Feedbacks between shrubland development and permafrost in the northwest Siberian Low Arctic

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Current knowledge

• Extensive evidence that shrubs are expanding in the North American Low Arctic, especially in northern Alaska...
  • observational studies
    – repeat photography (Tape et al. 2006, Jorgenson et al. 2007)
    – plot-level monitoring
  • field experiments (Chapin et al. 1995)

• ...but very limited data for Eurasian Low Arctic.
  • Recent warming trends generally not as strong as in North America
  • dendrochronology indicates increased shrub productivity in NW-Siberia (Forbes et al. 2010)

• Satellite observations indicate widespread increase in tundra vegetation productivity (NDVI) since early 1980s, but interpretation difficult.
Implications of shrub expansion

Changes to system components:

- surface energy balance
  - reduced albedo
  - feedbacks to local and regional climate
- hydrology
  - winter snow trapping
  - increased summer evapotranspiration
- ground temperature regime
  - permafrost stability
  - carbon flux
- biodiversity
- wildlife habitat structure
Shrubland feedbacks in high-latitude ecosystems

Myers-Smith et al. 2011, ERL
Previous arctic shrub studies

Myers-Smith et al. 2011, ERL
Cold War-era surveillance heralded beginning of modern remote sensing.
- Worldwide coverage.
- High spatial resolution (0.75 – 2 m).
- Allows detection of land-cover change over ~45 year timescale.
Arctic temperature trends, 1880-2006

Climate Research Unit - 2007
Shrubland extent increased ~11% at Kharp from 1968-2003. What are the key environmental drivers of recent expansion?

- regional-scale (climate)
- landscape- to meter-scale (disturbance, soils, geomorphology)
Field observations led us to hypothesize that alder recruitment is facilitated by patterned ground.
Patterned ground features are more or less ubiquitous in Arctic environments.
Sharp microsite contrasts in soil conditions develop due to differential frost-heave (Peterson and Krantz 2003 – Journal of Glaciology)
Initially, on a barren surface, a more or less hexagonal system of cracks develops due to seasonal freezing.
Cracks collect seeds and retain moisture, so vegetation and organic matter accumulate there. This creates a strong gradient in soil thermal properties.
In early winter, downward freezing occurs faster in exposed mineral soils that lack surface organics.
Pore-water is drawn to the advancing freezing-front in circles due to cryostatic suction.
Increased water-flux leads to stronger frost-heave at circles, as the water expands into ice.
Cryoturbation is strongest at the circle center. Tundra vegetation grows too slowly to withstand annual disturbance, so circles remain barren.
Widespread, severe fire sometime before 1821 removed organic soils and restored differential frost-heave across much of the landscape.
Non-sorted circles

~75 cm
Sorted-circles

\[ \sim 2 - 3 \text{ m} \]
Methods

• 22 transects (20-100 m length, 4-8 m width) in three shrubland successional stages
• mapped locations of alders and circles in colonization zones
• measured soil organic depth and mineral horizon thickness systematically along transect centerline and at alders
• recorded daily soil temperature profiles at 5-cm depth using iButton dataloggers
Surface mapping

Mapping of alder and circle locations
Surface mapping

Mapping of alder and circle locations
Soil stratigraphy

Soil measurements taken uniformly and at shrubs.
Results

Transect mapping
Results
Colonization
Mature
Paludified

Seedlings and saplings dominant
Tall, adult shrubs; seedlings local on remaining exposed circles

Alders exploit microsites that lack organic mat and competing vegetation

>90% of alders on <50% of available sites

Circles increasingly obscured by organic matter

Thick mineral horizon indicates presence of circle

All circles covered by organic mat

Microsite contrasts in mineral horizon remain evident

Paludified shrubland
Frost-susceptible soils are widespread in NW Siberia, likely due to extensive Siberian Traps basalts which weather to fine-grained silts and clays..
Frost-susceptible soils are widespread in NW Siberia, likely due to Siberian Traps basalts.
Station data from Salekhard, 35 km SE of Kharp. (NCDC dataset)
Near-surface active-layer temperatures

Tundra

Mean LAI = 0.36
Mean org = 6.9 cm

iButton dataloggers at 5 cm depth; measurements every 4 hours
Box-and-whisker plots of near-surface active-layer temperature, July 22-August 1, 2011. (Frost et al., in press)
Conclusions

- Differential frost-heave facilitates alder recruitment on circles
  - warmer soils
  - few competitors
  - alders grow fast enough to withstand frost-heave
  - frost-heave rapidly diminishes as alder canopies develop

- Annual disturbance within patterned-ground mosaics maintains a multitude of seedbeds that can be exploited during favorable climatic periods

- Low Arctic tundra with abundant, barren patterned ground features is highly susceptible to rapid, persistent changes in land-cover
  - requires moist, fine-textured soils
  - fire an important trigger-disturbance in boreal areas

- Spatial patterns of alder colonization persist throughout shrubland development, potentially explaining evenly-spaced “alder savannas”

- Alder shrublands are very long-lived and persist despite dramatic changes in soil conditions

- Shrubs strongly modify active-layer temperatures and disturbance regime.
Merci!

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Tundra (foreground)
Mature shrubland
Paludified shrubland