2016 Annual Progress Report for

Evaluating Adaptive Capacity of Desert Bighorn Sheep to Climate Change: Identifying Genetic Links to Climate Adaptations in Native and Reintroduced Populations

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Since the previous progress report for 2015, this project has been continued. Following is a summary of research activities for the project that have occurred to date.

Problem statement and implications: As outlined in our original proposal, we are studying the genetic basis for drought and heat tolerance among herds of desert bighorn sheep occupying the southwestern United States. Regional variability in climatic conditions throughout the native range of bighorn sheep suggests strong potential for local adaptation. Increased occurrence of extreme droughts, overall decline in precipitation and increase in temperature due to climate change has the potential to detrimentally affect desert dwelling species such as bighorn sheep. Better understanding of the alleles, or suites of co-adapted alleles, conveying adaptive advantage to specific climatic conditions will help facilitate conservation of this and other species in the face of continued climate change.

Goals and objectives: We propose to conduct reduced-genome scans to identify loci under selection. We will then correlate the presence/absence of alleles at those loci with specific climatic conditions. The overall project objectives are to: 1) assess whether bighorn sheep exhibit local adaptations to desert ecosystems experiencing different seasonal climatic conditions; and 2) develop recommendations for management actions that maximize the evolutionary potential of this taxon. Our hypothesis and predictions are as follows:

> *Hypothesis:* Variation in climatic conditions will create varying selection regimes among desert bighorn herds with regard to water availability, forage quality, heat/cold stress, and disease susceptibility to which individuals will show local adaptation.
>
> > *Prediction 1:* (*Population genomic approach*): Desert bighorn herds subjected to significantly different climatic conditions will have different allele frequencies at loci under selection.
> >
> > *Prediction 2:* (*Landscape genomic approach*): A correlation will exist between the gradient of climate variables and the distribution of allele frequencies at adaptive loci across the landscape.

Project activities during reporting period and current status: Postdoctoral researcher Michael Buchalski successfully integrated restriction enzyme-assisted digest sequencing (RAD-seq) library preparation methods into the existing laboratory infrastructure of Dr. Clinton Epps. A total of 411 bighorn sheep DNA samples were subsequently sequenced by RAD-seq on the Illumina 3000 platform by the Genomic Sequencing and Analysis Facility at the University of Texas. Genotypes were determined at ~ 9,076 single nucleotide polymorphism (SNP) loci, with < 20% missing data. Locations of the mountain ranges from which bighorn sheep samples were sequenced are shown in Fig. 1. The number of individuals sequenced per location is summarized in Table 1.

Environmental data suitable for landscape genomics analyses have been obtained from publicly available repositories. Data selection was guided by our hypotheses and literature review on the effects of different climatic variables on the fitness of domestic sheep and goats. Bioclimatic predictors based on 30-year averages were obtained for down-scaled PRISM data at 400 m resolution (http://pubs.usgs.gov/ds/691/ds691.pdf). A list of these bioclimatic predictors is

presented in Table 2. Digital elevation data was obtained from the USGS National Elevation Dataset. Elevation data tiles at 1-arc second resolution were downloaded to create a digital elevation model for the study area. In addition, we have obtained normalized difference vegetation index (NDVI) data layers at 1 km resolution from the CONUS AVHRR remote sensing phenology data set (http://phenology.cr.usgs.gov/get_data_1km.php). Lastly, shapefiles demarcating occupied bighorn sheep habitat for the sites included in our investigation were obtained from the Western Association of Fish and Wildlife Agencies (WAFWA). Habitat polygons are depicted in Fig. 1.

Table 1. Locations and sample sizes for which RAD-seq has been completed. Locations correspond to Fig. 1

Wheeler Ridge, CA	8	Arrow Canyon, NV	2
Sawmill Canyon, CA	2	Lone Mountain, NV	11
Mt. Baxter, CA	6	McCullough Mtns, NV	6
Mt. Williamson, CA	4	Mormon Mtns, NV	12
Mt. Langley, CA	8	River Mtns, NV	9
Carrizo Canyon, CA	3	Black Mtns, AZ	8
Vallecito Mtns, CA	9	Virgin Mtns, AZ	13
San Ysidro Mtns, CA	4	Cabeza Prieta NWR, AZ	5
C. Santa Rosa Mtns, CA	10	Canyon Lake, AZ	12
San Gabriel Mtns, CA	14	Castle Dome Mtns, AZ	7
Hackberry Mtns, CA	5	Kofa Mtns, AZ	6
Marble Mtns, CA	13	Grand Canyon NP, AZ	12
Queen Mtns, CA	7	Plumosa Mtns, AZ	4
Old Woman Mtns, CA	6	Silverbell Mtns, AZ	10
N. Bristol, Mtns, CA	10	Trigo Mtns, AZ	8
S. Bristol, Mtns, CA	12	Peloncillo Mtns, NM	2
Clipper Mtns, CA	12	Fra Crystobal Mtns, NM	14
Granite Mtns, CA	2	Red Rock WA, NM	9
Soda Mtns, CA	2	Manzano Mtns, NM	6
Old Dad Mtns, CA	13	Pecos Wilderness, NM	10
N. White Mtns, CA	19	Wheeler Peak, NM	9
S. White Mtns, CA	7	Beach Mtns, TX	9
Death Valley NP, CA	5	Sierra Diablo Mtns, TX	12
Panamint Mtns, CA	2	Elephant Mtn WMA, TX	3
Gabbs Valley, NV	9		

Table 2. List of environmental variables that will be screened against loci under selection to detect desert bighorn sheep local adaptation.

Suite	Description
Temperature	1. Annual Mean Temperature[1]
	2. Mean Diurnal Range – Monthly and annual[1]
	3. Isothermality (No. 2/No. 7) (* 100)
	4. Temperature Seasonality (standard deviation *100)
	5. Max Temperature of Warmest Month
	6. Min Temperature of Coldest Month
	7. Temperature Annual Range (No. 5 – No. 6)
	8. Mean Temperature of Wettest Quarter
	9. Mean Temperature of Driest Quarter
	10. Mean Temperature of Warmest Quarter
	11. Mean Temperature of Coldest Quarter
Precipitation	12. Annual Precipitation
	13. Precipitation of Wettest Month
	14. Precipitation of Driest Month
	15. Precipitation Seasonality (Coefficient of Variation)[1]
	16. Precipitation of Wettest Quarter[1]
	17. Precipitation of Driest Quarter[1]
	18. Precipitation of Warmest Quarter
	19. Precipitation of Coldest Quarter
	20. Number of day with > 0.1 mm rain per month[1]
Other	21. Altitude
	22. Normalized difference vegetation index (NVDI)

[1] Indicates climate variable that showed significant association with allele frequencies in domestic sheep and goat breeds.
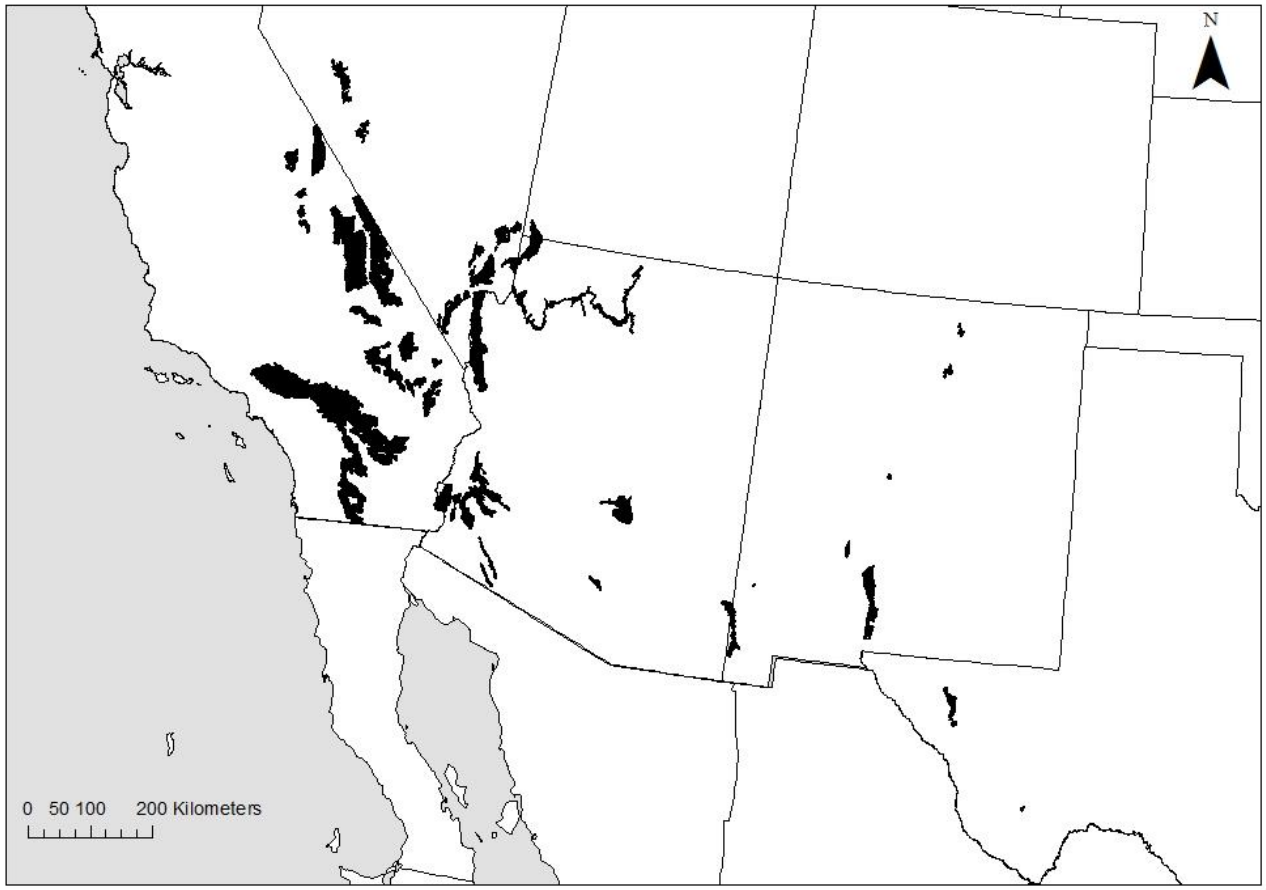
Fig. 1. Bighorn sheep-occupied mountain ranges sampled as part of this investigation.