The Immensity of Minutiae: Utilizing Bryophytes to Detect an Ice Age Refugium in the North Cascades

Barlow Pass

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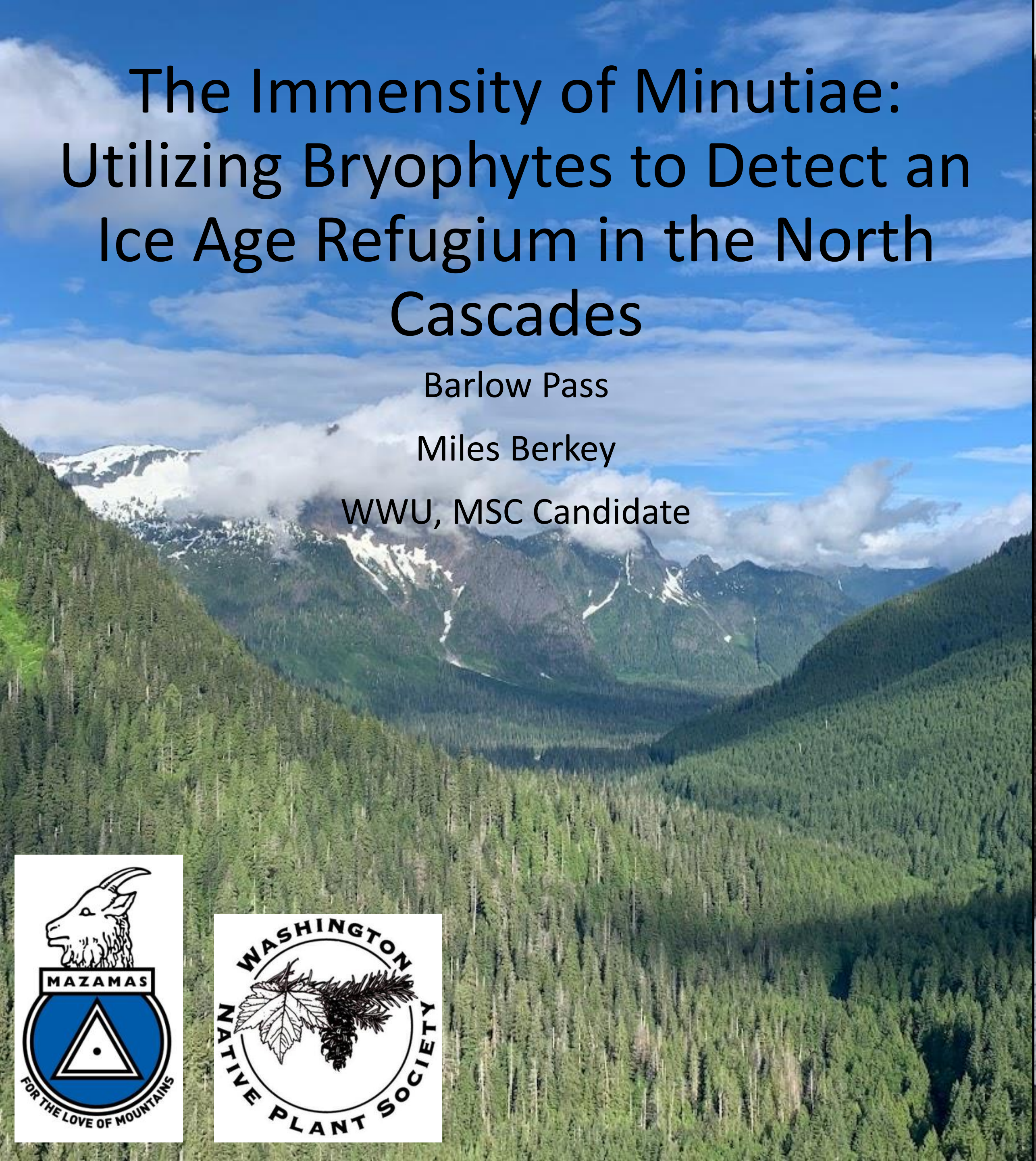
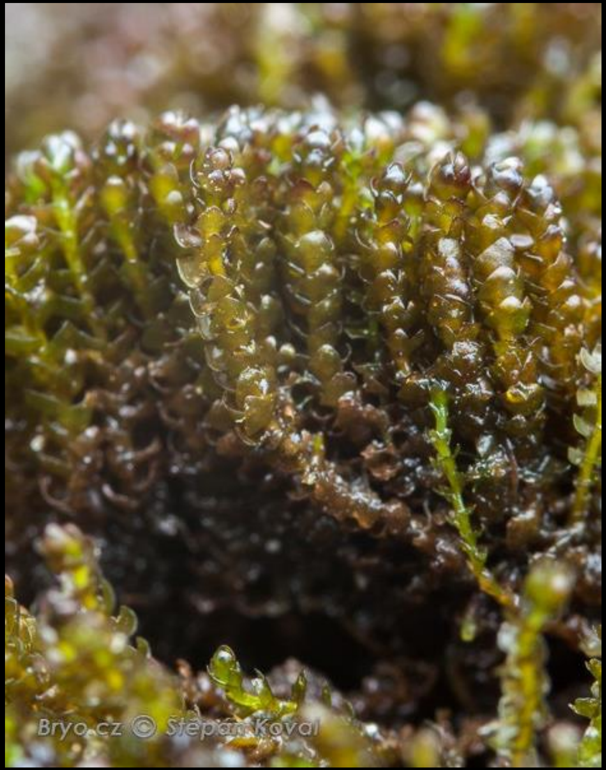


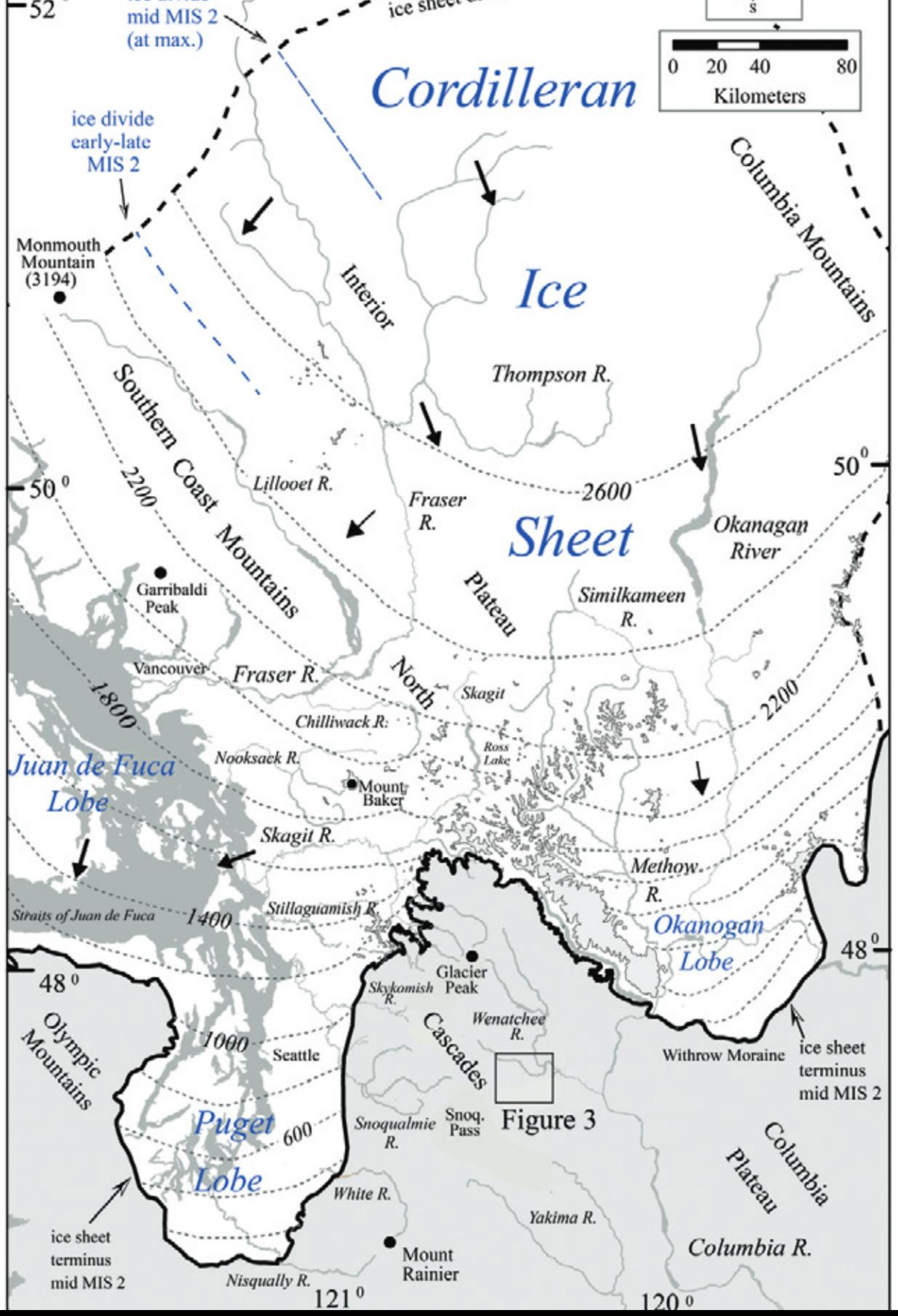
DICKERMAN MOUNTAIN
TWIN PEAKS
Monte Cristo
BIG FOUR MOUNTAIN
BARLOW PASS
SHEEP MOUNTAIN
SPERRY PEAK
VESPER PEAK
Skagit
LOOKOUT MOUNTAIN
8825 ft
HUCKLEBERRY MOUNTAIN
Darrington
GOLD MOUNTAIN
Suiattle River
White Chuck River
6851 ft
GREEN MOUNTAIN
10542 ft
Port Townsend
N
Granite Falls
Marysville
Snohomish
White River
Lake Stevens
WHITE MOUNTAINS
Everett
Port Ludlow
Spada Lake
WENATCHEE RIDGE
MOUNT STICKNEY
North Fork Skykomish River
Mukilteo
Sultan
Gold Bar
Monroe
ANDERSON



Significance of Barlow Pass

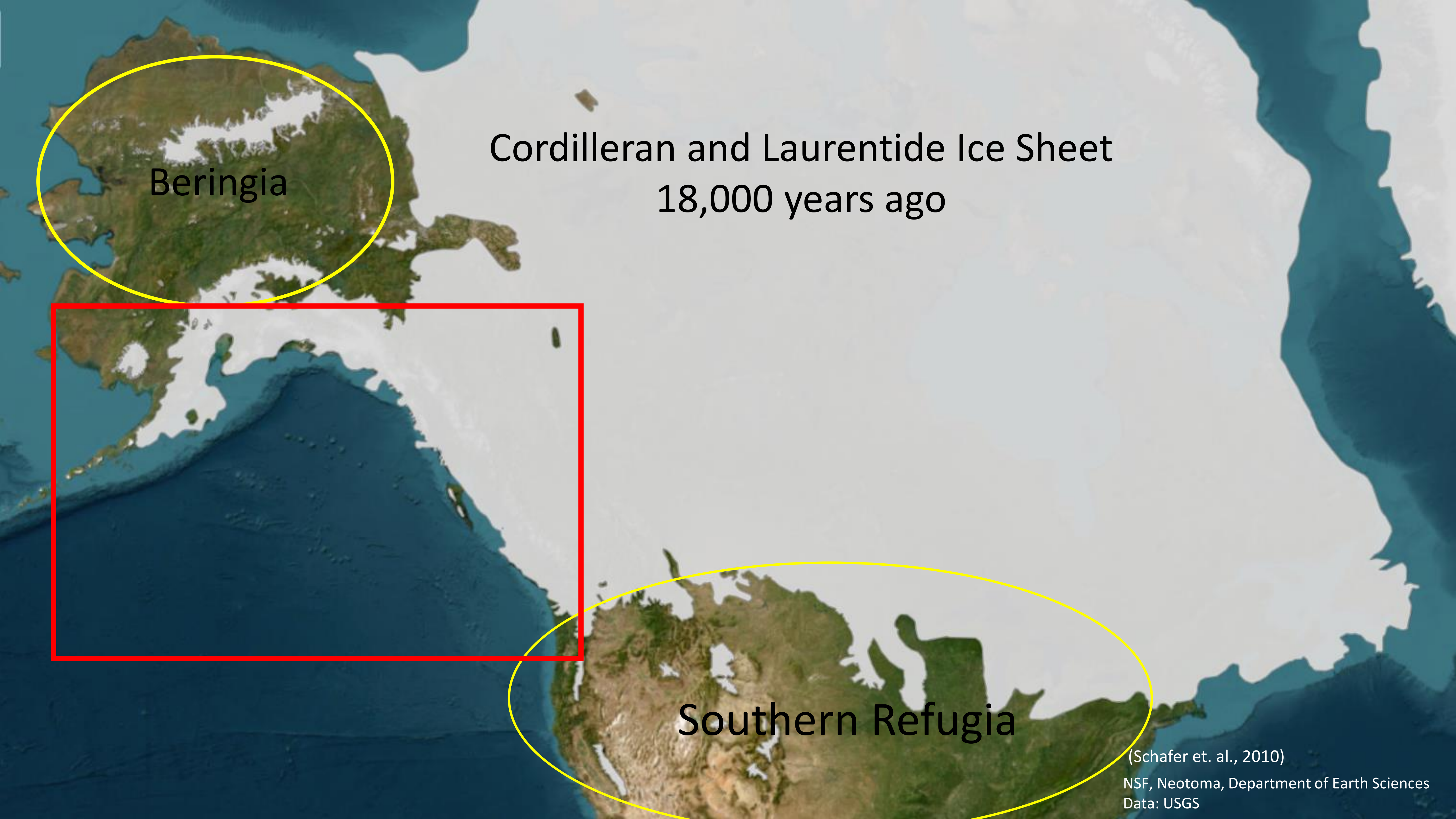
- Numerous disjunct northern bryophytes
- High Diversity of Moonworts
- Disjunct populations of northern flowering plants

Barlow Pass
Upper Skagit Reservation
Mt Vernon
Duncan
Victoria
Everett
Seattle
Tacoma
Olympic National Park
Olympic National Forest
Redmond
0 25 50 100 Miles
WA State Parks GIS, Esri Canada, Esri, HERE, Garmin, FAO, NOAA, USGS, Bureau of Land Management, EPA, NPS, Esri, USGS
Esri, NASA, NGA, USGS, WA State Parks GIS, Esri Canada, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land Management, EPA, NPS
Legend
Continental Ice Sheet Limit
0 5 10 20 Miles
N



Cordilleran Ice Sheet
mid MIS 2 (at max.)
ice divide early-late MIS 2
0 20 40 80 Kilometers
Monmouth Mountain (3194)
Interior Plateau
Columbia Mountains
Thompson R.
Southern Coast Mountains
Lillooet R.
Fraser R.
2600
2200
1800
1400
1000
600
Okanagan River
Similkameen R.
Garribaldi Peak
Vancouver
North
Skagit
Chilliwack R.
Ross Lake
Nooksack R.
Mount Baker
Juan de Fuca Lobe
Skagit R.
Methow R.
Straits of Juan de Fuca
Stillaguamish R.
Okanogan Lobe
Glacier Peak
Skykomish R.
Wenatchee R.
Cascades
Olympic Mountains
Seattle
Withrow Moraine
ice sheet terminus mid MIS 2
Puget Lobe
Snoqualmie R.
Snoq. Pass
Figure 3
Columbia Plateau
White R.
Yakima R.
Columbia R.
Mount Rainier
Nisqually R.
52
50°
48°
121°
120°

- (Riedel, 2017)


Cordilleran and Laurentide Ice Sheet
18,000 years ago
Beringia
Southern Refugia
(Schafer et. al., 2010)
NSF, Neotoma, Department of Earth Sciences
Data: USGS

Relictualism

Remnants of Glacial and Pre-glacial times

Refugia

Ice-free, ecologically stable

Arctic taxa

Speciation

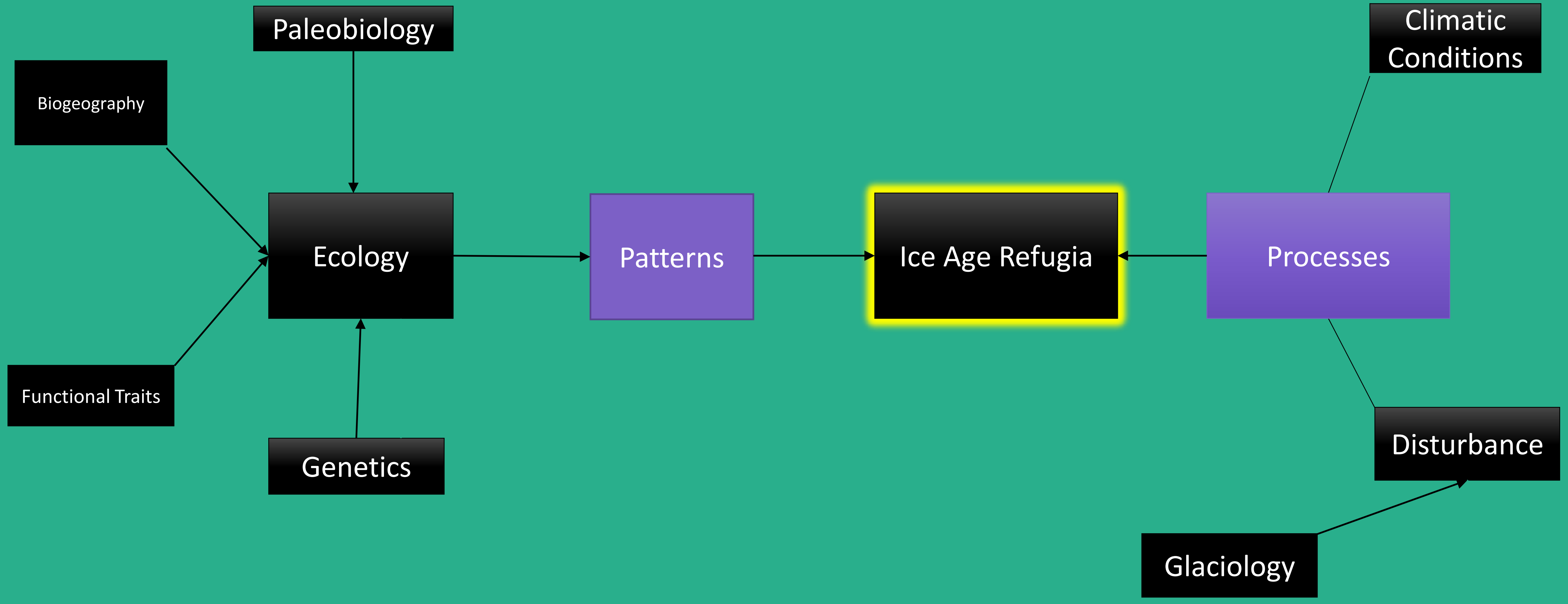
Evolutionary trajectory of northern taxa

Endemism

Importance today

- Biodiversity
- Host endemic and rare species
- Provide evolutionary histories
- “climate change refuges”
  - Havens for species intolerant of a warming climate
  - “Where will species retreat to?”

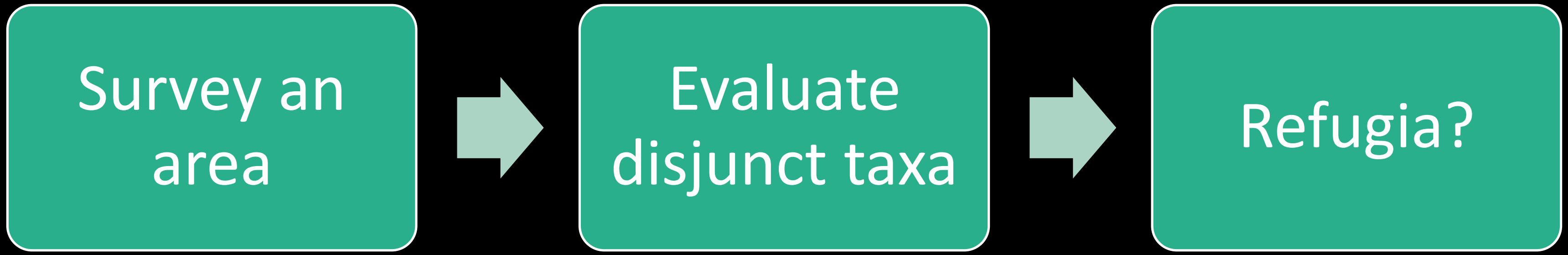
Identifying Ice Age Refugia



Simplified from Keppel, 2012

Ice Age Refugia testing: Biogeography

- Classical floristics approach



What about Barlow Pass?

What makes a glacial relict?

- Tolerant of Continental/glacial climates
- Disjunct distribution
    - Regionally rare
    - Ecologically conservative
- Associated with habitats that occurred during glacial times (Dítě et al., 2018)
- And for Bryophytes: Dispersal limitations (Patino, 2016; Wu,2020, Shaw, 2001)

What are Bryophytes?

- Mosses, hornworts, liverworts
- Evolved 450 – 350 myr
- Second most species rich division of plants
    - 19 – 24,000 species
- Non-vascular
    - Single-celled leaves
- Haploid dominant life-cycle
- Restricted niches
    - microhabitats

Bryophytes as ice age refugia Indicators

Dispersal limitations

Never or rarely produce sporophytes suggesting vicariance (Shaw, 2001; Patino et. al., 2016)

Niche Conservation

Retreat to microclimatic conditions analogous to previous climate (Anderson, 1963)

Ecological behavior

Reduce to clone-state in sub-optimal conditions (Longton & Schuster, 1983)

Approach

If Ice age refugia have a higher proportion of relictual/endemic taxa,

What is that proportion?

Step 1:
Determining proportion of refugial to non-refugial species in putative ice age refugia

Refugia Ranks

Non-Refugial
- Distribution not restricted to refugia
- Dispersal limitations or not

Weak Refugial
- Arctic or distribution showing higher frequency in refugia
- No dispersal limitations

Strong Refugial
- Arctic or mostly restricted to refugia outside of Arctic
- Dispersal limitations

Calvert Island - Brooks Peninsula comparative site

radius: 30 km

Totals	non -refugial	weak refugial	refugial
181	173	3	5
Proportions	0.9558	0.0165	0.0276
	95.50%	2.65%	2.76%

Brooks Peninsula Refugium

Radius: 8 km

Totals	non -refugial	weak refugial	refugial
259	244	7	8
Proportions	0.94208	0.02702	0.0308
	94.20%	2.70%	3.08%

Prince Rupert - Haida Gwaii comparative site

radius: 8km

Totals	non -refugial	weak refugial	refugial
205	194	2	7
Proportions	0.946	0.0097	0.034
	94.60%	0.97%	3.40%

Haida Gwaii refugium

Radius: 8km

Totals:	non -refugial	weak refugial	refugial
227	201	8	18
Proportions	0.8854	0.035	0.0792
	88.50%	3.50%	7.90%

Mean Proportion of ice age refugial species in non-refugial sites

3.08%

Mean Proportion of ice age refugial species in Refugia

5.49 %

What about Barlow Pass?

totals	non -refugial	weak refugial	refugial
214	206	5	3
proportions	0.962	0.023	0.014
	96.20%	2.30%	1.40%

- Current bryophyte flora of Barlow Pass shows a lower proportion of refugial species than the mean proportion of refugial species in non-refugia

1.4% < 5.49%

Barlow Pass not supported by current data

But how complete is the bryoflora of Barlow Pass?

- Need to develop

And, how does it compare to adjacent non-refugial areas?

- Need to develop floras to compare

How do we know if these disjuncts are only a result of Long-distance dispersal?

- By testing for similar species envelope between Barlow Pass and control sites.

Hypothesis:

The bryophyte flora of Barlow Pass shows a proportion of ice age relict species similar to the bryofloras of putative ice age refugia.

Experimental Design

T — Bryoflora

C1 — Bryoflora

C2 — Bryoflora

C3 — Bryoflora

Categorize Species based on frequency

Amphidium californicum (Hampe ex. Muller Hal.) Brotherus	4
Amphidium mougeotii (Bruch & Schimper) Schimper	3
Anacolia menziesii (Tuerner) Paris	1
Anastrophyllum minutum (Schreb. Ex Cranz) Schust.	3
Andreaea nivalis Hooker	2
Andreaea rupestris Hedwig	2
Aneura pinguis (L.) Dum.	2
Anoectangium aestivum (Hedwig) Mitten	3

Chi-Square Test for Homogeneity

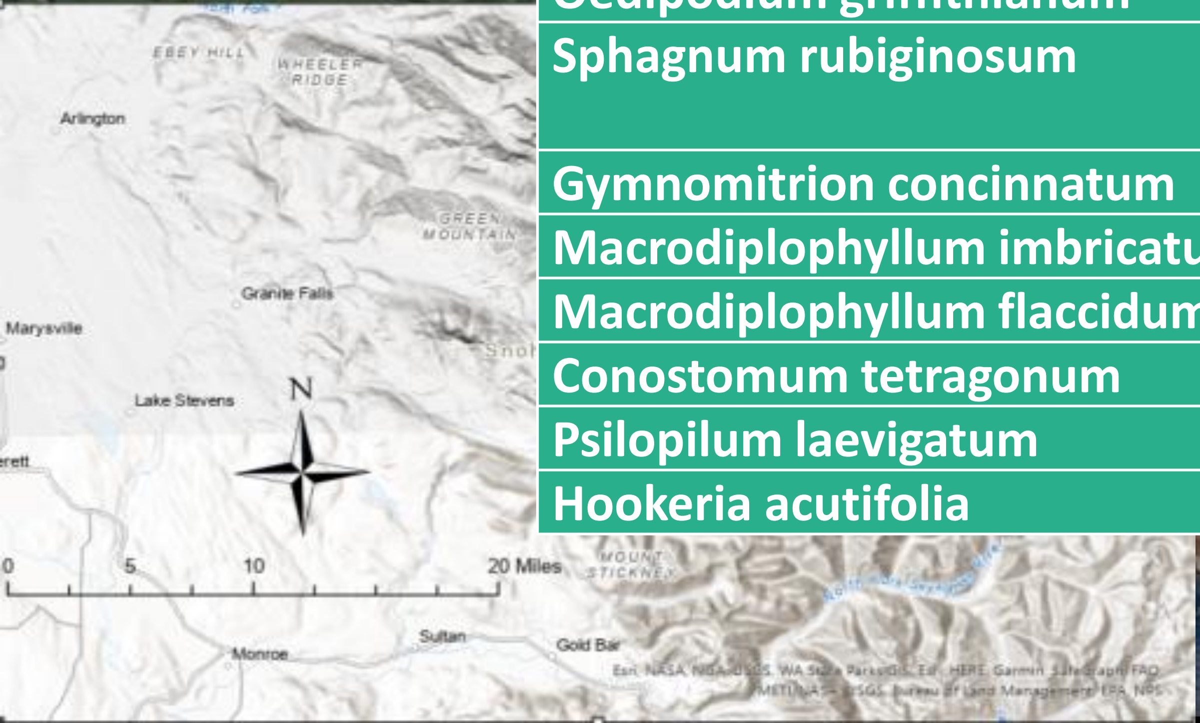
H_0 No difference among groups;
Micro Habitat available in all sites

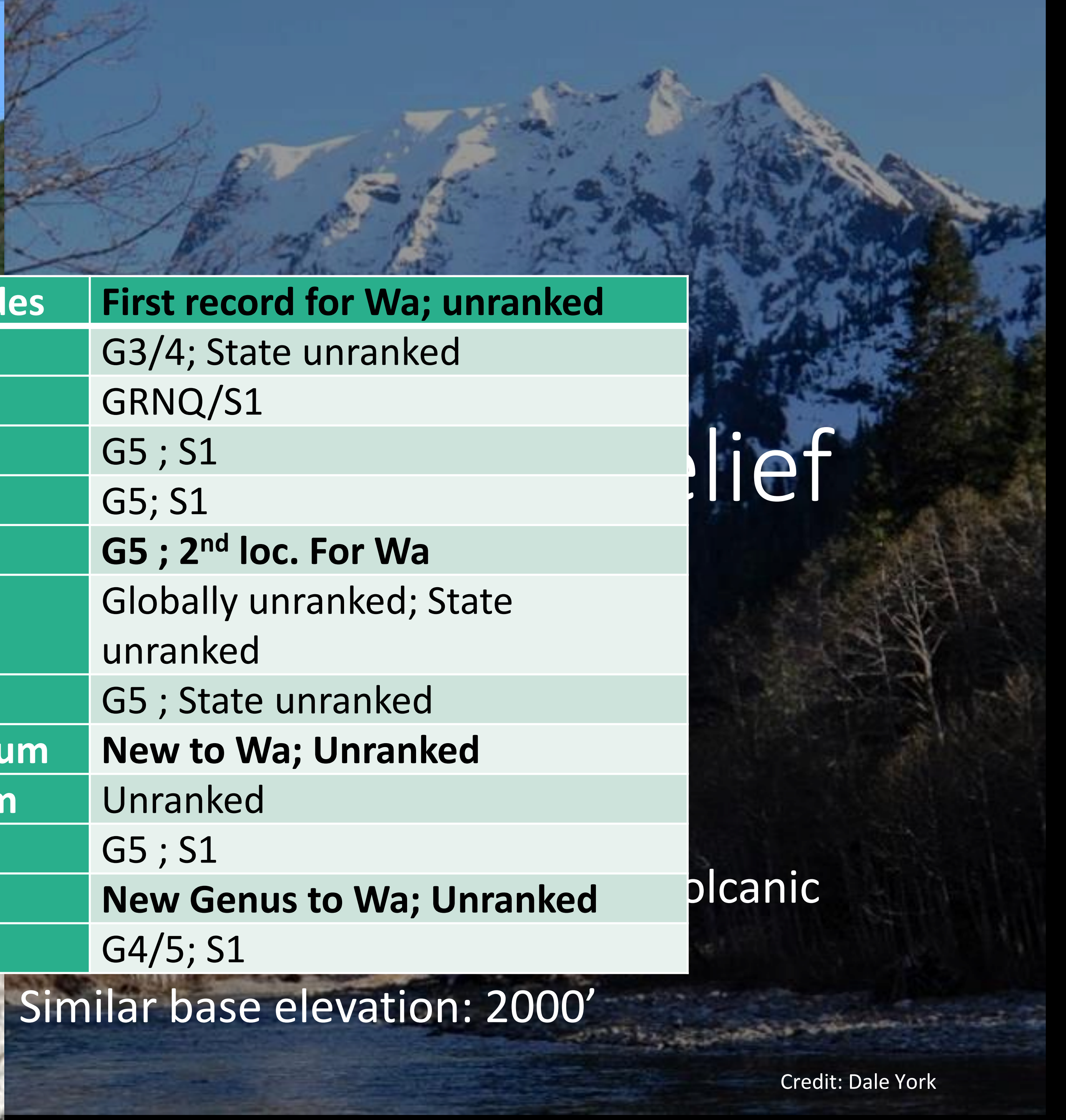
1. PCA analysis: Correlation Strength between Refugia Indicator Species (RIS) of Barlow pass and the putative ice age refugia in Part 1.
2. Repeat PCA for Barlow Pass and the non-refugial from above control sites

Sampling

- Sampling: Non-Random Floristic habitat sampling to capture entire bryroflora
- Restricted to cliff band base, and adjacent talus fields and all substrates that occur within

Big Four Mtn., Barlow Pass





Cyrtomnium hymenophylloides	**First record for Wa; unranked**
Bucklandiella lawtoniae	G3/4; State unranked
Bucklandiella micocarpon	GRNQ/S1
Campylopus atrovirens	G5 ; S1
Conostomum tetragonum	G5; S1
Oedipodium griffithianum	**G5 ; 2nd loc. For Wa**
Sphagnum rubiginosum	Globally unranked; State unranked
Gymnomitrion concinnatum	G5 ; State unranked
Macrodiplophyllum imbricatum	**New to Wa; Unranked**
Macrodiplophyllum flaccidum	Unranked
Conostomum tetragonum	G5 ; S1
Psilopilum laevigatum	**New Genus to Wa; Unranked**
Hookeria acutifolia	G4/5; S1

N… …lief

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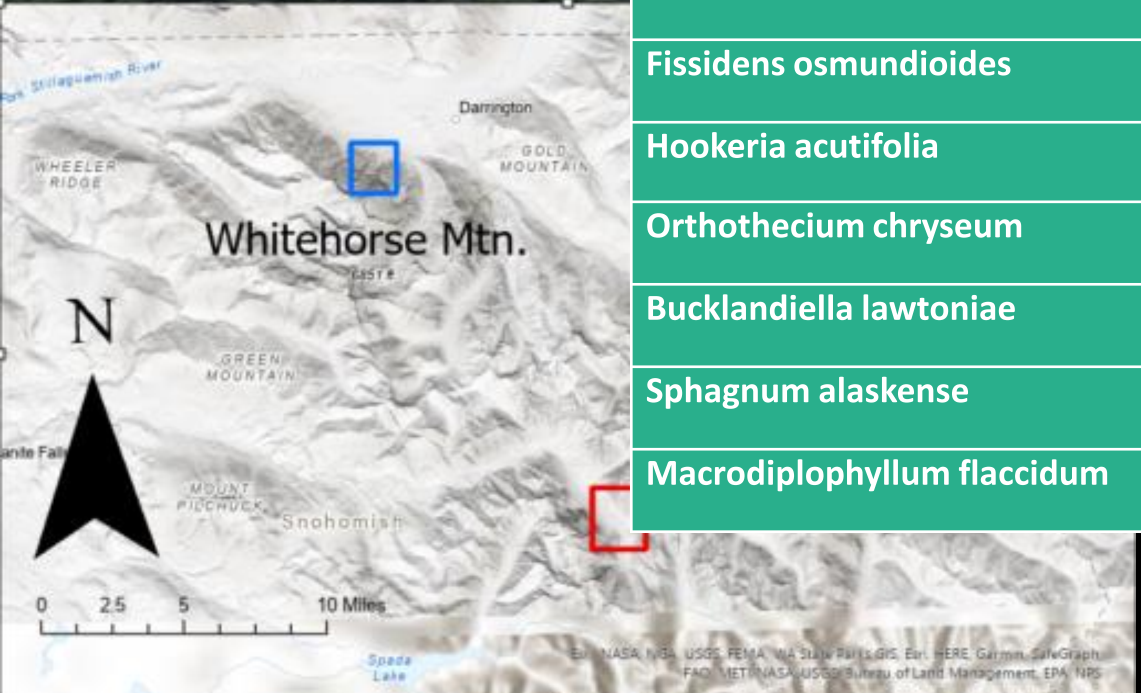
Similar base elevation: 2000’

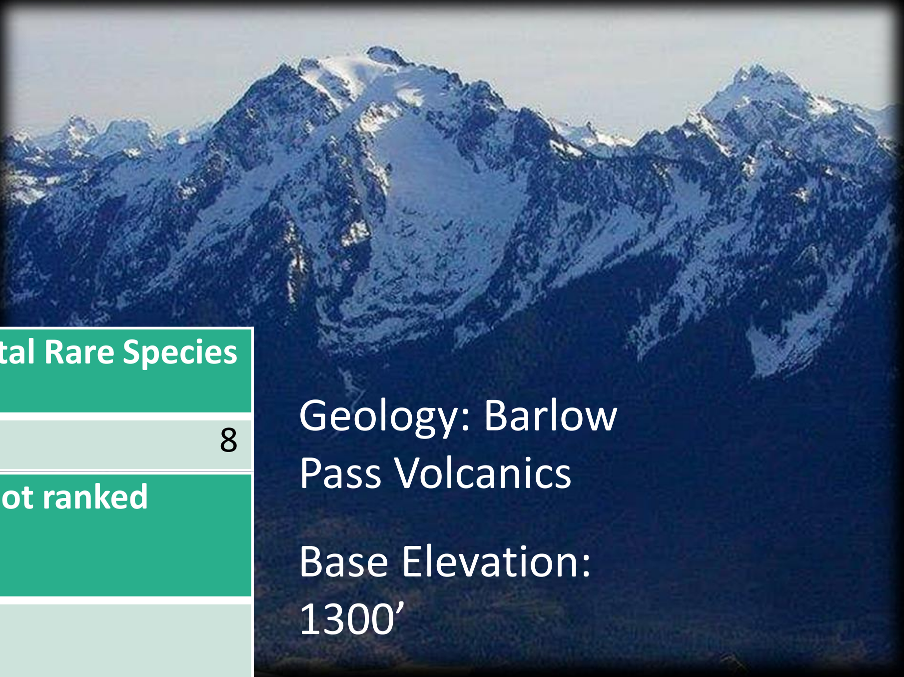
Credit: Dale York

Whitehorse Mtn.



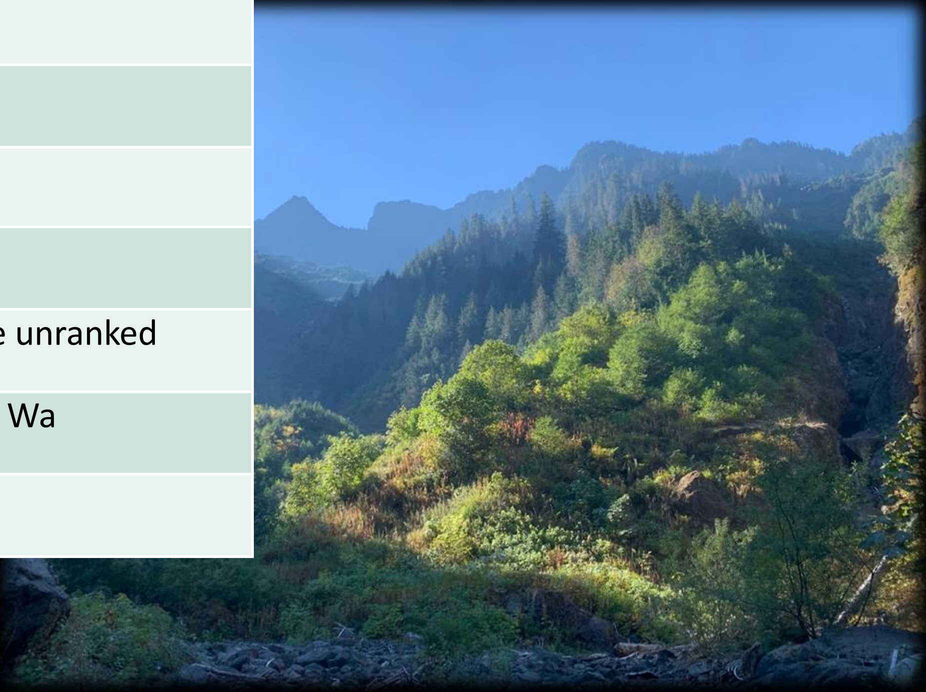
Total Species	Total Relicts	Total Rare Species
85	0	8

Bryoerythrophyllum columbianum	**G5/State not ranked**
Campylium stellatum	G4/5; SNR
Campylopus atrovirens	G5; S1
Fissidens osmundioides	G5; S1
Hookeria acutifolia	G4/5; S1
Orthothecium chryseum	G5; S1
Bucklandiella lawtoniae	G3/4; State unranked
Sphagnum alaskense	2nd loc. For Wa
Macrodiplophyllum flaccidum	Unranked



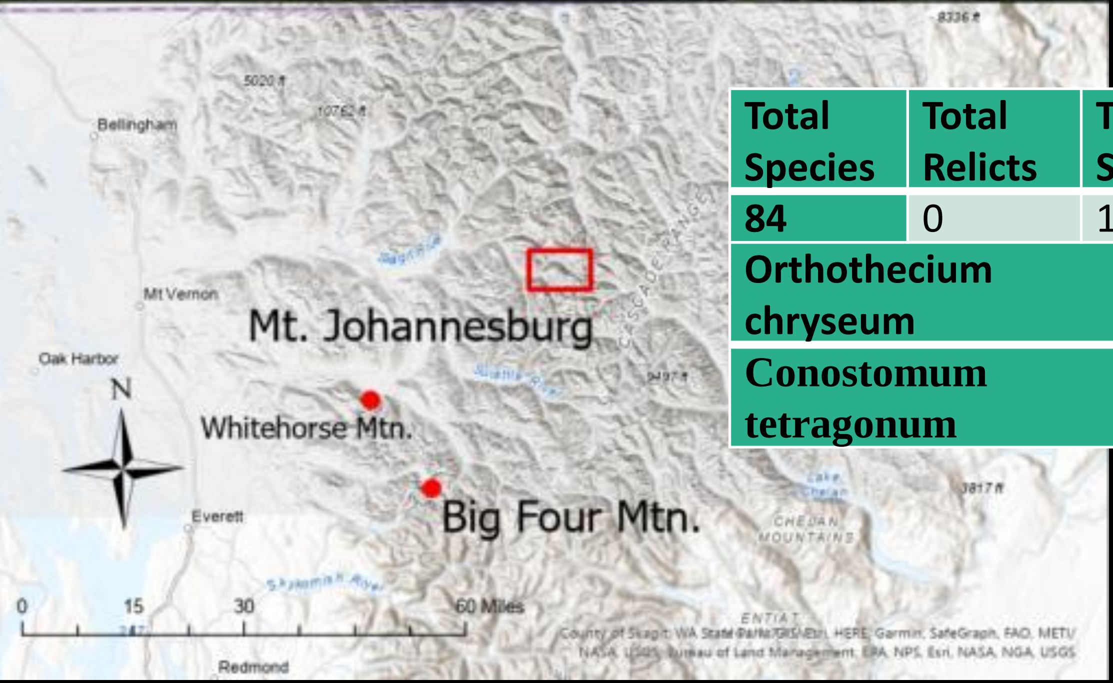
Geology: Barlow Pass Volcanics

Base Elevation: 1300’




Sphagnum alaskense
Campylopus atrovirens
Sphagnum alaskense

Base Elevation: 3000’
Geology: Shuksan Green Schist (Metamorphic)

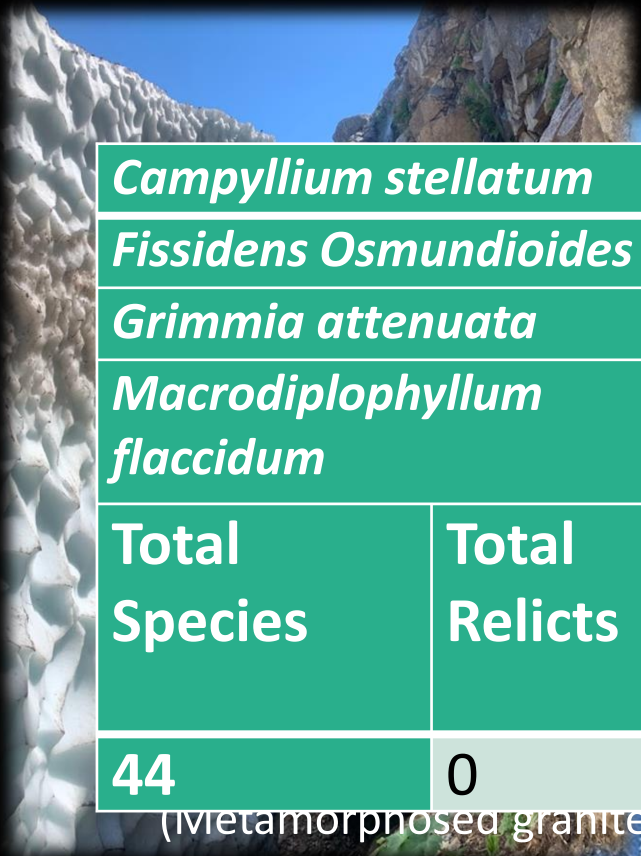


edit: Nick Sweeney

Mt. Johannesburg

Total Species	Total Relicts	Total Rare Species
84	0	1
Orthothecium chryseum		**G5; S1; new to NOCA**
Conostomum tetragonum		G5; S1; New to NOCA

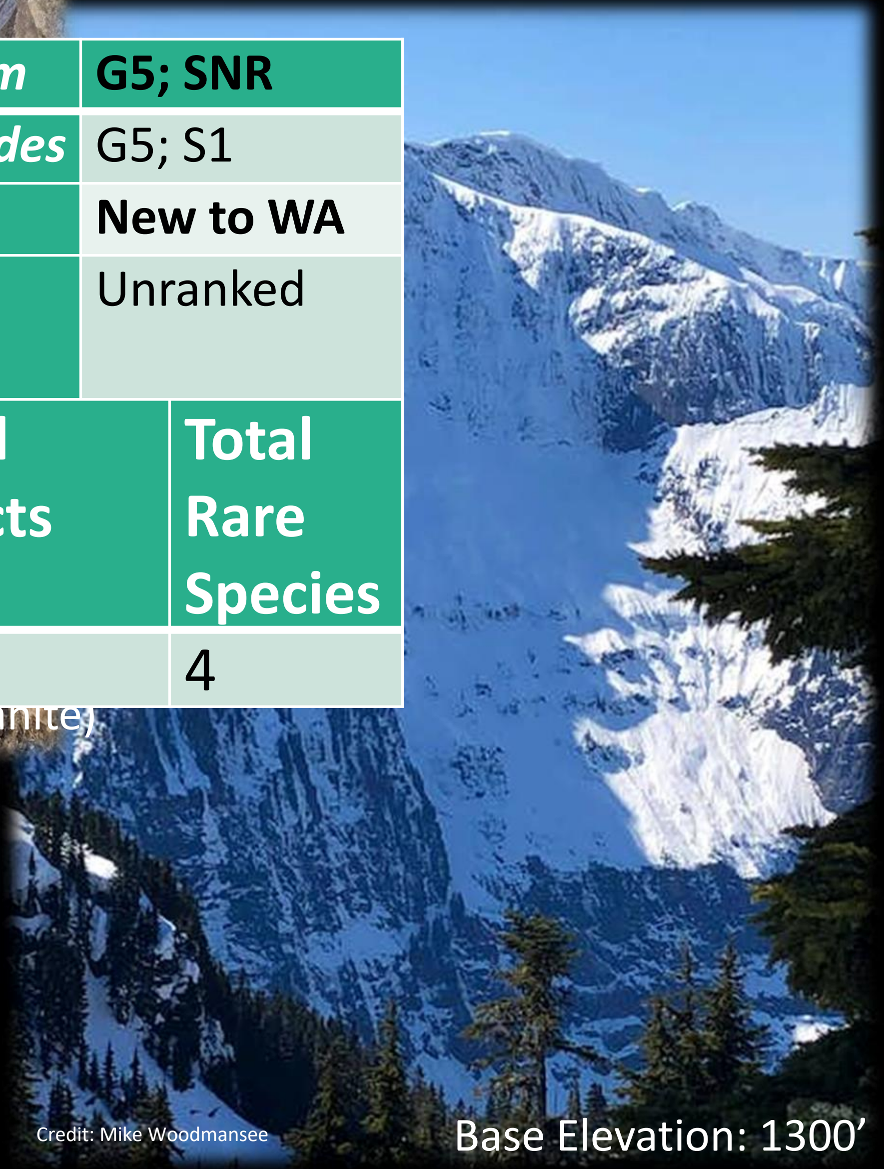
Davis Peak



Campyllium stellatum	**G5; SNR**	
Fissidens Osmundioides	G5; S1	
Grimmia attenuata	**New to WA**	
Macrodiplophyllum flaccidum	Unranked	
Total Species	**Total Relicts**	**Total Rare Species**
44	0	4

(Metamorphosed granite)

Sphagnum rubiginosum



Credit: Mike Woodmansee

Base Elevation: 1300’

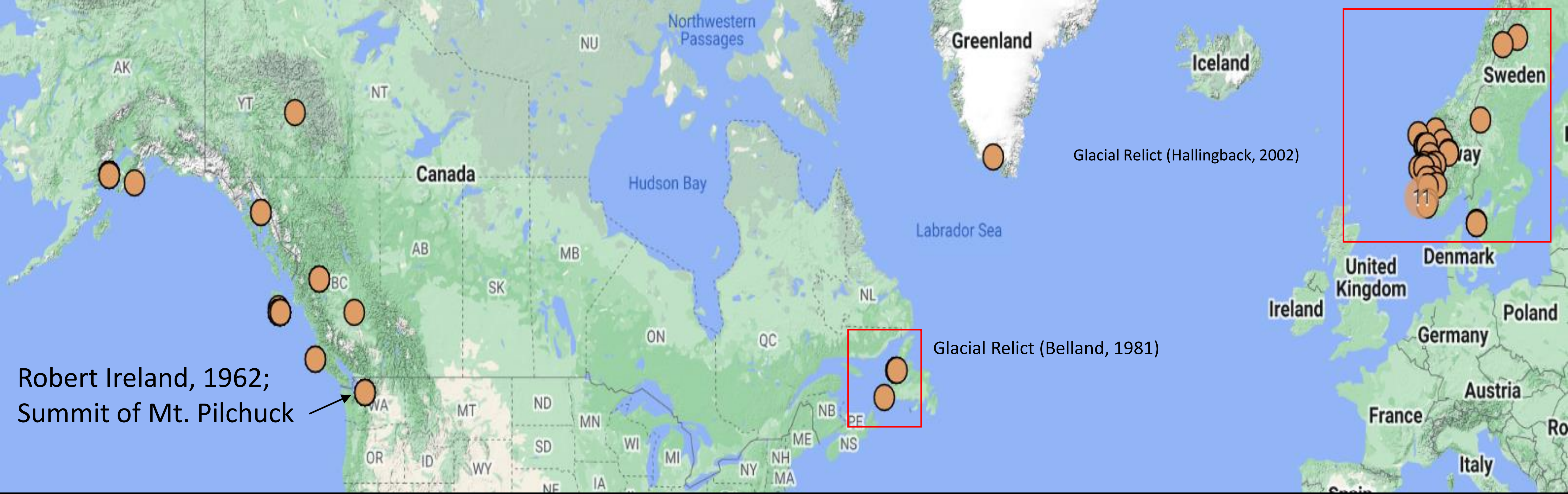
Results

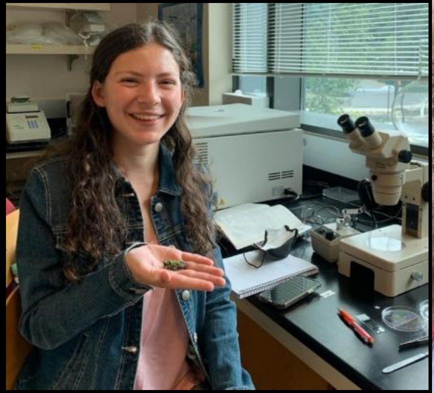
- Encountering many of the same species in all sites.
- Each site has rare species
- No strong refugial species in control sites
- Numerous Refugial species in Barlow Pass site

Collection count	904
Total Species	200+
Microscope determination time (hrs)	534+

Chi-Square result: No difference among floras; micro-habitat available in all sites

$X^2(9,n=310)16.91$ $p=0.08$, $\alpha=0.05$



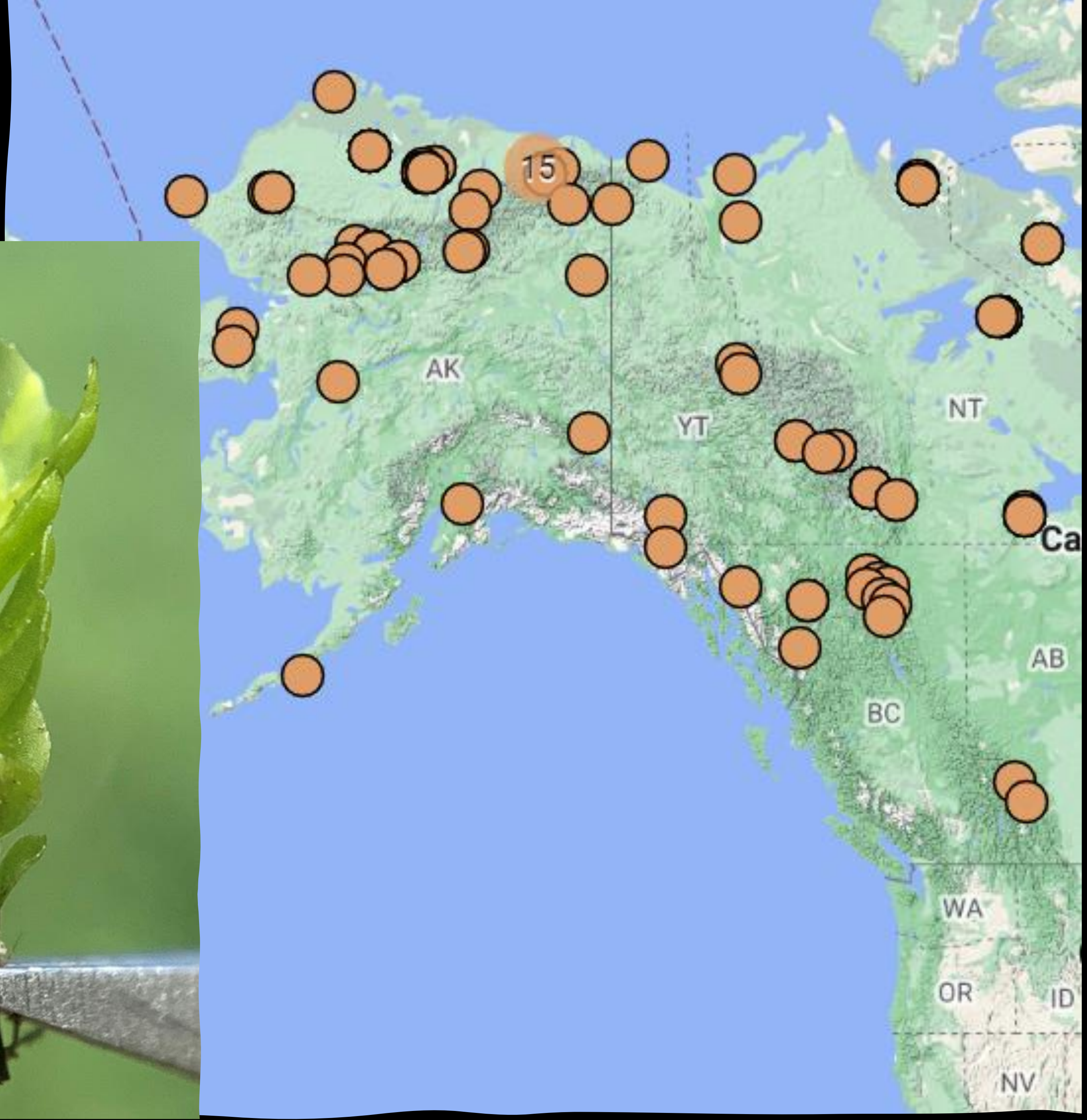


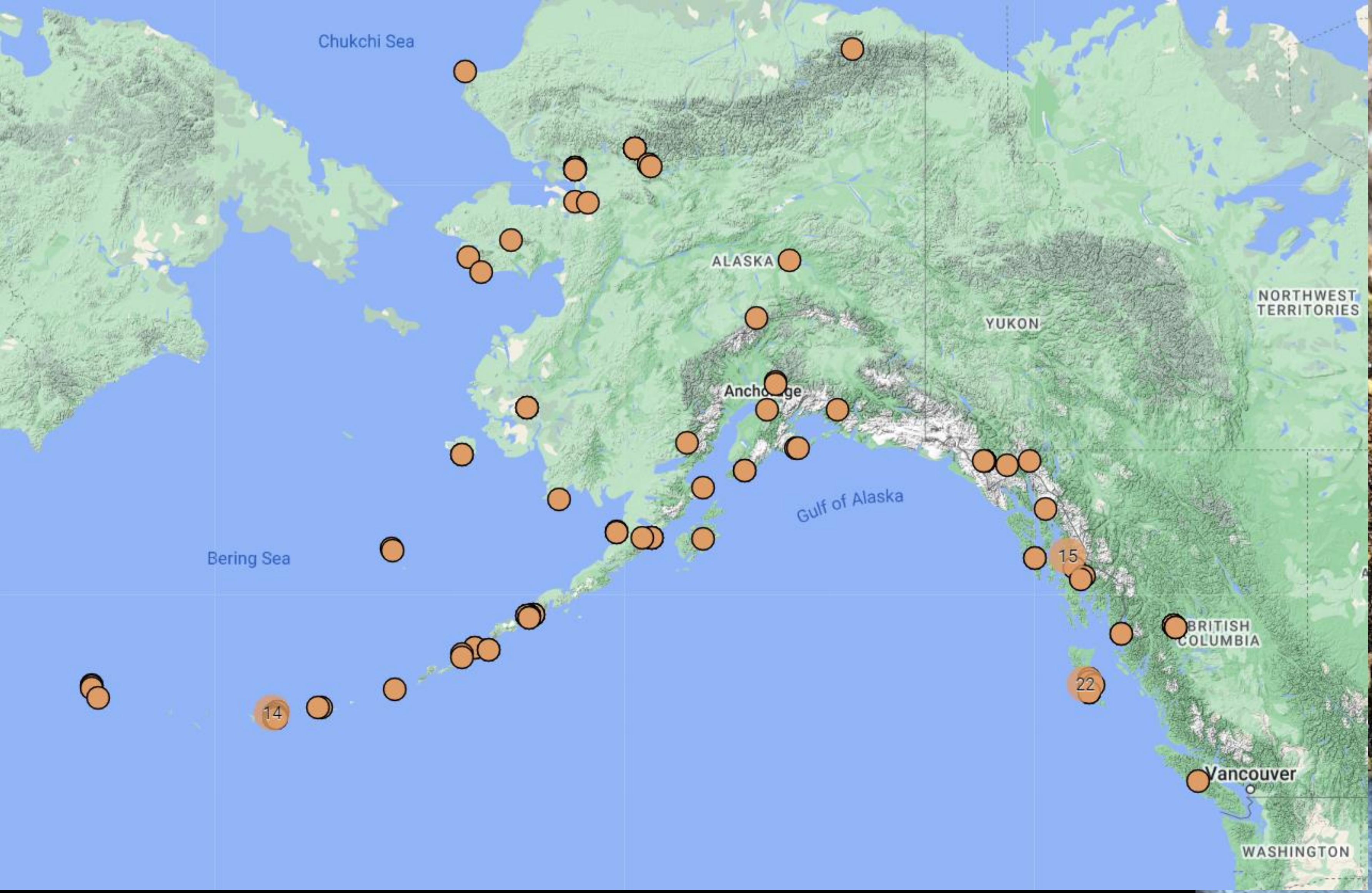
Oedipodium Griffithianum
Refugial Species

Cyrtomnium hymenolophylloides

Glacial relict in southern Stations
(Miller, 1996 & 1997)

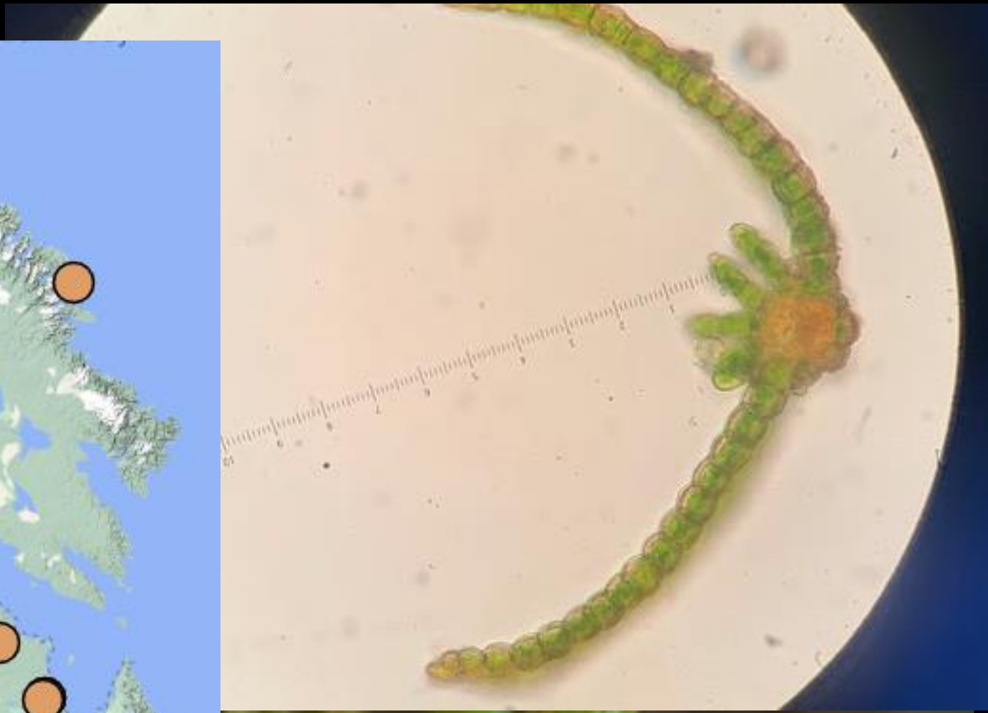
New to WA





Macrodiplophyllum imbricatum, New to Contiguous US.

Psilopilum laevigatum
New to Contiguous US
Weak Refugial,
regular production of sporophytes



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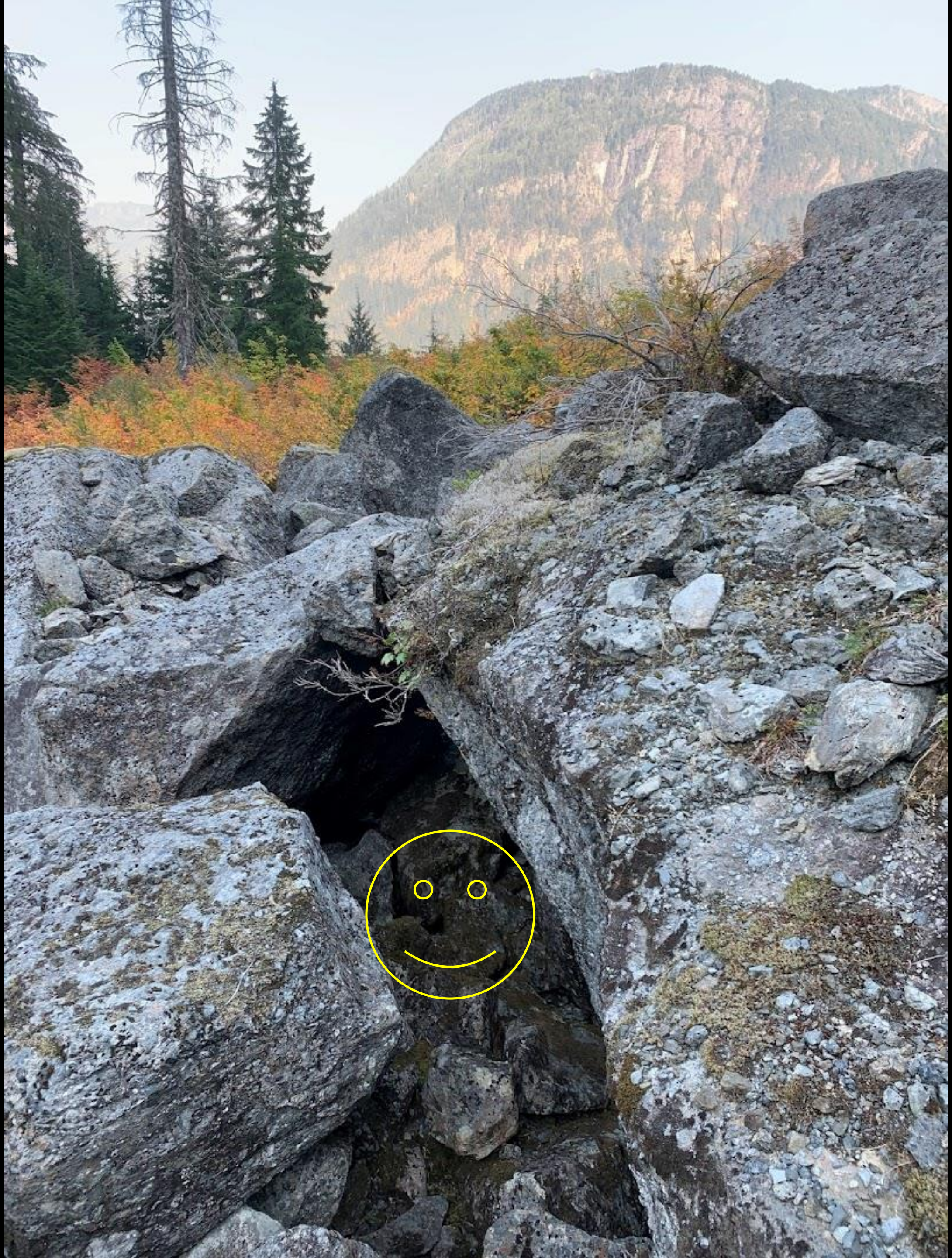

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