

AUTHOR RESPONSES TO REFEREE 1 COMMENTARY ON MANUSCRIPT 2022-38

Manuscript ID#: **2022-38**

Title: **Significant underestimation of peatland permafrost along the Labrador Sea coastline**

First Contact: **Yifeng Wang**

Second Contact: **Robert Way**

REFEREE 1

[Authors' Response]: We thank Referee 1 for taking the time to provide helpful comments on our manuscript. We have responded to each comment below and have made corresponding changes to the revised manuscript.

COMMENTS TO THE AUTHORS

Ln 48-49 – "... suggest that peatland permafrost is more abundant along the coast than in the interior". This seems to be an important point. Does this study confirm this suggestion? Does the study adequately cover the interior peatlands, or focus primarily on the coast? Despite an underestimation of the coastline peatlands, does this study conclude that permafrost is more abundant along the coast than within the interior?

[Authors' Response]: We have reworded this sentence to clarify that a combination of historical and ongoing use of coastal peatland permafrost environments and a compilation of observations from academic literature of peatland permafrost in coastal Labrador suggest that peatland permafrost is abundant and present along the coast. Prior research in the region, including early works by Roger Brown (1975; 1979), and more recently by Way and Lewkowicz (2016; 2018) and Way et al (2018), suggest a relative absence of peatland permafrost in the interior.

Ln 65 Another important point. To be clear, the study is a point-based inventory. Does this mean that peatland areas are not outlined, and that no coverage of their extent presently exists? In this case, we do not know the individual area or total area of these peatlands.

[Authors' Response]: This is correct. Based on our extensive experience from field validation, we are not confident that individual permafrost features can be reliably traced in many regions using the imagery available to us. Peatlands themselves are abundant along the coast but tracing out peatlands is beyond the scope of this study which is focused on peatland permafrost landforms. It should be noted that in Figure S1 (Supplement Sect. S1), we have shown that prior efforts to delineate the distribution of wetlands or peatlands in coastal Labrador show considerable disagreement and thus we do not feel they are reliable enough to use for areal quantification purposes. We have clarified the point-based nature of the inventory in the Abstract, the Introduction, and the Methods. The peatland permafrost complexes were not outlined, so this inventory does not provide any information on the individual area of peatland permafrost complexes or on the total area of peatland permafrost complexes in Labrador. However, we have conducted and included an additional analysis, in which we have classified each likely and possible peatland permafrost complex type as palsa, peat plateau, or mixed (palsa and peat plateau). This information has been included in the main manuscript (Figure 6) and will also help provide us with a solid platform for future area-based analyses, especially given the more

extensive permafrost coverage of peat plateaus relative to palsas. We have discussed some of the limitations of the point-based nature of the inventory in Section 5.3 (Challenges and limitations of a point-based inventory of peatland permafrost complexes in coastal Labrador).

Figure 4d – does the distribution of peatland permafrost landforms by MAAT say anything about past or present conditions in terms of temperature, for their development? That is to say, why does frequency decrease with cooler MAATs? What is the optimal MAAT for their formation?

[Authors' Response]: This is an excellent question, and we have made some amendments to the text to help clarify. We believe that there are several reasons which explain the discrepancy being noted here. First, peatlands are more extensive in locations with higher MAATs; therefore, the pool of potential locations for peatland permafrost is larger at these MAATs. Second, the importance of the proximity to the Labrador Sea coastline that we have noted for peatland permafrost complexes also shifts these features towards warmer MAATs as compared to if they were found at higher elevations in the interior. We have presented a general description of the distribution of wetlands and peatlands in Section 2.2 (Physical environment) and in the supplement (Supplement Sect. S1).

Do unlikely peatland permafrost landform areas say anything about past or recent loss of permafrost? Did unlikely areas have permafrost in the past or did they develop without permafrost?

[Authors' Response]: This is an area of future research that our research laboratory is exploring. We are not confident at this point deciding as to whether these locations previously had permafrost or not, but we do think it is likely that some did, given the presence of small bodies of water that resemble thermokarst ponds in some of these wetlands. Future work using aerial photography from the late 1940s and the early 1990s and satellite imagery from the 2020s will help to answer these important questions. All WOIs were initially identified as peatland complexes that have the potential to contain peatland permafrost and that are worthy of field- or imagery-based validation and additional review.

Ln 71 Study Area. What is the actual study area – being that area that is encompassed by this study? This section suggests that the study area is all of Labrador – suggesting that the inventory of wetlands of interest using satellite imagery is to cover all of Labrador. If this is not the case, then a specific section that defines the actual study area is necessary. On a map of Labrador, authors should show the actual area covered by their study, otherwise this is rather misleading as it seems that all of Labrador is the study area and has been examined. Suggest the inclusion of a Section 2.4 entitled “limits of study area” which clearly shows and defines the spatial limit that this survey encompasses. At the same time, some statement on what this implies is important as it appears that the study only identifies and attempts to validate peatland permafrost along the coast of Labrador, but not inland.

[Authors' Response]: We agree with this comment and have modified Figure 1 to include an outline for the study area, corresponding to the area within 100 km of the Labrador Sea coastline. As suggested, we have also included a Section 2.4 entitled “Inventory extent” which describes the extent of the inventory and the justification for our focus on the coast. The few sites included originally outside this domain were largely based on prior field experience in those regions, but their inclusion distracts from the broader intent of this study, so they have been removed.

Ln 94 Permafrost distribution. This figure should include the outline of the study area within which the surveys were conducted. In this way, readers will be aware of the area in which the study may

attempt to validate permafrost distribution. It seems, in fact, that the results of this study should be sufficient, based on observations, to redefine the distribution of permafrost zones along the coastline based on its findings. This could be an added objective and it seems reasonable that if the surveys found permafrost peatlands along the coastline but not inland – that the extent of sporadic permafrost could be extended along the coastline and shown as an additional result in this study. If the authors feel they do not have enough evidence in their study to extend the sporadic zone at present, then they should suggest what else is needed to do so either in the discussion or the conclusion.

[Authors' Response]: As suggested, we have modified Figure 1 to include an outline of the study area, corresponding to the area within 100 km of the Labrador Sea coastline.

We have conducted and included an additional analysis, in which we have classified each likely and possible peatland permafrost complex type as palsa, peat plateau, or mixed (palsa and peat plateau). This information has been included in the main manuscript (Figure 6) and helps to inform our discussions on amendments to the southern limit of the sporadic discontinuous permafrost zone in Labrador (Section 5.2, Implications for peatland permafrost and permafrost distribution in northeastern Canada). We feel that a high density of permafrost observations in locations that are currently classified as “isolated patches” or “no permafrost” does provide a compelling argument for this amendment, particularly if they are observations of peat plateaus, which correspond to large areas of permafrost. As suggested, we have included the revision of the current limits of permafrost distribution zones in coastal Labrador as an objective in the Introduction.

Ln 115 Methods. Again, it is important to define the area along the Labrador Sea and Gulf of St. Lawrence coastline that is actually covered by this study. In essence, the study only identifies and attempts to validate peatland permafrost within these areas – not within all of Labrador. Figure 1 can be used to show contiguous survey areas along coast and can also indicate that inland point features outside of these areas were also investigated.

[Authors' Response]: We have modified Figure 1 to include an outline of the main study area, corresponding to the area within 100 km of the Labrador Sea coastline. Strictly speaking, the lack of features in the interior is due to the lack of features, not the study design. There are members of our team (e.g., R.G. Way) who have spent decades on the land in the interior of Labrador without encountering these features regularly. Nevertheless, for the purposes of streamlining and outlining a clearer study design, we have made the requested changes.

Ln 115 Methods. The methods section needs to discuss issues of scale. Specifically, how large / how small an area was identified on satellite imagery. Not only the resolution of the imagery, but what is the minimum size of a permafrost peatland that was counted as a peatland complex and, similarly, how large. It seems that this study did not outline peatland permafrost complexes, but simply identified them as point-based features. Does this mean that each feature was contiguous, or does this include multiple features close together. Similarly, how far away does another feature need to be to be counted as a separate feature? As these are indicated only as point features, it is important to provide some methodological constraints on how a feature was included (minimum size) and how it was differentiated from a separate feature (minimum separation distance). It would be very useful if there were also some insight into the size range of these features – even if they were mapped only as point features.

[Authors' Response]: Information on the resolution of the imagery is included in both Section 3.1 (Data sources) and Section 3.2.1 (Identifying wetlands of interest (WOIs)), and we have provided additional information in Section 3.2.1 (Identifying wetlands of interest (WOIs)) on the range in size of the WOIs. We appreciate the suggestion to include information on the minimum separation distance between WOIs, but we run into challenges with this in relation to differences in the physiographic and geomorphologic characteristics of wetlands across Labrador. Based on field investigations, we have noticed that wetlands are more widespread in southern Labrador, but they tend to be smaller (as small as ~0.2 km²). Near the northern end of the study area, wetlands are less common, but the ones that are present are often very large (as large as ~3.5 km²). The largely geomorphological approach that mappers applied during the identification and mapping stage, based on differences in drainage, vegetation, and morphology between prospective wetland complexes, make it difficult to report a standard minimum separation distance between all WOIs within this study. We have also generated a new figure that shows how the delineation of the WOIs was interpreted and have included this figure as Figure 2 in the main manuscript.

It is not generally clear why a point-based inventory was approached, rather than outlining the potential peatland permafrost terrain units. Perhaps, at least, it could be stated why point-based mapping was undertaken rather than defining polygons and areas.

[Authors' Response]: Our focus was on identifying peatland permafrost landforms in wetlands and not on characterizing wetlands with peatland permafrost. While the distinction may not be obvious, we believe that our approach is all that can currently be produced given the uncertainties in mapping peatland permafrost distribution in our region. We also believe that the current lack of knowledge on these features in the region necessitates building a step-by-step baseline understanding. We have provided additional justification for the point-based nature of the inventory and have also included a discussion of some of the limitations of this approach compared to grid-based or areal-based inventorying in Section 3.2.1 (Identifying wetlands of interest (WOIs)) and Section 5.3 (Challenges and limitations of a point-based inventory of peatland permafrost complexes in coastal Labrador). It should be noted that unlike many regions elsewhere in Canada, there are no prior observations of permafrost in most of the regions we are describing.

As a note, it would have been beneficial for the authors to have perhaps differentiated the sizes of the peatland permafrost terrain into a least “small”, “medium” and “large” peatland units with some type of categorization. For example, in Figure S9 it becomes clear that permafrost peatlands are of different sizes, and may benefit from differentiation. In Figure S10 it is not really clear how one peatland unit is differentiated from another as they are shown only as point features and the boundaries of each are not easily distinguishable. Again, a simple differentiation of the size of each in categorization would have been beneficial.

[Authors' Response]: We have provided additional information in Section 3.2.1 (Identifying wetlands of interest (WOIs)) on the range in size of the WOIs. We have also generated a new figure that shows how the delineation of the WOIs was interpreted and have included this as Figure 2 in the main manuscript. While the peatland size is relevant to a wetland mapping initiative, we are worried about an implication that larger peatlands may have more permafrost area when that is not something that we can evaluate at this point. Instead, we have conducted and included an additional analysis, in which we have classified each likely and possible peatland permafrost complex type as palsa, peat plateau, or mixed (palsa and peat plateau). This information has been included in the main manuscript (Figure 6) and will be useful for future area-based analyses given the more extensive permafrost coverage by peat plateaus relative to palsas.

Ln 208-212 Even though areas were identified only as point features, something about their size should be included. What was minimum size, what was maximum size? Even point features have separation distances, so what was the minimum separation distance between features?

[Authors' Response]: We have provided additional information in Section 3.2.1 (Identifying wetlands of interest (WOIs)) on the range in size of the WOIs. We appreciate the suggestion to include information on the minimum separation distance between WOIs, but we run into challenges with this in relation to differences in the physiographic and geomorphologic characteristics of wetlands across Labrador. Based on field investigations, and informed by many wetland and peatland distribution maps presented in the supplement (Supplement Sect. S1), we have found that wetlands are more widespread in southern Labrador, but they tend to be smaller (as small as ~0.2 km²). Near the northern end of the study area, wetlands are less common, but the ones that are present are often very large (up to ~3.5 km²). The largely geomorphological approach that mappers applied during the identification and mapping stage and these differences in wetland characteristics make it difficult to report a standard minimum separation distance between all WOIs within this study.

Ln 280-285. Discussion regarding distribution of permafrost peatland complexes is intriguing, and also opens up additional discussion. Where are data showing which peatland complexes lie below marine limit, and which are above? This is alluded to but not shown.

[Authors' Response]: We agree with the reviewer that providing information about the distribution of peatland permafrost complexes relative to the marine limit would be extremely relevant and useful for this study and for understanding overall permafrost distribution in Labrador. Unfortunately, there is no existing marine limit or marine sediment dataset for the entire coast of Labrador, so it is difficult to provide an estimate of the elevation of each of the peatland permafrost complexes relative to the local marine limit. This is a typical issue in Labrador where there is a paucity of baseline information compared to other regions (e.g., the Northwest Territories). We have estimated the local marine limits for as much of our study area as possible using inverse distance weighted interpolation from a series of observations that were compiled in Dyke et al. (2005) and have presented this information in the supplemental (Supplement Sect. S3), but we have not presented it as part of the main manuscript given that the interpolation does not cover our entire study area. We have also included additional information in Section 5.1 (Distribution of peatland permafrost in Labrador) describing the lack of available data on marine limits or marine sediments.

The issue of deglacial history and marine recession history are relevant here, in terms of defining the oldest terrestrial age surface in the study area and, thus, oldest peatlands. It appears that deglaciation of the region was from as early as 11 ka BP, along the coastline and then younger moving inland to about 7 ka BP. At the same time, marine recession was occurring in the southern areas along the coastline. Presumably, along the coastline at certain elevations deglaciation and marine recession were the earliest, and these are the oldest peatlands. So – are the oldest peatlands generally also the ones with likely permafrost? Are they thickest, do they have the most syngenetic ground ice? It would be useful to tie the history of marine recession and deglaciation into this discussion a bit more. At present, this is portion of the discussion very limited and is worthy of further consideration.

[Authors' Response]: We agree with the reviewer on the relevance of deglacial history, marine recession, and peatland age to peatland permafrost distribution, but we are unfortunately limited

by the lack of available information on these variables. We have included additional information in Section 5.1 (Distribution of peatland permafrost in Labrador) describing the importance of considering peatland initiation timing and peat deposition rates for peatland permafrost distribution, based on their impacts on peat thickness and the thermal offset.

Ln 287-299. Again, there seems to be more to say here when speculating on the history of peatland initiation ages within the study area – which most of these products/datasets do not take into consideration (and presently, the authors do not either). Admittedly, few peatland initiation ages exist in the region, though theoretically the youngest may be constrained to near the coast. The authors might consider referring to the following articles as a starting points on understanding peatland ages in the region and their possible influence on permafrost peatland distribution:

Gorham, E., Lehman, C., Dyke, A., Janssens, J. and Dyke, L., 2007. Temporal and spatial aspects of peatland initiation following deglaciation in North America. *Quaternary Science Reviews*, 26(3-4), pp.300-311.

And:

Dyke, A.S., Giroux, D. and Robertson, L., 2004. Paleovegetation Maps of Northern North America, 18 000 to 1 000 BP. Geological Survey of Canada.

[Authors' Response]: We appreciate this comment and have included additional information in Section 5.1 (Distribution of peatland permafrost in Labrador) mentioning the importance of considering peatland initiation timing, peat deposition rates, and peat thickness for peatland permafrost distribution.

Ln312-313: It seems that this study could go a step further by outlining the proposed extension of sporadic permafrost based on their results. Providing an additional Figure 7 with proposed areas of sporadic permafrost would be a useful addition and seems reasonable based on the extent of the study and the results.

[Authors' Response]: We appreciate this suggestion. We do recognize that one's interpretation of the isolated patches of permafrost zone, as a zone within which less than 10% of the area is underlain by permafrost, can complicate areal estimates of permafrost coverage given this distribution zone's lack of a lower threshold. Despite these challenges, we do believe that a high density of permafrost observations in locations that are currently classified as "isolated patches" or "no permafrost" provides a compelling argument for the southerly extension of the sporadic discontinuous permafrost zone. To support this argument, we have conducted and included an additional analysis, in which we have classified each likely and possible peatland permafrost complex type as palsa, peat plateau, or mixed (palsa and peat plateau). This information has been included in the main manuscript (Figure 6) and is very useful for informing discussions regarding the potential southward extension of the sporadic discontinuous permafrost zone (Section 5.2, Implications for peatland permafrost and permafrost distribution in northeastern Canada). For example, we have used this information to help inform the proposed location for a new southern limit of the sporadic discontinuous permafrost zone in Labrador, and as suggested, we have included this in the main manuscript as Figure 6B.

Ln330-333: This may warrant an additional sentence or two for clarification. What is the basis for mis-identification based on? For example, most maps in Fig S5 show greater abundance of wetland or peatland areas in the south than in the north. Is it the absence of mapped peatlands along the coastline in these inventories that leads author's to suggest that their identified areas here may not

be peatland permafrost, but instead lithalsas? Or did field visits (Fig. 2) along the northern coastline confirm that these were lithalsas or in fact peatland permafrost? In general, the absence of peatlands shown in Fig. S5 suggests that either there are few peatlands here, or they are too small to be mapped at that scale.

[Authors' Response]: We agree and have included additional sentences in Section 5.3 (Challenges and limitations of a point-based inventory of peatland permafrost complexes in coastal Labrador) to clarify that the potential inclusion of lithalsas in the inventory is linked to the requirement for peatlands (and therefore peatland permafrost landforms) to contain 40 cm of peat. Segregated ice mounds found in wetlands with less than 40 cm of overlying peat may have been included in the inventory, particularly in the northern end of the study area where wetlands are less abundant and peat deposits are thinner.

Figure 6. Reference source for this map seems odd “audio tape?”. Whereas it is interesting to show palsa bogs mapped by ELC here, were there other terrain types related to peatlands that were mapped too? There seems to be a good agreement between the mapped palsa bogs and peatland permafrost, but what were other areas mapped as? Were these peatland areas that did not contain permafrost or other terrain types? Could be discussed in text if not in figure itself.

[Authors' Response]: We agree that it is an odd reference, but it seems to be the only available resource that describes the survey. The audio tape transcript is available for download from Natural Resources Canada, and we have included the download link for the transcript document to the reference. As suggested, we have included a sentence in the text to describe some of the other terrain units from the ELC within which the remaining likely peatland permafrost complexes were found.

This study seems almost purposefully vague about existing weather and climatic conditions occurring within the areas of identified permafrost peatland terrain. Given the adherence of these areas to the Labrador coastline, it is indeed interesting to speculate to what extent a maritime climate influences the distribution of permafrost across the study area. The authors allude to conditions of fog, cloud cover, snowpack and wind being potential factors in their distribution. Presumably, these factors are being examined in site-specific studies. The authors could elaborate somewhat further, in the discussion, and most certainly in the conclusion, for the need to investigate local climatic conditions that may support the presence of permafrost in these areas. In a way, this is similar to the examination of the role of inversions in some mountainous environments for sustaining permafrost. It would be suitable for the authors to provide some insight into the intent and value of local studies to understand the distribution of contemporary permafrost further. In addition, such work could aid in more accurately determining extent of sporadic permafrost along this maritime area.

[Authors' Response]: As suggested, we have included sentences in both the Discussion (Section 5.1; Distribution of peatland permafrost in Labrador) and the Conclusion describing the need for additional local, field-based investigations into the role of certain climatic variables on peatland permafrost distribution and persistence.

Figure S3. Not sure that depicting only locations of non-peatland permafrost locations is useful. Perhaps better to include both those that did as well as those that did not.

[Authors' Response]: Following previous suggestions, we have defined our study area more clearly as the area of Labrador and adjacent parts of Quebec that fall within 100 km of the

Labrador Sea coastline. We have described in Section 2.4 (Inventory extent) our justification for our focus on the coast, so we have removed this figure from the supplemental material as it is no longer necessary.

Suggest adding “northeastern Canada” to the end of the title

[Authors’ Response]: We have added “in northern Canada” to the end of the title.

Ln 12 Change “maps” to “depictions”

[Authors’ Response]: We have changed “maps” to “estimates”.

Ln 21 Ditto

[Authors’ Response]: We have changed “maps” to “estimates”.

Ln 27 consider replacing “perennially frozen ground” with “permafrost”

[Authors’ Response]: We appreciate the suggestion, but we have kept the text as is to avoid using the word “permafrost” too many times in the same sentence.

Ln 41 delete “they”

[Authors’ Response]: We agree and have deleted “they”.

Ln 43 consider replacing “have suggested that peatland permafrost is present” with “have depicted peatland permafrost as present”

[Authors’ Response]: We agree and have changed “have suggested that peatland permafrost is present” to “have depicted peatland permafrost as present”.

Ln 46 change “is” to “are”

[Authors’ Response]: We appreciate the suggestion, but we have kept the text as is.

Ln 58 change “have been” to “are”

[Authors’ Response]: We have changed this sentence to “Previous peatland permafrost mapping in Labrador has...”.

Ln 60 change “and no” to “with no”

[Authors’ Response]: We agree and have changed “and no” to “with no”.

Ln 60 change “efforts have been completed” to “effort completed”

[Authors’ Response]: We agree and have changed “efforts have been completed” to “efforts completed”.

Ln 75 provide location of coldest MAAT (-11.9C) and warmest MAAT (+1.5C) for context and, if possible, so locations on Figure 1.

[Authors’ Response]: We have included details describing the locations of the lowest MAAT, in the Torngat Mountains, and highest MAAT, near the community of Blanc-Sablon.

Ln 73-78. Unless provided elsewhere, indicate proportion of snowfall versus rainfall and range in total precipitation.

[Authors' Response]: We have included a sentence describing the maximum precipitation, based on the CHELSA dataset, and the annual proportion of snow to rain at two Environment Canada weather stations at opposite ends of our study area over the 1981-2010 climate normal.

Ln 87 How can glacial till be deposited following retreat of the Laurentide Ice Sheet, except by another glacial/glaciation? Explain, rephrase or delete.

[Authors' Response]: We agree and have removed "and following" from the sentence.

Ln 96 Try to keep spelling of words like "archaeological" and "paleogeographic" consistent. Decide on preferred spelling and use it throughout.

[Authors' Response]: We agree and have changed "archaeological" to "archeological".

Ln 141 change "that exceeded" to "exceeding"

[Authors' Response]: We agree and have changed "that exceeded" to "exceeding".

Ln 177-178. Change "wetland complex by wetland complex" to "WOI" if appropriate.

[Authors' Response]: We agree and have changed "wetland complex by complex" to "WOI by WOI".

Ln 188 Change "was" to "were".

[Authors' Response]: We agree and have changed "was" to "were".

Ln 189 Delete "of WOIs"

[Authors' Response]: We have deleted this sentence as suggested by Referee #3.

Ln 191 Delete "that was"

[Authors' Response]: We agree and have removed "that was".

Ln 251 95 % - remove space.

[Authors' Response]: We appreciate the suggestion but have retained the space to ensure that all units in the text are preceded by a space.

Ln 262 Delete "In this, study, we demonstrated that". Start sentence with "Peatland permafrost ...". Reference Figure 4b at end of sentence.

[Authors' Response]: We agree and have started the sentence with "Peatland permafrost ...". We have referenced Figure 5B at the end of the sentence.

Ln 265 Provide reference to a figure as supporting evidence.

[Authors' Response]: We agree and have provided reference to Figure 4 as supporting evidence.

Ln 535 Reference seems incomplete. Nordicana D?

[Authors' Response]: Thank you, we have reformatted the reference.

Ln 538-539 Reference incomplete.

[Authors' Response]: Thank you, we have reformatted the reference.