Ordination and gradient analysis of Yamal Peninsula relevé data

Gerald V. Frost[1], Skip Walker[2], Martha K. Raynolds[2], and Howard E. Epstein[1]

[1]Department of Environmental Sciences, University of Virginia, Charlottesville, VA, USA; [2]Alaska Geobotany Center, University of Alaska Fairbanks, Fairbanks, AK, USA

Abstract

Detailed species-cover, biomass, and environmental data were collected at 52 relevés at five study sites in the Yamal Peninsula region, northwest Siberia, as part of the Yamal LCLUC project. The study sites span a ~900 km transect from forest-tundra northward through four bioclimate subzones for Arctic tundra. At the tundra sites, two sampling grids were established in homogeneous areas with sandy and loamy substrates. Complete species lists and Braun-Blanquet cover-abundance scores were recorded at five 5 x 5 m relevés within each sampling grid. Additionally, data were recorded for a total of 102 biomass and environmental variables. These variables correspond to (1) aboveground biomass for each plant functional type; (2) field-based NDVI and LAI measurements; (3) soil texture and chemistry for the uppermost mineral soil horizon; (4) geomorphic attributes; and (5) geographic attributes. An indirect gradient analysis was performed in order to relate the species-cover attributes of the relevés to biomass and environmental gradients using Non-metric Multi-dimensional Scaling (NMS). Relevés were well-differentiated within the ordination space for each site and substrate, using only two NMS axes. The first axis represents a complex bioclimate gradient related to latitude and summer warmth, and the second axis represents a complex soil texture/moisture gradient related to the relative abundance of sand and silt. Bi-plots indicate that shrub biomass and total biomass increase with summer warmth, but other biomass and cover variables are much more sensitive to soil texture. Graminoid cover and moss thickness increased strongly with silt content, while liverwort and crustose lichen cover increased with sand content. The bi-plot for NDVI indicates that the productivity of vegetation is more sensitive to soil texture, cation exchange capacity, and cation concentrations rather than summer warmth. This is consistent with field observations across the Yamal Peninsula indicating that greening in the region is associated with landslide features where sandy uplands are eroded and relatively moist, nutrient-rich marine silts are exposed.

Study Area

The Yamal Peninsula is composed of relatively homogeneous, low-lying landscapes and is north-south trending. Thus, the Yamal is an ideal region in which to examine zonation of Arctic tundra vegetation and environmental attributes. In 2007-2009, relevés were established at four tundra sites on the Yamal encompassing Subzones B, C, D, and E of the Circumpolar Arctic Vegetation Map (CAVM Team 2003), as well as a forest-tundra site at Nadym (Figure 1). At the four tundra sites, two sets of five relevés were established in areas of loamy soil and sandy soil (Figure 2). Field campaigns are planned for 2010 at a Subzone A site (Franz Josef Land) and a treeline site at the southern end of the Yamal Peninsula near the town of Kharp.

Figure1. Location of relevés in the Yamal region.

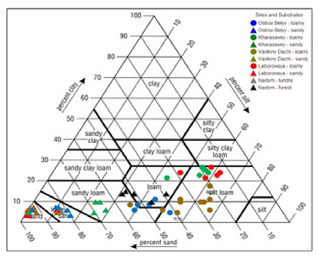
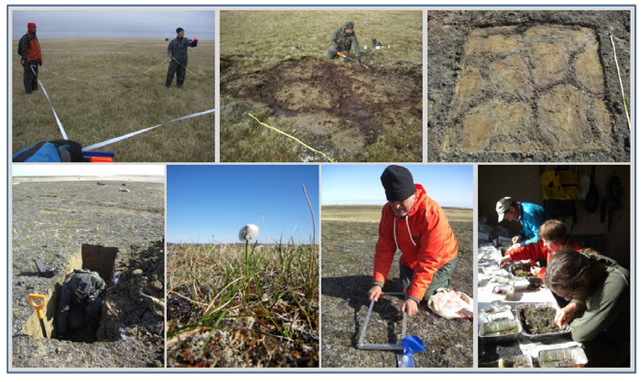


Figure 2. Soil texture of releves plotted on USDA soil texture triangle. Marine sand and silt deposits are prevalent in the region.

Field Methods

Complete species lists and Braun-Blanquet cover-abundance scores were recorded for vegetation at all relevés. In addition, data were recorded for 102 ancillary variables concerning biomass, cover of plant functional types, soils, geomorphology, and spatial attributes. Soil texture and chemistry were measured for the uppermost mineral soil horizon. Aboveground biomass samples were sorted and by plant functional type. NDVI and LAI were measured using hand-held instruments. Finally, soil stratigraphy and cryogenic features were described at a soil pit adjacent to each sampling area.



Data Analysis

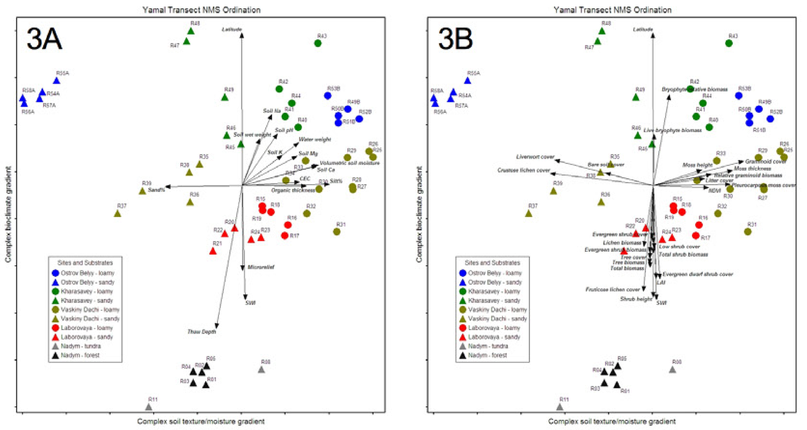
Ordination and indirect gradient analysis was performed using PC-ORD (McCune and Mefford 1999). Non-metric Multi-dimensional Scaling (NMS) was selected, primarily because the distance between any two releves in the ordination space best reflects the actual values in the original Soooerenson similarity coefficient matrix. Iterative ordinations using a variety of techniques confirmed that NMS extracted the most significant relationships between quantitative environmental parameters and the releve data. Table sorting of vegetation data was performed using JUICE (Tichy 2008) in order to identify differential taxa and to relate the ordination diagrams to the species composition of the releves.

Ordination and Gradient Analysis

Figure 3. Quantitative NMS ordination of 52 releves on Yamal Peninsula and at treeline site at Nadym. Releves at loamy sites cluster on the right hand-side of the diagram, sandy sites on the left. The vertical axis indicates a very strong relationship to latitude and summer warmth. Bi-plots of environmental variables with $r^2 > 0.25$are shown on diagram 3A, bi-plots of biomass and cover variables are on diagram 3B (far right).

Overlays of vegetation and environmental variables illustrate variation in biophysical characteristics across the Yamal transect. Graminoid cover is relatively high on loamy sites (3C). Environmental response curves can also be generated for individual plant species, such as *Salix polaris*, which is common on loamy sites but nearly absent from sandy sites (3D).

LAI is relatively high at southern sites where there is substantial cover of low shrubs and trees (3E). NDVI suggests that productivity is more responsive to soil texture rather than summer warmth on the Yamal (3F), but see Figure 4.



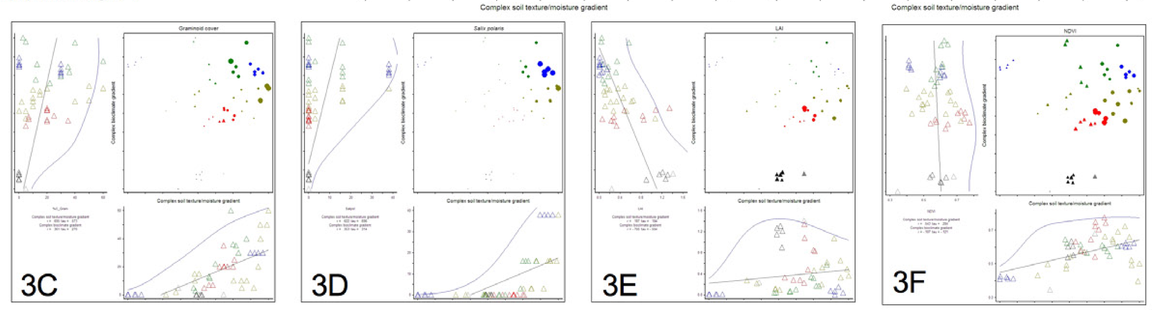
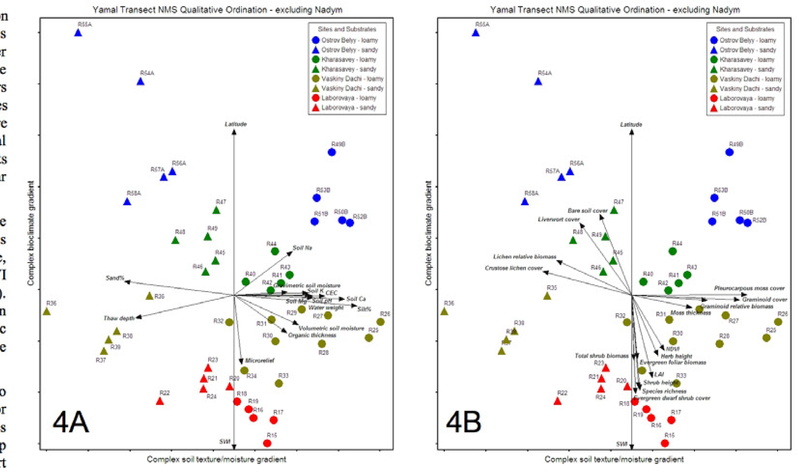
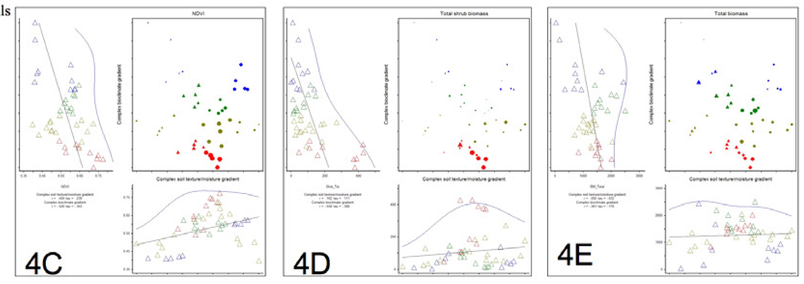


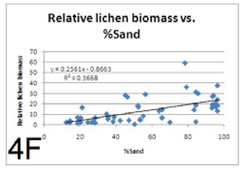
Figure 4. Qualtitative NMS ordination of 45 releves on Yamal Peninsula; Nadym is excluded. This ordination is constructed solely using species presence/absence; cover data are excluded. Some associations become more clumped than in the quantitative oridination, while others become spread out (e.g., Belyy sandy releves). The axes correspond to complex bioclimate and soil texture gradients much as in Figure 3. Bi-plots of environmental variables with $r^2 > 0.25$are shown on diagram 4A, bi-plots of biomass and cover variables are on diagram 4B (far right).

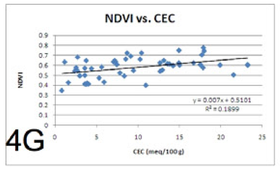
Most bi-plots appear similar to those in Figure 3, but there are important differences. For example, thaw depth is much more dependent on soil texture, rather than latitude, when Nadym is excluded (4A). On the other hand, NDVI is responsive to latitude as well as soil texture (4C). Additionally, total shrub biomass is greatest at southern sites (4D). Total biomass, however, shows no systematic relationship to summer warmth or soil texture along the tranect (4E).

Scatterplots of biological and environmental variables also illustrate patterns of variation on the transect. For example, the relative biomass of lichens increases significantly with sand content (4F). The relationship between NDVI and soil texture may be explained in part by the greater cation exchange capacity of loamy soils (4G).







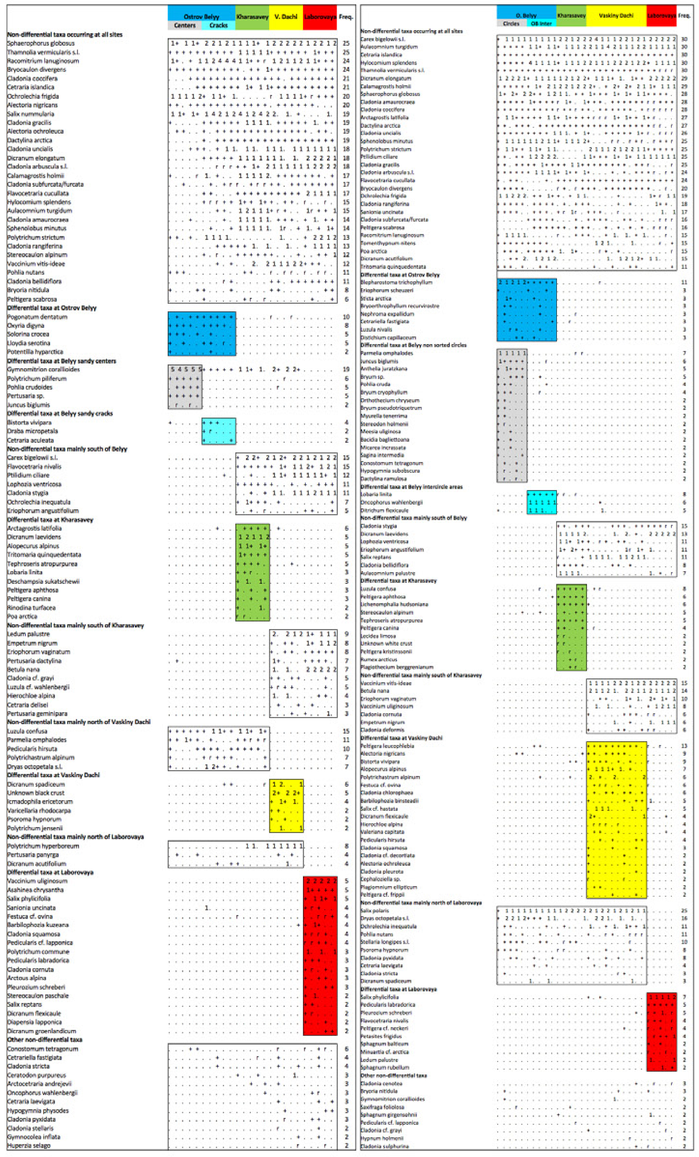


Acknowledgments

Support came from the Department of Environmental Sciences at the University of Virginia, and the NASA/NEESPI Land Cover Land Use Change Initiative, Grant NNG6GE00A; and NSF Grant No. ARC-0531180, part of the Synthesis of Arctic System Science Initiative.

Sorted Table Analysis

The ordination diagrams are constructed solely using vegetation species-cover or species presence/absence data. Below, sorted table analyses for sandy releves (left) and loamy releves (right) reveal similarities and dissimilarities among the releves. This table corresponds to the ordination in Figure 3, except that releves for the Nadym site are omitted. Differential taxa are identified for each site and substrate. Additionally, general patterns of species distribution are evident in the sorted tables.



Summary and Conclusions

The NMS ordination technique is a powerful tool facilitating analyses of detailed vegetation and environmental data. The ordinations distill a large dataset into diagrams that are easily viewed and useful for hypothesis generation. Many of the biological attributes of the releves vary predictably with environmental parameters. However, the relationships between total biomass, NDVI, and summer warmth are still unclear for the Yamal region. Increasing NDVI values in loamy sites are consistent, however, with observations of greening in landslide features that expose nutrient-rich marine silts across the Yamal region.

Literature Cited

CAVM Team. 2003. Circumpolar arctic vegetation map. Scale 1:7,500,000. Conservation of Arctic Flora and Fauna (CAFF) Map No. 1, U. S. Fish and Wildlife Service, Anchorage, AK.

McCune, B. and M. J. Mefford. 1999. Multivariate analysis of ecological data, Version 5.0. MjM Software, Gleneden Beach, Oregon, U.S.A.

Tichy, L. 2008. JUICE program for management, analysis, and classification of ecological data. Version 7.0.42. Institute of Botany and Zoology, Masaryk University, Brno, Czech Republic.