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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Annual Report, 10 May 2016

D.A. Walker, H.E. Epstein, G. Kofinas, T. Kumpula, M.O. Liebman

Table of contents

Summary

This report presents the major achievements of the first two years (April 1, 2014 to March 31, 2016) of synthesis for the NASA-LCLUC project entitled "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" (NASA Grant No. NNX14AD90G).

he two primary goals of the project are to 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 to 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. To accomplish this, the project is first publishing disciplinary syntheses of activities for three components of the project, which are summarized here. In the next phase of the project the focus will shift to interdisciplinary syntheses that will summarize activities in a more cross-disciplinary fashion. This accomplishments to date can broken down by the three main components of the study includes:

Component 1: Eurasia Arctic Transect (EAT)

- **Yamal landslide synthesis** (4 chapters in Shan W, Guo Y, Wang F, Marui H and Strom A 2014 *Landslides in Cold Regions in the Context of Climate Change* (Cham: Springer

International Publishing) (Leibman et al., 2014; Guberkov et al. 2014, Khomutov et al. 2014, and Ukraientseva et al. 2014)

- **Discovery of a large deep crater on the Yamal** produced by an explosive outburst of subsurface methane (Kizyakov et al. 2015, 2016; Liebman et al. 2016)
- **Synthesis of active layer and n-factor data from the EAT** (in progress)
- **ArcticBiomass workshop**, Fairbanks, AK, 2-3 September 2014, and several papers in press and submitted to a special issue of Environmental Research Letters devoted to Arctic Biomass (Walker et al, 2016; Buchhorn et al., 2016; Epstein et al., 2016; Bhatt et al. 2016)
- **Nature Geoscience: Pan-Arctic ice-wedge degradation** (Liljedahl et al. 2016)
- **Four disciplinary and interdisciplinary synthesis papers regarding the EAT**:
  - i) Vegetation (Ermokina, Walker et al, *Phytocoenologia,* in. prep.)
  - ii) Soils (Matyshak et al., in prep.)
  - iii) Permafrost and active layer conditions (Leibman, Drozdov, Khomutov, Romanovsky, et al., in prep.)
  - iv) Spectral-reflectance characteristics of the EAT (Epstein et al*., Environmental Research Letters,* in prep)
- **Synthesis comparing vegetation, soils, permafrost conditions along the EAT and NAAT** (Walker et al., in prep. to *Environmental Research Letters*)
- **Synthesis of sea-ice, land-temperature, vegetation interactions** (Bhatt et al. 2016 in prep. *Biology Letters*)

Component 2: Social-Ecological Effects of Rapid Transitions Due to Infrastructure and Climate Change

- **Yamal-Synthesis Workshop at the Arctic Change 2014 conference in Ottawa, ON, Canada, 9 December 2014** (Yamal LCLUC Workshop and 27 oral presentations and posters)
- **62-year history of cumulative effects infrastructure and climate change in the Prudhoe Bay region**, **AK** (Raynolds et al. 2014, Walker et al. 2015);
- **Rapid Arctic Transitions due to Infrastructure and Climate (RATIC) white paper** (Walker & Peirce ed. 2015) Prepared for ICARP III, Toyama, Japan, presented at the Arctic Science Summit Week 2016, Fairbanks, AK
- **Chapter on Permafrost-Infrastructure interactions in the Snow, Water, Ice, Permafrost in the Arctic (SWIPA) Update (**Romanovsky et al. 2016 in press, Mård et al. 2016 in press)
- **Review of Nenets social ecological systems** (Forbes 2013)
- **Comparison of social impacts Yamal and North Slope** (Kofinas, Forbes, et al. in prep.)
- **Synthesis of international best practices for adaptive management of Arctic local responses to cumulative effects of climate change and resource development** (Curry, Kumpula, Kofinas, Forbes et al in prep).
- **"Grand synthesis" Yamal-North Slope cumulative impacts of development: Biophysical, social, permafrost, remote sensing** (Walker, Kofinas, Forbes et al. *PNAS* in prep.)

Component 3: Remote sensing, modeling, and visualization tools

- **Arctic Report Card: Annual greening synthesis** (Epstein et al. 2015) Includes annual circumpolar sea-ice, land-temperature, and greening monitoring (Bhatt, Epstein, Raynolds, Walker, Comiso, Pinzon, Tucker, et al.) A new development is the recent decline in summer temperature and NDVI in Eurasia probably due to more open Barent and Kara seas, increased sea surface temperatures and increased cloudiness.
- **MODIS-based Circumpolar Arctic Vegetation Map** (Raynolds et al., in prep.)
- **ArcVeg modeling synthesis** (Yu, Epstein)
- **Arctic Biomass Special Issue of ERL** (Tommervik et al. editors)
- **Yamal Arctic Geoecological Atlas (YA-AGA)** (Walker, Ermokhina, Breen, Epstein, Raynolds, Buchhorn, Sibik, Chasnikova, Khumotov, Bartsh, Heim, in prep.)
- **Decision Theater North** (Curry, Kofinas et al. in prep.)

Other:

- **LCLUC All Scientist Meetings 2015 and 2016.** Posters both years and oral presentation in 2016.
- **Posters and talks at the AGU Fall 2014 and 2015 meetings**

The body of the report includes: (1) The proposed study objectives, (2) summaries of the highlights from the past two years, and (3) a list of Yamal Synthesis publications and presentations from 2015-16. A full list of the publications from the entire LCLUC Yamal project along with other project-related information including annual reports, proposals, photos, participants, and workshops is on the new Yamal-Synthesis web page (http://www.geobotany.uaf.edu/yamal/).

Yamal-synthesis study objectives

The two primary goals of the Yamal synthesis activities 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 Arctic 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.

During two earlier rounds of LCLUC funding our Yamal studies had three primary components devoted to: (1) a Eurasia Arctic Transect (EAT) that was originally proposed as part of the International Polar Year (IPY, 2007-2008) activities, (2) analysis of the effects of climate change and infrastructure development on the local social-ecological system that includes indigenous reindeer herders, and (3) modeling and remote sensing studies needed to exatrapolate the results to a larger circumpolar region.

Highlighted accomplishments

The Yamal LCLUC project began in 2007 as an endorsed project of the International Polar Year 2007-8 called "Greening of the Arctic", which focused on the trends in sea-ice, summer land temperature, greening trends, and human interactions with greening along two Arctic transects in North America and Eurasia (Fig. 1).

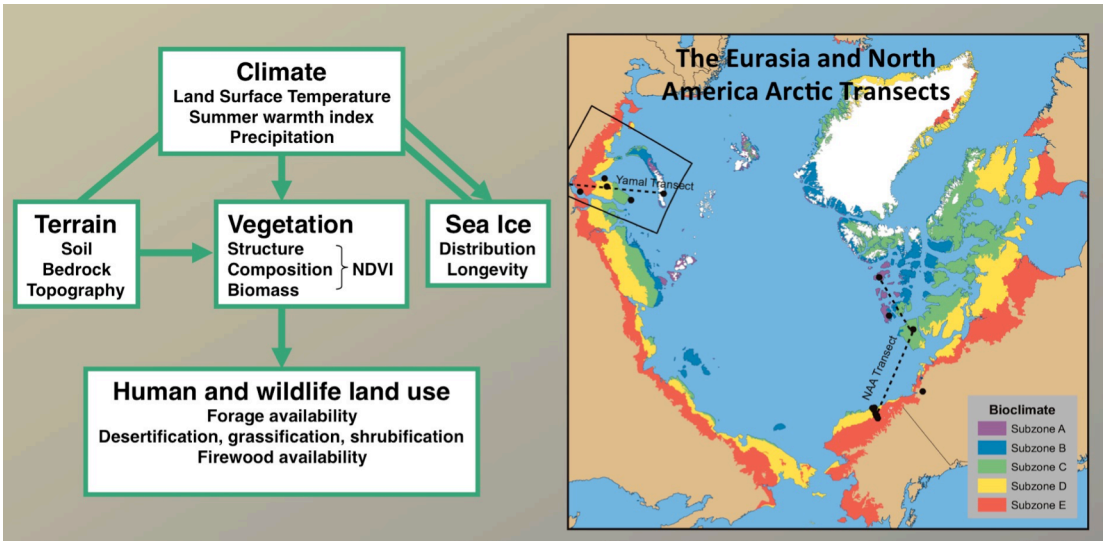

Figure 1. Conceptual diagram of the Greening of the Arctic Project. *The Yamal Synthesis project focuses on activities along the Yamal transect, which was later called the Eurasia Arctic Transect.*

A major achievement during previous rounds of LCLUC funding was the completion of the 1500-km Eurasia Arctic Transect (EAT), which traverses all five Arctic bioclimate subzones from the forest-tundra transition south of the Yamal Peninsula to the extreme High Arctic in Franz Josef Land. The synthesis of the biophysical data from these expeditions is first being accomplished in variety 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 EAT 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).

Progress on Eurasia Arctic Transect Synthesis

Our first Yamal Synthesis project meeting was held in Ottawa, Canada, during the Arctic Change 2014 conference (AC2014), 8-12 December 2014. We received $10,000 from the International Arctic Science Committee (IASC) for Association of Polar Early Career Scientists (APECS) to attend, and four of these were Russian students who participated in the LCLUC activities. There were 8 participants from the USA, 9 from Russia, and 2 from Finland. The meeting focused on review of the commitments in our NASA proposal. Seven disciplinary synthesis papers and three interdisciplinary synthesis papers focused on

results from five Euarasia Arctic Transect expeditions (Fig. 2) are currently in progress. One early highlight is our contribution to a cover story in *Nature Geoscience* that documents the circumpolar occurrence of recent ice-wedge thermokarst (Lijledahl et al. 2016)(Fig. 3).

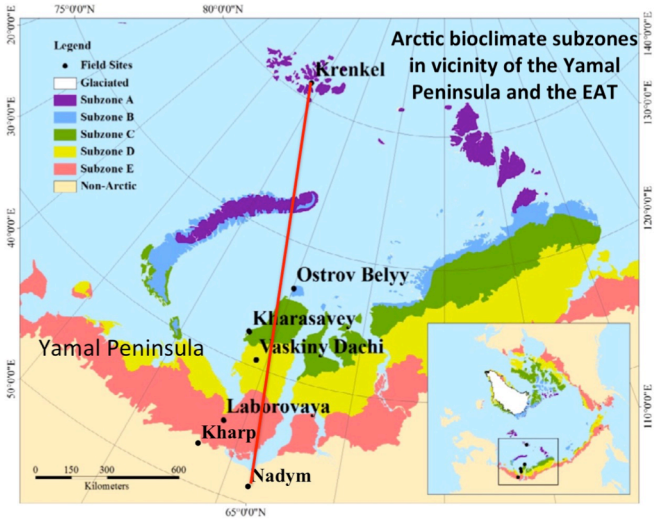

Figure 2. Location of the Eurasia Arctic Transect. The transect is about 1500 km long. It includes study locations in all 5 Arctic bioclimate subzones and two locations in the forest-tundra transition. The transects were established during during five LCLUC-sponsored expeditions in 2007-2011.

***Figure 3. Cover of April 2016 issue of* Nature Geoscience with article entitled "Pan-Arctic ice-wedge degradation in warming permafrost and its influence on tundra hydrology" (Liljedahl et al. 2016).** Five members of the Yamal Synthesis project contributed to the article.

Tundra Greenness and the Greening trends and NOAA Arctic Report Card

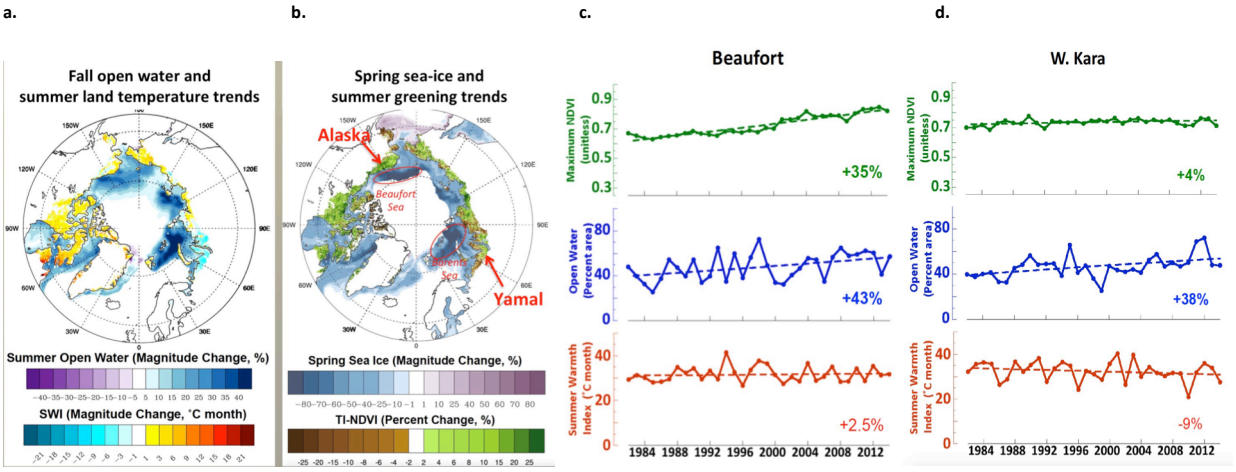

Figure 4. Analysis of trends in sea ice, summer land temperatures and greening. a. *Spatial distribution of trends in open water and summer warmth index (SWI),* ***b.*** *spring sea-ice trends and time-integrated NDVI (TI-NDVI).* ***c*** *and* ***d.*** *Trends in seasonal maximum NDVI, open water, and SWI for the Beaufort Sea and W. Kara. Bhatt et al. 2010 updated to 2015.*

The EAT the North America Arctic Transect (NAAT) (Fig. 1) are well situated to examine two areas of the Arctic that are most strongly affected by rapid sea-ice changes, the Beaufort Sea in the in the vicinity of the NAAT and the Barents/ West Kara seas in the vicinity of the EAT (Fig. 4a & b). Recent analysis of sea ice, land temperature and AVHRR NDVI trends from these two transects show (1) particularly strong positive open water and negative sea-ice trends in the Beaufort and W. Kara seas, (2) summer temperatures increasing in most areas except the Yamal and NW Siberia; and (3) greening is occurring in most areas of the Arctic except NW Siberia, Canadian Archipelago, and Y-K delta. Similar levels of sea ice retreat (blue trend lines, Fig. 4c & d) within 100 km coast along the Beaufort and W. Kara seas, a decline in summer land temperatures (red trend lines, Fig. 4c) on the Yamal vs. a small increase along the Beaufort coast (Fig. 4d). The MaxNDVI (green trend lines) has increased slightly along the W. Kara Sea and strongly increased along the Beaufort. The cooling summer temperature and muted NDVI response in NW Siberia is thought to be linked to midsummer cloudiness and cooling associated with much more open water in the Barents and Kara Seas. These trends are now being reported annually in NOAA's Arctic Report Card (Epstein et al. 2015) (Fig. 5).

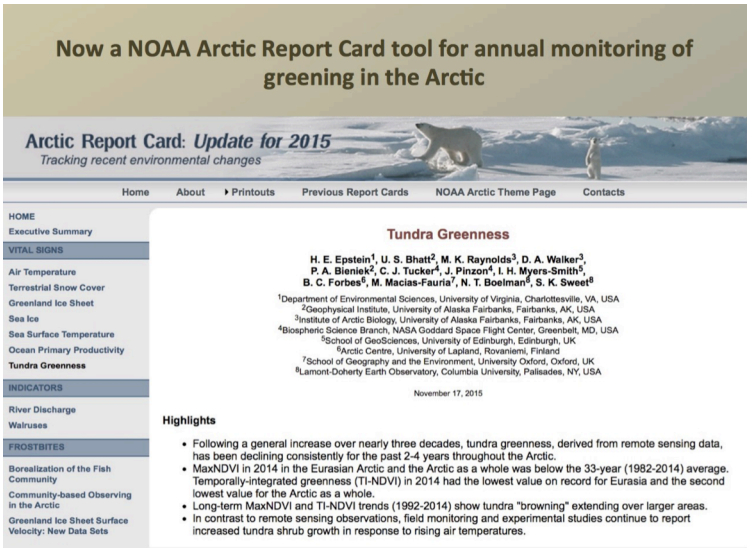

Figure 5. Tundra Greenness home page for the NOAA Arctic Report Card. *http://www.arctic.noaa.gov/reportcard/tundra_greenness.html.*

ArcticBiomass Workshop, Fairbanks, AK, 2-3 Sep 2014 and Environmental Research Letters *focus issue*

Hans Tommervik, Norwegian Institute for Nature Research (NINA), and Scott Goetz, Woods Hole Research Center, were the primary organizers of the ArcticBiomass Workshop, Members of the Yamal LCLUC project assisted in the conference organization and local logistics for the field trip. Twenty papers were presented during the workshop: http://www.geobotany.uaf.edu/yamal/workshops/arcticbiomass-agenda.php. The main topics were biomass estimation and monitoring from plot scale to satellite. Presentations on related themes, e.g. circumpolar arctic and boreal monitoring of vegetation, application of Unmanned Aircraft Systems, and hypersectral spectroscopy were also presented, The workshop resulted in ArcticBiomass special issue for *Environmental Research Letters* (Figure 6) http://iopscience.iop.org/journal/1748-9326/page/Arctic%20Biomass. Six articles have been published to date, with many more coming.

***Figure 6. ArcticBiomass special issue of* Environmental Research Letters.**

Hierarchical remote-sensing analysis of greening trends in Russia

The greening documented at the regional scale in northern Russia is also documented in the hi-res satellite record is reflected in landscape-scale patterns of greening in Landsat time-series across northwestern Siberia (Frost et al. 2013, 2014) (Fig. 7 & 8).

At the plot level, shrub mostly alders is commonly occurring in disturbed sites such as on frost-boil patterned-ground features (Fig. 7). Field studies showed that alder establishment

is closely linked to disturbed mineral soils. The highest rates of shrub expansion were found in northwestern Siberia, where active frost boils are common.

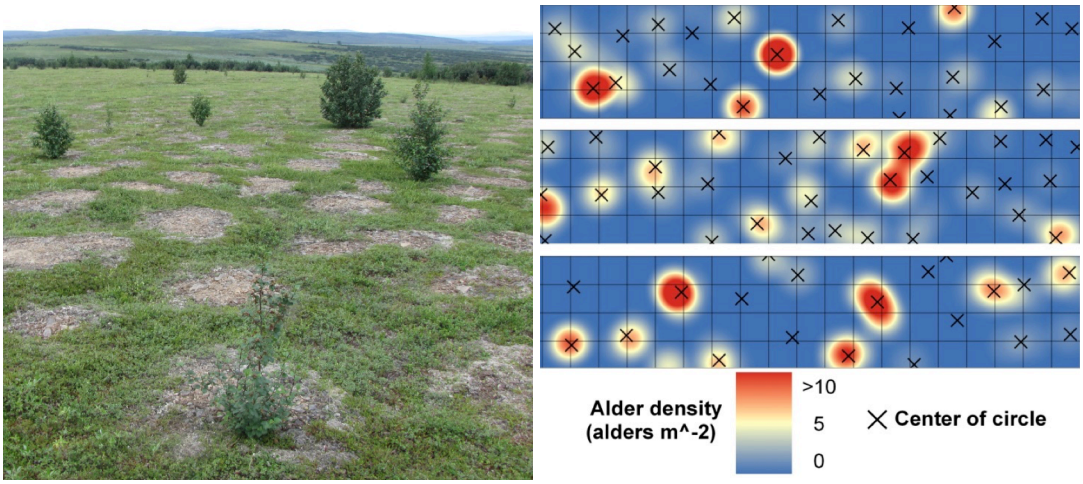

Figure 7. Alder establishment on frost boils near Kharp, Russia. *Frost et al. 2013.* Env. Res. Lett.

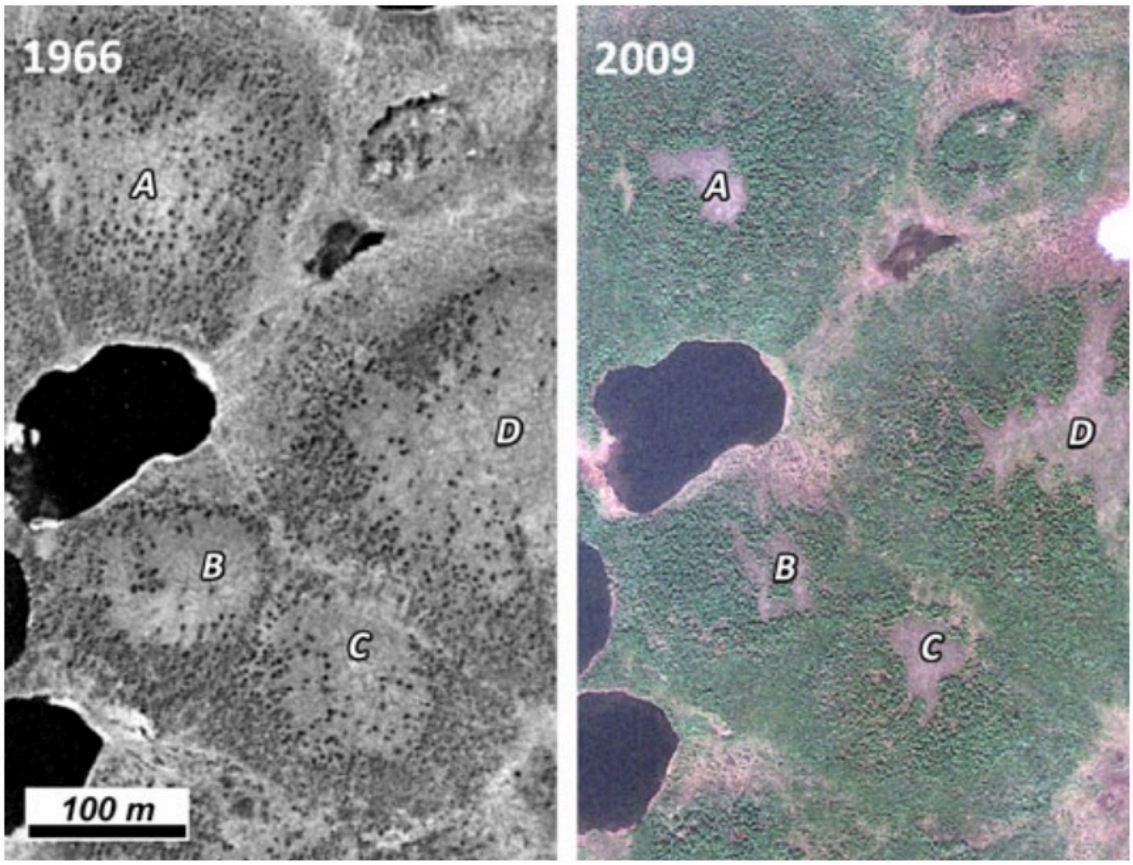

Figure 8. High-resolution imagery from two eras of satellites reveal broad patterns of alder establishment. *Comparison of 1966 (Gambit; left) and 2009 (GeoEye-1; right) imagery showing alder shrubland expansion on hilltops at Dudinka study landscape, northwest Siberia; alder abundance increased 25.9%. GeoEye-1 image © Digital Globe, Inc. (Frost et al. 2014,* Global Change Biology*).*

Synthesis of social-ecological effects rapid infrastructure and climate changes

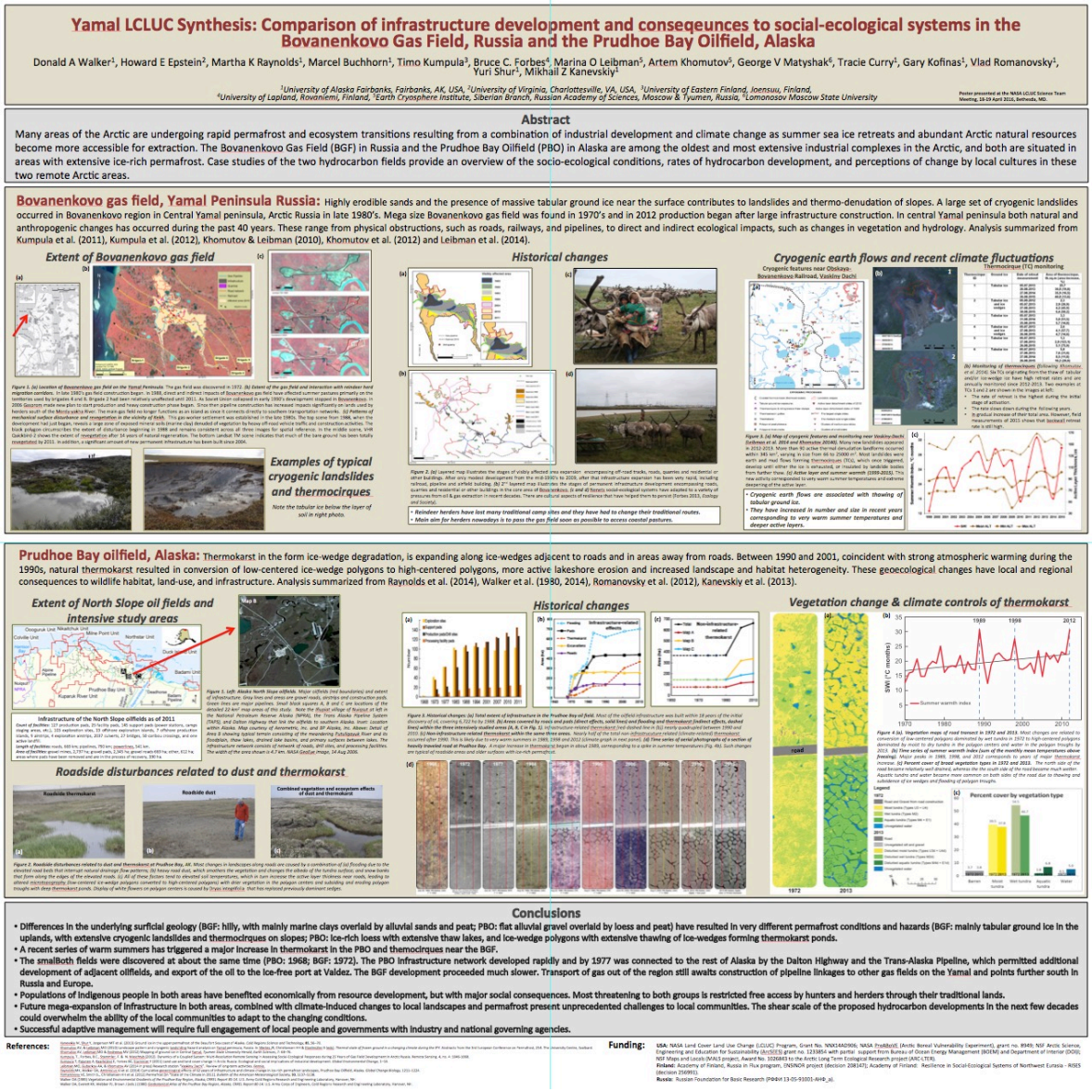

Figure 9. Poster focusing on infrastructure and human dimension at Bovanenkova and Prudhoe Bay presented at the 2016 LCLUC All Scientists Synthesis meeting, Rockville, MD.

The consequences of rapid climate change and resource development vary with different social-ecological systems across the Arctic. This human-dimension component of the study focuses on the different effects hydrocarbon development in the Bovanenkovo gas field and compares the results from a similar analysis of 62-years of history in the Prudhoe Bay oil field, Alaska. It also compares the effects on the reindeer-herding culture of the Yamal Nenets people on the Yamal compared to the hunting culture of the Iñupiat people in Alaska. 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.

To date several posters focused on the comparison of the effects of development on the Yamal Peninsula with those in northern Alaska. These have been presented at the Arctic Change 2015 meeting in Ottawa, AGU 2015 in San Francisco, and the Arctic Science Summit Week in Yohama, Japan, and the LCLUC All Scientist meeting in Rockville, MD (Fig. 9). Synthesis papers are in preparation that will focus on the remote-sensing aspects of these two studies and a grand synthesis of the biophysical and social cumulative effects.

An important synthesis paper was published by Bruce Forbes as part of a special feature in the journal *Ecology and Society* called "Heterogeneity and Resilience of Human-*Rangerfer* Systems: A CircumArctic Synthesis". The paper (Fig. 10) presents an integrated view of two groups of Nenets situated in specific tundra landscapes that face significantly different prospects for adaptation depending on existing or planned infrastructure associated with oil and gas development. The Nenets on the Yamal are affected by a suite of positive environmental factors the have contributed to their relatively positive success compared to the Nenets in another region just to the west of the Yamal, including an abundance of food resources on the Yamal, intact nuclear families with high retention among youth, the accepting attitudes toward climate change and industrial development, consciousness of their role as responsible stewards of the territories, Russian institutions administering reindeer herding accommodate decision-making that is sensitive to herders' needs and timetables, and smaller, privately managed herds that can better utilize available pastures.

Forbes, B. C. 2013. Cultural resilience of social-ecological systems in the Nenets and Yamal-Nenets Autonomous Okrugs, Russia: a focus on reindeer nomads of the tundra. *Ecology and Society* **18**(4): 36.
http://dx.doi.org/10.5751/ES-05791-180436

Research, part of a Special Feature on Heterogeneity and Resilience of Human-*Rangifer* Systems: A CircumArctic Synthesis

Cultural Resilience of Social-ecological Systems in the Nenets and Yamal-Nenets Autonomous Okrugs, Russia: A Focus on Reindeer Nomads of the Tundra

Bruce C. Forbes[1]

ABSTRACT. Empirical data on resilience in social-ecological systems (SESs) are reviewed from local and regional scale case studies among full-time nomads in the neighboring Nenets and Yamal-Nenets Autonomous Okrugs, Russia. The focus is on critical cultural factors contributing to SES resilience. In particular, this work presents an integrated view of people situated in specific tundra landscapes that face significantly different prospects for adaptation depending on existing or planned infrastructure associated with oil and gas development. Factors contributing to general resilience are compared to those that are adapted to certain spatial and temporal contexts. Environmental factors include ample space and an abundance of resources, such as fish and game (e.g., geese), to augment the diet of not only the migratory herders, but also residents from coastal settlements. In contrast to other regions, such as the Nenets Okrug, Yamal Nenets households consist of intact nuclear families with high retention among youth in the nomadic tundra population. Accepting attitudes toward exogenous drivers such as climate change and industrial development appear to play a significant role in how people react to both extreme weather events and piecemeal confiscation or degradation of territory. Consciousness of their role as responsible stewards of the territories they occupy has likely been a factor in maintaining viable wildlife populations over centuries. Institutions administering reindeer herding have remained flexible, especially on Yamal, and so accommodate decision-making that is sensitive to herders' needs and timetables. This affects factors such as herd demography, mobility and energetics. Resilience is further facilitated within the existing governance regimes by herders' own agency, most recently in the post-Soviet shift to smaller, privately managed herds that can better utilize available pastures in a highly dynamic environment experiencing rapid socio-economic, climate and land use change.

Key Words: *Climate change; Hydrocarbon extraction; Nomadism; Rangifer tarandus; Siberia; Stewardship; West Siberian Tundra*

INTRODUCTION

Tundra Nenets nomadism is well known within and outside Russia for both the high quality of the intensive or 'close' reindeer herding (*sensu* Ingold 1980) techniques used and the iconic imagery of a long-distance migratory lifestyle that has all but vanished from most other sectors of the circumpolar Arctic (Stammler 2005*a*). Nenets reindeer herding within the tundra zone straddles the Polar Ural Mountains, its rangelands encompassing >70% of the Nenets Autonomous Okrug (NAO) of the East European Arctic and the Yamal-Nenets Autonomous Okrug (YNAO) of West Siberia (Stammler 2005*a*, Rees et al. 2008). As neighboring federal districts they share key common characteristics. These include the presence of large semidomestic reindeer herds managed by the indigenous Nenets, ongoing large-scale hydrocarbon development and climate warming in the past few decades (Rees et al. 2008, Forbes et al. 2009). Other indigenous peoples practice reindeer herding on the tundra pastures of these regions, such as Komi-Izhemtsy and Khanty in YNAO and Komi-Izhemtsy in NAO, but the present analysis will be limited to tundra Nenets. Ecological drivers are certainly important, and there is evidence for extensive terrestrial and freshwater degradation across these regions from anthropogenic disturbance. Specifically, there has been a shift from shrub- to graminoid-dominated tundra that is persistent over sizable areas in the vicinity of active and abandoned oil and gas infrastructure (Forbes et al. 2009, Kumpula et al. 2011, 2012). At the same time the availability of fish, a critical source of protein for herders during summer migration, has decreased. This is a result of direct and indirect impacts from road, railway, and bridge construction combined with increasing competition from new workers, who fish in rivers and lakes during their free time (Forbes et al. 2009). Symptoms of warming air temperatures commented on by herders in recent years include earlier break up of rivers and lakes in the spring, later freeze up in autumn, more frequent and intensive rain-on-snow events in winter, and hotter summers with a greater degree of insect harassment (Rees et al. 2008, Forbes and Stammler 2009, Forbes et al. 2009, Bartsch et al. 2010).

Observers have often commented on the apparent flexibility of the Nenets when faced with a wide range of exogenous forces during the Soviet and post-Soviet eras (Golovnev and Osherenko 1999, Stammler 2002, Tuisku 2003, Zenko 2004). The Yamal Nenets social-ecological system (SES), in particular, has stood out as being resilient in the face of extreme shocks and pressures in the past 20-30 years (Forbes et al. 2009) and its tundra nomads are generally considered by other herding cultures within modern Russia to be the 'real' reindeer

[1]Arctic Centre, University of Lapland, Finland

***Figure 10. Paper published in special feature "Heterogeneity and Resilience of Human-Rangerfer Systems: A CircumArctic Synthesis" . Forbes 2013,* Ecology and Society.**

Rapid Arctic Transitions due to Infrastructure and Climate (RATIC) initiative

The Rapid Arctic Transitions due to Infrastructure and Climate (RATIC) initiative is a forum for developing and sharing new ideas and methods to facilitate the best practices for assessing, responding to, and adaptively managing the cumulative effects of Arctic infrastructure and climate change. The initiative is endorsed by the International Arctic Science Committee (IASC).

The indigenous people within the Arctic keenly feel the effects of the combination of resource development and climate change, as do governments, agencies, and industries operating in these regions. The effects of the combination of infrastructure and climate change, however, have not received much interdisciplinary scientific study.

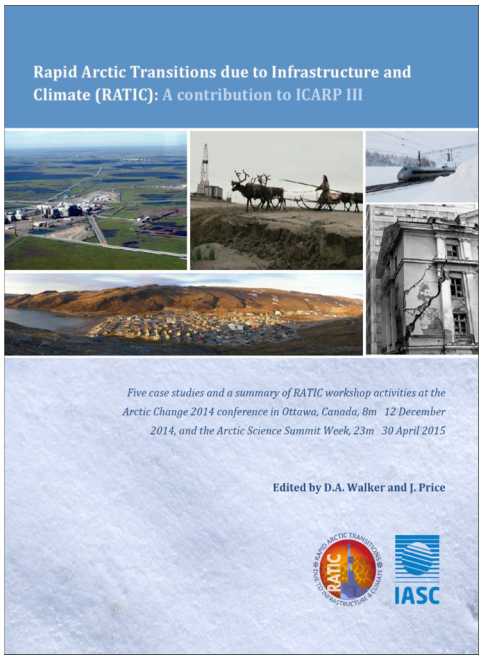

Figure 11. RATIC white paper. *The paper was developed during workshops in 2014 and 2015 and presented at the Arctic Observing Summit, Fairbanks, 11-18 Mar 2016* http://www.geobotany.uaf.edu/library/pubs/WalkerDAed2015-RATICWhitePaper-ICARPIII.pdf.

The RATIC initiatve was developed during workshop and topical sessions at the Arctic Change 2014 conference in Ottawa, 8-12 December 2014, and the Arctic Science Summit Week in Yohama, Japan 23-30 April 2015. The workshops were organized around infrastructure case studies from Alaska, Russia, Norway and Canada. The white paper was presented during the 2016 Arctic Observing Summit in Fairbanks, AK 15-18 Mar 2016. (Fig. 11). The intent of the white paper is to direct more scientific attention to complex infrastructure-related issues during the next decade. As first steps, the RATIC group recommends that the combined IASC Cryosphere, Human and Social, and Terrestrial Working Groups work together to (1) develop an IASC interdisciplinary RATIC Network, (2) incorporate infrastructure-related issues more explicitly in the working groups' research priorities, and (3) promote regular RATIC workshops at international scientific meetings.

Toward adaptive management of infrastructure: UAF Decision Theater North

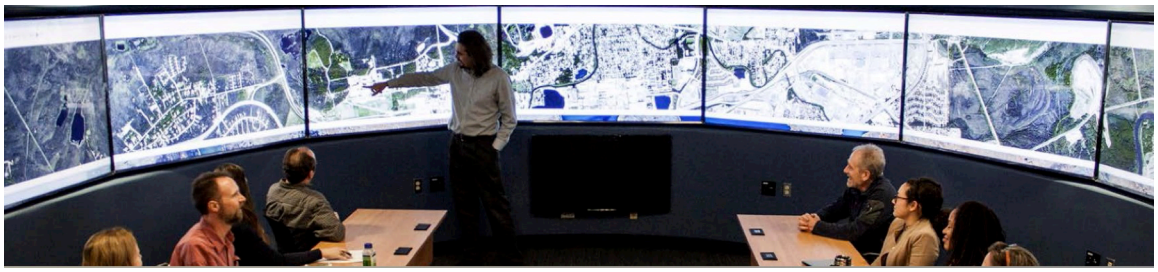

Figure 12. Decision Theater North at the University of Alaska Fairbanks.

A new visualization facility at University of Alaska Fairbanks is designed to facilitate dialogue and decision-making by agencies, industries, communities and academia. The facility contains 7 high definition monitors, high-performance computing and storage, and is configurable to serve as either a conference room or theater. A current focus is a demonstration project that highlights the cumulative effects of road dust and other social-environmental factors along the Dalton Highway in Alaska. The project is the part of a Ph.D. thesis by Tracie Curry at the UAF. She is developing Interactive video with narration and visual media (maps, info-graphics, animations, etc.) to enhance multi- stakeholder communication and collaborative planning efforts.

Special recognition for the Russian contributions.

Figure 13. Members of the 2010 LCLUC Expedition at the Krenkel Hydrometeorological Station, Hayes Island, Franz Jozef Land, 80˚38' N, the furthest north location on the EAT. *Members of the expedition from left to right: Marina Liebman, Artem Khomutov, Andrey Abramov, Dmitriy Drozdov, Elena Slagoda, G.V. (JJ) Frost, Pavel Orekhov, Ina Timling, Andrey Ermak, D.A. (Skip) Walker, Ivan Gameev, Grigory Matyshak.*

The Russian participants, several of which are shown in Fig. 13, have made the Yamal Synthesis possible through their major logistic efforts in arranging five expeditions along the Eurasian Arctic Transect (EAT) and with their many scientific achievements. Participants are from the Earth Cryosphere Laboratory in Moscow and Tyumen, led by Marina Leibman; Moscow State Univeristy, and the Komarov Botanical Institue in St. Petersburg. Their achievements have been made during a time of a difficult political and funding environment between the U.S. and Russia.

A brief summary of their achievements includes:

- Organized field studies and assisting in fieldwork along the EAT. Organized expeditions in 2007 (Nadym, Laborovaya, Vakiny Dachi), in 2008 (Kharasavey), in 2009 (Bely island), 2010 (Hayes island), and 2011 (Kharp).
- Permafrost, active layer, and soil studies at all locations, and revisit of locations to collect data. Annual visits to Nadym and Vaskiny Dachi before and after 2007. Revisited Laborovaya and Bely Island three summers.
- Continued research and recent major publications regarding the unusual landslides on the Yamal Peninsula.
- General physiographical and climate information for all sites along the EAT transect collected from a number of key publications, and presented at Workshops in Moscow, Rovaniemi, and Canada.
- Summary of existing information on vegetation, soils and permafrost for the transect locations and Yamal as a whole. Collected partially and published in a number of papers, mainly in Russian.
- Geobotanical studies at at all sites jointly with US colleagues.
- Organized a Workshop (First Yamal Land-Cover Land-Use Change Workshop Moscow, Russia – January 2008).
- Translation of two Russian (PhD dissertations). 20-page summaries translated.
- Discovery and publication regarding deep craters in Central Yamal.
- Publishing and presenting results at Russian at a number of international conferences, NICOP, EUCOP3, TICOP, EUCOP4, and AC2014.

A new book, *Landslides in Cold Regions in the Context of Climate Change* (Shan et al. 2014) (Fig. 12)*,* contains four chapters produced by Marina Leibman and her colleagues at the Earth Cryosphere Institute in Tyumen and Moscow that synthesize information from several aspects of the landslide situation in the central Yamal Peninsula. The landslides are the result of unusual geologic conditions that create highly dissected landscapes typical of the central Yamal region and which present hazards to gas development and other land uses in this region. Leibman and her colleagues have studied these features since 1989 during annual expeditions to Vaskiny Dachi and other key research sites on the Yamal and Yugorsky peninsulas. These expeditions have examined the strong impact of cryogenic landslides on all components of the geosystem including vegetation, soils, active layer, ground water, but detailed information on these studies were mainly available only in Russian and English abstracts from international permafrost conferences. The overview chapter describes discovery, description, dating and mapping of the Yamal landslides, and suggests mechanisms, forcing factors and triggers of landslide processes (Leibman et al. 2014b). Another chapter assesses the geohazards and mapping of these features using remote sensing methods

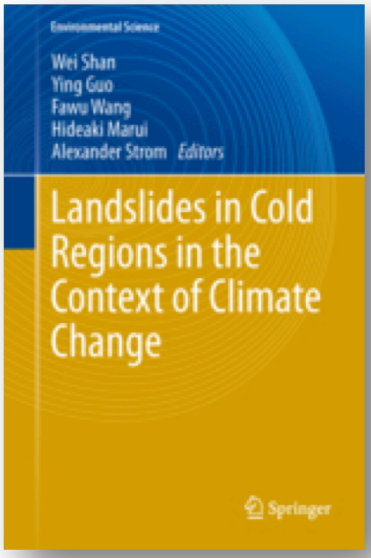

***Figure 12. Cover of* Landslides in Cold Regions in the Context of Climate Change.** Four chapter in the book were written by Marina Leibman and colleagues.

(Khomutov and Leibman 2014). A chapter by Anatoly Gubarkov describes the erosional processes involved with the formation of complex drainage networks associated with landslide terrain (Gubarkov and Leibman 2014). The fourth chapter describes the complex relationships between permafrost, soils, and vegetation (Ukraintseva et al. 2014). This study showed that the landslide process causes desalinization of marine sediments and enriches the active layer with salts that cause unique successional processes for plant communities that colonize the landslide surfaces. This is an important peculiarity of cryogenic landslides in the region with saline permafrost distribution.

The most exciting and totally unexpected event was the discovery of a deep crater that probably formed in fall of 2013 about 25 km southeast of the Bovanenkovo gas field (Fig. 13). Marina Leibman and colleagues described the crater in summer and fall 2014, and published a paper in the Russian journal *Geography, Environment, Sustainability* (Leibman et al. 2014a) and another is in press in *Earth Cryosphere* (Kizyakov et al. n.d.).

The Yamal crater is now known to be one of 3 or 4 that appeared within the last 2 years. A parapet that resulted from expulsion of ice and rocks from beneath to the surface surrounds the crater. The authors conclude that the origin of this crater can be attributed to the air-temperature-warming trend along with the extreme temperatures of 2012. The increased

Figure 13. Yamal crater in summer and winter. *The crater is believed to have formed recently during explosive release of methane that is present in the permafrost. (Photos courtesy of Live Science http://www.livescience.com/49966-siberian-craters-gallery.html).*

ground temperature and amount of unfrozen water in the permafrost, combined with expanding of pockets of methane gas that were produced by gas hydrate decomposition within permafrost, created a pingo-like mound that burst due to high pressure. The event was widely reported in the worldwide media. Two of the best accounts are a 2014 interview of Marina Leibman by Andrew Rivkin, NY Times climate change opinion writer and author of the blog Dot Earth https://www.youtube.com/watch?v=E5fK3TT2GAQ. Another film by the Russian documentary channel RTD provides shows more details of the crater since 2014 and provides video footage of the winter exploration of the crater, the local Nenets people, and good photographs of several other lakes and "pingo-like" features that are hypothesized to be precursors of the craters https://www.youtube.com/watch?v=jc-FFhdNG9A.

Recent and nearly completed publications and presentations

Journal publications in 2015-16

2016

Bhatt, U. S., Walker, D. A., Raynolds, M. K., Bieniek, P. A., Epstein, H. E., Comiso, J. C., Pinzon, J. E., Tucker, C. J., Steele, M. A., Ermold, W. and Zhang. J. 2016. Changing seasonality of Pan-Arctic tundra vegetation in relationship to climatic variables (in prep for special issue of *Environmental Research Letters* on biomass).

Bieniek, P.A., Bhatt, U.S., Walker, D.A., Raynolds, M.K., Comiso, J.C., Epstein, H.E., Pinzon, J.E., Tucker, C.J., Thoman, R.L., Tran, H., Mölders, N., Steele, M., Zhang, J. and Ermold, W. 2016 (in press). Climate drivers linked to changing seasonality of Alaska coastal tundra vegetation productivity. *Earth Interactions,* in press.

Bratsch, S.N., Epstein, H.E., Buchhorn, M. and Walker, D.A. 2016. Differentiating among four arctic tundra plant communities at Ivotuk, Alaska using field spectroscopy. *Remote Sensing* 8:10.3390/rs8010051.

Frost, G.V., Epstein, H.E., Walker, D.A. and Matyshak, G. 2016 (in prep). Changes to active-layer temperature after tall shrub expansion in arctic tundra. *Ecosystems,* in prep.

Kanevskiy, M., Shur, Y., Strauss, J., Jorgenson, M.T., Fortier, D., Stephani, E. and Vasiliev, A. 2016. Patterns and rates of riverbank erosion involving ice-rich permafrost (yedoma) in northern Alaska. *Geomorphology* 253:370-384. doi:10.1016/j.geomorph.2015.10.023.

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Leibman, M., Kizyakov, A., Khomutov, A., Dvornikov Y., Streletskaya I. and Gubarkov, A. Gas-emission crater in Central Yamal, West Siberia, Russia, a new permafrost feature. Geophysical Research Abstracts. EGU General Assembly 2016.

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Raynolds, M.K. and Walker, D.A. 2016 (in revision). Landsat analysis of vegetation change in the area of the Alaska North Slope oilfields, 1985-2011. *Environmental Research Letters*, in revision.

Romanovsky, V., Isaksen, K., Drozdov, D., Anisimov, O., Instanes, A., Leibman, M., McGuire, A.D., Shiklomanov, N., Smith, S., Walker, D.A., Grosse, G., Jones, B.M., Jorgensen, M.T., Kanevskiy, M., Kizyakov, A., Lewkowicz, A., Malkova, G., Marchenko, S., Nicolsky, D.J., Sterletskiy, D. and Westermann, S. 2016 in press. Changing permafrost and its impacts in *Snow Water Ice Permafrost in the Arctic* (Oslo: Arctic Monitoring and Assessment Programme).

Walker, D.A., Daniëls, F.J.A., Alsos, I., Bhatt, U.S., Breen, A.L., Buchhorn, M., Bültmann, H., Druckenmiller, L.A., Edwards, M.E., Ehrich, D., Epstein, H.E., Gould, W.A., Ims, R.A., Meltofte, H., Raynolds, M.K., Sibik, J., Talbot, S.S. and Webber, P.J. 2016 (in press). Circumpolar arctic vegetation: A hierarchic review and roadmap toward an internationally consistent approach to survey, archive and classify tundra plot data. *Environmental Research Letters*, in press.

Yu, Q., Epstein, H.E., Engstrom, R. and Walker, D.A. Circumpolar tundra vegetation dynamics in response to climate change. *Global Change Biology* (to be submitted).

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De Cáceres, M., Chytrý, M., Agrillo, E., Attorre, F., Botta-Dukát, Z., Capelo, J., Czúcz, B., Dengler, J., Ewald, J., Faber-Langendoen, D., Feoli, E., Franklin, S.B., Gavilán, R., Gillet, F., Jansen, F., Jiménez-Alfaro, B., Krestov, P., Landucci, F., Lengyel, A., Loidi, J., Mucina, L., Peet, R.K., Roberts, D.W., Roleček, J., Schaminée, J.H.J., Schmidtlein, S., Theurillat, J.-P., Tichý, L., Walker, D.A., Wildi, O., Willner, W., Wiser, S.K. 2015. A comparative framework for broad-scale plot-based vegetation classification. *Applied Vegetation Science* 18:543–560. doi:10.1111/avsc.12179.

Dvornikov, Yu. A., Khomutov, A. V., Mullanurov, D. R., Ermokhina, K. A., Gubarkov, A. A., Leibman, M. O. 2015 (in press). GIS- and field data based modeling of snow water equivalent in shrub tundra // *Fennia* 193:2, ISSN 1798-5617

Epstein, H.E., Bhatt, U.S., Raynolds, M.K., Walker, D.A., Bieniek, P.A., Tucker, C.J., Pinzon, J., Myers-Smith, I.H., Forbes, B.C., Macias-Fauria, M., Boelman, N.T. and Sweet, S.K.

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Jorgenson, T., Kanevskiy, M.Z., Shur, Y., Moskalenko, N.G., Brown, D.R.N., Wickland, K., Striegl, R. and Koch, J. 2015. Ground ice dynamics and ecological feedbacks control ice-wedge degradation and stabilization. *JGR Earth Surface* 120(11):2280-2297. doi:10.1002/2015JF003602.

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Muskett, R., Romanovsky, V., Cable, W. and Kholodov, A. 2015. Active-Layer Soil Moisture Content Regional Variations in Alaska and Russia by Ground-Based and Satellite-Based Methods, 2002 through 2014. *International Journal of Geosciences* 6(1):12-41. doi: 10.4236/ijg.2015.61002.

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Noetzli, J., H. H. Christiansen, V. E. Romanovsky, N. I. Shiklomanov, S. L. Smith, G. Vieira and L. Zhao, 2015: [Global Climate] Cryosphere, Permafrost thermal state [in “State of the Climate in 2014”]. *Bull. Amer. Meteor. Soc.* 96(7):S17-S18, 2015.

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Walker D.A. and Peirce J.L 2015. *Rapid Arctic Transitions due to Infrastructure and Climate (RATIC): A contribution to ICARP III.* AGC 15-02, Alaska Geobotany Center, University of Alaska Fairbanks, Fairbanks, AK.

Walker, D.A. Buchhorn, M., Kanevskiy, M., Matyshak, G.V., Raynolds, M.K., Shur, Y. and Wirth, L. 2015. Infrastructure-Thermokarst-Soil-Vegetation Interactions at Prudhoe Bay, Alaska. AGC Data Report AGC 15-01, Alaska Geobotany Center, University of Alaska Fairbanks, Fairbanks, AK.

Yu, Q., Epstein, H. E., Engstrom, R., Shiklomanov, N. and Strelestskiy, D. 2015. "Land cover and land use changes in the oil and gas regions of Northwestern Siberia under changing climatic conditions." *Environmental Research Letters* 10(12):124020.

Conference presentations in 2015-16

2016

Buchhorn, M., Prakash, A., Hampton, D.L., Cristóbal-Rosselló, J., Waigl, C.F., Stuefer, M., Graham, P., Walker, D.A. 2016. HyLab: Alaska's In-State Capability for Airborne Imaging Spectroscopy – Applications for Permafrost. XI International Conference on Permafrost, Potsdam, Germany, June 20-24, 2016.

Buchhorn, M., Raynolds, M.K., Kanevskiy, M., Matyshak, G., Shur, Y., Willis, M.D., Peirce, J.L., Wirth, L.M. and Walker, D.A. 2016. Effects of 45 years of heavy road traffic and climate change on the thermal regime of permafrost and tundra at Prudhoe Bay, Alaska. XI International Conference on Permafrost, Potsdam, Germany, June 20-24, 2016.

Dvornikov, Y. and Khomutov, A. 2016. The impact of permafrost thaw and climatic fluctuations on the geochemistry of thermokarst lakes of Yamal peninsula. Geophysical Research Abstracts. EGU General Assembly 2016.

Epstein, H.E., Walker, D.A., Frost, G.V., Raynolds, M.K., Bhatt, U.S. 2016. Plant biomass, NDVI, and LAI along the Eurasian Arctic Transect. XI International Conference on Permafrost, Potsdam, Germany, June 20-24, 2016.

Ermokhina K., Kizyakov A., Leibman, M. and Khomutov A. 2016. GIS of the gas-emission crater area (Yamal peninsula, Russia). XI International Conference on Permafrost, Potsdam, Germany, June 20-24, 2016.

Frost, G.V., Christopherson, T.C., Liljedahl, A.K., Macander, M.J., Walker, D.A. and Wells, A.F. 2016. Regional Patterns and Asynchronous Onset of Ice-wedge Degradation in Arctic Alaska. XI International Conference on Permafrost, Potsdam, Germany, June 20-24, 2016.

Frost, G.V., Epstein, H.E., Walker, D.A. and Matyshak, G. 2016. Changes to Permafrost Active-layer Temperature after Tall Shrub Expansion in Low Arctic Tundra. XI International Conference on Permafrost, Potsdam, Germany, June 20-24, 2016.

Heim, B., Bartsch, A., Buchhorn, M., Beamish, A., Duguay, C., Hoegstroem, E., Widhalm, B., Stettner, S., Elger, K., Walker, D.A., Epstein, H. (2016, in prep.): User and Expert-supported Validation and Evaluation Experiments for high-latitude permafrost landscapes: ESA DUE PERMAFROST (2009-2012) and ongoing programs EnMAP, PAGE21, HGF-EDA. XI International Conference on Permafrost (ICOP 2016), Potsdam, Germany, June 20-24, 2016.

Kanevskiy M., Shur, Y., Walker, D.A., Buchhorn, M., Jorgenson, T., Matyshak, G., Raynolds, M.K., Peirce, J.L. and Wirth, L.M. 2016. Evaluation of Risk of Ice-Wedge Degradation, Prudhoe Bay Oilfield, AK. In: Abstracts of the Eleventh International Conference on Permafrost, Potsdam, Germany, June 20-24, 2016.

Khomutov, A.V., Dvornikov, Y., Leibman, M.O., Gubarkov, A.A. and Mullanurov D.R. 2016. The rates of thermocirque development and driving factors of their activation on Central Yamal, Russia. XI International Conference on Permafrost, Potsdam, Germany, June 20-24, 2016.

Khomutov A.V., Leibman M.O., Dvornikov Yu.A., Khitun O.V. 2016. Study of off-road vehicle trails impact on tundra landscapes by field and remote-sensing methods, Central Yamal, Russia. XI International Conference on Permafrost, Potsdam, Germany, June 20-24, 2016.

Kizyakov A.I., Leibman M.O., Sonyushkin A.V., Zimin M.V., Khomutov A.V. 2016. Gas-emission crater, geomorphological characteristics and relief dynamics on Yamal Peninsula, Russia . XI International Conference on Permafrost, Potsdam, Germany, June 20-24, 2016.

Kumpula, T. and Forbes, B.C. 2016. Changing Pasture Land, Rapid Land Cover Changes and Their Impacts on Nenets Reindeer Herding on the Yamal Peninsula, Russia. Infrastructure in the Arctic (and elsewhere) as a Social and Ecological Challenge, Vienna, Austria, January 15-16, 2016.

Liljedahl, Anna K., Boike, Julia, Daanen, Ronald P., Fedorov, Alexander N., Frost, Gerald V., Grosse, Guido, Hinzman, Larry D., Iijma, Yoshihiro, Jorgenson, Janet C., Matveyeva, Nadya, Necsoiu, Marius, Raynolds, Martha K., Romanovsky, Vladimir, Schulla, Jörg, Tape, Ken D., Walker, Donald A., Wilson, Cathy, Yabuki, Hironori (6). 2016. Recent circum-Arctic ice-wedge degradation and its hydrological impacts. XI International Conference on Permafrost, Potsdam, Germany, June 20-24, 2016.

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Shur, Y., Kanevskiy, M., Walker, D.A., Jorgenson, T., Buchhorn, M., Raynolds, M.K., and Toniolo, H. 2016. Permafrost-Related Causes and Consequences of the Sagavanirktok River Flooding in Spring 2015. In: Abstracts of the Eleventh International Conference on Permafrost, Potsdam, Germany, June 20-24, 2016.

Walker, D.A**.** 2016. Yamal LCLUC synthesis. Invited oral presentation at the NASA-LCLUC All-Scientist Meeting, Bethesda, MD, April 18-19, 2016.

Walker, D.A.,Epstein, H.E., Raynolds, M.K., Buchhorn, M., Kumpula, T., Forbes, B.C., Leibman, M.O., Khomutov, A., Matyshak, G.V., Curry, T., Kofinas, G., Romanovsky, V., Shur, Y. and Kanevskiy, M.Z. 2016. Yamal LCLUC Synthesis: Comparison of infrastructure development and consequences to social-ecological systems in the Bovanenkovo Gas Field, Russia and the Prudhoe Bay Oilfield, Alaska. Presented at the NASA LCLUC Science Team Meeting, Bethesda, MD, April 18-19, 2016.

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Walker, D.A., Peirce, J.L., Kumpula, T., Liebman, M.O., Matyshak, G., Streletskiy, D., Raynolds, M.K., Shur, Y.S., Kanevskiy, M., Buchhorn, M., Kofinas, G., Ambrosius, K., Epstein, H.E., Romanovsky, V., Forbes, B.C., Khumotov, A., Khitun, O., Shiklomnanov, N., Grebenets, V., Lemay, M., Allard, M., Vincent, W., Lamoureux, S., Bell, T., Forbes, D., Fondahl, G., Kuznetsova, E., Roy, L-P, Petrov, A. and Schweitzer, P. 2015. Rapid Arctic Changes due to Infrastructure and Climate (RATIC) in the Russian North. Presented at

2015

Bhatt, U.S., Walker, D.A., Bieniek, P., Epstein, H., Comiso, J., Pinzon, J. and Tucker, C.J. 2015. Climate Variations and Alaska Tundra Vegetation Productivity Declines in Spring. Presented at AGU Fall Meeting, San Francisco, December 14-18, 2015.

Bhatt, U.S., Walker, D.A., Raynolds, M.K., Bieniek, P.A., Epstein, H. E., Comiso, J.C., Pinzon, J.E., Tucker, C. J., Steele, M.A., Ermold, W. and Zhang, J. *Changing Seasonality of Tundra Vegetation in Relationship to Climatic Variables.* Invited presentation at IARC Summer School 2015, Fairbanks, AK, May 2015.

Buchhorn, M., Kanevskiy, M., Raynolds, M., Shur, Y. and Walker, D. A. 2015. Landscape, permafrost, and social change in the Prudhoe Bay region, Alaska. Institute of Arctic Biology (IAB) Life Science Seminar series, Fairbanks, AK, January 23, 2015.

Buchhorn, M., Walker, D.A., Raynolds, M.K., Kanevskiy, M., Matyshak, G.V., Shur, Y. and Peirce, J.L. 2015. Effects of 45 Years of Heavy Road Traffic and Infrastructure on Permafrost and Tundra at Prudhoe Bay, Alaska. Presented at AGU Fall Meeting, San Francisco, December 14-18, 2015.Epstein, H.E., Bhatt, U.S., Raynolds, M.K., Walker, D.A. and Reichle, L.M. 2015. Circumpolar Dynamics of Arctic Tundra Vegetation in Relation to Temperature Trends. Presented at AGU Fall Meeting, San Francisco, December 14-18, 2015.

Forbes, B.C., Kumpula, T., Meschtyb, N., Laptander, R., Macias-Fauria, M., Zetterberg, P.

and Verdonen, M. 2015. Sea ice-induced cold air advection as a mechanism controlling tundra primary productivity. Presented at AGU Fall Meeting, San Francisco, December 14-18, 2015.

Kumpula, T., Verdonen, M., Macias-Fauria, M, Skarin A. and Forbes, B.C. 2015. Arctic Tundra land cover and biomass change on the Central Yamal peninsula, Russia. Presented at Arctic Biomass Workshop, Svalbard, October 20-23, 2015.

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Romanovsky, V., Cable, W., Kholodov, A., Nicolsky, D., Marchenko, S., Panda, S. and Muskett, R. 2015. Detecting and Forecasting Permafrost Degradation in a Warming Climate. Presented at AGU Fall Meeting, San Francisco, December 14-18, 2015.

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