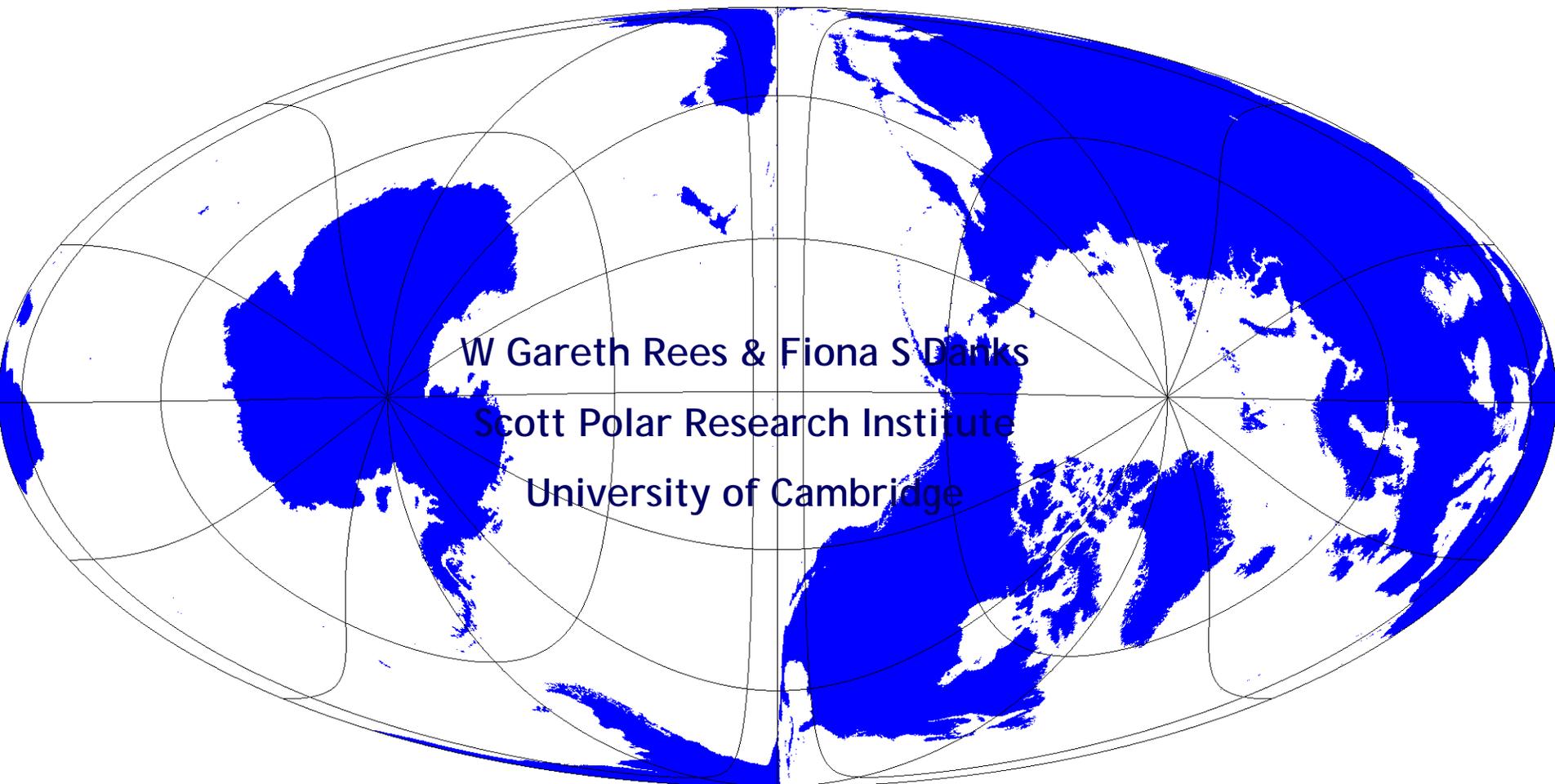


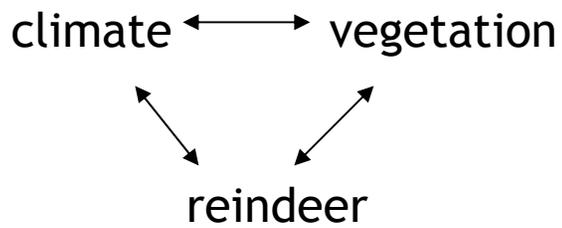
Derivation and assessment of vegetation maps for reindeer pasture analysis in Arctic European Russia



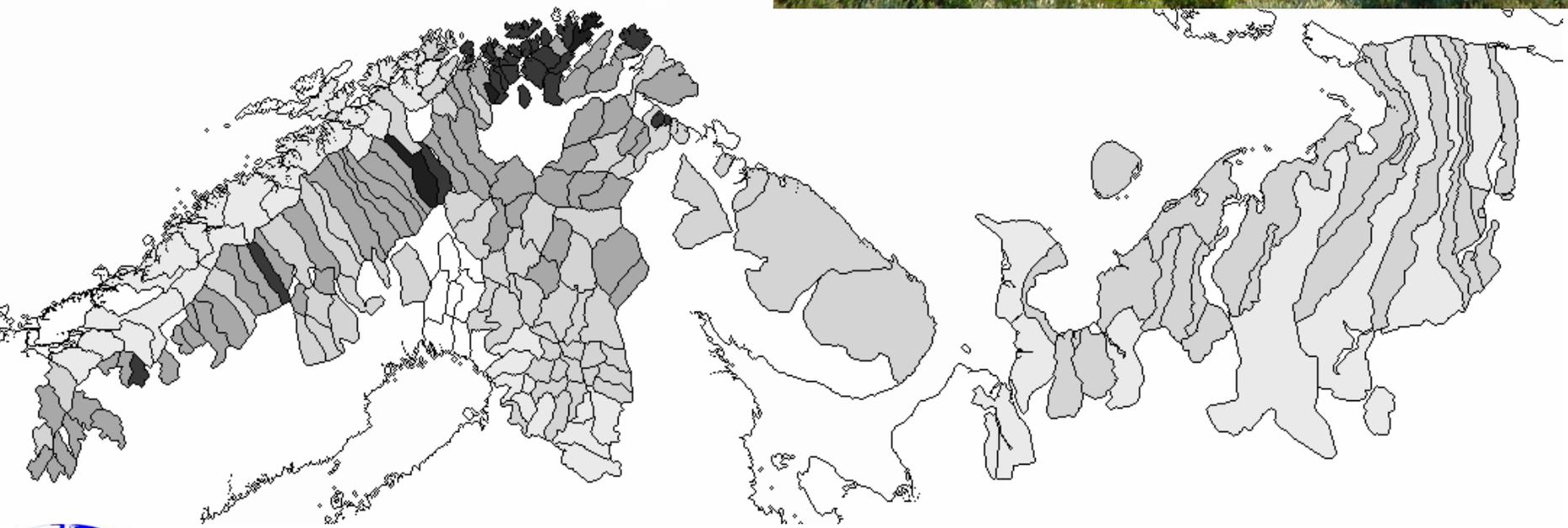
W Gareth Rees & Fiona S Danks
Scott Polar Research Institute
University of Cambridge



Is tundra vegetation changing in northern Europe? And why?



~ 10^6 reindeer, ~ 10^6 km², ~ 10^9 kg dry biomass consumed p.a.



Profound changes already occurring, though not spatially uniformly

- overgrazing, trampling and manuring by reindeer
- general shift away from lichen-dominance (and increase in graminoids)
- shrub encroachment



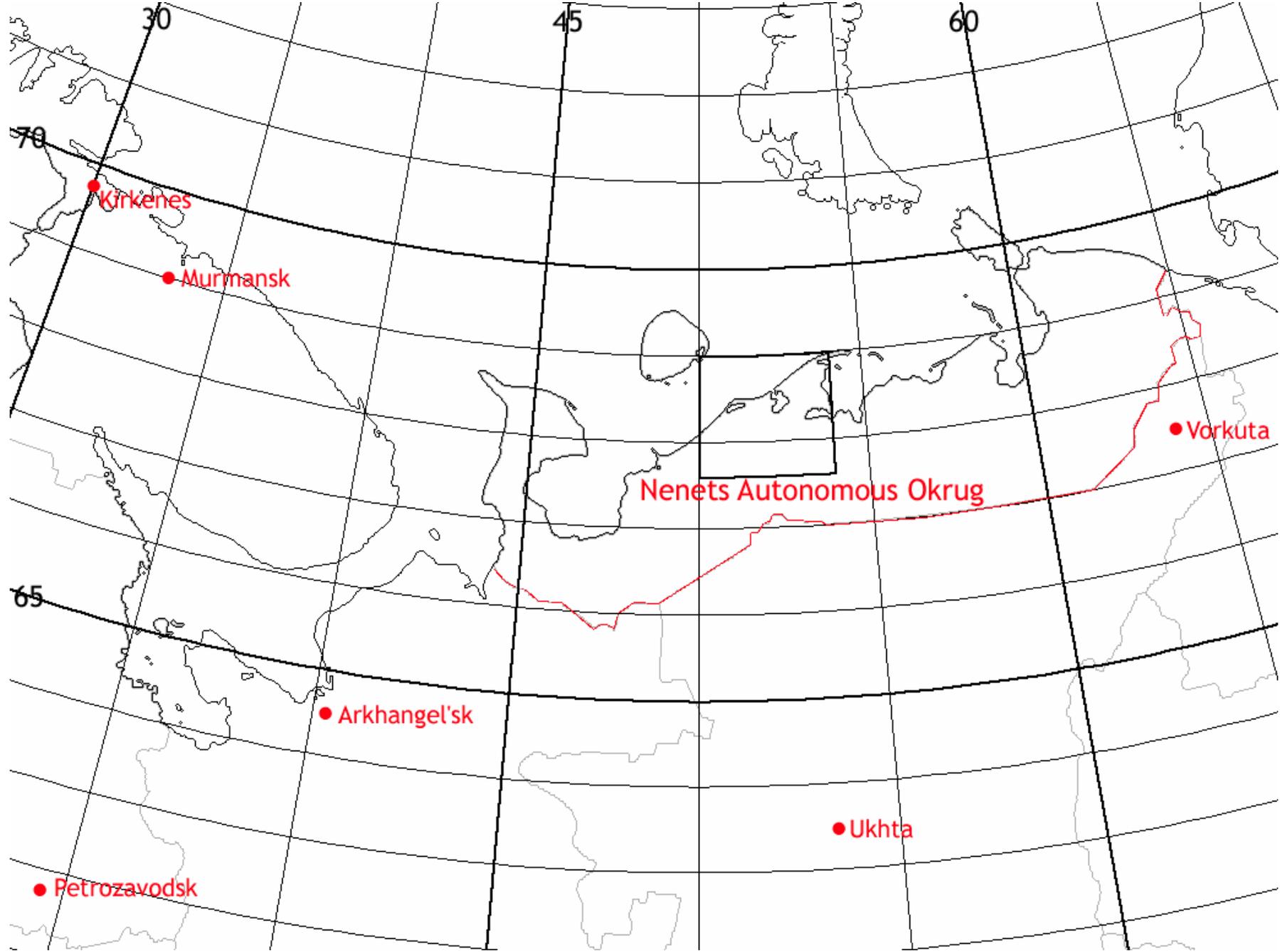
Data sparse for Russia

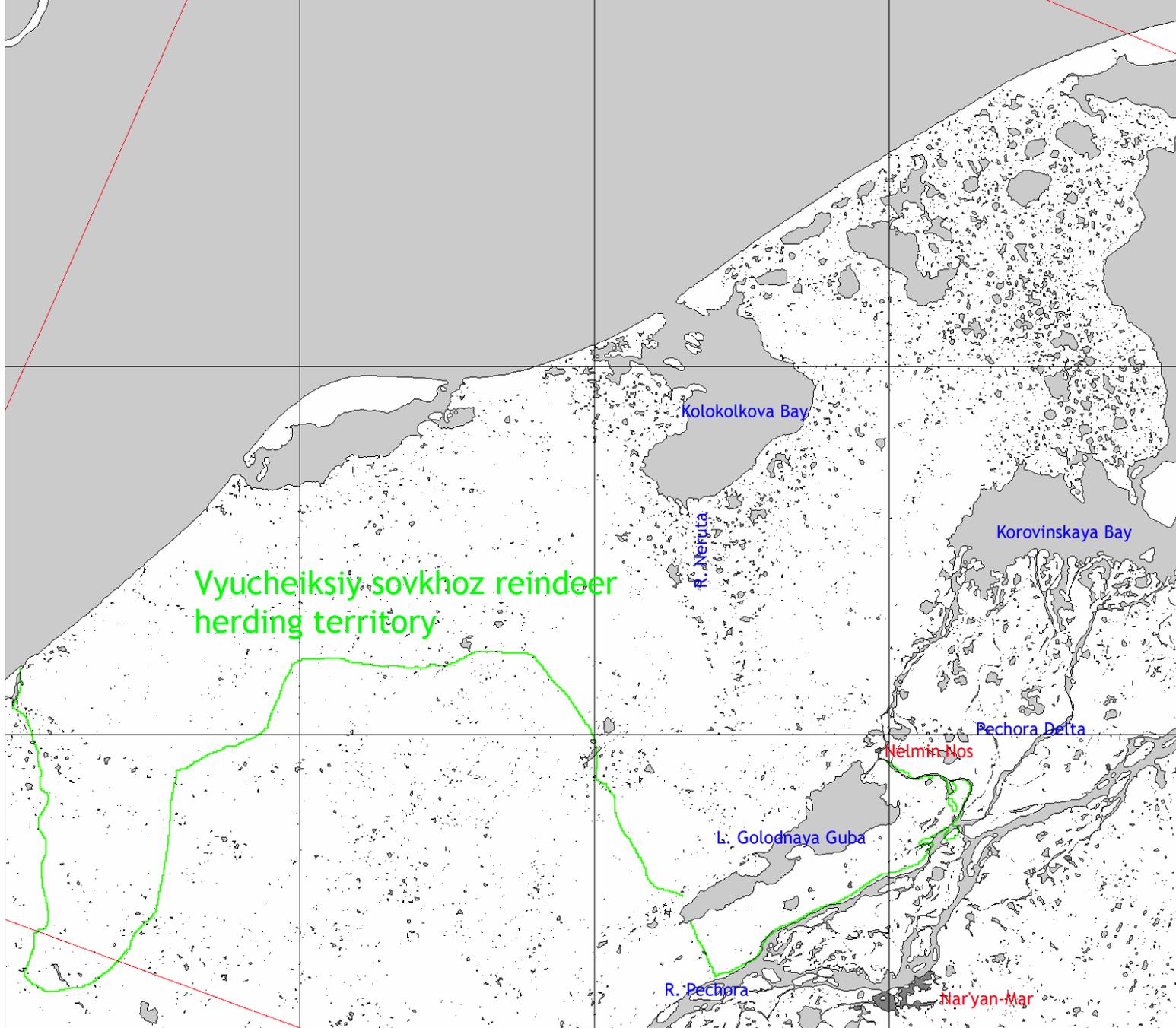
Monitoring vegetation change will need new maps from higher-resolution remotely sensed data or use of coarser-scale maps from low-resolution RS data

Do such maps capture variability in reindeer pasture types?

Preliminary case study in Nenents Autonomous Okrug, Russia







Vyucheiksiy sovkhos reindeer
herding territory

Kolokolkova Bay

R. Verjita

Korovinskaya Bay

Pechora Delta

Nelmin-Nos

L. Golodnaya Guba

R. Pechora

Nar'yan-Mar



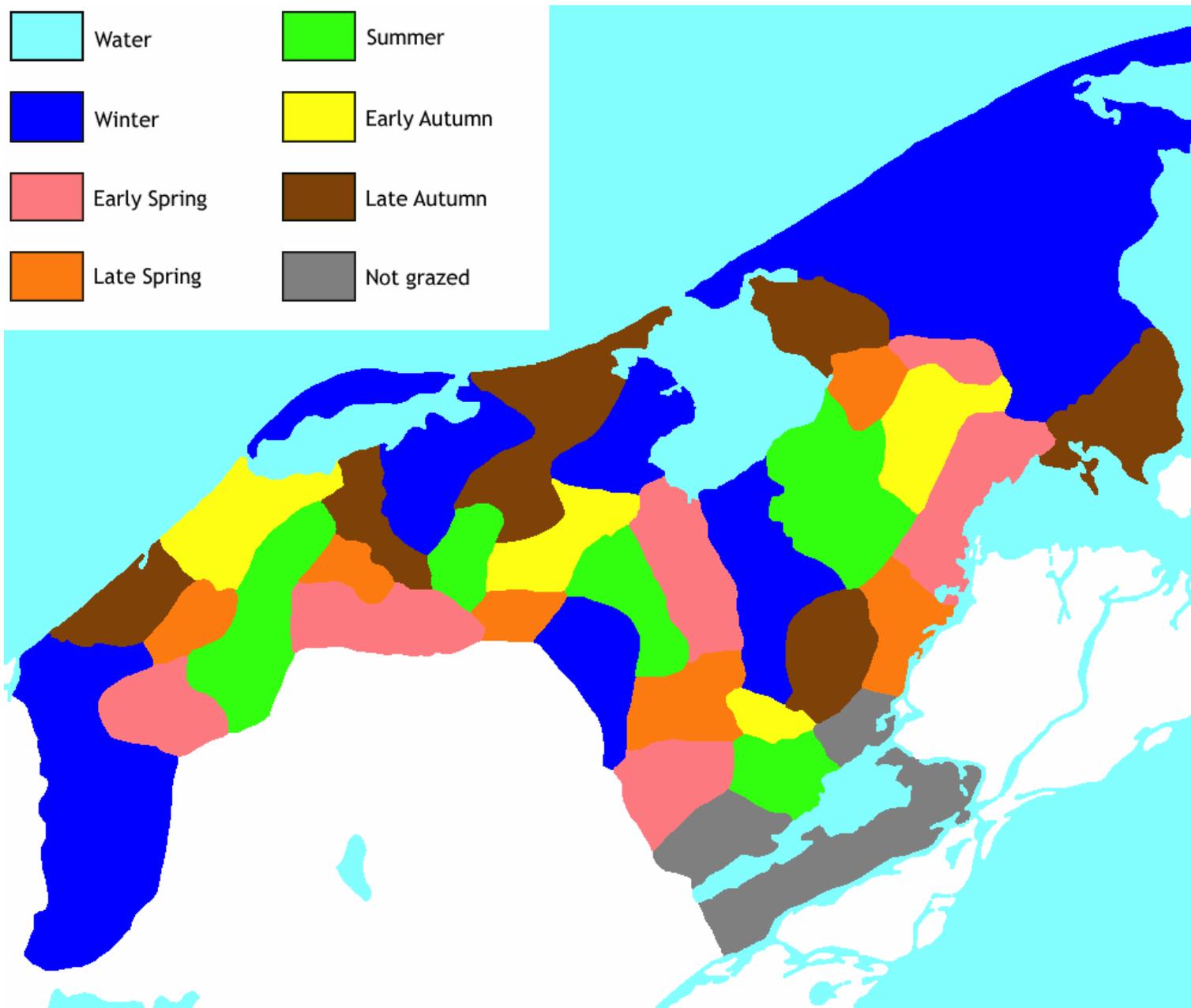
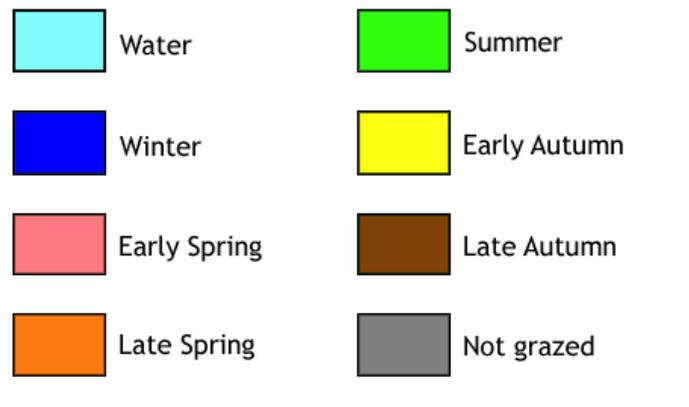
Reindeer husbandry in Russia through 'close herding' (24-hours-a-day management, no fences)

Typically follows a 6-season pattern, intended to reflect (*inter alia*) seasonal variations in diet. *Lichens* especially important in winter.

Herd migration is governed by official regulations with detailed maps - principles of compilation are not easy to establish.



Grazing pastures - Vyucheiskiy Sovkhoz



Maps of study area to be compared

| Map / database | Compilation | Input data | Resolution (m) at 67.6 °N | No of classes in sovkhos area |
|--------------------------|-------------|---------------------------------------|---------------------------|-------------------------------|
| Olson | 1994 | AVHRR, DEM | 925 × 350 | 16 |
| JRC GLC2000 | 2000 | VEGETATION | 1000 × 380 | 16 |
| CAVM | 2003 | AVHRR, DEM, ancillary data | ~ 2000 | 5 |
| Vegetation map | 1974 | Isachenko et al. (fieldwork) | ~ 500 | 17 |
| Pasture map | ? | ? | ~ 2000 | 6 |
| Landsat-7 classification | 2004 | ETM+ 2000; fieldwork 1999, 2003, 2004 | 120 | 7 |

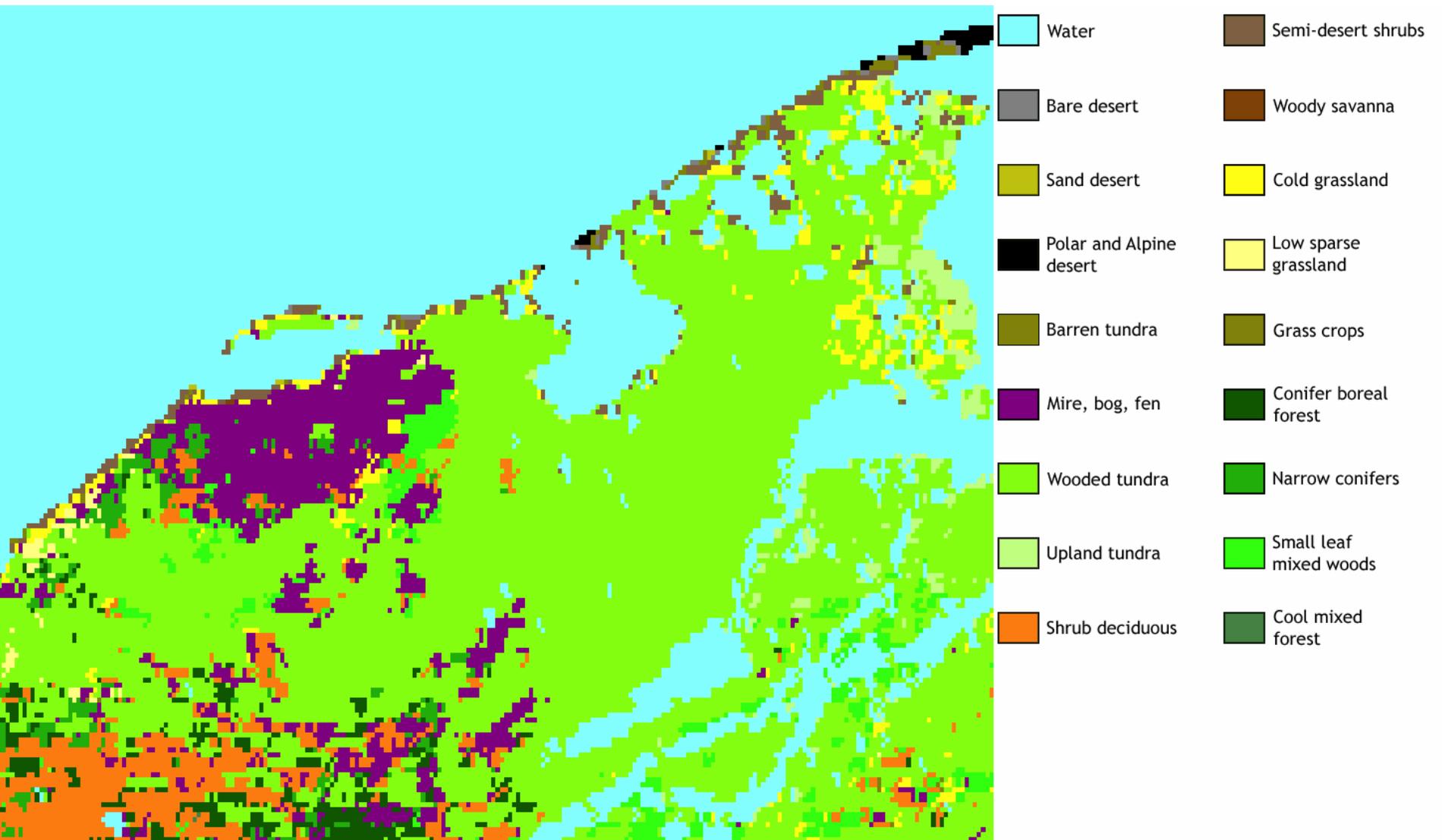
... all resampled to Plate Carrée projection

67.6 °N - 69.0 °N @ 600 pixels per degree (~185 m resolution)

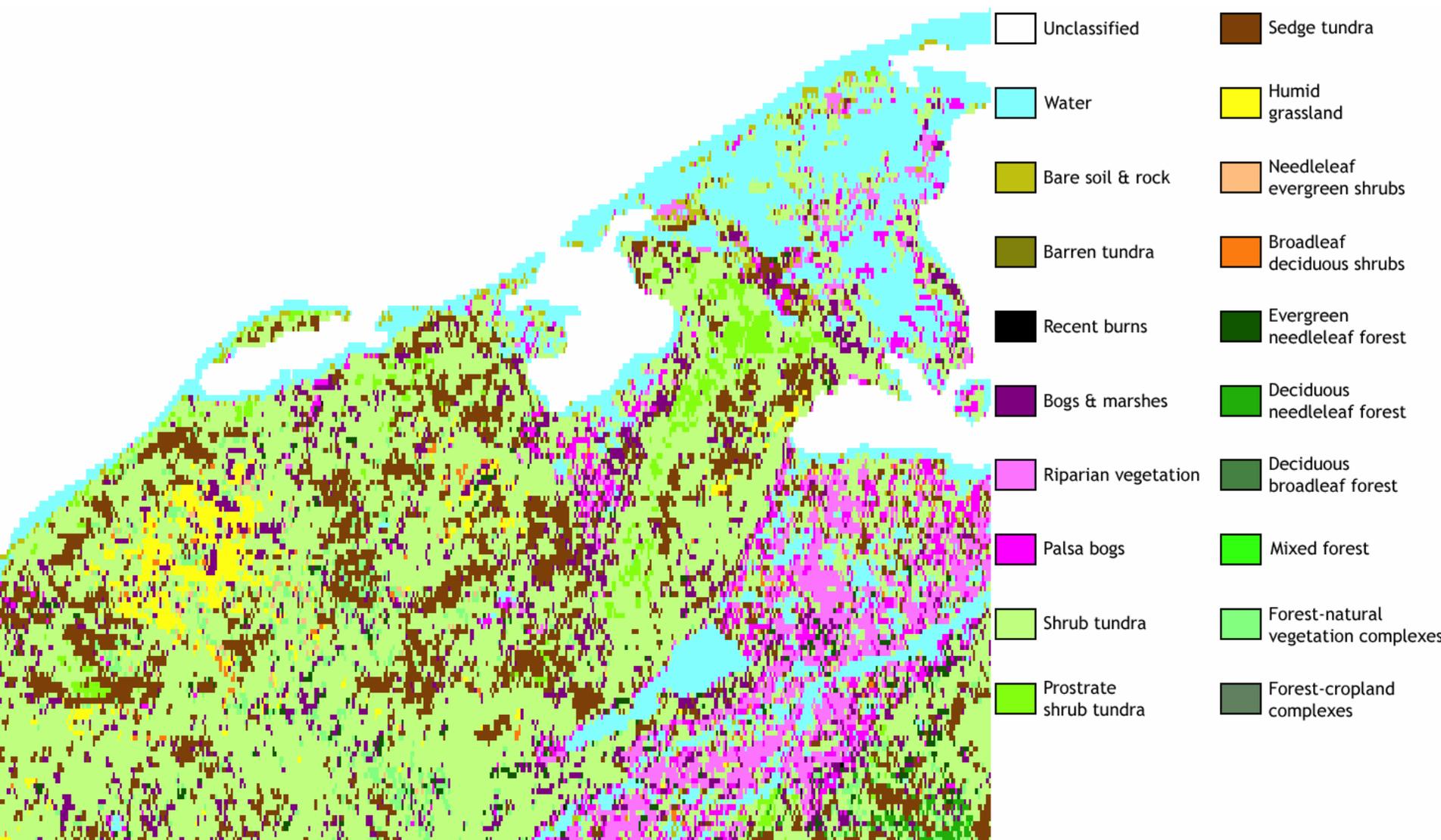
50.0 °E - 54.0 °E @ 250 pixels per degree (~170 m resolution)



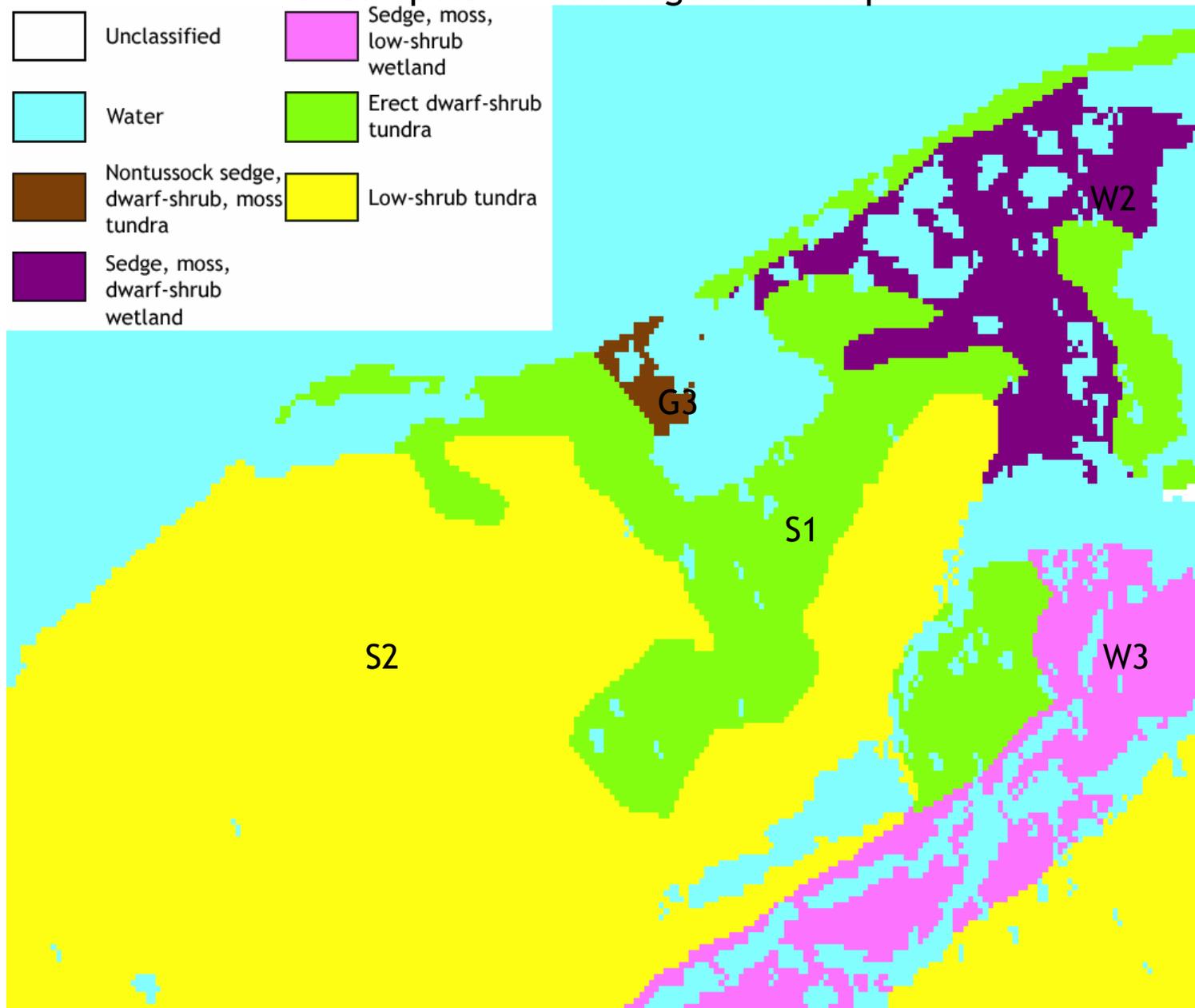
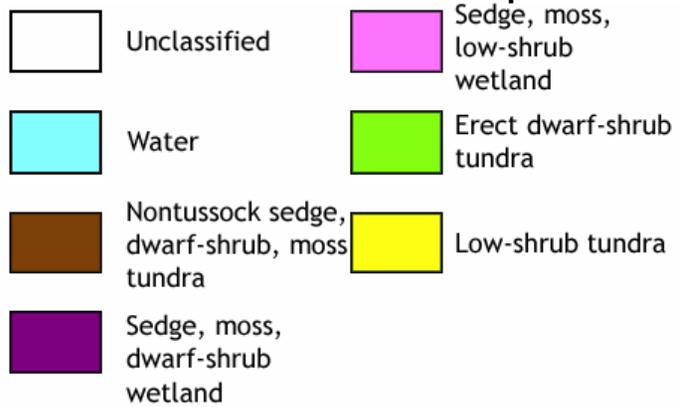
Olson classification



JRC GLC 2000



Circumpolar Arctic Vegetation Map



S1



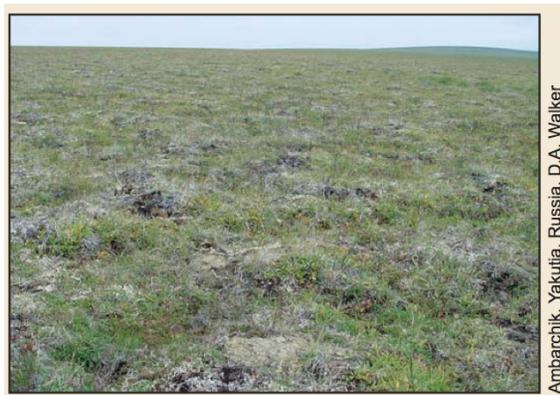
Daring Lake, Canada. D.A. Walker

S2



Seward Peninsula, Alaska. D.A. Walker

G3

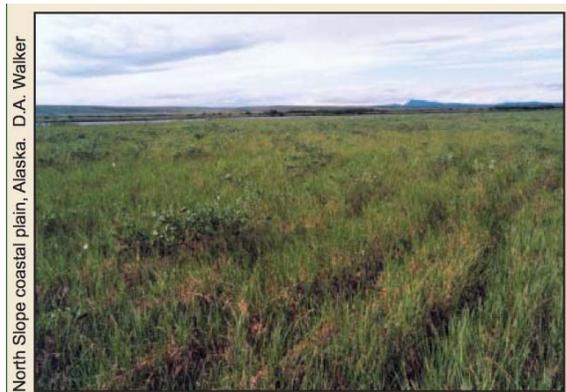


Ambarchik, Yakutia, Russia. D.A. Walker

Source: CAVM poster

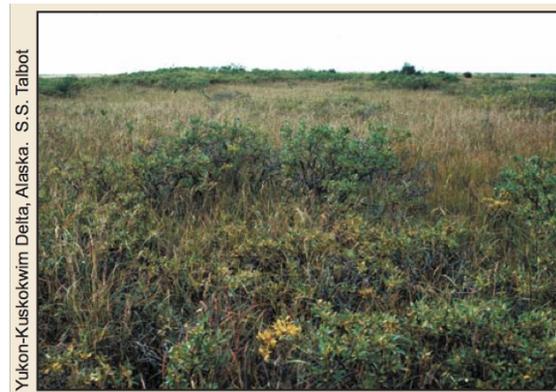
Credits: D.A. Walker, S.S. Talbot

W2



North Slope coastal plain, Alaska. D.A. Walker

W3

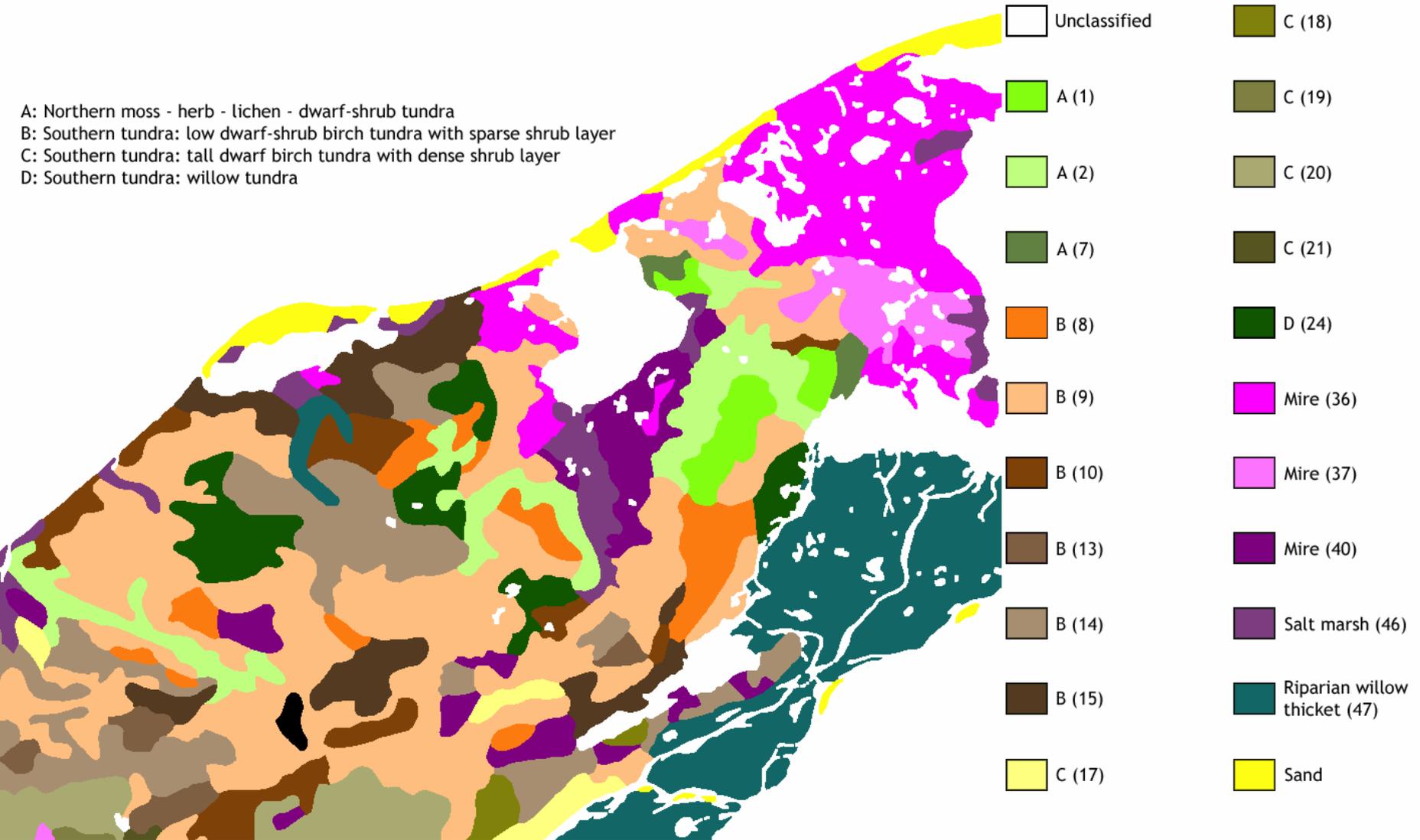


Yukon-Kuskokwim Delta, Alaska. S.S. Talbot



Russian (Isachenko et al.) vegetation map

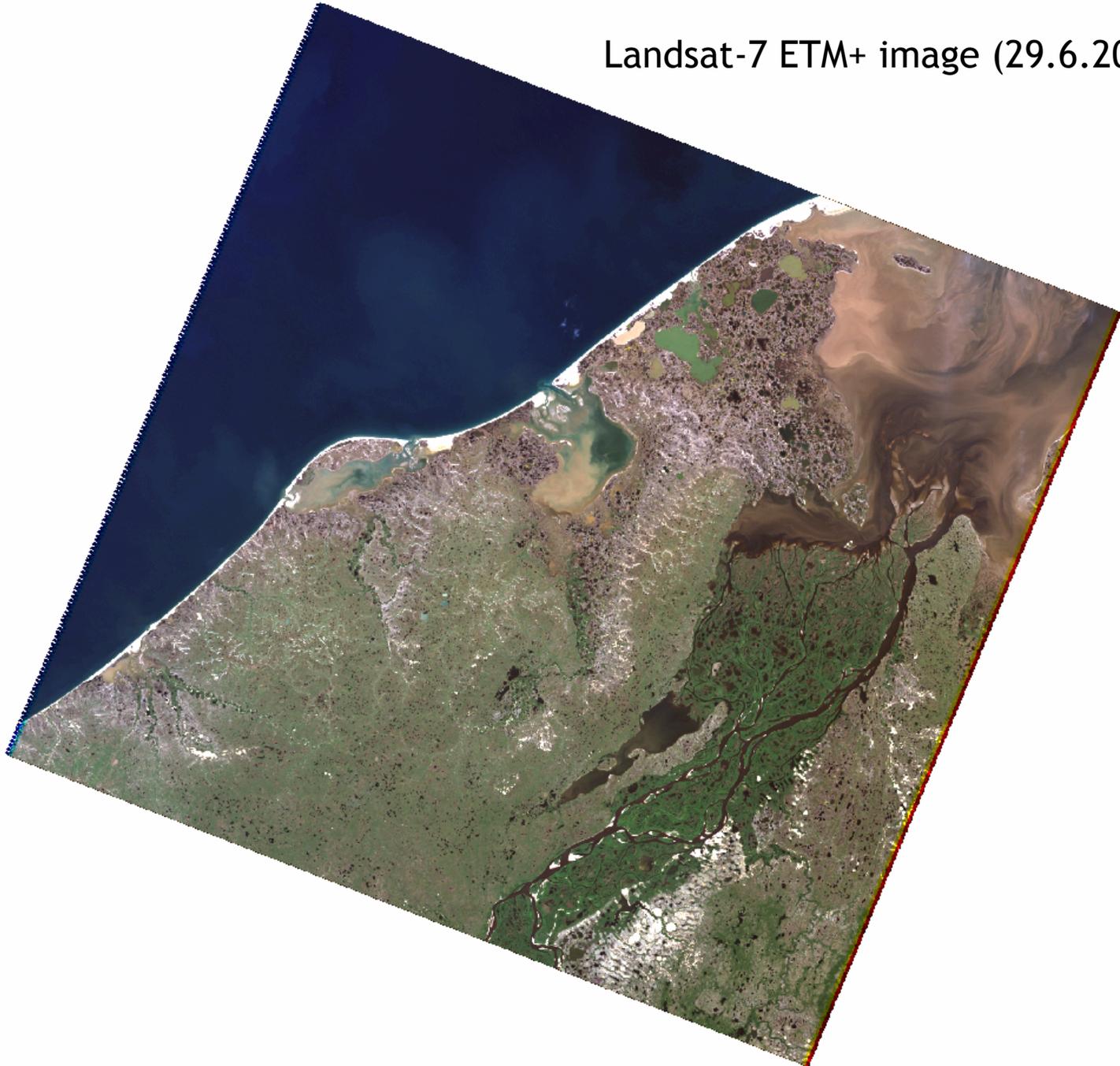
A: Northern moss - herb - lichen - dwarf-shrub tundra
 B: Southern tundra: low dwarf-shrub birch tundra with sparse shrub layer
 C: Southern tundra: tall dwarf birch tundra with dense shrub layer
 D: Southern tundra: willow tundra



- A Northern moss-herb-lichen-dwarf shrub tundra
 - 1 moss-sedge-herb
 - 2 lichen-dwarf shrub
 - 7 moss-sedge-herb with bogs and mires
- B Southern tundra: low dwarf birch tundra with sparse shrub layer of *Betula nana* and willow
 - 8 dwarf birch-willow, dwarf shrub sedge, moss, small hummocks
 - 9 dwarf birch willow, dwarf shrub, lichen moss, small hummock
 - 10 dwarf birch, dwarf shrub herb, moss, with bogs
 - 13 dwarf birch-willow-moss-dwarf shrub-sedge with bogs
 - 14 dwarf birch-willow-lichen-moss-dwarf shrub
 - 15 dwarf birch tundra with moss, dwarf shrub, herbs and bogs
- C Southern tundra: tall dwarf birch tundra with dense *Betula nana* shrub layer
 - 17 dwarf birch-willow, dwarf shrub, lichen-moss
 - 18 dwarf birch, dwarf shrub-herb, moss with bogs
 - 20 dwarf birch-willow lichen-moss-dwarf shrub with bogs
- D(24) Southern tundra: willow tundra
- Mires
 - 36 sedge-herb coastal
 - 37 sedge-cottongrass-moss subarctic
 - 40 dwarf birch, herb-dwarf shrub-moss-lichen
 - 46 Coastal salt marsh
 - 47 Riparian willow thicket



Landsat-7 ETM+ image (29.6.2000)



Classification procedure (see our poster!):

- fieldwork data collected in 1999, 2003, 2004 (~350 sites)
- topographic map data (1:200,000) for water bodies
- densest vegetation (shrubs) identified by density-slicing NDVI
- spectral purity method for bare ground
- mask image and perform unsupervised classification: identify clusters using field data

Final stable classification compared against straightforward supervised classification from training data (standard max-likelihood and ECHO spatial-spectral).

Very simple scheme with classes:

water

bogs, fens, mires

shrub

bare ground

water-vegetation mixture or submerged vegetation

moist heath

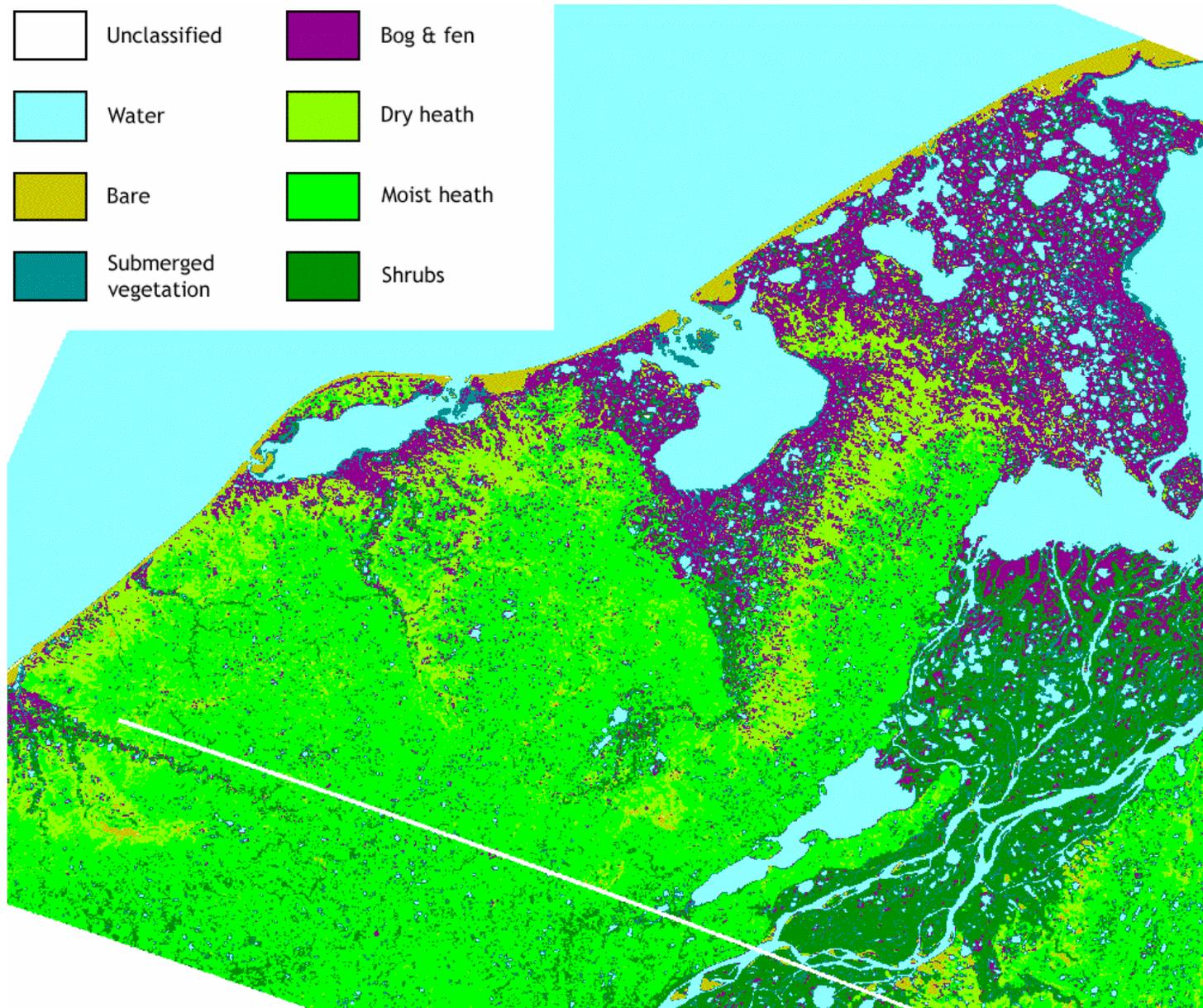
dry heath

Why no lichens? Problem of heterogeneity...





Landsat classification

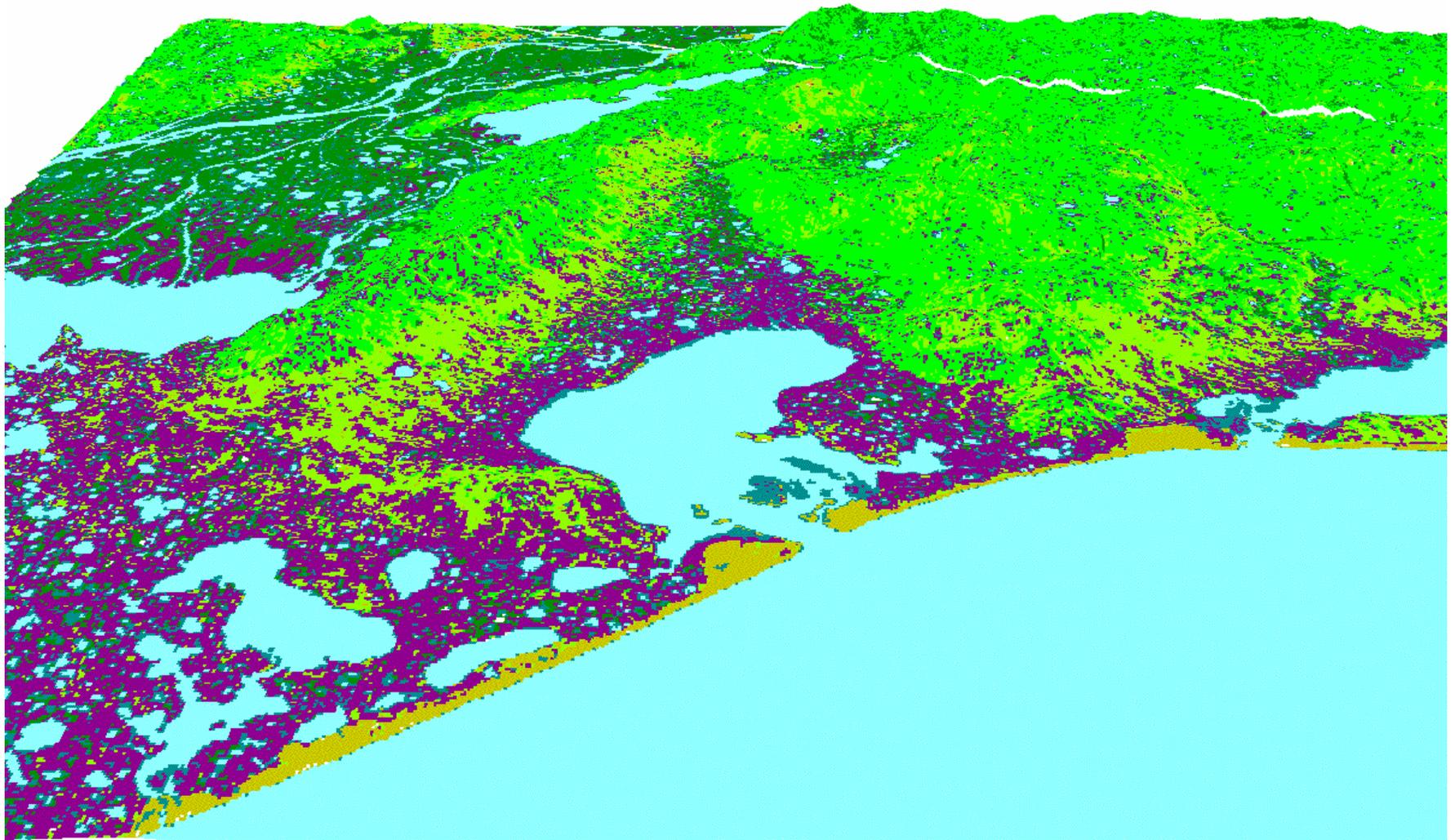


Generalised landscape units fairly easy to recognise

river deltas

wetlands

tundra



Contingency matrix approach to defining a spatial similarity metric

| | Water | Bog | Submerged | Bare | Moist tundra | Dry tundra | Shrub | Total |
|-------|-------|-------|-----------|------|--------------|------------|-------|--------|
| S1 | 2762 | 30429 | 6544 | 3681 | 17414 | 15586 | 6981 | 83397 |
| S2 | 1430 | 10596 | 3075 | 1091 | 90158 | 26396 | 8580 | 141326 |
| G3 | 215 | 1745 | 419 | 116 | 4 | 193 | 192 | 2884 |
| W2 | 2860 | 21858 | 5446 | 225 | 488 | 2742 | 2978 | 36597 |
| W3 | 116 | 88 | 314 | 1 | 1296 | 114 | 1285 | 3214 |
| Total | 7383 | 64716 | 15798 | 5114 | 109360 | 45031 | 20016 | 267418 |

Actual contingency matrix for Landsat classification *cf* CAVM

| | Water | Bog | Submerged | Bare | Moist tundra | Dry tundra | Shrub | Total |
|-------|-------|-------|-----------|------|--------------|------------|-------|--------|
| S1 | 2302 | 20182 | 4927 | 1595 | 34105 | 14043 | 6242 | 83397 |
| S2 | 3902 | 34201 | 8349 | 2703 | 57795 | 23798 | 10578 | 141326 |
| G3 | 80 | 698 | 170 | 55 | 1179 | 486 | 216 | 2884 |
| W2 | 1010 | 8857 | 2162 | 700 | 14966 | 6163 | 2739 | 36597 |
| W3 | 89 | 778 | 190 | 61 | 1314 | 541 | 241 | 3214 |
| Total | 7383 | 64716 | 15798 | 5114 | 109360 | 45031 | 20016 | 267418 |

Contingency matrix for random distributions with same totals

...in this case, *Moist tundra* class occurs in same place as *S2* class surprisingly often, and in same place as *W2* class surprisingly seldom, etc.

Leads to idea of non-randomness of contingency matrix, and approach to identifying corresponding classes



Theory:

Contingency matrix is a_{ij} (i in first classification, j in second)

$$i = 1..m, j = 1..n.$$

Total number of pixels is $S = \sum_i \sum_j a_{ij}$.

Random contingency matrix with same column and row totals is $e_{ij} = \frac{1}{S} \sum_k a_{ik} \sum_k a_{kj}$.

Measure of surprise is $\chi_{ij}^2 = \frac{(e_{ij} - a_{ij})^2}{e_{ij}}$, hence define $\langle \chi^2 \rangle = \frac{1}{mn} \sum_i \sum_j \chi_{ij}^2$.

Maximum value of this parameter is $\langle \chi^2 \rangle_{\max} = \frac{S(\min(m, n) - 1)}{mn}$,

hence define the spatial similarity metric as $F = \left(\frac{\langle \chi^2 \rangle}{\langle \chi^2 \rangle_{\max}} \right)^{1/2}$.

This has $0 \leq F \leq 1$.

Can assign statistical significance if we know the number of independent samples (which we probably don't).



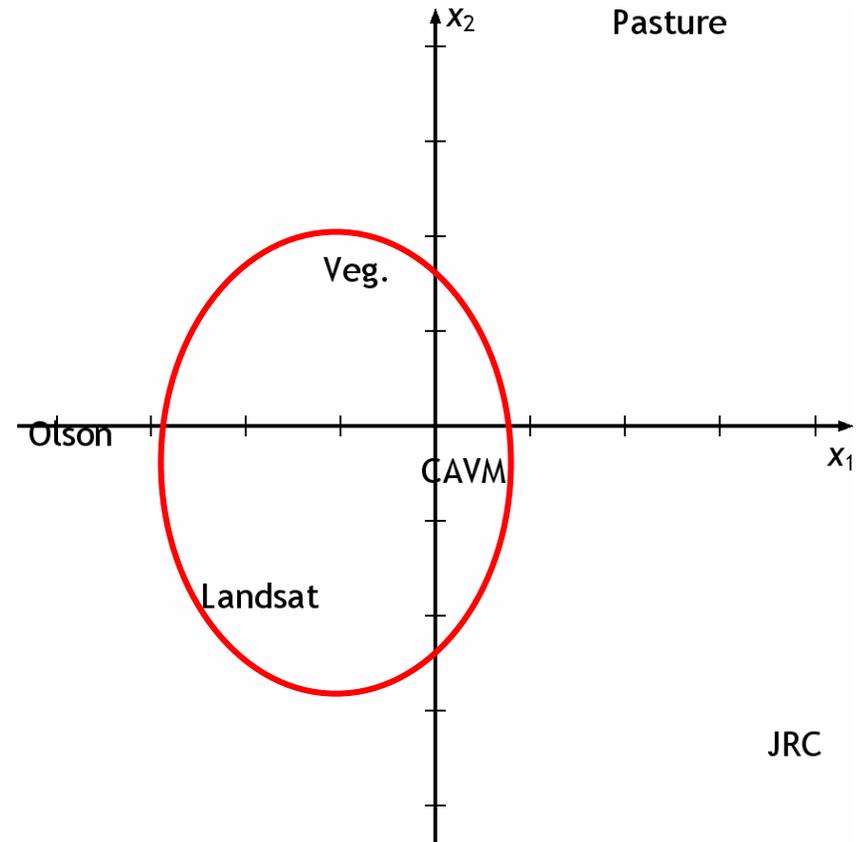
Matrix of spatial similarities

| F | Landsat | JRC | Olson | CAVM | Veg. map |
|----------|---------|-------|-------|-------|----------|
| JRC | 0.251 | | | | |
| Olson | 0.309 | 0.142 | | | |
| CAVM | 0.322 | 0.310 | 0.265 | | |
| Veg. map | 0.366 | 0.195 | 0.277 | 0.465 | |
| Pasture | 0.182 | 0.202 | 0.176 | 0.246 | 0.315 |

- classifications with most detailed input data are most similar (!)
- 30-year old vegetation map best captures seasonality of reindeer pasture map (may not be independent)
- CAVM best of the global/circumpolar maps

Multidimensional scaling diagram

- Places similar things close to one another
- 6-dimensional diagram with unitless axes
- First two dimensions contain most of the variation



The 3 closest classifications generally agree:

- Low DS birch tundra with sparse shrub layer ↔ Moist tundra ↔ CAVM low shrub tundra S2
- Mires ↔ Bog ↔ CAVM sedge-moss-dwarf shrub tundra wetland W2

...but mapping of shrubs and drier tundra is less consistent.

Both of these are significant problems in characterising reindeer pasture.

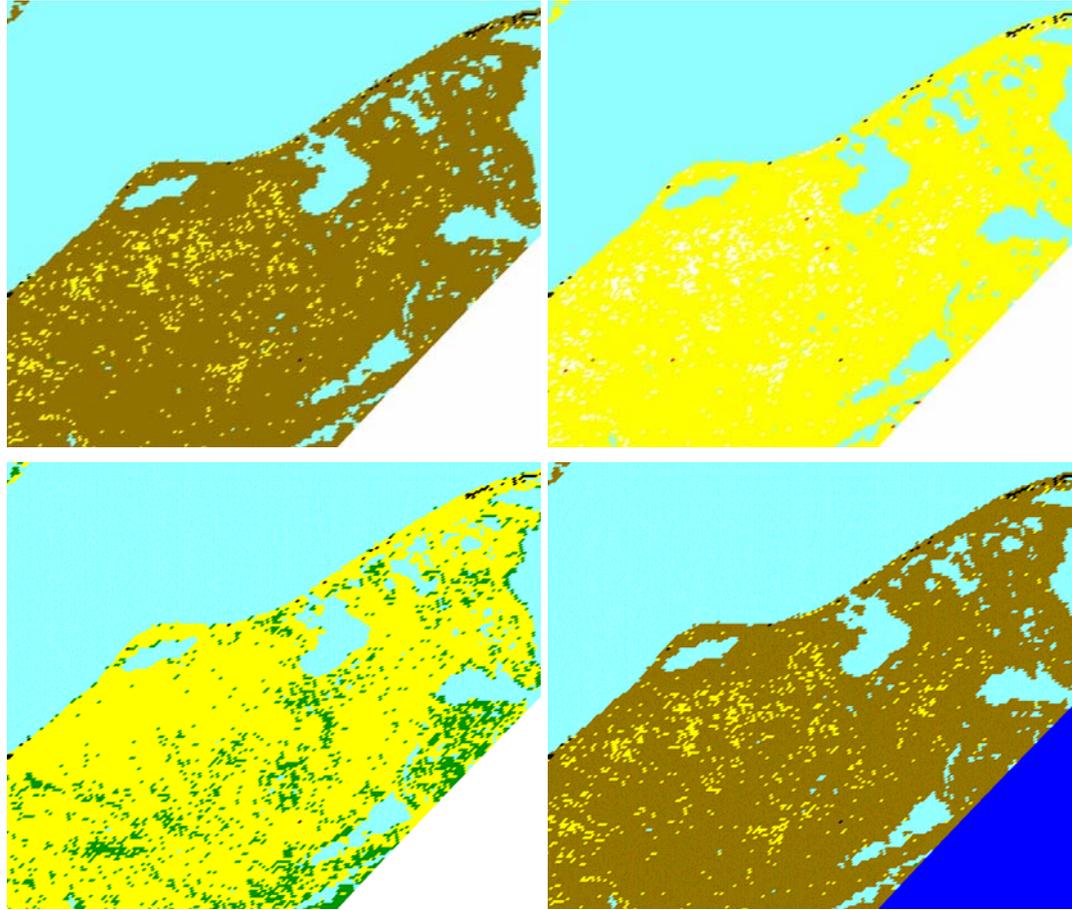
Points to need for improved mapping

Lichen mapping from MODIS using 'lichen index' (and phenology?)

Shrub mapping through vegetation index stratification?



Current MODIS vegetation classifications are not optimal for Arctic regions:



MOD12Q1 land cover product

(in 4 variants)

Brown = shrubland

Yellow = grassland, crops

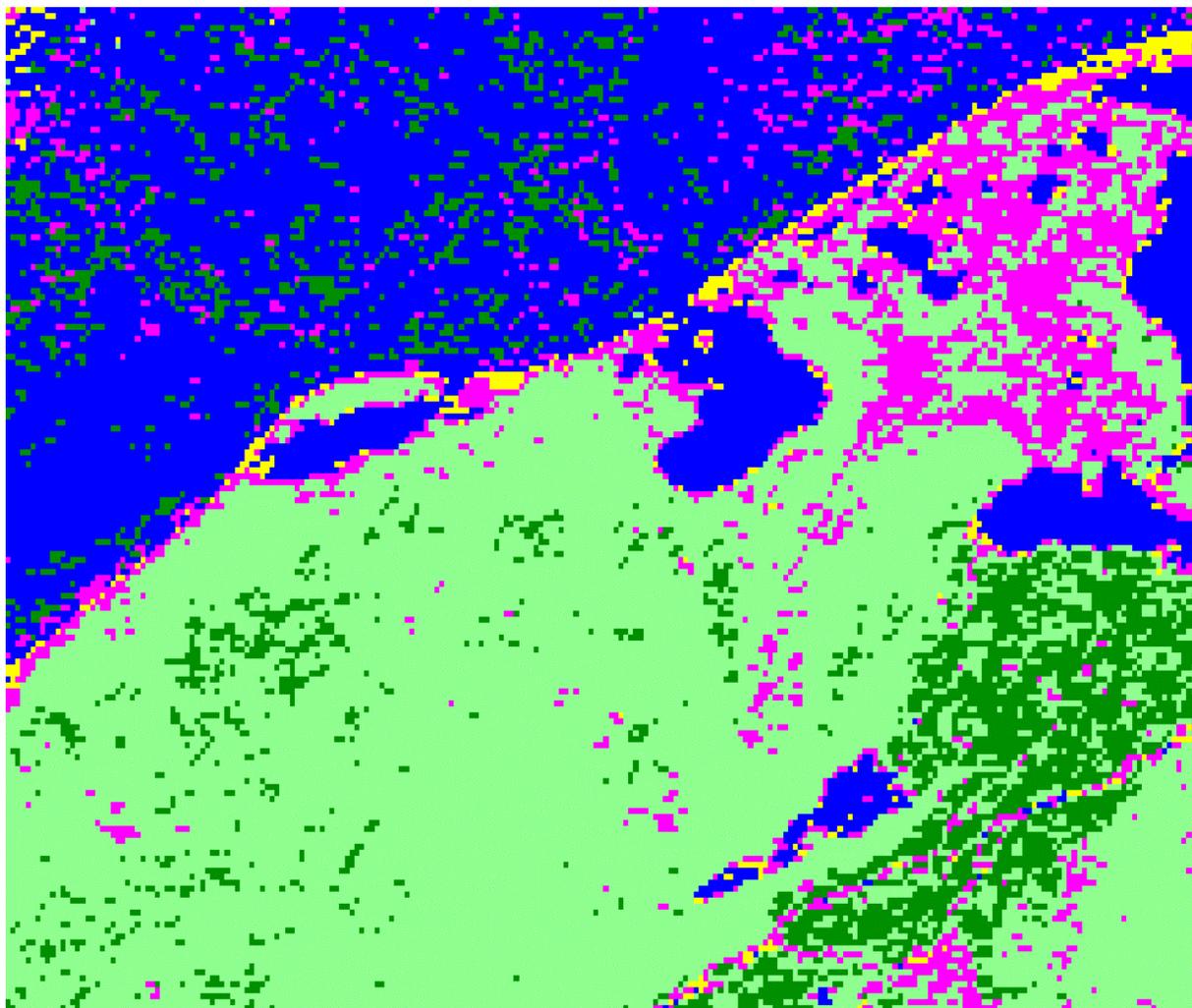
Green = forest

White = ice and snow

Black = unvegetated



MODIS NDVI stratification - reasonable for shrubs?



Thresholds:

Blue < 0

Yellow 0-0.2

Purple 0.2-0.6

Lt green 0.6-0.8

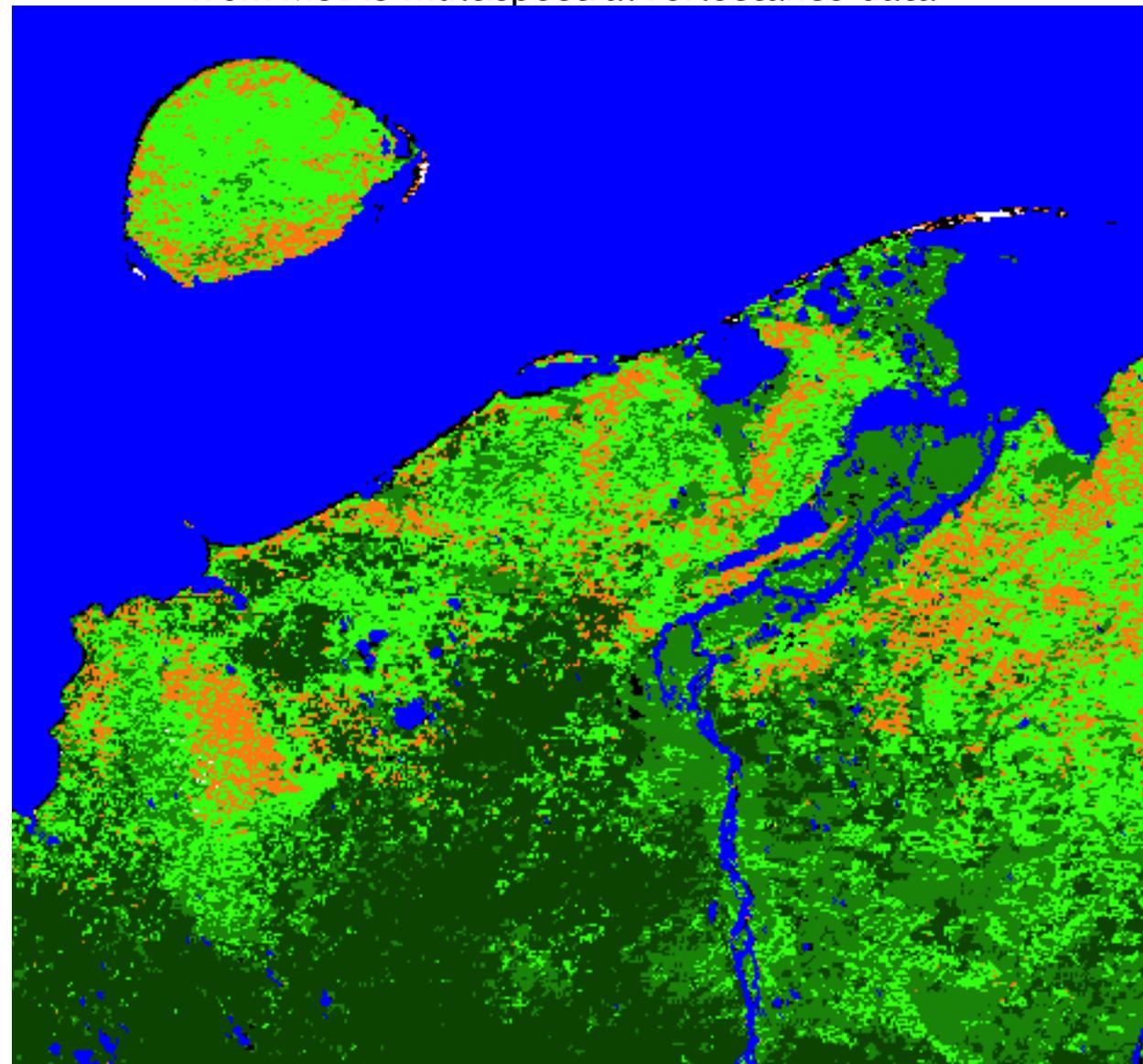
Dk green > 0.8

Include July
temperature data *cf*
Martha Reynolds'
presentation?



Towards a circumarctic lichen map...?

Merge non-tundra classification (from Olson, JRC etc) with lichen classification from MODIS multispectral reflectance data



Darkest green: forest

Mid-green: shrubs

Light green: dwarf shrub tundra

Orange: lichen tundra (?)

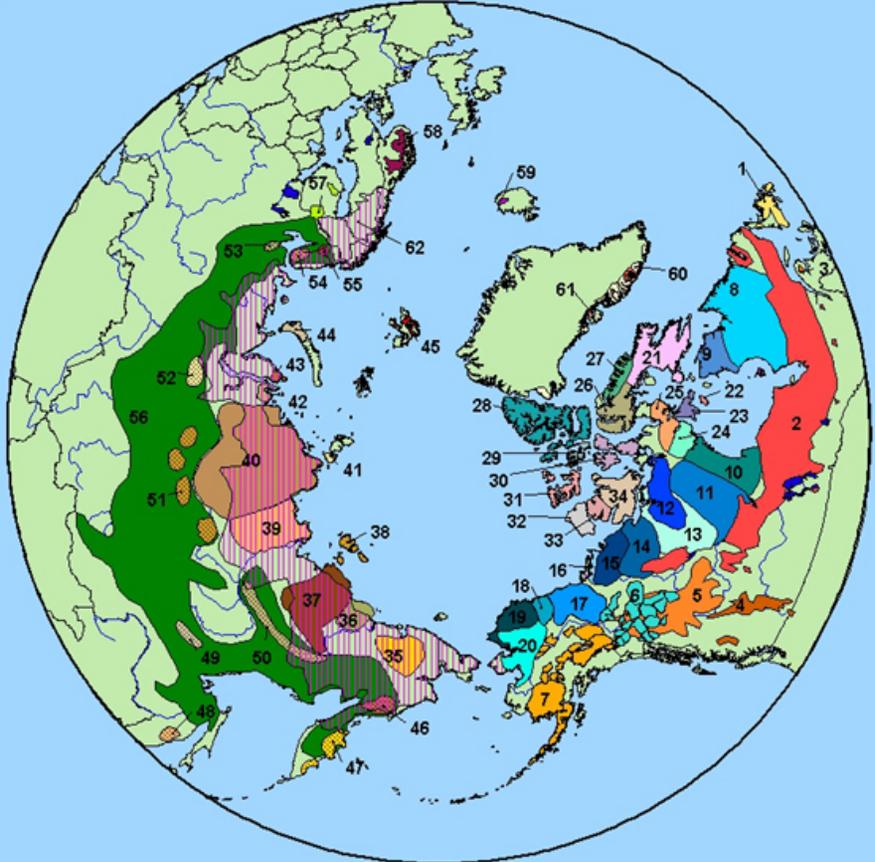


Summary:

- CAVM best of the circumpolar/global maps/data products for representing pasture differences...
- but none of them represent lichen heaths well, and shrub encroachment also needs addressing...
- *in situ* methods work, of course,
- and there is possible scope for shrub and lichen mapping using MODIS.
- We hope, in collaboration, to develop a Circumpolar Arctic Lichen Map
- ...which has a reassuring acronym: CALM







| | | | |
|---------------------|-------------------------------------|------------------------------|----------------------------------|
| 1 Newfoundland | 17 Porcupine | 33 Northwest Victoria Island | 49 Okhotsk |
| 2 Boreal | 18 Central Arctic | 34 Dolphin-Union | 50 Yakutsk |
| 3 Atlantic | 19 Teshekpuk | 35 Chukotka | 51 Evenkiya |
| 4 Southern Mountain | 20 Western Arctic | 36 Sudrunkaya | 52 Nadyin-Par (Yamal Okrug) |
| 5 Northern Mountain | 21 South Baffin Island | 37 Yana-Indigirka | 53 Arkhangelsk Oblast |
| 6 Yukon | 22 Coats Island | 38 Novosibirski Ostrova | 54 Terskii Bereg (Kola) |
| 7 Alaska | 23 Southhampton Island | 39 Lena-Olenek | 55 Laplandskii Zapovednik (Kola) |
| 8 George River | 24 Lorillard | 40 Taimyr | 56 Range of Forest Reindeer |
| 9 Leaf River | 25 Wager Bay | 41 Severnaya Zemlia | 57 Finland |
| 10 Qamanirjuaq | 26 North Baffin Island | 42 Gydan | 58 Norway |
| 11 Beverly | 27 Northeast Baffin Island | 43 Belyi | 59 Iceland |
| 12 Ahiak | 28 Eastern Queen Elizabeth Islands | 44 Novaya Zemlia | 60 Greenland |
| 13 Bathurst | 29 Bathurst Island | 45 Svalbard | 61 Greenland Feral Reindeer |
| 14 Bluenose East | 30 Prince of Wales-Somerset-Boothia | 46 Parapolskii | 62 Range of Domestic Reindeer |
| 15 Bluenose West | 31 Western Queen Elizabeth Islands | 47 Kamchatka | |
| 16 Cape Bathurst | 32 Banks Island | 48 Amur | |

Range Map (Compiled from Burt and Grossenheider, 1976; Whitehead, 1993)

