Modeling dynamics of circum-arctic tundra plant communities in response to climate warming and grazing pressure

Qin Yu[1], Howard Epstein[1], Donald Walker[2], Bruce Forbes[3]
1. University of Virginia; 2. University of Alaska, Fairbanks; 3. University of Lapland

Introduction

The Arctic is a complex system with strong interconnectedness among system components. Understanding the responses of the arctic tundra biome to a changing climate requires knowledge of the complex interactions among climate, soils, and the biological system. In this study, we investigate the individual and interaction effects of projected climate change and reindeer/caribou grazing across a variety of climate zones and soil nutrient levels on tundra plant community dynamics using an arctic vegetation model – ArcVeg across the Arctic. This study is motivated by previous work (Yu et al. 2009), which concluded that grazing and warming can have opposite effects on plant total biomass and net primary productivity. We thus assessed the following forcings on tundra plant aboveground biomass across the Arctic:

1) projected climate warming
2) grazing
3) projected climate warming and grazing

Methods and data

ArcVeg (Figure 1) simulates the dynamics of tundra biomass, productivity, and plant-community composition based on fluxes and pools of nitrogen, which typically limits tundra productivity. The key forcings in the model are climate (temperature), disturbances such as grazing and freeze-thaw processes, and the soil organic nitrogen quantities in the active layer (Epstein et al. 2000). We collected reindeer population data from Arctic Portal and CARMA (The CircumArctic Rangifer Monitoring and Assessment Network), based on which we calculated grazing intensity across the Arctic (Figure 2). With model input data (Figure 3), we simulated a total of 600 years. At year 500, the projected warming was initiated and ramped linearly for 100 years. We calculated the mean aboveground biomass for 100 years before warming (year 400 to year 500) and for 100 years after warming (year 500 to year 600).

ArcVeg – Arctic tundra vegetation dynamics model

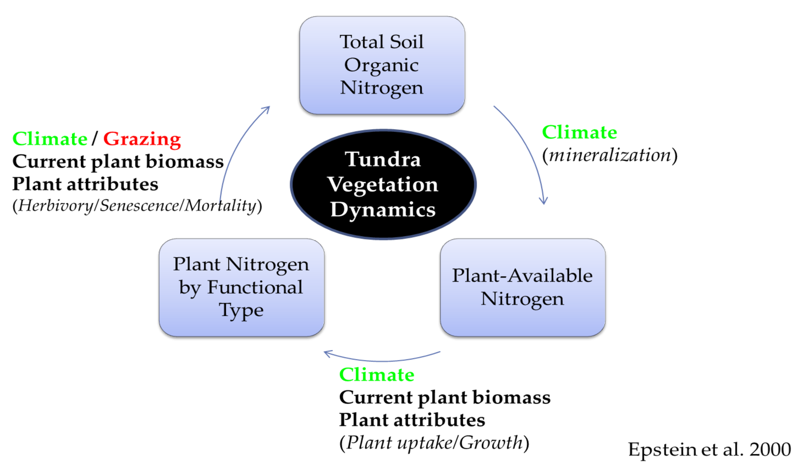

Figure 1. ArcVeg model diagram

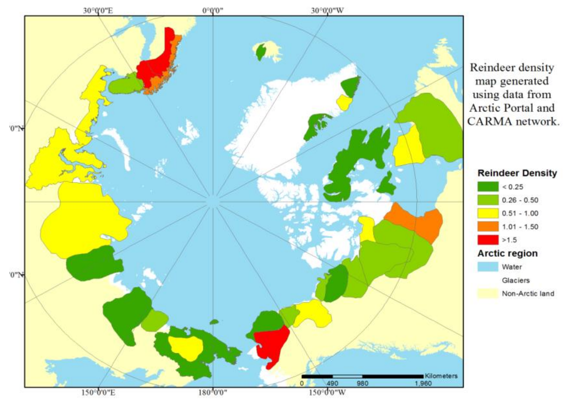

Figure 2. Reindeer density map derived based on reindeer population data from Arctic Portal and CARMA.

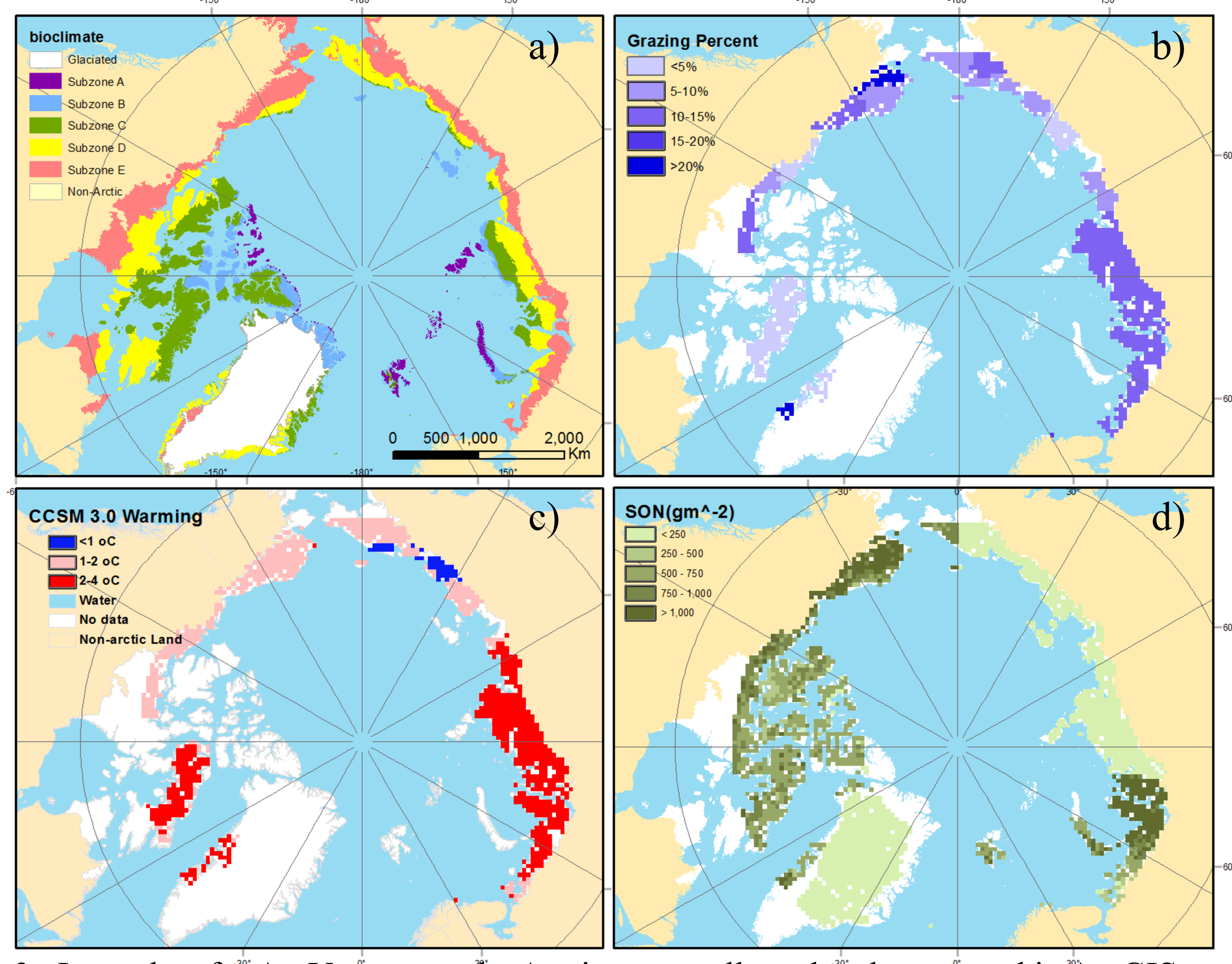

Figure 3. Input data for ArcVeg across the Arctic were collected and processed in ArcGIS.
a) bioclimate subzones layer; b) grazing percent derived based on population density (Figure 2); c) projected warming magnitude based on CCSM 3.0 surface temperature data; d) mean soil organic nitrogen simulated by TEM (Terrestrial Ecosystem Model).

Results

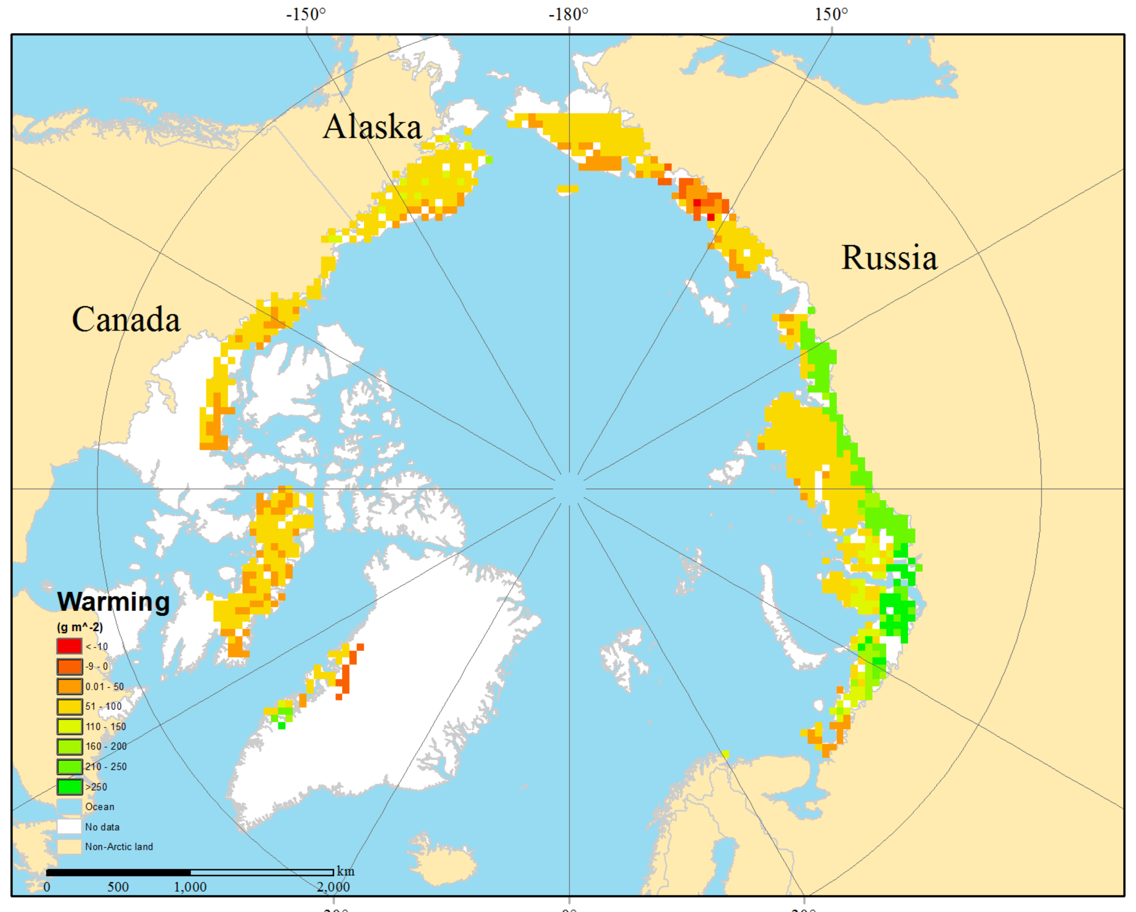

Figure 4. Change in aboveground biomass in response to projected climate warming without presence of grazing (ArcVeg simulation with ONLY warming).

Figure 5. Change in aboveground biomass in response to Grazing. (ArcVeg simulation with ONLY grazing – before warming scenario).

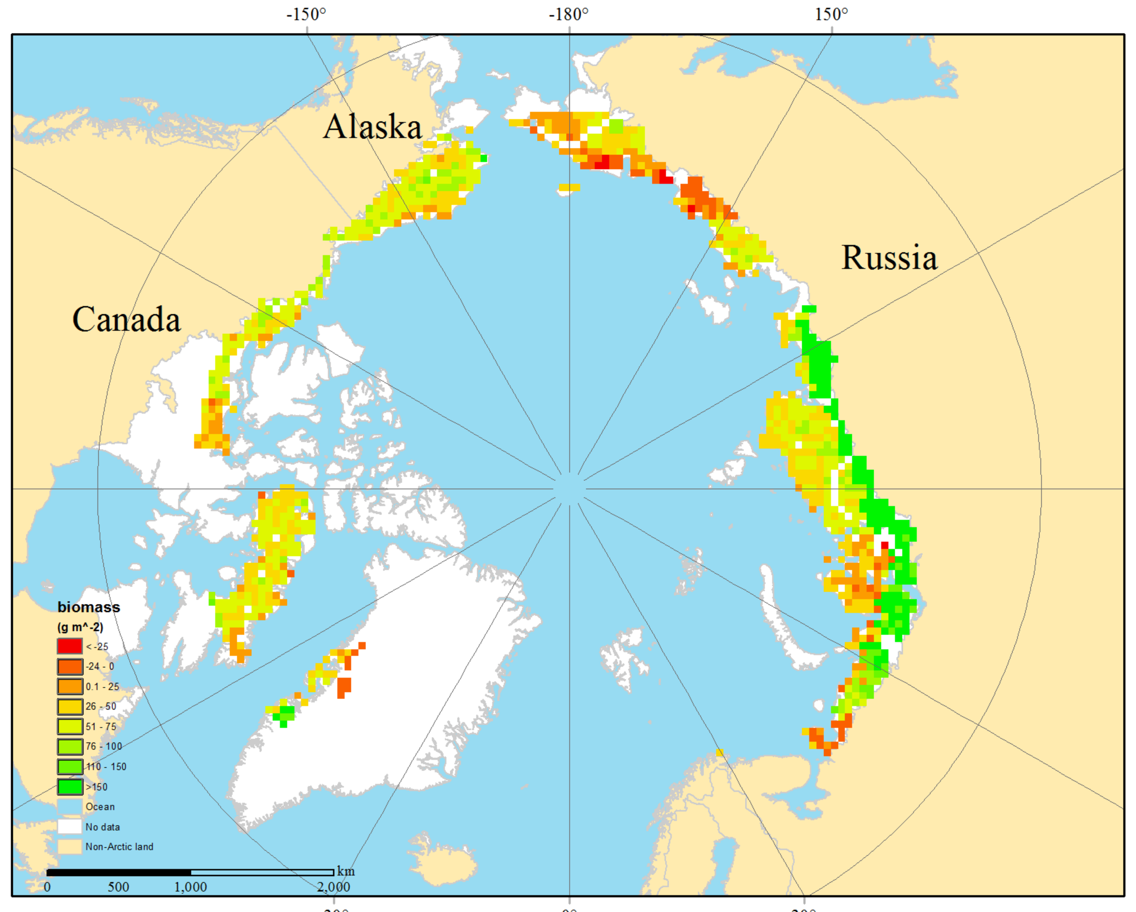

Figure 6. Warming caused biomass change + Grazing caused biomass decrease.

- Greater magnitude of warming will cause greater biomass increase, e.g. Russian Arctic tundra tends to be greener than other regions of the Arctic. Southern subzones will respond more quickly due to existing biomass.
- Greater biomass decrease in Figure 5 also happens in the Russian Arctic, which indicates greater reindeer population and thus density may affect tundra biomass substantially. There are also interactions between soil organic nitrogen and grazing.
- Warming seems to have greater effect on tundra plant biomass in Russian Arctic than grazing (Figure 6), especially in southern subzones where shrubs can likely respond to warming quickly than other species.

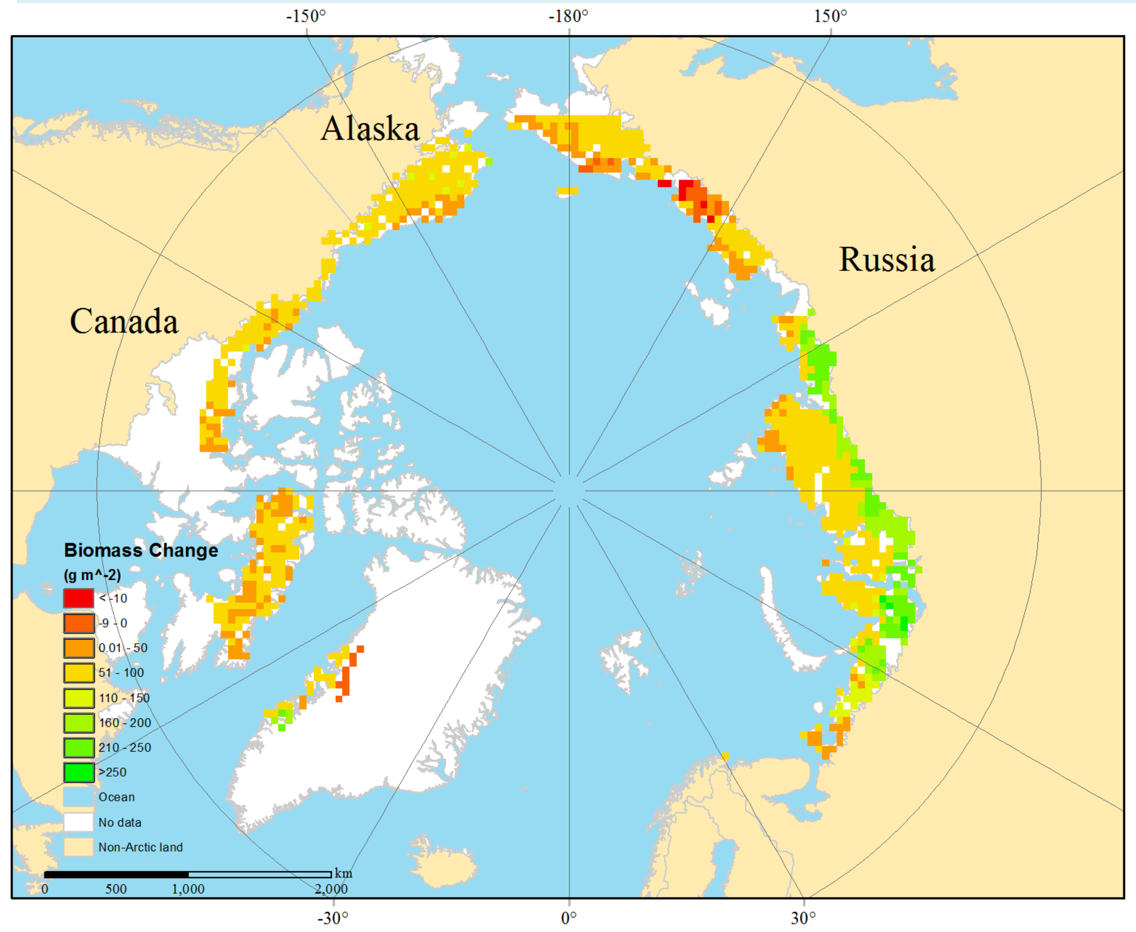

Figure 7. Change in aboveground biomass in response to projected warming with presence of grazing

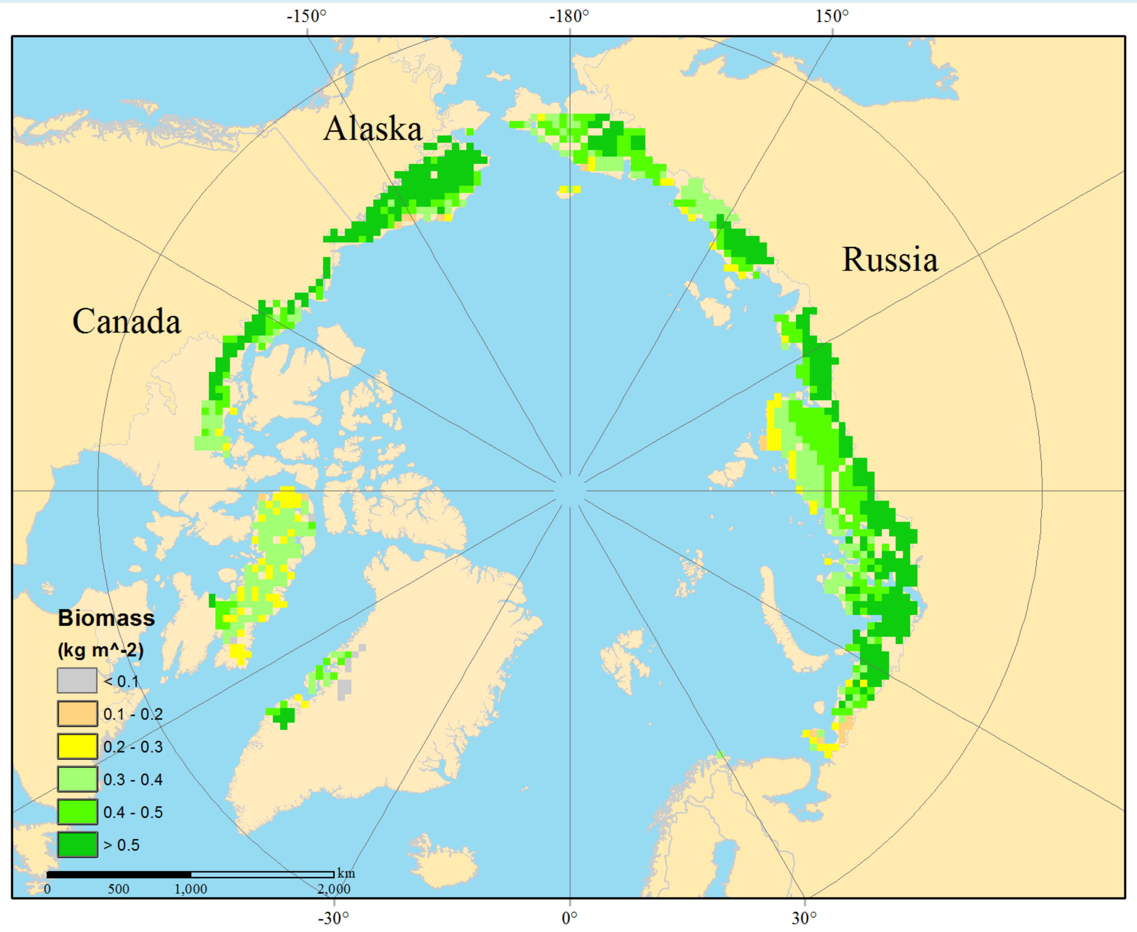

Figure 8. Simulated aboveground biomass in response to warming and grazing (data used here is 100 year after warming started).

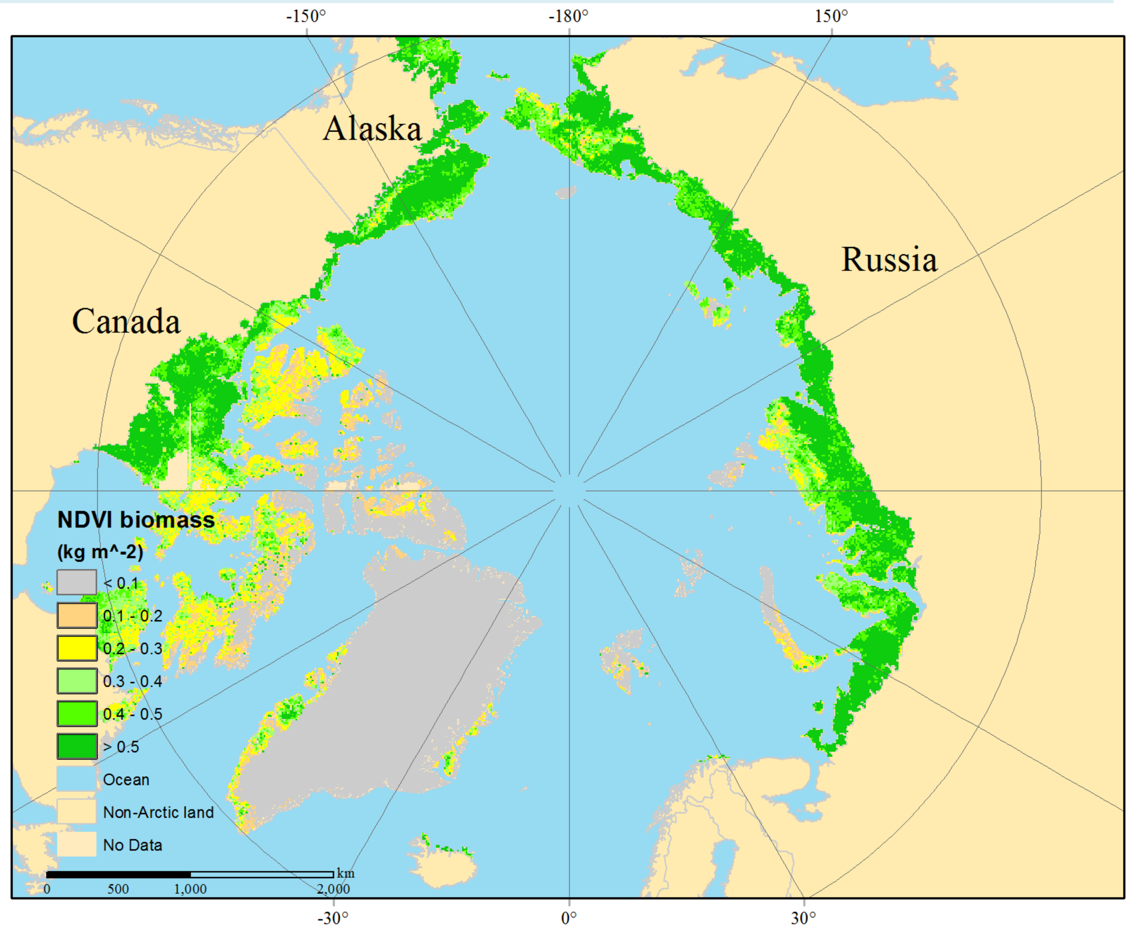

Figure 9. GIMMS NDVI 3g derived biomass in year 2010 (figure adapted from Raynolds et al. 2012)

- Plant biomass in response to warming when grazing is present is shown in Figure 7. Warming dominates tundra plant response in Russian Arctic, especially in the southern subzones.
- Plant biomass after 100 year of warming is similar to the NDVI-derived biomass in year 2010.

Discussions

What affects tundra vegetation more? Climate warming, grazing, soils or their interactions? Our model suggest that all can have substantial effects. But when heavy grazing and trampling becomes an issue with increased reindeer herds in the Russian Arctic, how vegetation will change remains unknown. Additionally, the interaction of warming and grazing can have greater impacts on some species, e.g. deciduous shrubs, which can respond to warming quickly, but also contributes largely to the reindeer diet during the growing season (Yu et al 2011).

Photo: D.A. Walker

Acknowledges

- NASA/NEESPI Land Cover Land Use Change Initiative, Grant No. NNG6GE00A
- NSF Grant No. ARC-0531180, part of the Synthesis of Arctic System Science initiative (Greening of the Arctic)
- NSF Grant No. ARC-0902152, part of the Changing Seasonality of Arctic Systems initiative
- Department of Environmental Sciences, Univ. of Virginia

References

- Epstein, H. E., M. D. Walker, et al. (2000). "A transient nutrient-based model of Arctic plant community response to climatic warming." Ecological Applications 10(3): 824-841.
- Raynolds, M. K., D. A. Walker, et al. (2012). "A new estimate of tundra-biome phytomass from trans-Arctic field data and AVHRR NDVI." Remote Sensing Letters 3(5): 403-411.
- Yu, Q., H. E. Epstein, et al. (2011). "Modeling dynamics of tundra plant communities on the Yamal Peninsula, Russia, in response to climate change and grazing pressure." Environmental Research Letters 6(4): 045505.