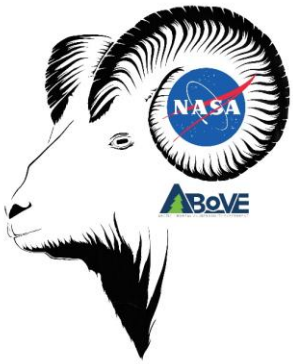
Assessing Alpine Ecosystem Vulnerability to Environmental Change Using Dall Sheep as an Iconic Indicator Species



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Year 2 Annual Report (June 2017)

PI:
Laura Prugh, School of Environmental and Forest Sciences, University of Washington

Co-PIs:
Anne Nolin, Oregon State University
Todd Brinkman, University of Alaska Fairbanks
David Verbyla, University of Alaska Fairbanks

Key Collaborators:
Janet Rachlow, University of Idaho
Glen Liston, Interworks Consulting, Inc.

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 2 Accomplishments

Activities proposed for Year 2 of this 4-year project consisted of 10 tasks: (1) development of snow extent and NDVI products, (2) development of an alpine shrub extent product, (3) SnowModel development/validation, (4) habitat selection modeling, (5) population viability modeling, (6) sheep captures, (7) snow surveys, (8) supervision and training, (9) stakeholder engagement, and (10) 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 in Year 2. Habitat selection modeling, harvest modeling, and manuscript preparation are proceeding ahead of our original schedule. Accomplishments led by each PI, co-PI, and key collaborator are described below.

Laura Prugh (University of Washington)

Prugh's activities in Year 2 consisted of fieldwork, supervision of postdoc Madelon van de Kerk and technician Kelly Sivy, manuscript preparation, participation in the ABoVE science team, and management the overall project.

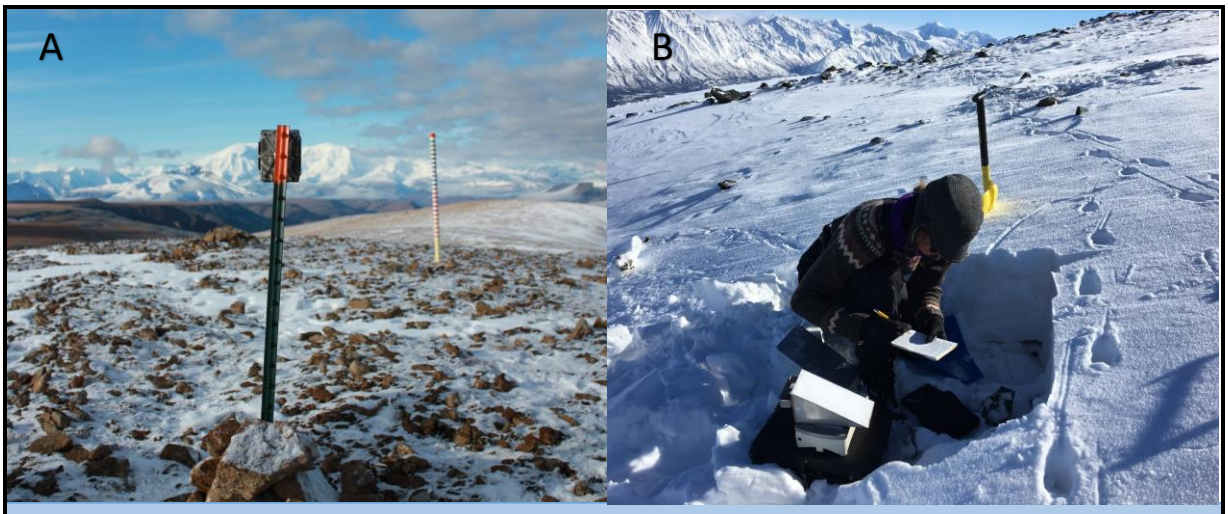

Figure 1. (A) Snow depth station, September 2016, and (B) K. Sivy measuring snow density and Dall sheep track depths during snow surveys in Wrangell St. Elias National Park, March 2017.

Fieldwork. We conducted two field campaigns in Year 2, during Sept 15-21, 2016 and March 17-26, 2017. In September, team members were Prugh, van de Kerk, Nolin, and Cosgrove (Nolin's PhD student). We were flown by Kirk Ellis in his Piper Supercub fixed-wing aircraft to a small hunting cabin on an alpine mesa ~7,000 ft in elevation, where we spent 5 days scouting the area on foot and setting up snow depth stations. We installed 22 stations along three elevational transects. Each station consisted of a game camera set to take a photo of a snow stake every hour (Fig. 1A). We returned in March to swap SD cards in the cameras and conduct snow surveys. The site is not accessible by fixed-wing aircraft in winter, and our only option for accessing the site was via helicopter. Hank Margolis generously provided additional funds ($4,818.40) to cover this unexpected cost. The park was reluctant to allow helicopter use because our study site is in designated wilderness, and amending our permit required weeks of discussions. Team members were Prugh, Sivy, Nolin, and Cosgrove. Snow surveys were successful, and we collected additional data on snow density and sheep tracks (Fig. 1B). Prugh prepared an MSR slide highlighting the results, which are currently in preparation for publication (Fig. 2). This field trip was featured in a NASA Earth Observatory "Notes from the Field" blog entry. Our collaborators J. Putera (NPS) and T. Lohuis (ADFG) captured and GPS-collared 40 Dall sheep rams in our study area in October 2016.

Supervision and manuscript preparation. Sivy continued her work as a part-time technician based in Fairbanks under Prugh's remote supervision. She finalized our geodatabase of sheep surveys, assisted with March snow surveys, and is leading the preparation of a manuscript resulting from the March fieldwork. M. van de Kerk started her postdoctoral position with Prugh at UW in August. She was a member of the September field trip. She developed and maintains our project website: http://dallsheep.weebly.com/. For her first paper, van de Kerk used Verbyla and Nolin's snow products and our sheep survey database to determine how snow conditions affect sheep recruitment. We found late spring snow cover negatively affected recruitment, and this effect strengthened with latitude (Fig. 3). These

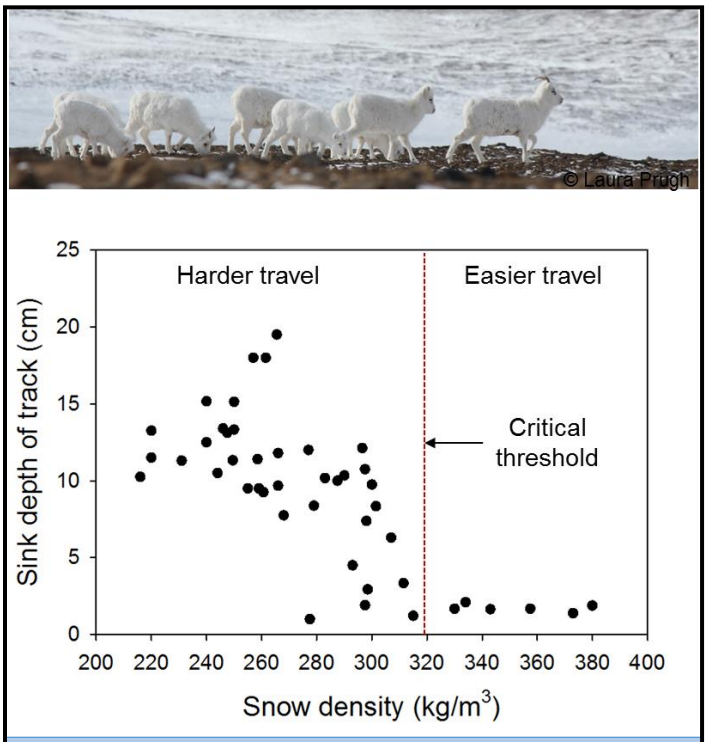

Figure 2. Effect of snow density on Dall sheep snow track sink depths (*n* = 44 tracks).

results show that climate impacts can vary strongly across a species range, which needs to be considered when predicting climate-induced species range shifts. Van de Kerk created a poster for the ABoVE Science Team meeting in Boulder about the findings, which Prugh presented, and she submitted the paper for peer-review publication (van de Kerk et al. submitted, *Journal of Biogeography*). She is giving a talk about the paper on June 23, 2017 at the American Society of Mammalogists meeting in Moscow Idaho, and she will also present the paper at the Ecological Society of America (ESA) meeting in Portland, OR in August 2017. She has begun analyses for her next paper, which will examine climate impacts on Dall sheep survival. She has compiled and quality-checked 10 datasets of radio-collared sheep, and has also compiled climate and snow datasets to use as predictors. Prugh and van de Kerk also assisted with the paper led by Verbyla (Verbyla et al. in revision, *Remote Sensing*).

Science team participation. Prugh participated in the ABoVE Airborne meeting and Science Team meeting in Boulder. She is an active participant in the Wildlife and Ecosystem Services Working Group. Prugh and her Animals on the Move postdoc Peter Mahoney are leading a WES working group collaborative paper, evaluating how modeled and remotely-sensed snow products perform as predictors of animal movements. Liston ran SnowModel at multiple resolutions in our Lake Clark study area, and Mahoney evaluated these products as well as MODIS snow cover and MODSCAG products. Our range-wide analyses have shown that MODSCAG products are useful in predicting Dall sheep recruitment in spring (van de Kerk et al. submitted), but

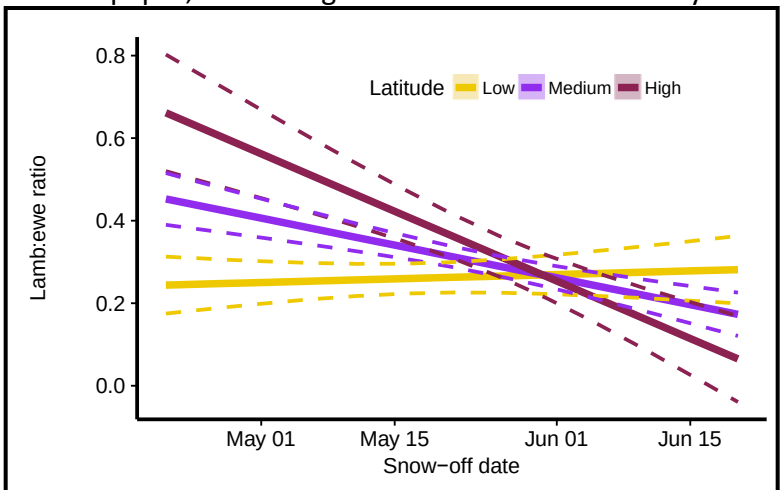

Figure 3. The negative effect of spring snow cover on Dall sheep recruitment rates increases with latitude.

Mahoney's analyses found that MODSCAG coverage was inadequate for use at finer spatial scales during winter in the Lake Clark region. However, his results indicate that Normalized Snow Difference Index (NDSI) derived from MOD/MYD10A1 predicts winter locations of sheep surprisingly well at moderate (500-m) resolutions. A first draft of Mahoney's paper has been completed, and he will present the paper at the ESA meeting in Portland in August.

Project management. Prugh led teleconferences with the project team to coordinate activities and maintain communication among lab groups and agency collaborators. Meetings occur every other month and have included 14-20 participants. These meetings have been a great way to keep our agency collaborators and one another updated about our activities.

David Verbyla (University of Alaska Fairbanks)

Verbyla's Year 2 activities consisted of manuscript preparation, supervision, and analysis. Verbyla led and submitted a manuscript to *Remote Sensing*, which received a "major revisions" decision. A revised manuscript has been submitted. In this paper, we present a novel application of MODSCAG, in which we estimate spring snowline elevation each year from 2000-2016 within 28 mountain areas. The elevation of spring snowline is important for Dall sheep and other alpine species. A late spring and low snowline elevation could delay plant phenology and reduce forage availability and quality. In addition, snow cover may hamper movements and increase the risk of predation. We used Landsat OLI surface reflectance to compute a Normalized Difference Snow Index (NDSI) to validate our MODSCAG based estimates of elevation of spring snowline. The Landsat NDSI and MODSCAG regression estimates had a close agreement (mean difference = 53 m, SD = 78 m) across a wide range of elevations and geographic extent (Fig. 4).

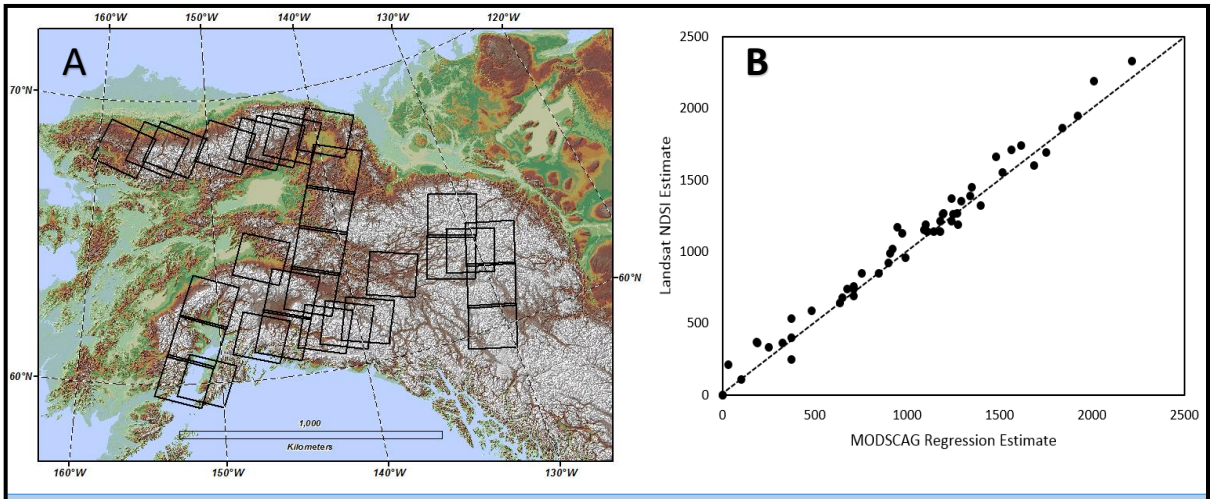

Figure 4. (A) Landsat-8 OLI scenes used to validate MODSCAG-based regression models, and (B) comparison of May snowline elevation estimates from Landsat NDSI and MODSCAG regressions (*n* = 53).

Verbyla is supervising MSc student Mark Melham, who started at UAF in August 2016. Melham has assisted in processing Landsat and NGA imagery that will be used to map shrub expansion in alpine areas. Melham has also added an exciting new component to our project by collaborating with our NPS partners in Gates of the Arctic National Park. He is in the field during summer of 2017 sampling shrub locations to ground-truth Landsat and NGA imagery, and he will also collect sheep pellets for fecal nitrogen analysis. Sheep populations in parts of Gates have experienced alarming declines, and the fecal nutrient analysis will help to link changes in vegetation with impacts on sheep. In addition, Melham put his graphic design skills to use and created a logo for our project (top of page 1).

Verbyla and Melham have made considerable progress developing alpine NDVI products (Objective 1). They merged MODIS NDVI at 250m and 500m pixels (tiles H10V02,H11V02,H12V02), and reprojected from Sinusoidal to Albers NAD38 projection to match the last day of spring snow grids for each year from 2002-2016. They used a reliability flag to filter out unreliable NDVI values for each 8-day composite period and then computed a maximum NDVI from the Aqua and Terra NDVI products for each year. This dataset will be used to examine the relationship between snow cover and NDVI, and it will also be a useful covariate in models of sheep habitat selection and population viability.

Verbyla has actively engaged in ABoVE Science Team activities. He is a member of the Vegetation Dynamics and Distribution Working Group and participates in the ASC webinars. He is an active user of the ABoVE Science Cloud.

Anne Nolin (Oregon State University)

Nolin's Year 2 activities consisted of fieldwork, supervision, analysis, manuscript preparation, and outreach. Nolin is supervising PhD student Chris Cosgrove, who started at Oregon State in September 2016. Nolin and Cosgrove participated in both the September 2016 and March 2017 field campaigns in Wrangell St Elias National Park. The first campaign installed remote camera/snow-stake pairs at 22 sites, the second collected data from the cameras and conducted detailed snow surveys via 22 snow-pits and depth probing both with a Magnaprobe instrument and manually.

In January 2017, Cosgrove spent one week with Liston at Colorado State University receiving expert training in running SnowModel with in-situ observations of snow using the DataAssim package. Using snow observations from the March 2017 fieldwork, Cosgrove has produced SnowModel runs at resolutions between 30m and 1km for the Jacksina Park Unit in Wrangell St Elias (Fig. 5).

Cosgrove made time-lapse videos of the hourly photographs taken by the 22 remote cameras between September 2016 and March 2017, and he developed an image analysis algorithm to extract snow depths. These photos produce a finely resolved time-series of snow depth at each location, which will be used to validate and calibrate SnowModel to produce accurate models of snow-properties at 3 hourly to daily time-steps. The time-lapse videos can also be examined for Dall sheep presence, which may be a useful supplement to the GPS collar data.

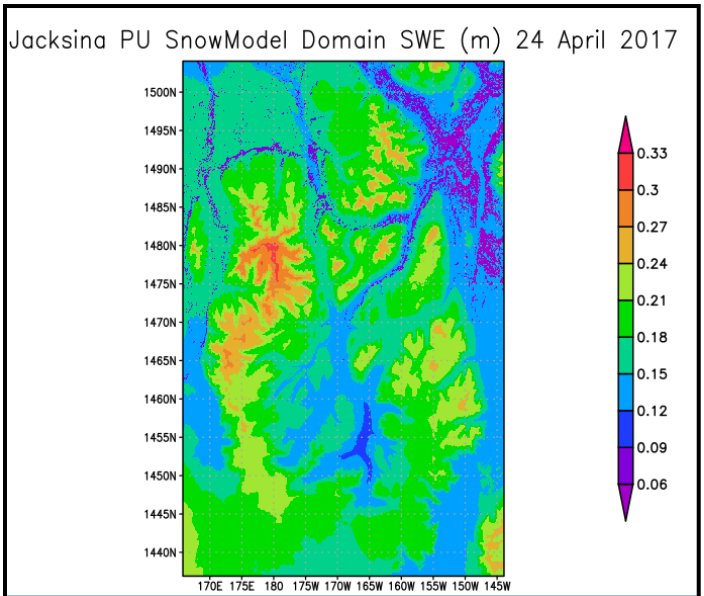

Figure 5: Snow water equivalent from SnowModel, 24 April 2017, in Wrangell St Elias National Park. Axes are in Alaska Albers (m).

In support of Rachlow's habitat selection modelling, Cosgrove produced SnowModel runs with assimilated data from SNOTEL and snow courses for Denali National Park (1 September 2006 to 20 September 2007) and Gates of the Arctic National Park (1 September 1996 to 1 May 2000). Modelling was conducted at daily time steps with a cell resolution of 90m.

We will move snow stations to new locations in September 2017 to increase coverage of the study area and to avoid the need for helicopter transport in March 2018. To aid site selection, Cosgrove wrote a Python/ArcGIS program to randomly locate the 22 cameras in the new area. The program produces sets of randomly selected locations (stratified by distance) until every 90m pixel of the sampling domain has had a camera located within it once. Each set of 22 randomly located points is then programmatically scored for how well it represents the distribution of landscape variables (elevation, aspect, slope, roughness, viewshed). These scores are then used to optimize site selection.

Cosgrove secured a small grant ($750) from the American Alpine Club to develop an open-source, low-power, wireless sensor network of 'weather bots' connected to the inReach satellite network. These bots will be deployed in September 2017 alongside the remote cameras, and they will greatly improve the meteorological data used to force SnowModel because they will be in-situ as opposed to a reanalysis product such as MERRA-2.

Nolin and Cosgrove attended the Mountain Sentinels Participatory Modelling of Social-Ecological Systems workshop in Bend, OR to improve understanding of modelling approaches in social-ecological systems research with a view to employing such methods at the Wrangell St Elias field site. In related work, Nolin collaborated on developing a Future Earth proposal in which the Wrangell site would be part of a social-ecological systems study of mountain environments. Nolin was interviewed for a Protect Our Winters blog focusing on the Dall Sheep project and fieldwork in Alaska (https://protectourwinters.org/blog/sheep-locals-wet-snow/).

Using the NASA MeASURES EASE-Grid 2.0 TB ESDR (an enhanced resolution passive-microwave product – see https://nsidc.org/pmesdr/), Nolin and Cosgrove have performed a preliminary analysis of passive microwave observations over Alaska to begin trying to identify melt/freeze and rain-on-snow events.

Nolin and her team have developed a set of satellite-based snow metrics that can be readily produced using Google Earth Engine (GEE). The two snow metrics relevant to the Dall sheep project include Snow Cover Frequency (SCF, the number of times snow is observed in a pixel over a user-specified date range) and Snow Disappearance Date (SDD, the number day of the year when snowcover is no longer observed in a pixel). SCF and SDD are derived from the MODIS snow cover product and cover the period February 2000 - present. Currently the SCF and SDD are offered via the GEE developers interface but a website version will soon become available in summer 2017. Nolin presented a poster about these new products at the ABoVE meeting in Boulder, and they were used in our paper submitted to the *Journal of Biogeography*.

Todd Brinkman (University of Alaska Fairbanks)

Brinkman's Year 2 activities consisted of supervision, stakeholder engagement, and analyses. Brinkman is supervising Scott Leorna, who started as an undergraduate student in Year 1 and became a MSc student in Fall 2016. Brinkman and Leorna are examining the impacts of weather on Dall sheep harvest in Alaska. Leorna obtained sheep harvest data from our ADFG collaborators, which went back to 1984. He then compiled daily weather data from the Western Regional Climate Center (WRCC) for the state of Alaska for August and September (sheep hunting season) between 1984 and 2015. There were 522 weather stations with average daily weather data available within our time range. Compiled weather data was quality checked, and daily weather was averaged among stations in each Game Management Unit (GMU) subunit to match with harvest data. There were 179 weather stations that had weather data that matched Dall sheep harvest data, and a total of 14,462 harvested Dall sheep that aligned with available average daily weather data.

Brinkman led the stakeholder engagement efforts for the team. He attended the Wild Sheep Foundation Thinhorn Summit II, which was held in Anchorage in April 2017. There, he raised awareness of our project and discussed a future contribution to Wild Sheep Magazine about our study. Brinkman also maintained communication with the Alaska Board of Game Dall Sheep Working Group. He met with the Working Group facilitator to discuss conflict among Dall sheep interest groups and barriers to resolution. These efforts are critical in ensuring the relevance and applicability of our efforts.

Glen Liston (Interworks Consulting, Inc.)

In Year 2, Liston worked with Mahoney to run SnowModel at multiple spatial resolutions in the Lake Clark study area. He participated in the Animals on the Move meeting that preceded the ABoVE meeting in Boulder, which helped to facilitate the collaborative WEG paper Mahoney is leading. Liston also trained Cosgrove in running SnowModel during a week in January 2017.

Janet Rachlow (University of Idaho)

Rachlow 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, Adam Wells, and Oz Garton) have conducted a pilot study using compiled and quality-checked telemetry datasets, multiple modeling covariates (including SnowModel outputs snow extent and snow depth), and a synoptic modeling approach for Lake Clark National Park and Preserve. Currently, we are analyzing the synoptic modeling results by season and by year for our pilot study and writing a paper for publication, which is expected to be written by end of Summer 2017. We are currently running synoptic models for Denali National Park.

3) Year 3 Objectives

Prugh will continue to organize team conference calls and participate in the ABoVE Science Team. Prugh and van de Kerk will submit the Dall sheep survival analysis for publication and complete analysis for a paper on population viability. Van de Kerk will present findings at ESA in August, and she will attend an ABoVE meeting. Prugh and Mahoney will finalize the WES Working Group collaborative paper focusing on snow and Dall sheep movements. Sivy will participate in the September 2017 and March 2018 field campaigns, and she will complete the snow track paper. Prugh will participate in the March 2018 field campaign. Agency collaborators Lohuis and Putera will GPS collar an additional 40 rams in the Wrangells study area. We will upload finalized datasets to the ORNL DAAC in Year 3.

Brinkman and Leorna will complete analysis of the impacts of weather on sheep harvest and submit a paper for publication. They will also begin an assessment of the association between recent Project findings (snow characteristics, range quality, population size) on sheep hunting opportunities (success and effort), and potentially, viewing opportunities. They hypothesize that large fluctuations in annual snow characteristics (especially late spring snow conditions) will be reflected in sheep harvest data. Sheep population declines, particularly those resulting from low lamb survival, will be reflected in the sheep harvest data approximately 6-8 years after the low survival year. The time lag is a result of the full-curl harvest regulation. They also hypothesize that declines in range quality of sheep populations will cause a gradual decline in sheep harvest trends. Brinkman and Leorna will explore the relationship between sheep population trends and Board of Game proposals and regulation changes. At the request of ADFG, they will begin assessing the relative effects of biological factors (i.e., population change) on BOG proposals and regulations, relative to social factors (e.g., hunter competition and conflict).

Verbyla will develop a time series of 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. 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. Melham will be in the field summer of 2017 with collaborators from the National Park Service sampling for shrub location and sheep fecal nitrogen within the south slope and north slope of the Brooks Range.

Nolin and Cosgrove will finalize the calibration and validation of SnowModel for use in Wrangell St Elias. They will produce a 30-yr historical daily time-series of snow conditions including depth, density, and melt status. Snow stratigraphy measurements from the March 2017 field campaign will inform parametrization of SnowModel's function that models a multi-layered snowpack. Emphasis will be placed on modelling the density and hardness of the snowpack in support of Prugh/Sivy's research into the energetics of Dall sheep winter travel and foraging. Higher atmosphere MERRA-2 gridded meteorological data will be used with the aim of improving simulation of wind transport and sublimation of snow on high mountain ridges. Additionally, SnowModel will be run for additional study areas in Rachlow's habitat selection modelling. Cosgrove will develop the wireless sensor network weather bots over summer for deployment in September 2017, and he will author an accompanying publication. Nolin and Cosgrove will complete their investigation into detecting melt/freeze and rain-on-snow events across the ABoVE domain, with special attention to the Dall sheep ranges. These results will be examined alongside SnowModel output and Dall sheep observation data. Nolin and Cosgrove will produce a publication describing the results of the passive microwave investigation. Cosgrove will lead the August/September 2017 field campaigns in the Wrangell St Elias to take in the remote camera/snow-stake pairs and redeploy them in a new location. He will participate in the March 2018 field campaign to gather the data and conduct further snow surveys. Cosgrove will present his research at AGU 2017, the Western Snow Conference 2018 and AAG 2018.

Rachlow and the U Idaho team will expand habitat selection modeling in other areas with sheep telemetry data, including Denali National Park and the White Mountains. They will complete 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 continue to advise Cosgrove in running SnowModel, and he will contribute to publications.

4) Changes

Our plans in Year 2 did not deviate from our proposal; tasks are being completed according to or ahead of schedule.

5) Publications and Products

Peer-reviewed publications

1) Verbyla, D, T Hegel, A Nolin, M van de Kerk, T Kurkowski, L Prugh. In revision. Remote sensing of alpine spring snowline in Dall sheep mountain ranges of Alaska and western Canada. Remote Sensing.
2) van de Kerk, M, D Verbyla, AW Nolin, KJ Sivy and LR Prugh. Submitted. Effects of climate on population performance vary with latitude. Journal of Biogeography.
3) Mahoney PJ, Liston G, LaPoint S, Gurarie E, Mangipane B, Wells A, Brinkman T, Hebblewhite M, Nolin A, Boelman N, Prugh L. In prep. Navigating snowscapes: scale-dependent responses of mountain sheep to snowpack properties. For Journal of Applied Ecology.
4) Sivy, KJ, AW Nolin, C Cosgrove, LR Prugh. In prep. Critical snow density threshold for Dall sheep. For Canadian Journal of Zoology.

Presentations

5) van de Kerk, M, D Verbyla, AW Nolin, KJ Sivy, LR Prugh. 2017. Climate change may adversely affect Dall sheep populations through variation in snow extent. Annual Meeting of the American Society of Mammalogists, Moscow ID (oral presentation).
6) van de Kerk, M, D Verbyla, A Nolin, K Sivy, L Prugh. 2017. Effects of snow cover on Dall sheep recruitment. NASA ABoVE Science Team Meeting, Boulder CO (poster presentation).
7) Cosgrove, C, and A Nolin. 2017. Characterizing mountain snowpack for Dall sheep. NASA ABoVE Science Team Meeting, Boulder CO (poster presentation).
8) Nolin, A, R Crumley, E Mar. 2017. Innovations in snow cover mapping for Dall sheep. NASA ABoVE Science Team Meeting, Boulder CO (poster presentation).

Outreach

9) Project website: http://dallsheep.weebly.com/
10) UW “notes from the field” blog entry (18 Oct 2017): http://depts.washington.edu/sefsblog/notes-from-the-field-alaskas-wrangell-mountains/
11) NASA Earth Observatory “notes from the field” blog entry (9 May 2017): https://earthobservatory.nasa.gov/blogs/fromthefield/2017/05/09/snow-surveys-and-dall-sheep/
12) Protect our Winters blog entry (6 June 2017): https://protectourwinters.org/blog/sheep-locals-wet-snow/