**Current major research themes and questions in the Grogan lab:**

(Last updated Jan 10th, 2024)

**ARCTIC research** (primarily at Daring Lake, NWT, but also as part of collaborations at other sites including Umuijaq in N. Quebec, Abisko in N. Sweden, and Toolik Lake in Alaska)

The most surprising broad-ranging conclusions from my research group’s arctic studies in the past two decades include:

* Although summer greenhouse warming stimulates growth of the deciduous shrub birch (as widely reported elsewhere), biomass increases can be dominated by the evergreen shrub *Rhododendron* (Zamin, 2012, 2014, Gu, 2020)
* Enhanced snow depth (- that is predicted during future arctic winters) increases growth of *Rhododendron* but not Birch, and may stimulate significant mineral soil carbon losses (Christensen, 2018)
* Contrary to the dogma of plant growth being generally primarily limited by nitrogen (N) availability, high level NXP fertilization over multiple years clearly indicates that growth of Birch and Cottongrass can be co-limited by nitrogen *and phosphorus* availability (Zamin, 2012, 2014)
* Low-level N fertilizer annual additions for 8 years had no significant ecological impacts (Zamin 2012, Gu, 2020). However, birch measurements in 2022 indicated that current year’s new shoot extension and total shoot length for that species were both enhanced by low-level NXP additions (after 18 years for N, 10 years for P) – with significant increases by both N and P alone on both variables and a strong interactive NP effect for new shoot extension (i.e. strong support for NP colimitation of growth being an important factor influencing potential responses of birch to climate-warming enhanced soil fertility) (Dominic Wood MSc. thesis)
* Subsidence – ongoing change since the experiments were set up in 2004. Clear evidence of subsidence in some areas of both control and experimental manipulation plots across the main research valley, all of which were carefully located in birch hummock tundra vegetation back in 2004. Vegetation becomes completely dominated by *Eriophorum* cottongrass in the subsided heavily water-inundated areas. Total area monitored (i.e. total area of experimental plots) 1573 m2 of which 7% is now clearly subsided 18 years later.

Cause? Easy to suggest an impact of climate warming, but could simply be the natural temporal dynamic of palsa type landscapes... some areas subsiding as subterranean ice melts due to deteriorating thermal insulation during summer from the overlying moss layer as it becomes increasingly wet (dry moss has high insulation properties but wet moss has relatively high thermal conductivity), and other areas being pushed up by growing subterranean ice due to more severe freezing in winter as the overlying soil and vegetation cover grows up resulting in drying out and succession to lichens and eventually eroded peat.... when the cycle begins again... subsided areas developing a thickening sedge/moss layer that grows up, begins to dryout and eventually becomes a lichen-dominated peat plateau with near surface subterranean ice; neighbouring eroded peat areas with no insulating vegetation cover lose their thermal insulation, allowing summer heat to flow down and melt the subterranean ice leading to subsidence, water inundation and the onset of sedge and moss cover.

Conclusion? This palsa dynamic cycle and multiple others are playing out at several spatial and temporal scales. Starting out with the fundamental realization that change is ALWAYS happening (at multiple spatial and temporal scales) leads to a different way of knowing. There is NO equilibrium – a myth which leads to ineffective, misleading, or at least restricted perspectives in science, and more generally.

* Plant aboveground growth responses to experimental manipulations do NOT match belowground growth responses (Zamin, 2012, 2014, Gu, 2020)
* Fungi dominate mesic tundra soil microbial communities throughout the year, but there is a strong increase in the relative abundance of bacteria at the end of spring thaw (Buckeridge, 2013)
* Soil bacterial communities across the North American and European Arctic are no less diverse than at more equatorial latitudes and are structured much more strongly according to local variation in soil pH, than by spatial distance (i.e. no effect of distance in restricting dispersal across sites - some of which were directly adjacent, and some of which were 1000s of kilometers apart)(Chu 2010).
* The tundra soil microbial biomass was able to rapidly acquire almost all of a single year’s large N addition and retain it over at least two subsequent years (Churchland et al, 2010). This very rapid and substantial microbial N sink capacity suggests that the moderate increases in tundra soil N supply expected due to climate warming could be largely immobilized by microbes, resulting in slower and more evergreen-dominated plant community responses than are predicted from long-term, annually repeated, high-level fertilisation studies.
* Birch shrub cover in large long-term monitoring plots (100m2 x 10), and multiple landscape repeat photographs, clearly indicate that birch growth has been enhanced across a variety of habitat-types in the Daring Lake landscape since 2006 (Andruko et al 2020). Although very recent evidence suggests that the Daring Lake region has been warming over the past few years, analysis of the climate record from 2006 to 2016 (when the birch cover was carefully measured by Andruko) indicated no substantial warming leading to the suggestion that the ongoing and very severe caribou herd declines may be at least as important as climate warming in driving birch shrub expansion in the Canadian central low Arctic.

These conclusions form the basis for the following arctic research themes:

**Role of phosphorus as well as nitrogen in determining tundra plant community structure and responses to climate change**

Phosphorus as a plant growth regulator: Do the unanticipated (and unique?) Daring Lake results indicating NP co-limitation of deciduous shrub (birch) and graminoid growth (Tara Zamin, 2012, 2014) apply more widely across the low arctic? (pan-Arctic N:P ratio study; N P addition study at Umiujaq)

Are the increases in IEM(ion exchange membrane)-based phosphate availability in the low P addition plots and the corresponding increases in plant P concentrations (Qian Gu), resulting in enhanced plant biomass, and if so, for which species?

Is growth of mesic tundra plant communities enhanced by low-level N and P additions that more realistically simulate increased fertility due to climate warming, and are species differences in N versus P growth-limitation an effective predictor of their individual responses to warming? What can we learn by comparing low level with high level N and P addition effects on mesic tundra plant communities, and what are the implications in terms of potential climate change responses?

What is the mechanistic nature of the NP co-limitation, given that birch (at least) responds to high level N only additions, but not to low level N only additions after 8 years at least (Tara Zamin, 2012, 2014; Gu 2020)? Are the responses different now (as suggested by Qian Gu’s recent work), and Dominic Wood’s?

Soil P availability to plants and how it might be affected by climate change – What is the relative importance of microbial and abiotic processes on the availability of P as compared to N within the soil solution? In addition to mineral forms, what organic P and N compounds are most important to supplying plant and microbial demands? Will warming-induced soil organic matter decomposition enhance soil N availability proportionally more than soil P availability?

Transfers to downslope ecosystems – Are there significant movements of N and P in snowmelt water to downslope ecosystems? Is P (and/or N) deposition on snow (in dust and/or biota) a significant P input to tundra ecosystems?

What is the influence of factorial N and P fertilisation (and greenhouse warming) on mesic tundra soil bacterial and fungal community structure (Noah Fierer collaboration)?

**Tundra plant community responses to summer warming**

Is the relatively strong greenhouse warming response of evergreen compared to deciduous shrubs at Daring Lake (Tara Zamin, 2014) compared to other arctic experimental study sites a widespread phenomenon? Will evergreen shrubs continue to dominate greenhouse warming responses at Daring, or will birch ‘win out’ in the longer term (as suggested by analogous Alaskan and Swedish studies)?

Is the dominant evergreen shrub response to greenhouse warming explained by the **microbial N uptake ‘sponge saturation’ hypothesis** (i.e. the concept that the microbial community is more competitive than plants for enhanced nutrients, and therefore must become nutrient-saturated before there will be any additional nutrients available to plants)(Churchland, 2008; Gu PhD thesis data on single NXP addition responses)? If so, then following microbial saturation, if the concept of superior evergreen capacity for nutrient uptake in nutrient-limiting environments is valid, evergreens may be the most effective plant group at acquiring subsequent enhanced levels of available nutrients in the soil solution.

Coupled to the above question, what is the outcome of tundra plant-soil microbial competition for ambient and climatically realistic, slow and moderate increases in nutrient availability over a 5-10 year time scale (low level N and P addition plots, the one-year only high N addition plots (Churchland, Gu), Abisko (Michelsen) and Daring 15N plots (Vankoughnett)?

Are the recent data suggesting declining impacts of greenhouse warming on annual plant growth (Qian Gu c.f. Tara Zamin) a climate anomaly (cold early July) or a result of depleting labile soil organic matter pools (i.e. **the labile SOM/short-term ferility enhancement hypothesis** that warming-enhanced SOM decomposition will be short-term until the labile SOM fraction is depleted and that afterwards decomposition rates/soil nutrient fertility will no longer be substantially enhanced)?

Are we being oversimplistic in focussing on N (and lately P) availability as drivers of plant community change – What are the impacts of experimental warming on potential plant growth limitation by the availabilities of Mg, K, S, Ca, Fe, Mn, Zn, B, Cu and Mo?

What will happen to the graminoids – which are a small component of total community biomass but strongly responded (2-fold) to greenhouse warming (Tara Zamin 2014)? Is herbivory the primary constraint on their potential response to warming. If so, does the severe caribou decline partly explain the recent data indicating substantial growth increases that is correlated with recent ambient climate warming at Daring Lake (Gu, 2020)? Or could the greenhouse response Tara observed really be due to the frames and plastic restricting large herbivore access? Graminoids are clearly highly responsive to soil fertility but are also preferred caribou forage (e.g. growth response to N+P is greater than for N or P alone, and is also very noticeable as tall grass (*Calamagrostis*?) patches in the N+P areas within exclosure plots, and over a buried caribou carcass).

**The potential for transition from low to medium stature (~ 1m tall) shrub tundra vegetation – How, When, Where, Which?**

Are the increases in birch ground cover in our large long-term monitoring plots between 2006 and 2016 caused at least partly by reduced herbivory due to declining caribou populations (- on the basis that no climate warming signal was detected in that period) (Andruko, 2020)?

What is the landscape-scale significance of the strong correlations between soil ammonium availability (Ion exchange membrane fluxes) beneath individual shrubs and their growth rates (Andruko, 2020) for predicting responses to perturbations (climate warming; declining caribou herbivory...)?

Do dendrochronological analyses of birch shrub growth rates at warming and relatively stable sites (Umiujaq and Daring Lake respectively) match climate trends at those sites?

Do growth rates of the major deciduous shrub species (birch, willow, alder) differ in relative N and P limitation?

Why is it that Birch seems to be the shrub that is most responsive to warming in Eastern Canada, while Alder seems to dominate responses in W. Canada and Alaska?

Are the scattered trees (black spruce) in the Daring region providing viable seed that could facilitate the climate equilibrium model predictions of treeline expansion from its current position about 75 km to the south into this area over the next 100 years?

**Soil microbial community and nutrient cycling dynamics between winter and summer**

Are there discrete ‘critical times’ associated with marked changes in osmotic potential around soil microbes that result in lysis and major nutrient release pulses (**e.g. – the snowmelt water percolation thaw-freeze microbial lysis hypothesis** ; the microbial crash at complete snowmelt; extreme rainfall events following long dry periods in summer) (Buckeridge; Wright; ??)?

Are fungi and bacterial communities similarly affected by such ‘critical time’ events?

What is the significance of these microbial dynamics for nutrient availability to plants, nutrient flushes downslope, and denitrification?

**The impacts of deepened snow in low arctic tundra**

Why are the evergreens most responsive to deepened snow (Christiansen, 2018), and is this a short-term response that will eventually be overwhelmed by birch responses (Sturm’s **shrub-snow hypothesis**)?

Are the follow-on effects of deepened winter snow on ecosystem and soil respiration in the following summer (Christiansen, 2018) explained by the **depleted soil labile carbon hypothesis**?

Is the mineral soil C pool in the active layer significantly depleted by prolonged deepened snow in successive winters (as strongly suggested by the soil profile data in Christiansen, 2018), and what is the range in magnitude of this effect across the low arctic?

**Soil microbial community (fungi and bacteria) structural patterns down the active layer and into the permafrost**

Can we infer functional impacts of the distinct depth-specific soil microbial communities all the way down into the permafrost (Christiansen, 2023 in revision), and what would be the impacts of a climate-warming induced deepened active layer?

Are the biogeochemical and physical factors that determine the composition and structure of depth-specific communities in the active layer and permafrost (Christiansen, 2023 in revision) influenced by the overlying vegetation-type?

Is variation in soil microbial community structure with depth greater or less than variation across surface soil horizontal space? (ADAPT trans-Canada cores)

Do the fundamental differences between prokaryotes and eukaryotes result in different pan-Arctic biogeographical community patterns for soil bacteria as compared to soil fungi? (Haiyan Chu, Anders Prieme Copenhagen collaboration)?

**TEMPERATE FOREST research** (primarily at Pangman tract deer exclosure experimental site, Queen’s Biological Station property)

Has the recent history of high deer browsing resulted in an alternative stable state in Ontario temperate forests? In essence, does abundant sedge cover in the forest understory inhibit growth of other plant species, and does it represent a resilience feedback that prevents the understory from recovering even when deer herbivory is removed (an alternative stable state)?

What are the primary controls on maple seedling production and progression to the sapling stage? (Our data clearly indicate VERY severe decline in seedling survivorship following the mast year 2013 over the next 8 years. – See Kira Henders poster 2022)

In Trillium (*Trillium* *grandiflorum*), for which our data clearly show that flowering is significantly impacted by deer, the short 3-leaved stage (often with small leaves) is dominant in heavily browsed sites and must maintain itself as a functioning plant via ongoing photosynthesis each year.... Can it return to flowering – with several years of low browsing pressure? The answer probably depends on multiyear carbon build-up in rhizome?? If continued high browsing pressure, does lack of flowering and subsequent seed production ultimately lead to extirpation once the full lifespan of the short 3 leaved stage is completed?

Our regular Trillium flowering frequency data since 2011 indicate recovery to flowering in ~5 years in exclosure plots but it is very patchy among those plots... implying dispersal (by ants) and/or environmental heterogeneity are key determinants of distribution. Is there ANY evidence of expansion?

For the Trillium, is the number or proportion of non-flowering plants changing (decreasing) in controls over the long term – leading to potential extirpation?

What triggers onset of flowering in the absence of deer, and is the pattern consistent over multiple years? High spatial scale resolution monitoring since 2019 of 42 plants in plot H indicate strong annual fluctuations in whether an individual plant flowers or not... and we can clearly conclude that these fluctuations are completely independent of deer herbivory since plot H is an exclosure plot.

**TEMPERATE OLD FIELD MEADOW GRASSLANDS research** (primarily at Bracken tract old field meadow (Queen’s Biological Station property) where we have experimental water manipulations (rainout, ambient, weekly additions), fertilisation, and exclosure treatments since 2009. Also ongoing nitrogen fertilisation experiment at Stoke’s Field hay meadow (Queen’s Biological Station property) where we have experimental low-level nitrogen additions to double atmospheric N inputs.

What is the relative importance of bottom up (water and/or nutrient availability) compared to top-down (deer herbivory) on plant community structure and productivity? (Serafini, 2019)

Is our weekly watering addition that seems to be having only minor effects on plant growth relative to fertilisation (Serafini, 2019) due to rapid drainage of the added water (i.e. that the temporary elevation of water following addition is too short be biologically significant (Julia White thesis 2022)? Or, is the general lack of a water addition effect on biomass (Serafini, 2019) due to the particular weather in the harvest year – 2015? Using datalogger records since 2019, Julia White showed that soil moisture is only elevated by the water addition in the latter part of the growing season... in the early part of the growing season, high snowmelt water inputs saturate the soils. Furthermore, Julia showed very substantial variation in the growing season threshold date beyond which water addition significantly elevated soil moisture.... leading to the hypothesis, that biomass responses to water addition are only likely in low spring rainfall years (-and low snow?), and only if water is added from the beginning of May.

Maybe water availability is simply not as critically important to community production and species competition in this ecosystem as we thought. Perhaps all species here are evolutionarily adapted to mesic/dry climate during the growing season, and those adaptations represent a trade-off whereby they cannot respond to significantly enhanced water availability??? Or maybe only certain invasive species have that capacity, and it takes more than 5 years for that effect to become significant at the whole community production level?

Is watering leading to enhanced soil nutrient availability (Mike Hann U/G thesis), and does the plant shoot P concentration data (Serafini, 2019) indicate that growth is stimulated in the watering manipulations as a result of enhanced availability of P more than N?

What are the likely impacts of decreased summer precipitation (simulated by the rainout shelters) on these grasslands as climate changes over the next 100 years, and are invasive species such as Bromus likely to increase in dominance?

Will increased atmospheric nitrogen deposition significantly alter plant species diversity (richness and evenness) and primary production (above and below-ground)?

Why are the plant community growth and relative abundance responses to added N negligible compared to the influence of soil texture (Jordan Constant 2015 UG thesis, Meghan Hamp 2022 thesis). Could these responses, and Meghan’s lack of response to single year high level NXP additions, be primarily because of low rainfall inputs in the harvest years (2014, 2020).

Why does the less productive sandy soil (compared to clay) result in significantly higher shoot N concentrations (Jordan Constant 2015 UG thesis)?

**SUSTAINABILITY initiatives**

**What can an understanding of our fundamental biology tell us about our likely future?** (Grogan, Free Inquiry 2012; Grogan 2019 poster -see lab website for downloadable links)

Would enhanced awareness of ‘mindful’ perspectives result in more sustainable living, and if so what practical, tangible, feasible methods could be used to achieve that enhancement?

Our strong consciousness trait provides our civilisation with a unique capacity not just to be aware of our activities’ impacts, but also the root biological causes, as well as the inherent suffering and impermanence of each human existence. What would be the impact of humans truly and fully acknowledging and embracing the fundamental realities of our biology and of our existential predicament? Would/Could we choose to live differently, and if so what practical, tangible, feasible methods could be used to achieve that change?

**Raising awareness among scientists of the environmental impacts of doing their research**: Engaged awareness is the fundamental pre-requisite to addressing a problem. Every research activity – not just lab experiments and field work, but also online surveys and computational analyses - involves environmentally-damaging impacts.  We scientists are all undeniably part of the problem – even those who are specifically trying to do research that would be part of the solution.  Accordingly, as the overall impacts of humanity’s activities on the biosphere become ever more apparent, we scientists have a particular responsibility to: a) openly acknowledge the impacts of our research; and then b) to mitigate where possible.

How can these two processes be promoted? At the research-planning stage, some scientists may deliberately set out to identify the environmental impacts associated with completing a particular study, and then choose to take specific actions to reduce some of them.  Wouldn’t it be a significant step forward if such scientists were to explicitly state those mitigation actions in journal and thesis publications (as a dedicated appendix/electronic supplemental file)? Furthermore, journals and grant agencies could actively encourage researchers by inviting such statements in their ‘Author Guidelines’. This simple idea could be a ‘ground-breaker’ in promoting an improved sustainability mindset across the scientific community because briefly describing such actions would raise awareness among other researchers of not just the environmental impacts of doing their particular science, but also of potential actions to avoid/reduce/mitigate those impacts.