Author responses to: "Brief Communication: Early season snowpack loss and implications for over-snow vehicle recreation travel planning"

Responses to reviewers are in **bold,** *new text is in italics* ***(bold italics for emphasis)***

Responses to Reviewer 2

I appreciate the opportunity to review this brief communication, as there is very limited work on the implications of changing cryosphere for the multi-billion dollar over-snow vehicle (OSV) ('snowmobile') industry. This industry is far more at risk to cryosphere changes than the ski industry, which has much higher adaptive capacity through cost-effective snowmaking. I concur with G. Patterson that the paper is very well written and the comments on methods and interpretation, and will build on those remarks.

Dear Dr. Scott,
We appreciate your constructive comments and positive feedback. Please find below responses and our revisions to address all of your comments. We have included your insightful comment about the greater risk to climate change the snowmobile community faces due to the absence of snowmaking in the introduction (please see the response to your first comment below).

The dual data sources are very important to enable the exportability of the method to other regional markets across North America (mostly via reanalysis, as Snotel stations are limit in Eastern markets) that would allow inter-regional market comparisons.
A limitation to the paper is that literature review is not comprehensive and given how limited this literature is, it should be complete in my opinion. While I acknowledge space is limited in a brief communication, this will provide future authors with a complete and current state of knowledge to build on. This will also strengthen some of the threshold assumptions made in this paper and comparisons with other regional markets. Specifically, the authors should consider the work on snowmobile tourism under climate change that was completed in New England (Scott et al. 2008. Mitigation and Adaptation Strategies to Global Change, 13, 5-6, 577-59) and parts of Canada (McBoyle et al. 2007. Managing Leisure, 12, 4, 237-250) about 10 years ago.

We agree and have included these citations (thank you for providing these) and relevant discussion in the introduction and discussion section. Specifically, we added two sentences summarizing the results of these two studies to the introduction:
"Due to the dependence on natural snowfall and reduced adaptive capacity compared to the ski community, which can use cost-effective snowmaking to augment the natural snowpack, over-snow vehicle (OSV) recreation is highly vulnerable to climate variability and change (Scott et al. 2007; Mcboyle 2007). Climate change projections for Canada and the northeastern United States under an aggressive greenhouse gas emissions scenario suggest that by the mid-21st

century, OSV season lengths will be reduced by 50-100% in most areas (Mcboyle et al., 2007; Scott et al. 2007)."

Discussion of impacts for visitor experience or economic impacts could be strengthened. Analyses of the impacts of recent record warm winters on the ski industry have revealed that shorter, more varied seasons result in increased congestion, which has adverse impacts on visitor experience (and thus economic surplus). The same impact is likely with OSV (particularly at trailheads) if demand remains stable.

Thank you for the suggestion to add the concept of increased congestion and the resultant impact on high quality experiences to the discussion. We utilized recent results from Perry et al. (2018) to highlight these adverse impacts:
"A survey of the OSV community in Vermont found that reductions in the length of the winter season with sufficient snow coverage for OSV use were observed by 45% of respondents, with 74% of respondents decreasing their OSV use in response to low snow conditions (Perry et al., 2018). This survey also found that encounters with other recreationalists, including OSV users, detracted from a high-quality recreation experience."

Have recent record warm winters revealed any impacts on visitor use patterns or increased impacts on landscapes/ecology?

We are not aware of local (regionally-relevant) changes in visitor use (grouping this with economic impacts in an implicit sense) or ecological impacts, but we have added the latter to the concluding remarks sentence noting the need for additional studies on these topics (see bold italics below):
"Additional studies on achieving regionally-relevant minimum snow depths and better quantification of economic ***and ecological*** *impacts from reduced snow cover area and duration will guide more robust travel management plans in national forests."*

The work of Hagenstad et al. (2018) does provide insight regarding visitor use pattern change as a function of recent climate variability, and we have added sentences on this to the introduction:
"*Skier visits are positively correlated to snowfall (Hagenstad et al., 2018) and we assume that such a correlation is consistent across winter recreation activities."*

"The net effects of reduced season length, more congestion, and lower quality experiences result in lower economic benefits from consumer surplus, or the amount a person is willing to pay over the amount actually spent. For OSVs, consumer surplus is estimated to be approximately 61 USD day^{-1} (Hagenstad et al., 2018)."

The adaptation table is very useful for resource managers to consider appropriate responses. I fully agree with the authors that there is no one-size-fits-all approach, and that climate adaptation has to be informed by local circumstances and stakeholders. Other options the might be included in this table could include: (1) improve smoothness/durability of trailhead and corridor trails, so to require less snow and reduce impacts; (2) restrict access to marked trail areas in early/late season or during mid-season low snow periods; (3) if trail groomers are not used in this region, introduce them to improve the durability of corridor trails.

Great suggestions, thank you. We have added suggestions (1) and (3) to Table 1 and have adjusted an existing adaptation measure to include the marked trails noted in suggestion (2). Our new table is as follows (and includes the suggestion from Reviewer 1 as well):

Adaptation Measure	**Benefit(s)**	**Challenge(s)**
Requirement of minimum snow depth off trail, but not on roads/marked trails, or a lower minimum snow depth on roads/marked trails	Allow OSV use even under extremely low snow conditions, limits resource damage in wildlands; grooming could be utilized to maximize snow depth on road	Preventing users from going off trail under low snow conditions; enforcement, resources required to obtain snow condition information
Ensure high elevation access via a right-of-way	During warmer/drier years, snow conditions are likely to be better (deeper snowpack) at higher elevation	User group conflicts; presence of Wilderness at high elevation; impacts to snow-dependent wildlife species; demand; parking
Removal of blanket opening dates	Prevents opening before SWE_{min} achieved and will limit damage to landscape	Resources required to obtain snow condition information
Identify corridors that collect/retain more snow	During otherwise poor snow conditions, these areas may allow OSV recreation to occur, particularly at lower elevation areas	Need for data on these corridors
Improve durability of trailhead and corridor trails	Allows OSV recreation to occur when minimal snow exists thereby reducing negative impacts in high-use areas	Need for specific quantification of how to improve durability; potential permitting problems
Trade-off: closure of low elevation/sensitive habitat for improved high elevation access	Eliminate chance of damaging landscapes in low elevation regions, increase in the number of days/year that OSV recreation can occur by enhanced high elevation access	Need for collaboration between stakeholders/user groups to identify areas where compromise could occur; may be opposed by those who must travel much further for OSV use.
Fee increases to enhance access and offset impacts from higher demand (i.e., restoration projects)	Would provide for additional resources to monitor trailhead conditions, improve parking/bathrooms at trailheads, fund restoration projects and creation of low-snow OSV trails	Fees are generally opposed by members of the public.
Additional grooming	Allows additional area for OSV use when conditions are insufficient for off-trail use	Costs for grooming equipment and personnel, many OSV users are primarily interested in off-trail use
Clear designation of non-motorized areas (i.e., signage)	Reduces user conflicts by improving knowledge and awareness of areas open (or closed) to OSV use	Costs related to enforcement as well as installation and upkeep of signage

Table 1: Adaptation strategies to address loss of early winter snowpack for OSV recreation.

Based on reviewer 2's comments, we have added the following references:

Hagenstad, M., Burakowski, E.A., and Hill, R. Economic contributions of winter sports in a changing climate, available at: https://scholars.unh.edu/cgi/viewcontent.cgi?article=1190&context=ersc, (last accessed 25 November 2018), 2018.

Mcboyle, G., Scott, D., and Jones, B. Climate change and the future of snowmobiling in non-mountainous regions of Canada, Manag. Leisur., 12 (4), 237–250, https://doi.org/10.1080/13606710701546868, 2007.

Perry, E., Manning, R., Xiao, X., Valliere, W., and Reigner, N.: Social climate change: The advancing extirpation of snowmobilers in Vermont, J. Park Rec. Admin., 36, 31-51, https://dx.doi.org/10.18666/JPRA-2018-V36-I2-8307, 2018.

Scott, D., Dawson, J., and Jones, B. Climate change vulnerability of the U.S. Northeast winter recreation–tourism sector, Mitig. Adapt. Strat. Glob. Chang., 13 (5–6), 577–596, https://doi.org/10.1007/s11027-007-9136-z, 2008.