Final Report for "A web-based multi-scale Arctic Geobotanical Atlas (AGA) for the Toolik Lake Field Station, Arctic Alaska, and the Circumpolar Region."

By D.A. Walker, H.A. Maier, E.M. Barbour, and M.K. Raynolds

Overview: goals of the project, and present status

The central goal of this project was to develop a web-based multi-scale *Toolik-Arctic Geobotanical Atlas* (T-AGA) for the Toolik Lake Field Station, the North Slope of Alaska, and the circumpolar region. The T-AGA includes a framework set of geobotanical map themes (vegetation, soils, landforms, surface geomorphology, geology, hydrology, and topography). For the most part the goals of the project were achieved although we are continuing working on some aspects described below, primarily the Google Earth interface and the detailed descriptions of some of the map units.

The maps span plant to planet scales — seven scales in all. The map themes, map legends, and map colors are consistent across map scales. Prior to the T-AGA these were only available as hard copy maps or by ftp of data files. The web site makes all the maps and data available in a variety of formats. The T-AGA is part of an envisioned circum-Arctic GIS network and Arctic atlas that are currently underdevelopment by the University of the Arctic and Conservation of Arctic Flora and Fauna. The current version of the T-AGA can be viewed at http://www.arcticatlas.org/.

Year 1 activities:

1. Web-site design and developing the GINA Map Server component as a means to visualize the maps and do simple analyses. (See the draft web site at: http://www.arcticatlas.org/
2. Development of the Circumpolar Arctic Vegetation Map component of the Atlas. index.shtml.)
3. Text to describe the various map themes (vegetation, bioclimate subzones, floristic subprovinces, etc.) and map units (e.g each vegetation type, and floristic province.)
4. A Swathviewer component allows the user to visualize the circumpolar data set on a rotating globe and select portions of the map for more detailed analysis.
5. On going activities include: (a) development of an EarthSLOT component that will provide an overflight of the bioclimate subzones in North America with stops at key sites to see the typical vegetation and terrain; (b) development of the Bibliography links, and a photo gallery.

Year 2 activities:

1. Completion of the *Arctic Alaska Tundra Vegetation Map* component of the Atlas(http://www.arcticatlas.org/atlas/aatvm/index).
2. Completion of the bibliography web page (literature cited on the maps) http://www.arcticatlas.org/biblio/cites/index.shtml.
3. Development of the Supporting Data web page (PDF images and GIS data) http://www.arcticatlas.org/support/index

4. Development of the Photo and Image Library
    (a) list of photos and images from the CAVM and the AATVM
    http://www.arcticatlas.org/photos/index
    (b) up to five photos of each plant species, in progress (still adding information and photos);Nonvascular Plants:
    http://www.arcticatlas.org/photos/pltspecies/nonvascular
    Vascular Plants:http://www.arcticatlas.org/photos/pltspecies/vascular
5. Completion of web pages to describe:
    (a) Vegetation Units in the CAVM,
    http://www.arcticatlas.org/atlas/cavm/cavmvg/index
    (b) Bioclimate Subzones in the AATVM,
    http://www.arcticatlas.org/atlas/aatvm/aatvmbz/index
    (c) Vegetation Unit in the AATVM,
    http://www.arcticatlas.org/atlas/aatvm/aatvmvg/index
6. Upgraded web server software and installed PHP (allows server side scripting) software on web server.
7. Created PHP applications that allow the web server to extract species and photo information from databases (applications allow the server to create dynamic web pages and respond to user queries).
8. Created VBA application that allows the GIS to generate legends using the colors and descriptions from an exported data file.
9. GINA Map Server component delivers dynamic maps and GIS products via the web, including data sharing between multiple sites. Allows the user to access GIS data to create custom maps and perform GIS analyses
10. Presented Arctic Atlas and Arctic Alaska posters at ESRI International User Conference.
11. Provided updated map data to GINA.

Year 3 activities:
Major focus was completion of a new hard-copy map entitled 'Geobotanical Maps in the vicinity of the Toolik Lake Field Station, Alaska' and incorpoation of the data into the web site. In addition, effort has been directed at a new guidebook of the Dalton Highway as part of the Ninth Internatinoal Conference on Permafrost (NICOP).

1. Hard copy maps of three areas within the Toolik Lake/Kuparuk River region were created (Upper Kuparuk River Region (751 km^2 area mapped at 1:25,000 scale), Toolik Lake region (20 km^2 area mapped at 1:5000 scale), and Toolik Lake Grid (1.1 km^2 area mapped at 1:500 scale). These are being published as a hard copy maps as part of the University of Alaska Biological Papers series (Walker and Maier, in prep.).
2. The infomation from above maps are in the process of being included in the web-based *Arctic Geobotanical Atlas*. All the map units are described (with photos) and linked to the legends on the maps. Photos of all plant species mentioned on the maps are linked to the legends and unit descriptions. Maps and raw data are being made available on line. All supporting maps and metadata are being digitized. Maps of many other themes (landforms, surficial geomorphology,

water cover, glacial geology, satellite imagery) are being included in the on-line data base.

3. Supporting data from the Imnavait Creek Data Report (Walker et al. 1987)and Toolik Data Report (Walker and Barry 1991)were formatted electronically and added as supporting information., http://www.arcticatlas.org/support/index). All vegetation plots are shown on maps and linked to the soils, plant, and site information, and photos of each plot.

4. The plant photo database has been greatly expanded.

5. The maps and GIS database have been presented at several conferences and workshops including:

(a) The 2006 Arctic Science Conference, Arctic AAAS Division Meeting, University of Alaska Fairbanks, Fairbanks, Alaska, October 2-4, 2006.

(b) 26th Annual ESRI International User Conference, August 7-12, 2006, San Diego, CA.

(c) 41st Alaska Surveying and Mapping Conference, 19-23 March 2007, Westmark Hotel, Fairbanks, AK

(d) Fourth International CAFF Flora Croup Workshop, 15-18 May 2007, Tórshavn, Faroe Islands.

(e) Ninth International Conference on Permafrost, Fairbanks, AK, 29 Jun-3 Jul 2008, Abstract accepted.

Year 4 (no-cost extension) activities:

1. <u>Publication of Toolik Lake maps</u>: A hierarchy of Toolik maps are included on a 2-sided map publication entitled *Vegetation in the Vicinity of the Toolik Field Station, Alaska* (Walker and Maier 2008). These maps were the main ones that had not been previously published and were a critical step for making the Atlas. These maps will now be included in the Atlas and are a template for other maps at similar scales that will be included from Toolik Lake and Imnavait Creek. The publication took much longer than anticipated because of difficult issues matching the colors from our plotter with those of publisher. These issues have been overcome, and the map is now in press as part of the IAB Biological Paper series and as part of a book that will describe the research at the Arctic LTER site at Toolik Lake. The difficulties prevented progress on several other aspects of the atlas and were partially responsible for our needing another no-cost extension to complete the proposed work.

2. <u>Ninth International Conference on Permafrost (NICOP)</u>: Two papers and a field trip were conducted as part of NICOP meeting (Fairbanks, AK, Jun 29- Jul , 2009). Much of this work will find its way into the *Arctic Geobotanical Atlas* as explanatory material for the Dalton Highway portion of the Atlas.
    a. Two papers related to the Arctic Geobotanical Atlas were presented at the conference (Raynolds and Walker 2008, Munger et al. 2008).
    b. 45 conference attendees participated in a five-day pre-conference field trip that was led by D.A. Walker. A 117-page *Dalton Highway Field Trip Guide for the Ninth International Conference on Permafrost* (Walker et al.

2008d) is in press at the State of Alaska Geological and Geophysical Surveys.

3. Corinne Munger M.S. thesis: Corinne Munger completed her M.S. thesis entitled "Spatial and temporal patterns of vegetation, terrain, and greenness in the Toolik Lake and Upper Kuparuk River region" (Munger 2007). Several of the maps and explanatory text will appear in the Arctic Geobotanical Atlas and a chapter in the Arctic LTER book (Walker et al. 2009 submitted).

4. Contribution to the University of the Arctic "Arctic Atlas": The *Arctic Geobotanical Atlas* will be a major contributor to *Arctic Environmental Atlas*, a project initiated by the University of the Arctic in collaboration with UNEP Grid-Arendal. Discussions during three meetings during the past year have resulted in the development of a broad framework for two major contributions: (1) a project focused on the Toolik Lake Field Station and the science at the station, and (2) a project focused on the Yamal Peninsula where we are also developing maps and products that will eventually be part of the T-AGA. The UArctic team has scheduled a launch of the Arctic Atlas for January 2009.

5. CircumBoreal Vegetation Map (CBVM): A new initiative was launched to develop a vegetation map of the global boreal forest that will be compatible with the Circumpolar Arctic Vegetation Map (CAVM). Current maps of the boreal biome do not rely on a unified international method for classifying and mapping boreal vegetation. By recognizing the boreal region as a single geo-ecosystem with a common set of cultural, political and economic issues, the CBVM project will be the first detailed vegetation map of the entire global biome. Such a map is needed for a wide variety of purposes related to resource development, land-use planning, studies of boreal biota and biodiversity, education, anticipated global changes and human interaction. A circumboreal vegetation map will have numerous other application uses for boreal scientists and managers such as impact studies on wildlife and feedback mechanisms in models or increased emission of greenhouse gases. The CBVM will also contribute to global efforts to improve understanding and communication with policy-makers. A secondary goal is to make the map compatible with the Circumpolar Arctic Vegetation Map (CAVM, scale 1:7,500,000) to the north. Linking these two global-scale maps is necessary because very few issues relevant to the Arctic or the boreal regions stop at tree line. For example, most rivers flowing into the Arctic Ocean have their origin far to the south of the tree line. Climate and vegetation-change models, analysis of animal migrations, roads and industrial developments, and arctic-human interaction all require maps that include both the Arctic tundra and boreal forest regions. The idea for the proposed map was launched in 2004 at the final meeting of the CAVM Team at Tromsø, Norway. Since then two major workshops in Tórshavn, Faroe Islands (May 2007) (Talbot 2008)and Helsinki, Finland (November 2008) (http://www.cbvm.org/) have further advanced the idea to the point of proposal writing. The CAVM is serving as a model for the CBVM and papers were presented at both meetings to present the broad rationale for making

the CBVM and to present the CAVM methodology as a model for the CBVM (Walker 2008). We also presented a scheme for interlinking the *Arctic Flora* with a proposed Arctic vegetation database (Kuss and Walker 2008). This work is endorsed by the Conservation of Arctic Flora and Fauna International Secretariat.

6. <u>Progress on the T-AGA web page</u>: The primary achievement for the T-AGA web site this year was the switch from a static HTML-based website to a dynamic database-driven website. Many of the pages are now based on PHP and MySQL. PHP is a scripting language that allows us to display data, drawn from a MySQL database, on a webpage. This will make it much easier to manage information that goes into the website, particularly when adding new maps or plant species, but also when making changes to existing data. It also gives us the ability to present data in multiple display formats. The database-driven website has enhanced access to the maps as well as the plant species information. New maps can be added to the website simply by adding the information to the database and putting the image files in the appropriate location on the website. The same is true of the plant species pages, especially since these are presented in two formats; one presentation is a page for a single species and the other is a list of plant photos, currently split into vascular and nonvascular pages respectively. Four student assistants were hired to assist developing the web pages and databases for the literature, photos, and maps to be included in the T-AGA web site.

7. <u>Progress on the maps to be included in the T-AGA</u>: Metadata have been embedded in all GIS data files for the Upper Kuparuk River Region, the Toolik Lake Region and the Toolik Lake Grid. Metadata updates for the Imnavait Creek data (1:500 and 1:6,000 scale) are in progress. Attribute lookup tables, legends and theme maps have been created for all themes of the Upper Kuparuk River Region, Toolik Lake Region and Toolik Lake Grid datasets. Themes include: vegetation, surficial geomorphology, surficial geology, glacial geology, soil carbon and landforms. The creation of legends and maps for the Imnavait Creek data is in progress. GINA has recently configured a Spatial Database Engine (SDE) interface to the master database server. The new SDE interface will allow multiple users and multiple applications to simultaneously access the GIS data files. The GINA MapServer will access map data directly through the SDE, eliminating the need to manually perform export and import operations when updating GIS data. The SDE interface is currently being tested by the Alaska Geobotany Center and will soon be available for testing by the Toolik Field Station GIS staff and other desktop GIS users.

Year 5 (supplemental funding) activities:

A $168K supplement was granted to finish the main part of the Atlas. The funds were requested to pay 6 mo salaries of our web page designer, Edie Barbour, and our GIS/system manager, Hilmar Maier. Some of the support was also used to pay for help from Gayle Neufeld, who is helping to reformat and include the many maps from the Toolik and Imnavait Creek hierarchy of maps. Martha Raynolds has helped to write the vegetation descriptions and layout the web pages for the maps associated with Alaska Arctic Tundra Vegetation Map.

1. GIS Data, Maps and Graphics

- Updated all theme maps using current legends and layouts for the: Circumpolar Arctic, Arctic Alaska, Upper Kuparak River Region, Toolik Lake Area and Toolik Lake Grid data sets.
- Converted updated datasets to standard graphic and GIS formats (Shapefile, TIF, PNG, PDF) and posted to the FTP and Web servers
- Updated GIS metadata for core datasets to comply with minimum FGDC standards
- Updated core datasets with most recent legends
- Converted theme datasets to KML files for use by Google Earth map server
- Updated GIS data catalog and moved to production status for access by all FTP and Web servers.
- Created draft of Imnavait Creek Area Map.
- Created draft of Toolik Lake and Imnavait Creek plot maps
- Created layouts for Google Earth
- Created poster and graphics for Iceland (and other?) meetings

2. Database Status

- GIS database tables normalized, documented in data dictionary and moved to production status:
- GIS data catalog (geobotany.agcFtpfiles)
- Literature catalog (geobotany.agcPubs)
- GIS theme lookup table (geobotany.agcThemes)
- GIS region lookup table (geobotany.agcRegions)

3. Ongoing Data Collection Maintenance

- Continued refinement and documentation of databases and and GIS data
- Developed scripts for the management and conversion of GIS data and to perform database error checking
- Developed scripts to display Toolik and Imnavait plot data.
- Created custom ArcGIS symbol set for display of plant species
- Created scripts to manipulate plot datasets and species symbol sets
- Created scripts to format species abundance tables as web pages

4. Photos for map unit descriptions, scanned images

- Terrain and Vegetation Types of the Sagavanirktok Quadrangle, Alaska. 1988.
- Scott A. Elias, Susan K. Short, Donald A. Walker, Nancy A. Auerbach. March 1996. Final report: Historical biodiversity at remote air force sites in Alaska. Department of Defense, Air Force. Legacy Resource Management Program Project #0742 Point Barrow and Barter Island Long Range Radar Sites, Alaska.
- Walker, Donald A. Illustrated surface-form and vegetation legend for geootanical mapping of the arctic coastal plain of northern Alaska. Preliminary Draft, June 21, 1985.
- Slides for Alaska Map plant communities.

5. Webpage

- Added overview page describing major sections of the Atlas
- Continuing the transition to dynamically generated webpages using MySQL database and PHP

a. Maps - map list is generated dynamically in two different ways:
    i. http://www.arcticatlas.org/maps/
    ii. http://www.arcticatlas.org/maps/catalog/
b. Photo Library - vegetation unit & bioclimate subzone webpages, images and enlargements are all generated dynamically
    i. http://www.arcticatlas.org/photos/mapunits/cpvegPhotos (CAVM veg. units)
    ii. http://www.arcticatlas.org/photos/mapunits/akvegPhotos (AATVM veg. units)
    iii. http://www.arcticatlas.org/photos/mapunits/cpbzPhotos (CAVM bioclimate subzones)
c. Photo Library - list of plant species webpages and enlargements are listed alphabetically, generated dynamically
    i. individual species webpages and photo enlargements are generated dynamically
d. Vegetation unit descriptions are generated dynamically
    i. http://www.arcticatlas.org/maps/themes/cp/cpvg (CAVM)
    ii. http://www.arcticatlas.org/maps/themes/ak/akvg (AATVM)

- Alaska Arctic Tundra Vegetation Map plant community descriptions have been added; pages are generated dynamically
    - In process of adding photos of plant communities
- In process of adding Upper Kuparuk River Region, Toolik Lake Area, and Toolik Lake Grid maps
    e. Text from published map, and map images, have been added to
        i. Upper Kuparuk River region: vegetation, false-color infrared image, glacial geology, NDVI & phytomass (need map image), surficial geology, and surficial geomorphology pages (need text for elevation, hydrology and watershed boundary, landforms, and releve locations webpages)
        ii. Toolik Lake Area: vegetation, (need text and map image for elevation, landforms, and releve locations webpages); (need text for glacial geology, surficial geology, percent water, soil carbon, and surficial geomorphology webpages)
        iii. Toolik Lake Grid: vegetation, (need text and map image for elevation, landforms, and releve locations webpages); (need text for glacial geology, surficial geology, percent water, and surficial geomorphology webpages)
- Added PDF and HTML versions of Tom Hamilton's *Glacial Geology of the Toolik Lake and Upper Kuparuk River Region*s; appendix includes dynamically generated map unit descriptions
- Supporting Data section now includes the Toolik and Imnavait Creek data reports; includes data tables from both reports
    f. One table still needs to be proofread (IC Table 4, Environmental Variables)
    g. Need to finish making downloadable PDF, Excel, and .txt files for all the data; add to database and then to website

- In process of making map images, GIS data, pdfs available (link from appropriate symbols) for theme pages
- Database is continually being updated and streamlined for efficiency and speed

6. ***Ph.D. thesis completion of Martha Raynolds***
   Martha Raynolds completed her PhD in Geobotany in August 2009. Her thesis titled "A geobotanical analysis of circumpolar arctic vegetation, climate, and substrate" (Raynolds 2009) was published in a series of papers, the last of which is being submitted in March 2010 (Raynolds et al. 2006a, Raynolds et al 2008, Raynolds et al. 2009, Raynolds et al. 2010 in prep.) Martha Raynolds worked closely with Edith Barbour on the web presentation of the Alaska Arctic Tundra Vegetation map (Raynolds et al. 2006b). She attended the Second Yamal Land-Cover Land-Use Change Workshop held at the Arctic Centre, Rovaniemi, Finland, 8-10 March 2010 and presented an analysis of trends in satellite measures of temperature and vegetation for the Yamal Peninsula and the circumpolar Arctic. This analysis used the CAVM, data from her thesis, and the most recent AVHRR satellite data sets for land surface temperature and NDVI. Most recently she presented a paper at the Circumboreal Mapping Workshop in Helsinki, Finland 12-14 March 2010, where she described the process of synthesizing map information from all the circumpolar countries to produce the Circumpolar Arctic Vegetation Map.

Scientific findings:

The data in the T-AGA are being used for a wide variety of circumpolar, regional, and local analyses. Four examples are presented here:

a. At the <u>circumpolar scale</u>, the Arctic bioclimate subzones and vegetation maps are being used in combination with the land-surface-temperature (LST) and normalized-difference-vegetation Index (NDVI) data to understand the relationship between climate and existing vegetation and production patterns in the Arctic. The analyses have shown that at the circumpolar scale, there is a strong non-linear relationship between vegetation greenness and LST (Raynolds et al. 2006a, Raynolds et al. 2006b, Raynolds et al., Raynolds et al. 2008a, Raynolds et al. 2008b). The circumpolar patterns of NDVI are also strongly affected by a variety of other considerations such the age of landscapes (Raynolds and Walker 2008 in press), permafrost distribution (Raynolds and Walker 2008) abundance of water bodies and rocks, and the soil types, such as acidic and nonacidic soils (Raynolds et al. 2006b). Atmospheric and ocean circulation patterns also affect local NDVI patterns, and the patterns is closely tied the distribution of coastal arctic sea ice (Walker et al. 2008a, Bhatt et al. 2010 in revision, Walker et al. 2009). This work is the Ph.D. research of Martha Raynolds, who completed her degree in 2009.
b. At the <u>regional scale</u>, the vegetation map of the upper Kuparuk River region was used to analyze the spatial relationships of the vegetation and vegetation greenness (as measured by the Normalized Difference Vegetation Index (NDVI)) in relation to the surficial geomorphology and glacial history of the region (Munger et al. 2008). The study also examined the temporal changes in vegetation greenness during the period 1985-2002 (Munger 2007). The spatial

analyses found that there is progression of increasing greenness (and hence greater amounts of biomass) with landscape age. The oldest surfaces (Sagavanirktok-age, deglaciated at least 125,000 years ago) had average NDVI values of 0.530 compared to 0.509 for the Itkillik I surfaces (deglaciated about 53,000 years ago) and 0.492 for the Itkillik II surfaces (deglaciated about 11,500 years ago). The older surfaces had more hill-slope water tracks with shrubby vegetation that contributed to higher NDVI values. The younger surfaces had more abundant nonsorted circles and nonacidic tundra with few shrubs that contributed to the relatively low NDVI values. Previous remote-sensing analyses of temporal NDVI changes have used much coarser-scale AVHRR data with 8-km resolution. The new temporal Landsat analysis provides much more detailed information regarding where the changes are occurring on landscapes. These studies were part of the research of Corinne Munger, who completed her Masters Thesis in 2007.
These data are now being reanalyzed with the availability of more Landsat scenes and an analytical method that calculates time series trends for every pixel in the region (Raynolds et al. 2010). The results indicate that most of the landscape did not show significant change between 1985 and 2009 (+3.2% overall increase in NDVI). The greatest changes were in areas associated with anthropogenic disturbance and areas that appear to be affected by thermal erosion features, such as landslides and thermally eroded gullies (up to +14% change). Field work in summer 2011 will examine these areas in more detail. The results are also being compared with local data from the 8-km-resolution circumpolar analysis that utilized the AVHRR GIMMS 3g data set (Walker et al. 2010). Preliminary results indicate that the GIMMS 3g trends are much greater (14% overall increase) than those detected with Landsat (3.2% change). This suggests that there may be problems in the calibration of the GIMMS 3g data set.

c. At the plot scale, map data of vegetation, snow, active layer, and biomass were used to examine the complex relationships between patterned ground, climate, vegetation, and soils. The analysis included 20 sites located along an 1800-km north-south transect through all five Arctic bioclimate subzones in North America. The maps document the gradients of patterned ground morphology, vegetation, active layer depths, and snow cover that occur on zonal sites along the climate gradient. Small non-sorted polygons are dominant in north; larger nonsorted circles are dominant in middle part of the gradient, and large hummocks are dominant in the south. Principal components analysis revealed underlying relationships between patterned-ground landscapes and measured vegetation and environmental variables. Climate in combination with the vegetation is the most important factor affecting patterned ground on zonal sites, but soil moisture, texture and chemistry were also important. The maps and analyses clearly illustrate the important controls that vegetation have on a wide variety of physical processes related to patterned-ground formation and critical ecosystem processes such as soil-carbon sequestration and the annual freezing and thawing of the active layer. This work was part of a multidisciplinary analysis of patterned ground that was funded by the NSF Biocomplexity in the Environment program (Raynolds et al. 2008c, Walker et al. 2008b, Walker et al. 2008c).

d. In another plot-scale dataset, maps depict the baseline plant species and structure information at 85 1-m^2 plots in the 1.2 x 1.1-km Toolik Lake Grid and 72 plots in the nearby Imnavait Creek grid.. Permanent plots at each grid point were sampled in 1989 and 1990 for monitoring changes to the vegetation (Walker et al. 2009). Dr. Bill Gould and his students are currently continuing to monitor the plots and have presented the data at ITEX and LTER conferences (Gould et al. 2008, 2009). The observations are the first quantitative results to document changes in Low Arctic zonal vegetation structure and composition. Average plant canopy height at each point increased by a factor of 3; shrub cover and graminoid cover increased, while moss cover decreased. These results demonstrate an unambiguous change to arctic vegetation that can be used to help verify the trends observed with the satellite data (Jia et al. 2003, Bhatt et al. 2010).

Other accomplishments:

The *Arctic Alaska Tundra Vegetation Map* was published, analyzed and incorporated in the T-AGA web site (Raynolds et al. 2005a, Raynolds et al. 2005b). This map is an important tool for research and management of vegetation resources at the Alaska regional level. It illustrates how the Circumpolar Arctic Vegetation Map (CAVM), which was necessarily generalized to contain only 15 physiognomic map units, can be applied to develop more detailed plant-community level maps of smaller regions. In this case, the plant community-level legend contains 33 map units and reference to over 81 tundra plant communities.

The map entitled *Vegetation in the Vicinity of the Toolik Field Station, Alaska* (Walker and Maier 2008). Maps at three scales are included on a 2-sided glossy map sheet. These maps were the main ones that had not been previously published and were a critical step for making the Atlas. These maps are now included in the Atlas and are a template for other maps at similar scales that will be included from Toolik Lake and Imnavait Creek.

A new initiative was launched to develop a *Circum-Boreal Forest Vegetation Map* (CBVM). Linking the two global-scale vegetation maps, the CAVM and CBVM, is necessary because very few issues relevant to the Arctic or the boreal regions stop at tree line. For example, most rivers flowing into the Arctic Ocean have their origin far to the south of the tree line. Climate and vegetation-change models, analysis of animal migrations, roads and industrial developments, and arctic-human interaction all require maps that include both the Arctic tundra and boreal forest regions. The idea for the proposed map was launched in 2004 at the final meeting of the CAVM Team at Tromsø, Norway. Since then workshops in Tórshavn, Faroe Islands (May 2007) (Talbot 2008), Helsinki, Finland (November 2008) (http://www.cbvm.org/), Sault Ste. Marie, Canada (November 2009) and Helsinki (March 2010) have further advanced the idea to the point of proposal writing. D.A. Walker presented papers at three meetings describing the rationale for making the CBVM and to present the CAVM methodology as a model for the CBVM (Walker 2008, 2009, 2010). We also presented a scheme for interlinking the *Arctic Flora* with a proposed Arctic vegetation database (Kuss and Walker 2008). This work is endorsed by the Conservation of Arctic Flora and Fauna International Secretariat.

The T-AGA was presented several other conferences as posters and talks: Barbour et al. 2006; Maier et al. 2006; (Walker et al. 2007b, Walker and Maier 2008, Walker et al. 2008e). The Toolik Lake site (Walker and Maier 2008) were selected for inclusion in *2009 ESRI Map Book*.The *Circumpolar Arctic Vegetation Map* (CAVM Team et al. 2003) was featured in the *2005 ESRI Map Book*: http://www.esri.com/mapmuseum/mapbook_gallery/volume20/conservation3.html. Most recently the T-AGA was presented in a keynote talk at the Mapping and Monitoring of Nordic Vegetation and Landscapes meeting, Hverager∂i, Iceland, (Walker et al. 2009).

The web site has been used as a teaching tool in Introduction to Geoinformatics (GEOS 378), and is the education/outreach component of the Greening of the Arctic IPY initiative (Walker et al. 2007a, Walker et al. 2008a).

Training and Development:
Two graduate students have used the GIS data base for their thesis research:

C.A. Munger (M.S. thesis)
M.K. Raynolds (Ph.D. thesis)

Two post-doctoral students have helped in the database and web-page development and used the atlas in their research:

P. Kuss
C. Vonlanthan

Seven undergraduate and one graduate students have been employed and trained to help in the web page design, database development, and map making:

K. Annakkah (undergraduate student)
T. Buxbaum (undergraduate student)
S. Carlson (undergraduate student)
G. Neufeld (graduate student)
K. Okano (undergraduate student)
C. Pylant (undergraduate student)
S. Vockerroth (undergraduate student)
S. Walden (undergraduate student)

Outreach Activies:
The Arctic Geobotanical Atlas is the primary education and outreach tool for the Greening of the Arctic IPY project and the Biocomplexity of Patterned Ground project. It is being used in several contexts to both examine the spatial and temporal relationships of Arctic biomass and production patterns (e.g. Raynolds, 2007, 2008 submitted; Raynolds et al. 2008 submitted, Munger and Walker 2008 submitted), and also to convey the

results of these studies to students, researchers and government entities (e.g. Barbour et al. 2006; Maier et al. 2006; Walker et al. 2007, 2008f). The University of the Arctic and the Conservation of Arctic Flora and Fauna are working with us to incorporate our web site into their circumpolar atlases.

In addition the web site has had the other following outreach activities:

1. The web site has been used as a teaching tool in Introduction to Geoinformatics (GEOS 378).
2. The T-AGA was presented at 4 conferences as posters: Barbour et al. (2006), Maier et al. (2006), Walker et al. (2007, 2008f), Walker et al. (2009).
3. The Atlas was also used for the Ninth International Conference on Permafrost (NICOP) as a means for visualizing the routes of the field trips.

References:

Barbour, E.M., H.A. Maier, D.A. Walker, A.W. Balzer, J.P. Grimes, T.A. Heinrichs, M. Nolan, P. Prokein, C.L. Pylant, M.K. Raynolds, L.M. Rogan, V.L. Sharpton, D.L. Stahlke, and S.G. Vockeroth. 2006. Arctic Geobotanical Atlas. Arctic Science Conference, Arctic AAAS Division Meeting, University of Alaska Fairbanks, Fairbanks, AK, October 2-4, 2006.

Bhatt, U.S., Walker, D.A., Raynolds, M.K., Comiso, J.C., Epstein, H.E., Jia, G.J., Gens, R., Pinzon, J.E., Tucker, C.J., Tweedie, C.E., and Webber, P.J., 2010, Circumpolar Arctic tundra vegetation change is linked to sea-ice decline: Earth Interactions, v. 14, p. 1-20.

CAVM Team, (D.A.Walker, W. A. Gould, L. C. Bliss, S. A. Edlund, M. K. Raynolds, S. C. Zoltai, F. J. A. Daniëls, C. Bay, M. Wilhelm, E. Einarsson, G. Gudjonsson, A. Elvebakk, B. E. Johansen, G. V. Ananjeva, D. S. Drozdov, A. E. Katenin, S. S. Kholod, L. A. Konchenko, Y. V. Korostelev, E. S. Melnikov, N. G. Moskalenko, A. N. Polezhaev, O. E. Ponomareva, E. B. Pospelova, I. N. Safronova, R. P. Shelkunova, B. A. Yurtsev, M. D. Fleming, C. J. Markon, D. F. Murray, and S. S. Talbot). 2003. Circumpolar Arctic Vegetation Map. Conservation of Arctic Flora and Fauna (CAFF) Map No. 1, U.S. Fish and Wildlife Service, Anchorage, AK.

Gould, W. A. , J. A. Mercado-Díaz. 2008. Twenty year record of vegetation change from long-term plots in Alaskan tundra. Eos Trans. AGU, 89(53), Fall Meet. Suppl., Abstract C11C-0524.

Kuss, P., and D. A. Walker. 2008. Project for interlinked Arctic flora and vegetation databases. Pages 63-65 *in* S. S. Talbot, editor. Proceedings of the Fourth International Conservation of Arctic Flora and Fauna (CAFF) Flora Group Workshop, Tórshavn, Faroe Islands, May 15-18, 2007. CAFF Technical Report No.15, Akureyri, Iceland.

Maier, H.A., D.A. Walker, E.M. Barbour, A.W. Balzer, J.P. Grimes, T.A. Heinrichs, M. Nolan, P. Prokein, C.L. Pylant, M.K. Raynolds, L.M. Rogan, V.L. Sharpton, D.L. Stahlke, and S.G. Vockeroth. 2006. Arctic Geobotanical Atlas. 26th Annual ESRI International User Conference, August 7-12, 2006, San Diego, CA.

Munger, C. A., D. A. Walker, H. A. Maier, and T. D. Hamilton. 2008. Spatial analysis of glacial geology, surficial geomorphology, and vegetation in the Toolik Lake region: Relevance to past and future land-cover changes. Pages 1255-1260 *in* D. I.

Kane and K. M. Hinkel, editors. Ninth International Permafrost Conference. Institute of Northern Engineering, University of Alaska Fairbanks, Fairbanks.
Munger, C. M. 2007. Spatial and temporal patterns of vegetation, terrain, and greenness in the Toolik Lake and Upper Kuparuk River region. Masters Thesis, University of Alaska Fairbanks, Fairbanks.
Raynolds, M. K., Comiso, J. C., Walker, D. A., and Verbyla, D., 2008: Relationship between satellite-derived land surface temperatures, arctic vegetation types, and NDVI. Remote Sensing of Environment, 112: 1884-1894.
Raynolds, M. K., 2009: A geobotanical analysis of circumpolar arctic vegetation, climate, and substrate, University of Alaska, Fairbanks. 260 pp.
Raynolds, M. K., Huettmann, F., Walker, D. A., and Verbyla, D., 2010 in prep.: Environmental controls of the distribution of circum-Arctic vegetation. Ecography.
Raynolds, M. K., and D. A. Walker. 2008. Circumpolar relationships between permafrost characteristics, NDVI, and arctic vegetation types. Pages 1469-1474 *in* D. I. Kane and K. M. Hinkel, editors. Ninth International Conference on Permafrost. Institute of Northern Engineering, University of Alaska Fairbanks, Fairbanks.
Raynolds, M. K. and Walker, D. A., 2009: The effects of deglaciation on circumpolar distribution of arctic vegetation. Canadian Journal of Remote Sensing, 35: 118-129.
Raynolds, M. K., D. A. Walker, and J. C. Comiso. 2008a. Spatial patterns of land-surface temperature and NDVI, and their relation to vegetation distribution on the Yamal Peninsula, Russia. Poster presented at the Carbon Cycle and Ecosystems Joint Science Workshop, 1-2 May 2008, Adelphi, MD. Abstract 365. http://cce.nasa.gov/cgi-bin/meeting_2008/mtg2008_ab_search.pl.
Raynolds, M. K., D. A. Walker, A. Kade, C. Vonlanthen, S. G. Vockeroth, C. A. Munger, and P. Kuss. 2006a. Aboveground phytomass of vegetation communities along an arctic climate gradient. Eos Trans. AGU, 87(52), Fall Meet. Suppl.:Abstract C51A-0395.
Raynolds, M. K., D. A. Walker, and H. A. Maier. 2005a. Alaska Arctic Vegetation Map, Scale 1:4 000 000. Conservation of Arctic Flora and Fauna (CAFF) Map No. 2. U.S. Fish and Wildlife Service, Anchorage, AK.
Raynolds, M. K., D. A. Walker, and H. A. Maier. 2005b. Plant community-level mapping of arctic Alaska based on the Circumpolar Arctic Vegetation Map. Phytocoenologia **35**:821-848.
Raynolds, M. K., D. A. Walker, and H. A. Maier. 2006b. NDVI patterns and phytomass distribution in the circumpolar Arctic. Remote Sensing of Environment **102**:271-281.
Raynolds, M. K., D. A. Walker, C. A. Munger, C. M. Vonlanthen, and A. N. Kade. 2008c. A map analysis of patterned-ground along a North American Arctic Transect. Journal of Geophysical Research - Biogeosciences **113**:G03S03 (p01-18).
Raynolds, M. K., D. A. Walker, D. Verbyla, C. A. Munger. 2010. Changes in tundra vegetation over 25 years as measured by Landsat NDVI in the Upper Kuparuk River Basin, North Slope Alaska, 1985-2009. Abstract GC43B-0984 presented at the 2010 Fall Meeting, AGU San Francisco, CA, 13-17 Dec.

Talbot, S. S. 2008. Proceedings of the Fourth International Conservation of Arctic Flora and Fauna (CAFF) Flora Group Workshop, May 15-18, 2007, Tórshavn, Faroe Islands. CAFF Technical Report No. 15, Akureyri, Iceland.

Walker, D. A. 2008. The Circumpolar Arctic Vegetation Map, the Alaska Arctic Tundra Vegetation Map, and the Arctic Geobotanical Atlas. Pages 60-62 *in* S. S. Talbot, editor. Proceedings of the Fourth International Conservation of Arctic Flora and Fauna (CAFF) Flora Group Workshop, Tórshavn, Faroe Islands, May 15-18, 2007. CAFF Technical Report No.15, Akureyri, Iceland.

Walker, D.A., E.M. Barbour, H.A. Maier. 2008. A Web-based Arctic Geobotanical Atlas and a New Hierarchy of Maps of the Toolik Lake Region, Alaska. Ninth International Conference on Permafrost, June 29 - July 3, 2008.

Walker, D.A., Bhatt, U.S., Raynolds, M.K., Comiso, J.E., Epstein, H.E., and Jia, G.J., 2009, The Arctic: Land: Vegetation, in Peterson, T., and Baringer, M., eds., State of the Climate in 2008, Bulletin American Meteorological Society Vol.90, Volume 90, p. S104-S105.

Walker, D.A., H.A. Maier, E.M. Barbour, A.W. Balser, J.P. Grimes, T.A. Heinrichs, M. Nolan, P. Prokein, C.L. Pylant, M.K. Raynolds, L.M. Rogan, V.L. Sharpton, D.L. Stahlke, and S.G. Vockeroth. 2007. Legacy IPY Hierarchic GIS Database for the Arctic Observatory at Toolik Lake. 41st Alaska Surveying and Mapping Conference, 19-23 March 2007, Westmark Hotel, Fairbanks, AK.

Walker, D. A., and N. Barry. 1991. Toolik Lake permanent vegetation plots: site factors, soil physical and chemical properties, plant species cover, photographs, and soil descriptions. Institute of Arctic and Alpine Research, University of Colorado, Boulder, CO.

Walker, D. A., U. S. Bhatt, and H. E. Epstein. 2008a. The Greening of the Arctic IPY Project. Eos Trans. AGU, 89(53), Fall Meet. Suppl.:Abstract U23F-05 INVITED.

Walker, D. A., H. E. Epstein, and U. S. Bhatt. 2007a. Greening of the Arctic: Synthesis and models to examine pan-Arctic vegetation change. *in* NSF ARCSS Synthesis of Arctic System Science Workshop, Oct 2008, Seattle WA.

Walker, D. A., H. E. Epstein, U. S. Bhatt, M. K. Raynolds, G. Jia, J. C. Comiso, J. Pinzon, C. J. Tucker. 2010. Greening of the Arctic: Spatial and temporal (1982-2010) variation of circumpolar tundra NDVI and aboveground biomass. Abstract GC53B-01, presented at 2010 Fall Meeting, AGU, San Francisco, CA, 13-17 Dec.

Walker, D. A., H. E. Epstein, V. Romanovsky, and C.-L. Ping. 2007b. A North American Arctic Transect: An interdisciplinary study of permafrost and patterned ground across the Arctic climate gradient. Pages 66-67 *in* Invited talk at the Arctic AAAS meeting, Partnering for Northern Futures, Anchorage, AK, 24-26 Sep 2007, http://www.arcticaaas.org/meetings/2007/2007_aaas_abstract_book.pdf.

Walker, D. A., H. E. Epstein, V. E. Romanovsky, C. L. Ping, G. J. Michaelson, R. P. Daanen, Y. Shur, R. A. Peterson, W. B. Krantz, M. K. Raynolds, W. A. Gould, G. Gonzalez, D. J. Nickolsky, C. M. Vonlanthen, A. N. Kade, P. Kuss, A. M. Kelley, C. A. Munger, C. T. Tarnocai, N. V. Matveyeva, and F. J. A. Daniëls. 2008b. Arctic patterned-ground ecosystems: A synthesis of field studies and models along a North American Arctic Transect. Journal of Geophysical Research - Biogeosciences **113**:G03S01 (p01-17).

Walker, D. A., H. E. Epstein, and J. M. Welker. 2008c. Introduction to special section on Biocomplexity of Arctic Tundra Ecosystems. Journal of Geophysical Research — Biogeosciences **113**:G03S00 (p01-05).

Walker, D. A., T. D. Hamilton, C.-L. Ping, R. P. Daanen, and W. W. Streever. 2008d. Dalton Highway Field Trip Guide for the Ninth International Conference on Permafrost. Alaska Diverision of Geological & Geophysical Surveys, Guidebook 9, Fairbanks.

Walker, D. A., T. D. Hamilton, M. D. Walker, A. Balsar, H. Maier, C. Munder, and N. A. Auerbach. 2009 submitted. Vegetation of the Toolik Lake region in relationship to glacial geology. *in* J. Hobbie, editor. Toolik Lake LTER Book.

Walker, D. A., N. D. Lederer, and M. D. Walker. 1987. Permanent vegetation plots: site factors, soil physical and chemical properties, and plant species cover. Data report for R4D Program U.S. Department of Energy.

Walker, D. A., and H. A. Maier. 2008e. Vegetation in the vicinity of the Toolik Field Station, Alaska. Biological Papers of the University of Alaska, No. 28, Institute of Arctic Biology, University of Alaska Fairbanks.

Walker, D. A., H. A. Maier, and E. M. Barbour. 2008f. A web-based arctic geobotanical atlas and new hierarchy of maps of the Toolik Lake region, Alaska. Pages 1893-1898 *in* D. I. Kane and K. M. Hinkel, editors. Ninth Internaitonal Conference on Permaforst. Institute of Northern Engineering, University of Alaska Fairbanks, Fairbanks.

Walker, D. A., M. K. Raynolds, H. A. Maier, E. M. Barbour, and G. P. Neufeld. 2009. Circumpolar geobotanical mapping: a web-based plant-to-planet approach for vegetation-change analysis in the Arctic. Keynote Talk at the Mapping and Monitoring of Nordic Vegetation and Landscapes meeting, Hverager∂i, Iceland, 16-18 September 2009:4.