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Circumpolar geobotanical mapping: A web-based plant-to-planet approach for vegetation-change analysis in the Arctic

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Introduction

Vegetation maps of entire global biomes are needed for a wide variety of issues related to international development, climate change, and education. Maps that are made and accepted by the global vegetation-science community are required at several scales and should be accessible and easily used by students, scientists, land managers, and private industry in all countries. The worldwide web makes it possible to provide maps and digital data in a variety of formats, along with ancillary background and explanatory material.

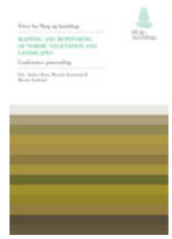
A new «plant-to-planet» Toolik-Arctic Geobotanical Atlas (T-AGA) (http: //www.arcticatlas.org/) was designed to meet research and site management needs at the Toolik Field Station in northern Alaska. The ideas may prove useful for groups such as the Nordic countries that desire a more international approach that makes cross-border studies and applications easier. At the heart of the T-AGA is the desire to develop techniques for the worldwide vegetation-science community to map other entire biomes and eventually the whole Earth with a coordinated international approach.

The T-AGA hierarchy of maps

The atlas currently presents seven different scales of maps from the circumpolar Arctic down to 1 x 1-m plots (Figure 1). The T-AGA provides maps and information mainly for the Circumpolar Arctic, Arctic Alaska and the region around Toolik Lake, Alaska. The atlas is still in progress, but the intent is to eventually provide many more maps produced by the first author and many collaborators during 35-years of research in northern Alaska and circumpolar Arctic, including maps for the International Biological Programme Tundra Biome at Barrow (Walker 1977) the Prudhoe Bay Geobotanical Atlas (Walker et al. 1980), the Kuparuk River watershed (Muller et al. 1998), North Slope mapping (Muller et al. 1999), the Circumpolar Arctic Vegetation Map (CAVM) (CAVM Team et al. 2003), Arctic Alaska Tundra Map (Raynolds et al. 2006) and a hierarchy of maps developed for research at Imnavait Creek (Walker & Walker 1996) and Toolik Lake (Walker & Maier 2008).

There are four key aspects of the hierarchy of maps: (1) The «geobotanical mapping approach» provides information on a wide variety of variables important to vegetation at all scales. The geobotanical mapping methods were developed in the late 1970s at Prudhoe Bay, AK in recognition of the key role that landforms and parent material play in the spatial distribution of plant communities (Everett et al. 1978, Walker et al. 1980). The approach is similar in principal to a variety of other landscape-guided and integrated terrain-unit mapping approaches, whereby landforms are used to guide the delineation of map-polygon boundaries, and the map polygons are coded with a variety of independent geobotanical attributes (Zonneveld 1988, Dangermond & Harnden 1990). The GIS databases at most scales of the T-AGA hierarchy include dominant and subdominant vegetation, surface geomorphology, glacial geology, landforms, water cover, topography derived from digital elevation models, and NDVI. (2) The Braun-Blanquet approach is the standard for plant community nomenclature where ever possible. This system provides plant-community names that are widely accepted worldwide. (3) Detailed descriptions of all units are linked to field information from permanent

Mapping and Monitoring of Nordic Vegetation and Landscapes
Anders Bryn, Wenche Dramstad, Wendy Fjellstad



Viten fra Skog og landskap 1/2010

plots with further links to important literature, photographs, and other supporting data, including photos and descriptions of all plant species mentioned in the atlas. (4) Standardized map legends and color systems make comparison and extrapolation between map scales and regions easier.

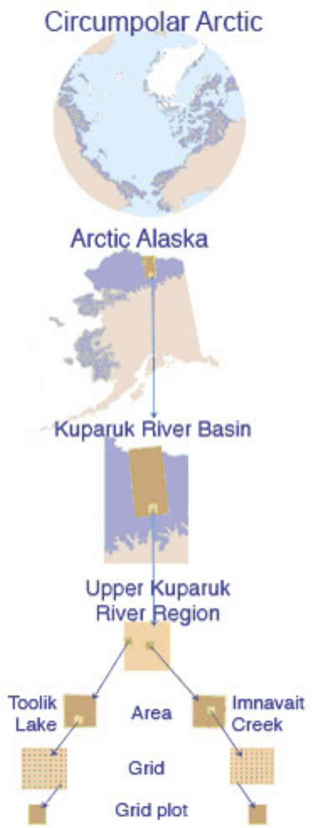


Figure 1: Hierarchy of map areas in the T-AGA.

This paper focuses on maps developed for the circumpolar Arctic and the Toolik Lake area to illustrate how the map hierarchy (Figure 1) is being used to address questions related to a multi-scale analysis of Arctic climate change. This is part of the «Greening of the Arctic» project of the International Polar Year (http: //www.alaska.edu/ipy/news/AGUWalker.xml, http: //classic.ipy.org/development/eoi/details.php?id=569#TOP),

Circumpolar and the Alaska Arctic vegetation maps

The CAVM is the result of an international 13-year effort that required considerable collaboration and compromise among the circumpolar countries to reach the final product (CAVM Team et al. 2003, Walker et al. 2005). The CAVM GIS database includes circumpolar maps of vegetation, bioclimate subzones, floristic subprovinces, substrate pH, landscape types, topography, wetlands, and plant biomass. The vegetation map was published at 1: 7.5 M scale (CAVM Team 2003) and the rationale, review of previous maps, methods, and analyses are presented in several papers (Walker 1995, Walker et al. 1995b, Walker 1999, Walker et al. 2002, Walker et al. 2005).

At the global scale the CAVM is proving to be a useful tool for a wide variety of scientific applications related to Arctic change analysis. Several recent papers have analyzed the spatial distribution of circumpolar vegetation and biomass with respect to variables in a circumpolar Arctic GIS database, including Arctic land temperatures permafrost distribution, lake cover, parent material pH, and glacial history (Raynolds et al. 2008, Raynolds & Walker 2008, Raynolds 2009, Raynolds & Walker 2009). The analysis found that land temperatures and glacial history are by far the most important variables affecting the fraction of photosynthetically active radiation recorded by satellite sensors and expressed as the Normalized Difference Vegetation Index (NDVI).

The 27-year record of NDVI derived from the NOAA AVHRR sensors (Tucker et al. 2005) is now being analyzed with respect to changing sea-ice and land-temperature conditions (Bhatt et al. 2008b, a, Bhatt et al. 2009a, Bhatt et al. 2009b). The study found that sea-ice concentrations in the 50-km coastal strips of 14 Arctic seas are strongly correlated with tundra summer land temperatures and NDVI of the tundra areas south of these strips. Another finding from this study shows that some of the largest percentage changes in NDVI are occurring in

North America and in the coldest parts of the Arctic. A newly funded study will examine the atmospheric and oceanic circulation patterns that underlie the observed patterns of NDVI and land temperature change.

Another important derived set of products from the CAVM is a 1: 4-M scale vegetation map and GIS of Arctic Alaska (Raynolds et al. 2005, Raynolds et al. 2006). The vegetation map utilizes the underlying plant-community data of the CAVM to transform the 15 physiognomic vegetation units of the CAVM into 33 more detailed units. The map provides detailed information regarding the literature sources behind the vegetation units displayed on the map. A table on the back of the map presents the major plant communities that have been described in the literature for each combination of bioclimate subzone, floristic subprovince, parent material pH class, and mesotopographic position in Arctic Alaska (Raynolds et al. 2006).

Another map of the Kuparuk River watershed was used for extrapolating a wide variety of plot- and landscape-level research involving measurement of plant productivity, soil-carbon storage, trace-gas fluxes and active-layer depths to an entire large river watershed (Hobbie et al. 1998, Nelson et al. 1998, Ping et al. 1998, Reeburgh et al. 1998).

Regional-, landscape-, and plot-level maps of the Toolik Lake region

A new set of maps at three scales in the Toolik Lake region provides information for a variety of studies at this Arctic observatory (Walker and Maier 2008). At the regional level, the upper Kuparuk River basin (850 km^2), was mapped at 1: 25,000 scale (published at 1: 63,360 (1 inch = 1 mile, a standard mapping scale in the US). The resulting GIS database has been used for a wide variety of studies including a regional analysis of methane emission (Shippert 1997); extrapolation of biomass and NDVI measurements from plot studies to large regions (Shippert et al. 1995) and analysis of the role of glacial-surface age in biomass patterns (Walker et al. 1995a, Munger et al. 2008, Walker et al. 2009 submitted). Most recently repeat Landsat images have been used to examine where changes in plant production have been occurring most rapidly in the Toolik Lake region (Munger 2007). These studies indicate that changes between 1985 and 1999 were focused in areas of disturbance, especially along roads where dust and altered hydrology occur. Other areas of change occurred in the research areas at Toolik Lake, possibly due to the concentrated activities of field researchers, and on south-facing slopes with shrubby water tracks.

At the most detailed-level, a new set of maps depicts the baseline at 85 grid points of the 1.2 x 1.1-km Toolik Lake Grid. Permanent 1 x 1-m plots at each grid point were sampled in 1990 for monitoring changes to the vegetation (Walker et al. 2009, this volume). A similar dataset is in progress for the nearby Imnavait Creek grid. A methodology developed for the International Tundra Experiment (ITEX) permits near-exact repositioning of the frame for long-term monitoring (Walker 1996). Maps of each plot portray the height of the plant canopy, microrelief of the soil surface, and the species composition of the top and bottom layers of the plant canopy. The plots are monitored every 6 years using the same methods. Dr. Bill Gould and his students are currently monitoring the plots. Large changes occurred between 1990 and 2008. Average plant canopy height at each point increased by a factor of 3; shrub cover and graminoid cover increased, while moss cover decreased.

Conclusion

The Toolik-Arctic Geobotanical Atlas is still a work in progress. Eventually it will consolidate over 35 years of geobotanical mapping in northern Alaska and the circumpolar Arctic and will make the data available in an easily accessible format via the worldwide web. It has proven to be a useful tool in many studies including multi-scale analyses associated with the on-going «Greening of the Arctic» project and long-term monitoring of vegetation changes as part of the ITEX project. The approaches developed at Toolik Lake and the Arctic would be even more useful if extended to other Arctic observatories and to areas south of the Arctic tree line. A new initiative for mapping the circumboreal forests using similar methods is currently in the planning phase (http: //www.arcticportal.org/en/projects/cbvm) (Talbot 2008).

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