5. How are ABR flora and fauna responding to changes in biotic and abiotic conditions, and what are the impacts on ecosystem structure and function?

Long-term satellite data records indicate that vegetation characteristics in undisturbed areas of the Arctic-Boreal region (ABR) are undergoing directional change at regional and in some cases, pan-Arctic-scales. While tundra regions of Alaska have been increasing in productivity (greening), some interior boreal regions have been browning, both in response to climate warming. The same satellite sensors are revealing that at the pan-Arctic scale, growing seasons are lengthening primarily because warmer springs alter freeze-thaw dynamics and advance spring snowmelt and onset of plant growth. Climate-sensitive disturbance regimes in the ABR are intensifying, including those associated with wildfire, insect and pathogen outbreaks, and thermokarst activity. These, too, are altering vegetation characteristics by initiating successional processes, altering the age structure of ecosystems on the landscape, and changing the composition of dominant species and growth forms. Overlain on these major trends in vegetation are more subtle changes revealed by repeat aerial photography and long-term, ground-based ecological and paleo-ecological records. These include shifts in the geographic ranges and/or dominance of species and growth forms that alter ecosystem structure and function, interactions with disturbance agents, and feedbacks to climate. Finally, human activities related to resource extraction are having increasing local and regional impacts on vegetation characteristics as cold regions become more accessible and the economic imperative for both global and local energy sources increases. The main drivers of all of these changing vegetation characteristics include the abiotic conditions associated with climate change (including Arctic sea ice dynamics) and altered disturbance regimes. However, there are many aspects of these concurrent changes in ABR vegetation that are not yet well understood, including the degree of interaction between the underlying processes driving them, and how they feedback on climate, disturbance regimes, and anthropogenic activities.

Even less well understood is the degree to and mechanisms by which organisms at higher trophic levels exhibit top-down control over the ABR's changing vegetation characteristics - and vice-versa - how changing vegetation impacts ABR fauna. Fauna can significantly influence ABR ecosystem form and function, including, but not limited to, large herbivores inhibiting woody shrub growth and net ecosystem CO_2 uptake in the tundra, rodents altering cycles of tundra productivity that are detectable from satellite greening records, arthropod infestations regularly defoliate entire stands of boreal forest, moose grazing altering the trajectory of secondary succession following boreal wildfire, and large mammal grazing on seedlings/sapling inhibiting northward treeline advancement. From a bottom-up perspective, the ABR provides unique habitat to both resident and migratory populations of a wide range of fauna - from arthropods to caribou to waterfowl - all of which depend on the ABR for food and shelter. Because the vegetation growing season and animal breeding seasons are very short in the ABR relative to temperate and tropical ecosystems, many faunal species are proving particularly vulnerable to changes in climate, vegetation, disturbance regimes and anthropogenic activity. Trophic mismatches have developed, for example, between advanced tundra vegetation phenology and the specific nutritional needs of nursing caribou, resulting in major declines in their reproductive success. Boreal wildfire results in forest sucessional stages that differ significantly in biophysical structure and hence the mammal and bird communities that each stage supports.

Satellite records have also revealed significant and contrasting trends in surface water extent within the ABR, with widespread and consistent increases in surface water inundation (wetting) occurring in zones of continuous permafrost, but drying trends in regions of sporadic/isolated permafrost. Similar to observed trends in vegetation growing season lengths, ice-cover duration on lakes and streams is shortening, and freeze-thaw dynamics are being altered. In addition, there is recent evidence that tundra stream reaches are drying up in late summer. These changed patterns of ice cover, wetting and drying are likely to alter habitat availability and quality for the ABRs aquatic and semi-aquatic fauna, including birds, fish, mammals, and invertebrates. Every spring, millions of shorebirds, ducks, geese, loons and swans migrate to the ABR to breed, raise their young and feed in wetlands. Fresh water fish inhabit lakes and streams, and move between spawning and overwintering areas via stream networks. Beavers are a semi-aquatic and critical keystone species of the boreal forest, and thus changes in their habitat quality will likely have cascading impacts on ecosystem form and function.

It is largely unknown which faunal species will be able to adapt and be resilient to the many biotic and abiotic changes occurring in the ABR, yet the resulting changes in both plant-animal and fresh water-animal interactions will strongly influence the response of ecosystem form and function. Further, because the ABR is relatively low in floral and faunal species diversity compared to temperate and tropical ecosystems, they likely have low functional redundancy – i.e. only one or very few species perform a given ecological role - leaving ABR ecosystem functions particularly vulnerable to the loss of individual and groups of species. Studies are needed that incorporate interactions among organisms at all trophic levels and examine their communal and interacting responses so that their collective impacts of ecosystem form and function can be quantified.

Finally, ongoing data collections for NASA's CARVE mission are showing that variations in boundary layer concentrations of CO_2 and CH_4 exhibit complex, emergent patterns at large spatial scales that cannot be predicted from ground-based measurements of these trace gasses, illustrating the need for additional research on how variations in vegetation and surface water extent regulate feedbacks to climate in the ABR.

Objectives for research on ABR flora and fauna include:

(a) Identify and understand the combination of factors driving longer-term temporal and spatial changes in vegetation characteristics, including habitat quality, productivity and extent, as observed in the satellite data record.

(b) Determine to what degree variations in ABR disturbance regimes are driving driving direct and indirect changes at both the ecosystem and landscape-scale, including successional rates and pathways within ecosystems, the age and compositional structure, and plant-animal interactions.

(c) Document how changes in vegetation characteristics, surface water extent, and/or changes in faunal communities influence ecosystem processes and services, in particular net feedbacks to climate.

Research to address these objectives will include ecosystem, landscape and regional scale observations of vegetation characteristics and surface water extent derived from remotely-sensed data, as well as other observations to assess changes in terrestrial and aquatic growing season length (e.g. visible, infrared, and microwave data). While satellite data are needed to assess long-term trends at scales of 30 to 5000 m, airborne data may be required to collect data not available from satellite systems (in particular LiDAR and hyperspectral data) and provide observations of vegetation and surface characteristics at finer spatial scales (1 to 10 m). Assessing factors controlling vegetation characteristics, surface water extent, and growing season length will also require geospatial data on climate (air temperature, relative humidity, precipitation, climate indices), sea ice volume, burned area metrics, resource extraction sites, active layer thickness, temperature, and moisture, topography and soils. Regional scale observations of spatial and temporal dynamics in wildlife habitat could include satellite (e.g. using ARGOS satellite) and/or airborne and telemetry tracking of tagged or observed animals. Ground-based, plot level observations stratified across different tundra and boreal ecoregions/subzones, vegetation community types, burn scar properties, and wildlife habitats and migratory corridors will be required. Ground observations will be necessary to gain a mechanistic understanding of the interactions and feedbacks among abiotic and biotic changes that together result in net changes in ecosystem form and function. Refinement of dynamic vegetation models will be needed to more realistically depict the interactions between the abiotic and biotic controls on terrestrial ecosystems, including both flora and fauna.