Dear Referee,

Thank you for taking the time to review our paper, provide constructive suggestions, and share your extensive knowledge to improve our study. Below we provide detailed responses to each of your comments, with our responses in blue.

The authors have completed the first comprehensive inventory of Alaskan glacier marginal lakes, subdividing them both by dam type, topological relationship to the glacier, and size. This is a useful approach and as a baseline the number of lakes in each category and their respective area changes is useful. At present the paper does not provide the reader with sufficient context to understand the unique nature of many of the ice marginal lakes in Alaska, particularly the largest. There is a lack of referencing of previous studies that have explored specific areas identifying the relationship of the lakes and glaciers in away that would lend much better context to the inventory. An over reliance on references to the Himalayan and Peruvian Andes, which are not the best or in most cases even useful analogs underscores this issue. For Alaska it is indicated that large glacier lakes have an area greater than 10 km2, whereas inventories of both Cordillera Blanca and High Mountain Asia often use 0.1 km2, a two order of magnitude difference in scale (Emmer et al 2016; Chen et al 2021). The combination of these issues limits the value of the inventory data.

Thank you for this feedback. We acknowledge that we focus on comparisons to other regions, or to a few regional inventories, rather than including the many individual case studies to help describe the physical processes underlying the trends we observed in Alaska. We focus our introduction on regional lake inventories which classify dam type even if they are not the best analog regions, to illustrate why dam type and topological position classification is important when analyzing regional lake trends. This type of study has not been done thus far in Alaska (nor other glaciated regions that might provide the most logical comparisons) and only occurs in limited regional-scale studies. However, in revision, we will add an Alaska-specific subsection that describes some of the examples you provide in detail to elaborate on the unique characteristics of the lakes found in this region.

There are several common features of the Alaskan lakes that are unusual leading to different behavior than for most glaciated alpine regions. I will review another of examples that illustrate this with referencing where appropriate. These illustrations are meant as examples, and not specific ones the authors may choose to use or need to specifically address.

Thank you for all these excellent examples and providing citations for the specific studies. As previously mentioned, we will incorporate examples to illustrate Alaska-specific context.

An examination of Figure 5 illustrates how context is vital. The frequency of lakes is broken down by actual area in 2016-2019 in panel A, with the largest four groups greater than 2 km2 in area representing few of the total, but dominating the spatial area change noted in panel B. There are a significant number of Alaskan glacier lakes with an area greater than 20 km2. There are some specific unique characteristics of these larger lakes.

Most of the largest Alaskan glacier lakes are found in a coastal plain environment and are impounded by a coastal shoreline systems and/or proglacial deltas formed when the glacier terminated at the lake margin and outwash plains more than by moraine. They can be categorized as moraine dammed. But there is no potential for a dam failure to cause issues at near coastal lakes such at Mendenhall Glacier, Yakutat Glacier, Excelsior Glacier or Bear Glacier. All of these lakes are less than 20 m in elevation. Johnstone Lake the proglacial lake of Excelsior Glacier it is less than 1 km from the ocean with the highest elevation between tidewater and the lake being ~10 m (Figure 1). This lake has expanded from 9-18 km2 from 1994-2018, but still poses no GLOF risk. At Bear Glacier terminates in expanding Bear Glacier Lake, which is 0.5 km from the ocean with a maximum elevation of ~7 m between the ocean and the lake. Malaspina Lake (~85 km2) is the proglacial lake at the southeast margin of Malaspina Glacier. It is 2 km from the ocean with a maximum elevation of about ~10 m. Grand Plateau Glacier Lake (~45 km2 Figure 2) is in a similar position.

While it is true that these lakes do not pose any GLOF risk, we emphasize that GLOF risk is not the main motivating factor behind this inventory. We will modify our introduction to better communicate that while GLOF hazards are important and will be the focus of a subsequent study, here we are interested in looking at decadal scale changes to glacial lakes in Alaska to better understand where lakes are on the landscape, what changes are occurring, and attempting to parse whether these changes can be generally categorized by dam type and topological position to capture decadal scale trends. Therefore, we believe it is pertinent to include these large, low lying proglacial lakes in our inventory as they do have an impact on ecosystems, sediment transport, glacier dynamics, etc, even if they do not pose a GLOF risk.

Many of these lakes have filled basins developed by the loss of the piedmont lobe terminus formed when the glacier exited the mountains onto low slope forelands/coastal zones. Giffen et al (2014) examined retreat and expanding lakes of glaciers in the Kenai and Katmai regions. ie. Bear, Fourpeaked, Spotted (Figure 3), Hallo Glaciers are examples of glacier lakes filling former piedmont lobe depressions. Mendenhall, Grand Plateau are examples from southeast Alaska. This is not a proglacial lake type seen in High Mountain Asia or the Andes north of Patagonia. Should you separate out this group of moraine dammed proglacial lakes terminating in a coastal environment? Loriaux and Casassa (2013) found a total lake area of the Northern Patagonia Icefield of 167.5± 8.4 km2 for 2011, an increase of 64.9% from 1945 (101.6±19.1 km2). They noted an 18 km2 expansion of San Quintin Lake accounting for 27% of the total expansion. This also is a coastal environment piedmont lobe terminus depression filled proglacial lake.

We agree that it would be valuable to separate out these lakes (>10 km^2) for a subanalysis to show that the majority of area change documented was experienced by these large lakes. We will include a description of these lakes in the discussion that emphasizes their unique nature and occurrence in Alaska.

The size of the lakes combined when depth also allows for the production of large tabular icebergs, such as seen at Excelsior, Ellsworth, Field and Yakutat in recent years. Trussel et al (2013) examined the rapid retreat of Yakutat Glacier in Harlequin Lake (in 2020 ~70 km2), with sections going afloat (Figure 4 and 5). They note this ability the ability to calve large tabular icebergs is largely due to the limited subaqueous melt compared to tidewater glaciers. The buoyancy also requires substantial water depth. The other unique element to these lakes given the large glaciers that feed them and the coastal setting, is they can be much deeper than examples from the Himalaya or Peruvian Andes. Trussel et al (2013) reported a depth of 325 m at the 2010 calving front of Yakutat Glacier. Loso et al (2021) note water depths of 330 m in Alsek Lake. For this inventory when do you draw the line between a glacial lake and one that is sufficiently tidally fed to not be a lake? Is Vitus Lake in front of Bering Glacier a part of the inventory?

For this inventory, we use distance from the RGI (<1 km) to determine a glacial lake. Though a lake may have tidal influence, if there is a clear outline of the lake with a majority physical barrier (i.e. moraine with an outlet stream), we consider it an ice-marginal lake. We acknowledge that some of these low lying lakes may have tidal influence, however, their presence and change in area is linked to glacier dynamics, and therefore of relevance. We will clarify our definition of a glacial lake in the text, and explain that some of the lakes may have a tidal influence. Vitus Lake is included within this inventory, and is classified as a proglacial moraine-dammed lake.

For Ice Dammed lakes it has to be emphasized that there are many that have had a long history of consistent GLOF events. Neal (2007) provides a detailed examination of glacier lake outbursts from beneath Tulsequah Glacier into the Taku River. They report on 41 GLOF’s during the 1987-2004 period with the main source migrates from Tulsequah Lake to Lake No Lake, with little change in maximum outburst discharge. After 1984 a large proglacial lake has formed at the terminus of the glacier as well, which can help mitigate peak flows (Figure 6) (Pelto, 2017). Carrivick and Tweed (2016) list Tulsequah as the glacier lake with the most outburst floods. Wilcox et al (2014) report on the migration of Ice Lake which is ~17 km upglacier. This lake drains once or twice each year usually in late summer or early fall. This is another attribute worth noting that if a ice dammed lakes or supraglacial lakes drain into large proglacial lakes, there impact on discharge will be limited. Lake Linda on Lemon Creek Glacier is at the head of the glacier, and typically drains near mid-summer and does not refill.

While GLOF events, particularly from ice-dammed lakes, are an important factor in Alaska, we emphasize that documenting GLOF events is not the focus of this study. We are looking at decadal scale changes in lake area which unfortunately do not capture drainage events that occur on a sub-annual to annual timescale. This point was also raised by Reviewer 1, and we will add a section to our discussion explicitly explaining why these types of lakes and events are difficult to capture within our study (i.e. five year mosaics, lakes which are frequently drained or ice-filled).

Pelto et al (2013) examined the expansion of nine lakes at distributary termini of Brady Glacier that are a combination of ice-dammed and proglacial and expanded from 8.5 km2 in 1948 to 18.2 km2 in 2010 (Figure 7 and 8). How did you classify these lakes? Capps et al (2011) identified a depth of 200 m for Abyss Lake. Brady Glacier an exceptional case having so many proglacial calving terminus fronts.

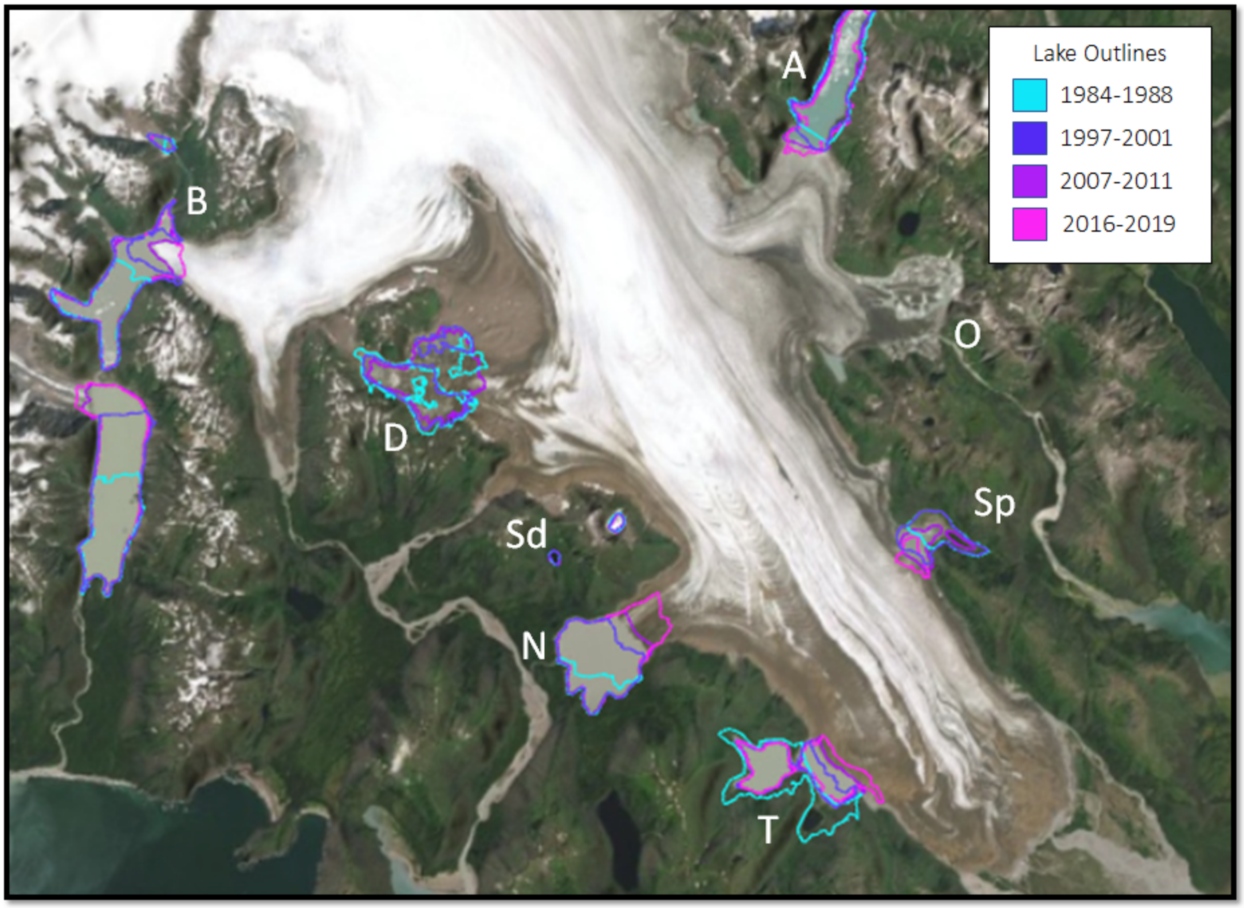

Figure R2.1. Ice-marginal lake outlines around Brady Glacier. Lakes noted are: A = Abyss, B = Bearhole, D = Dixon, N = North Deception, O = Oscar, Sd = South Dixon, and T = Trick.

Figure R2.1 illustrates our derived lake outlines for the lakes adjacent to Brady Glacier. Our inventory did not identify Oscar lake (O) due to the ice-choked nature of the lake. Spur lake (Sp) is an example of an ice-dammed lake that has decreased in area. Trick Lake (T) is an example of a lake which separated into two lakes. Bearhole (B) is an example of an expanding ice-dammed lake.

Merging of lakes can also occur for these large lakes. Loso et al (2021) note that glacier thinning in the region can alter which lake a glacier feeds in this case Alsek Lake (~60 km2) and Grand Plateau Lake (Figure 3). Another future merging of lakes will be at Fingers Glacier. The merging of lakes has been observed at Melbern Glacier (Clague and Evans, 1993) Gilkey Glacier (Figure 9) and Llewellyn Glacier (Pelto, 2017).

We also observed the merging of lakes, though most frequently with supraglacial lakes. If two lakes merged at some point in time, we gave them the same Lake ID so as not to have a false signal of a lake disappearing when the two lakes merged.

Specific Comments:

43: In fact large area change is dominated by large lakes, does this suggest you need a separate categorization for them?

As previously mentioned, we agree that providing a subanalysis of large (>10 km^2) lakes would be useful and will include this in our revised manuscript.

45: I would avoid the ecological consequences discussion until later. There is a complexity that is not examined here particularly in this region. For example the pro-glacial lakes in front of Excelsior Glacier as it has expanded has hosted numerous harbor seals, which will diminish as the glacier retreats form the lake. Loso et al (2021) further examine the issue of river capture changes impact on fisheries.

Here we are just acknowledging that lake changes have ecological implications rather than diving into much of a discussion of the specifics. We believe it is important to state that ecological consequences are a piece of the equation, though we do not explore it extensively.

50-65: This section references numerous examples from the Himalayan and Peru Andes region. The majority of references here should be specific to the study region Alaska. Glacier lake inventories from the Northern and Southern Patagonia icefield are probably more relevant as a comparison than the Himalayan or Peruvian Andes (Warren et al 2001; Loriaux and Casassa, 2013). Is there value in indicating that the best analog regions varies depending on which range you are examining? Emmer et al (2016) notes that only 7.3% of the 8882 Cordillera Blanca lakes have an area greater than 0.1 km2, which is a different magnitude of size than the Alaska glacier lakes.

Thank you for this feedback. We will include a highlight of Alaskan studies in the text. It is true that the best analog region depends on which range we are comparing it to, and we will add these details to our discussion section comparing various regions. We reference the studies in the Himalaya and Peruvian Andes because they are examples of studies which classify dam type and topological position, and demonstrate the importance of such classifications. We also believe it is important to put our work in its global context, in addition to an Alaska-centered lens.

150: Why are unconnected lakes used in this study, since they are neither fed by or connected to glaciers? I understand if it is just a validation tool, but then they should not be included in most of the analysis.

The criteria for our study is lakes within 1 km of the RGI. Therefore we include unconnected lakes, but specify that they are unconnected. Table 2 separates each dam type by location, showing how many lakes of each dam type were classified as unconnected. Apart from 4 moraine dammed lakes, all unconnected lakes are classified as bedrock dammed. Therefore, excluding unconnected lakes would only impact the statistics for bedrock dammed lakes, which experienced a median change of 0.0 km^2 whether or not unconnected lakes are included.

187: Given the ephemeral nature, which will make an accurate inventory impossible, and there limited importance base on extent, is this study stronger with or without supraglacial lakes? I would suggest the data set is more robust without. I offer this as a suggestion, but leave it to the authors to determine and will trust that answer.

Supraglacial lakes have large spatial and temporal variations, and tend to be quite dynamic. Though this does make an inventory difficult, we think it is valuable to include these snapshots within the study as supraglacial lakes contribute to glacier hydrology. As the lakes are classified by dam type and topological location, for most analysis we separate out supraglacial lakes and therefore the inclusion or exclusion of these lakes does not substantially change analysis or interpretation. By including differing lake types, different readers can focus on the information that is most relevant to them. For example, a researcher interested in debris-covered glacier mass loss may be particularly interested in supraglacial lakes because they play a role as “melt hotspots”. Removing supraglacial lakes from analyses means that our study will not address this researcher’s interest, with little downside produced by their inclusion.

We will be more explicit in our discussion, particularly when discussing lakes which have drained, about how many lakes were supraglacial and why drainage and appearance is frequent among supraglacial lakes.

213: “…decreasing by 9 lakes”, you indicate that 22 lakes were lost later in this section.

Ice dammed lakes decreased by 8 lakes (we will correct this discrepancy) in total number (from 69 in 1984-1988 to 61 in 2016-2019). Twenty-two individual lakes were lost, meaning that 14 lakes appeared as well, to equal a decrease in 8 lakes overall. We will clarify the text to better explain what each of these numbers represent.

310: This is where a reference to Brady Glacier would be useful given the number of ice dammed lakes, and that this a large low slope glacier (Capps et al, 2011; Pelto et al., 2013).

Thank you -- the addition of specific examples will strengthen our discussion. We will include a reference to Brady Glacier and the associated references.

315: Neal (2007) is a good reference here as well for changing drainage from different ice dammed lakes of Tulsequah Glacier.

349: Should note the trends observed both at Tulsequah Glacier (Neal, 2007) and Bear Glacier (Wilcox et al 2014).

We will incorporate these references -- thank you.

358: What is the importance of knowing normalized lake area variation by region?

We present normalized lake area in order to account for differences in glacierized area between the different subregions and therefore make inter-region comparisons more comparable. We wanted to look at the normalized lake area for each region to see whether the amount of lake area per region is consistent given the large variation in glacierized area, or rather, whether lake area scales with glacierized area.

387: Yes this is true but here is where a closer look at the main area changing lakes will define the key topological elements.

We agree and will revise the manuscript to identify and further discuss the lakes which are responsible for the largest amount of absolute area change (i.e. large proglacial lakes).

388: I do not see specific evidence supporting this assertion. You have identified that supraglacial lakes are limited to a few large debris covered glaciers and have a small area. This does not suggest the range or role is expanding.

Here we are looking at the increasing median rate of change for supraglacial lakes and decreasing median rate of change for moraine-dammed lakes (Figure 10a), such that the median rate of change is nearly the same for supraglacial and moraine-dammed lakes between the time periods of 2007-2011 and 2016-2019. We believe this is significant, and try to use qualifying language such as “could be”. We believe the median rates of change supports an increase in the role of supraglacial lakes, not necessarily that the entire mechanism for change is shifting. We will clarify the language to better present this idea.

397: What are the similarities and just as importantly what are the differences? Many of the debris covered glaciers in Alaska are not confined glacier tongues, but instead have an expanding terminus lobe either in a wide river valley (Battle, Donjek, Kaskawulsh, Lowell etc.) while others terminate on a coastal plain (Fingers, La Perrouse, Bering, Malaspina etc.). In terms of debris cover change and proglacial lake changes how does this compare to the data from the Northern Patagoina Icefield from (Glasser et al 2016). “North Patagonian Icefield (NPI) in southern South America between 1987 and 2015 shows that the total amount of debris cover has increased over time, from 168 km2 in 1987 to 307 km2 in 2015. The area occupied by proglacial and ice-proximal lakes also increased from 112 to 198 km2”

We have focused our comparisons on other studies that similarly split their analysis of lake behavior on dam type and lake location. We acknowledge that the style of glaciation in NPI (and other glaciated regions of the world) might provide other suitable comparisons, but in the absence of similar comprehensive yet also detailed glacial lake studies, we feel that the former comparisons are most suitable for the scope of this paper. For example, Glasser et al. (2016) found an overall increase in lake area, though they do not separate areas for proglacial and ice-dammed lakes which makes comparison difficult. While completing revisions, we will consider opportunities to expand the comparisons to other glaciated regions, noting that the best analog region depends on which Alaska subregion is considered.

415: I do not see the close correlation in the nature of the glaciers. They differ in their climate setting, size, thickness, velocity, slope and elevation range. The trend in lake dam type that is similar is relevant. It must be emphasized that the size of the lakes between the two regions is vastly different.

Thank you, and we will add this clarification. We are most interested in the documented change in dam type and are using the Cordillera Blanca as an example of shifting dam types. We are comparing to studies which classify lakes by dam type, whereas most other lake inventories do not provide this additional classification.

435: No need to speculate given the glacier by glacier thinning data from Juneau Icefield and Stikine Icefield for example that illustrate variations Melkonian et al (2014 and 2016).

Thank you -- we believe speculative language is still appropriate here as we are referring to future events, but will add additional information along the lines of "though variations in thinning have already been observed from the Juneau and Stikine icefields".

451: Why use the Cordillera Blanca as an analog instead of the Northern Patagonia Icefield?

We agree with your suggestion that the Northern Patagonia Icefield makes an excellent analog for current conditions, however, we chose to use the Cordillera Blanca to illustrate what could occur farther into the future. Again, we focus on studies which document lake dam type.

456: What do the observations from Tulsequah, Brady and Bear Glacier suggest as to diminishing number of ice dammed lakes?

The inventory revealed variable (and interesting!) behavior across the ice dammed lakes we studied. We find that these three glacier examples contain persistent ice-dammed lakes over the study period, but when we assess all ice-dammed lakes in the region, we find that this class of lakes decreased in area and number. We acknowledge that the variability in individual lake behavior provides an interesting topic for future studies, but the scope of the current study limits the level of detail we can include on these individual lakes. We will include Suicide Basin as an example of an ice-dammed lake that has formed in the recent past (2011), and could illustrate what kind of ice-dammed lakes will form in the future, i.e. an example of a tributary valley where ice has retreated and created a lake basin. The question is how these competing processes will play out in terms of changing total number of ice-dammed lakes, ice thinning and retreating, and removing ice dams vs tributary ice retreat and the formation of lake basins. This is where modeling of glacier retreat would be useful, though it is outside the scope of this study.

Thank you again for your excellent suggestions that will undoubtedly improve our manuscript, and for including references which will be helpful when revising the manuscript. We appreciate the time and effort you've invested and the wealth of specific knowledge you have shared.