A HIERARCHIC GEOGRAPHIC INFORMATION SYSTEM FOR NORTHERN ALASKA: INSIGHTS TOWARD A CIRCUMPOLAR ARCTIC VEGETATION MAP

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Introduction

We are in the process of building a hierarchic geographic information system for northern Alaska as part of the Arctic System Science Program (Walker and Walker 1991). The hierarchy consists of three principal spatial domains: (1) plot-level, 1-10^4 m^2 (maps at 1:10-scale), (2) landscape-level, 10^4 to 10^8 m^2 (maps at 1:500- to 1:5,000-scale), and (3) regional-level, 10^8 to 10^{10} m^2 (maps at 1:25,000- to 1:250,000-scale). At the plot-level, we are using permanent plots to (1) map and monitor species composition and vegetation structure to examine long-term changes in vegetation, (2) examine trends in species composition, soils, and site factors along environmental gradients, and (3) classify the vegetation according to the Braun-Blanquet approach. At the landscape level, we are making vegetation maps based primarily on photo-interpreted information supplemented with detailed ground observations. At the regional level, we are using a combination of photo-interpretation and classification of satellite-derived digital data. This paper summarizes what we have learned regarding the controlling environmental factors at the plot-, landscape-, and regional-levels, with insights toward the development of a circumpolar vegetation map.

Controlling environmental factors for vegetation patterns

Plot scale

At the microscale, Cantlon (1961) defined the principal controls on vegetation patterns as those associated with the soil moisture and microsite gradients as influenced by microtopography, cryoturbation, winter snow depth, and small scale disturbances. Although this scale is relatively unimportant to a circumpolar vegetation map, the species and their distribution patterns are very important to plot-based process-level studies that are being used to address global-scale issues and for landscape and regional analyses of biodiversity. It is, therefore, important that the classification developed for the circumpolar Arctic be hierarchically linked to vegetation units based on floristic criteria. The advantages of using an internationally accepted method of vegetation classification such as the Braun-Blanquet approach were outlined at the 1991 International Circumpolar Vegetation Classification Workshop (Walker and others, 1994b).

Landscape scale

At the landscape level, vegetation patterns are largely controlled by soils and site factors that vary over distances of hundreds of meters. At this scale, vegetation patterns are defined by (1) longer topographic gradients associated with hillslopes, moraines, and mountains, (2) hydrologic features associated with small watersheds and water tracks, and (3) parent material associated with glacial, glaciofluvial, eolian, and marine events. Maps at 1:500- and 1:5000-scales clearly show the patterns related to hydrological features and different age glacial surfaces. Large-scale disturbance features also have major effects on the overall productivity of landscapes. For example, at Toolik Lake, Alaska, the normalized difference vegetation index (NDVI) on different age glacial surfaces is strongly correlated with time since deglaciation (Walker and others,1994a; Figure 1). NDVI has been shown to be strongly correlated with biomass in moist tundra ecosystems (Shippert and others, 1994). Similar patterns are associated with loess deposits and river floodplains.

Regional scale

The regional level is the most important with respect to development of a circumpolar map. At this level, regional temperature, floristic consideration, and large-scale substrate patterns are important.

Temperature

The latitudinal temperature gradient is compressed on the North Slope due to the presence of the cold Beaufort Sea and the Brooks Range, which blocks the flow of warm air from interior Alaska (Conover 1960). Within 100 km of the coast, the mean July temperature increases from about 4^{o}C at the coast to about 10^{o}C at the northern edge of the Arctic Foothills and approaches 12^{o}C in some valleys of the foothills. Along the coast, north of the 7^{o}C mean July isotherm, the vegetation is dominated by wet sedge-grass meadows composed of *Eriophorum angustifolium*, *Carex aquatilis*, and *Dupontia fisheri*. At some extreme sites along the coast and on the off-shore islands, the vegetation has a High Arctic character with no low shrubs, open vegetation cover, and less than 100 vascular plant species. The region north of 7^{o}C isotherm is within the Arctic Tundra zone of Yurtsev (1994; subzone II of figure __, page __). A few kilometers inland and south of the 7^{o}C July isotherm, the dominant vegetation on upland sites consists of shrub-poor tussock tundra. Tussock tundra is better developed in the Arctic Foothills, where it dominates most landscapes. This region corresponds to the hypoarctic zone of Yurtsev (1994; subzone III figure __, page ___) and subarctic zone of Sochava (1964). Shrub tundra is dominant in western Alaska and on favorable sites in the warmer sections of the Arctic Foothills, and in areas receiving higher amounts of ground water (Yurtsev 1994; subzone IV figure __, page ___). Birch (*Betula nana*) and alders (*Alnus visidis)* are major components of many vegetation types in these areas.

Floristic considerations

The floristic influences, described thoroughly by Murray (1978), Young (1971), and Yurtsev (1994), define the regional floras which are shaped by climatic and environmental factors. Along a north-south gradient, the zones of Yurtsev (1994) and Young (1971) provide a good framework for the increase in floristic diversity with temperature. Along an east-west gradient, the influences of Asian and Beringian floras are quite strong, particularly in western Alaska, and decrease toward the east. Yurtsev (1994) has divided the Alaskan province of the Beringian Sector into two subprovinces. The Northern Alaska subprovince includes the more continental (central and eastern) parts of the Brooks Range, the northern foothills, and the arctic coastal region. The Beringian subprovince has a much richer flora and includes the Yukon River delta, the Seward Peninsula, and Lisburne Peninsula.

Substrate

Soil pH controls many large-scale patterns of vegetation related to a variety of disturbance factors, including loess areas, glaciated regions, and floodplains of the larger rivers (Figure 2; Walker and Walker, 1991; Walker and Everett, 1991; Walker and others, 1994). There is little overlap of dominant vascular plants, mosses or lichens in acidic and nonacidic tundra areas (Table 1). Moist acidic tundra has high cover of deciduous shrubs, primarily *Betula nana* and *Salix planifolia ssp. pulchra*, and relatively low cover of barren frost scars (frost medallions). Areas dominated by deciduous shrubs have relatively high NDVI. In contrast, moist nonacidic tundra has relatively low cover of deciduous shrubs, more open plant canopies due to the presence of more frost scars, and relatively low NDVI. The distinctions between acidic and nonacidic tundra are so fundamental that they are the primary criteria for separating vegetation units at the second level of a vegetation classification hierarchy developed for the foothills region (Table 2).

Satellite-derived classifications

It is generally not possible to use satellite data to interpret floristically-derived community types across very broad regions because different vegetation communities do not have distinguishing spectral characteristics. However, classifications of Alaskan tundra derived from Landsat MSS data suggest that most tundra landcover units can be derived from a combination of only a few spectrally distinct materials that do occur across broad regions, including open water, green deciduous vegetation (particularly deciduous shrubs), evergreen vegetation, light colored standing dead vegetation (particularly standing-dead graminoid leaves), and bare soil (Fig. 3; Walker and others, 1982; Walker and Acevedo, 1987). Spectral mixture analysis is a promising recently-developed technique for remote-sensing, whereby the percentage of major components of the landcover can be determined for each pixel by considering each pixel's spectrum to be a linear combination of spectra of these components (Adams and others, 1986).

Integration of NDVI values derived from multiple Advanced Very High Resolution Radiometer (AVHRR) observations through the growing season portray seasonal biomass production (Goward and others, 1985). Integrated NDVI maps of Alaska display a clear trend of higher NDVI, indicating higher biomass, inland from the northern coast (Binnian and Ohlen, 1993). This is due to a combination of higher temperatures and the influences of other factors such as high cover of lakes on the coastal plain. Relatively low NDVI is seen in loess affected areas in the Prudhoe Bay area and the northern front of the Arctic Foothills and is thought to be caused by high relative cover of bare soil due to frost scars, high amounts of standing dead vegetation, and relatively low cover of deciduous shrubs. In northwestern and western Alaska, higher productivity of shrub-tundra vegetation is associated with a wetter and warmer summer climate.

Because biomass is such an important variable for numerous biogeographic and global change questions, it may be desirable to produce two maps at the same scale: one that displays patterns of NDVI derived from AVHRR data, and one that displays dominant plant communities as derived from photo-interpretation and synthesis of existing maps.

Conclusions: toward a circumpolar vegetation map

(1) The tundra portion of Alaska forms a very small part of the total circumpolar arctic vegetation. However, climate gradients are strongely compressed here and the vegetation includes broad representations of most of Yurtsev's (1994) zones, except for Zone I (Polar Desert).

(2) At the regional level, important influences on vegetation patterns are (a) the major physiographic regions, (b) north-south latitudinal variation in primary production and floristic diversity (i.e., Yurtsev's zones), (c) east-west variation in floristic composition (i.e., Yurtsev's sectors), and

(d) large-scale variation in substrate.

(3) The latitudinal gradient seems to follow the criteria established for Yurtsev's zones. However, the high biomass in wetter portions of northwestern Alaska suggests that temperature and precipitation need to be considered to establish a predictive relationship with biomass. Composite NDVI images derived from AVHRR data appear to accurately portray broad trends in seasonal biomass production across northern Alaska. This needs to be confirmed with more detailed ground observations.

(4) Yurtsev's sectors provide a good framework for separating the relatively depauperate flora of Northern Alaska, from the rich Beringian flora of western Alaska.

(5) Within these broad zones and sectors, regions of dominant vegetation can be delineated based on physiographic features, large landforms, and disturbance features. It may be possible to define a circumpolar set of terrain types that could be used to stratify the satellite-derived data. Boundaries separating the coastal strip, thaw-lake plain, foothills, and mountains are relatively easy to draw.

(6) We should consider making two circumpolar vegetation maps: one derived from AVHRR data portraying seasonal biomass production, and another derived from photo-interpretation and synthesis of existing maps that portrays dominant vegetation types.

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Table 1. Comparison of moist acidic and non-acidic tundras (Walker and Acevedo, 1987).

	Unit				
	IIIa **Moist non-tussock-sedge, dwarf-shrub tundra**	***IIIb*** **Moist tussock-sedge, dwarf-shrub tundra**	***IVa*** **Moist tussock-sedge, mixed-shrub tundra**	***IVb*** **Moist non-tussock-sedge, mixed-shrub tundra**	***Vb*** **Moist low-shrub tundra**
Character					
Soil pH	Neutral to alkaline	Slightly alkaline to slightly acidic	Acidic	Acidic	Acidic
Cryoturbation	Generally high	Moderate	Moderate to low	Low to moderate	Low
Soil flow (solifluction)	Low to moderate	Low	Low	Moderate	Low to moderate
Occurrence near coast (north of 7 °C July mean isotherm)	Common on mesic sites	Occasional on stable sites	Rare	Absent	Absent
Occurrence inland	Mesic stream banks and frost-active slopes	Moderately frost-active slopes	Abundant on all mesic acidic substrates and stable sites	Slopes with moderate solifluction	South-facing slopes and stable warm upland sites
Composition (partial list of important species):					
Low shrubs (0.2–1.5 m):					
Alnus crispa	0*	0	0	0	0–4
Betula nana spp. *exilis*	0	0	3	3	3–4
Ledum palustre spp. *decumbens*	0	0–2	3	3	3
Salix glauca	0	0–2	1	1	3
S. lanata ssp. *richardsonii*	0–2	0–2	1	1	2
S. pulchra†	0	0	3	3	3–4
Vaccinium uliginosum	0	0–2	3	3	3
Dwarf shrubs (< 0.2 m):					
Dryas integrifolia	3	3	1	1	2
Rubus chamaemorus	0	0	2–3	2–3	2–3
Salix arctica	3	3	1	1	2
S. pulchra†	0–3	2	3	3	3
S. reticulata	3	3	1	1	3
Vaccinium vitis-idaea	0	1	3	3	3
Graminoids:					
Arctagrostis latifolia	2	2	1	1	1
Carex aquatilis	0–3	1	0	0	0
C. bigelowii	3	3	3	3–4	2
Eriophorum angustifolium	3–4	3	0–3	0–2	2
E. vaginatum	1	3–4	3–4	0–2	2
Bryophytes:					
Aulacomnium palustre	2–3	2–3	3	3	3
Dicranum spp.	0–3	0–2	3	3	0–3
Ditrichum flexicaule	0–3	0–2	1	1	1
Hylocomium splendens	0–3	3–4	3–4	3–4	3–4
Polytrichum juniperinum	0–3	0–2	3	0–3	3
Ptilidium ciliare	0–2	0–3	0–3	0–3	0–3
Sphagnum spp.	1	1	2–4	2–4	2–4
Tomenthypnum nitens	2–4	2–4	2	0–3	1
Lichens:					
Cetraria cucullata	3	3	3	3	2–3
C. islandica	3	3	3	3	2–3
Cladina arbuscula	0	0–2	2–3	2–3	2–3
C. rangiferina	0	0–2	2–3	2–3	2–3
Dactylina arctica	3	3	3	3	2–3
Peltigera aphthosa	2	2	2–3	2–3	3
Thamnolia subuliformis	3	2–3	0–2	0–2	0–2

* 0 = absent; 1 = rare; 2 = occasional; 3 = frequent to abundant; 4 = dominant within the respective canopy layer.
† *S. pulchra* is listed as a dwarf shrub and a low shrub; near the coast it is prostrate; inland it grows up to 2 m tall.

Table 2. Hierarchic vegetation classification for the Toolik Lake and Imnavait Creek region. The community names are composed of two six letter taxa abbreviations, each of which includes the first three letters of the genus name and the first three letters of the species names (Walker and Walker, 1994).

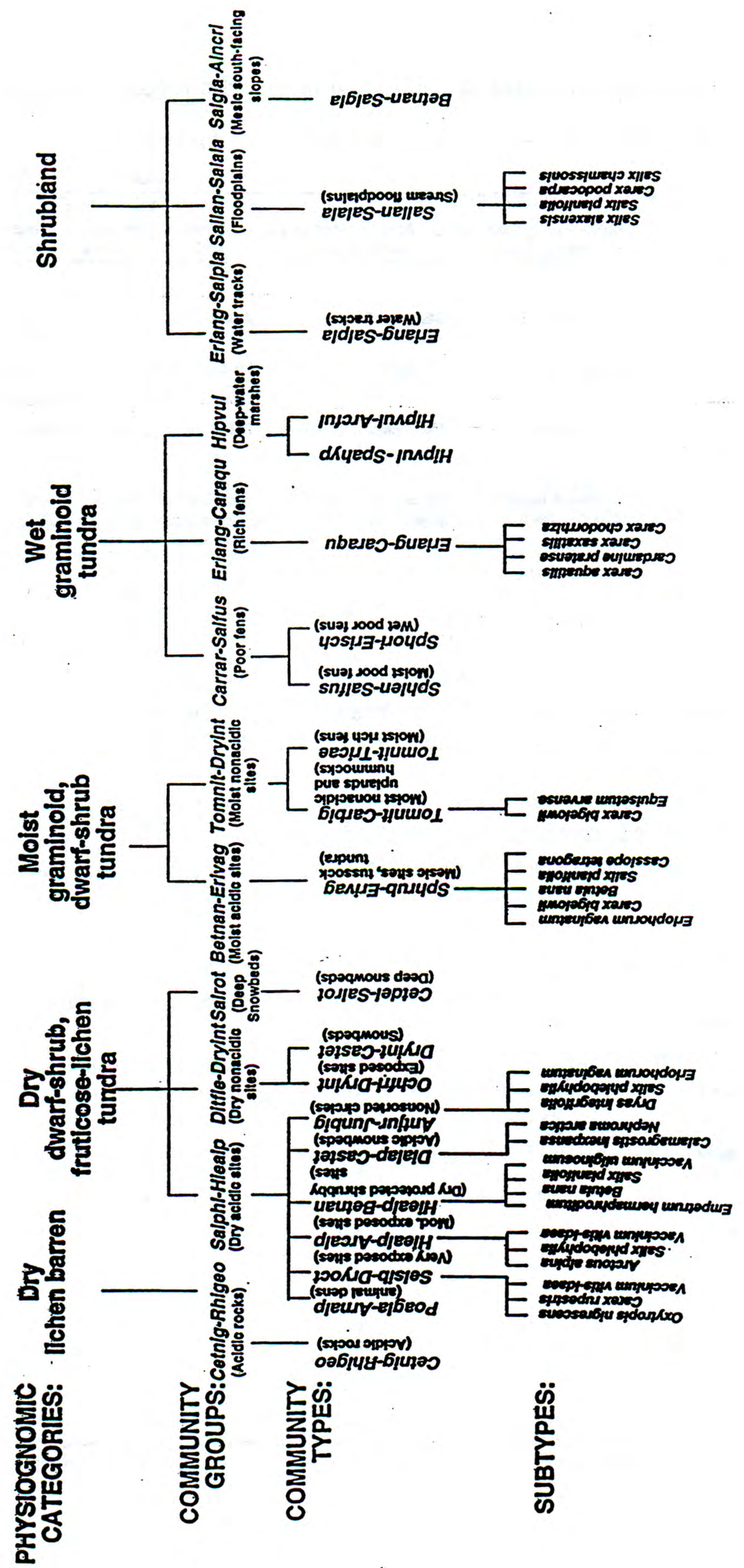


Figure 1. Distribution of NDVI on three different age glacial surfaces (a) in northern Alaska (approximate de-glaciation dates: Itkillik II, 11.5 ka; Itkillik I, 60 ka; Sagavanirktok, 125 ka.). NDVI vs. time since de-glaciation (b). The reasons for this biomass-age correlation are complex and are thought to be due in part to the evolution of drainage networks (extensive willow shrublands in the stream channels and water tracks on older surfaces) and the development of moss carpets on upland sites that increase the water-holding capacity of the soils and the occurrence of deciduous shrubs. This same approach could be used to examine the relationship between NDVI and other natural disturbances such as age of floodplain terraces and effects of loess (Walker and others, in prep.).

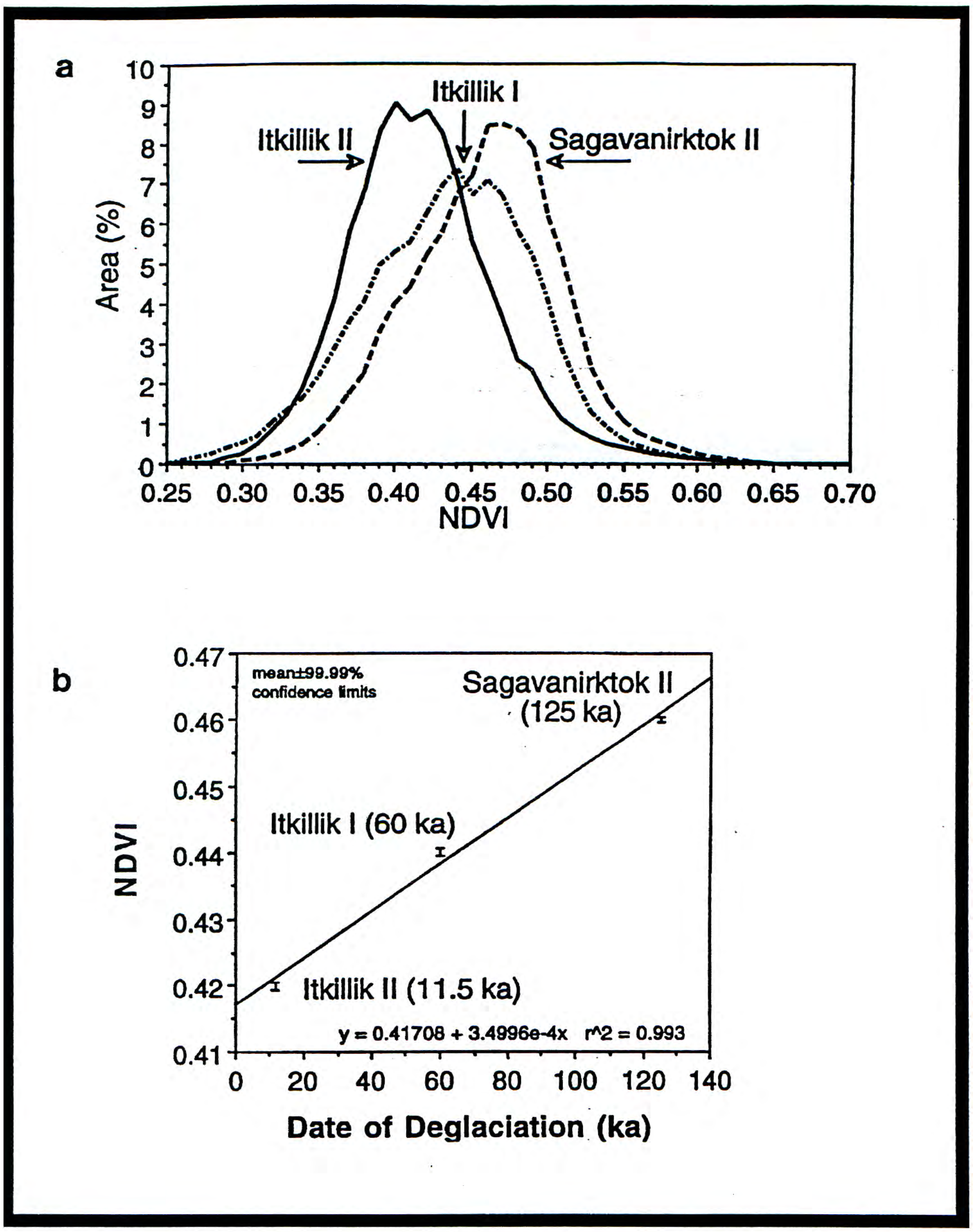
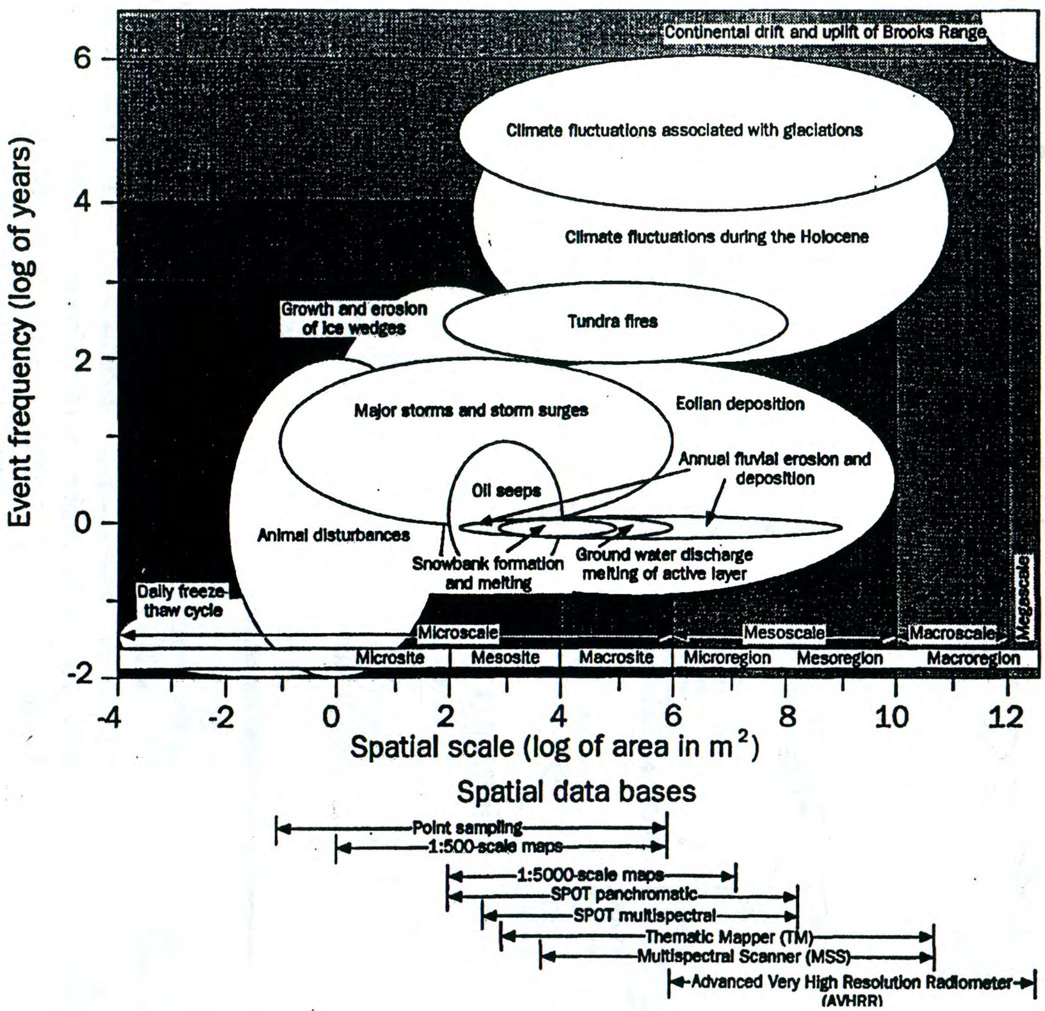


Figure 2. Spatial and temporal scales of natural disturbances in northern Alaska. Scales of various data collection methods are shown along the x-axis. The lower scales (left arrows) are the minimal sample area, or pixel size, of each sensor. The upper limit (right hand arrows) are the size of a standard image. Disturbances relevant for a circumpolar vegetation map at 1:5,000,000 are those of meso-region to macro-region size: climate fluctuations associated with glaciations, Holocene glaciations, eolian deposition, and fluvial erosion of the larger floodplains (Walker and Walker, 1991).



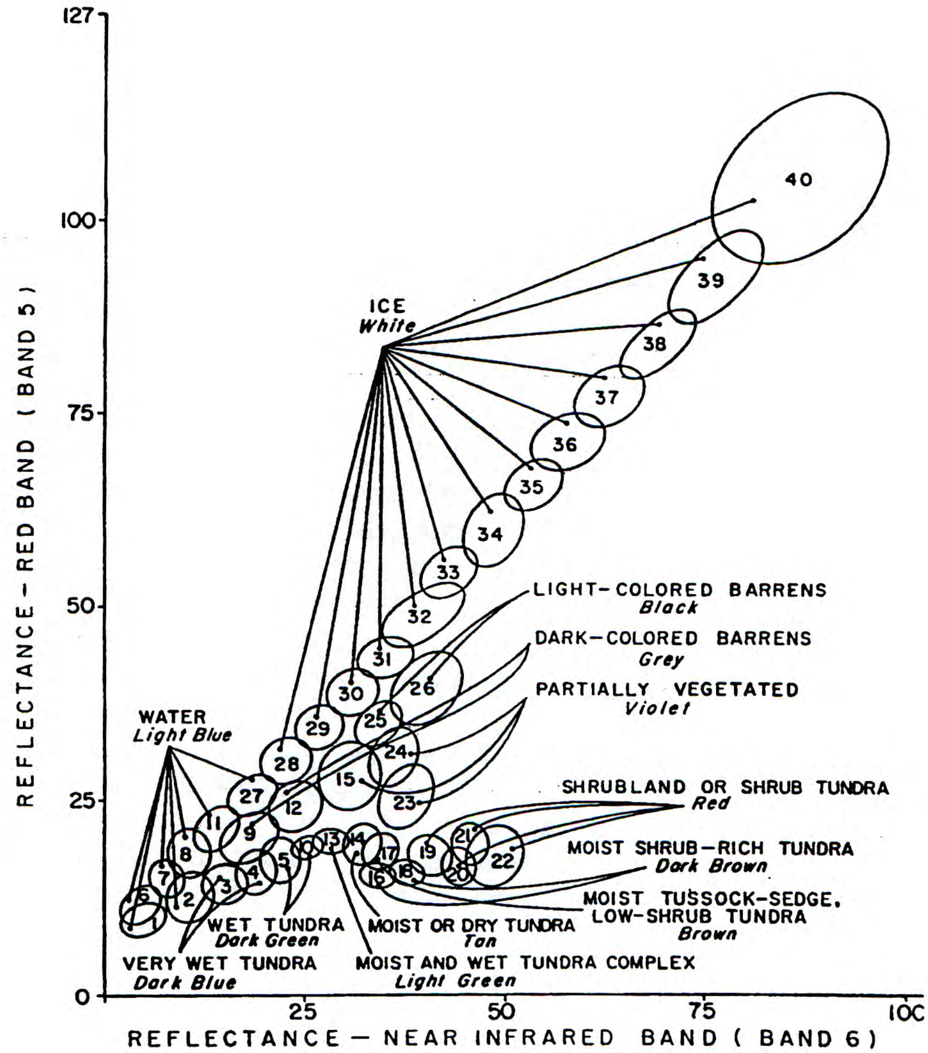


Figure 3. Cluster diagram for classification of the Beechey Point Quadrangle, Alaska. Each cluster represents a group of pixels with a range of reflectance values in the red and infrared bands. The pixels assigned to each cluster can be displayed independent of the other pixels. The dominant vegetation in each cluster was determined either from aerial photographs or from ground observations. A vegetation type was then assigned to each cluster. Similar patterns of clusters occur for all the tundra regions we've examined. Most of the vegetation types fall along an arc of clusters, whereby the left-hand portion of the arc consists of vegetation types that have increasing amounts of open water (open water at the extreme left, followed by aquatic vegetation an pond complexes, wet tundra, moist/wet complexes, moist tundra, and dry tundra: clusters 2-5, 10,13, and 14). At about the mid-point of the arc the vegetation types begin having increasing percentages of deciduous shrub vegetation. Deciduous shrubs have high absorption in the red band and high reflectance in the infrared band, such that further to the right along the arc, the vegetation is increasingly dominated by shrubs (tussock tundra, followed by shrub-dominated tussock tundra, and true shrublands on the far right; clusters 17-22; Walker and Acevedo, 1987).