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Dramatic changes to glacial volume and extent since the late 19th century at Mount Rainier National Park, Washington, USA

I. Introduction

Glaciers are important resources at Mount Rainier National Park (MORA) because of their direct influence on Park geology, geomorphology, biology and aquatics. The glaciers on Mount Rainier provide a year-round water source for aquatic ecosystems and major regional river systems. Many glaciers at Mount Rainier have also been the source of damaging outburst floods throughout the Park's history. These floods are most often caused by periods of high temperatures or intense rainfall and can quickly mobilize material from the steep, unstable hillslopes on glacial margins into debris flows. These outburst floods and debris flows can have disastrous impacts on Park infrastructure and have led to changes in Park management throughout MORA.

Quantifying changes in Mount Rainier glaciers is important for assessing glacier health and climate change impacts at MORA. Glaciers are an important indicator of climate change because the physical changes that occur in glaciers provide visible evidence of changes in temperature and precipitation. To study glacier change within MORA over the past century, surface area extents and estimates of total volume of glacial ice and perennial snow were inventoried in 2015 and 2017, respectively. Surface extents in 2015 were compared with inventories from 1896, 1913, 1971, 1994, and 2009, while volume estimates were compared with inventories completed in 1913, 1971, 1981, 1994, 2003, 2008, and 2009.

Our data shows an overall loss of ice extent and volume at MORA. Despite a relatively gradual decrease in glacial area, glacial volume loss is accelerating as glaciers thin. This loss is significant since glaciers at MORA represent a major source of fresh water for the region. If the regional climate continues to change in ways that shrink glacial extent, further volume loss park-wide is anticipated, as well as the complete loss of small, lower-elevation glaciers in the next few decades.

II. Methods

Mapping of 2015 glacial extents in this study was completed by hand digitizing features from aerial imagery at a 1:1,000 scale. The primary image product used in this study was panchromatic satellite photography acquired from the WorldView-2 (WV2) satellite. When WV2 images were clipped or had cloud cover, imagery from the USDA Forest Service's (USFS) National Agriculture Imagery Program (NAIP) were used. Due to the difficulty in delineating debris cover on glaciers, lower resolution (1:5,000) images were used to map debris cover. Manually digitizing glacial boundaries inherently introduces error into final measurements. For the purposes of this study, the horizontal accuracy of a point at 1:1,000 scale is 0.847 m (2.778 ft) and 1:5000 scale is 4.233 m (13.889 ft). To account for all other potential errors, a relatively high 5% value was used for potential variability error.

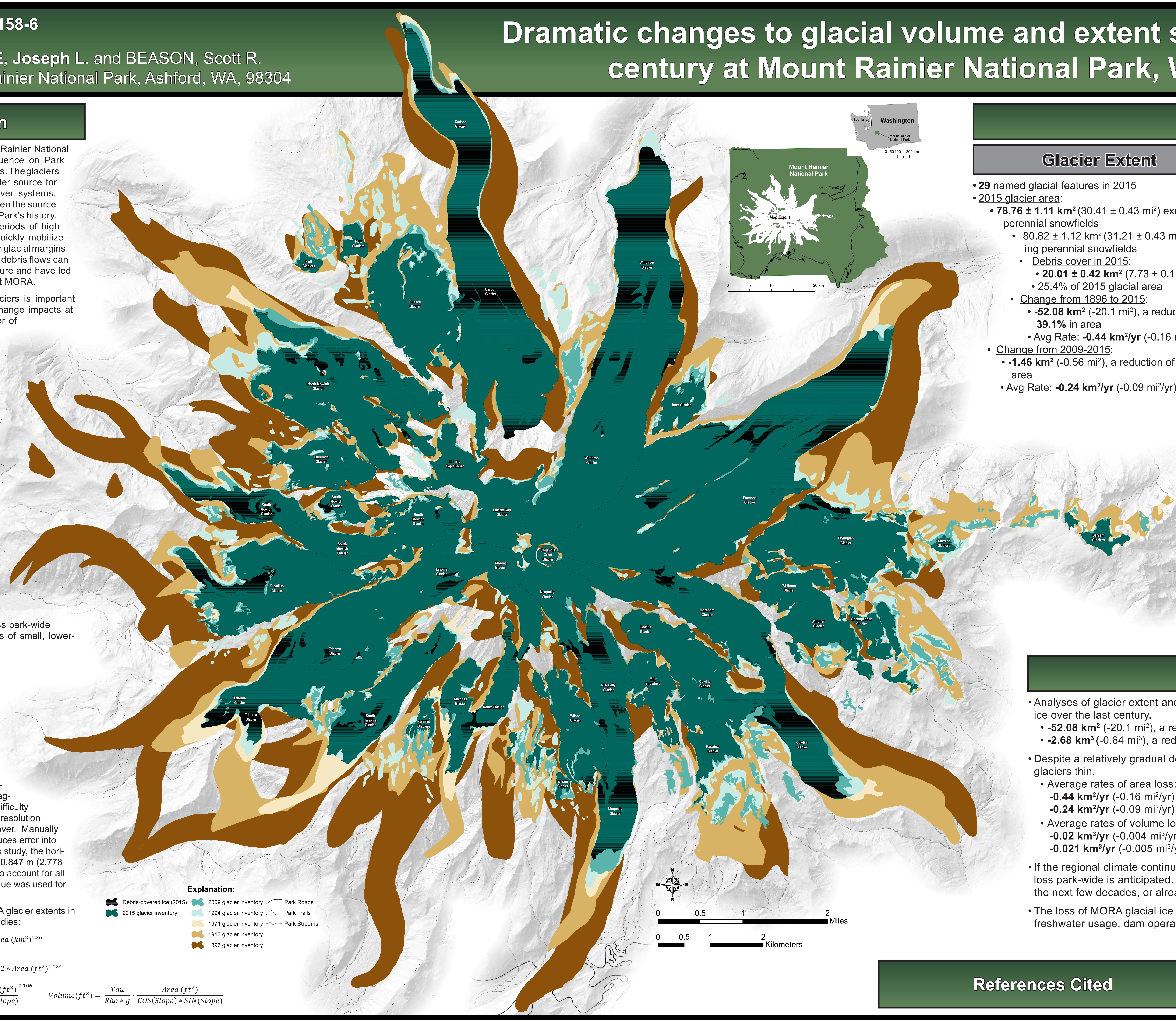
Glacier volumes were calculated using MORA glacier extents in combination with equations from previous studies:

From Nylen (2001): $Volume\ (km^3) = 0.0255 * Area\ (km^2)^{1.36}$

From Driedger & Kennard (1986)

Smaller glaciers (Length ≤ 8500 ft) $Volume\ (ft^3) = 9.62 * Area\ (ft^2)^{1.124}$

Larger glaciers (Length > 8500 ft) $Tau = 45.1 * \frac{Area\ (ft^2)}{COS(Slope)}^{0.106}$ $Volume(ft^3) = \frac{Tau}{Rho * g} * \frac{Area\ (ft^2)}{COS(Slope) * SIN(Slope)}$



III. Results

Glacier Extent

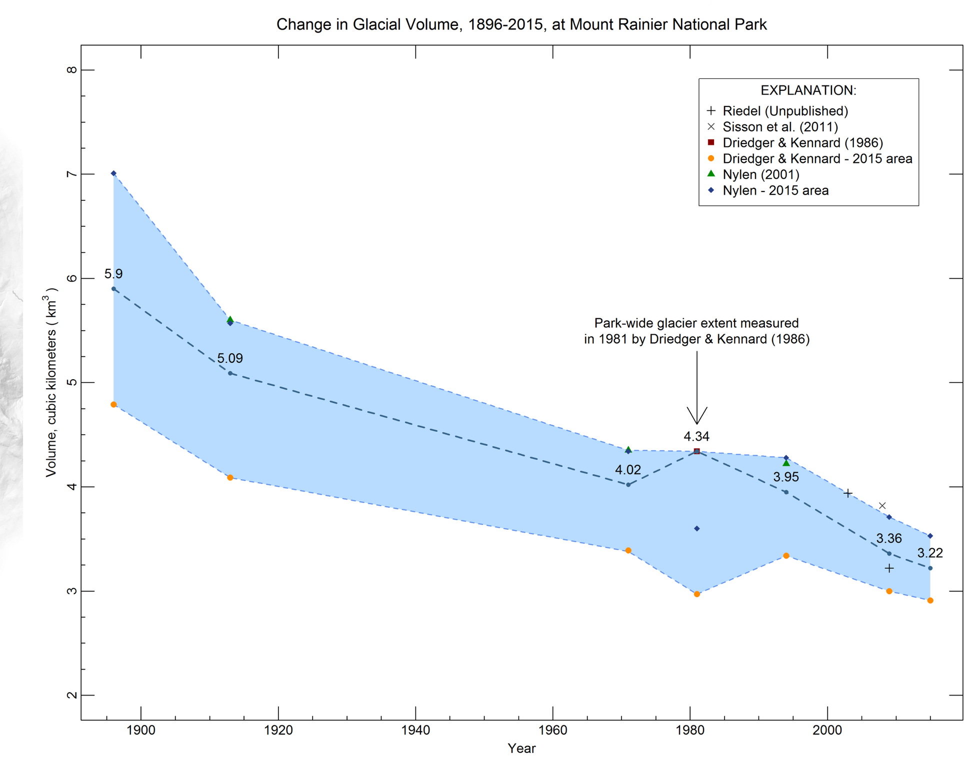
- **29** named glacial features in 2015
- 2015 glacier area:
  - **78.76 ± 1.11 km²** (30.41 ± 0.43 mi²) excluding perennial snowfields
    - 80.82 ± 1.12 km² (31.21 ± 0.43 mi²) including perennial snowfields
    - Debris cover in 2015:
      - **20.01 ± 0.42 km²** (7.73 ± 0.16 mi²)
      - 25.4% of 2015 glacial area
  - Change from 1896 to 2015:
    - **-52.08 km²** (-20.1 mi²), a reduction of **39.1%** in area
    - Avg Rate: **-0.44 km²/yr** (-0.16 mi²/yr)
  - Change from 2009-2015:
    - **-1.46 km²** (-0.56 mi²), a reduction of **1.8%** in area
    - Avg Rate: **-0.24 km²/yr** (-0.09 mi²/yr)

Glacier Volume

- 1896 volume:
  - **5.9 ± 1.11 km³** (1.41 ± 0.26 mi³)
- 2015 volume:
  - **3.22 ± 0.31 km³** (0.77 ± 0.07 mi³)
- Change from 1896 to 2015:
  - **-2.68 km³** (-0.64 mi³), a reduction of **45%** in volume
  - Avg Rate: **-0.02 km³/yr** (-0.004 mi³/yr)
- Change from 2009-2015:
  - **-0.13 km³** (-0.03 mi³), a reduction of **3.8%** in volume
  - Avg Rate: **-0.021 km³/yr** (-0.005 mi³/yr)

Previously published MORA glacier volumes

- Driedger & Kennard (1986)
  - 1981: **4.34 km³**
- Nylen (2001)
  - 1913: 5.62 km³
  - 1971: 4.35 km³
  - 1994: 4.21 km³
- Sisson et al. (2011)
  - 2008: 3.7 km³
- Reidel (unpublished)
  - 2003: 3.94 km³
  - 2009: 3.22 km³



IV. Conclusions

- Analyses of glacier extent and volume at Mount Rainier National Park show an overall loss of ice over the last century.
  - **-52.08 km²** (-20.1 mi²), a reduction of **39.1%** in area between 1896 and 2015
  - **-2.68 km³** (-0.64 mi³), a reduction of **45%** in volume between 1896 and 2015
- Despite a relatively gradual decrease in glacial area, glacial volume loss is accelerating as glaciers thin.
  - Average rates of area loss:
    - **-0.44 km²/yr** (-0.16 mi²/yr) between 1896 and 2015
    - **-0.24 km²/yr** (-0.09 mi²/yr) between 2009 and 2015
  - Average rates of volume loss:
    - **-0.02 km³/yr** (-0.004 mi³/yr) between 1896 and 2015
    - **-0.021 km³/yr** (-0.005 mi³/yr) between 2009 and 2015
- If the regional climate continues to change in ways that shrink glacial extent, further volume loss park-wide is anticipated. Several smaller, lower-elevation glaciers are likely to disappear in the next few decades, or already have (e.g. Stevens & Williwakas glaciers).
- The loss of MORA glacial ice stores can have severe implications for aquatic organism health, freshwater usage, dam operations, and geologic hazards in the region.

References Cited

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