Authors’ Response to Reviewers and Associate Editor Feedback:

Thank you kindly for these constructive reviews and positive feedback from the Associate Editor Ben Bond-Lamberty, who has already reviewed our response letter (see below). We very much appreciate the helpful suggestions. We have endeavoured to respond to each comment in turn, by inserting our responses between the paragraphs written by Reviewers in the letter below. To better differentiate our comments from those of the Reviewers, we have highlighted our text in green and use Times New Roman font to contrast with the sans serif font of the text written by Reviewers.

In our responses, we describe how we revised the manuscript to address any concerns raised and to incorporate the suggestions that we agree will improve the final paper. We also provide additional data on wetland sizes and climate normals for precipitation in our study area to better contextualize our work. In addition, we describe how future research should address some of the interesting questions that Reviewers have raised.

We hope that our responses and the changes we made to the manuscript are sufficient to warrant consideration of a revised draft for publication in Biogeosciences.

Sincerely,
Dr. Rebecca Rooney (on behalf of co-authors Dr. Jody Daniel and Dr. Derek Robinson).

Associate Editor comments to the author:
This manuscript was read by two reviewers, who both are generally complimentary while having thoughtful comments and suggestions that focus on analytical clarity, use of factors such as wetland size, better consideration of previous literature in this area, and other factors. Thanks for your responses to these comments, which are considered and balanced; the revisions you propose seems appropriate and doable, and will I think substantially strengthen the manuscript.

Thank you for the opportunity.

Reviewer 1

Overall, the paper “Climate and topography: the two essential ingredients in predicting wetland permanence” is written very clearly and represents a needed analysis of the individual and combined effects of climate, land use, and topography on the permanence of wetlands in the Prairie Pothole Region. The authors looked at several variables in each category and region and predicted the permanence classes of wetlands. They found that terrain was a nearly as important to predicting permanence class as climate in two regions. This works stresses the importance of including terrain in modeling the effects of climate change on wetlands in the PPR.

General comments:
Many relevant results/methods are relegated to the appendices. Specifically, the variables used and their definitions (especially the topographic variables where the name of the variables doesn’t make it obvious how it was calculated) should be in the main text. There are also analyses, the PCA analysis specifically, that are mentioned in the methods but not discussed in the results and only have a figure in an Appendix. Even if the analyses don’t warrant an actual figure in the main text, the results should be mentioned in the main text.

We agree. There were some analyses that are mentioned in the methods that are not explicitly discussed in the Results section and are instead provided in the appendix. We incorporated the overall outcome of these methods in the Results section as well as added more references to the results in appendices to the Results section to better link the materials in the appendices with the main text. The PCA figure is now in the results (Figure 2). We also ensured that all variables are defined clearly and explained in the main text (e.g., Table 2 gives the equations for the terrain metrics, Table 1 defines the wetland permanence classes).

Several potentially correlated variables are used in the analyses and could present issues when interpreting the variable importance. For instance, including % of land cover types as independent variables in the same model is potentially problematic, i.e. a wetland with more % cropland will automatically have less of the other land cover types. While correlation itself is not an issue with gradient boosting models, it could affect the inference of the importance of these variables. The variable importance could be split among % cropland and % natural because the two are likely negatively correlated but if you remove one, the other could have a higher variable importance. Had you considered limiting the correlated variables % cropland or % natural veg vs. including both?

We agree that when variables are highly correlated, their relative importance can be obscured in xgboost, especially when they were not selected the same number of times across iterations/trees. We recognize that this could be true in our models; however, we sought to compare the importance of variables in aggregate (i.e., land cover vs. climate vs. terrain) across Natural Regions, rather than focusing on comparisons of importance among different land cover types. Also, the degree of correlation among land covers varied between Natural Regions. For instance, the Pearson correlation between cropland and natural cover was only –0.64 in the Parkland but was -0.9 in the Grassland, where cropping was the dominant land use, which we describe using the PCA in Figure 2, panels D-F. We agree that by removing either cropland or natural land cover would likely increase the importance of the remaining land cover type in the final model. However, that removal should not affect the relative importance of land cover overall, which was still the second most important predictor of permanence class in the Grassland. Thus, we do not believe that removing natural cover or cropland would change the rankings of climate, land cover/land use and terrain in predicting permanence class.

It seems like one of the largest factors in determining the permanence class of a wetland would be wetland depth/volume and wetland size I can't see how/where you are getting at either of those. You might be getting to a proxy of depth this with some of the terrain variables but if I understand correctly, those are only calculated in the wetland buffer?? Also knowing the average size of the wetland will help determine how effective a DEM of 25 meters is. Is a wetland generally about 1 cell or several cells? You discuss not including soils in the models in the discussion but including other variables that are likely to make a difference in permanence class will be helpful.

The designation of wetland permanence class comes from the Central and Southern Alberta Wetland Inventories and is not something we derived from data on water volume, wetland size or depth. We describe this briefly around L70 and Figure 1, but agree it needs to be made more explicit. We revised Section 2.1 Study Area with the following text to ameliorate the reviewer's concern:

"Publicly available wetland data (Canada Wetland Classification System Wetland Inventory, published by Environment and Climate Change Canada) for our study area lack definition of permanence class or measurements (e.g., water volume, depth) that could be used to classify the wetlands within by permanence type. Despite this data gap, we were able to acquire data from two wetland inventories (Government of Alberta, 2014) that delineated the location, boundary and permanence class of PPR wetlands based on Stewart and Kantrud's classification (Stewart and Kantrud, 1971; Table 1)."

Likely, water volume is the main determinant of permanence class as the wetland will retain open water until the entire volume has evaporated, transpired, or infiltrated, and our focus on external factors is likely why our predictive power was not very high. Unfortunately, we did not have data on the water volume or depth of the 40,000 wetlands in our analysis, and so we could not include estimates of volume. There is no extensive dataset on wetland bathymetry, though this would be very valuable and a timely acquisition of bathymetric LiDAR data (i.e., LiDAR using green spectrum lasers) over large areas might facilitate future development of such a dataset, or as new technologies come available that are able to use satellite-based methods in shallow waters. We agree that these data would certainly improve model fit over our initial efforts with currently available data, though we contend that our approach is still useful in assessing the role of larger scale domains of variables in determining permanence class. We have included the following text to (Section 4.5) clarify our data gap and provide direction for those seeking to acquire baythemetric wetland data

“The lack of extensive bathymetric data identifies a gap that would enrich the presented research by enabling direct classification of wetland permanence from raw bathymetric data. Furthermore, these data would provide added value to those conducting research on above and below ground hydrologic connectivity and contributing areas (e.g., citations), evaluation of the impacts of climate change on wetland permanence and subsequently flora and fauna health and resilience (e.g., citations), as well as reduce the error in our analysis of the contributions of climate, land use, and topography on wetland permanence. As new technologies for mapping wetland bathymetry become more widely available (e.g., baythemetric LiDAR, Wang and Philpot 2007, Paine et al. 2015) an opportunity will exist to better understand the link between wetland pattern and process.”

Thank you for the excellent suggestion to incorporate wetland size, which we do have access to from the wetland inventories. We agree that this would be helpful in contextualizing results. We have modified text in Section 2.2 so that it now provides context about wetland sizes within our study region. The text is provided as follows:

“The distribution of wetland sizes was strongly right-skewed across the three Natural Regions of interest. Wetlands were typically small, with Boreal wetlands possessing the largest median size (2.26 ha), followed by Parkland wetlands (1.54 ha) and Grassland wetlands (0.58 ha, Appendix A). The combination of wetland size and our digital elevation model (DEM) resolution of 25 m suggest that our median wetland sizes would occupy 904, 616, and 232 cells for Boreal, Parkland, and Grassland natural regions, respectively, and demonstrate our ability to capture variability among wetland sizes and shape.”

Specific comments:
Line 10/line 29 – I am not sure that wetlands that hold water year-round are most sensitive to climate change. Wouldn’t temporarily ponded wetlands that have a decrease in hydroperiod and disappear completely also be pretty sensitive to clime change? The reference provided state they are the most rare so justify why they are most sensitive

This seemingly counterintuitive prediction comes from work by Fay et al (2016) and others, who noted that the effects of climate change on evapotranspiration rates in the PPR are projected to be greatest later in the summer when evapotranspiration rates are maximized. Because seasonal and temporary class wetlands are already naturally drawn down by this time, they are spared the impact of increased peak evapotranspiration later in the summer. Yet, semi-permanent and permanently ponded wetlands that 'normally' hold water through the late summer will be subjected to the effects of this higher summer evapotranspiration and are thus predicted to be more sensitive to the projected effects of climate change in the Prairie Pothole Region. We elaborated ~L36.

Fay, P. A., Guntenspergen, G. R., Olker, J. H. and Carter Johnson, W.: Climate change impacts on freshwater wetland hydrology and vegetation cover cycling along a regional aridity gradient, Ecosphere, 7(10), e01504, doi:10.1002/ecs2.1504, 2016)

Line 30 – this citation refers to potential -20% or +205 changes in precipitation that included with warming may decrease hydroperiod but doesn't specify a 20% decline in hydroperiod definitively

Thank you for catching this. We revised the manuscript to more accurately represent the projected precipitation changes. ~L32

Line 83-84 – providing average and sd of wetland size in each region would be helpful

Below, we provide the median, mean and standard deviation of wetland areas from the Alberta Merged Wetland Inventory covering the three different Natural Regions in our study. We emphasize that while there are differences in wetland size among Natural Regions, wetland sizes evidence a similarly skewed distribution with most wetlands being smaller than the average size and few reaching an order of magnitude larger than average. This is summarized in the manuscript ~L96 and in Appendix A.

Region	**Median (km²)**	**Mean (km²)**	**Standard Deviation (km²)**
Boreal	0.0226	0.08008235	0.9564564
Grassland	0.0058	0.02209926	0.2327619
Parkland	0.0154	0.04341342	0.3077994

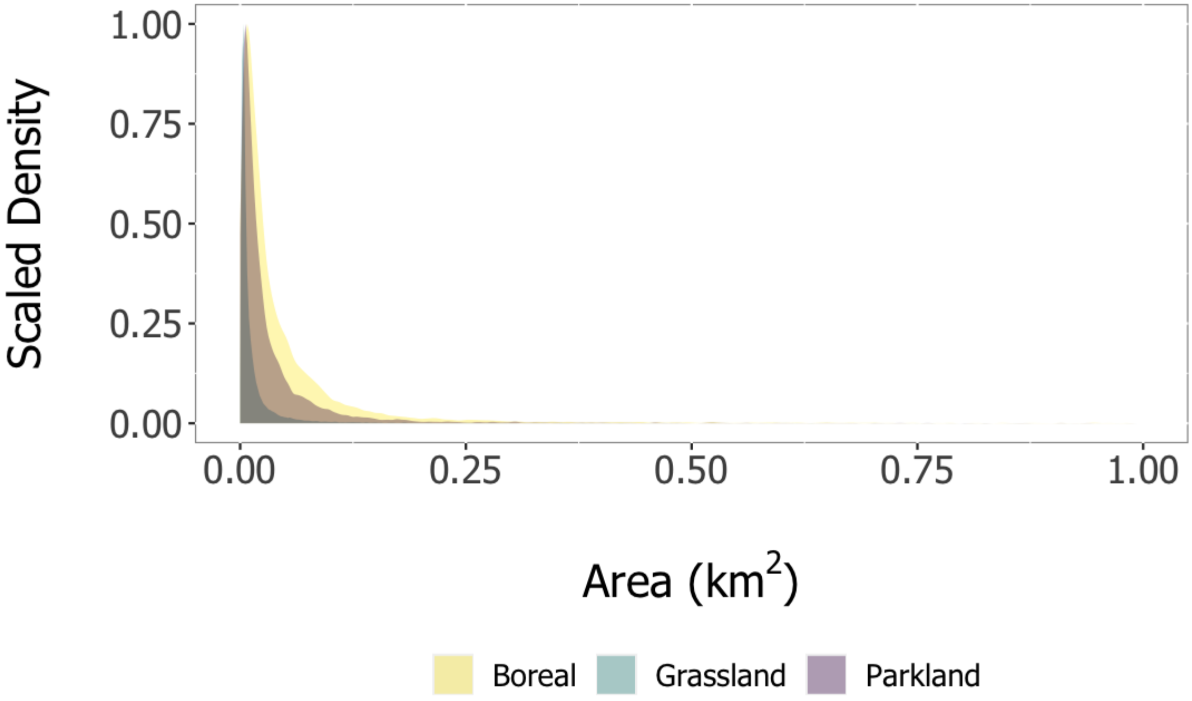


Figure 1: Histogram showing the frequency distribution of wetlands by their area for the Boreal, Grassland, and Parkland natural regions of Alberta, based on the Alberta Merged Wetland Inventory.

Line 97 – why only one year of climate data? Some studies have suggested that longer time frames of climate data explain water levels better. A justification for this is needed. Also, is this time frame in any way related to when the permanence classes for the wetlands were determined for the wetland inventories?

We agree that these are important points, which both Reviewers raised, and we should have more explicitly addressed. We modified the manuscript to better defend and address these points (~L122-134). Throughout the manuscript, we also revised mentions of "climate data" to ensure we are clearly describing annual data for climate variables, rather than long-term climate normals or other index values, which were not available in the same spatial detail as the annual values for our study region.

We selected one year of climate variables for three reasons. First, the year we selected – 2014 – was a very typical year, in that the annual conditions closely agreed with the climate normals for the study area. For example, below we show cumulative precipitation for the 2013-2014 period compared to the 1981-2010 climate normal for the Grassland and Parkland Natural Regions. Testing for deviations from the 1981-2010 climate normals in terms of mean annual precipitation, we find no significant differences in 2013-2014 or 2014-2015: neither in the Grassland (2013-2014 – paired t-test: t = 1.833, *p*-value = 0.652, df = 9; 2014-2015 – paired t-test: t = 1.833, *p*-value = 0.878 , df = 9) nor the Parkland (2013-2014 – t-test: t = 1.833, *p*-value = 0.344, df = 9; 2014-2015 – t-test: t = 1.833, *p*-value = 0.315 , df = 9) is negligible.

Second, though we agree with Reviewer 2's comments (see below) that the influence of climate variables on wetland permanence classes will exhibit time lag or legacy effects, these will be moderated by things like soil storage, groundwater movement, vegetation succession within the catchment, etc. Consequently, we considered that the temporal window of relevant weather would be site-specific and we felt we lacked a defensible justification on which to base a threshold. Should we include data from the past 3, 5, 10, Or 30 years? This is complicated by the designation of wetland permanence class in the Central and Southern inventories comprising a temporal mosaic. Confronting the need to make an arbitrary decision on what data to include or exclude in considering climate and knowing that 2014 was a particularly "typical" year, we elected to focus on our primary goal: comparing the relative importance of different domains of influence on aggregate (i.e., Climate vs. Terrain vs. Land cover). We concluded that fine-tuning how climate was defined with respect to the permanence class designation of each wetland would only strengthen the relative importance of climate variables, which were already identified as the most important predictor category in our models and so we did not modify our characterization of annual data on climate variables. We endeavoured to make this scoping clear in the manuscript (L122-134). Consequently, using the annual data on climate variables from the study period is representative of average conditions for the study area. Incidentally, the same argument could be made about land cover having legacy effects that are not captured by using a snapshot of cover types, but we suggest that the complexity of weighted averages or other indices integrating land covers or climate variables through time are best reserved for follow-up research and we opted for simplicity and comparability in our initial effort to better integrate terrain into considerations of the drivers of permanence class and hydroperiod in PPR wetlands.

Third, we have some practical considerations that influenced the selection of 2013-2014 annual data on climate variables. This includes that the terrain and land cover data also came from 2014, and so using the same time span was defensible for comparison purposes. More, this corresponded with field work we carried out as part of a larger research program on PPR wetlands in Alberta between 2013 and 2015. By using annual data on climate variables from the same period, we were able to better relate this project to the field work we conducted and satisfy stakeholder and funding requirements.

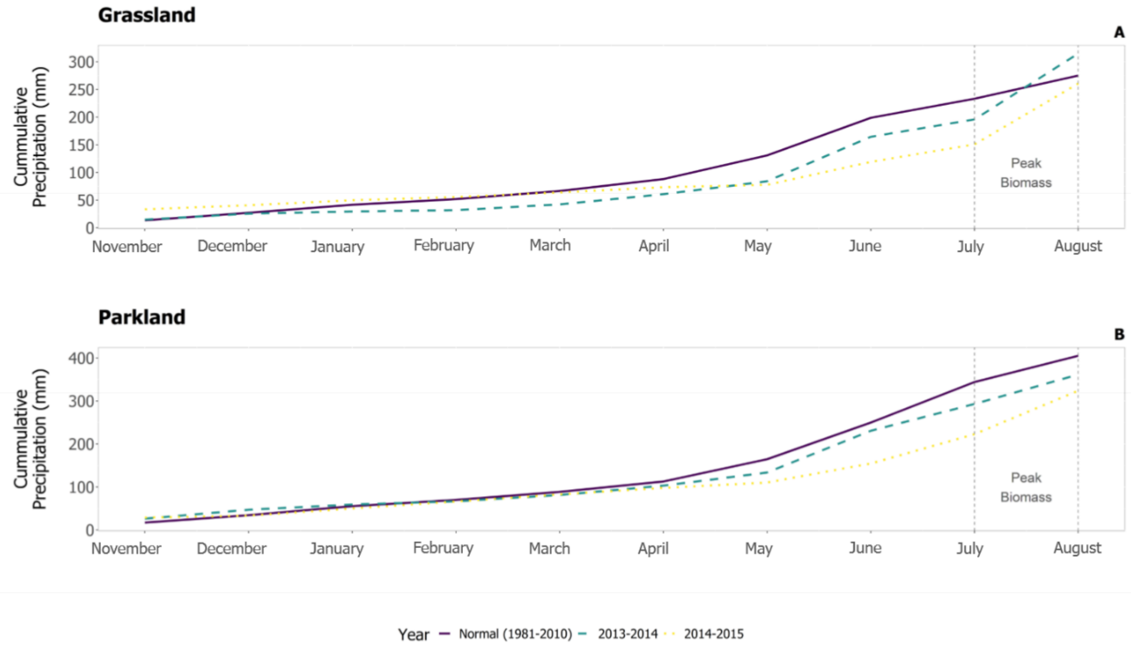


Figure 2: Comparison of cumulative precipitation from 2013-2014 against the 1981-2010 climate normals in two Natural Regions of Alberta. We do not show the Boreal here because the wetlands we included from this Natural Region were restricted to the very southern margin and are not likely representative of the full Natural Region (see Figure 1 in the manuscript), climatically they are more similar to the Parkland than the Boreal.

Line 100 – Appendix B - I think moving these variables into the main part of the paper would be helpful. Knowing the specifics of how each of these were calculated, especially the topographic variables which aren't as obvious.

As we describe in our response to general comments above, we pledge to better integrate these appendices into the main text. We have brought Appendix B into the main manuscript now as Table 2. However, we are cognizant of space limitations and defer to the editor's recommendation around whether to move appendix materials directly into the main text or rather to enhance the degree of reference to them and bring in only limited details.

Line 113-115 - Does this mean that it is only using data from the buffer and not the wetland itself? DEMs don't tend to get below surface water unless the data is collected in a particularly dry time. Thus, the DEM is not likely able to get at depth of a wetland although that may be an important factor in wetland permanence. But depending on how big these wetlands themselves are and when the DEM data was collected, you might be better to include the wetland itself as well

This is correct, the characterization of terrain was within the wetlands' catchments, and not the bathymetry of the wetland basins. Regarding the relative size of the wetlands and the DEM cell size, please see our comment above. We revised the ms to clarify ~ L146 in the track changes version.

Line 119-120 – How did you use the PCA analysis and was it used to reduce the number of variables? Does Appendix B represent the reduced set of variables or was it further refined? Providing some additional information about why/how you did this and used the results of the PCA will be helpful. Many permanence classes appear to overlap here a lot so how did you use the PCA to visualize if wetlands could be partitioned?

We used the PCA to visualize any partitioning of permanence classes in accordance with the climate, land cover, and terrain variables and to facilitate comparison among the three Natural Regions. We incorporated it to help the reader see how the permanence classes in the Grassland appeared better aligned with all three domains of variables than those in the Parkland and especially in the Boreal Natural Regions. We did not use these PCAs as a variable reduction technique.

We describe how the annual data on climate, land cover and terrain variables were selected in more detail in Table 2 and in the main text at around L107. We now better expand on the results of variable selection ~L180. For climate and land cover metrics, we carried out a literature review to identify key variables likely driving wetland permanence class and then selected representative metrics for each of these variables based on available data. For the terrain metrics, we used those identified in a previous study (Branton and Robinson 2019), which did incorporate some control on collinearity: specifically, they generated a large list of candidate metrics based on a literature review and then refined that list based on correlation coefficients and selecting representative metrics from each correlated group, and then they used PCA to further refine the set of representative metrics. This study was carried out on the same wetland inventories and using the same datasets as we used in our study, and so we deemed it an excellent source of terrain metrics.

Line 134 – remove parentheses

We made this change ~L173 in the track changes version

Line 142 – you mention the high error rates here but have again moved this information to an Appendix so it gets lost and might be better if discussed further

As with the other comments about important information in our Appendices, we defer to the editor on whether to include it entirely in the main text or to better reference it in the main text but leave the details in an Appendix (now Appendix D) for brevity. In this case we left it in the Appendix, but added more references to it in the main text - e.g. ~L278

Line 153-167 and throughout – please check the Figure numbers in this section and throughout because a few appear to be referring to the wrong figure. An Appendix I is referred to but there is no Appendix I. It is also difficult to tell if you are referring to Figures 5 & 6 with "(Figure 5-6)" or Figure 5-VI. Using letters instead of roman numerals in those figures might also be helpful

Thank you for catching this error – we revised the paragraph substantially in response to reviewer 2's comments. It now says (L207):

"Our findings suggest that wetland permanence class in the Prairie Pothole Region of Alberta correlates with climate, terrain and, to a lesser extent, to surrounding land cover/ land use. Generally, across the three Natural Regions, wetlands with shorter hydroperiods (e.g., temporary and seasonal) were typically situated in landscapes with higher spring snowpack amounts (Figure 3A-C) and spring temperatures (e.g., Figure 5A). Longer hydroperiod wetlands were typically situated in landscapes with more summer precipitation and lower spring temperatures (e.g., Figure 5C), occupying relatively low topographic positions with low terrain convexity (e.g., Figure 5G, H), and were surrounded by less natural cover (e.g., Figure 5D,F). Interestingly, the relative importance of variables in predicting the occurrence of both shorter and longer-hydroperiod wetlands were shared, and this agreement was strongest between the Southern Boreal and Grassland (Appendices F & H)."

Line 215 – add space before citation

Space added. Thank you.

Line 238 – while you account for elevation, it could be better accounted for with a higher resolution DEM and including a more direct proxy for wetland depth/volume could also help improve the models

Yes, we agree that a higher resolution DEM would be valuable, if one were available for the whole of our study region. We used the best data available for our study area. A finer resolution DEM (e.g., 10 m) is available for small sections of Alberta's PPR, such as the Beaverhills Subwatershed or the area immediately around Calgary, but not the full extent of the PPR.

Line 247 – add space before citation

Space added. Thank you.

Reviewer 2

Overall, the topic of this research effort is very important. Understanding the relationship between climate, topographgy, and land use/cover are critical for forecasting how critical migratory bird habitat in the future and helping management agencies strategize their conservation planning investments. The approach this group took is unique and uses large data sets to try and determine climate, land use, and topography variables that might correlate with the permanence class of a wetland. The lack of detail given in this manuscript makes it hard for me to understand the exact reasoning behind including such a large amount of covariates in this modeling exercise and the authors need to do a better job of explaining the proposed mechanisms of why and how different covariates would impact a wetland's permanence class. Currently the results presented have little utility for other researchers or managers.

We thank the reviewer for their feedback and have made revisions to the manuscript to better communicate our findings, per their suggestions.

Defining pond permanence is critical for establishing the utility of such a metric for managers and for creating more direct links between your plethora of statistical covariates and your response variable (categorical and static wetland permanence class). In your introduction you define hydroperiod (L20, L26), mention wetland water levels (L24) as well as ponded frequency (L22), and declines in pond permanence (L28), wetland sensistivity (L29), and wetland permanence (L57). You then skip to mentioning wetland permanence class (L62) without first defining that term or how wetlands are categorized into these different classes. In L70-71 you introduce Stewart and Kantrud's wetland pond permanence classes, but bury the details in the appendix. Please define those classes in the methods and move Appendix 1 to the main body of the manuscript. Or, at least some version of that appendix that allows the reader to understand what variables could influence a wetland from being defined in one permanence class or another. This would make a much more clear link between your model covariates and response variable.

We agree that defining pond permanence earlier in the manuscript would improve general understanding on what variables could affect water levels in a wetland. As such, we define pond permanence in the introduction (L20) and moved the table in Appendix 1 to the main text (i.e., Table 1).

Use of the term climate when only considering 11 months of temperature, precipitation, and one winter's snowpack data. There is a temporal mismatch between your response variable that is a very statically defined permanence class of a that is the result of many centuries of wetland ecosystem development in response to long-term (>30 years) climate variables as well as the topographic and land use/cover setting of each wetland. I have a hard time making this connection and the methods and discussion do not go into enough detail for me to be convinced that the data used to develop your covariates could sufficiently explain mechanisms of how climate can determine the permanence class of a given wetland.

Reviewer 1 also raised this important consideration and we give a fulsome explanation in response to Reviewer 1 above. However, we agree and have revised the manuscript to clarify our use of annual (2013-2014) data on climate variables rather than long-term average climate data. We also provide reasoning for use of the 2014 data in the manuscript (Section 2.3.1), similar to what we explain above in response to Reviewer 1.

L89 2018 excludes a rapidly growing body of research

We acknowledge this limitation. With COVID and related delays, it is taking longer than perhaps it did previously to move from literature review to publication and new papers are always bringing new knowledge into the sphere of scientific discourse. However, we contend that the last three years has not materially changed our scientific understanding of the key variables characterising land cover/land use and climate, as it pertains to wetland permanence classes – at least not in terms that would alter the representative metrics we could calculate with available data.

L29- semiperms most sensitive…confusing and potentially irrelevant

In setting up the context for our analysis of factors affecting wetland permanence class, we believe it is relevant to note that non-permanent wetlands have an ecology that is based on variable hydroperiods and eventual complete loss of water. Therefore, increased evaporation and reduction of precipitation inputs render semi-permanently ponded wetland ecosystems more susceptible to climate change impacts. With your suggestion we have clarified why semi-permanently ponded wetlands are more sensitive with the following text (L30):

"Simulations for the PPR suggest that the magnitude of change in climatic conditions between 1946 and 2005 were vast enough to drive declines in pond permanence (Werner et al., 2013). Modelling suggests that these wetlands may experience up to a 20% decline in precipitation due to climate change, which could reduce hydroperiods (Fay et al., 2016). Furthermore, forecasts suggest that many of the wetlands in the southern and western PPR may be lost completely, driven by drier climate conditions in these areas (Johnson et al., 2005, 2010; Reese and Skagen, 2017). Wetlands that contain ponded water year-round will be most sensitive to climate change because they contain water in late summer, when they will be subjected to greater evapotranspiration-driven losses (Fay et al. 2016). They are also relatively rare (Ridge et al., 2021)."

L30 – change will to may experience as much as….there are many different accepted models for the future, see

McKenna, O. P., Mushet, D. M., Kucia, S. R., and McCulloch-Huseby, E. C.. 2021. Limited shifts in the distribution of migratory bird breeding habitat density in response to future changes in climate. Ecological Applications 00(00):e02428. 10.1002/eap.2428

We modified the text ~L32-34

L31 -wetlands "may be lost forever" unless this is talking about draining/filling the wetlands are not lost it is the ponded water that is lost. Depressional wetland basins persist if wet or dry.

Where we said "Furthermore forecasts suggest that many of the wetlands in the southern and western PPR may be lost completely, driven by drier climate conditions in these area…" we have revised the text to say "may lose their ponded water completely…" to more accurately reflect that the wetland boundary is not defined by the open water and that dry wetlands are still wetlands (L35).

L40-41 different font "areas lower in the watershed"

Thank you and your eagle eyes for catching this.

L57- This wording is a bit too strong. There are other examples of this in the southern PPR:

McKenna, O.P., Renton, D.A., Mushet, D.M., DeKeyser, E.S. 2021, Upland burning and grazing as strategies to offset climate-change effects on wetlands: Wetlands Ecology and Management, https://doi.org/10.1007/s11273-020-09778-1

McKenna, O.P., Mushet, D.M., Anteau, M.J., Wiltermuth, M.T., Kucia, S.R. (2019) Synergistic Interaction of Climate and Land-Use Drivers Alter the Function of North American, Prairie- Pothole Wetlands: Sustainability [Special Issue "The Importance of Wetlands to Sustainable Landscapes"], https://doi.org/10.3390/su11236581

In this statement we meant to emphasize that terrain is not commonly considered in studies that quantify the individual and combined effects of climate and land use on wetland permanence. We revised (L63).

Methods

Overall, much more detail is needed to understand how your response variable and your covariates are defined. By defining these with more detail and citation then the reader can better understand the mechanisms by which the different continuous covariates could potentially influence or correlate with a categorical permanence class

In response we incorporated Appendix B into the main text as Table 2. There, we provide a list of the key variables identified by our literature review, some citations of papers from which we derived them, metrics that we considered representative and a bit about why they are likely to affect wetland permeance class/wetland hydroperiod. We also added a section on the results of our variable selection process to the main text (L182).

L70 write out the permanence classes and what criteria are involved with classifying wetlands

We have moved the table in Appendix A, which details this information, to the main text as Table 1 and integrated discussion of Table 1 into the text.

L73 add a citation for “Natural Region” boundaries.

We have included a citation for Natural Region boundaries (Schneider, 2013).

L81 add citation for your spatial layers used to map those boundaries in figure 1.

Citations for spatial layers have been added to Figure 1.

L84-85 please explain why no wetlands were within 1000m of each other. This is potentially a huge limitation of this modeling approach. In some areas of the density of PPR wetland basins can be almost 10 wetlands per sq km See McKenna, O. P., Mushet, D. M., Kucia, S. R., and McCulloch-Huseby, E. C.. 2021. Limited shifts in the distribution of migratory bird breeding habitat density in response to future changes in climate. Ecological Applications 00(00):e02428. 10.1002/eap.2428. Prairie-pothole wetlands also can be connected to each other via surface flows that create wetland complexes. To only choose one wetland in a complex without classifying the rest of the wetlands seems to not have much utility for scientists or managers studying these systems.

The region we studied has complexes of wetlands, though in the NW edge of the Prairie Pothole region we see more arid conditions and less surface runoff or fill-and-spill connectivity among them than in less arid portions of the PPR.

We did not exclude wetlands that were part of a complex, rather we did not select wetlands as one of our focal study sites that were within 1000 m of another focal wetland. To do so would have given rise to a lack of spatial independence that would compromise our analyses of terrain and land cover variables because their surrounding landscapes would have overlapped. Spatial autocorrelation is often ignored, but this violates standard assumptions of statistical inference and has been shown to bias quantitative outcomes in ecology. Previous investigation into spatial autocorrelation in our study system identified a lack of spatial relationship (i.e., structure) among land cover and wetland conditions beyond 1000 m (Kraft et al. 2019). This range of spatial autocorrelation (i.e., threshold) has supported the analysis of spatially independent wetlands and wetlandscapes with a focus on open water wetlands (Ridge et al. 2021), topography (Branton et al. 2020), and land cover (Evans et al. 2017). Therefore, not only do we ensure a spatially independent sample of wetlands, but we also contribute to on-going research that has consistently operated at this dimension of spatial independence and strengthens the relationship among those scientific investigations.

We agree that connectivity to a wetland complex would influence a wetland's hydroperiod and incorporating this in future research would likely increase model fit, but excluding this driver of wetland hydroperiod should not have altered our conclusions about the relative importance of climate, terrain and land cover domains.

We have changed the text in question from "No wetlands were within 1000 m of each other." to the following:

"To ensure spatial independence among sampled wetlands and their relationship to land cover as well as coincide with previous analysis of open water wetlands (Ridge et al. 2017), topography (Branton et al. 2020), and land cover (Evans et al. 2017), we did not select wetlands that were within 1000 m of another selected wetland."

L89 I understand that limitations of this approach and the challenge of summarizing pertinent literature, but I think there are some key papers missed that are summarized in McKenna, O.P., Mushet, D.M., Anteau, M.J., Wiltermuth, M.T., Kucia, S.R. (2019) Synergistic Interaction of Climate and Land-Use Drivers Alter the Function of North American, Prairie- Pothole Wetlands: Sustainability [Special Issue "The Importance of Wetlands to Sustainable Landscapes"], https://doi.org/10.3390/su11236581.

The inclusion of some of these papers might have allowed for inclusion of soil moisture/drought indices variables that are much more appropriate uses of the term “climate” that the 11 months of precipitation and temperature variables currently included in the model. The current “climate” covariates may be decent predictors of the current year wetland inundation status, but do not seem to me to be appropriate for predicting a static categorical permanence class of a wetland.

Certainly, McKenna et al. (2019) is a relevant paper that our literature review would have captured if we redid our review in 2021. Indeed, we added the referenced paper to our discussion section (L226). Unfortunately, as we describe above, we needed to complete the literature review to identify the variables to represent with metrics in the modelling, and this – with COVID related delays – took time. We contend that it would not have substantively altered which metrics we could use to represent different relevant variables because our metric selection was also constrained by data availability. Regarding the comment about annual data on climate variables vs. climate data, we have improved the manuscript to provide reasoning as to why we used 2014 data (Section 2.3.1) and explain that fine tuning the climate representation would potentially strengthen the relative influence of climate variables, but given climate already emerged as the most important domain of variables it would not likely alter our conclusions.

L105 similarly, land cover data from one year (2014) seems to be on the wrong temporal scale of the wetland permanence class. I would suggest something more stable like a multi-decadal average

Based on work by Kraft et al 2019, we see that physiochemical conditions in a wetland (measured by soil and water chemistry) are quite congruent with surrounding land cover determined from the same year of sampling, at least in our study area. More, attempting to take a multi-decadal average of nominal data introduces issues of weighting through time – should the land cover from 10 y ago be weighted the same as the land cover last year? This is analogous to the argument raised above about time lags in climate data and how to determine what years to include or exclude. Future research could investigate a defensible approach to do this, but based on our work published in Kraft et al. (2019), we contend that the result would not substantively change our conclusions about the relative importance of climate, terrain and land cover variables.

Kraft, A. J., Robinson, D. T., Evans, I. S. and Rooney, R. C.: Concordance in wetland physicochemical conditions, vegetation, and surrounding land cover is robust to data extraction approach, edited by D. G. Jenkins, PLoS One, 14(5), e0216343, doi:10.1371/journal.pone.0216343, 2019.

L106 more detail is needed to understand why distance to road would be included as a covariate in your model. I do not see the direct connection between that and permanence class. Much more detail could be made in your selecting variables section as well as in your introduction as you hypothesize how climate, land use, and topography

Thank you for this suggestion. We have integrated a former appendix as Table 1 to provide more justification for the selection of variables used in our analysis, including wetland distance to roads. Since roads cut off hydrological flow and divert surface runoff, wetlands that are closer to roads, or perhaps, are in landscapes with higher road density, typically have shorter hydroperiods. We have added this explanation to the text in Section 2.3.2 as follows:

"The landscape fragmentation created by road networks has been shown to alter hydrological flow and divert surface runoff (Shaw et al. 2012) such that wetlands in proximity to roads typically have shorter hydroperiods." L 144

L110-111: List a range of the size wetland basins and the catchments somewhere so the reader can determine if 25m DEM is high enough resolution compared to the size of the wetlands. In my experience 3m DEM is a much more appropriate resolution for prairie pothole wetlands. Also, list the different terrain variables here and allude to why they may influence wetland permanence class.

Unfortunately, a 3 m DEM is not available for our study area. As we describe in our response above, our metric selection (Appendix B) was also constrained by data availability and as new technology and data layers become available, future research could build upon the foundation we lay in this manuscript.

In a previous paper (Kraft et al. 2019) we compared the 25 m DEM to a 10 m DEM that was available for a small sub-section of our study area and found that smaller resolution DEMs led to little material difference in the strength of concordance with land cover from catchments and land cover extracted from symmetrical buffers between 200 and 500 m in radius, though catchments were typically smaller and more variable in size when defined with the 10 m DEM.

To provide additional context about wetland size we added Appendix A and modified text in Section 2.2 Wetland Locations and Extent to include the following:

"The distribution of wetland sizes was strongly right-skewed across the three Natural Regions of interest. Wetlands were typically small, with Boreal wetlands possessing the largest median size (2.26 ha), followed by Parkland wetlands (1.54 ha) and Grassland wetlands (0.58 ha, Appendix A). The combination of wetland size and our digital elevation model (DEM) resolution of 25 m suggest that our median wetland sizes would occupy 904, 616, and 232 cells for Boreal, Parkland, and Grassland natural regions, respectively, and demonstrate our ability to capture variability among wetland sizes and shape."

In Appendix A we provide the mean, standard deviation, and histograms of wetland size distribution for each of the three natural regions (Boreal, Parkland, and Grassland).

Importantly, we did not use the DEM to delineate the boundaries of the wetlands in our study – they were taken from the Alberta Merged Wetland Inventory, and so this would not be at play in determining the sizes of our study wetlands. While there are differences in wetland size by Natural Region, generally, wetlands were smaller than (2.26 ha)

L114: which variables are global? At 100m resolution how can you relate that elevation, slope, etc. to an individual wetland basin?

We have incorporated Table 2 into the manuscript that describes the variables used in our analysis. Among our terrain variables, two are global variables (surface convexity and surface texture) and are based on the work of Iwahashi and Pike (2007). Other variables such as elevation and slope are defined in terms of their average or variation within a 500 m buffer of the wetland as noted in the text. With reference to Table 2 and an additional reference to Branton and Robinson (2019) that provides additional details, we provide sufficient information for replication of terrain metrics by readers.

L117: Since this is a stats model and not a mechanistic model my understanding is that you did not quantify relative contribution, you quantified correlation strength. Also, when you say, “land cover/land use and terrain for different wetland permanence classes” you need something between for and different.

We agree that, strictly speaking, regressions and their statistical siblings are measuring correlation, yet it is standard practice to assume directionality and describe one dependent variable as being influenced by the independent variable(s). This is also true in boosting models. For consistency with the literature using this modelling approach, we believe it is appropriate to say, “relative contribution” instead of “correlation strength,” though we agree with the Reviewer that causality is not experimentally established in our study.

We have altered the last sentence of the section in question to the following:

“These analyses were performed in R (R Core Team, 2019) and while they quantify a relationship among our independent variables with wetland permanence, they do not infer causation.”

Also, in this data analysis section please describe the relative importance methods and what the relative gains metric used in figure 2 means.

We added a brief explanation of what relative gains means in Figure 3 (formerly 2) and also to the relevant appendices (E, F, and G).

2.4.1 Predicting wetland permanence class: This section could use more defense of why you used the covariates you did and help elucidate the mechanisms of how they could influence permanence class.

We understand the importance of this point. A list of these variables and literature that cite them for their relevance was provided in Appendix B and we have added a section on the results of our variable selection process, as described above.

Results

Overall, much more detail is needed. Currently, the results as presented in the figures 4-8 are extremely hard to interpret. More work is needed to consolidate results to communicate the most pertinent findings to the readers.

We consolidated Figures 4-8 to make it easier to follow the main points in the partial dependence plots. Rather than showing plots for climate, topography and land cover/land use separately, we are now only showing the waterfall plots for the top metrics (Figure 5). Furthermore, we revised the text in the results section to improve reader comprehension (L208-215).

L142-143: How can you point this error to lack of correlation between covariates and response variable and not a mismatch of spatial and temporal scales between covariates and response variable? I would love to see this model re-run with improvements on selection of covariates and the inclusion of wetlands close to each other with better elevation data to map wetlands of different permanence classes in the same wetland complex.

As we describe above, we are unfortunately constrained by what data exist at a large spatial scale in our study area. Ideally, we would have a high-resolution DEM (e.g., 3 m), high accuracy data on hydroperiod, land cover/land use, and climate collected over the same interval simultaneously across the full study extent for all 40,000 wetlands. Yet we contend that the issues of climate change and habitat loss are urgent and the absence of perfect data should not prevent us from attempting to understand the drivers of wetland permanence class using the (admittedly imperfect) data that do exist: the Alberta Merged, South and Central wetland inventories, the 25 m DEM, and the AAFC land cover data. We can support these efforts by interrogating the effects of the data limitations we face. For example, we found only minor differences in outcomes between 10 and 25 m DEMs (e.g., Kraft et al. 2019); temporal mismatch is a function of remotely sensed data (e.g., landcover) that is typically reported annually; spatial mismatch will almost always be present across multiple variables represented across large spatial extents, and it is just as likely that if we ignored spatial autocorrelation (i.e., spatial independence in sample wetlands) that a reviewer would have requested we ensure our samples are spatially independent. Because our level of analysis covers a large spatial extent with data limitations we focused on the aggregate comparison between the domains (i.e., types) of variables: climate, topography, and land use/cover, rather than issues that can be resolved at plot or small-spatial extents.

In a previous response, we explain why we selected landcover and climate data for one year and we also explain that we did not exclude wetlands that were part of a complex, but did not select two wetlands to be part of our 40,000 from within 1 km of each other to defend against spatial autocorrelation.

L147-148: explain the directionality of this relationship between spring temp and permanence class.

We removed the figure 5 in our consolidation that the reviewer requested above, but the relationship we mention here comes from Figure 5 IV-VI, which shows the probability of the wetland belonging to each permanence class across the observed range of spring temperatures. The pattern was clearest in the Grassland (Figure 5VI) where warmer spring temperatures coincide with more temporary and less permanently ponded wetlands. Not being a mechanistic model, we are not presupposing why this association occurs, rather we are reporting associations that exist within the data. We could speculate that warmer spring temperatures could result in greater evapotransporation losses. We could also speculate that warmer springs might lead to faster soil thaw and perhaps less runoff over frozen ground. Either reduced inputs or increased losses would account for lesser permanence classes dominating at higher spring temperatures.

We rather like the waterfall plots for visualizing the change in probability of a given wetland belonging to a particular permanence class across the range of the given predictor variable but recognize that it was a lot of figures to present. If the AE is amenable, we could replace these in an Appendix to continue referencing the details. If that were the case, our text for L207-215 would also revert to directly discussing the full set of waterfall plots:

"Our findings suggest that wetland permanence class in the Prairie Pothole Region of Alberta correlates with climate, terrain and, to a lesser extent, to surrounding land cover/ land use. Generally, across the three Natural Regions, wetlands with shorter hydroperiods (e.g., temporary and seasonal) were typically situated in landscapes with higher spring snowpack amounts (Figure 4IV-VI) and spring temperatures (Figure 5IV-VI). Longer hydroperiod wetlands were typically situated in landscapes with more summer precipitation (Figure 4VII-VX) and lower spring temperatures (Figure 5IV-VI), occupying relatively low topographic positions (Appendices F-H) with steep slopes (Figure 7 X-XII), and were surrounded by less natural cover (Figure 6X-XII). Interestingly, the relative importance of variables in predicting the occurrence of both shorter and longer-hydroperiod wetlands were shared, and this agreement was strongest between the Southern Boreal and Grassland (Appendices F & H)."

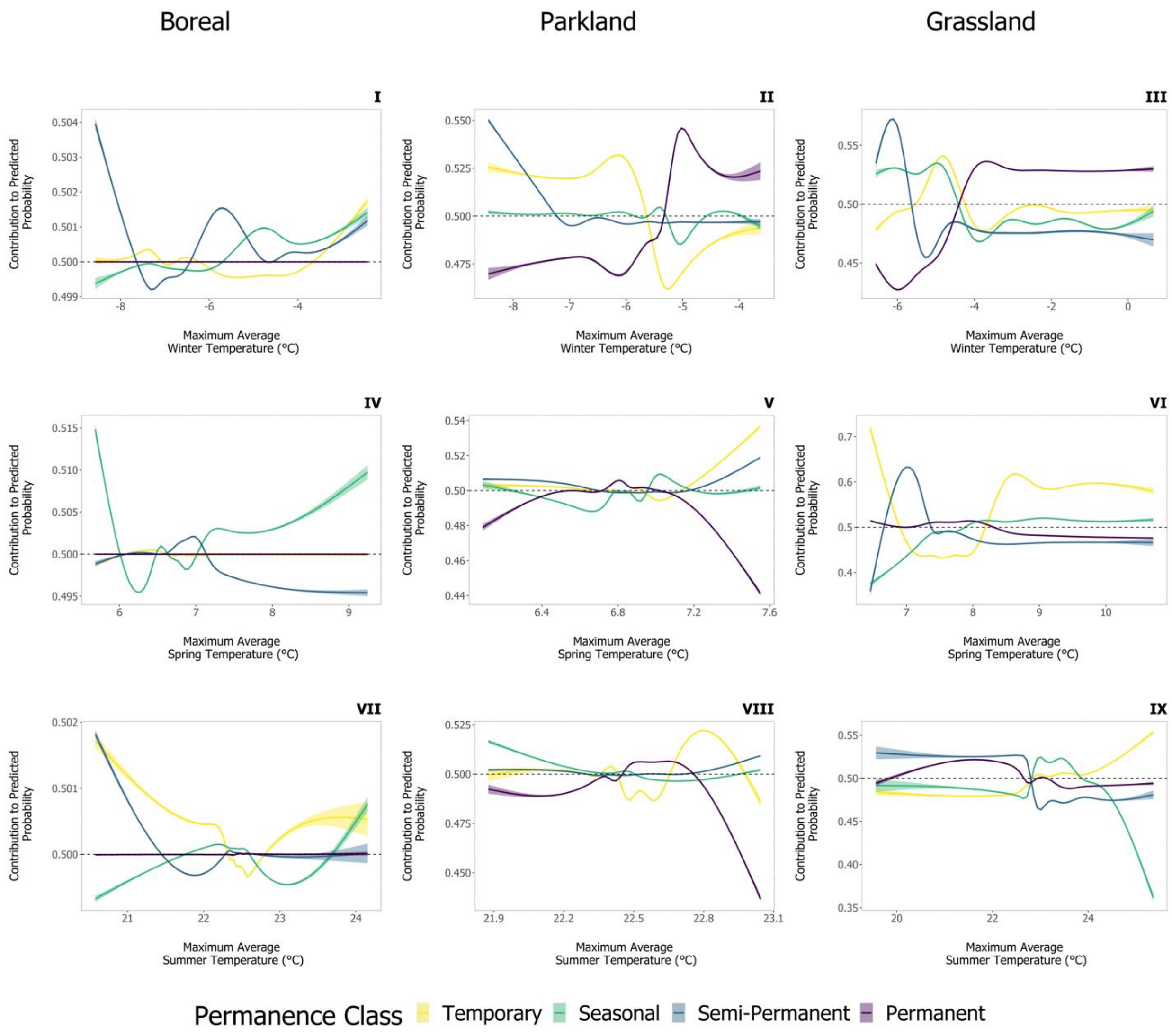


Figure 5. Partial dependence plots for the four wetland classes – temporary, seasonal, semi-permanent and permanent based on temperature metrics. Predicted probabilities below 0.5 suggest that at this measured value of the metric, observing that permeance class is unlikely. We show 95 % confidence intervals and used a generalized additive model-based trend line. Probabilities were derived from extreme gradient boosting models for wetlands delineated in the 1) Boreal (totalling 12,000 wetlands), 2) Parkland (totalling 12,000 wetlands) and 3) Grassland (totalling 16,000 wetlands) Natural Regions.

L152-153: move last sentence to the discussion.

This seems to refer to the sentence "Yet, unlike climate, land cover/ land use did not vary systematically among the three Natural Regions (Figure 4E-H)." Reviewer 1 caught that some of our references to figure numbers are incorrect and this is one such instance, for which we apologize. We double checked all figure numbers and insured their accuracy in the revised submission. This alteration changed the figure reference from 4E-H to “Figure 5E-H" and consequently, we do not believe this sentence should move to the discussion section.

L159: instead of “is sensitive” should read “correlates to observed differences in”

We have made this change, but would also like to emphasize that this terminology is consistent with descriptions of regression and boosting models.

L161: higher snowpack amounts? There was only one season of snowpack, how is this plural?

Thank you for catching this. Yes, it should not be plural and the error has been rectified.

Discussion

Explore more what your results mean for your different climate, land use, and topography variables. There is much lacking for linking correlations to causality.

As described earlier, we incorporated Appendix B and gave more details about the variable selection . This gave us the opportunity to better defend our interpretations as supported by both our model and the literature.

L168: This is a very bold leap based on your data to say, “our findings support the assertion that climate change will affect wetland hydroperiod” Your model does not simulate wetland hydroperiod and it only used 11 months of precipitation and temperature data.

We have revised the manuscript to more clearly articulate that

“our finding support the assertion of other published studies (e.,g., Fay et al., 2016; Johnson et al., 2010a, 2005; Johnson and Poiani, 2016; Reese and Skagen, 2017; Werner et al., 2013), which conclude that climate change will affect wetland hydroperiod or permanence class.” (L225)

Given that our model to predict wetland permanence class identified annual data on climate variables to be the most important domain of predictors compared to land cover and terrain, we see this as support for other published studies that assert that climate change will affect wetland hydroperiods because permanence classes are assigned to categorize prairie pothole wetlands into bins of differing ponded water permanence. As we describe above, fine tuning our representation of climate in our models should only increase the importance of this domain of variables.

Johnson, W.C. and Poiani, K.A., 2016. Climate change effects on prairie pothole wetlands: findings from a twenty-five year numerical modeling project. *Wetlands*, *36*(2), pp.273-285.

McKenna, O.P., Mushet, D.M., Anteau, M.J., Wiltermuth, M.T., Kucia, S.R. (2019) Synergistic Interaction of Climate and Land-Use Drivers Alter the Function of North American, Prairie-Pothole Wetlands: Sustainability [Special Issue "The Importance of Wetlands to Sustainable Landscapes"], https://doi.org/10.3390/su11236581

L171: climate is not the only element driving. Replace with "element correlated with"

We have made this change.

L173: unpack the term "terrain" what aspects about terrain specifically were related to permanence class of a wetland?

Thank you for this comment. We were interchangeably using topography and terrain throughout the manuscript, resulting in confusion. We have revised our usage to topography for all general references to the shape of the terrestrial surface and reserve terrain for use in specific measurements about the terrestrial surface.

The line in question now says "Yet, annual data on climate is not the only element correlated with wetland permanence class in Alberta's PPR - our analysis used a relatively coarse DEM (25 m), and we nonetheless found that topography was important in predicting permanence class." L231

Here we are referring to the terrain metrics we analysed in our modelling, which is more explicitly defined for the reader now in Table 2. The relative importance of individual terrain metrics in the three Natural Regions is depicted in Figure 3 and Figure 5 indicates some of the key variables and how the probability of different permanence classes occurring varies across the range of these variables. We also elaborate on this in section 4.2 of the text. Collectively these and other modifications noted in our responses to reviewer comments have defined the relationship between topography and wetland permanence class.

L176 see previous comment

Again, we refer to Table 2, Figures 3 and 5 and additions to the text (e.g. section 3.4)

L185: Figure 3B is Max temp in winter

Apologies, this was a typo and should have been Figure 5b (formerly figure 4II), not Figure 3b. We mistakenly failed to update figure numbers in the text after adding a map to the manuscript, shifting many of the references off by one number. We have since revised the figure numbers further and confirm that they are adjusted in the text.

L187: your modeling exercise does not include future changes in climate and does not explicitly explore sensitivity to climate change

The sentence now reads "Because climate forecasts suggest that warmer springs and changes in precipitation timing are likely (Zhang et al., 2011), our finding that climate was the most important domain of variables in predicting permanence class supports previous studies that suggest PPR wetlands are sensitive climate change (Johnson et al., 2010; Paimazumder et al., 2013; Schneider, 2013; Viglizzo et al., 2015; Zhang et al., 2011)" L 245.

As with the Reviewer's comments about L168, here we are not intending to suggest that our model involved climate forecasts, but rather that our finding that climate was the most important domain of variables predicting permanence class, and that this is in alignment with other published studies who also conclude that wetland permanence class or hydroperiod will be sensitive to climate change because climate variables exert an important influence on wetland hydroperiod. We revised to make this more clear

L199: the "natural frequency" I think this should read the "classified frequency"

Thank you, the change has been made. L 261

L224. This fires sentence is misleading. All depressional wetlands occur in topographic lows by definition.

Yes, we agree that depressional wetlands occur in local depressions, but at a larger spatial scale of consideration (e.g. 2 or 5 km) some depressional wetlands may form in lower topographic lows than others. Prior work looking at such networks or wetlandscapes finds that more permanently ponded wetlands tend to be in lower topographic positions at the wetlandscape scale, with more temporarily ponded wetlands more typically in higher positioned depressions. We have modified the sentence to explicitly note this differentiation as follows:

"Semi-permanent and permanently-ponded wetlands typically occur in regional or spatial neighourhood topographic lows (as opposed to simply local depressions, e.g., perched wetlands)"… L 286

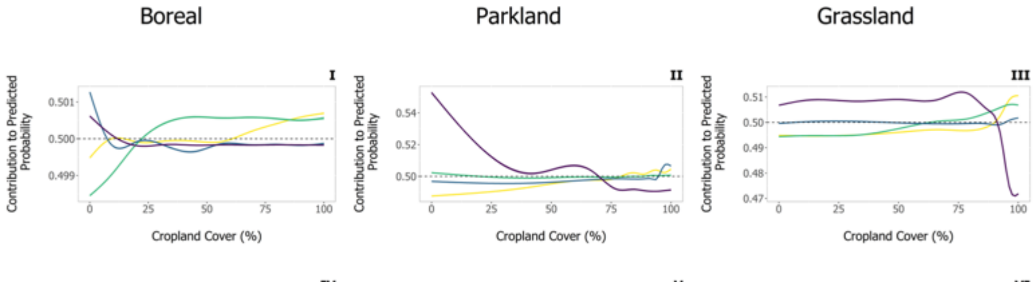
L233: "which aligns with our model results" How does this align? I need a lot more description here to be convinced of that.

Here we were referring to the partial dependence plots (formerly 6, but now partially represented in Figure 5 as the Boreal based on the requested consolidation of figures 4-8. We modified the text to better explain our point L 297-300.

Crop cover ranked as the most important land cover/ land use parameter in the Boreal, but was relatively less important in the Grassland and Parkland natural regions (see Figure 3), so with the consolidation, it is represented in panel A of Figure 5, for the Boreal. However, the pattern is the same for all three natural regions: in landscapes with crop cover below a certain threshold, the probability is greatest that a wetland in that landscape would be a permanent (purple) or semi-permanent (blue) class. Focusing on the Boreal plot, that is at about 12% Whereas, for the Parkland it is closer to 75%. In landscapes above that threshold of crop cover, a wetland is most probably going to be seasonal (green), up to a point (e.g., 80% cover in the Boreal or maybe 95% cover in the

Grassland), and then at the top end of the range of crop cover the wetland is most probably temporarily ponded (yellow).

When we say that our modeling results align with this idea that consolidation drainage might be operating in our system, it is because the threshold at which this flip from wetlands being most likely permanent or semi-permanent to being most likely seasonal or temporary occurs at a different level of crop cover, depending on which natural region you are considering (see below). Where there is more farm activity (Grassland) the threshold is at a much higher level of crop cover. This supports an interpretation that in the heavily farmed and arid region of the Grassland, consolidation drainage has reduced the probability of observing lower permanence-class wetlands.



Unfortunately, a consequence of consolidating the figures 4-8 into just figure 5 showing the most important variables of each domain in each natural region, this comparison is not really clear. We hope the AE can offer some guidance on whether to keep the proposed consolidation of figures or to revert to our original set of all the partial dependence plots.

4.5 Model Error: Need to explicitly address how mismatch in “climate” variables, only one year of land-cover classification, and overly coarse elevation data could all contribute to model error.

Thank you for the encouragement to explicitly include these issues in our description of Model Error. We have now included the following paragraph:

“It is also likely that some proportion of model error can be attributed to the use a single year of climate and land use data as well as our relatively course (25 m) digital elevation model. However, it is likely that the contributions of these factors are minimal given that 1) the climate data used (year 2014) is representative of average conditions, coincides with fieldwork, and yielded the strongest among the variables interrogated and therefore improving the quality of its contribution will not change the qualitative outcome of the presented analysis; and 2) previous research found that physiochemical conditions in a wetland are quite congruent with surrounding land cover of the same year with only minor differences when catchments were defined with 10 m versus 25 m resolution DEMs (Kraft et al. 2019).“

Figures

Overall, these figures need to be distilled to better visualize the main takeaway and results of your study. In Figure 3 it would also help to convert to a fractional frequency to standardize the differences in number of wetlands between Natural Regions and avoid visualizing differences in frequency distribution that are not relevant to your analysis.

We revised (now) Figure 4 to show scaled density. We also revised our references to figures throughout the text to correct any misnumbering and better describe them. We also tried to reduce the number of figures by consolidating figures 4-8 (all the partial dependence plots) down to figure 5, which only highlights the top-ranking variable for each domain in each natural region. As mentioned elsewhere in the response letter, we leave it to the AE to determine whether this consolidation should stay or revert to the original version of the figures.