Utilization of Fine-Scale Mapping to Quantify Landscape, Permafrost, and Vegetation Evolution in Prudhoe Bay, Alaska

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INTRODUCTION

Ice-rich permafrost landscapes are a key feature in Arctic ecosystems that are increasingly susceptible to change caused by climate warming due to their high ground ice content. Common landforms in these landscapes include ice-wedge polygons and ice-cored mounds known as pingos. Due to their sloping sides, unique hydrology, and relatively small footprints, pingos provide important micro-habitats for plants and wildlife in the tundra landscape. However, little is known about the life cycle of pingos, including their surficial changes overtime. This study aims to quantify the small-scale changes occurring on pingos and in these polygonal landscapes through the use of fine-scale mapping and analysis of landform and vegetation change in a drained thaw-lake basin that contains ice-wedge polygons and a small pingo known as Lemming Pingo. The analysis focuses on the change to the width of ice-wedge polygon troughs, distribution of polygon rims, and changes in hydrology near the foot of Lemming Pingo.

Figure 1. The top panel shows an overview of the study site, with Lake Colleen in the bottom left corner and the pingo study site outlined in black (Walker & Peirce, 2023). The bottom panel shows a side profile of Lemming Pingo taken from the east-southeast side facing west-northwest in July of 2024.

MAPPING

Figure 2. Base maps produced using the Integrated Terrain Unit Mapping approach. The first panel on the left shows the complete map boundaries drawn on the 1988 airborne imagery. The middle panel shows the differences between the two time periods, with the orange color showing areas that have exhibited change in surface features, surface feature elements, or primary vegetation and the blue color showing areas with no change. The panel on the right shows the modern map boundaries drawn on the 2020 airborne imagery. The red inset shown on the maps aligns with Figure 3.

The mapped area is contained within a drained thaw lake basin with a well-developed polygonal network and pingo. The mapped pingo is known as Lemming Pingo, aptly named for the population of collard lemmings that utilizes the mound. A 350 x 300m section (10.5 hectares) located in Prudhoe Bay, Alaska, was mapped for two time periods spanning 32 years using the Integrated Terrain Unit Mapping (ITUM) method developed by Dr. Donald A. Walker. The map boundaries delineate landforms, surface features, surface feature elements, primary vegetation types, and secondary vegetation types. Photo interpretation and ArcGIS Pro 3.3.1 elevation surface geoprocessing tools were used to perform the mapping. The maps were drawn on airborne imagery from 1987, 1988, and 2020 alongside digital surface models, established vegetation plots, and accuracy assessment points obtained by Olivia Hobgood and Briana McNeal. The changes in vegetation, surficial features, and surficial feature elements were compared between the two time periods, with the results from this analysis shown in Figure 6. Significant changes in pingo drainage features were also observed, as seen in Figure 3 below. The drainage features appear on both the north and south sides of the pingo.

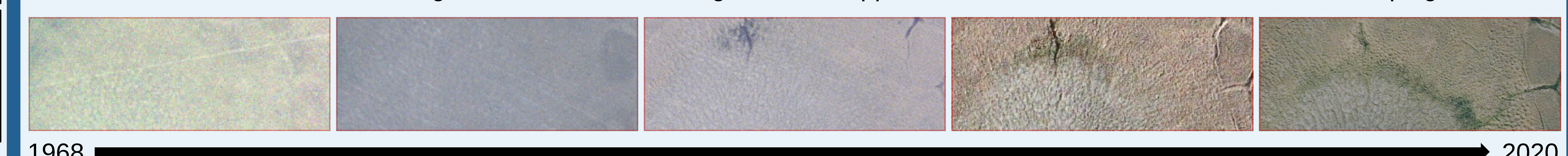

Figure 3. Series of airborne photographs taken from 1968, 1990, 2000, 2010, and 2020 showing the development of the drainage channel on the lower north side of Lemming Pingo, shown by the red inset in Figure 2. Color differences in the photographs can largely be attributed to equipment differences, but the first signs of the large crack seen on the pingo now began developing around 1998.

TROUGH ANALYSIS

The trough network was mapped based on the relationship between adjoining polygons and supported by depressions in the elevation surface. To determine the width of troughs throughout the polygonal network, a centerline was added to the mapped trough network. Transects were then drawn orthogonal to the centerline at one-meter increments, intersecting the sides of the trough network. The transects were then clipped at these side intersection points to represent the full width of the trough at every meter. Transects that were determined to not represent cross-sections of the trough network were also removed to reduce over-estimates and under-estimates. The trough analysis was done separately using the 1988 mapped trough network and the 2020 mapped trough network. The figures on the right show the frequency of trough widths between the two time periods, with a mean trough width of 1.16m in 1988 and 1.37m in 2020. This 18% increase in average trough width over the 32-year period indicates significant trough widening and filling as expansion occurs. The increase in narrow trough widths also indicates continual network development. Additionally, the number of transects increased significantly from 1988 to 2020, indicating a lengthening of the trough network. This indicates that more troughs are developing as the polygonal basins drain and the network between the polygons expands. The widening of the troughs is also evident through the recent formation of small, non-vegetated thermokarst ponds that form at the corner of ice-wedge polygons within the trough network. The increase in these water-filled features can impact a variety of ecosystem functions, such as carbon cycling and wildlife utilization.

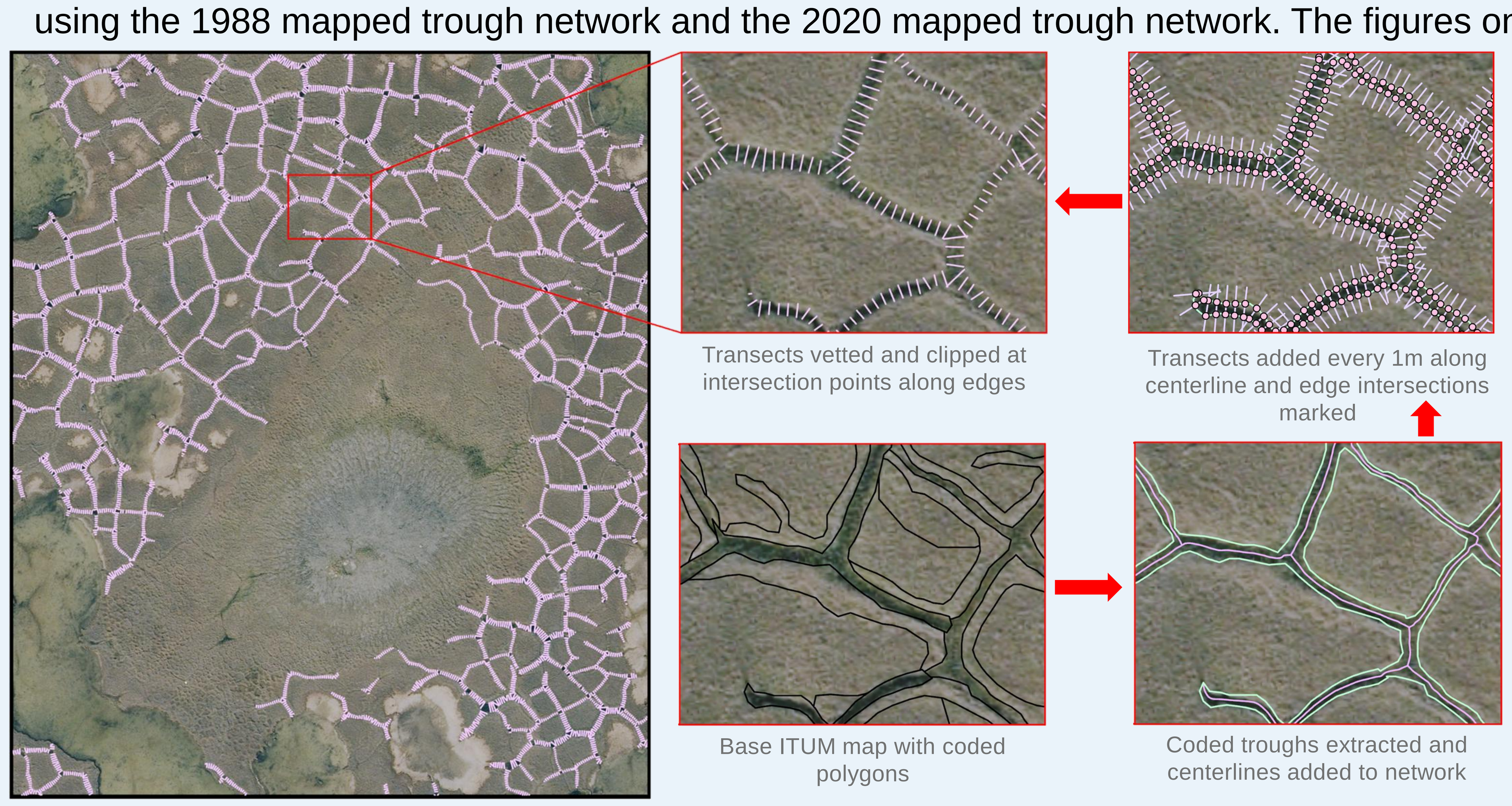

Figure 4. Process for calculating trough widths along the entire mapped trough network. The large left panel shows the final stage of the trough analysis for 2020, and the right four panels show the main stages of analysis beginning in the bottom left panel.

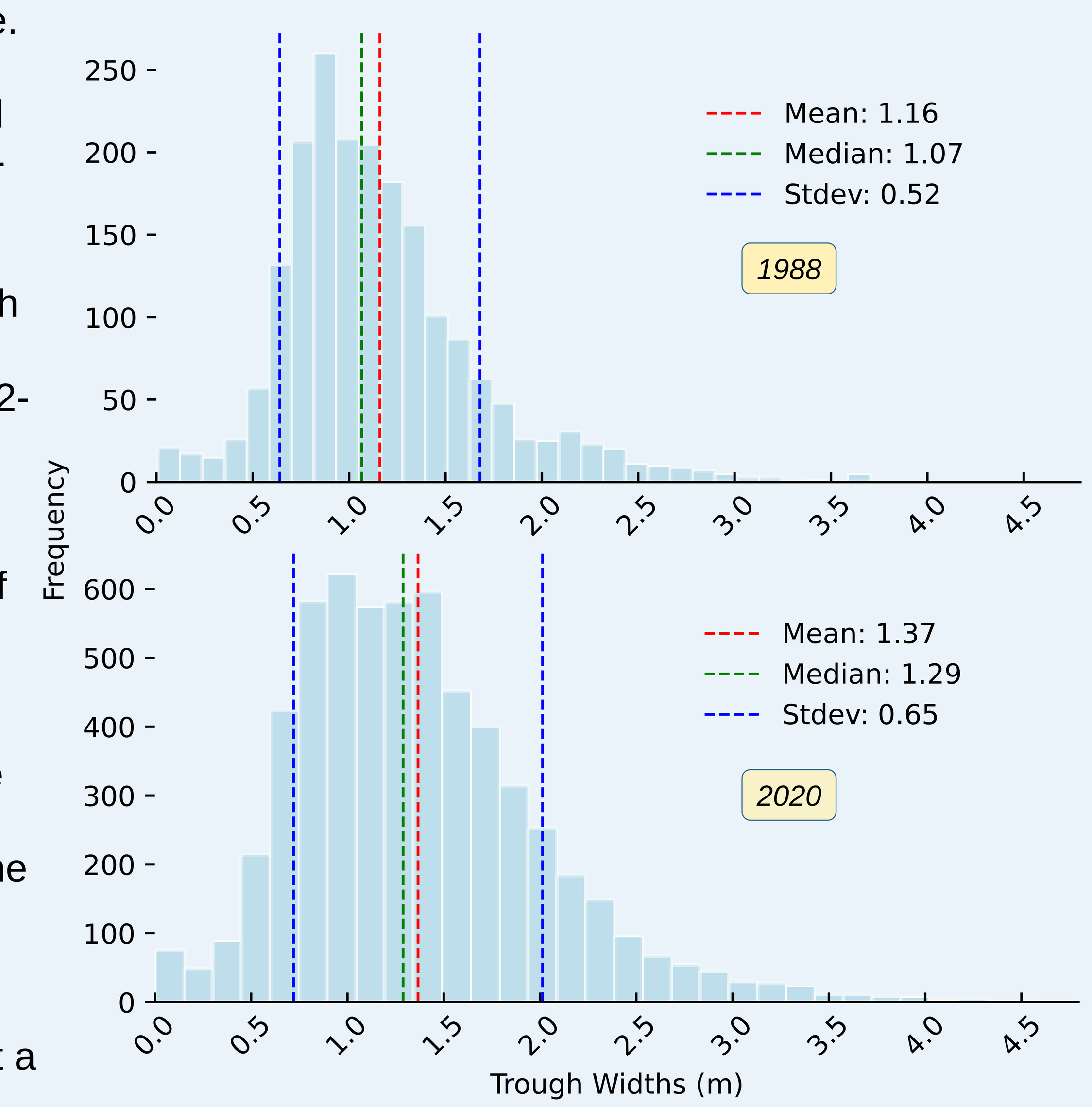

Figure 5. Histograms showing the frequency of trough widths in 1988 (top panel) and 2020 (bottom panel). The mean, median, and standard deviation for each year are also shown.

DISCUSSION

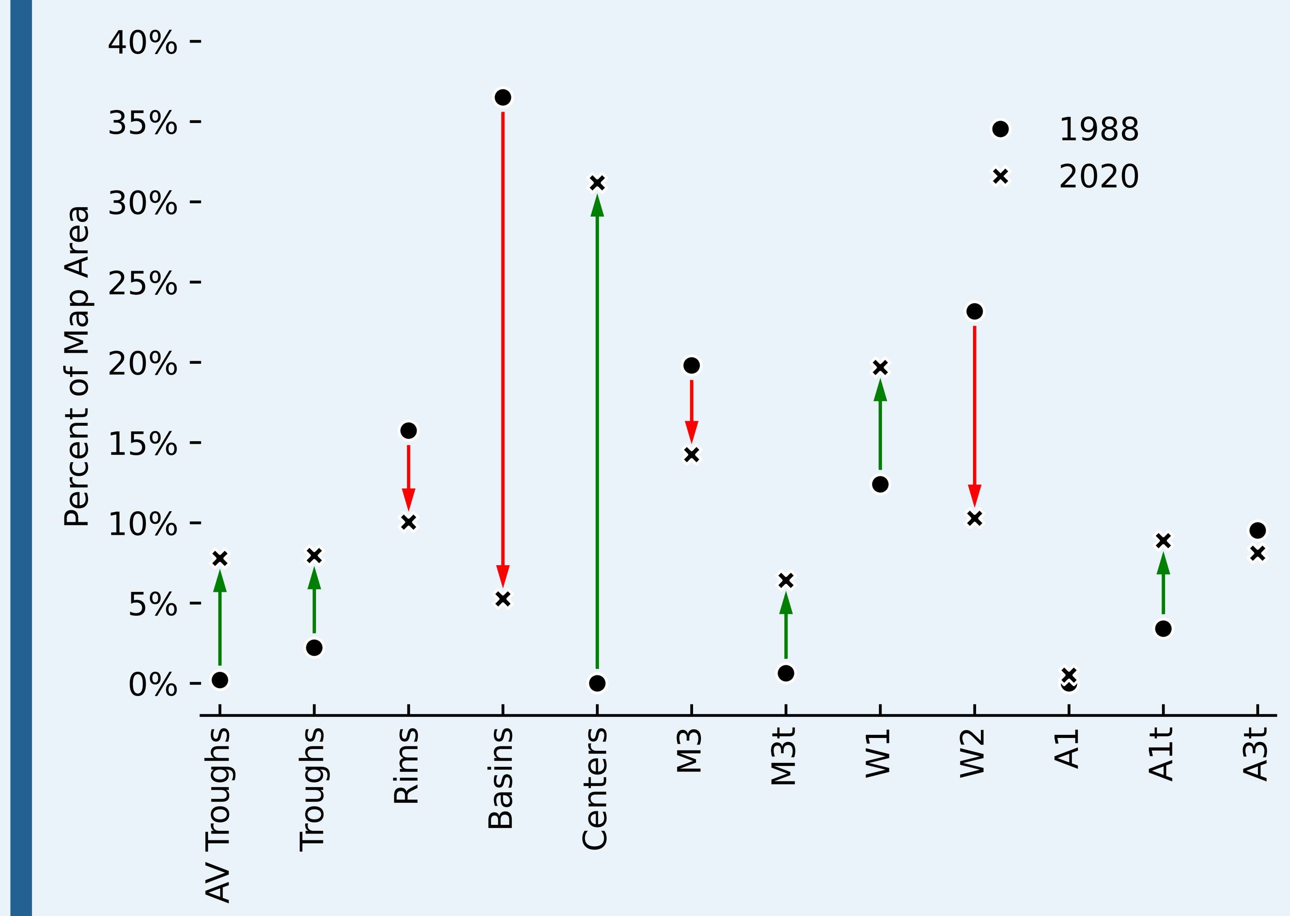

Figure 6. Changes in key surficial features and vegetation types characteristic to the polygonal tundra landscape in Prudhoe Bay. Green arrows indicate increasing trends overtime and red arrows indicate decreasing trends. Below are the listed variables. AV troughs are those filled with aquatic vegetation.

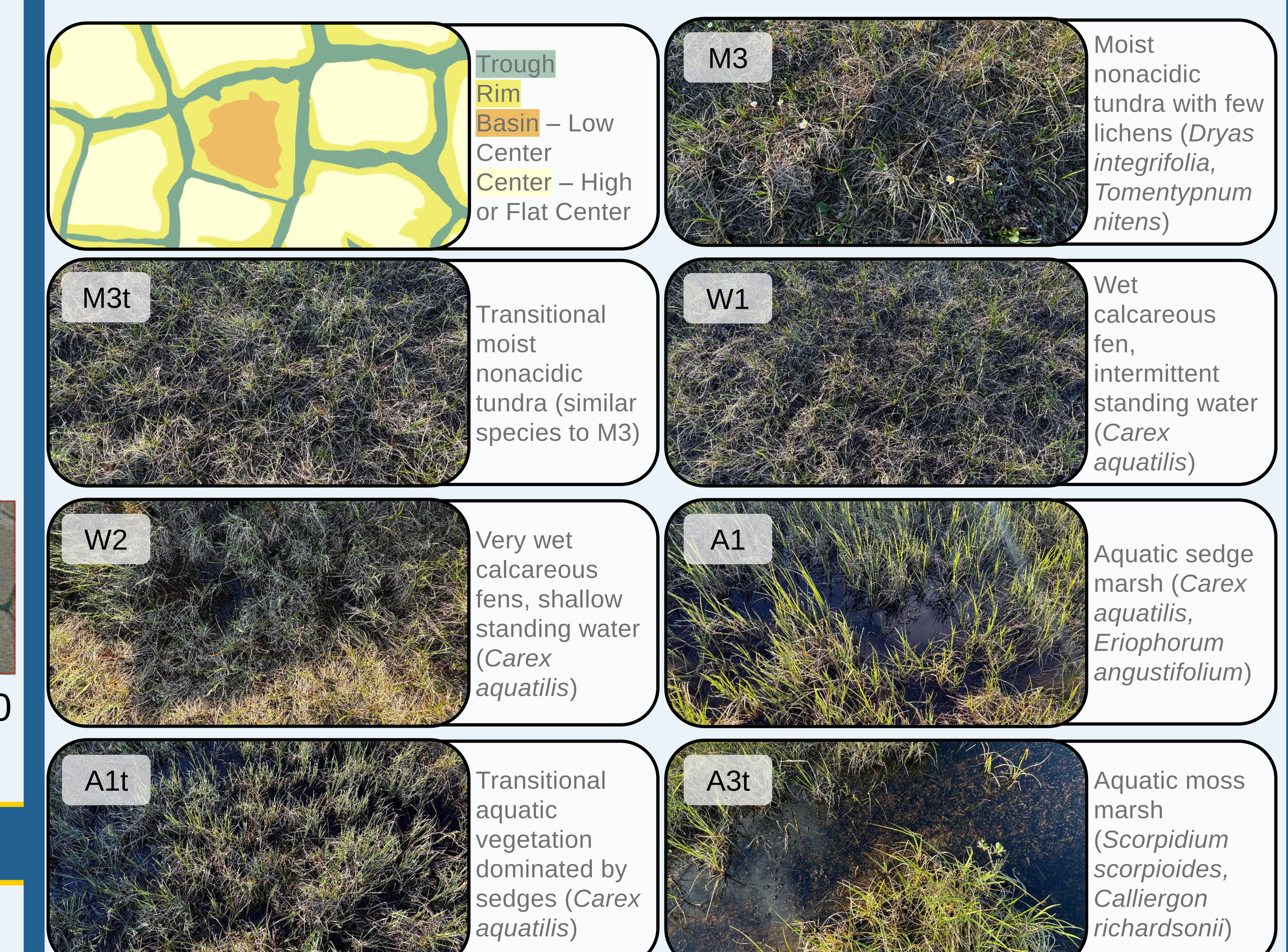

Figure 7. The top left panel shows the surficial feature elements of the polygonal landscape shown in Figure 6. The remaining panels show photos of key vegetation types taken around the pingo that are described by Dr. Donald A. Walker and adapted from Walker., 1985.

The preliminary analysis reveals a decrease in low-centered polygons and very wet vegetation. The knowledge of these fine-scale changes can be used to predict future ecosystem changes in these vulnerable Arctic ecosystems. Future work will aim to extend this study to a range of pingos in the Prudhoe Bay Oilfield and include an automated object-based mapping approach.

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