THE BOREAL-ARCTIC WETLAND AND LAKE DATASET (BAWLD)

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DATA INFORMATION

The Boreal-Arctic Wetland and Lake Dataset (BAWLD) provides estimates of fractional land cover of 19 land cover classes within 0.5° ×0.5° grid cells. The total area of the BAWLD domain is 25.5×10^6 km^2, i.e. 17% of the global land surface. The domain includes the boreal and tundra biomes, as well as areas of rocks and glaciers at >50°N. The dataset is comprised of 23,469 0.5° ×0.5° grid cells. Each grid cell includes information on the fractional cover of five wetland classes, seven lake classes, three river classes, along with glacier, rockland, tundra, and boreal forest classes. The descriptions of each land cover class are provided at the bottom of this document. Estimates of land cover fractional extents are based on an expert assessment, and a subsequent extrapolation to the full study region using random forest analysis. The dataset also includes an assessment of the uncertainty of the fractional cover estimates, represented by the 95% high and low estimates for fractional land cover. Each grid cell is further classified as one of fifteen "wetscapes", which are defined by a characteristic land cover composition.

File format: The data is provided both as an ESRI shapefile (.shp), and a Keyhole Markup Language (.kml) file.

Dataset projection: North Pole Lambert Azimuthal Equal Area

GRID CELL ATTRIBUTES

Cell_ID: Unique cell ID.

Lat: Latitude of centre point of grid cell (decimal degrees). In cases where grid cells have been intersected (coast or ecoregion), the center point still indicates the centre of the grid cell prior to intersection.

Long: Latitude of centre point of grid cell (decimal degrees). In cases where grid cells have been intersected (coast or ecoregion), the center point still indicates the centre of the grid cell prior to intersection.

Area_Pct: The percent of a grid cell that is included in the BAWLD database after intersection with coast and ecoregions (%).

Shp_Area: Area of grid cell (after intersection, where applicable) (m^2).

GLA: Percent cover of glaciers and permanent snow within grid cell (%).

ROC: Percent cover of rocklands within grid cell (%)

TUN: Percent cover of dry tundra within grid cell (%).

BOR: Percent cover of boreal forest within grid cell (%).

WET: Percent cover of wetlands within grid cell (%). Wetlands include the five wetland sub-classes, permafrost bogs, wet tundra, marsh, bog, and fen.

PEB: Percent cover of permafrost bogs within grid cell (%).

WTU: Percent cover of tundra wetland within grid cell (%).

MAR: Percent cover of marsh within grid cell (%).

BOG: Percent cover of bog within grid cell (%).

FEN: Percent cover of fen within grid cell (%).

LAK: Percent cover of lakes within grid cell (%). Lakes include the seven lake sub-classes; large lakes (>10 km^2), mid-size peatland, yedoma, and glacial lakes (between 10 and 0.1 km^2), and small peatland, yedoma, and glacial lakes (<0.1 km^2).

MPL: Percent cover of mid-sized peatland lakes within grid cell (%).

MYL: Percent cover of mid-sized yedoma lakes within grid cell (%).

MGL: Percent cover of mid-sized glacial lakes within grid cell (%).

SPL: Percent cover of small peatland lakes within grid cell (%).

SYL: Percent cover of small yedoma lakes within grid cell (%).

SGL: Percent cover of small glacial lakes within grid cell (%).

RIV: Percent cover of rivers within grid cell (%). Rivers include three river sub-classes: large rivers (6^{th} order or greater), and small organic-rich and organic-poor rivers (<6^{th} order).

LAR: Percent cover of large rivers within grid cell (%).

SRR: Percent cover of small organic-rich rivers within grid cell (%).

SRP: Percent cover of small organic-poor rivers within grid cell (%).

The subsequent attributes provide the 95% confidence interval for the central estimates of land cover extents, indicated by the low estimate (**xxx_L**) and the high estimate (**xxx_H**).

WETSCAPE: Each cell in BAWLD has been categorized into one of 15 wetscapes. The wetscapes were determined through a K-means clustering. The wetscape classification is indicated by numbers from 1 to 15, which correspond to:

1. Permafrost Peatlands

2. Sparse Boreal Peatlands

3. Rivers

4. Glaciers

5. Upland Tundra

6. Common Boreal Peatlands

7. Large Lakes

8. Lake-rich wetlands

9. Dominant Boreal Peatlands

10. Wetland-rich Tundra

11. Alpine and Tundra Barrens

12. Wetland and Lake-rich Tundra

13. Lake-rich Shield

14. Upland Boreal

15. Wetland and Lake-rich Yedoma Tundra

LAND COVER CLASS DESCRIPTIONS

The land cover classification in BAWLD was constructed with the goal to enable upscaling of CH_4 fluxes for large spatial extents. As such, we aimed to include as few classes as possible to facilitate for large-scale mapping, while still including classes that allow for separation among ecosystems with distinct hydrology, ecology, biogeochemistry and thus net CH_4 fluxes. The BAWLD land cover classification is hierarchical; with five wetland classes, seven lake classes, and three river classes, along with four other classes; glaciers, dry tundra, boreal forest, and rocklands.

WETLAND CLASSES

Wetlands are defined by having a water table near or above the land surface for sufficient time to cause the development of wetland soils (either mineral soils with redoximorphic features, or organic soils with > 40 cm peat), and the presence of plant species with adaptations to wet environments. Wetland classifications for boreal and arctic biomes can focus either on small-scale wetland classes that have distinct hydrological regimes, vegetation composition, and biogeochemistry, or on larger-scale wetland complexes that are comprised of distinct patterns of smaller wetland and open-water classes. While larger-scale wetland complexes are easier to identify through remote sensing techniques (e.g. patterned fens comprised of higher elevation ridges and inundated hollows), our classification focuses on wetland classes due to greater homogeneity of hydrological, ecological, and biogeochemical characteristics that regulate CH_4 fluxes.

Several boreal countries identify four main wetland classes, differentiated primarily based on hydrodynamic characterization; bogs, fens, marshes, and. The BAWLD classification follows this general framework, but further uses the presence or absence of permafrost as a primary characteristic for classification and excludes a distinct swamp class, yielding five classes; *Bogs*, *Fens*, *Marshes*, *Permafrost Bogs*, and *Tundra Wetlands*. The swamp class was omitted due to the wide range of moisture and nutrient conditions of swamps, as well as the limited number of studies of swamp CH_4 fluxes. We instead included swamp ecosystems in expanded descriptions of *Bogs*, *Fens*, and *Marshes*. The presence or absence of near-surface permafrost was used as a primary characteristic to distinguish between *Permafrost Bogs* and *Bogs,* and to distinguish *Tundra Wetlands* from *Marshes* and *Fens*. The presence or absence of near-surface permafrost is considered key for controlling CH_4 emissions given its influence on hydrology, and for the potential of permafrost thaw and thermokarst collapse to cause rapid non-linear shifts to CH_4 emissions. Finally, while some classifications include shallow (e.g. 2 m depth), open-water ecosystems within the definition of wetlands, we have included all open-water ecosystems without emergent vegetation within the lake classes (see below) due to the strong influence of emergent vegetation in controlling CH_4 emissions.

Bogs are described as ombrotrophic peatland ecosystems, i.e. only dependent on precipitation, and snowmelt for water inputs. Peat thickness is at least 40 cm, with maximum thickness > 10 m. The peat profile is not affected by permafrost, although in some climatically colder settings there may be permafrost below the peat profile. *Bogs* are wet to saturated ecosystems, often with small-scale (<10 m) microtopographic variability, with stagnant water and a water table that rarely is above the surface or more than 50 cm below the surface (Figure 1). *Bogs* have low pH (<5), low concentrations of dissolved ions, and low nutrient availability resulting from a lack of hydrological

connectivity to surrounding mineral soils. Vegetation is commonly dominated by *Sphagnum* mosses, lichens, and woody shrubs, and can be either treed or treeless. Our description of *Bogs* also includes what is commonly classified as treed swamps, which generally represent ecotonal transitions between peatlands and upland forests.

Fens are described as minerotrophic peatland ecosystems, i.e. hydrologically connected to surrounding mineral soils through surface water or groundwater inputs. A *Fen* peat profile is at least 40 cm thick, although maximum thickness is generally less than for bogs. The peat profile is not affected by permafrost. *Fens* are wet to saturated ecosystems, with generally slow-moving water. *Fens* have widely ranging nutrient regimes and levels of dissolved ions depending on the degree and type of hydrological connectivity to their surroundings, ranging from poor fens to rich fens. Vegetation largely depends on wetness and nutrient availability, where more nutrient poor fens can have *Sphagnum* mosses, shrubs, and trees, while rich fens are dominated by brown mosses, graminoids (sedges, rushes), herbaceous plants, and sometimes coniferous or deciduous trees (e.g. willows, birch, larch). Our description of *Fens* also includes what is commonly classified as shrubby swamps, which often are associated with riparian ecotones and lake shorelines.

Marshes are minerotrophic wetlands with dynamic hydrology, and often high nutrient availability. Vegetation is dominated by emergent macrophytes, including tall graminoids such as rushes, reeds, grasses and sedges – some of which can persist in settings with >1.5 m of standing water. *Marshes* are saturated to inundated wetlands, often with highly fluctuating water levels as they generally are located along shorelines of lake or coasts, along streams and rivers, or on floodplains and deltas. It is common for marshes to exhibit both flooded and dry periods. Dry periods facilitate decomposition of organic matter, and can prevent the build-up of peat. As such *Marshes* generally have mineral soils, although some settings allow for the accumulation of highly humified organic layers – sometimes indicating ongoing succession towards a peatland ecosystem. Salinity can vary depending on water sources, with brackish to saline conditions in some areas of groundwater discharge, or in coastal settings.

Permafrost Bogs are peatland ecosystems, although the peat thickness in cold climates is often relatively shallow. *Permafrost Bogs* have a seasonally thawed active layer that is 30 to 70 cm thick, with the remainder of the peat profile perennially frozen (i.e. permafrost). Excess ground-ice and ice expansion often elevate *Permafrost Bogs* up to a few meters above their surroundings, and as such they are ombrotrophic and generally the wetland class with the driest soils. *Permafrost Bogs* have moist to wet soil conditions, often with a water table that follows the base of the seasonally developing thawed soil layer. Ombrotrophic conditions cause nutrient-poor conditions, and the vegetation is dominated by lichens, *Sphagnum* mosses, woody shrubs, and sometimes stunted coniferous trees. *Permafrost Bogs* are often interspersed in a fine-scale mosaic (10 to 100 m) with other wetland classes, e.g. *Bogs* and *Fens*. Common *Permafrost Bog* landforms include palsas, peat plateaus, and the elevated portions of high- and low-center polygonal peatlands.

Tundra Wetlands are treeless ecosystems with saturated to inundated conditions, most commonly with near surface permafrost (Figure 1). Tundra Wetlands can have either mineral soils or shallow organic soils, and generally receive surface or near-surface waters from its surroundings, as permafrost conditions preclude connectivity to deeper groundwater sources. Vegetation is dominated by short emergent vegetation, including sedges and grasses, with mosses and shrubs in slightly drier sites. *Tundra Wetlands* have lower maximum depth of standing water than *Marshes,* due to the shorter vegetation. *Tundra Wetlands* can be found in basin depressions, in low-center

polygonal wetlands, and along rivers, deltas, lake shorelines, and on floodplains in regions of continuous permafrost. Despite the name, limited wetlands with these characteristics (hydrology, permafrost conditions, and vegetation) can also be found within the continuous permafrost zone in boreal and sub-arctic regions.

LAKE CLASSES

Lakes are in BAWLD considered to include all lentic open-water ecosystems, regardless of surface area and depth of standing water. It is common in ice-rich permafrost lowlands and peatlands for open-water bodies to have shallow depths, often less than two meters, even when surface areas are up to hundreds of km^2 in size. While small, shallow open-water bodies often are included in definitions of wetlands, we include them here within the lake classes as controls on net CH_4 emissions depend strongly on the presence or absence of emergent macrophytes. Further classification of lakes in BAWLD is based lake size and lake genesis, where lake genesis influences lake bathymetry and sediment characteristics. Previous global spatial inventories of lakes include detailed information on size and location of individual larger lakes, but do not include open-water ecosystems <0.1 km^2 in size, and do not differentiate between lakes of different genesis (e.g. tectonic, glacial, organic, and yedoma lakes). Small water bodies are disproportionately abundant in some high latitude environments, have high emissions of CH_4, and therefore require explicit classification apart from larger water-bodies. Furthermore, lake genesis and sediment type haven been shown to influence net CH_4 flux from lakes. In BAWLD we thus differentiate between large (>10 km^2), midsize (0.1 to 10 km^2) and small (<0.1 km^2) lake classes, and further differentiate between three lake types for midsize and small lakes; peatland, yedoma, and glacial lakes.

Small and *Midsize Peatland Lakes* are described as lakes with thick organic sediments that are mainly found adjacent to or surrounded by peatlands, or in lowland tundra regions with organic-rich soils. *Small Peatland Lakes* includes the numerous small pools often found in extensive peatlands and lowland tundra regions, e.g. including the open-water parts of string fens and polygonal peatlands. *Peatland Lakes* generally form as a result of interactions between local hydrology and the accumulation of peat which can create open water pools and lakes, but can also form in peatlands as a result of permafrost dynamics. As such, these lakes with thick organic sediments are often shallow and have a relatively low shoreline development index. *Peatland lakes* have dark waters with high concentrations of dissolved organic carbon.

Small and *Midsize Yedoma Lake*s are exclusive to non-glaciated regions of eastern Siberia, Alaska, and the Yukon where yedoma deposits accumulated during the Pleistocene. Yedoma permafrost soils are ice-rich and contain fine-grained, organic-rich loess which was deposited by wind and accumulated upwards in parallel with permafrost aggradation, thus limiting decomposition and facilitating organic matter burial. Notable thermokarst features, including lakes, often develop when yedoma permafrost thaws, causing labile organic matter to become available for microbial mineralization. *Small Yedoma lakes* typically represent younger thermokarst features, whereas *Midsized Yedoma Lakes* represent later stages of thermokarst lake development. *Small Yedoma Lakes* are thus more likely to have actively thawing and expanding lake edges where CH_4 emissions can be extremely high, largely driven by high ebullition emissions. Century-scale development of yedoma lakes can shift the main source of CH_4 production from yedoma deposits to new organic-rich sediment that accumulate from allochtonous and autochthonous sources – resulting in such lakes here being considered as *Peatland Lakes*.

Small and *Midsize Glacial Lakes* include all lakes with organic-poor sediments – predominately those formed through glacial or post-glacial processes, e.g. kettle lakes and bedrock depressions. However, due to similarities in CH_4 emissions and controls thereof, we also include all other lakes with organic-poor sediments within these classes. *Glacial Lakes* typically have rocky bottoms or mineral sediments with limited organic content. Lakes in this class are abundant on the Canadian Shield and in Fennoscandia, but can be found throughout the boreal and tundra biomes. Many *Glacial Lakes* have high shoreline development index, with irregular, elongated shapes. Generally, *Glacial Lakes* are deeper than lakes in the other classes, when comparing lakes with similar lake area.

Large Lakes are greater than 10 km^2 in surface area. Most *Large Lakes* are glacial or structural/tectonic in origin. Lake genesis is not considered for further differentiation within this land cover class.

RIVER CLASSES

We include three river classes in BAWLD, *Large Rivers*, *Small Organic-Rich Rivers*, and *Small Organic-Poor Rivers*. *Large Rivers* are described as 6th Strahler order rivers or greater, and generally have river widths >~75 m. *Small Organic-Rich Rivers* include all 1st to 5th order streams and rivers that drain peatlands or other wetland soils, thus being associated with high concentrations of dissolved organic carbon and high supersaturation of CH_4. Conversely, *Small Organic-Poor Rivers* drain regions with less wetlands and organic-rich soils, and generally have lower concentrations of dissolved organic carbon and dissolved CH_4.

OTHER CLASSES

Four additional classes are included in BAWLD; *Glaciers, Rocklands, Dry Tundra,* and *Boreal Forests. Glaciers* include both glaciers and other permanent snow and ice on land. *Rocklands* include areas with very poor soil formation and where vegetation is largely absent. Rocky outcrops in shield landscapes, slopes of mountains, and high Arctic barren landscapes are included in the class. The *Rocklands* class also includes artificial surfaces such as roads and towns. *Glaciers* and *Rocklands* are largely considered to be neutral with respect to CH_4 emissions. The *Dry Tundra* class includes both lowland arctic tundra and alpine tundra; both treeless ecosystems dominated by graminoid or shrub vegetation. *Dry Tundra* ecosystems generally have near-surface permafrost, with seasonally thawed active layers between 20 and 150 cm depending on climate, soil texture, and landscape position. Near-surface permafrost in *Dry Tundra* prevents vertical drainage, but lateral drainage ensures predominately oxic soil conditions. A water table is either absent or close to the base of the seasonally thawing active layer. *Dry Tundra* is differentiated from *Permafrost Bogs* by having thinner organic soil (<40 cm), and from *Tundra Wetlands* by their drained soils (average water table position >5 cm below soil surface).. *Boreal Forests* are treed ecosystems with non-wetland soils. Coniferous trees are dominant, but the class also includes deciduous trees in warmer climates and landscape positions. *Boreal Forests* may have permafrost or non-permafrost ground, where absence of permafrost often allow for better drainage. The *Boreal Forest* class also includes the few agricultural/pasture ecosystems within the boreal biome.