

Snow refugia: Managing temperate forest canopies to maintain winter conditions

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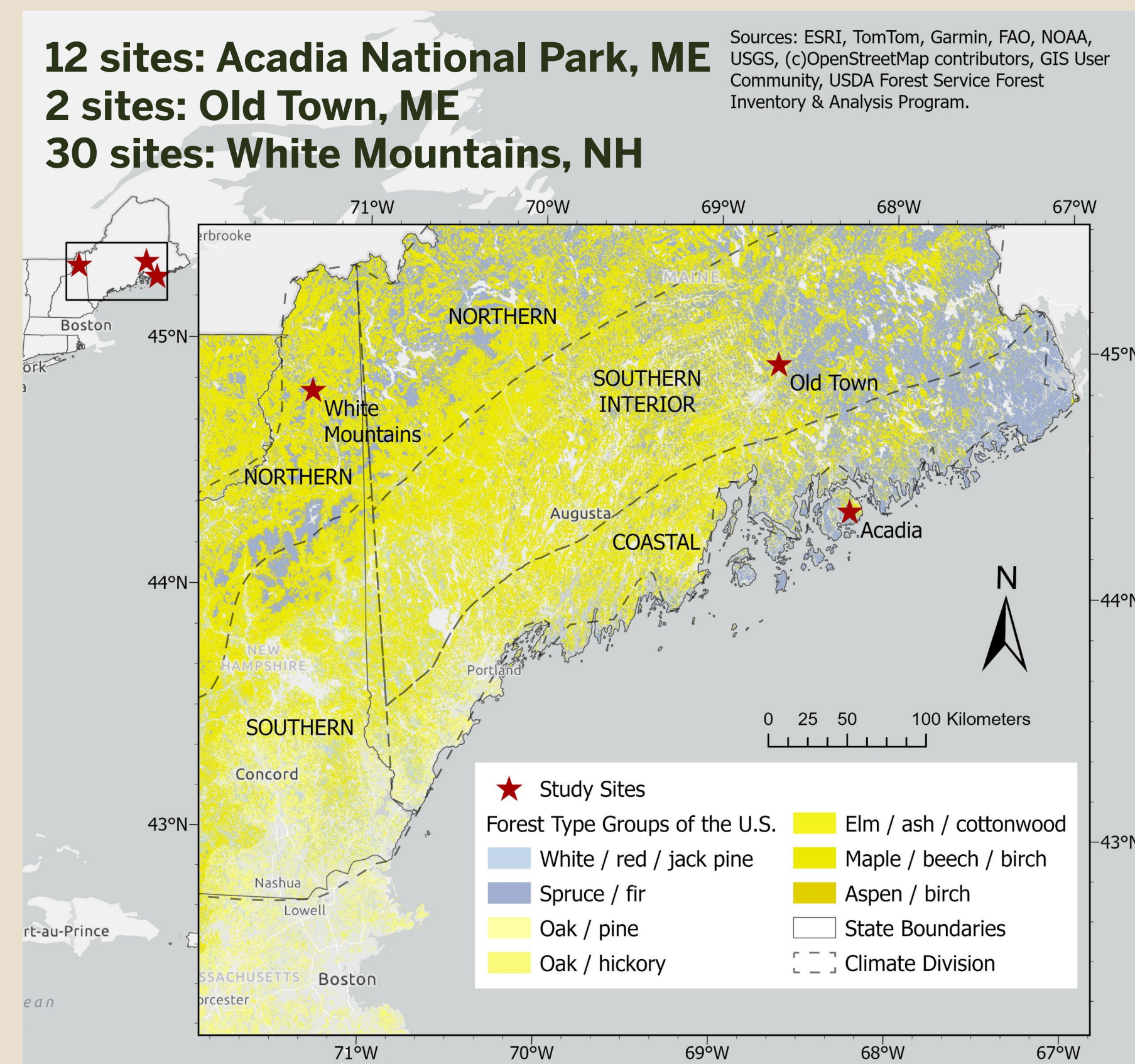


Introduction

Climate change is reducing snowpack across temperate regions with negative consequences for human and natural systems.¹ Because forest canopies create microclimates that preserve snowpack, managing forests to support **snow refugia – areas that remain relatively buffered from contemporary climate change over time that sustain snow quality, quantity, and/or timing appropriate to the landscape** – could reduce climate change impacts on snow cover, sustaining the benefits of snow.

- Most studies in N. America focus on closed-conifer forests vs. open areas and snow interactions; there are knowledge gaps for deciduous and mixed forests with dormant season leaf loss.
- We propose that there is an optimal, intermediate zone along a gradient of dormant season canopy cover (**DSCC; proportion of the ground area covered by the canopy during the dormant season**) where peak snowpack depth and the potential for snow refugia will be greatest because the canopy-mediated effects of snowpack sheltering (which can preserve snowpack) outweigh those of snowfall interception (which can limit snowpack). *Figure 1, Figure 2*
- As an initial test of our hypothesis, we leveraged snowpack measurements in the northeastern US spanning the DSCC gradient (*low*/ $<25\%$ DSCC, *medium*/ $25\text{--}50\%$ DSCC, *high*/ $>50\%$ DSCC). *Figure 3*

Approach – Case Studies



Leveraged measurements of snowpack depth among a variety of forest stand types, canopy cover conditions, within open areas, and along elevational gradients across three climate divisions

Used quartiles of DSCC, when quantitative data were available, or estimated DSCC based on qualitative characteristics such as forest type and harvest history to classify forest sites

Conceptual Model

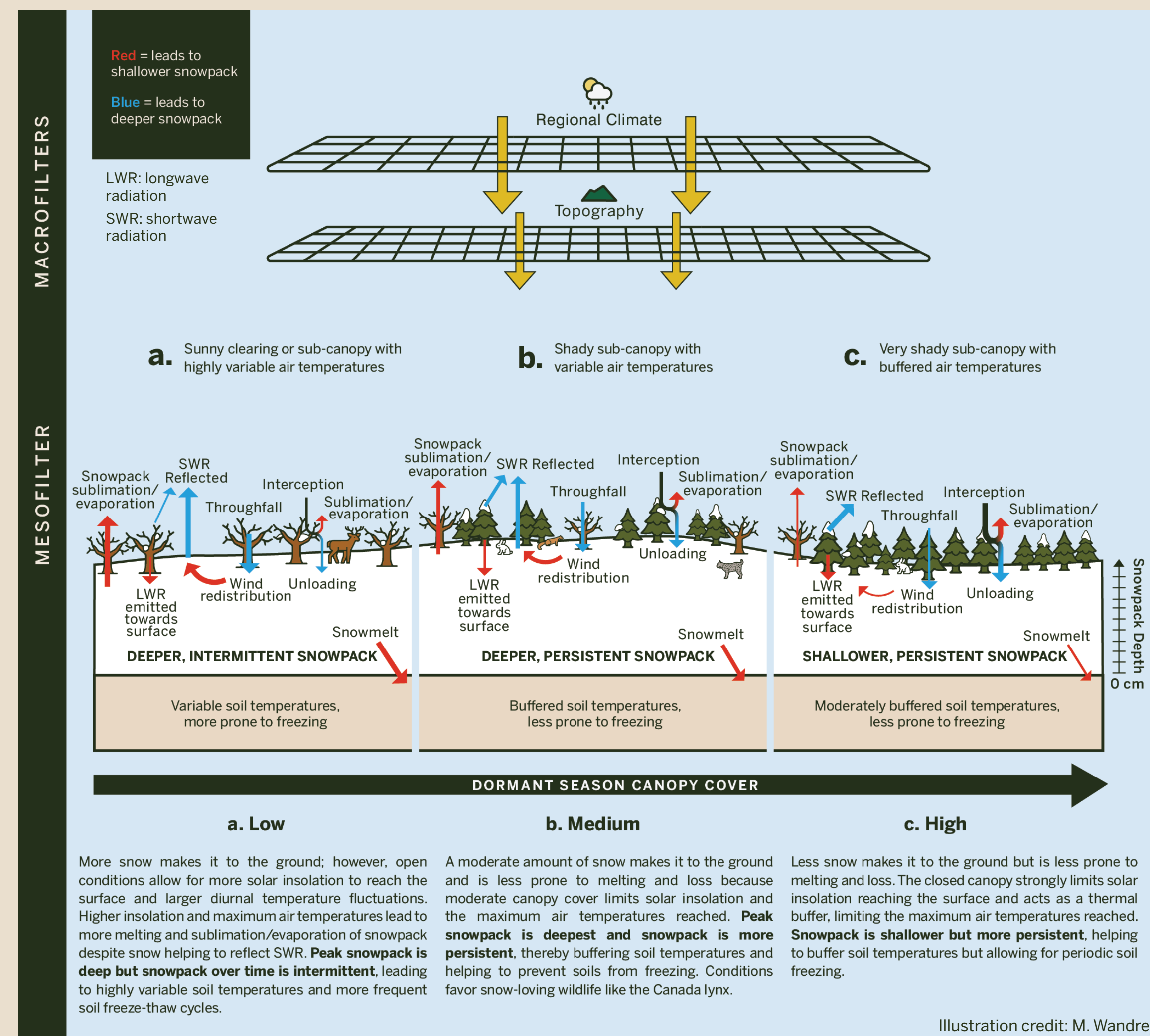


Figure 1. Conceptual diagram of the mechanisms driving differences in snowpack along a continuous gradient of DSCC.

Macrofilters such as regional climate and topographical characteristics (e.g., elevation, slope, aspect) determine base conditions, which are modified by the interrelated vegetation mesofilter characteristics that determine canopy cover (e.g., forest type/composition, canopy density, leaf area, spatial arrangement, gap distributions/sizes).

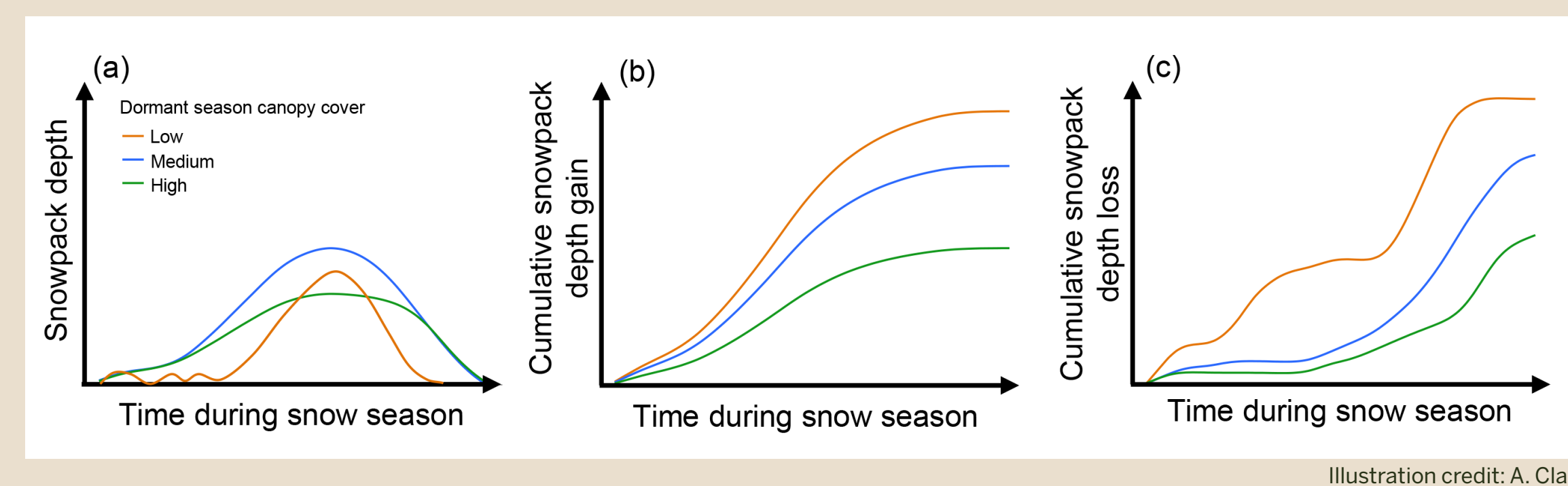


Figure 2. (a) Hypotheses of how differences in DSCC affect sub-canopy snowpack depth and snow cover duration during the snow season. At a given point in time, snowpack depth is the difference between (b) cumulative snowpack depth gain (i.e., snow that reaches the surface) and (c) cumulative snowpack depth loss (i.e., losses from sub-canopy snowpack).

Differences in cumulative **gain** among levels of DSCC are driven by differences in snow throughfall and sublimation/evaporation from intercepted canopy snow. Differences in cumulative **loss** among levels of DSCC are driven by differences in snowpack melt, sublimation, and evaporation.

- Medium DSCC, hypothesized optimal zone with highest peak snowpack depth. Example: vertically stratified mixed coniferous–deciduous forest
- Low DSCC example: recently disturbed area with even-aged regenerating seedlings/ saplings and little to no dormant season leaf area
- High DSCC example: dense coniferous forest with multiple age classes

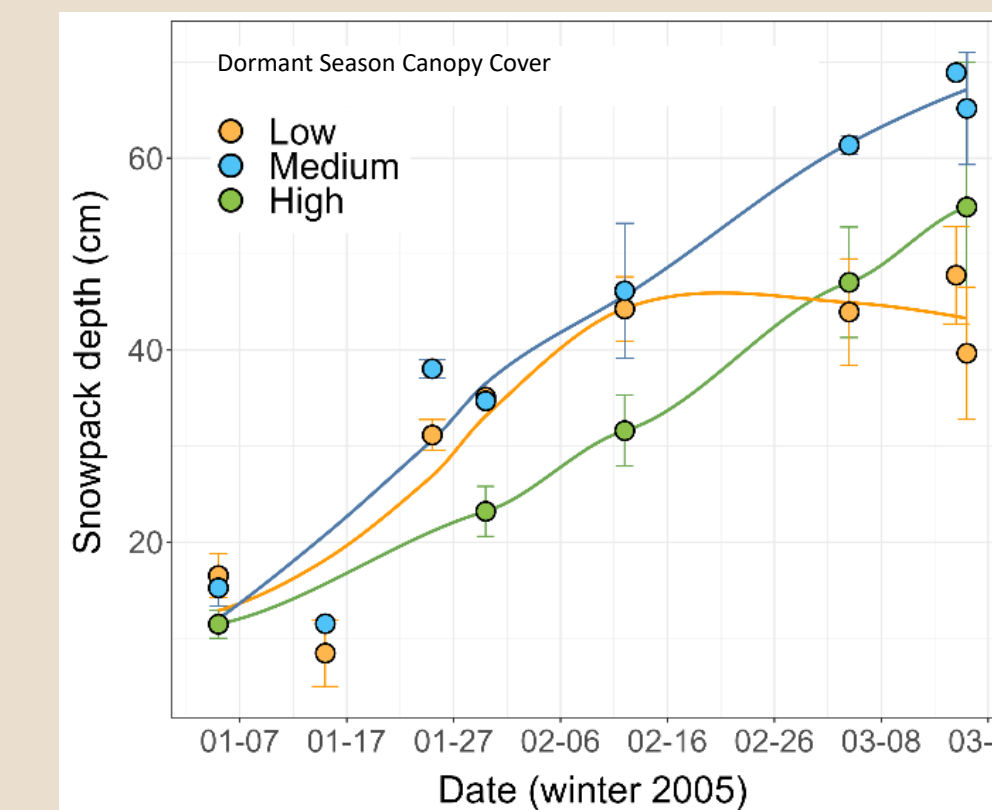
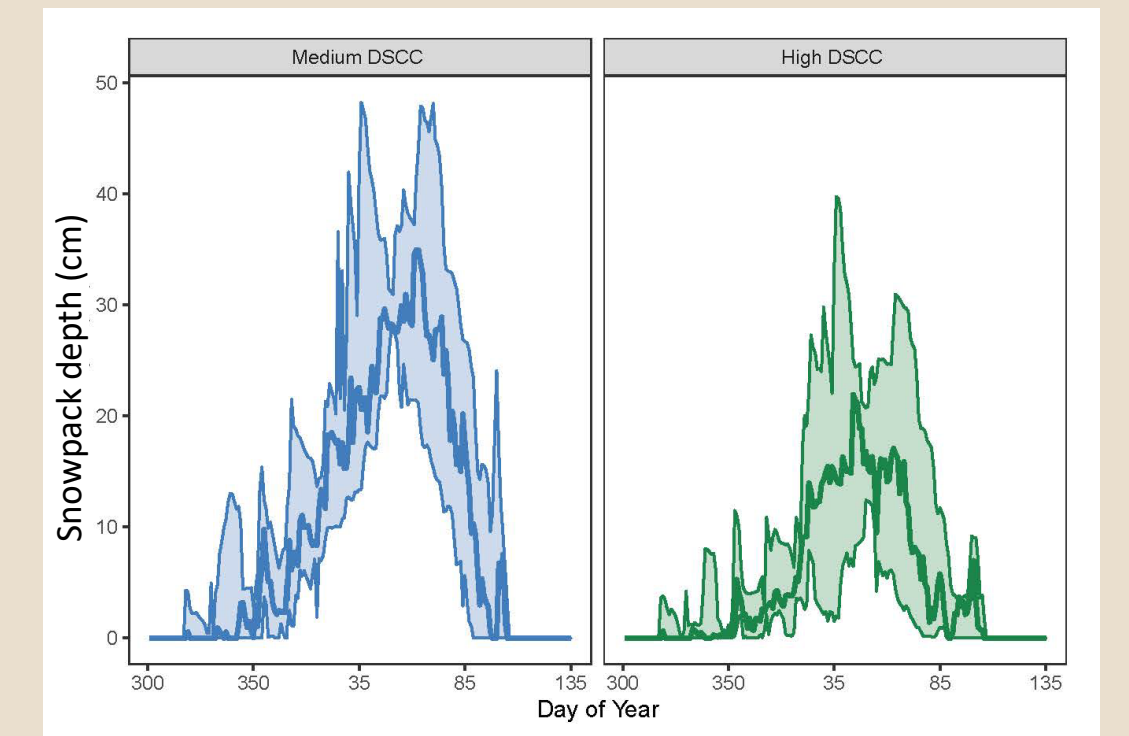
DSCC is illustrated with discrete categories here for simplification but is a continuous gradient

Findings – Case Studies

a. Old Town, Maine:

Snowpack depth in medium DSCC mixed and high DSCC coniferous forest stands over five consecutive winters.

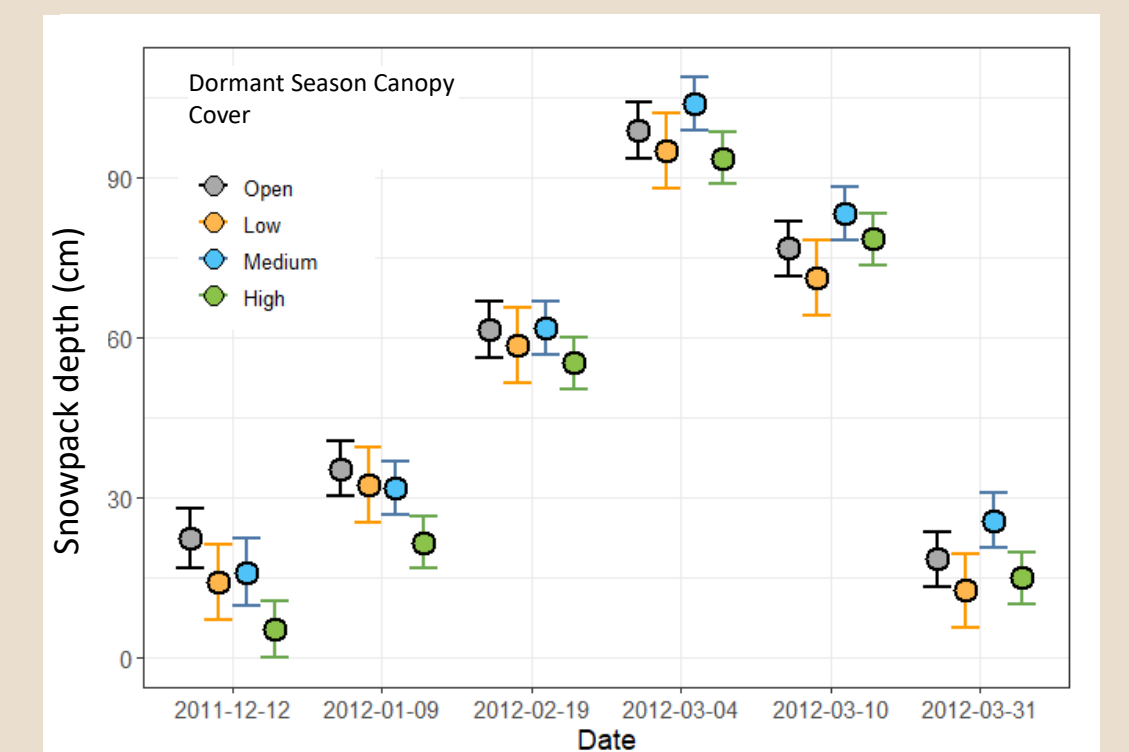
- 15 cm deeper snowpack in medium than high DSCC stands on average
- Similar snow cover duration, but up to >1 month later date of maximum snow depth in medium DSCC than high DSCC stands



b. Acadia National Park, Maine:

Snowpack depth as mean (+/- SE) for 12 sites during winter 2004-2005.

- Sites with medium DSCC had the greatest snowpack depth after the early season accumulation as hypothesized in Fig. 2a
- Low DSCC snow depth was greater than high DSCC after early season but leveled out and began declining February



c. White Mountains, NH:

Mean (+/- SE) snowpack depth (cm) predictions by DSCC for each survey from snowpack data collected at 30 sites during the winter of 2011-2012.

- Early through mid-winter: Deepest snowpack at open sites vs. shallowest at high DSCC sites
- Peak snowpack through late winter: Deepest snowpack at medium DSCC sites

Figure 3. Snowpack depth over time in forests spanning DSCC gradient.

Take-home Messages

Medium DSCC forests (typically, mature mixed coniferous–deciduous) exhibited the deepest peak snowpacks, likely due to reduced snowfall interception compared to high DSCC forests and reduced snowpack loss compared to low DSCC forests.

*This is consistent with our conceptual model, which suggests that there is an optimal, intermediate zone along a gradient of DSCC that enables snow accumulation while protecting against loss, a balance long recognized but rarely tested across forest types or DSCC gradients.*²⁻⁴

Many snow accumulation or snowpack studies focus on the contrast between coniferous and open sites, but our results indicate a need for enhanced focus on mixed canopy sites that could serve as snow refugia.

Measuring snowpack depth and timing across a wider range of DSCC would advance understanding of canopy-snow interactions, expand the monitoring of changing winters, and support management of forests and snow-dependent species in the face of climate change.

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