Spatio-temporal trends in tree and tall shrub cover in the Eurasian Low Arctic: evidence from 1960s and contemporary satellite imagery and ground observations

Abstract

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Expansion of trees and shrubs into tundra-dominated areas is one of the principal changes to arctic land cover expected with climatic warming, and there is evidence that ecological state-shifts are already occurring in ecotones of the North American Low Arctic. The ubiquity of these state-shifts across the circumpolar Low Arctic is unclear, however, because few data exist for the vast Eurasian continent. Large-scale expansions have occurred in the past (e.g., mid-Holocene) and associated changes to land surface-atmosphere interactions could have far-reaching effects on atmospheric circulation and global climate. This study is quantifying state-level vegetation change in tundra ecotones at ~20 sites in northern Eurasia and Alaska using comparisons of circa 1965 Corona and contemporary high-resolution satellite photography. Corona was the world's first operational satellite surveillance system and offers a readily available data source for land-surface change studies over a ~40 year temporal interval. Remote sensing and ground-based data indicate that mean annual temperatures have increased over the last ~50 years at all study sites, although the magnitude of warming varies (~1.5 - 4 ºC). The degree to which patterns of vegetation change are shared among sites will indicate the ubiquity of ecological state-shifts in the Low Arctic, as well as the relative influence of large-scale forcing mechanisms (e.g., climate change) and local environmental controls (e.g., disturbance regime, geomorphology) on tree and tall shrub expansion.

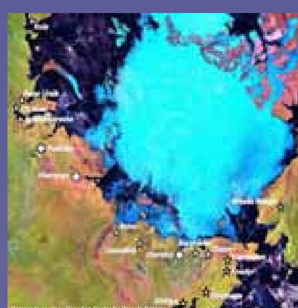
Preliminary findings indicate that tall shrublands have expanded at several sites in northwestern and far eastern Siberia. Recent expansion is most apparent on floodplains, uplands, and drained lake basins. Ground data indicate that dramatic expansion of alder shrubs at a tree-line site near Kharp, northwest Siberia has occurred in areas affected by an antecedent high-intensity wildfire that removed the surface organic layer. Additionally, alder recruitment both inside and outside of the burn is concentrated on disturbed mineral soils associated with cryogenic patterned-ground features. On the southern Yamal Peninsula, Russia, comparison of 1968 Corona and 2009 aerial photographs indicate that alders have colonized retransported sands derived from barren uplands near Ozero Yaroto. Additionally, alders and willows have rapidly colonized fluvial terraces and point bars on the Tanlova River that were barren in 1968. On the Kolyma River floodplain near Cherskiy, larch woodlands have expanded since 1965 although some forest die-back has occurred in association with rapid permafrost degradation. These findings indicate that local-scale disturbance events that create mineral-dominated edaphic conditions have promoted recent shrubification and enhanced productivity in parts of the Low Arctic.

Corona and Gambit satellite photography

The escalation of the Cold War led to rapid advances in aerospace technology in the 1950s, culminating in the dawn of the Space Age. In 1959, the U.S. Department of Defense initiated the development of "Corona", the world's first satellite reconnaissance system. Corona's primary objectives were to monitor Soviet military assets and acquire cartographic data (NASA 2009). Today, Corona imagery provides historical land-cover data for many remote areas of the Arctic. Corona achieved spatial resolution of 2 m for 1968-1972. A related mission, "Gambit", operated from 1963-1967 and achieved spatial resolution of ~0.75 m. The resolution of Corona and Gambit is comparable to that of modern commercial satellites such as Quickbird and IKONOS, facilitating delineation of vegetation and geomorphic features.

Methods

This research examines recent vegetation change in low Arctic ecosystems at sites with a much broader geographic distribution than achieved by previous studies. About 20 eco-tonal study areas have been identified with co-incident 1960s and contemporary photography.



Study sites are ~40 km² in size. After image co-registration, a sampling grid overlay is applied to each photo pair and vegetation attributes are determined at each grid node in a GIS. The distance between grid nodes is ~20 m. Additionally, the number of trees within each grid cell is counted for sites with higher-resolution Gambit imagery. From these data, the absolute (m²) and relative (%) change in tree and shrub cover are determined for each photo pair. Change in tree abundance is also determined for sites with Gambit imagery.

Ancillary environmental data are also incorporated into the vegetation change GIS. These data include (1) geomorphic and physiographic units digitized for each scene; (2) disturbance footprints; (3) elevation and hillslope extracted from ASTER DEMs; (4) climate data; and (5) multi-temporal NDVI data from AVHRR. These data are then used to rank the importance of local- and regional environmental factors in driving the observed vegetation changes.

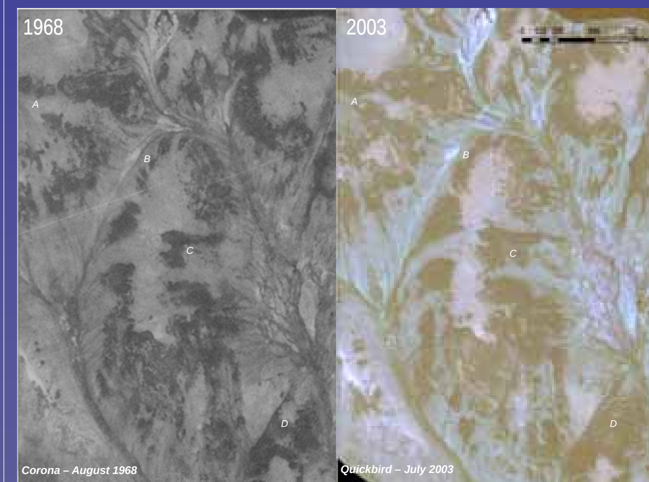
Data summaries will relate the vegetation metrics and environmental strata within and among study areas. Inferential statistics (e.g., ANOVA) will be used to evaluate the relative influence of the environmental strata as determinants of the changes. Finally, NDVI data will be added to the vegetation change GIS to estimate the contribution of changes in shrub cover to NDVI anomalies since 1981. Quantitative assessments of the pace and extent of changes in the structure of northern ecosystems will improve understanding of associated impacts to a range of climatic, hydrological, and biogeochemical processes within—and beyond—the Arctic.

Study Components and Questions

1. Is tree and shrub expansion a ubiquitous phenomenon in eco-tonal regions of the circumpolar Low Arctic?
2. What environmental factors are important determinants of the observed changes?
3. What do observed changes indicate regarding the relative influence of large-scale forcing mechanisms and local environmental controls on tree and shrub expansion?
4. What is the role of disturbance in driving recent vegetation dynamics?
5. To what extent do changes in tree and shrub cover explain anomalies detected in the Normalized Difference Vegetation Index (NDVI) over the last ~25 years?

Observations at Kharp, northwest Siberia

Corona (left) and Quickbird (right) satellite photos indicate rapid shrub expansion in foothills of the Ural Mountains near Kharp. A 2009 field visit to the area revealed patterns of vegetation change related to geomorphology and disturbance regime.



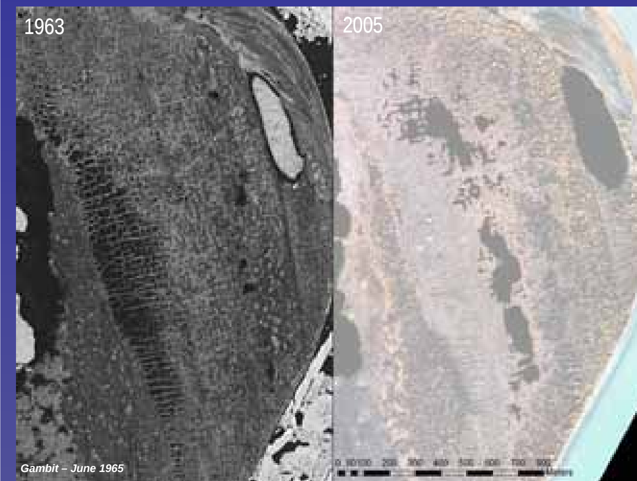
Field observations (left) revealed that alder has colonized sites where surface organic soils were removed by intense wildfire ~100 years ago (inset). Recruitment is concentrated on mineral-dominated frost-boil centers. This could explain the regular spacing of shrubs in Low Arctic open alder shrublands.

Yamal Peninsula

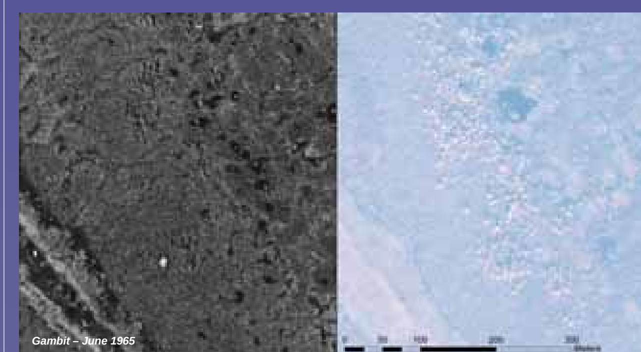
1968 Corona and 2009 oblique aerial photos along the Tanlova River indicate that most shrub expansion has occurred on microsites with mineral-dominated soils. Here, alder has recently established on dune margins (A) and the point bar (C).

Vegetation change near Cherskiy, northeast Siberia

Gambit (left) and Quickbird (right) satellite photos of lower Kolyma River floodplain north of Cherskiy, northeast Siberia. Rapid permafrost degradation has occurred at this site, resulting in die-back of larch woodland. The total area of the young thermokarst ponds is ~0.1 km².



Elsewhere along the Kolyma River, larch trees have become more numerous. Here, afforestation is evident on a large island in the active floodplain.



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