Changes to Active-Layer Temperature after Tall Shrub Expansion in Arctic Tundra

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Abstract

Vegetation, active-layer soils, and snow cover regulate energy exchange between the atmosphere and permafrost. Therefore, feedbacks between changes to tundra vegetation and soil thermal regime will fundamentally affect permafrost in a warmer world. We recorded soil temperatures for ~1 year in a Low Arctic landscape with a known history of alder (*Alnus*) shrub expansion on disturbed microsites in patterned ground. We recorded near-surface soil temperatures and measured physical properties of soils and vegetation on sorted-circle microsites in four stages of shrubland development: (1) *tundra* lacking tall shrubs; (2) *colonization* zones with newly established shrubs; (3) *mature*, dense-canopied shrublands; and (4) *paludified*, long-established shrublands with thick soil organic layers. Summer soil temperatures declined with increasing shrub cover and soil organic thickness; shrub colonization suppressed cryoturbation, facilitating the development of continuous vegetation and a surface organic mat on circles. Compared to tundra, mature shrublands cooled soils by up to 9°C during summer, but deep snowpacks warmed soils by >10°C in winter and some mature shrublands were probably underlain by taliks. Paludified shrublands had the coldest summer active-layers, but winter temperatures were much lower than mature shrublands and were similar to earlier stages. Our results indicate that while tall shrub establishment dramatically increases winter soil temperatures within decades, much of this warming is transient at sites prone to paludification because the buildup of saturated peat increases soil thermal conductivity in winter, and the stature and snow-trapping capacity of shrubs diminishes. In the system we studied, shrub expansion has contrasting long-term effects on active-layer temperature due to successional processes and local topography.

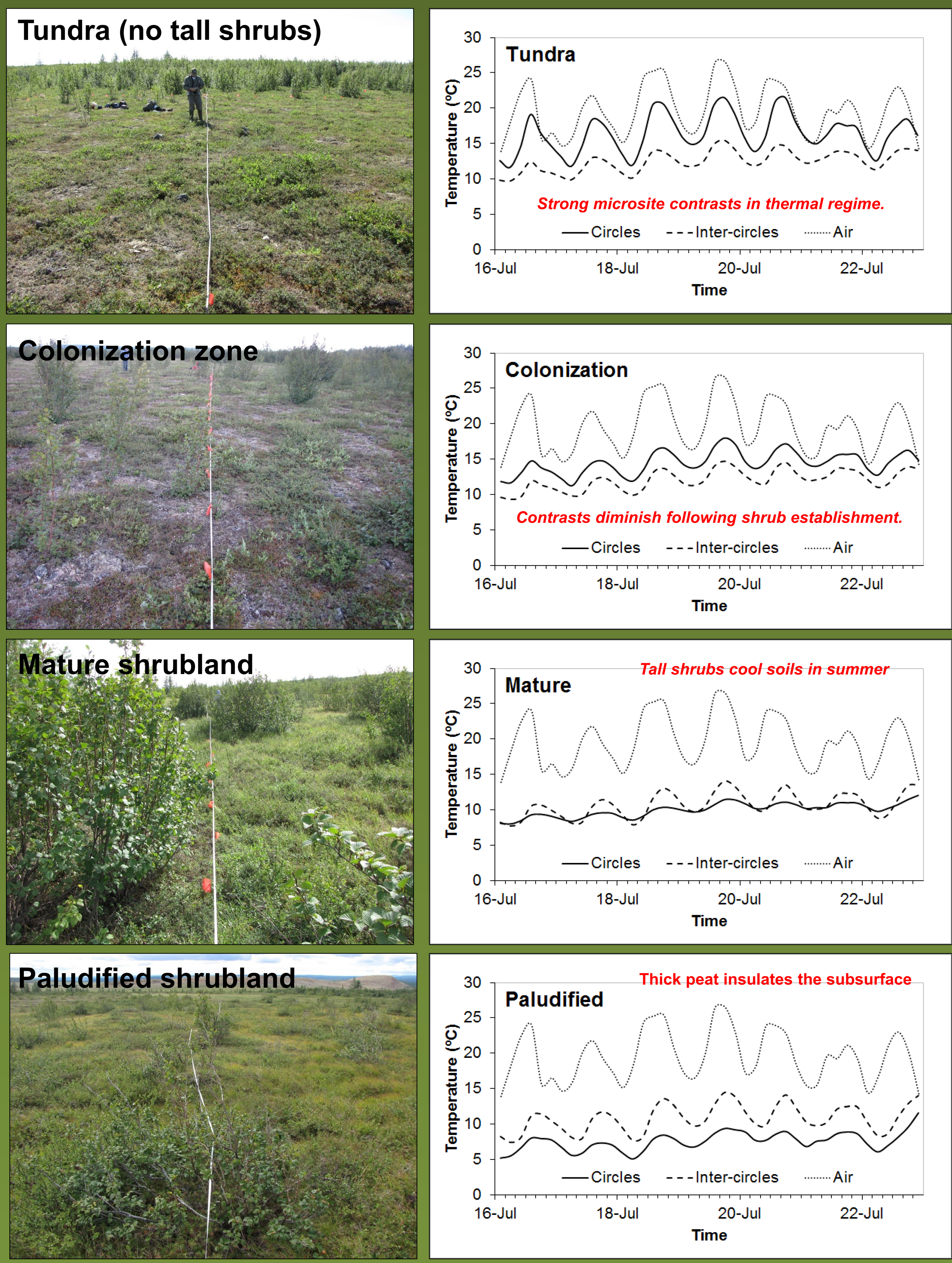

Fig. 4. Example photos (left column), and time-series of mean daily midsummer air and soil temperature at 5 cm depth (right column) for four shrubland stages, 16–22 July 2012.

Methods

This study was conducted in northwestern Siberia near the town of Kharp. Recent changes in shrub cover were known on basis of comparisons of high-resolution satellite imagery from 1968 and 2010 (Frost *et al.* 2013) and we used this record to select field sites. Sorted- and non-sorted circles are widespread at Kharp and the cryoturbated, mineral-rich circle centers facilitate shrub recruitment.

In the field, we measured:

- **Soil temperatures at 5 cm and 20 cm depth** at circle centers and inter-circles areas within four successional stages of shrubland development. iButton loggers recorded data every four hours (2 Jul 2012–8 June 2013).
- **Surface organic thickness** at each temperature station.
- **Leaf Area Index.**
- **Shrub height.**

Fig. 1. Location map showing Kharp study site in northwestern Siberia.

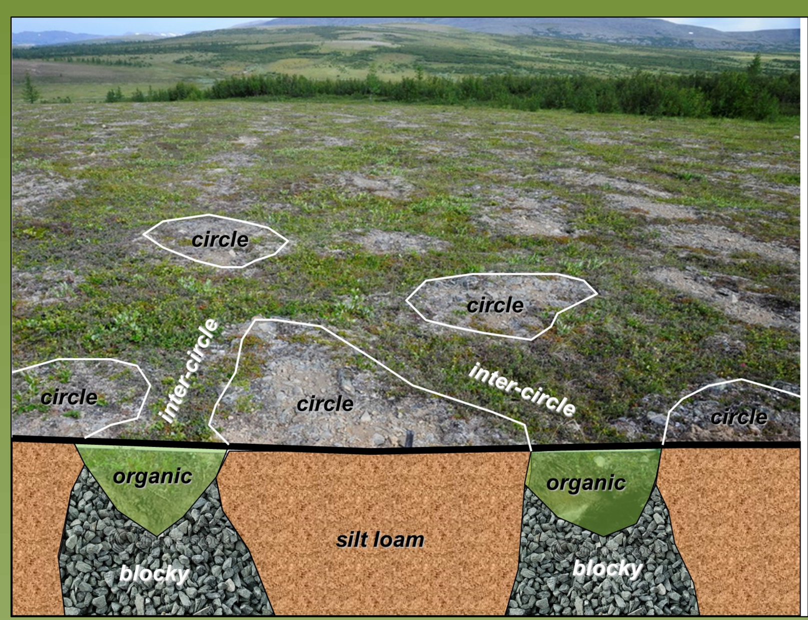

Fig. 2. Overview and cross-section of sorted circle and inter-circle microsites in patterned ground at Kharp.

Results

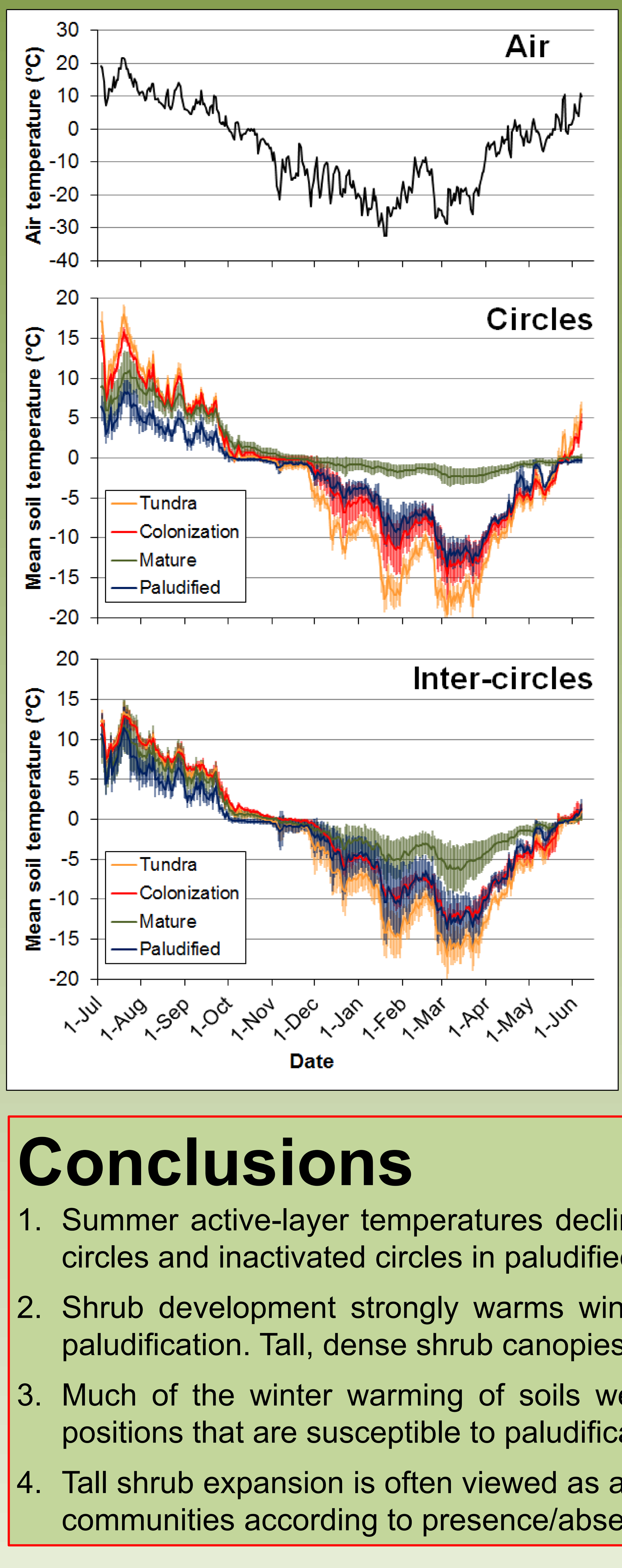

Fig. 3. Time-series of mean daily air (top) and soil temperature at circle (middle) and inter-circle microsites (bottom) for four shrubland stages at 5 cm depth. Shading represents +/- one standard deviation.

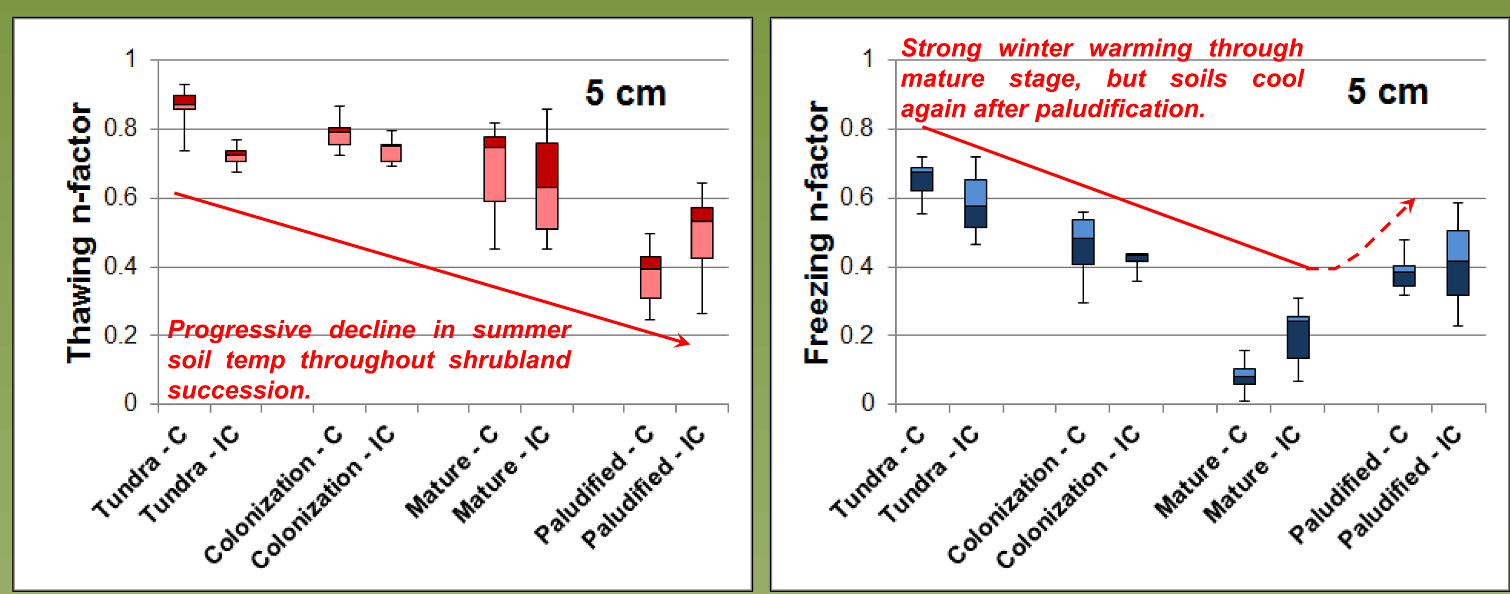

Fig. 5. Box plots of thawing N-factor (left) and freezing N-factor (right) for soils at 5 cm depth at circle and inter-circle microsites for each shrubland stage. Box plots indicate ranges, 1st and 3rd quartiles, and medians.

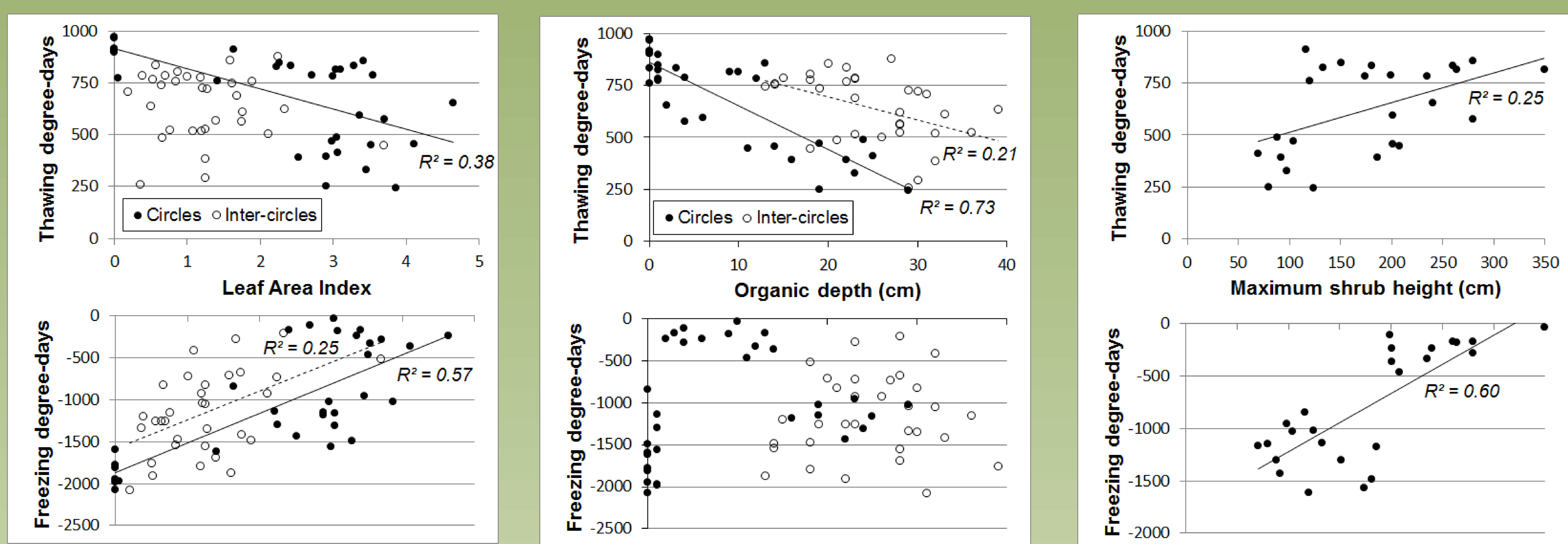

Fig. 6. Correlations between surface organic depth (left column), Leaf Area Index (middle), and shrub height (right) with thawing (top row) and freezing degree-days (bottom) at 5 cm depth at circle and inter-circle microsites. Trendlines are fitted to significant correlations ($p < .05$).

Conclusions

1. Summer active-layer temperatures declined throughout shrubland succession, with ~10°C difference at 5 cm depth between tundra circles and inactivated circles in paludified shrublands.
2. Shrub development strongly warms winter soils through the mature shrubland phase, but then winter soils get colder again with paludification. Tall, dense shrub canopies in mature shrublands likely trap more snow and may form small taliks.
3. Much of the winter warming of soils we observed in mature shrublands is likely to be transient in moisture-gathering landscape positions that are susceptible to paludification.
4. Tall shrub expansion is often viewed as a persistent state-shift in arctic ecosystems, but our results indicate that a binary split of tundra communities according to presence/absence of tall shrub cover neglects successional changes that occur *within* arctic shrublands.

Acknowledgments

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