Assessing Alpine Ecosystem Vulnerability to Environmental Change Using Dall Sheep as an Iconic Indicator Species

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Year 1 Annual Report (June 2016)

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1) Project Summary and Objectives

Lack of knowledge about climate change impacts in alpine ecosystems represents a critical gap in our understanding of resilience and vulnerability to environmental change in the Arctic and boreal region of western North America. Declines in Dall sheep populations throughout their range have led to emergency harvest closures and made sheep harvest by far the most contentious wildlife management issue in Alaska. Dall sheep likely function as bellwethers of alpine ecosystem health, and signs are pointing towards increasing ailment. **The overarching goal of our study is to address the question: How are vegetation and snow conditions changing in alpine ecosystems throughout the ABoVE domain, and how do these changes impact iconic northern wildlife and critical ecosystem services?**

We have 4 specific objectives:

(1) Produce time series of snow extent, NDVI, and shrub encroachment throughout alpine areas of the ABoVE domain
(2) Evaluate how these factors affect Dall sheep movements, habitat selection, and population viability
(3) Validate and apply a spatially-explicit snowpack evolution model to produce maps of snow properties at a spatial resolution relevant to wildlife management
(4) Relate our improved understanding of alpine ecosystem dynamics to the societal implications of altered sheep harvest.

2) Year 1 Accomplishments

Activities proposed for Year 1 of this 4-year project consisted of 7 tasks: (1) compilation of existing Dall sheep data, (2) development of snow extent and NDVI products, (3) fieldwork preparation, (4) sheep captures, (5) supervision and training, (6) stakeholder engagement, and (7) meetings and workshops. These activities are shown in the context of our complete project timeline below (Table 1, which is Table 3.4 in the Project Management Plan of our proposal).

Table 1. Dall sheep project timeline.

Activity	Year 1				Year 2				Year 3				Year 4			
	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Product Development & Modeling																
Compile existing sheep data (*Obj. 2*)																
Develop snow extent & NDVI products (*Obj. 1*)																
Develop alpine shrub extent product (*Obj. 1*)																
Snow model development/validation (*Obj. 3*)																
Habitat selection modeling (*Obj. 2*)																
Population viability modeling (*Obj. 2*)																
Harvest modeling (*Obj. 4*)																
Fieldwork																
Preparation (permits, purchasing)																
Sheep captures (*Obj. 2&3*)																
Snow surveys (*Obj. 3*)																
Project Management & Outreach																
Supervision and training																
Stakeholder engagement activities (*Obj. 4*)																
Meetings and workshops																
Manuscript preparation																
Prepare/distribute outreach materials																

Our study has progressed as planned, except that sheep captures have been delayed by a year and will now be conducted in Years 2 and 3. The habitat selection modeling and harvest modeling are already underway, ahead of our original schedule. Accomplishments led by each PI, co-PI, and key collaborator are described below.

Prugh (University of Washington) hired and supervised a technician (Kelly Sivy) to compile existing data on Dall sheep. Data sharing agreements were developed and put in place with the Alaska Department of Fish and Game, National Park Service, Bureau of Land Management, US Fish and Wildlife Service, Parks Canada, Yukon Territory Government, Gwich'in Renewable Resources Board, and Government of Northwest Territories. Harvest data have been compiled, and our database of sheep surveys (aerial counts of sheep in sex and age classes) is 95%

complete. To date, we have compiled data from 4,356 surveys conducted in 1,613 survey units between 1936-2015. We are in the process of creating and quality checking a geodatabase for the survey data, in which the survey data are stored in an Access database and linked to an ArcMap project containing location information for each survey. This geodatabase will be completed by the end of Year 1. We have obtained all available datasets from radio-collared sheep, and the Wrangell St-Elias dataset will be available in 2017-2018. The 11 datasets in hand include a total of 582,193 locations from 448 Dall sheep monitored during a 30-year period (1983-2012; Table 2), as well as associated demographic information (sex, age, body condition, survival, cause of mortality).

Table 2. Datasets of radio-collared Dall sheep.

Dataset	Animals	Years	Locations	Collar type	Data owners
Lake Clark	39	2005-2008	72,171	GPS	Mangipane (NPS)
Denali	18	2007	54,234	GPS	Phillips (NPS)
Yukon-Charley	20	1999-2002	64,000	GPS	Burch (NPS)
Yukon-Charley	23	1997-2000	1,464	VHF	Lawler (NPS)
Gates of the Arctic	25	1998-2002	947	VHF	Lawler (NPS)
Central Alaska Range	150	1999-2005	--	VHF	Arthur (USFWS/ADFG)
Brooks Range	27	2009-2012	36,939	GPS	Arthur (USFWS/ADFG)
Brooks Range	49	2009-2012	--	VHF	Arthur (USFWS/ADFG)
Richardson Range	14	2006-2007	20,267	GPS	Callaghan (GRRB)
White Mountains	27	1983-1989	779	VHF	Herriges (BLM)
White Mountains	56	2004-2008	331,392	GPS	Bertram/Herriges (USFWS/BLM)
Total (in hand)	**448**	**1983-2012**	**582,193**		
Wrangells (future)	*60*	*2016-2018*	*131,400*	*GPS/VHF*	*Lohuis/Putera (ADFG/NPS)*

Prugh participated in the ABoVE Science Team meetings in Minneapolis and Anchorage, and she is an active participant in the Wildlife and Ecosystem Services Working Group. She drafted material about snow-related airborne remote sensing needs for the ABoVE Implementation Plan and Airborne Campaign, and she provided input on Peter Griffith's successful proposal to deploy weather stations at USArray seismic stations. Prugh participated in the first ABoVE Science Cloud webinar, and she has completed the process of obtaining an ASC account.

Prugh arranged quarterly teleconferences with the project team to coordinate activities and maintain communication among lab groups. Three teleconferences have been held so far, with a fourth one planned for the end of Year 1.

Prugh met with collaborators T. Lohuis, J. Putera, B. Borg, J. Lawler, and K. Rattenbury at the ABoVE Science Team meeting in Anchorage. These meetings greatly facilitated plans for fieldwork in the Wrangells and the sharing of NPS sheep survey data. She had several follow up phone calls with T. Lohuis and J. Putera to develop plans for fieldwork. In May, Prugh submitted a permit application for fieldwork in Wrangell St-Elias National Park, which is currently under review. She has begun ordering field equipment and will complete purchasing by the end of

Year 1. In preparation for fieldwork in September, Prugh completed the Wilderness First Aid course offered in Anchorage prior to the science team meeting.

Prugh gave an Earth to Sky webinar about the project on June 14. This webinar was a great opportunity to introduce the project to the public, and to engage with stakeholders and data-sharing collaborators. Twenty people joined the webinar, which was recorded and is available on the Earth to Sky website: http://www.earthtosky.org/professional-development/climate-change/earth-to-sky-climate-change-webinar-archive/details/23/196.html

Prugh completed a successful search for a postdoctoral researcher in March. Four top applicants were interviewed, and an excellent candidate (Madelon van de Kerk) was offered and has accepted the position. Madelon is completing her PhD at the University of Florida and will start a 2-year postdoc position on the project in early August 2016. She will lead population viability analyses of Dall sheep using the survey and telemetry datasets. She has extensive experience with population modeling and an excellent publication record, and we are excited for her to join the Dall sheep team.

Verbyla (UAF) used the MODSCAG daily snow percent product to produce maps of the last day of spring snow throughout the range of Dall sheep from 2000-2015 (Figure 1 shows the 2015 map).

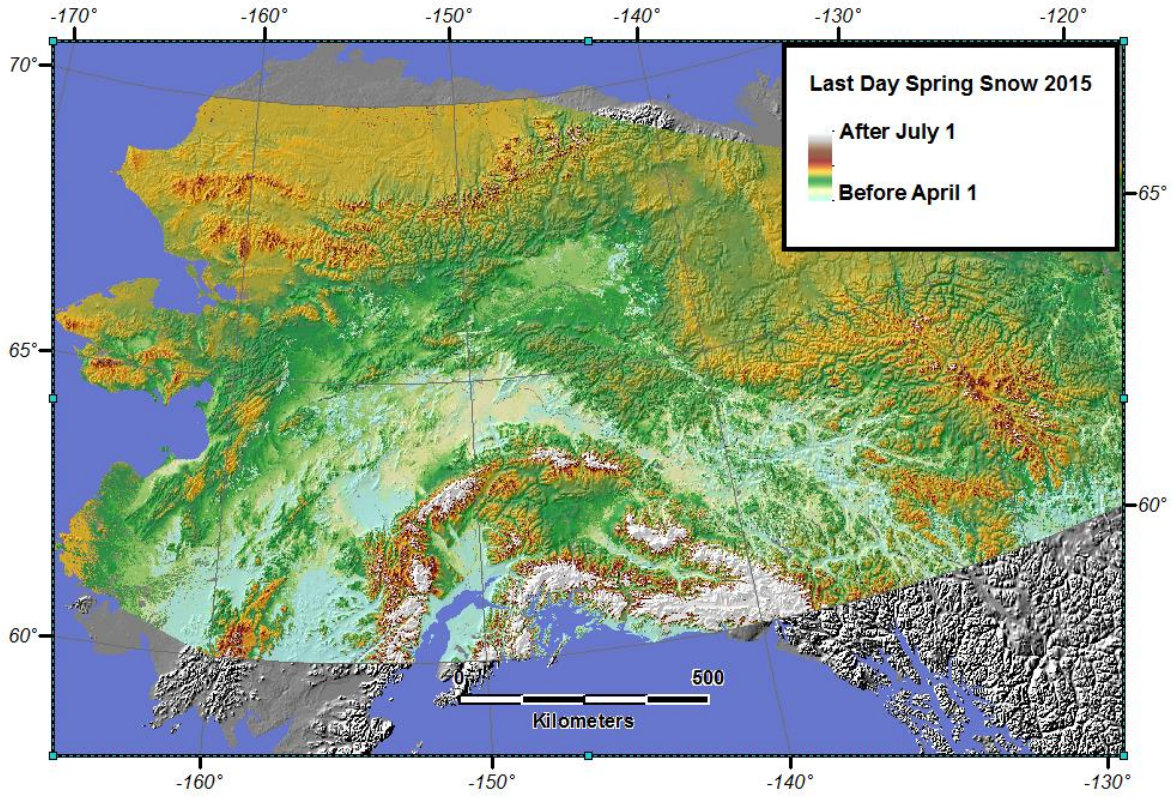

Figure 1. Last day of spring snow throughout the range of Dall sheep in 2015.

Verbyla has successfully recruited a MSc student, Mark Melham, who will start at UAF in August 2016. Under Verbyla's supervision, Melham will map shrub expansion in alpine areas using high-resolution imagery for his master's thesis.

Verbyla has actively engaged in ABoVE Science Team activities. He participated in the meeting in Anchorage, is an active member of the Vegetation Dynamics and Distribution Working Group, participated in Prugh's Earth to Sky webinar, and participated in ASC webinars. He completed the process of setting up an ASC account and has explored use of the ASC.

Verbyla gave an Earth to Sky webinar on April 27, 2016 titled "Remote sensing of greening and browning trends in Alaska." Although not specifically linked to the Dall sheep study, Verbyla explained many of the techniques he will be using to examine alpine vegetation responses to climate change during the webinar.

Nolin (Oregon State University) successfully recruited a PhD student (Chris Cosgrove) to begin at OSU in September. Chris received his MSc from Uppsala University, where he compared snow properties in mountainous areas of the Yukon Territory and Sweden. Under Nolin's supervision, his PhD project will focus on modeling snow properties in the Wrangell St-Elias study area, where he will be conducting ground-based snowpack surveys.

Nolin participated in the International Snow Working Group Remote Sensing meeting held at the University of Washington March 29-31, 2016. A major goal of the meeting was to plan the NASA snow remote sensing field effort (SnowEx). At the meeting, Nolin raised awareness about ABoVE and highlighted the potential for synergies if SnowEx surveys occurred in the ABoVE domain during Phase 1.

Brinkman (UAF) collaborated with state (ADFG) and federal agencies (NPS, USFWS) to organize 30+ years of Dall sheep harvest data. He has been supervising an undergraduate student (Scott Leorna) on this project. They applied a rigorous QA/QC protocol to the harvest database to prepare it for future analyses. They also began collecting fine-scale historic climate data in game management units with high levels of Dall sheep harvest.

Brinkman engaged several stakeholder groups. He initiated an ongoing line of communication with members of the Alaska Board of Game, the ADFG Dall Sheep Working Group, the Resident Hunters of Alaska (RHAK), the Backcountry Hunters and Anglers (BHA), and the Wild Sheep Foundation.

Brinkman has engaged with the ABoVE science team by participating in the meetings in Minneapolis and Anchorage, and he is an active member of the Wildlife and Ecosystem Services working group.

Liston (Interworks Consulting, Inc.) modeled snow properties in the Lake Clark Dall sheep study area to assist Rachlow's habitat selection modeling. Model simulations were performed using SnowModel, a spatially-distributed snow-evolution modeling system designed for application in all landscapes, climates, and conditions where snow occurs. It is an aggregation of four sub-models: EnBal calculates surface energy exchanges and snowmelt; SnowPack is a multi-layer

snowpack sub-model that simulates snow depth and water-equivalent evolution; SnowTran-3D accounts for snow redistribution by wind; and SnowAssim is available to assimilate field and remote sensing datasets.

SnowModel simulations were performed for the period 1 September 2005 through 31 August 2008 (1096 days) over a spatial domain that covered an 88-km by 124-km area in southwest Alaska. Model simulations were performed using a 90-m horizontal grid increment over the domain (~1.35 million grid cells). The simulations used a 1-day time increment.

SnowModel-simulated variables included: surface (skin) temperature, albedo, outgoing longwave radiation, latent heat flux, sensible heat flux, liquid precipitation, solid precipitation, snowmelt, sublimation, snowmelt runoff, and snow water equivalent. Secondary products relevant to Dall sheep were generated, such as the timing and distribution of rain-on-snow events, and changes in snow and growing season lengths. Figure 2 shows a snapshot of the daily snow depth output.

A movie of the snow-depth evolution can be found here: ftp://gliston.cira.colostate.edu/dallsheep/

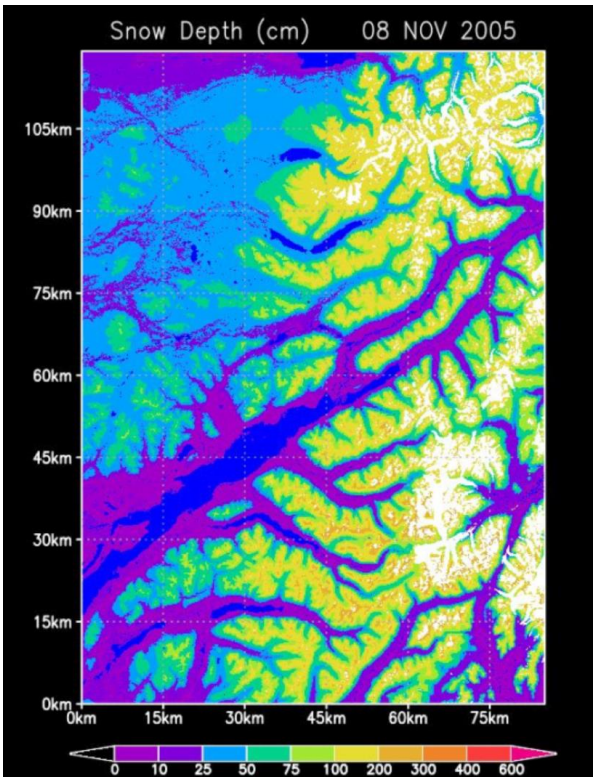

Figure 2. Daily snow depth output of SnowModel runs in the Lake Clark study area.

Rachlow (University of Idaho) is a key collaborator funded by a contract with the National Park Service to model habitat selection of Dall sheep. Rachlow and her team (Jocelyn Aycrigg and Adam Wells) have compiled and quality-checked the telemetry datasets and begun analyses of the Lake Clark dataset as a case study. They collaborated with Liston on snow modeling and

compiled and developed other products such as NDVI, land cover, a ruggedness index, a solar radiation index, slope, and aspect for Lake Clark. The Lake Clark analyses are expected to be completed by the end of Year 1.

3) Year 2 Objectives

Prugh will work with and supervise postdoctoral researcher Madelon van de Kerk in Year 2, with the goal of completing initial Dall sheep population viability analyses and a manuscript for publication. Prugh will assist with fieldwork in the Wrangells in September 2016 and April 2017, and van de Kerk will assist with one field trip. Prugh will participate in science team meetings and workshops in Year 2, and van de Kerk will attend at least one ABoVE meeting and present findings at a scientific conference in summer 2017. Prugh will give an invited talk at the University of Idaho in November 2016, where she will meet in person with Rachlow and her team. Prugh will continue to organize quarterly team conference calls.

Brinkman will model the effects of weather on Dall sheep harvest in Year 2. As more biophysical products become available from project co-PIs, they will be integrated into harvest models to assess the relative influence of several factors on hunting opportunities. Brinkman will attend stakeholder meetings and conferences to provide presentations and updates on project progress and to identify ways that our research can address stakeholder needs and concerns.

Verbyla will assess the temporal and spatial variability of last day of spring snow by elevation zone within each Dall sheep mountain range in Alaska and western Canada. He will also use a time series of daily July snow extent (2000-2015) to delineate the upper snow limit within each Dall sheep mountain range. Within the elevation range of Dall sheep, he will develop a time series of peak summer NDVI at 250 meter pixel size based on the MODIS vegetation index product and assess the relationship between spring snow phenology and peak summer NDVI. M.S. student Mark Melham will use a Landsat TM imagery from the 1980s and Landsat OLI imagery since 2014 to assess shrubline advance in Dall sheep mountain ranges in Alaska and western Canada.

Nolin and the OSU team will validate SnowModel output using field measurements and ground-based climate and snow data. Nolin and Cosgrove will participate in fieldwork reconnaissance in September 2016, potentially adding snow depth sensors to climate stations to be installed by Peter Griffith. Snow validation fieldwork will take place in spring 2017. Under Nolin's mentorship and supervision, Cosgrove will run SnowModel for the study area prior to the spring field season. Nolin will coordinate with Verbyla on analysis of snow remote sensing time series data including MODIS fractional snow covered area, snow disappearance date, and snow cover duration; and passive microwave derived snowmelt onset trends. Nolin will participate in the

SnowEx field campaign and International Snow Working Group for Remote Sensing, and will informally liaise between these groups and ABoVE.

Rachlow and the U Idaho team will complete habitat selection modeling for Lake Clark National Park and Preserve. They will expand habitat selection modeling in other areas with sheep telemetry data, including Denali National Park and the White Mountains. They will draft a habitat selection modeling manuscript. They will begin exploring how to project habitat selection modeling into the future with climate change. They will continue coordinating with the project team to integrate habitat selection analyses into broader project goals.

Liston will work with Nolin and PhD student Cosgrove to expand the snow modeling to other regions with collared sheep datasets. He plans to participate in fieldwork in the Wrangells in April 2017.

4) Changes

Capture and radio-collaring of Dall sheep in the Wrangells was not initiated in November 2015 as originally planned. This component of the study is funded by ADFG and NPS and will be conducted by collaborators Tom Lohuis and Judy Putera. Lohuis and Putera conducted reconnaissance flights in March to finalize selection of study areas, and they met with local hunting guides to coordinate fieldwork plans. Fieldwork is scheduled to begin in 2016. The delay will have minor adverse effects on our project. The GPS collars being deployed on sheep will store location data on the collar, and collars will be retrieved 1-2 years after deployment. Thus, we may not have access to the location data of sheep collared in 2017 before the end of our project. Locations from sheep collared in 2016 should allow us to model the effects of snowpack characteristics on sheep movements before the end of the study, but the sample sizes and variability in snow conditions will be reduced.

5) Publications and Products

None to date.