (52). Since oxygen is required for efficient respiration of microbial organisms, when the soils are saturated to the surface, oxygen diffusion rate can be reduced on the scale of ten thousand times (33). With continued demand of oxygen by decomposing organisms and reduced diffusion rate of replacement of oxygen, the system quickly shifts from an aerobic to anaerobic state. In essence, the decomposition processes dramatically slows with continued saturation of the peat, with the eventual shift to a methanogenic metabolic pathway in the most extreme reduced soil conditions (35, 34)

But decomposition rate is not uniform through the peat profile. Structurally peat has two zones the acrotelm and the catotelm (25). The upper acrotelm layer of peat is primarily living biomass. It is the zone where the greatest microbial activity is found and the corresponding highest rate of nutrient cycling in the peat profile. This is because, it is both closest to atmospheric oxygen, and it is a zone that experiences the greatest water table fluctuation, alternating between aerobic and anaerobic conditions. This "pulsing" regime actually speeds up peat decomposition and related nutrient cycling (27). As a result, in the lower acrotelm, one sees a transition from fibric to hemic peat with depth. Underlying the acrotelm is the catotelm, which is continuously saturated and under anaerobic conditions. In this zone, decomposition shifts at the cellular level from a metabolic pathway of respiration to fermentation. This fermentation pathway reduces the creation of cellular metabolic energy by as much as ninety percent (14*,* 45, 45). With such a reduction of metabolic energy, decomposing processes slow dramatically.

With oxygen deprivation, two biochemical processes also occur that contribute to decomposition inhibition. Enzymes that are essential for breakdown of complex carbon molecules in aerobic environments (e.g. phenol oxidase) do not operate under anaerobic conditions. This ceases the degradation the carbon-based phenols/polyphenols. These non-degraded substances inhibit the activity of decomposing organisms. Also, as the decomposition slows with peat depth, there is a build-up of intermediate acidic decomposition by-products, which lowers the water pH. Such acidification creates a reinforcing feedback, increasing the inhibition of microbial processes that contribute to the decomposition. (15, 16, 34).

However, there are other dynamics occurring that increases soil acidity, especially in *Sphagnum* dominated systems. Such peat has a very high cation exchange capacity. Meaning that positive cations, such as K^+, Ca^{2+}, $Mn^{2+}$and Fe^{3+}, adsorb to the peat, which release hydrogen ions into the water. Such an increase in hydrogen ions results in a lowering of the soil pH further. (9, 18, 6).

The saturated, anaerobic, high acid conditions slows decomposition, while concurrently limiting nutrient cycling. Not only are important cations trapped by the peat, which are micronutrients important for growth, but macronutrients such as nitrogen and phosphorus are sequestered in complex organic molecules of the peat. As such, these peat system favor species adapted to nutrient-poor conditions (32, 37).

So what is being projected for New Hampshire's climate parameters that can influence the hydrology and bio-geochemistry of peatlands? Since 1958, when atmospheric measurements began, carbon dioxide (CO_2) concentrations have increased every year, with latest measurement at 412 ppm; a level that has not been seen in 800,000 years (39). The slope of the atmospheric CO_2 trend is non-linear; it is showing an annual increase, at an increasing rate. What future atmospheric CO_2 concentrations may be is hard to project, since it based on societal choices of energy use, land use, economic development path and population growth. A number of experimental studies has shown that by increasing atmospheric CO_2 levels one sees an increase in photosynthetic activity and a resultant greater plant growth in peatlands (53, 57). However, the research also points to a difference in plant response by species (41, 21).

Transpiration rates increase with growth rate, which creates a greater water demand by vegetation, which could lower the peatland water table, allowing for increased peat aeration in the upper layers, and thus greater peat decomposition. Surface evaporation also increases with temperature, which can also lower the peatland water table. Since the beginning of the industrial revolution, average global atmospheric temperatures have increased by approximately 1^{o}C (1.8^{o}F) (40). The rate of atmospheric warming has doubled since 1975, with ten of the warmest years since the 1890s occurred after 1998 (3).

Even if there is a stabilization of greenhouse loading into the atmosphere, average annual temperature is projected to increase throughout this century. For the most optimistic future, it is projected that there will be 4^{o}F increase in global average annual temperature by then end of the century. If we stay on our current path of greenhouse gas loading, this could be as high as a 8-9^{o}F increase (31). The impacts from such temperature increases will only be exacerbated by the *urban heat-island* effect associated with developed landscapes, for example by the end of the century, we may be looking at seventy days per year over 90^{o}F in Manchester NH (56).

The increase in annual temperature will be accompanied by longer dry periods between rainfalls. An increase in seasonal droughts are likely in summer and fall due to a combination of greater evapotranspiration, due to increasing temperatures and CO_2 levels, as well as earlier winter and spring snow melts (23). Short-term drought (1-3 months) is expected to be a yearly event by the end of the century (20).

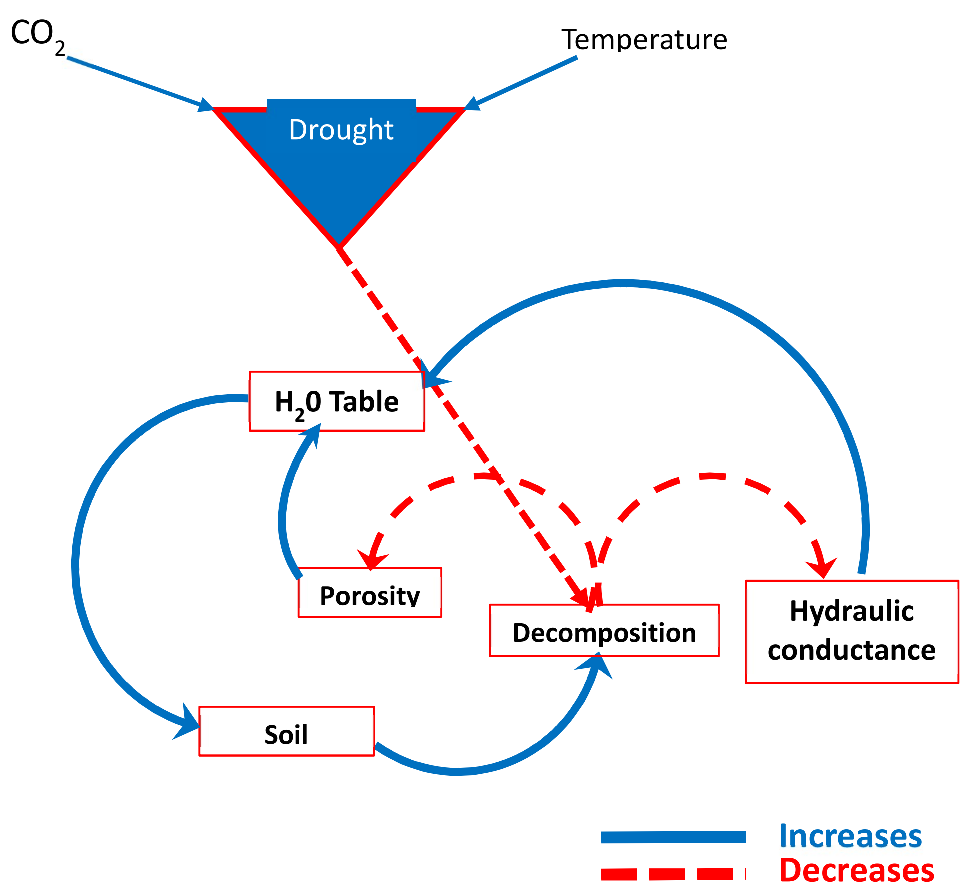
So there will be longer periods between precipitation events, but when it does rain, there will be more precipitation falling. In our area, we have seen a 15 % increase in the annual average rainfall over the last 50 years. However, we have also seen a 50% - 70% increase in the frequency of very heavy precipitation (23). For NH, the extreme storms since 1960 has shown a four to ten times increase depending on the weather station observed (56). Such a trend is expected to continue as the planet heats and more water is moved into the atmosphere. One estimate is that by end of the century the increase in heavy precipitation events will be six to sevenfold increase in the frequency of such events over than we are experiencing today (38).

With these countervailing dynamics, of increased atmospheric CO_2 and temperature, potentially lowering peatland water tables and increased annual average precipitation counteracting the droughty conditions, it is difficult to project how peatlands will respond. When one looks at the spectrum from bogs and fens to peat marshes and swamps, there may be a different possible response because of the hydrologic budget and dominant species (18, 53, 59, 60). Interestingly, *Sphagnum* dominated bogs and poor fens, which are peatlands with the most limited hydrology, least plant diversity and poorest nutrient budget, may be the most resilient of the spectrum of peatland systems.

Of all the factors that drives peat accumulation, distance to the water table is consider the most important (6, 36, 21). *Sphagnum*, being a bryophyte, lacks xylem/phloem found in many wetland plants, thus it is well adapted to be in saturated conditions. The living *Sphagnum* mat, due to its porosity can draw water up from the water table surface. Measurements have shown that capillary action by living peat can draw water up by as much of 50 cm above the water table, but experimental treatments suggest this can be expanded to 100 cm (30). (2, 55).

It is this ability to draw up and retain water above the water table that permits the survival of peatland surface vegetation during drought. Sphagnum is particularly important in this process because its elastic properties allow expansion and contraction with water availability (36). During longer-term dry periods, the resultant aerated peat begins to decompose, which increases the density of the deeper peats, as the pore structures begin to collapse. Such collapse lowers the acrotelm, both bringing the surface vegetation closer to the water table and reducing hydraulic conductance, and thus reducing evaporation, which mediates the lowering of the water table (21, 43).

Sphagnum Resilience



This elasticity of the *Sphagnum* peat mat provides more adaptability to the effects of higher CO_2 levels, increased temperature and greater frequency of droughts than one may see in peats dominated by vascular herbaceous vegetation (57, 52, 28). However, there is a limit to such adaptability. Since the last glacial retreat, peat stratigraphic records have seen rapid change in vegetation assemblages attributed to even small climatic shifts (26, 44, 1, 48, 43, 29). Those historic climatic shifts may be considered relatively small compared to the ecosystem climatic drivers that is being projected into the 22nd century.

Worldwide peatlands cover approximately 3% of the land surface. Roughly 85% of the world's peatlands can be e found in the temperate zone, and of these, 99.4% are located in the northern hemisphere (19, 54). It is calculated that there are approximately 3.5 million km^2 (1.4 million mi^2) of northern peatland (11, 42). These northern peatlands hold approximately 15% terrestrial stored-carbon (28), which equates to approximately 40% of the CO_2 currently in the atmosphere (31).

How these peatlands will respond to a changing climate is of concern by climate scientists (28, 50, 59, 49). Such peat systems have been, and may continue to be, carbon sinks. The more pessimistic future climate projections, with increased temperatures, coupled with longer droughts and possible associated peatland wildfires, could release a significant component of the sequestered greenhouse gases back into the atmosphere, possibly developing a global reinforcing feedback dynamic that could contribute to a more abrupt climatic shift (13).

In the face of a changing climate, understanding implications for future New Hampshire peatlands ecology begins with water-table monitoring, since it is clear that water availability (together with atmospheric nitrogen deposition) are the most important factors driving peat formation (1, 28). Such water table level measurements can coupled with monitoring: decomposition of the peat lens, heterotrophic respiration in the acrotelm, peat hydraulic conductivity and carbon sequestration to assess trends of possible peatland ecosystem shifts into the future.

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