Yamal LCLUC Synthesis:

A synthesis of remote-sensing studies, ground observations and modeling to understand the social-ecological consequences of climate change and resource development on the Yamal Peninsula, Russia and relevance to the circumpolar Arctic

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SUMMARY

The two primary goals of this synthesis are to 1) develop a better understanding of variations in Arctic ecological systems along the Eurasia and Circumpolar Arctic climate gradient to aid in interpretation of remotely sensed imagery and 2) develop remote-sensing tools that can be used for adaptive management that will help Arctic people, government agencies and policy makers predict and adapt to impending rapid climate change and rapid resource development. We propose to synthesize a wide variety of biophysical and social data that have been collected during five LCLUC expeditions along an 1800-km Arctic transect in the Yamal-Franz Josef Land region and from related projects on the Yamal and in Alaska conducted by collaborators. The project consists of the three science components; the first focuses on the landscape patterns of change; the second on the industrial and social aspects of change; and the third on modeling tools for predicting future landscape responses. **Component 1: Synthesis of Eurasia Arctic Transect (EAT) Data**: A major achievement during previous rounds of LCLUC funding was the completion of the Eurasia Arctic Transect (EAT) that traverses all five Arctic bioclimate subzones of the Yamal Peninsula and Franz Josef Land. Component 1 will examine the EAT data hierarchically by first developing a compendium of disciplinary papers that synthesize the vegetation, soil, permafrost, and remote-sensing information from the EAT. The results from these papers will then be used in an interdisciplinary overview paper that summarizes the main results and conclusions from the transect. We will further address science questions related to landscape and spectral-reflectance variation along the EAT in comparison to a similar transect in North America, which is much less intensively grazed, and has more loamy soils and a more continental climate. At a circumpolar scale, the results from both transects will be combined with Arctic-wide climate, sea-ice, and land temperature data to help interpret spatial and temporal variations of regional and Arctic-wide patterns of productivity as indicated by the Normalized Difference Vegetation Index (NDVI). **Component 2**: **Synthesis of Social-Ecological Data:** The consequences of rapid climate change and resource development vary with different social-ecological systems across the Arctic. This component will focus on the reindeer-herding culture of the Yamal Nenets people compared to the hunting culture of the Iñupiat people in Alaska, and changes associated with the expanding networks of oil and gas infrastructure in both regions. Project collaborators conducted social-ecological studies in these two regions primarily with funds from other sources. Both studies relied heavily on remote-sensing information to trace the history of development and for use in studies of local perceptions of change. A synthesis paper will focus on the remote-sensing aspects of these two studies. We are furthermore requesting funds to develop an Arctic-SES remote-sensing theme for an International Arctic Infrastructure and Climate Change Workshop to be held in conjunction with the International Conference on Arctic Research Planning (ICARP III). The proceedings from the conference will be used to formulate general principals of adaptive management that can be used by the local governments, industry, and policy makers to adjust to the impending rapid changes. **Component 3: Synthesis of Modeling Studies**: ArcVeg is a plot-level, tundra vegetation dynamics model that focuses on the response of a suite of common tundra plant functional types to changes in temperature and soil nutrients. The modeling component of our previous LCLUC projects helped develop the ArcVeg Model for application to questions related to climate change reindeer herding on the Yamal Peninsula. The field observations along both the NAAT and EAT were used to improve the parameterization of the ArcVeg Model. This component will synthesize the earlier studies and apply the ArcVeg model to a circumpolar synthesis. Another task of this component will be to synthesize information from our and other studies regarding tall-shrub-expansion across Russia. **Data management** will consist of three major elements: a Yamal Arctic Vegetation Archive (YAVA), a Yamal Arctic Map Archive (YAMA), and a Yamal Arctic Atlas Portal (YAAP).

OVERVIEW

The Arctic is among the most rapidly changing regions of the Earth. Much recent attention has focused on the resilience of the local people and governments to adapt to rapid resource development and climate change (ACIA 2004, Callaghan et al. 2004, Huntington et al. 2005, Chapin et al. 2006, AMAP 2010a, Arctic Council 2013). Our project focuses on the Yamal Peninsula, Russia and the large Bovanenkovo gas field where industrial-development is expected to expand greatly in the next few years. The synthesis will summarize information from the Eurasia Arctic Transect (EAT), which traverses all five Arctic bioclimate subzones (CAVM Team 2003) of the Yamal Peninsula and Franz Josef Land. The results will be compared with similar information from the North America Arctic Transect (NAAT) (Walker et al. 2008a) (Fig. 1).

In this proposal, we first review the past eight years of our research funded by the NASA LCLUC Program, the key social-ecological issues related to gas development and climate change on the Yamal Peninsula, the relevance to U.S. Arctic policy, and how the proposal addresses the 2012 LCLUC call for proposals. We then describe the proposed research, organized according three synthesis research components and eleven specific tasks. We then describe the education and outreach component and overall project management and data management.

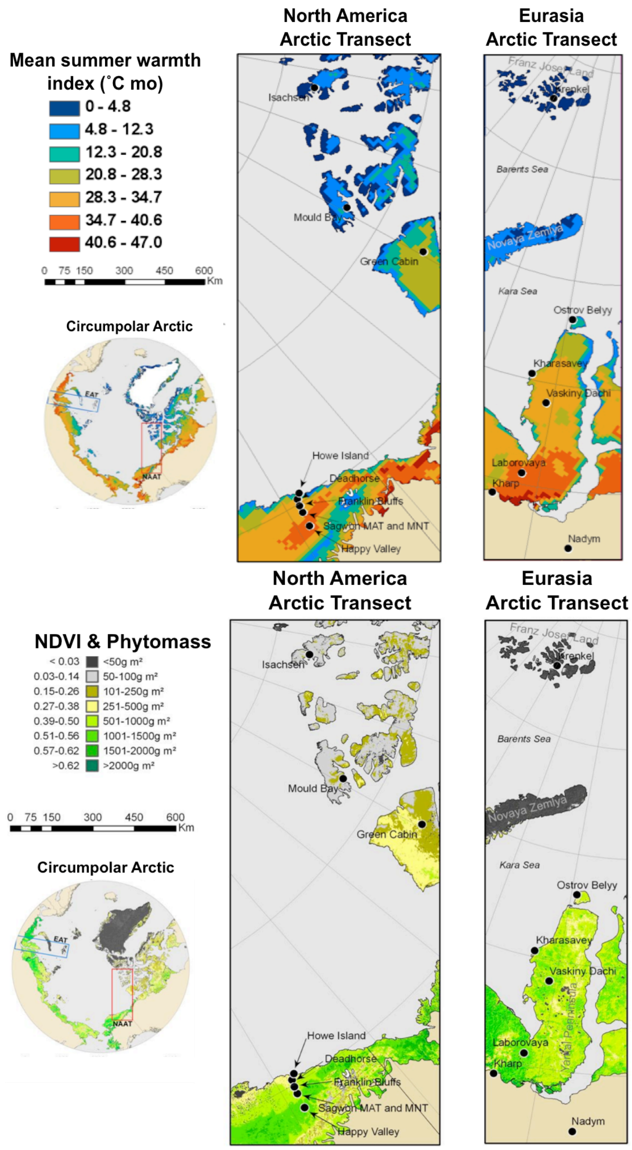

Fig. 1. The Circumpolar Arctic, North America Arctic Transect (NAAT) and Eurasia Arctic Transect (EAT). *The upper diagrams show the summer warmth index (SWI = sum of mean monthly temperatures above freezing), and the lower diagrams show NDVI/phytomass. Both data sets portray mean values based on 1982-2010 AVHRR data. The dots are the primary study locations. Bovanenkovo gas field is located near the Vaskiny Dachi location of the EAT, and Prudhoe Bay Oilfield is located near Deadhorse on the NAAT.*

PREVIOUS RELEVANT LCLUC RESEARCH

Two prior LCLUC/NEESPI projects in 2005-2013 addressed issues related to resource development and climate change and their relevance to the indigenous Nenets people in northwest Siberia. These projects involved a group of over 40 investigators and students from the University of Alaska Fairbanks, the University of Virginia, NASA Goddard, the Earth Cryosphere Institute (ECI) in Tyumen and Moscow, Russia, the Arctic Centre (AC) in Rovaniemi, Finland, and the Alfred Wegener Institute, Potsdam, Germany. There were four major sets of observations and findings derived from these projects: 1) *Climate-change studies* found strong correlations between coastal summer sea-ice trends, land-surface-temperatures (LST), and vegetation greenness (using the Normalized Difference Vegetation Index, NDVI) for most Arctic regions and the circumpolar Arctic as a whole (Forbes et al. 2009, Forbes et al. 2010, Walker et al. 2009b, Bhatt et al. 2010, Walker et al. 2011a, Goetz et al. 2011, Fauria et al. 2012, Walker et al. 2012c, 2012a, Kumpula et al. 2012, Parmentier et al. 2013). The study found strong heterogeneity across the climate gradient related to summer temperatures, reindeer grazing, soil texture. Partitioning the drivers underlying this heterogeneity is critical to our understanding and modeling how future changes will play out in different regions and landscapes as the ongoing warming continues. 2) Environmental and remote-sensing studies along the *Eurasia Arctic Transect* (*EAT)* (Fig. 1) produced a deep integrated set of measurements of vegetation, soil, active layer, permafrost temperature, and spectral information from the EAT (Walker et al. 2009a, 2011c, Frost et al. 2012; Epstein et al. 2012, Buchhorn et al. 2013). Remote-sensing studies examined the regional effects of climate, terrain, permafrost, soil, and disturbances on the EAT land surface (Raynolds et al. 2008, Raynolds and Walker 2009, Raynolds et al. 2011, Epstein et al. 2012a, Frost et al. 2013, Buchhorn et al. 2013a). 3) The field observations from the EAT were used to improve the parameterization of the *ArcVeg model* so it is suitable for vegetation-change studies in tundra regions. Specifically, it models changes in the biomass and productivity of different plant functional types using different scenarios of changing summer warmth, soil substrates, and reindeer foraging (Yu et al. 2009, Epstein et al. 2007, Goetz et al. 2011, Yu et al. 2011). 4) Several papers addressed the *cumulative effects of resource development and climate change on the local Nenets people* (Forbes and Stammler 2009, Walker et al. 2009b, Forbes et al. 2010, Kumpula et al. 2011, 2012, Stammler and Forbes 2007) and permafrost (Leibman et al. 2008, Khomutov et al. 2009). These and other results were presented at three Yamal Land-Cover Land-Use Change Workshops and numerous conferences related to the International Polar Year. The project web site has complete results from the previous rounds of funding, including pdfs of past proposals, publications, posters and talks at conferences and workshops, annual data reports, annual reports to NASA, and list of participants (http://www.geobotany.uaf.edu/yamal/index).

KEY SOCIAL-ECOLOGICAL ISSUES ON THE YAMAL PENINSULA

A combination of rapid climate change, industrial development, complex social-ecological dynamics, and extraordinarily sensitive permafrost landscapes make the Yamal Peninsula in northwest Siberia a focal point of NASA's Land-Cover/Land-Use Change (LCLUC) research in Eurasia. The largest land-use changes on the Yamal are related to expanding oil and gas development and changing reindeer-herding practices (Forbes et al. 2009). The Yamal region has 200 identified natural gas fields containing an estimated 58 trillion m^3 of gas reserves and is poised for widespread development of industrial infrastructure and concomitant growth of urban centers and human population (Gubarkov 2010, Kumpula et al. 2012). So far, most industrial infrastructure is concentrated in a 450-km^2 area of the super-giant Bovanenkovo gas field on the central Yamal. Development of other gas fields is now accelerating following the completion in 2011 of a major railway linking Bovanenkovo to the rest of Russia (Gubarkov 2010, Kumpula et al. 2012). Amidst the backdrop of rapid industrial development, changing climate and altered ecosystems, about 6,000 indigenous Nenets people and their 310,000 domestic reindeer migrate annually across the Yamal (Stammler 2005). The seasonal movements of the Nenets and their reindeer are directly impacted by the spread of pipelines, roads, and other infrastructure, and the rapidly expanding herds have their own effects on the landscape through extensive grazing and trampling (Forbes et al. 2009, Kumpula et al. 2012). Thus, the Nenets' ability to sustain their traditional land-use practices is challenged by complex socio-economic and environmental factors and uncertainties about future climate change, industrial development, and regional population growth.

RELEVANCE TO U.S. ARCTIC POLICY AND TIMLINESS OF THIS PROPOSAL

The situation on the Yamal is in many ways similar to what has occurred in other hydrocarbon basins in the Arctic (AMAP 2010). Developing Arctic oil & gas resources requires extensive networks of roads, pipelines and other forms of infrastructure. The cumulative environmental and social effects of expanding developments vary from region to region and are difficult to assess and impossible to predict — especially in the face of rapid climate change and unpredictable politics, oil markets, and social and economic changes. Several assessments of the cumulative effects of oil and gas development have noted that there is little coordinated research between natural and social scientists to address the combined effects of land-cover and land-use changes in the Arctic (NRC 2003, AMAP 2010, Streever 2011).

During the International Polar Year (IPY 2007-2008) a new emphasis emerged that was not seen in previous International Polar Years — the engagement of local people to achieve better coordination of polar research between scientists and the needs of local stakeholders (Krupnik et al. 2011). A major effort was made to consider both climate-change effects and the changing social, economic and political status of Arctic people. A sustainable approach to adaptively manage CE requires collaboration between indigenous people, industry, and scientists from a broad spectrum of disciplines to address these infrastructure-related concerns (Kofinas et al. 2013). This new emphasis is reflected in national and international science policies that consider the changing demands on Earth's resources that accompany changes in climate, sea-ice cover, and land-use. For example, the recently released National Strategy for the Arctic Region succinctly states the issue:

> *"…As we consider how to make the most of the emerging economic opportunities in the region, we recognize that we must exercise responsible stewardship, using an integrated management approach and making decisions based on the best available information, with the aim of promoting healthy, sustainable, and resilient ecosystems over the long term."* (White House 2013)

We propose to use the information derived from remote-sensing studies and detailed historical ground information to work with local communities, industry, and international partners to develop effective adaptive management approaches. Our previous research was directed at understanding the cumulative effects of climate change, reindeer herding, and resource development on the Yamal Peninsula. This was part of a coordinated effort between NASA and the Northern Eurasia Earth Science Partnership Initiative (NEESPI) to "…provide pathways to strategies for adaptation to the observed and predicted changes, and facilitate assessments of the impacts and opportunities related to natural resource management of energy and transportation developments" (Gutman and Reissell 2011). Summaries of our Yamal research appear in numerous publications, the proceedings of three Yamal LCLUC meetings in Moscow (2008) and Rovaniemi, Finland (2010 and 2012), (http://www.geobotany.uaf.edu/yamal/index), and the annual LCLUC science team meetings.

A synthesis of this body of information is timely because of the accelerated rate of both resource development and climate change that is occurring on the Yamal Peninsula and the surrounding Kara/Barents Sea region. The broader value of the synthesis from the Yamal region will be in the lessons learned and the applications of those lessons to other areas of development. A primary area of this comparison will be the North Slope of Alaska where there is a similar Low Arctic environment, vast industrial infrastructure, a long history of scientific research, and a similar body of information from the local people that is well-suited for comparative studies. We propose to complete the synthesis of the Yamal observations and to broaden the adaptive management strategies by comparing the changes on the Yamal with those of the northern Alaska oilfields and elsewhere in the circumpolar Arctic.

RESEARCH COMPONENTS (DELIVERABLES IN ITALICS AND THE END OF EACH COMPONENT)

Component 1. Synthesis of ground-based, remote-sensing and climate information from the Eurasia Arctic Transect.

Task 1.1. Synthesis of information from the EAT. The key questions to be addressed with Task 1.1 is, *"How do key landscape factors (e.g., vegetation composition and structure, soil chemical and physical properties, soil surface temperatures, NDVI, active layer, permafrost temperatures, disturbance patterns) vary spatially and temporally with summer temperature and soil texture along the EAT?"*

A detailed understanding of the land environment is a key to interpreting the remote-sensing information from the Arctic. A major achievement during previous rounds of LCLUC funding was the 1,800-km Eurasia Arctic Transect (EAT), which extends from the forest-tundra transition at the base of the Yamal Peninsula near Nadym (65˚ 18' N), spans a series of four bioclimatic subzones of Arctic tundra along the length of the peninsula, and terminates at the northernmost High Arctic tundra subzone at the Krenkel hydrometeorological station, Hayes Island, Franz Josef Land (80˚ 36' N) (Fig. 1c). The goal of the transect was to collect information from mesic loamy and sandy sites along the complete Arctic climate gradient that could be used in the interpretation of remotely sensed images of zonal tundra at several scales. We studied seven locations at Nadym, Kharp, Laborovaya, Vaskiny Dachy, Kharasavey, Ostrov Belyy, and Krenkel (Fig. 1). We surveyed the vegetation composition and structure, soils, active-layer thickness, the normalized difference vegetation index (NDVI), leaf area index (LAI), and plant biomass. At some sites, where appropriate, we also examined patterned-ground features, shrub distribution, reindeer foraging patterns, spectro-radiometric and bidirectional reflectance distribution function (BRDF) characteristics. The data from five expeditions are summarized in seven data reports that are available online http://lcluc.umd.edu/project_details.php?projid=198. Partial syntheses of the GOA EAT studies are available in four key publications (Goetz et al. 2011, Walker et al. 2011b, Epstein et al. 2012b, Raynolds et al. 2012b). During the proposed work we will complete the synthesis of information from the EAT with deliverables as outlined below:

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The deliverables from Task 1.1 include: Four major disciplinary synthesis papers focused on the geoecological conditions along the EAT will parallel analyses from a comparable North America Arctic Transect: a) vegetation (authors: Walker, Breen, Ermokina); b) soils (Matyshak): permafrost conditions (Liebman, Romanovsky), and spectral-reflectance characteristics of the EAT (Epstein, Buchhorn).

***Task 1.2. Comparison of the EAT and NAAT**.* The key question addressed with Task 1.2 is, *"How do the spatial and temporal patterns observed along the relatively maritime EAT compare with the patterns along the relatively continental North America Arctic Transect (NAAT)?"*

The vegetation, soil, permafrost conditions and spectral characteristics of the EAT will be compared with a similar 1,750-km North America Arctic Transect (NAAT) in Alaska and Canada

(Fig. 1b) (Kade et al. 2005, Epstein et al 2008, Ping et al. 2008, Michaelson et al. 2008, Romanovsky et al. 2008, Walker et al. 2008a, 2008b, 2011, Buchhorn et al. 2013 in press). Both transects traverse all five Arctic bioclimate subzones as portrayed on the Circumpolar Arctic Vegetation Map (CAVM Team 2003, Walker et al. 2005) (Fig. 1a). The EAT and NAAT are both situated in close proximity to areas of extraordinarily rapid sea-ice changes in the Beaufort, Barents and Kara Seas. The transects were placed in areas of the Arctic with contrasting continental (NAAT) and maritime (EAT) climate regimes.

The comparison of the two transects would be greatly facilitated by a land-cover map with a common consistent classification approach for both transects and with greater resolution than the existing Circumpolar Arctic Vegetation Map polygon map (CAVM Team 2003). We propose to derive a raster-based vegetation map from an existing AVHRR mosaic with 1-km resolution that was used as a base map to produce the CAVM (Walker et al. 2005). We would stratify the AVHRR spectral data according the vegetation, bioclimate subzones, floristic province, landscape, elevation, and percent water attributes contained in the GIS database for the CAVM. The legend for the map would contain the same 15 map units as the CAVM, but would display much greater detail related to wetlands, shrublands, geology, and topography within the map units.

This map and circumpolar maps of the annual and seasonal dynamics of sea-ice distribution, land-surface temperatures and NDVI would will be used to make a detailed comparison of the trends along the EAT and NAAT.

The deliverables for Task 1.2 include: i) a circumpolar raster-based vegetation map and area analysis (Raynolds), ii) a manuscript comparing of the climate, vegetation, soils, permafrost conditions and spectral properties of the maritime EAT to the continental NAAT (Walker et al.), and iii) a paper comparing the seasonal dynamics and long-term trends of land-temperature and NDVI along EAT and NAAT (Bhatt, Walker).

Task 1.3. Circumpolar comparison. The key question for Task 1.3 is, "*How are the patterns of soil temperatures and NDVI along both transects related to circumpolar summer sea-ice and climate drivers?"*

The record low extent of perennial sea ice in 2012 increased the concern regarding the consequences of sea-ice changes to the climate, permafrost and vegetation of Arctic terrestrial areas. The two Arctic transects offer a unique opportunity to examine ongoing terrestrial change from space in the context of an extensive ground-based dataset that was collected along the full climate gradient in continental and maritime regions of the Arctic. A synthesis of information from the two transects will allow better prediction of the consequences of sea-ice retreat in continental vs. more maritime areas of the Arctic. Recent evidence indicates that Eurasia and North America Arctic areas are responding differently to reduced sea ice (Walker et al. 2012c). North America has shown virtually flat land-surface temperature and NDVI during the past decade, and Eurasia has shown a decline in both parameters. A hierarchy of ground based information and the AVHRR-derived vegetation map will be used to place the location-specific studies in the broader context of the circumpolar Arctic. The baseline ground information and remote-sensing-based AVHRR-derived time-series of change from both transects will be analyzed in relationship to regional and global patterns of climate, land-temperature and sea-ice. Our circumpolar updates of trends in sea-ice, land-temperatures, and NDVI in 22 Arctic sea seas and adjoining land areas have become a key long-term monitoring component of NOAA's annual State of the Climate and the Arctic Report Card (Richter-Menge and Jeffries 2011, Walker et al. 2012c, Epstein et al. 2013). The analysis of sea-ice, land-temperatures, and greenness (NDVI) relationships in the Barents and Kara Sea area will apply a new, much-needed recalibration of the circumpolar AVHRR-derived NDVI dataset that is in progress by

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Jorge Pinzon (NASA Goddard). The new work will include a circumpolar analysis of the relationship between greening, the duration of the snow-free season, and regional snow-depth patterns. The Global Precipitation Climatology Project (GPCP version 2) is based on merging infrared and microwave satellite estimates of precipitation with rain gauge data and will be used to investigate the role of moisture and snow-depth on recent vegetation changes.

The primary deliverables for Task 1.3 include: i) annual updates of the sea-ice, Arctic land-temperatures, and Arctic NDVI patterns for the NOAA State of the Climate publication and the Arctic Report Card (Bhatt, Epstein), and ii) a paper that summarizes the global seasonal patterns of sea ice, land temperatures, and NDVI in relationship to snow, humidity, and other precipitation data (Bhatt et al.).

Component 2. Synthesis of social-ecological changes related to Arctic oil and gas development.

Task 2.1. Synthesis of studies from the Yamal Peninsula and Northern Alaska. *The key question for Task 2.1 is, "How have underlying climate and social-ecological systems influenced the impacts of infrastructure expansion and climate change in Bovanenkovo gas field, Russia, compared to those of the Prudhoe Bay oil field, Alaska?"*

This task will use remote-sensing products and social-ecological information from the Yamal studies and similar information collected from the North American Arctic transect to develop general principals of adaptive management that can be applied elsewhere. Both the EAT and the NAAT transects contain areas with rapid arctic industrial development related to oil and gas development — with strong consequences to the local people. The local Nenets people of the Yamal are reindeer herders, whereas the Iñupiat and Gwitchen of northern Alaska are subsistence hunters. Researchers from the Earth Cryosphere Institute (ECI in Moscow) and the Arctic Centre (AC in Rovaniemi) collaborated with the NASA Yamal LCLUC/NEESPI project during five field seasons (2007-2011) and published their work in several high profile journal articles (Forbes et al. 2009, Macias-Fauria et al. 2012, Kumpula et al. 2011). The AC studies drew on resources from a project called Social Impacts of Industrialization in Northern Russia (ENSINOR). The project undertook a multidisciplinary analysis of the social and environmental consequences of energy development in northern Russia. A comparative study of effects in two key federal districts in northwest Russia - Nenets Autonomous Okrug (NAO) and Yamalo-Nenets Autonomous Okrug (YNAO) linked the global level changes to local scientific and traditional knowledge. Scientists travelled with the herders and used remote sensing technology to help trace the changes to the landscapes and Nenets' perceptions of those changes. A new study funded by the Academy of Finland called Resilience in Social-Ecological Systems of northwest Eurasia, (RISES) is developing a Yamal-focused social-ecological synthesis.

In Northern Alaska, the cumulative effects of oil and gas development were first addressed in studies conducted by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) and the oil industry during the International Biological Programme in the 1970s (Brown 1975, Walker et al. 1980), and then expanded in studies by the U.S. Fish and Wildlife Service in the 1980s (Walker et al. 1986, 1987), and a more comprehensive study conducted by U.S. National Research Council (NRC 2003). The last study included assessment of potential impacts of development to the Iñupiat and Gwitchen peoples (Kruse et al. 2004, Berman et al. 2004, Berman and Kofinas 2004). Although there have been several agency initiatives within the U.S. to examine various aspects of oil and gas exploration since then, there is still not a comprehensive holistic approach to address the social and ecological effects. An NSF Arctic LTER-funded project called "Maps and Locals" (MALS, http://www.lter.uaf.edu/bnz_MALS.cfm) has updated some aspects of the NRC analyses, including an up-to-date inventory of the total extent of infrastructure, and an updated assessment of indirect landscape impacts (Raynolds et al. 2013 submitted). This historical analysis of 62 years of landscape change used aerial photographs dating to 1949, remote-sensing images and the oil industry's GIS infrastructure database. The results, submitted to the *Proceedings of the National Academy of Science* (Raynolds et al. 2013) show the industrial footprint grew rapidly during the early development phase and leveled off after 20 years, covering 74 km^2 by 2011. Indirect effects continued to expand after the main construction phase ended. By 2010, over 40 percent of the intensively mapped areas was affected by oil development. A surprising result was the rapid expansion of both infrastructure-related and natural climate-induced thermokarst between 1990 and 2001. Over 18 percent of the natural landscapes previously dominated by low-centered ice-wedge polygons changed to mixed high- and low-centered polygons with many thermokarst pits (small water bodies resulting from thawing of ice-wedges) and flooded polygon troughs. The expansion of both infrastructure- and climate-change-related thermokarst coincided with strong atmospheric warming during the 1990s. The changed landscapes extensive infrastructure networks, more complex micro-topography, and more abundant wet and aquatic habitats have major implications for the distribution of tundra organisms and for the local people's use of the land (Braund and Associates 2010). A recently awarded NSF Experimental Program to Stimulate Competitive Research (EPSCoR) "Alaska Adapting to Changing Environments (ACE) – Northern Case Study" (http://www.alaska.edu/epscor/focus/physical/) is building on the MALS study.

Both the Yamal and northern Alaska studies depend heavily on satellite imagery to develop time series of change. The visual products derived from remote-sensing and GIS historical analyses are also integrated as part of interviews with the local subsistence harvesters in the village of Nuiqsut to help trace their local and traditional knowledge of land use. Our proposed synthesis will focus on the use of remote-sensing products in combination with findings from the interviews with community leaders, resource manager, and industry personnel to formulate adaptive approaches to the changes.

The main deliverables from Task 2.1 are: i) a manuscript comparing cumulative effects of climate and infrastructure changes to the Nenets (reindeer-herding) and Iñupiat (hunting) cultures (Kofinas, Forbes, Kumpula), and ii) a manuscript focused on the applications of remote sensing and GIS as tools for Arctic cumulative-impact research.

Task 2.2. An international Arctic cumulative-effects workshop. *The major goal of this task is a synthesis of best practices of remote-sensing applications for addressing Arctic social-ecological issues related to expanding networks of infrastructure and rapid climate change.*

Currently the consequences of and prediction of land-use changes in the Arctic, including the extensive networks of infrastructure needed for exploration and development of mineral resources, are not adequately addressed in an international initiative. We are requesting funds for an International Social-Ecological Effects of Industrial Infrastructure in Arctic Permafrost Landscapes session and workshop at a major international conference. Our first choice for a venue for the session is the 3rd International Conference on Arctic Research Planning (ICARP III) and the Arctic Science Summit Week in 2015 planned to be held in Japan. A proposal to the International Arctic Science Committee (IASC) will be submitted soon to initiate the workshop. Funds from this NASA grant will used to invite participants that have a specific interest in applications of remote sensing to Arctic social-ecological and land-use-change issues. This focus is needed because the areas of the Arctic under development are so vast, remote, and the land cover and historical changes so poorly mapped that remote sensing is the only feasible approach to detect and quantify the changes. A clear understanding of these historical changes is needed to properly assess how Arctic systems will respond to current climate and land-use changes.

Other studies that have examined changes in social-ecological systems are being conducted in the Canadian diamond fields, the Mackenzie River delta, potential areas of development in far northern Canada, the North Sea and Barents Sea developments, and mining operations in the Russian Far East. One example of an integrated regional impact study in Canada is called Arctic Development and Adaptation to Permafrost in Transition (ADAPT) IRIS (Integrated Regional Impact Study http://www.arcticnet.ulaval.ca/research/iris_4_info.php) focuses in part on activities in the Inuvialuit communities of the Mackenzie River delta area.

The proposed workshop would draw on these studies to address the following issues: 1) *Quantify the existing changes within areas of development at several spatial scales.* Site-specific models and case studies are needed to examine the combination of climate effects and infrastructure changes, to hydrology, permafrost, vegetation, and local wildlife habitat. Landscape- and regional-level models are needed that examine effects over larger watersheds and regions including an assessment of the full extent of industrial development. 2) *Incorporate social drivers of change.* Economic, political, demographic, land-use planning, and technology-change aspects need to be incorporated into the analyses. 3) *Develop new tools and models to help predict and respond to the coming changes.* Predictive models involving remote sensing and GIS are needed to help mitigate the placement of new roads, pipelines, and drilling sites in areas of ice-rich permafrost. 4) *Involve the local leaders and industry directly in the science of assessing and responding to change.* Communicating with local people through the use of remote sensing and GIS products and developing interactive planning tools that are available to local communities are keys in this process.

The main deliverables for Task 2.2 are: i) a proceedings volume from the international workshop to examine the cumulative effects of infrastructure growth and climate change (Kumpula, Raynolds, Forbes, Walker), and ii) a synthesis of international best practices for adaptive management of Arctic local responses to cumulative effects of climate change and resource development (Kofinas, Forbes).

Component 3. Synthesis of modeled effects of climate change on vegetation.

Task 3.1. Circumpolar ArcVeg modeling synthesis. *The key question for Task 3.1 is "How will regional and circumpolar Arctic vegetation respond to differing scenarios of climate change and land use?"*

ArcVeg is a plot-level, tundra vegetation dynamics model that focuses on the response of a suite of common tundra plant functional types to changes in temperature and soil nutrients (Epstein et al. 2001). The modeling component of our previous LCLUC projects helped develop the ArcVeg Model for application to questions related to climate change and reindeer herding on the Yamal Peninsula. The field observations along both the NAAT and EAT were used to improve the parameterization of the ArcVeg Model (Epstein et al. 2009, Yu et al. 2009, 2011). The model was applied on the Yamal Peninsula to examine climate-change and grazing effects on arctic ecosystems across the Yamal climate gradient. Major progress was made enhancing the ArcVeg model for vegetation-change studies in tundra regions — specifically to account for the effects of snow, moss-dominated and permafrost-dominated systems, and reindeer foraging. The model now includes a more comprehensive representation of plant functional types and enhancements to our grazing and nitrogen cycling sub-components (Yu et al. 2011, Epstein et al. 2007). We applied our latest-generation models to a variety of climate and anthropogenic land-use change scenarios. Preliminary results indicate that while climate change may lead to major changes in the floristic composition of many Yamal landscapes in the coming decades, plant species migration and dispersal rates will play important roles in delaying the response of vegetation to climate, particularly at the forest-tundra boundary. Additionally climate warming and grazing interact in the tundra ecosystems of the Yamal to influence the response and resistance of the plant communities to these two disturbances. In fact, negative feedbacks may exist, given that grazing and warming have opposing effects on tundra productivity.

Using the ArcVeg model in combination with the proposed 1-km-pixel Circumpolar Arctic Vegetation Map (see Task 1.2), soil organic nitrogen data from the Terrestrial Ecosystem Model (TEM), climate change scenarios from the Community Climate System Model (CCSM 3.0), and grazer population and extent data from the Circum-Arctic Rangifer Monitoring & Assessment (CARMA) Network, we will simulate the projected effects of both climate and grazing on arctic tundra productivity and plant community composition throughout the circumpolar arctic tundra. The modeling analysis will allow us to potentially separate the effects of climate change from those of grazing, in addition to examining their interactions. One key implication here is that we are able to assess the "potential greening of the Arctic" (i.e. just the effect of climate change) in the absence of large grazing herbivores, which may be mitigating the apparent greening trend. We will also be able to examine the climate-grazer-vegetation interactions by region, for areas with different grazing management regimes.

The main deliverables from Task 3.1 is a manuscript on the circumpolar ArcVeg modeling synthesis of climate and grazing effects (Yu, Epstein).

Task 3.2. Shrub expansion synthesis. *The major question for Task 3.2 is "What is the history of tall-shrub expansion across the forest-tundra ecotone of northern Siberia in relationship to landscape variables and climate change?"*

An additional model-related synthesis effort will continue to analyze the expansion of tall shrubs along the forest-tundra ecotone throughout northern Siberia. Recent analyses suggest that patterned-ground disturbances are facilitating the expansion of tall alder shrubs into otherwise shorter-statured, graminoid-dominated tundra at the Kharp site at the southern end of the Yamal Peninsula (Frost et al. 2013). Very high resolution imagery from Cold-War era satellite missions and recent commercial satellites indicate that this phenomenon may be rather widespread throughout several areas of southern Siberia. We propose to examine the expansion of tall shrubs at the forest-tundra ecotone of Siberia, through the use of several remote sensing products of different resolutions (VHR e.g. Corona, Quickbird; Landsat, and AVHRR/MODIS), in combination with shrub growth-ring analyses conducted by Bruce Forbes, and ArcVeg simulation output.

The main deliverable from Task 3.2 is a manuscript on tall shrub expansion synthesis throughout northern Siberia (Frost, Epstein, Forbes, Yu).

EDUCATION AND OUTREACH

Findings from this project, if appropriately communicated to local residents and industry representatives, may help both groups adapt more effectively to impending changes. They could also influence the way in which the oil industry and local populations interact. The indigenous people in both regions feel that they can adapt to the changes occurring if they are involved and can influence decisions that affect their ability to use the land and their resources (Forbes and Stammler 2009, Stammler and Forbes 2009). A major element of our human-dimension studies is adaptive co-management and active engagement of the local populations in the science (see Component 2). In this project we also will actively engage industry. Dr. Bill Streever, environmental studies leader for BP Exploration (Alaska) Inc., will facilitate involvement of oil-industry employees in the project and promote the project to North Slope residents in Barrow, Alaska by informing them about scientific results relevant to their interests while also showing appropriate follow-through to individuals interviewed as part of Component 2. Industry employees will be reached through briefings in Anchorage and in the North Slope oilfields. Initially, Anchorage briefings will be managed through the Alaska Oil and Gas Association (the regional industry trade association) to capture representatives from all of the companies working in northern Alaska. North Slope residents will be reached through public presentations in Barrow managed through Ilisagvik College (the two-year tribal college in Barrow) and the Barrow Arctic Science Consortium. The presentation and/or a question-and-answer session will be transmitted over the North Slope public radio station, KBRW, which is received by all of the North Slope villages. Also, one or more articles will be written in nontechnical language describing the project and its outcomes for publication in the North Slope's newspaper, *The Arctic Sounder*. Throughout the outreach effort in both the oilfields and in the Yamal and North Slope villages, remote sensing products and interview responses will help nonspecialists understand both the methods and the relevance of this project.

Additional outreach will be via the project web page http://www.geobotany.uaf.edu/yamal/, and the EPSCoR ACE Project is building an educational program for schools based on MapTeach http://mapteach.org/. Products from this research will be incorporated into the MapTeach curriculum that will be piloted in Nuiqsut and later used in other rural communities of Alaska. Other outreach efforts include our continued participation in the production of the NOAA annual State of the Climate report (e.g.,Walker et al. 2012c) and the Arctic Report Card (http://www.arctic.noaa.gov/reportcard/index.html) which are produced annually by NOAA to update the scientific community and the public about ongoing Arctic changes.

PROJECT, ORGANIZATION AND MANAGEMENT

Science management and schedule

The project will have a science management team composed of the PI Walker, and Co-Is, Bhatt, Epstein, Forbes, Kofinas, Leibman and Romanovsky. Decisions will be made with the consensus of all members of the science management team. The project consists of three components as described in the proposal (Fig. 2), with Walker leading Component 1, Forbes and Kofinas leading Component 2, and Epstein leading Component 3. The three science components have eleven tasks (synthesis products) (Table 1) that will be completed within three years (Table 2).

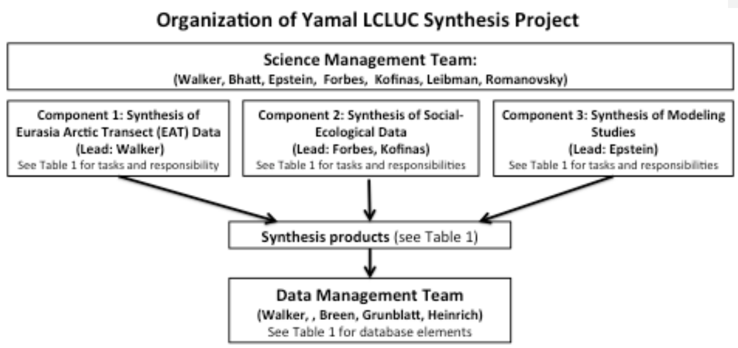

Figure 2. Organization of Yamal LCLUC Synthesis Project.

Data management

D.A. Walker, J. Grunblatt, T. Heinrich, and A. Breen will lead the data management team and will be in charge the database elements indicated in Table 1 and described in the *data management plan* below. The data and metadata will be organized into three primary database elements: a Yamal Arctic Vegetation-plot Archive (YAVA), a Yamal Arctic Map Archive (YAMA) and the Yamal Arctic Atlas Portal (YAAP). This are similar in structure to one developed for Northern Alaska as part of recently funded data gathering effort for the NASA Arctic-Boreal Vulnerability Experiment (ABoVE, Kasischike et al. 2010) (Walker et al. NASA proposal # 12-

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TE12-2-0076). Each of the research teams at UVA, ECI, UAF, and the Arctic Centre will be responsible for the data within their individual tasks. Overall, project data management will be coordinated through the Geographic Information Network of Alaska (GINA), described below.

Types of data to be archived in the course of the project

Table 1. Yamal LCLUC Synthesis: Components, tasks (products), and responsibility.

Science Components:
Science management team: Walker, Bhatt, Epstein, Forbes, Kofinas, Leibman, Romanovsky.

Component 1: Synthesis of EAT Data
Task 1.1. Four major disciplinary and interdisciplinary synthesis papers regarding the EAT: i) vegetation (Ermokina, Walker), ii) soils (Matyshak), iii) permafrost and active layer conditions (Leibman, Romanovsky), and iv) spectral-reflectance characteristics of the EAT (Epstein).
Task 1.2. Paper comparing the seasonal dynamics and long-term trends of land-temperature and NDVI along the maritime EAT to the more continental NAAT (Bhatt, Walker).
Task 1.3a. Raster-based vegetation map of the circumpolar Arctic (Raynolds).
Task 1.3b. Annual updates of sea-ice, land-temperature, and NDVI for the State of the Climate and Arctic Report Card (Bhatt, Pinzon, Comiso, Epstein).
Task 1.3c. Paper that summarizes the global patterns of sea ice, land temperatures, and NDVI in relationship to snow, and other precipitation data (Bhatt et al.).

Component 2: Synthesis of Social-Ecological Data
Task 2.1. Manuscript comparing cumulative effects of climate and infrastructure changes to the Nenets (reindeer-herding) and Iñupiat (hunting) cultures (Kofinas, Forbes, Kumpula)
Task 2.2. Proceedings volume from the international workshop to examine the cumulative effects of infrastructure- and climate-change (Kumpula, Raynolds, Kofinas, Forbes, Walker)
Task 2.3. Synthesis of international best practices for adaptive management of Arctic local responses to cumulative effects of climate change and resource development (Kofinas, Forbes).

Component 3: Synthesis of Modeling Studies
Task 3.1. Circumpolar ArcVeg modeling synthesis (Yu, Epstein).
Task 3.2. Shrub expansion synthesis (Frost, Epstein, Forbes).

Data management:
Data management team: Walker, Breen, Grunblatt, Heinrich,

Database element 1: Yamal Arctic Vegetation Archive (YAVA) (Breen)
Database element 2: Yamal Arctic Map Archive (Grunblatt, Walker)
Database element 3: Yamal Arctic Atlas Portal (YAAP) (Heinrich, Grunblatt)

Plot data include spatial location, species composition and cover values, brief soil descriptions, soil data, active-layer depth and many other environmental site factors, and photographs. Typically, data were recorded in the field on hard-copy field data sheets using standard protocols and then entered into Excel spreadsheets in the lab. Voucher specimens of plants collected in the field were verified by taxonomic experts and archived for future reference. Plot data are in two main matrices. One contains the estimated cover for species (matrix rows) for each plot (columns). The second matrix contains the environmental information for each plot, which in most cases includes GPS location, soil data for the rooting zone, and a variety of site factors. Species cover information can often be compared between locations and investigators, because the methods are similar between investigators. Environmental information is more variable between investigators, but many of our plots have been sampled by the same observers, using similar protocols and are thus largely comparable. A very important aspect of our procedures that is often missing in other data sets is a hardcopy and digital format data report for every data set, which provides full documentation for all the data collected.

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Maps and remote sensing products from digital raster format satellite images include land-cover maps and change analyses of NDVI (derived from time-series of Landsat images) and digital vegetation classification (derived from VHR QuickBird or WorldView images) of the same areas. Yearly time-series of peak NDVI change and changes in seasonality of greening (derived from AVHRR) will be made for the Prudhoe Bay region and the Bovanenkovo region and other key locations if time permits. All published products, and other selected processed images and image products that would be useful to others will be archived.

Table 2. Schedule for the Yamal LCLUC Synthesis project.

Component & Task	Year 1	Year 2	Year 3
Science			
Component 1: Synthesis of EAT Data			
Task 1.1a. EAT synthesis papers			
Vegetation	x	x	
Soils	x	x	
Permafrost	x	x	
Spectral reflectance	x	x	
Task 1.2. Seasonal dynamics of EAT vs. NAAT paper		x	
Task 1.3a. Raster-based circumpolar vegetation map	x	x	
Task 1.3b. Annual updates of SOC and ARC	x	x	x
Task 1.3c. Synthesis circumpolar paper			x
Component 2: Synthesis of Social-Ecological Data			
Task 2.1. Cumulative effects to the Nenets and Iñupiat cultures paper	x	x	
Task 2.2. International cumulative effects workshop & proceedings		x	x
Task 2.3. Synthesis best practices paper			x
Component 3: Synthesis of Modeling Studies			
Task 3.1. Circumpolar ArcVeg modeling synthesis	x	x	x
Task 3.2. Shrub expansion synthesis	x	x	x
Project Management			
Organizing workshop (Moscow)	x		
LCLUC workshops	x	x	x
Presentations at AGU and other forums	x	x	x
Data Management	x	x	x
Yamal Arctic Vegetation Archive (YAVA)	x	x	x
Yamal Arctic Map Archive (YAMA)	x	x	x
Yamal Arctic Atlas Portal (YAAP)	x	x	x

Social data will be managed and archived through the "Catalog" system being created by the EPSCoR Alaska Adaptive to Environmental Change project, which will provide public web access to non-sensitive data. The Catalog is also integrated with the North Slope Science Initiative (NSSI) database compilation efforts.

Standards to be used for data and metadata format and content

Plot data: We will assure plot-database compatibility with international approaches currently being developed for the Arctic Vegetation Archive (AVA) (Walker and Raynolds 2011, Walker et al. 2013), European Vegetation Archive (Chytrý et al. 2012) and the U.S. National Vegetation Classification (Jennings et al. 2009). A key aspect of this compatibility is the use of a standard PanArctic Species List (PASL-1) that we have developed specifically for AVA (Elven et al. 2012, Raynolds et al. 2013a). The list is unique in the world and covers the whole Arctic. It was developed from the checklists of vascular plants, lichens, mosses, and liverworts by taxonomists within the Conservation of Arctic Flora and Fauna Working Group. The species-cover and environmental information will be stored in a Turboveg plot database. Other types of data from the plots, including geographic locations, site and soil descriptions, photographs, hyperspectral data, and the original data reports will be linked to the plot species information. Methods and standards of vegetation database management will follow those developed for Turboveg databases (Hennekens and Schaminee 2001) and the Global Inventory of Vegetation Databases (GIVD) (Dengler et al. 2011). We will archive our data in the U.S. VegBank (Peet et al. 2012), developed for the U.S. National Vegetation Classification (Jennings et al. 2009) and develop crosswalks of unit terminology that are appropriate for both the U.S. and European approaches. This is important because of the circumpolar nature of Arctic vegetation and the potential relevance of the LCLUC studies to global initiatives. This aspect has been endorsed by the Arctic Council's Conservation of Arctic Flora and Fauna (CAFF) and the International Arctic Science Committee (IASC).

GIS and remote sensing data: GIS data will be in ArcGIS shapefile format. The Federal Geographic Data Committee (FGDC) coordinates the sharing of geographic data, maps, and online services through an online portal, GeoPlatform.gov that searches metadata held within the National Spatial Data Infrastructure (NSDI) Clearinghouse. We will follow the Content Standard for Digital Geospatial Metadata (CSDGM) and the standards approved by the NASA Earth Science Division (ESD) for use in the Global Change Master Directory (GCMD) or whatever other standard is agreed on by the LCLUC science team.

iii) Social data: All human dimension research is subject to Human Subjects review by the Institutional Review Board protocols of the University of Alaska Fairbanks, which ensure that no undue harm occurs to research participants. These protocols require thorough informed consent, anonymity, and proper archiving of data, and destroying of personal identifiers.

Data management plan

We will hire a data manager to handle the GIS and remote sensing data and work closely between the Alaska Geobotany Center (AGC), where most of the data are currently housed, and the Geographic Information Network of Alaska (GINA), which will have primary responsibility for data management. Both groups are located in close proximity to each other on the University of Alaska Fairbanks campus. Data from all the components will be centrally archived and accessible to project researchers via the project web site and the portal developed for the Yamal LCLUC activities. Plot data will be managed within AGC following the procedures developed for the large databases contained in the European Vegetation Archive (EVA) (Chytrý et al. 2012). Map data will be managed through GINA, which has the facilities, computer power, and expertise for handling large remote sensing databases. They already are managing large Landsat and AVHRR datasets for northern Alaska as part of the Pre-ABoVE effort funded by the NASA Terrestrial Ecology program, and we will take advantage of these efforts. The data management plan consists of three main elements:

Database element 1. Plot databases: Yamal Arctic Vegetation Archive (YAVA). For the plots we propose a Turboveg database (Hennekens and Schaminee 2001). Plot data will include species cover values, biomass, structure data, soils data, and environmental summaries from approximately 3000 plots on the Yamal Peninsula. We propose to combine the plot data we have collected from northern Alaska with similar arctic tundra vegetation data collected by other investigators on the Yamal to achieve the most complete and consistent database of relevant plot data possible for the Yamal region. The plot database will be compatible with both the U.S. and European approaches to database management and vegetation classification. The YAVA will contain species cover data within vegetation plots and selected site variables that describe the plots. We also have extensive ground-based information from the plots that varies with the project, including environmental site factors, biomass, detailed soil descriptions and data, biophysical and spectral measurement including leaf-area index (LAI), hyperspectral measurements (e.g., NDVI), and bidirectional reflectance radiation function (BRDF) measurements from many of the plots. A wide variety of reports and documents associated with this work also exist. All these data and information products will be compiled, inventoried and added to a web based data-management tool to form an searchable archive that is connected to the map data catalog and archive (Database element 2).

Database element 2. Map data catalog and archive: Yamal Arctic Map Archive (YAMA). We produced numerous types of maps using remote sensing products at several scales that utilize a consistent legend and display approach across scales. The YAMA would be part of a Catalog infrastructure has been developed by the International Arctic Research Center (IARC) - Geographic Information Network of Alaska (GINA) and is currently used in similar archive/distribution portals. YAMA assets would be shared with other Catalog entities and associated metadata made available to other metadata archives such as GCMD data directory in NASA. Map data in a variety of formats could be downloaded from the YAMA and associated information, including detailed map unit descriptions, photos, and links to species photographs, and plot information, could also be downloaded.

Database element 3. Yamal Arctic Atlas Portal (YAAP). For the raster and vector GIS source data and selected remote-sensing imagery we propose to provide a web based mapping portal to allow visualization of GIS data, sample point locations and imagery and access to all data collected during the Yamal LCLUC activities. This web-based approach will provide an opportunity to view maps and datasets as well as access summary plot information for field locations. Initial work will focus on a review of the existing data and determine how it can integrated with this portal. The plot data will be accessible in the YAMA at two scales: by project at regional scales, and by plot at local scales. At the project level, information on publications, data reports, general site information and photos will be provided. At the plot level, information regarding vegetation types, soil types, plot photographs will be provided in a quick look with links to more detailed information regarding species composition, soil data, and other site information.

Methods and policies for providing access to data, and provisions for sharing, re-use, re-distribution, and the production of derivatives

All data reports and processed field data will be freely available to the academic community and the public in the databases via the YAAP and data archives. The project web site will be used to chronicle all publications and presentations related to the project, with links to information about access to the data used to support the scholarly findings.

Methods for archiving and preserving access to data and materials

All data and products will also be made available in digital form with metadata according to NASA protocols. All data and reports will also be archived with metadata and submitted to the GCMD data directory in NASA. Our archival research will be compiled into a bibliography with PDFs of documents where available, and also stored with all relevant data including those most relevant to the various NASA directories, the U.S. National Vegetation Classification, and the European Vegetation Archive (EVA). All data and reports will be archived with metadata and submitted to the NASA GCMD. All datasets will also be archived in the international data archive PANGAEA (Data Publisher for Earth & Environmental Science), where they can be identified, shared, published and cited by the DOI number and freely downloaded from the portal.

Errors and uncertainties

The vegetation data for the Yamal Arctic Vegetation Archive will be ranked according to quality of taxonomic determinations, quality of environmental data, and accuracy of geographic determinations. Plots with complete plant species lists (vascular plants, mosses, and lichens) lists identified or verified by taxonomic experts, and with accurate geographical location information will be ranked highest.

Conclusion: How the proposed research addresses the 2012 NASA LCLUC call for proposals and response to the panel evaluation of our Step 1 proposal

Our proposal addresses the three main items requested in Element 2, Synthesis of LCLUC studies in Eurasia, within section A.2 of the 2012 ROSES call for LCLUC proposals: 1) **Synthesis**: We will synthesize information collected along the Eurasia Arctic Transect (EAT) during earlier LCLUC activities in 2007-2013 and combine this with information from the North America Arctic Transect (NAAT) to achieve an integrated understanding of ongoing transitions and cumulative effects of expanding networks of infrastructure, local land-use (namely reindeer herding on the Yamal and subsistence hunting in northern Alaska), and climate change. The Yamal LCLUC research has had three main components that we will synthesize during the proposed project: i) ground-based and remote-sensing information from the Eurasia Arctic Transect (EAT) (described in Component 1 of our proposal); ii) social-ecological changes related to Arctic oil and gas development associated with the Bovanenkovo gas field (Component 2); and iii) simulation modeling efforts that examine the consequences of climate change and changing reindeer herding intensity to tundra plant communities (Component 3). 2) **Social and economic sciences:** The project has a strong social science component led by Bruce Forbes at the Arctic Centre in Finland and Gary Kofinas at the University of Alaska. Previous LCLUC research on the Yamal Peninsula examined the cumulative effects of resource development and climate change on the Nenets people. We propose to combine the information collected from interviews of the Nenets with a similar study of cumulative effects of oil development on the Iñupiat people of northern Alaska. Both these studies are being conducted with other funding sources. The request includes workshop support and publication of proceeding from a conference session devoted to a synthesis of remote sensing, GIS, and satellite data used in Arctic adaptive management approaches to address the cumulative effects of rapid climate change and infrastructure expansion. 3) **Remote-sensing**: All three components of the Yamal research rely on a hierarchy of remote-sensing data, including AVHRR, Landsat, SPOT, 1960s-era Corona, very-high resolution (VHR) satellite imagery, as well as low-altitude VHR aerial photographs. Data providers at NASA-Goddard (Josefino Comiso, Jorge Pinzon and Compton Tucker) are critical to the project, especially continuation of the circumpolar time-series AVHRR data, but also to helping with the time-series analysis at the regional and landscape level with MODIS, Landsat, and VHR imagery. The syntheses, first of all, involve data archiving of the project’s remote-sensing raw data and products as outlined in the data management plan. These data will then be used in describing and analyzing the spatial and temporal patterns of visible and near-IR spectral reflectance along the EAT in relationship to environmental and land-use variables. These data will be used in comparisons with similar information from the North America Arctic Transect. The remote sensing products are critical to the social-ecological studies in Component 2 as well as the modeling studies in Component 3.

The Panel Evaluation of our Step 1 proposal felt that while the proposed synthesis project was very relevant in all respects, the way in which we intend to conduct the synthesis could be more clearly described. Furthermore, it would be more effective if it described fewer but well defined products. More specifically, the reviewers asked for explanation of the synthesis methods, including scientific questions and methods used in the social interviews and types of synthesis for the EAT products. To address these comments, we structured the proposal so that the questions, goals, proposed synthesis methods, and deliverables of each component are clearly stated. We reduced the scope somewhat by eliminating the originally proposed book and one international workshop. We focus the scope of the social-science and modeling components on questions that are addressable with remote-sensing products. The data management section is an essential component of the synthesis and is structured parallel the data management plan for a recently funded NASA Pre-ABoVE project in Alaska. While the proposal is clearly ambitious, it is achievable because it integrates the information from several previous IPY projects and several completed and ongoing research projects in Russia and Alaska that involve the Yamal LCLUC collaborators These international partners will continue their collaboration on the synthesis and will provide their own research funds for participation in the project.

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