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Interactive comment on "Thermo-erosion gullies boost the transition from wet to mesic vegetation" *by* N. Perreault et al.

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Thermo-erosion gullies boost the transition from wet to mesic vegetation. Perreault, N., Lévesque, E., Fortier, D. and Lamarque, L. J.

Response to reviewers #1 and #2

We are grateful to the reviewers for their thoughtful and thorough comments that were very useful to improve the manuscript. We have carefully revised the manuscript following their suggestions. In particular, we improved the presentation of the methods, revised the statistical models by including 'gully' as a random factor (which did not change the results), and restructured the section 4.2 of the Discussion to better emphasize that the vegetation response to changes in soil moisture and thaw front depth

is a gradual but relatively rapid change in the context of High Arctic perennial plant communities.

We have responded to all comments as detailed below.

Reviewer #1

The study definitely contents the material for a publication that should provide important insights in the understanding of cold ecosystem functioning and in the assessment of potential consequences of current environmental changes at high latitude. However I think that the paper needs important revisions to reach these goals. I am particularly concerned by two points:

- First, the presented results do not support in a clear way the conclusion highlighted in the discussion. P12202 L5-7: the authors claimed that the soil moisture of disturbed sites is more responsive to rainfall while in fig. 1 there is no significant habitat x date interaction and the authors explained the difference in soil moisture date by summer rainfall. I assume that the not shown data give other view but the fig. 1 actually contradicts discussion claim.

Authors' response: Thanks for pointing this out. We wanted to highlight that, although both intact and disturbed polygons responded positively to rainfall events, disturbed polygons showed greater variability of moisture conditions. Our claim was based on the thorough examination of moisture dynamics Godin et al. (2015; companion paper) conducted at the same site along the gully A. We reworked the sentences to make this point clearer.

- The authors confront the decrease in graminoid biomass following disturbance to the expected increase in biomass due to warming climate. However, there is no mention about the total above-ground biomass, even limited to vascular plants, meaning: What about the change in biomass when considering graminoids, forbs and more particularly shrubs? Is the decrease in graminoid biomass due to unsuitable conditions (less

productive environment) or to the competition with mesic species (similar productivity level but other functional dominance)?

Authors' response: Thanks for pointing this out. Our study was part of a project that was specifically focused on the biomass of forage plants to estimate the effects of disturbance on wetland carrying capacity for snow geese (Legagneux et al., 2012; Doiron, 2014). Therefore, we unfortunately did not sample shrub biomass. There is a low occurrence of Salicaceae species in wet and disturbed polygons (see mean cover % in Table 2), and we are confident that the graminoid above-ground biomass we sampled in these habitats are a good proxy for total above-ground biomass. However, we agree that we underestimated total above-ground biomass in mesic environments where Salicaceae species mean cover averaged > 10 %. We therefore reworked the paragraph in the Discussion, especially by providing shrub and forb biomass estimation from adjacent mesic polygons (E. Lévesque, unpublished data). We also specified that the decrease in graminoid biomass was related to increasing unsuitable conditions. We finally added 'graminoid' in the y-axis title of Fig. 4 to avoid confusion.

- The authors present the results from the multivariate analysis as a clear discrimination of the vegetation of wet polygons from the other habitats (P12203 L1-3) while the fig. 5 rather shows some sort of continuum with the wet polygons and mesic habitats clearly segregated and the intermediated disturbed habitats somewhere between. From my point of view, this gradual change in plant composition should be the core of the message. The authors underlined the rapid changes (in a decadal time, P12201 L18, P12203 L 28) in vegetation but to me this point remains underused.

Authors' response: We agree that the vegetation change from wet to mesic environments is a continuum. We therefore maintained the terms 'gradual change' and 'gradually' throughout the manuscript (P12192 L12, P12201 L8 and L18, P12204 L3). Yet, the transformation of the landscape observed around the gullies within ten years also corresponds to a relatively rapid shift for such High Arctic perennial communities. We rephrased to stress this context.

- Moreover, the comparison between the immediate change in soil moisture and thaw front depth (undisturbed vs. disturbed habitats regardless the time since the beginning of the disturbance) and the gradual response of the vegetation represents by itself an interesting but unexploited result that should be linked to biological inertia or succession dynamics responses concepts.

Authors' response: We agree that this comparison has to be better emphasized. While the change in plant community follows a continuum, we do not clearly observe biological inertia (even though some perennial plants maintain themselves after disturbance), but rather a succession dynamic that is relatively rapid (transformation from wet to mesic environment), especially in the context of perennial species and High Arctic short growing seasons. This pattern consequently stresses even more the substantial effect of thermo-erosion on Arctic ecosystems. We reworked the section 4.2 of the Discussion to clarify the message.

- Second, the presentation of the methods, the justification of methodological choices as well as the presentation of the results remain unclear despite a visible effort from the authors to present exhaustive study. A first missing while crucial information is about the identification of the age of the disturbance for the intermediate habitats (<5, >5 years) as well as the mesic habitats. Can we imagine more accurate information about the age (from long-term monitoring?) that could lead to different habitat segregation analyses?

Authors' response: Unfortunately long term monitoring of all the studied polygons is not available and we cannot identify the exact age of disturbed and mesic habitats. However, the detailed monitoring and mapping work of gullies maintained by Daniel Fortier since 1999 (Fortier et al., 2007; Godin and Fortier, 2010, 2012) allows us to differentiate with confidence polygons by classes of increasing time since thermo-erosion disturbance. We reworked the section to better describe the habitat characteristics.

- The repartition of the habitats in each gully is also missing.

Authors' response: Thanks for pointing this out, we agree we should have been more precise. We added this information both in the Figure 1 and in the new Table 1.

- Concerning this point, I am also surprised to not retrieve the place of the gullies in the statistical models. Actually, the gullies look like true replicates and I assume that the four habitats occurred in each of them. While the presented analyses (the linear models) are based on unreplicated design (meaning poor statistical value), perform the analyses on average values per gully would improve the representativeness of the study.

Authors' response: Thanks for pointing this out. We agree and reanalyzed the dataset using gully as a random factor in a generalized mixed model (procedure MIXED, REML method in SAS). We obtained the same results, i.e. the differences in soil moisture, thaw front depth and graminoid above-ground biomass among habitats were independent from the gully location.

- The results section often repeats between brackets statistical results presented in the tables and the figures. Moreover the tables and figures also provide redundant information (the values in the table 1 are graphically presented in the fig 2 and 3). Such redundancy is at least unnecessary and can lead eventually to hide the message.

Authors' response: We agree and put Table 1 in the Supplement.

Specific comments

- P12194 L5-9: It seems illogical to state that the vegetation response is unknown along with this response contrasts with literature. Rephrase

Authors' response: We reworked the sentence emphasizing disturbances such as landslides that are related to permafrost degradation.

- P12196 L7-19: The first habitat category is marked by (i) and the 3 other not. (ii), (iii) and (iv) are missing.

Authors' response: We added (ii), (iii) and (iv) to mark the other habitat categories.

- P12196 L23: Was the thaw front depth measured in each site in 2009 and 2010 or did the data collection start in 2009 and was completed in 2010? Clarify.

Authors' response: Thaw front depth measurements started in 2009 and were completed in 2010. We added this information in the Methods.

- P12196 L25: Why the determination of thaw front depth necessitated 3 measures in the mesic sites and not in the other? Justify.

Authors' response: We conducted three measurements of thaw front depth in mesic environments because of their heterogeneity.

- P12197 L17-18: Why two different grid size for above-ground biomass harvesting? Justify

Authors' response: Two grid sizes were used because of the difference in vegetation structure and biomass of forage plants related to habitat heterogeneity. A smaller sampling area was necessary in homogeneous wet polygons than in heterogeneous mesic habitats. We added this information in the Methods.

- P12198 L5: The choice of statistical models is unclear: Why log transform the soil moisture and thaw front depth data to analyse them with GLM eventually (L3) while GLM are actually designed to analyse non-normal data set using link functions?

Authors' response: Thanks for pointing this out. We made a typing error, and actually used a General Linear Model and not a Generalized one. Because General Linear Models represent a standard approach that requires the assumption of normality to be valid, we log-transformed soil moisture and thaw front depth data prior to analyses. Following your suggestion above, we reanalyzed the data including the gully factor and used a mixed model approach. We therefore did not log-transformed the data this time. We reworked the sentences in the Statistical analyses section.

- P12198 L16: What is “eco-terrain”?

Authors’ response: “Eco-terrain” referred to habitat category. We replaced “eco-terrain sites” by “habitats”.

- P12198 L20: I know soil moisture and soil water content but “soil moisture content” sounds wrong.

Authors’ response: We replaced “soil moisture content” by “soil moisture” throughout the manuscript.

- P12198 L17: For “vegan” package, cite Oksanen et al. (2012) and for R, cite R development core team (2013).

Authors’ response: We added this information in the text and the references section.

- P12200 L1: Concerning this paragraph: I think the analyses of habitat effects for each plant group (shrubs, mosses) can be useful and provide new lightening.

Authors’ response: We already mention in this section of the Results the decline of graminoid cover and the increase of shrub cover between wet and mesic habitats (see also Table 2) while providing statistical analyses on changes in graminoid aboveground biomass (Fig. 4). We agree moss and shrub biomass would provide additional information. However, as we pointed out above, we unfortunately did not sample biomass for these groups and thus cannot provide additional analyses.

- P12200 L2: What about the 7 missing species, cryptogam species I presume, but why considered them for the CCA and not in the characterization of the plant community?

Authors’ response: Thanks for pointing this out. Aside from the 59 vascular plant species, we sampled 6 non-vascular taxa: lichens, green and dried mosses, Nostoc, fungi and cryptogamic crust (total number of taxa sampled = 65). We erroneously included a taxa referring to unidentified vascular plants, which was marginal and present in only two polygons. After double-checking, we removed it from the canonical cor-

respondence analysis. The mean cover of the 6 non-vascular taxa was included in a new version of Table 2 and we rephrased the plant community characterization by presenting how their abundance (especially that of lichens and mosses) differed among habitats.

- P12200 L17: What is B1 the authors refer to? Authors’ response: Fig. B1 is the figure that can be found in the Supplement.

- P12201 L15-18: Check for sequence of tense. Authors’ response: We checked, and only the present tense is now used throughout the sequence.

- P12202 L16-18: I don’t see the interest of this sentence. Authors’ response: We agree and removed the sentence.

Technical comments

- P12195 L7: “landscape” instead of “ladnscape”.

Authors’ response: We made the change.

- P12198 L2: There is a weird redundant typing error with the double “f” throughout the manuscript.

Authors’ response: Sorry but we do not see this typing error in the pdf version we have.

- P12203 L25: “to” instead of “and”.

Authors’ response: We made the change.

- P12204 L3: space between “decrease” and “in”.

Authors’ response: We made the change.

- P12205 L9: missing closing brackets after Massé et al., 2001.

Authors’ response: We made the change.

Reviewer #2

The authors present 2 years of soil moisture, thaw depth, and vegetation characteristic measurements from undisturbed low centered and degraded ice wedge polygons in the high Canadian Arctic. Large difference is found in biomass, species and abundance between all the groups, while it is only the undisturbed low centered polygon that is distinctly different in thaw and soil moisture. The manuscript is mostly clearly written, with clarification only needed at a few places. I was however disappointed at the discussion section as it is mostly read as a literature review and did not address the finding above (large vegetation characteristic differences not mimicked in the hydrology and thaw). I think there is a danger in simplifying (averaging) the hydrological characteristics like the authors have done (due to the large seasonal variability) and then performing fancy statistics and make conclusions when the results come out as statistically significant. I would like the authors to address the question (which is based upon observing Figure 2-4) why is there such a large site-to-site variability in vegetation characteristics while soil moisture and thaw is nearly identical in most of the groups?

- P12196 L8-9: Unclear what the authors mean with ". . .i.e. with intact rims and non-apparent ice wedges." If there are rims there should be ice wedges (??)

Authors' response: We agree. As stated above, we reworked the section to present more clearly the habitat characteristics.

- P12196 L7-14: The naming of the sites can be made clearer. I am specifically thinking about 1) the name choice of the "mesic" sites, which if I understand it correctly, has also experienced ground subsidence that occurred much earlier than the "more than five year disturbed polygons"; and consistency in naming of sites between text and figures. I think it would help the readability if the names referred to age or degree or absence of recent ice wedge degradation. I also recommend to expand the description of respective polygon group in general and include the photo of the sites in the manuscript (not the supplemental).

Authors' response: We reworked the habitat characteristics, especially to better high-

light that the mesic environments represent one common habitat of the valley and are not necessarily induced by thermo-erosion gullying (Hughes et al., 1994). We kept the site naming as it was since it refers to the common semantics used to describe the main plant communities of the study area (Gauthier et al., 1995; Duclos, 2002; Ellis and Rochefort, 2004; Gauthier et al., 2012). We finally checked for the consistency in the naming of sites between text and figures, and included the pictures of habitats in the manuscript (Fig. 2).

- P12199 L17: What does "habitat x date" mean?

Authors' response: This term refers to the response of habitats to rainfall events that occurred between the two monitoring dates (July 5 vs. July 30). Both intact and disturbed polygons responded positively to precipitations, i.e. soil moisture increased in all polygons between the two monitoring dates, and consequently the habitat x date interaction was non-significant.

- P12199 L21: I suggest removal of the second portion of the sentence, from "Which was also driven by significant differences between wet polygons and the other habitats. . .". It is unclear, while the next sentence provides the message much more effectively.

Authors' response: We rephrased.

- P12199 L23-25: This sentence is unclear. Please clarify.

Authors' response: We rephrased.

- It is rather intriguing that the difference in vegetation characteristics is so large between all polygon groups, while the differences in soil moisture and thaw (as presented) are relatively small. I would like to see the authors expanding on that observation (which is not currently addressed) in their discussion.

Authors' response: Thanks for pointing this out. We believe that the 37 % decrease in soil moisture and 30 % decrease in thaw front depth observed between intact and dis-

turbed polygons rather correspond to a marked than a small difference. We reworked the Discussion including comments on this observation.

- P12201: The observations of decreased soil moisture concur with an earlier model experiment on the role of ice wedge degradation or polygon type on water balance components (see Liljedahl et al. 2012), which is a quite relevant reference for this manuscript.

Authors' response: Thanks for pointing this out. We referred to this article in the Discussion.

- P12202 L5-7: If you are not presenting this data, then do not add this new information to the discussion! Is there a reference for it? Same goes for P12204 L4-5.

Authors' response: We agree and referred to Godin et al. (2015) for the information concerning soil moisture variability. We added information on mean cover of non-vascular plant taxa in Table 2.

- P12204 L10: Please be clear. What do you mean with "our results provide a new perspective"?

Authors' response: We deleted this sentence.

- The discussion is rather long and become a literature review at places. My recommendation would be to build the discussion on references that are already provided (intro/background) and focus the discussion on integrating those with your results. For example, there is a long description about geese in the discussion, but were they even mentioned in the intro?

Authors' response: We lightened the Discussion by deleting redundant comments. We had already mentioned in the Introduction that wetlands are critical habitats for Arctic herbivores, and therefore added "such as snow geese" to clarify the message.

- P12206 L5-7: What do the authors mean with this sentence? Please clarify.

Authors' response: We deleted this sentence.

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