The System is Changing: Take Note Wetlands Scientists[1]

Prof. Michael H. Simpson
Center for Climate Preparedness and Community Resilience
Antioch University New England

This is the first of a two-part synopsis of the projected climate mediated impacts on wetlands in the Northeast for which NH Wetland scientists and policymakers should take note. Part one will summarize the projected changes in temperature and hydrology that drive wetland ecosystem response. It will end with the wetland systems that should be the focus of subsequent discussion of how best to monitor and evaluate change over the short and mid-term. Part two will expand on the impacts to specific wetlands raised in part one and discuss possible maladaptive responses that may exacerbate impacts, as well as possible policies that might be considered to help best manage the change that may be unavoidable.

A very recent article (Moomaw et al. 2018) addresses the impacts to wetlands from a changing climate. This is the just latest in an assessment of projected climate change impacts to wetlands, not only in the US, but also across the world. (Burkett & Kusler 2000, Winter 2000, Bullock & Acreman 2003, Erwin 2009, Kernan et al. 2010, Beaver & Belant 2012, Mitsch et al 2013, Junk et al 2013, Mitsch & Gosselink 2015). Some of this information has been shared with the NHANRS membership at the annual meeting (Simpson 2014). The synopsis to follow is updating the status of the vulnerability of New Hampshire's wetlands to the impacts from a changing climate.

As wetlands ecologists, we are quite cognizant that an overarching driver for the existence, and type of, wetlands, is hydrology (Gosselink & Turner 1978, Brinson 1993, Pierce 1993, Keddy 2000, Mitsch and Gosselink 2015). In this regards, hydrology data metrics include frequency, duration, depth and source of water, which in turn drives the soil biochemistry. (Tiner 1999, Mitsch & Gosselink 2007) This biochemistry, catalyzed by bacteria, create the chemical transformations for nutrient cycling and biomass accumulation. (Nickus et al. 2010, Vepraskas 2012) The rate of such transformations is driven by the frequency, duration and timing of aerated vs anoxic soil conditions, as well as other factors as atmospheric CO_2 concentration, temperature, parent material and source of the water. The shift of these climate-mediated parameters will impact biotic response. And depending on the scale of change in the hydrology (Odum 1995), the resilience of the wetland community to such disturbance (Folke et al. 2004), one might see a dynamic shift to the system such that a new community assemblage arises. (Hollings 2001). An assemblage that may, or may not, provide similar ecosystem services (Folke 2006).

A good way to begin to build an understanding of the impacts to New Hampshire's wetlands from a changing climate is to investigate how a changing climate will impact the regions temperature regime, change in freshwater hydrologic parameters and sea-level rise (Hayhoe et al. 2006).

The Earth's surface temperature has shown a warming of .85^{o} C (1.4 ^{o} F) since 1880. (IPCC 2014) There has been a disproportional increase in temperature at the higher latitudes. Here in the Northeast, there has been an increase of average annual by almost 2˚F or a 0.16˚F increase per decade over the 20th century (Horton 2014). Since 1970, weather station data in southern NH, shows average annual maximum temperatures have increased on a range of 1.1 to 2.6^{o}F (Wake et al. 2014b). The recent change in USDA growing zones in NH (USDA 2018) are a reflection of a longer growing season based on

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soil temperatures being above biological zero for a longer duration. In New Hampshire, this has translated to the length of the growing season extended by 2-4 weeks. (Wake et al. 2014a, 2014b).

However, more importantly, one is seeing warmer winters, with spring run-off coming earlier (Hodgkins et al. 2003), ice-out on lakes coming sooner (Hodgkins et al. 2002) and more rain-on-snow events and a decrease of NH snowpack by fourteen days over the last 50 years (Keim & Rock 2001). This increased run-off while the soil is still frozen has major ramification for the ecology of aquatic systems, as well as the supply of water through the hotter and drier months of the year (Simpson 2014, Mote & Redman 2017). Specifically this means there will be less soil infiltration for the annual ground water budget, reducing aquifer supply and subsequently reducing the base-flow of streams during the driest time of year (Demaria et al. 2016).

Projections are that increase temperature will continue throughout this century, even with the stabilization of CO_2 loading into the atmosphere. In New Hampshire, over the next two decades the projection is that average annual temperatures will increase by 2^oF. For the most optimistic future scenario by the end of this century it is projected that there will be 4^oF increase and if stay on our current path this could be as high as a possible $8\text{-}9^o$ F increase. The impacts from such temperature increases will only be exacerbated by the urban heat-island effects, for example by the end of the century, we may be looking at seventy days per year over 90^oF in Manchester NH (Wake et al. 2014b)

Increased average temperatures is not all bad, as USDA plant hardiness zones shift, one can see new crops emerging for New Hampshire (Kane 2012, Connor 2018). However, one may see more traditional agricultural industries shift northward into Canada, such as one is beginning to see within the Maple syrup sector (Lauten et al. 2001, Mathew & Iverson 2017). The northward shift in species ranges will see a corresponding increase in exotic species showing up in New Hampshire that have heretofore had a northern range to the south of the state. (US EPA 2016) This will raise the question for wetland managers of what is an “invasive” species. (Pyke et al. 2008)

The increase in temperature will definitely impact soil moisture regimes, as well as increase water temperatures and evaporation rates within aquatic systems. Such ramifications could see the loss of cold-water species habitat (Herring et al. 2010), increased frequency of cyanobacteria blooms and eutrophication (Jeppensen et al. 2010), shorter hydroperiod duration in critical aquatic habitats such as vernal pools (Pyke 2005, Brooks 2008, Simpson 2016), and drying and increased decomposition rate and subsequent subsidence of peat dominated wetlands. (Winkler 1988, Weltzen et al. 2003, Schultheis et al. 2010)

The increase in annual temperatures is accompanied by projections that there will be 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 (Horton 2014). For the Northeast, a projection for short-term drought (1-3 months) is that there will be, on average, yearly events by the end of the century. (Hayhoe et al. 2006).

In short, what can be understood about this century is that there will be longer periods between precipitation events, but when it does rain, there will be more precipitation falling. Historically, in our area, we have seen a 15 % increase in the annual average rainfall over the last 50 years. However, we have seen a 50% - 71% increase in the frequency of very heavy precipitation. (Horton 2014). For NH, the extreme storms since 1960 has shown a four to ten times increase depending on the weather station observed. (Wake et al. 2014b).

This 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 seven times above what we are seeing today (NCA 3) Thus, with increased precipitation during a rainfall event, combined with the ever-increasing paving over of our watersheds, one should expect higher runoff and associated increase in erosion. Secondary effects will be added nutrient loads into waterbodies and greater shoreline scouring and destabilization (Simpson 2016). On the other hand, the increased frequency of higher run-off flows will see a potential of lateral expansion of riverine, and associated adjacent palustrian, wetlands as waters migrate further inland at a greater frequency. (Wake et al 2013a)

Sea-level has continued to rise post-glacier, and as a result one has seen salt marshes respond by migrating inland, the sunken white cedar forest off of Odiorne Point, and under the tidal peats of the adjacent Fairhill Swamp, is a testament to this. Historic tide gauge data from Portsmouth NH shows sea-level is increasing at a .7 inch rise per decade, (Wake 2013b); this translate to an increase of approximately .44 feet, which reflects what is being seen as a global average. (Kirshen 2014). And combined with storm surge flooding, there has been a significant increase in the frequency of inland migration of sea water (Cannon 2007, Schinella 2018, Carosa et al. 2018).

The rate of sea-level rise may be increasing; the most optimistic projections is a 1.8 - 2.3 feet rise by end of century. (IPCC 2014) The question then becomes can the build-up of salt marsh peat parallel the rise in sea level? With the projected increase in atmospheric CO_2 concentration, this may result in more robust biomass accumulation as peat. Thus, in northern New England, where post-glacial isostatic uplift continues, accumulation rate of salt marsh peat may parallel the rise in sea level over the immediate future. (Baustian & Mendelssohn 2018)

But then again, if one sees trends continue with the increased rate of northern latitudes permafrost melting, releasing significant amounts of methane into the atmosphere, thus increasing the warming of the planet and the oceans, or the increased rate of melting of the Greenland and Antarctica ice sheets, one will see an expansion of erosive storm surges moving landward. (National Research Council 2002, Rignot et al. 2014, Smith 2017)

Sea-level rise will shift the tidal marsh zones landward, if there is the space to do so. Both topography and the built environment may inhibit such salt marsh migration, which in turn will significantly reduce the total acreage of this wetland type. (Boorman & Hazelden 2017) A similar migration of tidal and freshwater tidal will be observed moving up the coastal drainages, that is if there is no barrier, such as a dam or an undersized culvert/or bridge, that will inhibit the increased frequency of tidal inundation (Simpson 1986).

One impact that may be less understood with increased tidal inundation, is the threat to freshwater surface and ground water sources that are adjacent to tidal systems (Nickus 2010). For example, due to a tide gate one has a freshwater system, Eel pond, right behind Jenness Beach in Rye that could be at risk to saltwater intrusion in the not too distant future. Even freshwater wetlands that are protected by fore-dunes are at risk when tides are high and there is a strong storm surge, which can breach such barriers. (Lum 2013, Stetson 2015, WCVB5 2018).

Thus, due to a combination of projected temperature CO_2 increase and the associated impacts from a changing hydrology, one needs to ask what does the future management of NH's wetlands look like?

Will one see drying of bogs and peat subsidence in freshwater systems due to more aeration, or will increased CO2 content offset peat subsidence in both fresh and saltwater systems? Will less snow pack and earlier run-off shorten the durations of water in wetland systems or lead to lower stream base-flows during the driest time of year? Will there be an increased frequency of larger run-off events, which may change the geomorphic footprint of riparian corridors through increasing sediment transport and expanding lateral flooding? Will increased temperatures threaten cold-water species and or exacerbate the northward movement of what might be initially consider invasive species? And will one see a diminishing tidal and freshwater tidal habitat along the New England Coast to inability to migrate landward? We will return to these questions in Part two of this article and to discuss how these climate stressors may be exacerbated by other anthropogenic changes to the landscape and atmosphere; as well as, consider what policies may need to be put in place in light of these changes.

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