Reasons for precaution in ecologically engineering peatland-based carbon sequestration

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There exists an increasing scientific consensus that rising atmospheric CO^2 levels, caused largely by fossil fuel emissions from energy supplies and land use changes, are of pressing concern as causal agents of climate change, ocean acidification, and ecological perturbation (IPCC 2007). There has also, regrettably, been a failure of the political establishment to create an effective and sustainable energy policy to greatly reduce these emissions. This failure, in combination with expanding technological innovation, has encouraged many researchers, politicians, and economists to consider geologically- and ecologically-based carbon sequestration methods, which may, at the least, provide a short-term boost to carbon emission reduction plans (Lal 2008). These schemes would capture and store either CO^2 from the atmosphere itself or from the point of emission. These plans tend to have promise at the small-scale, but none yet has been demonstrated as feasible for the scale of intervention necessary to reduce atmospheric CO^2 levels to those considered safe by the scientific establishment.

In this context, peatlands, which have naturally stored vast amounts of carbon for millennia, offer a hopeful model for ecologically-oriented sequestration methods (Dunn and Freeman 2011) as they have provided a number of other, related ecosystem services (Kimmel and Mander 2010). Peatlands have consistently maintained low or negligible rates of decomposition, and do so through a combination of acidic soil water conditions, plants whose phenolic exudates discourage microbial growth, and often, through relatively low atmosphere temperatures (Freeman et al. 2004). These systems, covering up to 3% of Earth's surface, therefore inspire a number of research ideas for how additional carbon can successfully be stored in response to the aforementioned problems. These proposals have included storing additional carbon within peatlands themselves, changing peatland water table conditions to encourage faster rates of sequestration, ecological modification to encourage phenol-producing plants to dominate peatland ecosystems, and genetically modifying peat species to more greatly amplify this phenol production.

This last scheme in particularly warrants additional discussion, and in response to a recent lecture (Freeman 2011) encouraging investigation into the phenolic system

with the explicit purpose of peatland-based ecological engineering, I wish to provide a few arguments to the research community in favor of different ecological strategies of carbon sequestration. This response is based on appeals to aesthetics and ethics, to potential ecological outcomes, and to economic utility, and is based on a mixture of reasoned scientific analysis and personal opinion. I also consider the practical importance of quick outcomes if carbon sequestration is to succeed in buying time for political action. After describing these concerns, I provide some suggestions for successful use of peatland-derived ideas regarding carbon sequestration in a managed, or even engineered, landscape context.

I find great ethical concern in applying ecological engineering methods to pristine landscapes, and in particular find applications of genetic modifications to these landscapes undesirable. These latter concerns are also relevant to the many anthropogenically-disturbed wetland or peatland sites which are undergoing restoration. Peatlands, and particularly pristine peatlands, represent a unique landscape class in their mixture of distinct hydrological functions, species diversity, and unusual contributions to the world's ecological services (including, for instance, their roles as libraries of atmospheric deposition, preservation of archeological materials, and functional role as regulators of water resources). Moreover, they are landscapes of exceptional beauty, harboring mixtures of colorful species in often spectacularly textured topographic settings. This topography includes hummock-hollow formations, raised bog mounds, and the patterning found in tundra polygons (Figure 1). These micro-niches provide zones for ecological growth and interaction, and should resonate with all those interested in maintaining natural systems, and indeed provide one source of worry for the effects of anthropogenically-induced climate changes. I appeal to this large-scale elegance to encourage great value to be given to the present status of peatlands, and to thereby promote precaution in risking modifications from this norm.

A more scientifically derived set of arguments is to consider the likely ecological outcome of attempts to encourage greater phenolic production in peat species, thus retarding decomposition and building up the stock of soil carbon. The complicating factor in this regard is due to the great energetic costs of generating phenols (usually for lignin or lignin-like cell wall components) at the biochemical level (van Breemen 1995). Sequestration research has suggested giving phenol-producers a boost, either through genetic modification or some kind of ecological farming pushing peatlands toward phenol production (Freeman 2011). Such plans could very easily have the effect of using up available phosphorus (Wetzel 1992) or allowing non-phenol producing plants to gain an additional competitive edge – though this is scarcely the sole

Figure 1: Polygonal Tundra Peatland in the Lena River Delta, Russia (Photo: K. Piel)

mechanism with which Sphagnum outcompetes other species in natural systems (van Breemen 1995). Restoration projects, though, often have difficulty (re-)establishing Sphagnum species (Rochefort 2000) due to pre-existing (degraded) water levels, species selection, nutrient conditions, and competition from birch trees. Knowledge on the ecology of peatland species interactions, especially within-Sphagnum interactions, is still evolving (Andersen et al. 2011), and so there is still considerable space for erroneous predictions of manipulation effects.

Next, there is a large scope of unknown variables that may interfere with peatland-based sequestration schemes. Peatlands are well-known to have complex interactions of hydrology, ecology, and biochemistry (Dise 2009). These systems are difficult to understand under normal circumstances, but adequate descriptions of potential changes resulting from changes in temperature, precipitation, and nutrient deposition have proven extraordinarily difficult to discern. For example, peatland responses to enhanced nitrogen and sulfate deposition over the mid-20th century are still being examined and debated, with considerable uncertainty regarding long-term ecological outcomes and adaptations to these changing driving circumstances (Bragazza et

al. 2006). The resilience of peatlands to these changes is still unknown, and I believe it will be nearly impossible to develop adequate tests in the short-term of their long-term ability to absorb substantial changes in carbon load (through carbon fertilization or storage) or biochemistry/ecology (through phenol-oriented interventions).

Finally, I present some thoughts regarding the economic utility of using peatlands as an amplified store of carbon. Such activities will necessarily involve mobilization of a large number of people in managing regions which have, up to now, often been left in pristine or lightly-managed states. This activity will be costly, difficult to coordinate, and will most definitely require local expertise regarding the efficacy of intervention within each peatland complex. The potential for mismanagement will create additional risk, especially considering the challenging interactions of maintaining a pseudo-pristine landscape. Whole new sectors of economic activities will need to be developed in order to support peatland-based ecological intervention, particularly if efforts would focus on more pristine sites. Additionally, the history of ecological interventions is also littered with unintended consequences, and includes introduced species causing ecological havoc and even extinction, growing antibiotic resistance, and the effects of slash-and-burn agriculture on the world's rain forests. The striking consequences of these short-sighted efforts should provide a lesson in humility in our collective ability to sustainably manage disruptions to natural settings.

This set of arguments may provide some cause for concern when considering the ecological engineering of peatland landscapes for improved carbon sequestration. However, I am more optimistic about the potential for another landscape sector in driving carbon-capture efforts: agriculture. A decade ago, an estimated 26% of the world's land surface was already actively managed for the production of food (World Resources Institute 2000). These agricultural lands do provide many ecological services, but are considered somewhat more ethically and practically amenable for human intervention based on their use history. Changing agricultural practices to re-grow their soil organic matter pool has two great advantages which can be reached in parallel: (1) carbon sequestration or at least prevention of further carbon loss to the atmosphere and (2) preservation of soil fertility which is the basis for world food production. Successful pilot studies on a number of changes to traditional agricultural practices have shown the potential for this sector to generate scalable outcomes, in part to restock pre-agricultural carbon stores (Lal 2004; Sun et al. 2010), though other research and reviews are more cautious on the real prospects for successful soil carbon sequestration (Powlson et al. 2011). That said, agriculturally-oriented alterations showing potential include albedo modification (through crop or breed switching) to increase

surface reflectance (Ridgwell et al. 2009), biochar production to increase the resilience of agricultural cuttings and residues to decomposition (Lehmann 2007), reducing tilling to prevent oxygen penetration into the subsurface (Govaerts et al. 2009), and changes to ruminant diets to reduce methane emissions (Iqbal et al. 2008). I believe that encouraging changes in these realms is also more politically feasible than to push for peatland-based sequestration, and will be much easier to manage within existing political-economic structures (such as tax and land-use policy).

Can peatlands research provide a role in assisting agriculturally-based sequestration methods? Undoubtedly the answer is yes, and I am grateful to Professor Freeman for his thought-provoking and intellectually rich contribution to this conversation. This community has great expertise with natural forms of carbon and the processes and parameters driving their decomposition. A number of landscape scale process descriptions from this community should be directly applicable to certain forms of agricultural efforts, particularly in rice production and fish farming. Moreover there is opportunity to expand research efforts into understanding the special role of phenols in constraining peatland decomposition, and this research should have great scientific and practical consequence. Much of this knowledge can be used in already-managed landscapes, including managed wetland or peatland restoration projects (Rochefort et al. 2003).

My suggestion is to encourage the gentle nudge of softer-path manipulations (re-seeding native species, careful water level manipulations) than the blunt instrument of biochemical and genetically-derived modifications to the production of phenols. In all cases I strongly suggest adhering to the precautionary principle in landscape-scale sequestration schemes, and prefer to change what we already change (i.e., agricultural landscapes) rather than to change what we have managed to escape changing (i.e., relatively pristine peatland and wetland ecosystems). Most of all, I encourage a political solution to adopt a sustainable and carbonless energy supply, though recognize that increasing carbon capture and storage will help in the eventual reduction of atmospheric CO^2 to pre-industrial levels.

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