Dartmouth in Namibia

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October-November 2015

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!Nara Phenology and Pollination

November 14, 2015

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Introduction

Successful plant development relies on a carefully orchestrated series of events. Plant phenology, or the timing of events in a plant's life, is in part determined by environmental variables. There is always a risk that environmental change will destabilize its phenological patterns or those of its pollinators, or even put the life cycles of pollinators and plants out of sync. This phenomenon is known as phenological mismatch, and in extreme cases it can result in the extinction of plants and pollinators (Harrison 2000; Wall et al 2003; Memmott et al 2007). Climate change presents one such extreme case, so it motivates research on phenology (Kearns et al 1998; Biesmeijer et al 2006; Memmott et al 2007). The primary objective of this research is to explore the relationship between a handful of environmental factors and plant phenology – emphasizing pollination – to begin to understand the phenological impacts of climate change.

Climate change predictions have been largely focused on rises in global temperature. Increasing mean temperatures are linked to advancement in plant and pollinator phenology. Temperature is one of the main indicators that plants use to determine when to flower. In temperate zones, the average advancement of first flowering and pollinator flight activity was four days per degree Celsius increase in temperature in the 20th century (Memmott et al 2007).

Water availability also cues plant phenology and is in flux due to climate change.
Earlier rainfall provokes earlier and prolonged flowering seasons (Sakkr et al 2015). Research predicts that rainfall variation will increase due to climate change, destabilizing patterns that plants depend on (Bates et al 2008). Fog events and groundwater availability are associated with phenological advancement in plants (Kidron et al 2002). Climate change may pose a serious risk to fog-reliant areas, increasing or reducing frequency of fog by as much as 30% (Torregrosa et al 2014). Sea level rise will make groundwater more saline and fluctuations in rainfall will make its availability less stable (Bates et al 2008). Changes to temperature, fog, rainfall, and groundwater will differ around the world and may occur slowly. There is a need for long term monitoring at sites where these variables and their relationships to plant phenology are being studied.

Long term monitoring of ecological systems is an important way to record changes and make predictions for future climate change impacts (Magurran 2010). Monitoring plant phenology is especially crucial in extreme environments with few species and sensitively balanced ecology. The Namib Desert, with its famous !nara (*Acanthosicyos horridus)* shrub, fits the bill. The !nara provides food and shelter to animals, and fruit and seeds to the local Topnaar people (Maggs-Kölling 2014; Henschel et al 2004). The !nara has been a long term focus of study at The Gobabeb Research and Training Center, particularly for visiting Dartmouth students in 2013 and 2014. Dartmouth groups have recorded !nara plant size, flower and fruit count, and have also set up a long term monitoring program. Beitler et al (2014) found that between November 2013 and 2014, live biomass and total fruit count decreased in the !Nara Valley. Our research, in conjunction with Gardiner et al (2015), provides an additional year of data on fruit counts and live biomass for the nearby Gobabeb Valley and initiates long term monitoring there. We also add a second year of data to the pollination study initiated by Beitler et al (2014). Due to the regional variability of climate change impacts, studying the Namib Desert at a small scale is essential before understanding the impacts of climate change on the !nara throughout Namibia. Finally, we

conducted new research on !nara phenology, as this has been minimally researched and may change due to climate change.

Fog in the Namib Desert

In and around the Namib Desert, the fog-rainfall gradient creates a stark contrast between the coastal and inland environments (Hachfeld and Jurgens 2000). For areas nearer to the coast, fog is a central source of moisture for plants and animals. Advection fog is transported by the Benguela current and moves from the southwest. The southwesterly wind, one of the region's two prevailing winds, carries the sea fog inland from the Atlantic Ocean, pummeling dunes and vegetation in the Namib with costal sand. This keeps the coast considerably colder and more humid than areas further inland (Dirkx et al 2008). Inland, plants source their water from small amounts rainfall rather than fog (Hachfeld and Jurgens 2000). Inland, the climate is generally very hot and dry due to the comparative absence of fog. Gobabeb Research and Training Center is situated in the middle of the fog-rainfall gradient. At Gobabeb, rainfall varies from 0 to 200mm per year, averaging around 22mm. The importance of fog for plants around Gobabeb is unclear.

Ecosystems in sensitive desert environments with limited water are vulnerable to even small changes in fog or rainfall induced by climate change. Temperature increases for Namibia in the twentieth century were three times the global average (Schneider et al 2015). Climate modeling for 2036-65 predicts surface temperature increases of 0.6-3.5 degrees Celsius. Temperature increases are estimated to be less dramatic near coastal areas and more severe inland (Schneider et al 2015). Unfortunately, most other impacts of climate change on the Namib are still unknown, particularly fog (Turpie et al 2010; Dieckmann et al 2013; Schneider et al 2015). One study using on-the-ground capture and satellite imagery predicts an increase in fog days per year for coastal areas and a decrease inland, with a strengthening of the southwesterly winds that carry fog (Haensler et al 2011; Dirkx et al 2008). Rainfall patterns are expected to change, but different models have predicted both an increase and a decrease in rainfall across the Namib (Schneider et al 2015: 11). The Namib Desert experiences dry spells linked to El Niño events, and climate change is expected to cause more erratic weather events and reduce the predictability of seasonal river floods (Dieckmann et al 2013). Sea level rise will increase flooding along the western Namibian coast. Saltwater intrusion into underground aquifers will likely decrease the survival of plants that rely on groundwater. Overall, the future quality and availability of fog, rainfall, and groundwater – the sources of water that the !nara requires for survival – are uncertain. Changes in water availability make the !nara vulnerable to changes in phenology.

!Nara Phenology Research

Male !nara flower year-round but the peak of the flowering season for female plants runs October-December (Henschel et al 2004). Our research occurs during the apex of the female plant flowering season. Our two primary study sites are in the Kuiseb Delta near the Atlantic coast, and at Gobabeb, which is inland and southeast of the Delta site. We explore the differences in !nara flower and fruit productivity and phenological advancement within and between these sites. Factors that may impact phenology and productivity include fog, rainfall, and groundwater. The extent to which !nara relies on fog remains unknown. Soderberg (2010) suggests that the !nara receives water from groundwater, but the plant's architecture, with its intertwined branches, wax

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bloom, grooved stems and conical thorns, implies fog interception and drip (Malik et al 2014). The !nara is remarkably independent of rainfall due to its famously long taproot, which can extend to be 100 m long to access groundwater (Henschel et al 2004).. !Nara close to the coast benefit from freshwater seepage under the dunes from inland rainfall, which is correlated with greater fruit production (Henschel et al 2004). Along the Kuiseb River, human impact is putting the !nara at risk: an increased number of boreholes and dams negatively impacts aquifer recharge and the availability of groundwater for the !nara (Dieckmann et al 2013). Because the !nara is so dependent on groundwater, a lower water table could limit the prevalence of the !nara. Taken together, these variables demand that research be done on how !nara productivity and phenological advancement differ depending on fog, rainfall, and groundwater availability. To start to fill this gap in the literature, we hypothesize that !nara rely more heavily on fog than on rainfall.

H1: !Nara plants in more humid, fog-fed environments will be more productive and phenologically advanced than !nara in more arid, rain-fed environments.

Our research looks at aspect as an additional variable which may have an impact on !nara phenology. In the northern hemisphere, south-facing slopes produce plants that are phenologically advanced compared to north-facing slopes (Albon and Langvatn 1992). The opposite is true in the southern hemisphere. In the Namib Desert, the strongest winds come from the southwest. They beat on the south side of !nara hummocks and barrage them with sand. As a result, the southern side of hummocks may be less productive and phenologically advanced. The difference between north and south may be accentuated by the fact that the northern side of hummocks receives more sunlight. Our research investigates the impacts of wind and sun on !nara production.

H2: !Nara productivity will be greater and phenology advanced on the northern side of hummocks.

!Nara Pollination Research

Phenological shifts in the !nara affect pollinators as there are few species for insects to pollinate in the sparsely-vegetated Namib. Studying pollination is essential to discovering potential phenological mismatch. This is especially crucial as the !nara may be more vulnerable to pollination challenges. Firstly, the !nara is a dioecious plant, meaning that male plants and female plants are entirely separate. Transfer of pollen must be done mechanically by outside forces. Secondly, the !nara is not pollinated by wind dispersal (Henschel et al 2004). Pollinators of the !nara plant have largely remained a mystery. However, some studies on the plant have suggested bee species like *Amegilla velutina*, *Anthophora auone*, and *Hylaeus sp*. are primary pollinators, in addition to the blister beetle, *Mylabris zigzag* (Henschel et al 2004). Few studies have been done to replicate those results.

The Dartmouth student research group in 2014 conducted a pollination study using fluorescent powder to pain flowers and mark pollinators, and bee bowl water traps to catch pollinators. Their research suggested that one or multiple unidentified midges could be the pollinators of the !nara plant (Beitler et al 2014). However, their study found fewer midges as the distance from the river increased, suggesting that midges are likely not the primary pollinators of non-riverine !nara plants. Our pollination research adds to that of 2014 by investigating the extent to which midges pollinate the !nara.

H3: Midges are one of a few insect species to pollinate !nara, and they do so within a small radius from water.

When mean flowering season temperatures increase, pollinator activity increases (Memmott et al 2007). Beitler et al (2014) found that the amount of midges found is correlated to the timing of flower opening in the morning but did not reach any conclusions about the temperature conditions preferred by midges. In light of information proposed in the literature (Memmott et al 2007; Hoye et al 2013), we hypothesize that the abundance of pollinators, including midges, will be higher during the middle of the day and at sites with higher daily temperatures.

H4: Pollinators are more abundant when daily temperature peaks and at sites with higher average daily temperatures.

Methods

This research was conducted at three sites along the Kuiseb River - two sites in the Gobabeb Valley (GV Site A and GV Site C) and one site in the Kuiseb Delta – all within the Namib-Naukluft National Park from November 4-8, 2015.
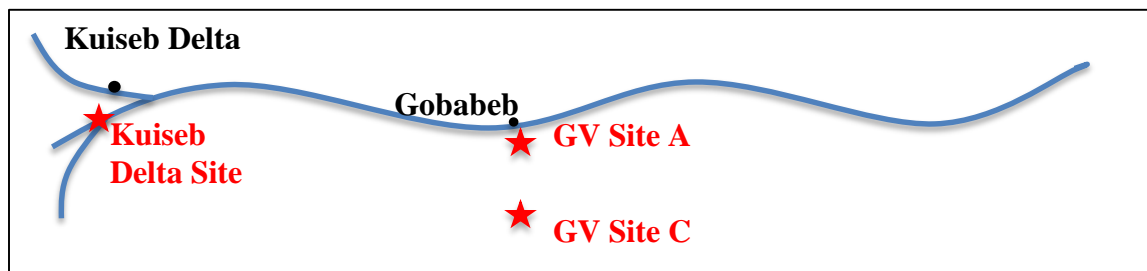

Figure 1. Site map. Map of sites, not drawn to scale.

Site Selection

Sites in the Gobabeb Valley (GV Site A and Site C) were selected in order to compare pollinator activity according to proximity to the ephemeral Kuiseb River. Site A is directly adjacent to the Kuiseb, while Site C is farther away in the inter-dune region; studies between the two sites could indicate the importance of water availability to !nara phenology, pollination, and pollinator activity. These two sites are also useful because they were used in previous monitoring projects and are easy to access for future long term phenology monitoring.

The Kuiseb Delta site was selected in order to compare phenology and pollination data of sites in coastal verses inland environments because of thefog-rainfall gradient. The Kuiseb Delta is located on the Atlantic Coast near Walvis Bay and therefore has much more annual fog than do the sites in the Gobabeb Valley. We measured pollination and/or phenology of ten !nara plants in GV Site A, twelve !nara plants in GV Site C, and ten !nara plants in the Kuiseb Delta site.

Phenology

The relative stage of !nara plant phenology and overall !nara productivity was assessed at each site by counting total flower number, total fruit number on females, and flower to bud ratio on all !nara plants at all three sites. At Site A we sampled four females and six males, at Site C we sampled four females and eight males, and at the Kuiseb Delta we sampled five females and five males. To examine the effect of aspect on phenology, we bisected each !nara hummock along its east-west transect and recorded fruit and flower counts on the northern and southern aspects. We also recorded flower-to-bud ratio on the north and south aspects to gauge phenological maturity and productivity. To determine the ratio, we randomly selected five branches on each side of the hummock (north and south) and counted the number of flowers and the number of buds on each branch. Temperature and wind speed were also recorded at each site and used in conjunction with data from Gobabeb's weather stations at each site.

Pollination

In order to understand pollination of the !nara, pollinator activity, and gather more information about the midge as a pollinator, we performed an experiment using water traps and fluorescent powder to mimic pollen and identify pollinators. Our procedure was based on that of Beitler et al. 2014, but was modified to be more specific with color selection of fluorescent powder and placement of water traps. At each of the three sights, we identified three male and three female !nara plants. We painted all female flowers with green fluorescent powder, specifically targeting the reproductive organs, and placed the water traps on female plants only. Water traps were filled with a solution of 60% water, 40% *propylene glycol* (anti-freeze), and a drop of dish soap to prevent evaporation and increase capture success. Each of the three males was painted a different color (either orange, yellow, or pink), and reproductive organs were again targeting in the painting. By painting each male a different color and only placing water bowls in female plants we were able to quantify the distance pollinators traveled between !nara plants to pollinate. To test whether or not the insects captured in the test bowls were attracted to the !nara flowers and not the water traps, we set up two control water traps at each site on rocks and in other nearby vegetation.

The painting of flowers and setting up of water traps took place between 8:00 and 9:00 AM, and the water traps were collected between 2:00 and 3:00 PM. Upon placing and picking up the water traps, the air temperature and wind speed were recorded. Once the water traps were collected, the contents were transferred to vials, which were subsequently examined in the Gobabeb laboratory. All insects in the traps were identified and counted, and an ultraviolet black light was used to highlight any fluorescent powder on the insect. The number and type of insects found in each trap was recorded, as well as the presence of any color or fluorescent powder. This was performed once time at GV Site C and the Kuiseb Delta site, but was repeated three times at GV Site A.

Results

Phenology

Site	Plant	Sex	Volume (m3)	Fruit Count			Fruit Density (fruit/m3)	Flower Count			Flower Density (flower/m3)
				N	S	Total		N	S	Total	
GV Site A	GV101	F	38.6164657	3	0	3	0.077687068	19	8	27	0.699183613
	GV102	M	24.5735074					74	106	180	7.324961678
	GV103	M	36.7849277					20	37	57	1.549547697
	GV104	F	18.1845224	28	10	38	2.089689196	14	22	36	1.979705554
	GV105	M	16.1153624					16	51	67	4.157523631
	GV107	F	169.308892	5	13	18	0.106314558	12	10	22	0.129940015
	GV108	M	22.8407996					8	8	16	0.744282175
	GV109	M	41.4142281					7	9	16	0.386340655
	GV110	F	41.9955457	17	11	28	0.666737377	4	7	11	0.261932541
	GV111	M						1	9	10	
GV Site C	GV302	F	26.8869329	9	7	16	0.595084611	4	6	10	0.371927882
	GV303	M						171	60	231	
	GV304	M	54.9627155					135	68	203	3.693412855
	GV305	F	67.4807382	13	6	19	0.281561828	13	5	18	0.266742784
	GV306	M	79.7173265					167	277	444	5.569680012
	GV307	M						18	20	38	
	GV308	F	36.9208476	3	12	15	0.40627453	5	0	5	0.135424843
	GV309	M	17.2566743					14	7	21	1.216920458
	GV310	F	28.6031444	9	4	13	0.454495485	1	3	4	0.139844765
	GV311	M						31	44	75	
	GV312	M						33	24	57	
	GV313	M						3	2	5	
Kuiseb Delta	KD101	M	115.259285					96	6	102	0.884961242
	KD102	M						67	38	105	
	KD103	M	64.3268187					196	132	328	5.098961936
	KD104	F	10.5488151	32	47	79	7.488992768	11	134	145	13.74561964
	KD105	F	8.5001647	16	20	36	4.235212054	25	10	35	4.117567275
	KD106	F		55	6	61		5	4	9	
	KD107	F	42.8219472	101	43	144	3.362761607	34	11	45	1.050863002
	KD108	M						58	0	58	
	KD109	F		0	11	11		0	0	0	
	KD110	M	8.20465665					25	54	79	9.628678368

Table 1. Unstandardized and standardized fruit and flower counts. The table shows flower and fruit counts for all plants at each site, organized by directional aspect (north or south). Total flower and fruit counts were standardized by above ground live plant volume to calculate flower and fruit density.

Effect of Location on Phenology:

There was no significant effect of aspect or site on unstandardized flower number, though sex did impact flower number ($F_{4,59}$=3.2097, p=0.0188). Generally, male plants had more flowers than female plants (t_{62}=3.099866, p=0.0026), though not higher flower density. Site impacted flower density, and the Kuiseb Delta had higher flower density than the two Gobabeb Valley (GV) sites (*Figure 4*). The Kuiseb Delta also had higher fruit density and the greatest number of fruits (*Figure 3; Table 1*).

Before comparing recorded fruit and flower counts at each site, the counts were standardized by measured above ground live plant volume in cubic meters. Volume was calculated using drone imagery, GIS analysis, and height measurements (Gardner et al., 2015).

Difference in fruit density (fruits per cubic meter of live plant volume) across the three sites was significant between coastal (Kuiseb Delta) and inland (Gobabeb Valley) sites, but not between the two inland sites ($F_{2,8}$=14.217, p=0.0023). The Kuiseb Delta had higher fruit density than both GV Site A and GV Site C (*Figure 3*).
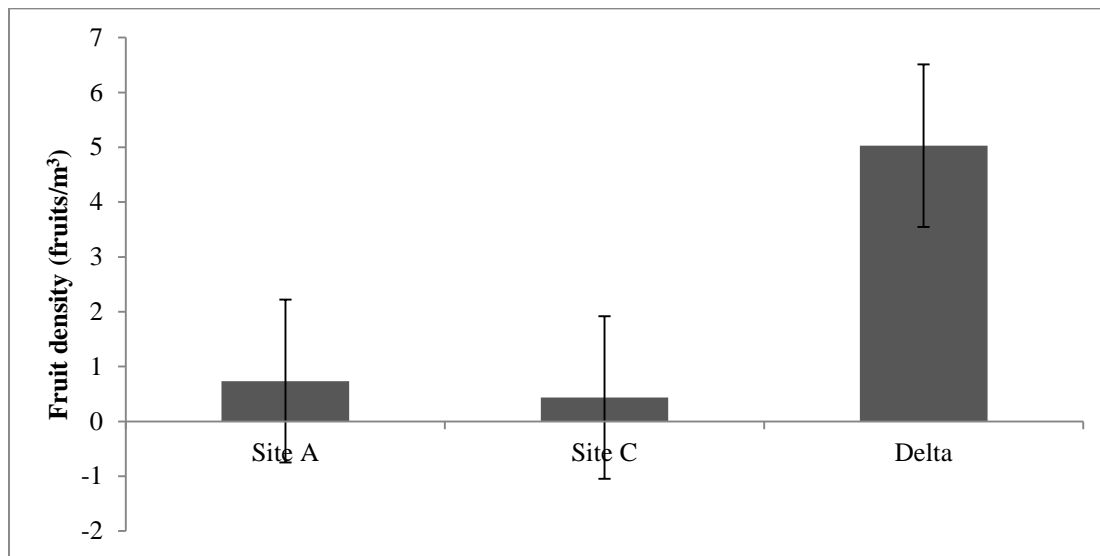

Figure 2. Average fruit density by site. Mean fruit density (fruits/m^3) was 0.735 fruits/m^3 (sd=0.942) at GV Site A, 0.434 fruits/m^3 (sd=0.129) at GV Site C, and 5.029 fruits/m^3 (sd=2.175) at the Kuiseb Delta. Fruit density varied between sites ($F_{2,8}$=14.217, p=0.0023). The Delta site had higher fruit density than GV Site A (t_8=-4.55714, p=0.0009) and GV Site C, but there was no difference between GV Site A and Site C.

Between the sites, difference in average flower density (flowers per cubic meter of live plant volume) varied for female !nara but not for males. Female flower density was different between sites ($F_{2,8}$=7.1642, p=0.0165). Female flower density in the Kuiseb Delta was higher than GV Site A (t_8=-2.926, p=0.0096) and than GV Site C, though female flower density did not vary between GV Site A and GV Site C. Male flower density did not vary between sites ($F_{2,7}$=0.3598, P=0.71). Overall, flower density was higher at the Delta than at GV Site A (t_2=2.56, P=0.0196) and GV Site C. Male flower density was higher than female flower density at GV Site C (t_5=3.0895,

P=0.0136). Though not significant, both GV sites had higher male flower density than female, while at the Kuiseb Delta, female flower density was observed to be higher than male (*Figure 4*).
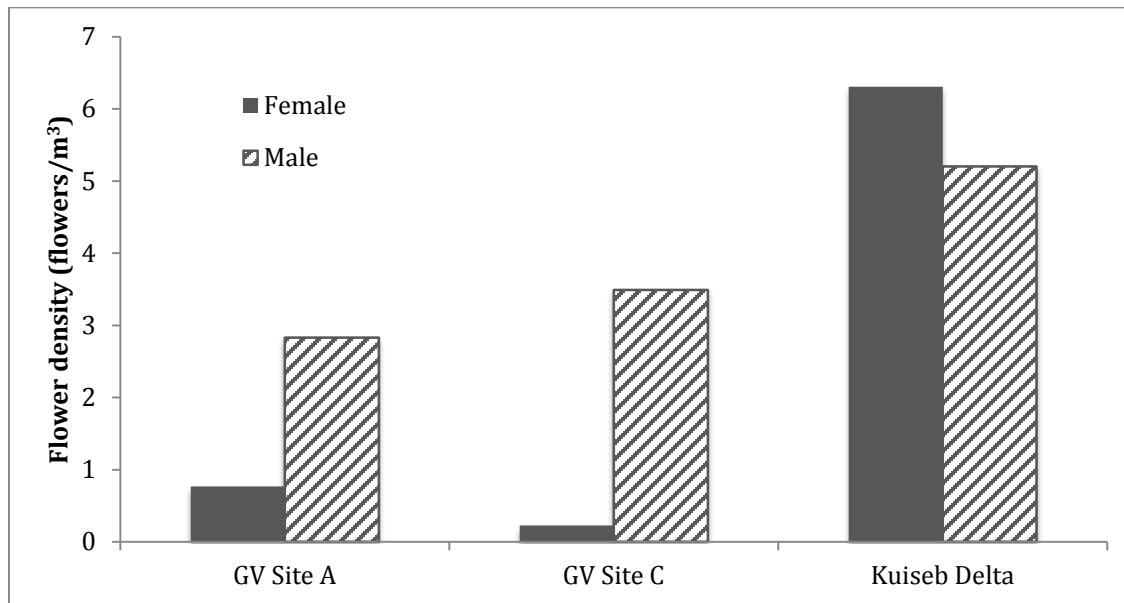

Figure 3. Average flower density by sex by site. Mean flower density (flowers/m3) was calculated for each sex at each site. At Site A, mean total flower density was 1.914 flowers/m^3 (sd=2.385), female was 0.767 flowers/m^3 (sd=0.844) and male was 2.832 flowers/m^3 (sd=2.912). At Site C, mean total flower density was 1.6277 flowers/m^3 (sd=2.154), female was 0.228 flowers/m^3 (sd=0.113) and male was 3.4933 flowers/m^3 (sd=2.183). At the Kuiseb Delta site, mean total flower density was 5.885 flowers/m^3 (sd=5.641), female was 6.305 flowers/m^3 (sd=6.624) and male was 5.204 flowers/m^3 (sd=4.372). Total flower density was higher at the Kuiseb Delta than at GV Site A (t_2=2.56, P=0.0196) and GV Site C. The Delta site had higher fruit density than GV Site A (t_8=-2.926, P=0.0096) and GV Site C; there was no difference between GV Site A and GV Site C.

Effect of Aspect on Phenology:

In comparing the North and South aspects of !nara hummocks, we found many general trends, though no relationships of statistical significance (Appendix I). At both the Delta and GV Site A, there were more fruits on the north side than on the south side (*Figure 4*). At GV Site A, there were more flowers on the South side of the hummock, while at the Kuiseb Delta there were more flowers on the north side of the hummock. Flower to fruit ratio was also calculated and was found to be higher on the southern side of the hummock than the northern side at GV Site A and at the Kuiseb Delta Site (*Figure 5*).
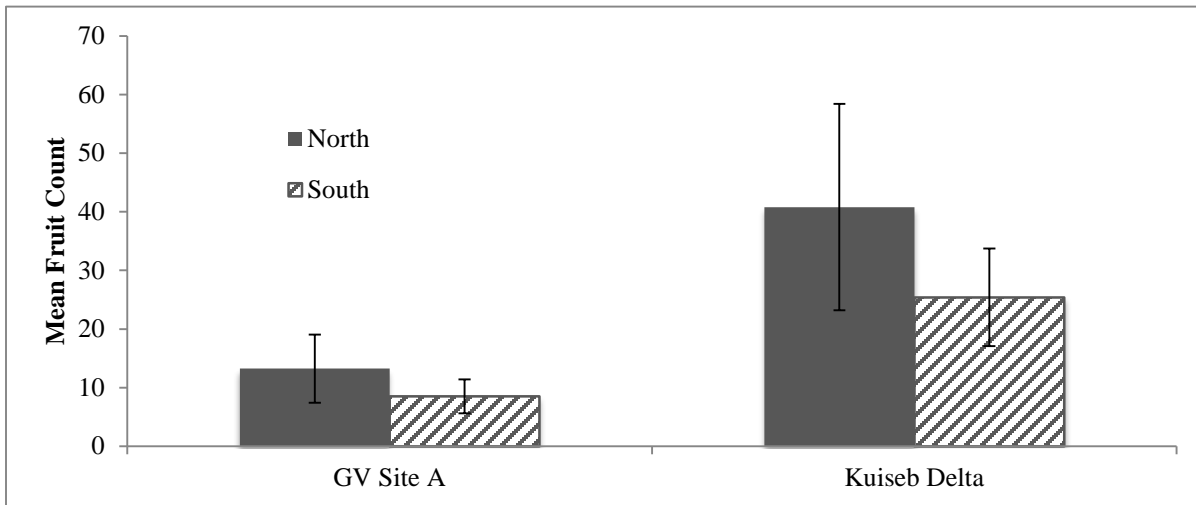
Figure 4. Fruit number by aspect. Mean fruit number was calculated on the north and south sides of each hummock. At GV Site A, mean number of fruits was 13.25 on the north side (SD= 11.6) and 8.5 on the south side (SD=5.80). At the Kuiseb Delta, mean number of fruits was 40.8 on the north side (SD=39.3) and 25.4 on the south side (SD=18.6). Results were not significant (Appendix I).
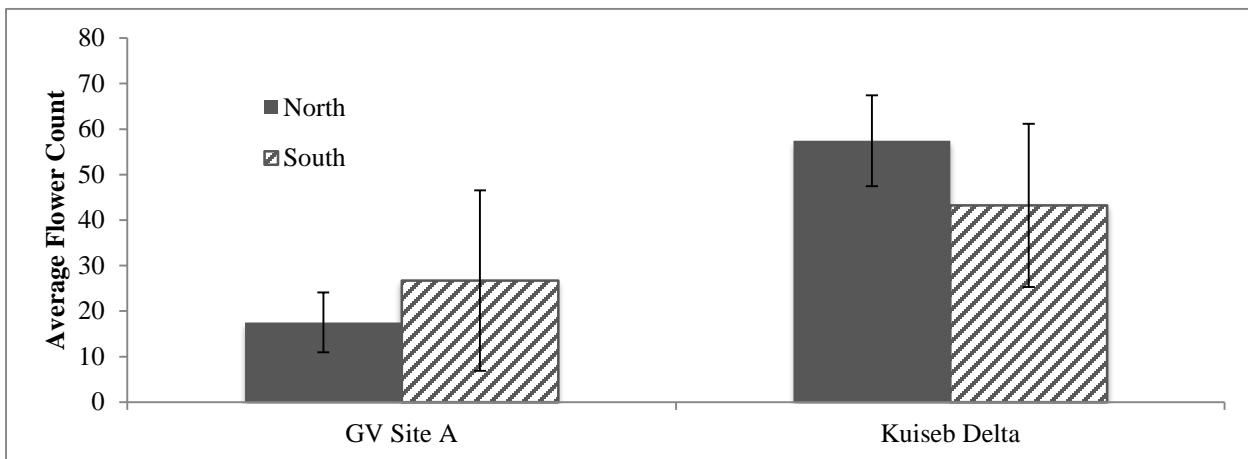

Figure 5. Flower number by aspect. Mean flower number was calculated on the north and south sides of each hummock. At GV Site A, mean number of flowers was 17.5 on the north side (SD= 20.8) and 31.6 on the south side (SD=3.16). At the Kuiseb Delta, mean number of flowers was 57.4 on the north side (SD=59.5) and 43.2 on the south side (SD=53.8). Results were not significant (Appendix I).

Colored Dust Pollination Experiment

The pollination study analyzed the effects of wind speed, temperature, and the number of flowers on pollinator species and the number of pollinators collected. Throughout the course of the experiment, 853 insects of eleven different taxonomic families were collected in 25 water traps placed in eight female !nara plants from November 5 to November 8. The midge was the most abundant species followed by the fruit fly and flying ant (*Table 2*).

Site	Plant	Trap (#)	Midge	Blister Beetle	*Scolidae* (Wasp)	Fruit Fly	Flying Ant (Formicidae)	Common Fly (calliphordae)	Other	Total
Site A	GV101	4	11	0	0	4	1	0	0	16
	GV104	7	485	0	1	14	2	0	2	503
	Control	2	5	0	0	0	2	0	0	7
Site C	GV308	1	37	1	0	0	0	0	0	38
	GV302	1	171	0	0	6	0	2	1	180
	GV305	1	57	1	1	0	0	1	0	60
	Control	2	0	0	0	0	0	0	0	0
Delta	KD104	2	1	0	0	2	0	0	0	3
	KD105	2	4	0	0	0	0	1	1	6
	KD107	2	30	1	2	0	2	1	1	37
	Control	2	2	0	0	0	0	0	0	2
Total			803	3	4	26	7	5	5	853

Table 2. Insects trapped. The table shows the total number of insects found at each plant organized by site. The category "Other" includes small beetles of the *Dermestidae* and *Cryptophagidae* family, the turd bug (*Bubresdidae Agrotis)*, wasp (*Tiphidae)*, and flesh fly (*Sarcophogidae).*

Insects collected from control bowls made up 39 of the 849 insects collected (4.6%). None of the insects had dusted powder on them. The difference between the numbers of midges collected per bowl between the control traps and !nara traps was significant ($t_2=2.147$, $p=0.02$).

Approximately 40 percent of the trapped insects had green dust from female plants while 2.12 percent had colored dust from male plants. All insects with male coloring also had female coloring. Four different species had female and male colors indicating they visited at least one male and one female flower before falling in the trap (*Table 2*). Of the 18 insects with male coloring, seventeen were orange and one was pink. No insect was yellow. These results are much different than the

2014 Long Term Monitoring study results, which reported 183 insects with male coloring of ten different species. It's unclear whether or not these insects had also visited female flowers.

Insect	Number of Insects with Female and Male Coloring
Unidentified Midge #1	13
Unidentified Midge #2	3
Blister Beetle	1
Flying Ant	1

Table 2. Number of insects trapped with male and female coloring. The distribution of insects of male and female color across insects including the unidentified midge, the blister beetle (*Mylabris zigzaga),* and the flying ant (family *Formicidae).*

Between the different sites, GV Site C had the largest number of midges per trap, followed by GV Site A and the Kuiseb Delta site (Figure 1). Midge numbers varied from 1 to 485 per trap (mean=73, sd=145.4). The difference in midge counts between Site A and the Delta site was significant (t=0.261, p=0.04). However, there was no significant difference in the number of midges trapped between GV Site A and GV Site C (t=0.257 p=0.42) or between GV Site C and the Delta site (t= 1.41, p=0.129).
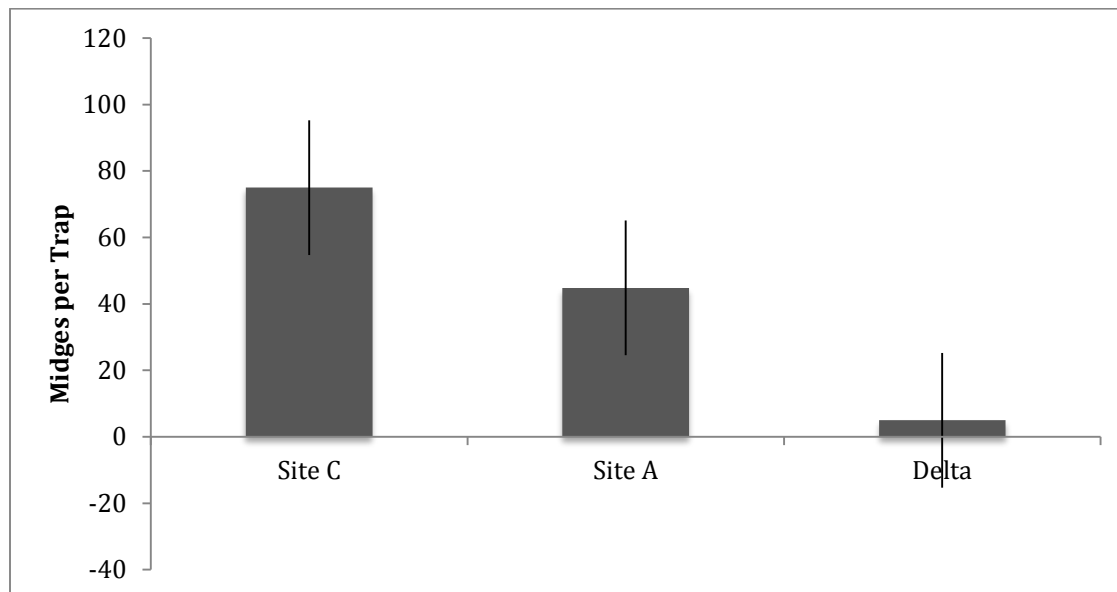

Figure 6. Midges per trap by site. Site C had 75.0 (sd= 49.5) midges per trap, while the Delta site had 5 (sd= 7.43) and site A had 44.8 (sd= 59.7).

The pollination data was collected over one sampling period for both Site C and the Delta site. Trials at Site A were completed on November 5, 7, and 8 under different temperature and wind conditions. The average wind speed was 1.13 m/s (sd=1.96) in the morning and 1.97 m/s (sd= 1.74) in the afternoon. There was no significant relationship between morning or afternoon wind speed and number of midges collected. Afternoon temperatures and the number of midges collected were negatively correlated (R^2=0.9954, p =0.032). There was also positive relationship

between the number of midges collected and the morning temperature ($R^2 = 0.95018$, $p = 0.021$). The trend lines converge where the population reached 74.2 midges at temperature was 33.2 degrees Celsius. However, these results are based on three observations alone (*Figure 7*).
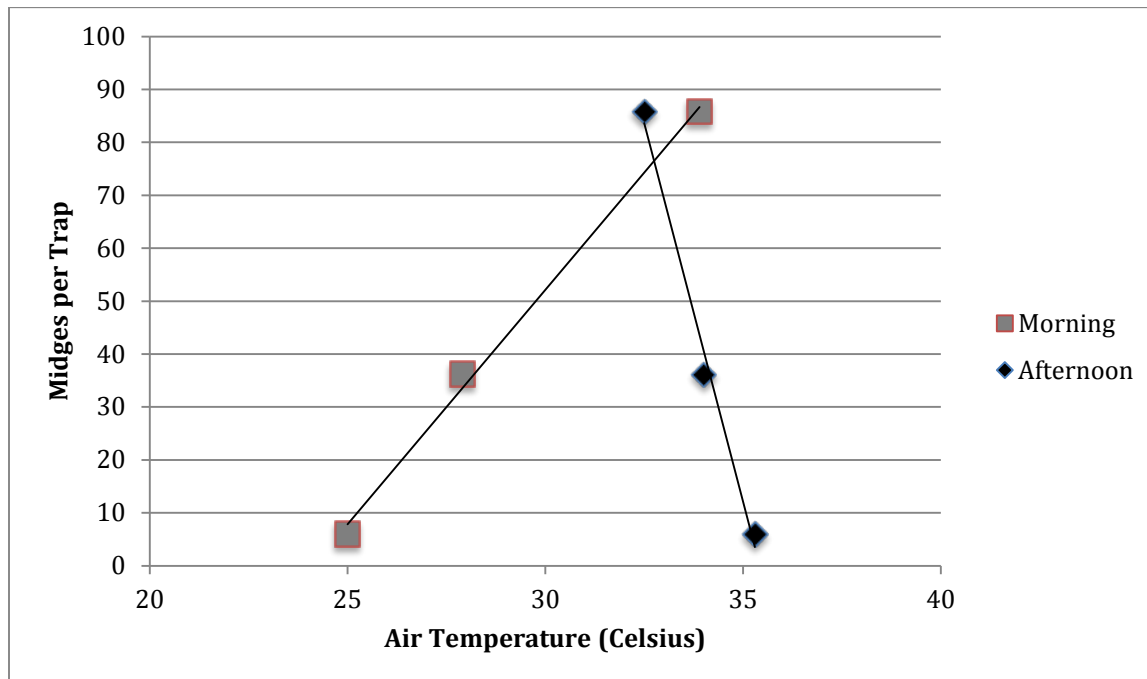

Figure 7: Air temperature and midges per trap. At site A, the number of midges collected increased with increasing morning air temperature and decreased with increasing afternoon temperature.

There was no relationship between the number of flowers on a plant and the number of midges trapped (*Figure 8*).
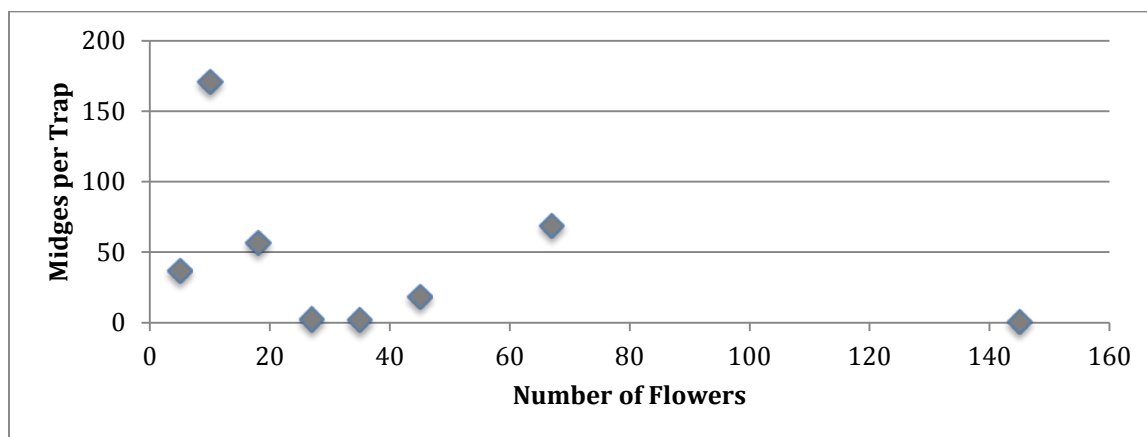

Figure 8. Relationship between number of flowers and insects trapped. There was no correlation between the number of flowers a !nara had and the insects per trap at each !nara ($R^2 = 0.017$, p=0.05).

Discussion

Phenology

The productivity of the Delta relative to the other sites suggests it is phenologically more advanced than the inland sites, which supports our hypothesis that areas with more fog will be more phenologically advanced. Higher fruit density implies the !nara at the Delta are fruiting earlier than at Sites A and C, though only long term monitoring with regular phenological counts will be able to confirm timing differences in phenology. There is still a valid possibility that the Delta !nara simply have access to resources which make them more productive. We observed a !nara fruit harvest campsite within our Delta sample site; it is likely there were many more mature fruits at the Delta site that were not recorded because they had been harvested. A disparity in flower and fruit density suggests there are temporal or climatic factors that trigger productivity in the Delta earlier in the year than at Gobabeb Valley (GV). Fog off the coast and consequential humidity may play a role in the phenological advancement of !nara at the Delta site. New growth, particularly flowers and sugary nectar, require energy from photosynthetic activity. Though !nara as a desert plant is particularly water-efficient, any photosynthetic activity requires water. It is possible that increased availability of water from fog, humidity, and ground water at the Delta cause those plants to be less water scarce than plants farther inland, and therefore more capable of producing new growth. Main flowering and fruiting season for female !nara is October to December, which coincides with peak fog as well as kicks off the summer wet season. While the inland plants wait for water from fog and rain, the Delta plants are less dependent on the seasonality and can afford to begin flowering earlier.

Lower water scarcity at the Delta, thanks to more fog, air humidity, soil moisture, and accessible ground water, likely makes the Delta generally more productive than the GV sites. Higher fruit density and high flower density for both males and females indicates the Delta's productivity compared to other sites. Again, access to water, particularly from fog, humidity, and groundwater, makes the Delta site significantly more productive than other sites. In such an arid environment, water is the limiting factor for biological productivity. At the Delta, plants can biologically afford to more liberally produce flowers, while at the Gobabeb Valley sites plants must conservatively budget their water and flower production. Comparing the three sites this is evident, as the Delta site has the most access to water and Site A is much closer to the Kuiseb River than Site C.

Females differed from site to site in flower density while males did not, indicating a phenological difference between female and male !nara. Our fruit data – and to a lesser extent our female flower data – suggests there is a phenological difference between females in the costal Delta site and the inland Gobabeb Valley sites. However male flower density does not reflect this difference; male flower density is the same across the two sites. There are slightly more total flowers at the Delta site than the inland sites, but this can perhaps be explained by the overall higher productivity at the Delta rather than phenological productivity. Instead, our data indicates that the male !nara plants have a less distinct and specific flowering season than female flowers. Unlike the females, which show significant differences in flowering, the male plants flower similarly across the different sites. This larger flowering period in males as compared to females has been documented in previous literature (Henschel et al 2004) and could be highly significant when thinking about

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and questioning phenology and productivity of the !nara plant throughout Namibia. This could have implications in terms of climate change, because the female flowering period is much smaller and may be more sensitive to environmental changes that occur in a changing climate (i.e. temperature, fog, rainfall, etc.) This could potentially lead to a mismatch between not only pollinators and flower phenology, but a mismatch in pollination of male and female flowers because males have a larger flowering period and their timing is presumably less sensitive to environmental factors.

In addition to having the highest number of fruits, the Delta also shows the greatest effect of aspect on phenology in terms of flower to fruit ratio; south side is less phenologically advanced in its production of fruit than the north side. Furthermore, aspect also has a greater affect on flower number and proportion of north-facing flowers at the Delta; the north side is favored on both counts. This further supports the idea that the northern aspect of the hummock is more phenologically advanced and is consistent with our hypothesis that the strong south-westerly winds off the Atlantic Coast pummel the south side of !nara hummocks while the north side remains sheltered. This may make it easier for flowers and fruits to develop on the north side while it would take longer for the south side to overcome the challenge of the southerly winds and become productive. The observed effect was most severe at the Delta, and less conclusive at Site A and Site C. However, sites A and C in the Gobabeb Valley also experience strong north-easterly winds that offset the south-westerly winds from the coast (Gardiner et al 2006). Although these results were also not statistically significant, a larger sample size may prove a larger trend. In the future, it would also be useful to analyze the plant volume on each side of the hummock to compare fruit and flower density and determine whether or not the difference in flower and fruit number is a product of phenological differences or if it is due to differences in plant volume on each side of the hummock.

Overall, our data were limited by our sample size and could have greater significance with a larger sample size or a longer period of data collection. We had small sample sizes (four to eight), limited locational flexibility, and worked under a limited time scale. The Delta, GV Site A, and GV Site C sites were chosen because they were comparable, but in limited and distinct ways. The Delta site and GV Site A were used particularly for this phenology study because they lie along a fog, humidity, and temperature gradient. Besides those variables, the two sites are both river-dependent – the Delta site being literally within the Kuiseb Delta, and Site A as directly adjacent to and participating in the nearby Kuiseb riparian zone (insects, wildlife, and water can easily interact between the riparian zone and Site A). Long term monitoring would address the limited time scale, and could uncover many of the trends only suggested by these findings.

Long term monitoring is essential for making sense of the data we collected. Not only could long term monitoring capture a larger sample size that might make these trends statistically significant, it could also show how these flowering times and difference between northern and southern sides of the hammock change with changing air temperature, winds, and fog counts. To make long term monitoring more successful, Gobabeb should add more plants to take phenological data of in convenient places. It would also be beneficial to add the crops of !nara to the far east of Gobabeb further along the fog gradient. It would be interesting to see how phenology in an area with less fog, more rain, and higher temperatures contrasts with what we've seen during the course of this

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research. Keeping a long term phenology monitoring plan is essential to understanding climate's impact on the !nara.

Pollination

We found three potential pollinators of !nara including the midge identified by Beitler et al 2014. This supports our hypothesis that midges are !nara pollinators. At site A, midge abundance was independent of wind speed and was greatest at high morning and low afternoon temperatures. The lack of correlation with wind speed disproves our hypothesis that midges abundance increases with less wind. The number of midges per trap was significantly smaller at the Delta site than site A or C. These results reveal that the midge is may be a temperature sensitive pollinator. In the context of climate change, the midge's relationship to temperature suggests that as sites like the Delta get warmer, the midge could fill the niches vacated by pollinators unadapted to warmer climates or fog dependent. It's unclear whether a pollinator assemblage more dominated by midges would be as effective as one dominated by larger insects like blister beetles that can carry more pollen. A previous study showed that a change in pollinator composition can reduce the efficiency and success of pollination (Rafferty and Ives 2012).

In terms of phenology, there was no relationship between the number of flowers and the number of midges caught in a female !nara plant's trap. The midge is less reliant on flowering times and more dependent on temperature signals for activity. The significant lack of midges at the Delta could be due to phenological differences as well as differences in temperature. Because the Delta was much more phenologically advanced, many of the flowers had already been pollinated and become fruits. The lack of midges could be because they aren't used to these earlier flower times. It would be interesting to see whether our observation of the midge as temperature dependent is confirmed by seeing if midge abundance increases in the delta later in the season as the air temperature increases or earlier in the season when the !nara is less phenologically advanced. Either way, our results suggest !nara pollination will most likely be effected by climate change. As climate change causes earlier flowering times as expected, the midge and other pollinators could fall out of phenological sync. Climate change's effect on temperatures will undoubtedly alter when midge's are most active. Long term phenology monitoring and hopefully future pollination studies could better identify whether or not the change in phenology and the change in midge activity will shift in the same or opposite directions.

Our quantified pollinator count contrasts with our field observations. During data collection and flower painting, multiple researchers observed the blister beetle interacting with !nara. Our observation of blister beetles being a main pollinators of !nara is consistent with previous studies. However, only two blister beetles fell into a trap and only one had colored dye. In a previous !nara pollination study, the blister beetle was found carrying high amounts of pollen after interacting with !nara and was regularly observed commuting between !nara plants and even !nara fields (Mayer 2000).We believe the bee-bowls used in the experiment aren't strong enough to trap larger pollinators like the blister beetle. One group member observed a blister beetle flying out of the bee-bowl trap. This would explain why there were more small pollinators like small beetles, flies, and midges than larger pollinators found in other studies like Mayer who found more bees and blister beetles.

When comparing this years pollination study to Beitler et al 2014, the data is extremely inconsistent. We took a critical look at the 2014 pollination study and tried to amend it by tightening our requirements for what we consider proof of pollination. Our stricter standards for pollination resulted in fewer trapped insects with colored dust than the 2014 year. We tried to look at the effect of distance between male and female plants by painting male !nara plants three different colors whereas the previous group only painted males orange. The significant lack of insects collected with pink or yellow colored dust suggests insects are either not attracted to the colors or that those colors don't cling as well to the insect. Results only from the orange painted males narrowed the amount of data we were able to collect relative to the 2014 group and prevented us from studying the effect of distance. The lack of a statistically significant difference between the number of midges caught at Site A and Site C contrasts with last year's results that found an inverse relationship between midge abundance and distance from the river.

Recommendations

To better understand how both phenology and pollination are changing, it is important to study pollination at different times of the year. Data across multiple seasons would show when certain insects are most active. It may be that midges are simply most active in early November, and not major !nara pollinators throughout the year. If climate change alters phenology as expected, it would be important to know which insects would be most affected by earlier flowering times. More data across seasons and within sites could provide more reliable information on the effect of wind and temperature on pollination.

At each site, especially the Kuiseb Delta, it would be good to do further research into insect trapping methods. Altering the trap to collect larger insects would give a more representative sample that would provide quantitative data on the blister beetle and other bees' roles as pollinators. It would be particularly helpful at the Delta, where pollination times and pollinators seem to differ. Understanding how pollinators change based on weather is crucial for anticipating the effects climate change could have on pollination and !nara productivity.

In addition to better insect traps, improved fluorescent markers would be helpful. The orange paint clearly stuck better to the insects. Our use of pink and yellow powder limited the number of insects collected with male coloring to just one plant. As a result, some important pollinator data was left out and we were unable to study the effect of distance between male and female !nara on pollination. We attempted to more directly connect the insects we collected to pollination by looking for pollen on the bugs in addition to dye. Alternatively, pollination studies that exclude pollinators or hand pollinate would give a better sense of the limits pollinators have in for !nara productivity.

For the phenology research, we recommend continuing to do flower counts, fruit counts, and flower to bud ratios on a weekly basis at the !nara plants adjacent to regularly monitored beetle traps in the Gobabeb Valley. Recording flower to bud ratios at the Delta site is also important whenever Gobabeb researchers go to the Walvis Bay weather station. A quarterly count of flowers and fruits at both the Delta and Gobabeb Valley sites would improve knowledge on the

phenological stages of !nara and help monitor long term changes that occur with changing weather patterns. Overall, long term temoral monitoring of phenology is the only means to develop a more complete picture of local !nara phenology. Understanding !nara productivity will have implications for its survival as a keystone species in the Namib, as well as the impact of human harvesting as an indigenous natural product.

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Appendix I. T Test Results

Test	T value	Df	P Value
Total Flower Number by Sex	3.099866	62	0.0026
Average Fruit Number by Site	-1.868	4.84	0.1225
Whole Plant Flower to Fruit Ratio	1.2186	7	0.2625
Flower Number by Site: Males	-1.444	9	0.1826
Flower Number by Site: Females	-.0767	7	0.4679
Flower to Fruit Ratio by Aspect: GV Site A	-0.678	5	0.5275
Flower to Fruit Ratio by Aspect: Kuiseb Delta	-0.4178	7	0.6886
Fruit Number by Aspect: GV Site A	-0.7316	6	0.4919
Fruit Number by Aspect: Kuiseb Delta	-.7915	8	0.4515
Flower Number by Aspect: GV Site A	-0.107	6	0.9182
Flower Number by Aspect: Kuiseb Delta	0.6363	8	0.5423

Towards a Comprehensive Environmental Education Program at Gobabeb: A Case Study of Grade 7 Curriculum Development for the J.P. Brand School, Namibia

November 14, 2015

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Introduction

The Namibian education system has a complex history due to Apartheid era policies that created a fragmented Bantu education system. Education, especially of blacks and colors, was informal, underfunded and influenced heavily by local tribal ways of life (Nekhwevha 1999). After gaining independence in 1990, the Namibian government sought to reconstruct and reform its social institutions in order to recover from apartheid and colonialism (Dalhstrom & Nyambe 2014). One of the key objectives of these reforms was to replace the rigid, authoritarian education system of the apartheid era with a newer, more modern system. In the past ten years, Namibia has made a concerted effort to include environmental education as a part of their education curriculum. Given the pressing environmental and development issues facing Namibia and countries around the world, environmental education has become increasingly important in order to prepare future generations to understand and address these issues. By nature, environmental education is interdisciplinary in nature, combining knowledge of natural sciences with pro-environmental values and behaviors. Furthermore, environmental education intertwines society and the environment, culture and nature through the lens of complex issues such as climate change, natural resource depletion, and endangered species, among others. Although Namibia has recognized the importance of environmental education by integrating content about the environment into national standards (Namibian Curriculum 2014), environmental education is not yet completely institutionalized or supported in Namibia. Environmental education could provide the opportunity to integrate cultural experience with empirical, natural science curriculum and begin to address the post-colonial legacies in the Namibian education system.

Taking this broader context into account, the focus of this report is to understand the challenges of designing an environmental education program in a specific context. This environmental education program will bring Grade 7 students from the J.P. Brand school in Utuseb, Namibia to the Gobabeb Research and Training Center for 5-days of curricular programming.

Gobabeb Research and Training Center, located in the Namib Desert, is an internationally recognized research center that specializes in dry land research and training. Founded in 1962 by entomologist Dr. Charles Koch, Gobabeb has expanded its work to conduct research in a variety of fields, from geology and climate change to desert conservation and archaeology. It has been a joint venture between The Ministry of Environment and Tourism and the Desert Research Foundation Namibia since 1998, and is home to staff members, interns and hosts hundreds of researchers annually. Gobabeb works to educate about the Namib Desert and dry land ecology in order to better raise awareness about the Namib Sand Sea and environmental issues.

The 2013 inscription of the Namib Sand Sea as a World Heritage Site provided the impetus to design educational materials for primary school students to learn about this new World Heritage Site. Given Gobabeb's strong capacity for primary level training, Gobabeb is well equipped to address this need for educational materials. A recent grant provided from the Finnish Fund for

Local Cooperation (FLC) gave Gobabeb funding to design a curriculum for grade 7 students train and teachers from the Topnaar community in content emphasized by the Namibian Institute for Educational Development.

We worked with Gobabeb and J.P. Brand Primary School to utilize the grant to develop a new curriculum that would effectively teach grade 7 learners about the environment, the Namib Sand Sea and World Heritage. Building upon Gobabeb's past experiences and training programs with local schools, we created a five-day program for grade 7 learners from J.P. Brand that includes five separate modules. These modules incorporate specific lesson objectives, educational content and activities that we compiled based off of Namibian Education requirements and various stakeholders priorities. Overall, this opportunity to create a new curriculum at Gobabeb allowed us to address and explore the challenges of environmental education in postcolonial nation.

Our paper first introduces both the grant proposal by Gobabeb to the Finnish Embassy Fund for Local Conservation and the new Namibian Ministry of Education primary school syllabus that provided us with the content needed to be included in the curriculum. We also give background on J.P. Brand Primary School, another key influence in our curriculum content. In addition to giving background on the content of our curriculum, we consulted literature in order to include both environmental education and pedagogy frameworks throughout our modules. After providing the methods of our process, we discuss the various curriculum components in greater detail and specifically explain the reasoning behind including particular content in its corresponding or relevant module. This includes identifying the various stakeholders involved in the curriculum and what they prioritized as being important and identifying where we applied each aspect of environmental education and educational framework. We discuss our success in incorporating these aspects into our curriculum and address any difficulties applying these concepts, given the specific context of this project. We then make recommendations to further develop environmental education in the future.

FLC Grant Context

In 2013, the Namib Sand Sea was accepted by the United Nations Educational Scientific and Cultural Center (UNESCO) as a World Heritage Site. Both the nomination process and inscription success were aided by Gobabeb Research and Training Center, which provided the scientific evidence and justification for why the Namib Sand Sea should be accepted as a World Heritage Site. Gobabeb was therefore designated to aid in the future monitoring and management of the site, by helping promote the Namib Sand Sea and helping community members learn new skills and gain knowledge necessary to better utilize the opportunities provided from the inscription.

After the successful inscription of the site, the Finnish Fund for Local Cooperation (FLC) in Namibia worked with Gobabeb to produce a plan that would better clarify and direct Gobabeb's

role in helping to transfer the benefits of the Namib Sand Sea back to the local Topnaar community. This grant was finalized in November 2014 and gave Gobabeb €210,000 to develop and implement a plan to successfully help local Topnaar take advantage of the World Heritage Site's benefits. As stated in the grant, the goals of this plan were to "realize the potential of the Namib Sand Sea's contribution to sustainable development in Namibia" and "to contribute to the sustainable management of the Namib Sand Sea through engaging local communities and sharing benefits accruing from its inscription." The grant outlined three project components as ways to advance and diversify educational and community training efforts at Gobabeb: Training course on the Namib Sand Sea for Topnaar Guides (Component A), Training course on the NSS for J.P. Brand Primary School, Grade 7 learners (Component B) and Collective legal entity to represent the communities interests in a protected area (Component C).

The focus of our research and of this paper is on Component B, Training course on the NSS for J.P. Brand Primary School, Grade 7 learners under Annex 1: Project Plan and Budget. (From here on, we refer to "training course" as "curriculum" and use learners and students interchangeably) Gobabeb hosts grade 7 students from J.P. Brand annually as a way to educate youth about the Namib Sand Sea. Within this project component, the FLC grant emphasized incorporating the World Heritage Site as an overarching learning tool in the curriculum of a five-day program. The goal was that students would develop a sense of pride and belonging to the Namib Sand Sea, and eventually an obligation and enthusiasm to help protect and preserve it. Students would also be encouraged to reflect on their own heritage and how heritage influences their daily lives.

With World Heritage being the key component to the curriculum, the grant specified four topics that should be taught to learners at Gobabeb. These include the importance of World Heritage Sites, background information on the inscription of the Namib Sand Sea, key features of the Namib Sand Sea and the flora and fauna of the area.

Although the grant specified that this program be implemented first with J.P. Brand Primary School, the goal is to create a long-term educational resource, and eventually make the curriculum applicable to other schools nationwide to promote the Namib Sand Sea. Realistically, not all grade 7 learners in Namibia will be able to visit Gobabeb and complete the program. Therefore, the grant emphasizes the importance of producing some sort of transportable exhibition, such as banners, workbooks, etc. that can be distributed throughout the country, hopefully having similar impacts on students that a visit to Gobabeb would have. The project plan also includes working not only with local teachers, but also with teachers in other areas of the country. The purpose for this was to ensure that students everywhere understand the value and uniqueness of the Namib Sand Sea. Although our work with the curriculum did not reach beyond the scope of bringing local schools to Gobabeb, it is important to note that the long-term goal for the grant and Gobabeb would be to expand the curriculum across Namibia.

Namibian Curriculum Context

In 2013, the Namibian Ministry of Education and National Institute for Educational Development (NIED) published a new Natural Science and Health Education syllabus for grades 4-7, to be implemented in 2016. The rationale behind the new syllabus was to encourage young students to learn more about the interaction of humans and the environment, and for them to gain the knowledge and skills that would help them understand the complexity of the physical and biological world. In recent years, the government of the Republic of Namibia has recognized the need to increase the amount of environmental education in order to improve sustainable development and quality of life. Through new education curricula, training and public awareness, the Namibian government hoped to emphasize the importance of education of the environment as a strategy to engage youth and ensure long-term sustainable development. The newly proposed syllabus supports this ongoing national goal to "build the best possible future for all Namibians" through environmental education (Education for Sustainable Development Strategy 2009).

Although both natural science and health education are within scientific areas of learning, the ministry found several overlaps between these topics and the broader, national curriculum. The new syllabus, therefore, integrates aspects from the sciences with social sciences, economics, math and technology, with the objective to motivate students to use scientific knowledge and health education to change behaviors and pursue careers in the sciences. By improving scientific education of students at a young age, the hope was that learners could gain the knowledge and skills needed to help improve living standards of the Namibian people. As identified in the rationale of the syllabus, Namibia is rich in natural resources and there is an opportunity to utilize these resources, but this requires relevant science and technological skills. In order for more learners to achieve these skills, it is crucial that students become scientifically literate, beginning at a young age. Only then will the country be able to better utilize technology and advance economically.

The new curriculum identifies the importance of integrating the natural sciences with other subjects and cross-curricular issues. In order to effectively teach these issues and subjects and the links between them, the syllabus identifies nine specific topics that students should be competent in following completion of primary school. These include Health Education, Scientific Processes, Matter, Forces and Energy, Light, Electricity and Living Organisms and Energy. We focused solely on the required grade 7 topics. They are organized as follows:

Table 1: Namibian Natural Science and Health Education Syllabus Topics

Grade 7 Learning Topics	Subtopics
Topic 1: Health Education	1.1 Sexuality and sexual health 1.2 STDs, HIV and AIDS 1.3 Teenage pregnancy and family planning
Topic 2: Scientific Processes	2.1 Estimating & measuring 2.2 Observing 2.3 Classifying
Topic 3: Matter	3.1 Nature of matter 3.2 Building blocks of matter 3.2.1 Atoms and molecules 3.2.2 Elements and compounds 3.2.3 Mixtures and solutions 3.3.1 Air around us
Topic 4: Forces and Energy	4.1 Nature and effects of forces 4.2 Weight and mass 4.3 The solar system and gravitation 4.4 Sources of energy 4.5 Energy in everyday examples
Topic 5: Light	5.1 Basic concepts of light 5.2 Dispersion of light 5.3 Transmission, absorption and reflection 5.4 Reflection by mirrors
Topic 6: Electricity	6.1 Static electricity 6.2 Electroscope 6.3 Electric current 6.4 Electrical sources 6.5 Conductors and insulators 6.6 Cells and bulbs in series and parallel
Topic 7: Living Organisms	7.1 Characteristics of living organisms 7.2 Plants 7.2.1 Flowering and non-flowering plants 7.2.2 Movement of particles and molecules: diffusion 7.2.2 Animals: variations among animals (including mammals, birds, reptiles, fish insects and amphibians)
Topic 8: Human Body	8.1 Physical development 8.2 Different systems of the human body 8.3 Digestion 8.4 Excretion 8.5 Nervous system and drugs
Topic 9: Environment	9.1 Ecosystems 9.2 Conservation of soil 9.3 Air pollution

J.P. Brand School Context

J.P. Brand, the closest school to Gobabeb, is a boarding school for students from grades 1-7. There are 272 students and ten teachers; the average class size is about 45 students. The majority of the students, approximately 80%, are from rural areas in Northern Namibia. The student population is ethnically diverse, with six main ethnic groups and several more subdivisions of these groups. There are currently 24 students at the school who are from the Topnaar community. Students speak a variety of languages, with at least six different languages and fourteen dialects represented (Principal Keib, personal communication, November 5, 2015). Classes are taught in English, but students are also required to learn Afrikaans. Some of the challenges currently facing the school are the lack of resources available to teachers and language barriers in the lower grade levels. Mr. Sheehama, a teacher at the J.P. Brand School, mentioned that often there is information that teachers would like to look up online but the school does not have access to the internet. This lack of internet access presents a significant barrier to education in the school. Another teacher mentioned that because many of students have no pre-primary education, grade 1 students often do not know any English.

Environmental Education Framework

Although the term "environmental education" did not arise until the 1960s, the modern environmental education movement has its roots in natural sciences and the conservation movement (Palmer 2002; McCrea 2006). This varied history underlies the variety of goals encompassed within environmental education today. According to the UNESCO Intergovernmental Conference on Environmental Education of 1977, the goals of environmental education are threefold: awareness of the interconnections between social, political, economic and ecological systems; knowledge and skills necessary to protect the environment; and values and behavior change to accompany this knowledge (Palmer 2002). Throughout the 1970s and 1980s, environmental education remained focused on scientific and naturalist work, as discussed in subsequent sections (see: Scientific Current, Naturalist Current). However, in the mid 1990s, Environmental Education for Sustainability (EEFS) emerged to address the "need to place any understanding of environmental concerns within a socioeconomic and political context" and the apparent contradictions between development and conservation (Tilbury 1995: 197). Overall, since its definition in the 1960s, "environmental education" has come to take on a wide variety of goals and definitions.

In light of this, it is important to remember that Namibia was still under apartheid rule throughout this initial process of defining the goals of environmental education. By the time Namibia was even able to begin develop its own environmental education curriculum, the field had diverged to address more than just conservation or science. In order to make sense of the priorities of environmental education in a post-colonial, post-apartheid Namibia, we drew on author Lucie Sauvé's fifteen "currents of intervention" (Sauvé 2005: 11) in environmental

education. Out of these fifteen currents, we chose to address the five most relevant currents to both the Namibia and J.P. Brand contexts: the scientific, naturalist, humanist, systemic, and ethnographic currents. The first four currents are considered to have a long tradition in environmental education while the ethnographic perspective is a more recent development (Sauvé 2005).

Scientific Current

The scientific current of environmental education supports the acquisition of knowledge in the environmental sciences and focuses on the environment as the 'hook' to encourage students to study science (Sauvé 2005). Several authors have emphasized this need to connect science to more "affective" or emotional issues in order to prevent negative associations of science by students (Duit and Treagust 2003; Littledyke 2008). On the other hand, science education can support the larger environmental education movement by providing "better understanding in order to better orient action" (Sauvé 2005: 17) Despite this potential for mutualism and global interest in science by many students, science education has received criticism for insufficiently incorporating and emphasizing environmental knowledge (Gough 2002; Gough 2009). As Tyler (2007) discusses, "[environmental education] constitutes a challenge to conventional subject based curriculum and pedagogy." (cited in Gough 2009: 38) Our curriculum seeks to address this challenge by utilizing science education to support environmental education.

Naturalist Current

The naturalist current of environmental education emphasizes positive human-environment relationships and the inherent right of nature to exist (Suavé 2005). This current has manifested itself in the movement of "outdoor education" where students conduct fieldwork or directly engage with the natural environment. Outdoor education programs vary in duration, content and emphasis, making comparative studies difficult to conduct. For example, one study of 255 Grade Six students in California found that a five-day, outdoor education program had no significant short-term effects, but, after six weeks, students who had been on the program retained more positive attitudes toward science and environmental behaviors than the control group. On the other hand, another study involving Grade 6 Slovak students found that short-term attitudes towards and knowledge of ecosystems and food webs did improve after only one day on a biology field trip (Prokop, Tuncer and Kvasničák 2007). Despite this variety of programs and outcomes, a review of 150 research papers on outdoor learning from 1993 to 2003, concluded that outdoor education as a whole not only increases student knowledge about the environment but also improves student attitudes toward the environment (Dillon et al. 2006). Our curriculum will incorporate outdoor education in the Namib Sand Sea with the hopes of ensuring more positive student attitudes to the environment while improving scientific knowledge.

Humanist Current

The humanist current of environmental education focuses on human place in the landscape and that "environment as a 'heritage' is not simply natural, it is also cultural" (Suavé 2005: 18). The humanist current is most directly tied to place-based education, which integrates learning about the environment and culture by focusing on interaction between students and the local community. This movement, as highlighted by the U.S. State Education and Environment Roundtable, is "not primarily focused on learning about the environment nor is it limited to developing environmental awareness. It is about using a school's surroundings and community as a framework within which students can construct their own learning, guided by teachers and administrators using proven educational practices." (Lieberman and Hoody 1998: 16). In a practical sense, place-based environmental education initiatives have involved students working with a community on an environmental project such as a garden, water-quality testing, or even coming up with a wetland management plan (Powers 2004; Smith 2002). While there has yet to be a comprehensive review of the effectiveness of place-based education about the environment, two notable studies have shown that place based education significantly increases place attachment, therefore increasing students' awareness and knowledge of the local environment (Semken and Freeman 2008; Ernst and Monroe 2004). Overall, place-based environmental education offers students the chance to not only improve their environmental knowledge, but also feel connected to the local community. In the case of our curriculum, we hope to improve knowledge about the Namib Sand Sea in particular and allow students to connect with the Topnaar community

Systemic Current

In the systemic current, analysis of the environment must be done with an "ecosystem approach" whereby any environmental situation is analyzed by examining the interaction of its component parts (Suavé 2005). This approach can be used in an experiential learning situation context. For example, students could be asked to follow an experiential learning cycle where they actively engage with their environment and then reflect on and analyze that experience through a series of questions or discussion (Jacobson, McDuff and Monroe 2006). Experiential learning emphasizes the importance of this experience-reflection cycle and process, rather than the specific experience or outcomes (Kolb 1984). This cycle can also be described as "the 5E's": engage, explore, explain, elaborate, and evaluate process (Saguaro 2004; cited in Jacobson, McDuff and Monroe 2006). This steps are elucidated further in Table 2. As a study in Colorado, U.S. demonstrated, even if students only go through the engage, explore and explain aspects of this process, they still gain significant increases in environmental knowledge compared to groups that went through all five stages (Powell and Wells 2002). This suggests that effective systemic learning about the environment can build upon student experience and teacher explanation of environmental phenomena. This systemic current will be utilized in our curriculum to help teach more complex systems and processes.

Table 2: Description of "5E's" of Experiential Learning[1]

Stage of Experiential Learning	Description of Stage
Engage	Instructors ask questions and present introductory information to encourage learners to ask questions
Explore	Learners engage with activities (ie. field work, games) where they interact with others and are able to ask questions
Explain	Instructor explains relevant concepts to activity and introduces any abstract concepts
Elaborate	Learners utilize these concepts in other situations
Evaluate	Instructors assess learner's progress and give feedback

Ethnographic Current

The ethnographic current is the newest addition to environmental education of these five currents. Like the humanist current, the ethnographic current has a cultural element; however, the ethnographic current demands that environmental education should not impose a single worldview or value set on learners but acknowledge multiple, overlapping conceptions of the environment (Suavé 2005). The ethnographic current is perhaps best represented in the Multicultural Environmental Education movement. In summation, "Multicultural Environmental Education (MEE) refers to increased access of culturally diverse—not only the dominant— groups to environmental education and increased representation of their worldviews in it." (Marouli 2002: 28) MEE is a process of learning about the environment through diverse cultural lenses while instilling respect for all cultures (Marouli 2002). Similarly to place-based education (humanist current), MEE calls for integration of the community into environmental education. However, MEE is more radical than place-based learning in that it demands that the "environment" must be conceptualized as a cultural landscape rather than an unpopulated wilderness (Martin 2007).

In addition to the MEE movement, the ethnographic current encompasses many aspects of post-colonial analysis of environmental education. In general, post-colonial theory addresses the end "process of disengagement with the colonial experience" and the issues of race, culture, and oppression that linger even after the official end of colonial rule (Crossley and Tikly 2004). In education, postcolonial theory can be used to analyze the elitism, detachment from local contexts, failure to incorporate indigenous knowledge, and "continuing hegemony of western forms of knowledge/power" seen in the education systems of post-colonial nations (Crossley and Tikly 2004). Science education in particular has garnered criticism for being "reticent to engage

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[1] Table adapted from "Conservation Education and Outreach Techniques" by Jacobson, McDuff and Monroe

with powerful discourses like post colonialism" (Carter 2004: 821). However, environmental education has provided the impetus to evaluate cultural diversity in science education and the level of western hegemony in science and environmental education content.

Pedagogy Theory Framework

In order to design an effective environmental education curriculum, we also researched the most effective methods of general student education. According to the Namibian Grade 4-7 Natural Science Curriculum, Learner-Centered Education (LCE) is a recommended approach to teaching the sciences. Thus, in the diverse body of literature on pedagogy, we decided to focus on LCE and its roots in Multiple Intelligences and Constructivism theories.

Multiple Intelligences

Two aspects of pedagogy theory that we considered as we were developing our curriculum were multiple intelligences and learning styles. Multiple intelligences theory recognizes that there are different types of intelligence, such as interpersonal, intrapersonal, and linguistic, that should be accounted for when designing activities. Learning styles theory acknowledges that learners have different preferred learning styles, such as visual, auditory and tactile-kinesthetic, and that activities should cater to a variety of learning styles (Jacobson, McDuff, and Monroe 2006).

Constructivism

In the early 1990s, constructivism emerged as a new dominant paradigm in educational theory that focused on the importance of personal experience and individual construction of knowledge. According to Lochhead, "knowledge is not an entity which can be simply transferred from those who have to those who don't… knowledge is something which each individual learner must construct for and by himself" (Lochhead 1985; cited in Robottom 2004: 95). Overall, constructivism is concerned with understanding students' prior knowledge, helping students to challenge their misconceptions, and encouraging student exploration to build upon their experiences (Robottom 2004; Jacobson, McDuff and Monroe 2006). It is difficult to evaluate the efficacy of "constructivism" because it is a conceptual basis for many related educational interventions (O'Connor 1998). While there are some quantitative studies that evaluate the effectiveness of "constructivism" (Kim 2005; Loyens, Rikers & Schmidt 2006), the vast majority of the research on constructivism focuses on evaluating the contextual applications of this theory. Some applications of constructivist theory are problem-based learning, cooperative learning and learner-centered education, among others (Loyens & Gijbels 2008).

Learner-Centered Education

Learner-Centered Education (LCE) is a learning and teaching approach that allows students to develop learning with the understanding, skills and attitude required to contribute to societal development. While "constructivism is a vague concept" (Powell and Kalina 2009: 241), LCE

has been shown to be an effective application of constructivist concepts in the educational environment. In recent years, it has been found that a "one teaching and learning methods fits all" approach has been unsuccessful (Brown 2013). Therefore, educators have started using the LCE approach as a way to improve both teaching and learning in schools. LCE requires both the learner and the teacher to engage in the learning process in order for it to be a successful method of learning (Brown 2013). Some of the techniques of LCE include asking students reflection questions, small-group discussions and bringing learners' previous knowledge into the learning process (Gayford 1995). LCE, to a certain extent, addresses multicultural elements of education by making the culture, heredity, and context of the learner's background essential in the learning process (Cornelius-White 2007). The learner brings this knowledge and experience to school that he/she has gained from interactions within family, community and the environment. As a result, the learner can expand and challenge what he/she has already learned when at school, and contribute to the learning process. (Republic of Namibia Ministry of Education 2013) Due to the importance of bringing personal experience to the classroom, teachers are encouraged to incorporate local examples and provide varied learning opportunities to address the diversity of student experience and personalities (Republic of Namibia Ministry of Education 2013). Overall, LCE programs have been proven to be more effective than traditional, "one size fits all" education. A synthesis of 119 studies from 1948 until 2004 found that there was a strong correlation between elements of learner-centered classrooms and positive student outcomes. (Cornelius-White 2007). Given its effectiveness and prioritization by the Namibian Curriculum, LCE will be a teaching method we employ throughout the curriculum we develop.

Methods

To develop our curriculum we reviewed relevant documents, researched literature on environmental education and pedagogy theory and conducted interviews with key stakeholders. The documents we reviewed include the FLC grant, formally titled as the *Agreement between the Embassy of Finland in Namibia and Gobabeb Research and Training Centre;* the *Ministry of Education, Arts and Culture Senior Primary Phase Natural Science and Health Education Syllabus*; and *The Republic of Namibia Education for Sustainable Development Strategy*. We conducted our literature review primarily using Google scholar, beginning with these keyword searches: "Environmental education"; "Environmental education children"; "Environmental education theory"; "Environmental education children"; "Education theory"; "Education for sustainable development"; "Learner-centered education"; "Science education constructivism"; "Science education Namibia"; "Science and indigenous knowledge". We also interviewed Gillian Maggs-Kölling, the Director of Gobabeb, on 11/3 and 11/6 about the grant and Gobabeb's long term plans for educational initiatives, and reviewed feedback forms from Gobabeb's previous programs. On 11/4, we met with the chief of the Topnaar people, Seth Kooitjie,. Finally, we interviewed Immanuel Keib, the J.P. Brand principal, Abraham Sheehama, a J.P. Brand grade 7 science teacher, and 40 J.P. Brand grade 7 students on 11/5 when we visited

the school. We also returned to J.P. Brand on 11/9 to present our curriculum to teachers and get their feedback (See Appendix III for Interview Questions).

Results

We developed a total of 5 modules for our curriculum.

Module 1 covers World Heritage sites, and focuses on the basics, importance of, and inscription of the Namib Sand Sea as a World Heritage Site. It includes two activities- Personal Nature and Culture, where students are guided to reflect on their own conceptions of nature and culture, and Namib Sand Sea Nature Walk and Card Game, where students use what they learned and apply it to specific features of the Namib Sand Sea.

Module 2 focuses on the Namib Sand Sea Flora and Fauna, teaching students how to identify the various plants and animals of the Namib Sand Sea and understand the uniqueness of these species and their adaptations. The activity included is the Animal Interview Game, which is essentially a trivia game emphasizing the most important Namib Sand Sea species.

Module 3 incorporates the scientific method into a research project for students where they are required to make observations, collect data and come to conclusions in their own experiments. Students learn about the three different ecosystems of the Namib Sand Sea by conducting soil temperature measurements, and at the same time are able to learn by working on their own, independent research project.

Module 4 applies general climate change and global warming to the Namib Sand Sea, and teaches students about how humans have negatively impacted the environment. The included activity is an interactive Climate Change Game, where students use role-play to engage with one another and learn about how global warming happens and how we can reduce its effects.

Module 5 addresses the cultural aspects of the Namib Sand Sea by including a lesson on the Topnaar culture and their interaction with the environment. There is an informal storytelling presentation where students listen to a Topnaar community member talk about Topnaar life, community and culture.

We have provided just a brief description of each module in this section to provide the reader with some context. For more information, refer to Appendix I, a complete list of each module with its objectives, content and activity.

Table 3: Summary of Curriculum Modules

Modules	Stakeholders	Activities	Relevant EE Currents
Module 1: World Heritage Criteria	Gobabeb (mandate of FLC grant)	Personal Nature and Culture and Namib Sand Sea Nature Walk and Card Game	Humanist, Naturalist, Scientific, Ethnographic
Module 2: Namib Sand Flora and Fauna	Gobabeb (mandate of FLC grant) Students, Principal, Educators	Animal Interview Game	Scientific, Naturalist
Module 3: Scientific Process	Educators, Gobabeb	Soil Temperature Experiment	Systemic, Naturalist, Scientific
Module 4: Climate Change	Students, Chief, Educators, Gobabeb	Climate Change Role Play	Systemic; Scientific
Module 5: Environment and Topnaar Culture	Chief, Gobabeb, Dartmouth	Story telling about Topnaar culture by Gobabeb Topnaar staff member	Humanist, Ethnographic

Stakeholder Priorities in Curriculum Development

According to Athman and Monroe, "effective environmental education programs involve stakeholders in all stages of the program from the development of the program to its evaluation." (2001: 40). By identifying stakeholder priorities, we hope to design a curriculum that will effectively address environmental education for the specific audience of J.P. Brand School's Grade 7 students at Gobabeb Research Center. With stakeholder priorities in mind, we began to design five curriculum modules for a 5-day program for Grade 7 J.P. Brand Students at Gobabeb. All the education content of the five modules can be found in detail in Appendix I.

1. J.P. Brand Principal: Principal Keib said that it was important for us to ensure that our curriculum was in line with the national curriculum. We accounted for this by using the J.P. Brand School curriculum based off of the national syllabus provided to us by Mr. Sheehama to ensure that each module was relevant to some aspect of the curriculum. Specifically, we incorporated content from Topics 2, 4, 7 and 9: Scientific Processes, Energy, Living Organisms and Environment into the objectives, content and/or activities of our modules. Principal Keib also expressed the desire to have a long-term relationship with Gobabeb, which is hopeful, as the grant provides for multiple years of funding for bringing J.P. Brand students to Gobabeb.

2. J.P. Brand Teachers: One of priorities we identified from our conversation with Mr. Sheehama was the scientific process; he emphasized this as a concept that was difficult for students to grasp. The Namibian Curriculum emphasized that learners should be competent in this area upon completion of grade 7. This informed our decision to create a project on the scientific process that students would work on throughout the curriculum. Module 3 includes a soil research project where students are required to use the scientific method to make observations, collect data and synthesize their findings into a final report. The other priority we identified from our conversation with Mr. Sheehama was energy, which he had mentioned as another topic that was difficult to teach; we incorporated this into our activity in Module 4 on climate change. In this activity, we address how power plants can contribute to greenhouse gasses and solar energy is an alternative to power plants that do not relieve greenhouse gasses.

3. J.P. Brand Students: While talking to the students, we identified ecosystems as a concept that students struggled to understand. In addition, out of 40 students that we asked about climate change, none were familiar with the concept. Therefore, we felt that it is was important to incorporate both ecosystems and climate change into our curriculum to address these needs. We developed a module specifically on the impacts of climate change, and incorporated ecosystems into two of our modules.

4. Chief: Despite preparing interview questions for Chief Kooitjie, we were not able to ask him many of the questions regarding his views on education due to other priorities dominating the conversation. However, we did identify that the chief may want the curriculum to include content about Topnaar culture and the environment and climate change. Furthermore, we acknowledged that the chief was taking a humanist perspective towards environmental education by emphasizing community integration into Gobabeb's long term planning and, by extension, educational initiatives. In his discussion, he identified that he wanted Gobabeb to better include the community and traditional knowledge in their planning and to make sure they look at the impact of environmental issues on the lifestyle of the Topnaar people. Additionally, he expressed that young Topnaar people don't have as much knowledge about the environment as their elders and that "they need to have a knowledge about the changes in the environment" including how the climate is changing (Chief Kooitjie, personal communication, November 4, 2015).

5. Gobabeb (as reflected in FLC Grant): Due to decades of scientific research and monitoring, Gobabeb has accumulated a vast amount of scientific knowledge on the Namib Sand Sea to contribute to the curriculum. In addition to this knowledge, Gobabeb has to include components from the FLC grant into the 5-day curriculum for the J.P. Brand School. Given that the grant is specifically intended to address the Namib Sand Sea as a World Heritage Site, we designed Module 1 to encourage students to reflect on

their notions of nature and culture and explain why the Namib Sand Sea is a World Heritage Site. In addition, Module 2 focuses further on the Namib Sand Sea by having students engage with information about the flora and fauna of the Namib Sand Sea.

Environmental Education Currents

In the next part of our curriculum development process, we considered how we could apply the five currents of environmental education to our Modules. While a large portion curriculum content was dictated by stakeholder priorities, the environmental education currents were addressed where they aligned with stakeholder priorities. Furthermore, all of the currents were heavily considered in the final design of the curriculum activities to ensure that these activities are supported as effective ways to teach and learn by the extensive literature on environmental education.

1. Scientific Current: As a scientific research center, Gobabeb is already well positioned to address the scientific bases of environmental education and inspire student engagement in and passion for the natural environment. The scientific current of environmental education was easily incorporated into the curriculum given the specification of the FLC Grant. As mentioned in the FLC Grant Context section, the grant specifies that J.P. Brand Students learn about the Namib Sand Sea, which is replete with science content. Through the three modules, students will learn about ecology, geology, the scientific process and environmental science.

2. Naturalistic Current: Throughout our modules, we tried to incorporate outdoor learning about the Namib Sand Sea in the Namib Sand Sea itself wherever possible. Modules 1 and 3 specifically take place outside in the Namib Sand Sea environment and emphasize the flora and fauna that are specific to this outdoor environment. In addition to this direct interaction with the environment, we sought to encourage positive relationships between students and the environment. This broadly informed our curriculum by inspiring us to include exciting, informative outdoor activities such as the Dune Walk in our curriculum. In addition, we included the Scorpion Hunt, that Gobabeb already has designed, in the curriculum (Appendix II); according to informal feedback from Gobabeb staff, this is one of the students' favorite activities.

3. Humanist Current: In order to address the humanist current, we created Module 5 about Environment and Topnaar Culture. Although Module 5 does not directly incorporate place-based learning through a community environmental project, it does bring together students and community members as one of Gobabeb's staff shares a story about the Topnaar culture. In addition to this community interaction, various activities throughout the modules are inspired by the place attachment that is emphasized in the humanist

current. This often overlaps with the naturalist current where we have tried to find ways to encourage positive student attitudes towards the natural environment.

4. Systemic Current: In order to incorporate the systemic current in our curriculum, we focused on incorporating the experiential learning cycle into our curriculum. Specifically, we sought to include at least the first 3 out of the "5E's" of experiential learning process: engage, explore, explain. The topic of climate change lends itself to this experiential learning cycle as it is a part of a complex, socioecological system with many component parts. In our "Climate Change Game" in Module 4, we identified several parts of this system that students can engage with to better understand the system as a whole. This experiential learning cycle and the systemic current of environmental education was also considered in the creation of Module 3 about the Scientific Process.

5. Ethnographic Current: To address this current, we focused on incorporating Multicultural Environmental Education (MEE) into our curriculum. First, bringing J.P. Brand students to Gobabeb for an environmental education program addresses MEE by increasing the access of a culturally diverse group of students to environmental education. This is especially important given that many of the student groups that come to Gobabeb are not from the local area, but Walvis Bay or Swakopmund. Second, to incorporate more diverse worldviews into the curriculum, we designed an activity that has students discuss their own viewpoints on nature and culture. In Module 1, we designed an activity called "Personal Nature and Culture". Since J.P. Brand students come from all different cultural backgrounds and parts of Namibia, this exercise is intended to validate students' current perceptions of nature and culture before even addressing the idea of World Heritage, which was defined by extra-local stakeholders. This allows students the ability to understand "heritage" from their own perspective before being told what "heritage" means in the Namib Sand Sea.

Application of Pedagogy Theory

1. Multiple Intelligences and Learning Styles: We applied multiple intelligences theory and learning styles theory throughout our curriculum to ensure that students have a variety of activities they feel they can connect to, enjoy and learn from. Instances where these theories were integrated into the curriculum activities are noted in the copy of the modules found in Appendix I.

2. Learner-Centered Education (LCE): Like multiple intelligences, LCE techniques were included throughout our curriculum by encouraging small group discussions, individual activities. First, LCE techniques naturally lend themselves to the humanist and ethnographic currents of environmental education. As discussed in the Background, LCE acknowledges that students' culture and previous knowledge is essential to the learning

process and should be engaged and acknowledged. We were sure to include the "Personal Nature and Culture" Activity in Module 1 in order to do just this. Furthermore, we designed every module with opportunities for students to ask questions and engage with the activity based on their thoughts and ideas. We also ensured that small group discussion would be included in many of the activities. Although we provided guidance to the instructor as to how to deliver the lesson, we did not specify an exact method of lecture, discussion, etc. for the instructor to use. With a diverse group of students , we felt it was best to allow instructor flexibility in order to be responsive to student needs and interests.

Finally, the intent of LCE is to ensure each student is engaged with the educational activities, thereby leading to increases in student knowledge. While we cannot definitely say what activities would most engage students without testing and observation , from talking to students at the school and reviewing feedback forms from previous Grade 7 school visits, it seems that students enjoy active activities that allow them to discover things for themselves. A former Gobabeb employee noted that "The learners seemed to really enjoy the scavenger hunt in the river bed as many of them cited this as their favorite activity." We also incorporated this element of student discovery into the Module 2 activity. We included activities with movement through the Dune Walk and Climate Change Game, in Modules 1 and 4, respectively.

Discussion

While developing our curriculum, we met some challenges addressing all of the currents of environmental education we identified as relevant. Of the five currents, we grappled most with the humanist and ethnographic currents. Fundamentally, both of these currents focus on the inclusion of culture in environmental education. However, when we attempted to include culture in the curriculum in Module 5, we were largely unsuccessful as we were not able to find a community member who would definitively commit to speaking to students. All of the individuals we spoke to expressed that they felt someone else from the community should come tell the story. Furthermore, our method of including culture in the curriculum, in hindsight, is not as well informed by the humanist and ethnographic currents as we intended. From the perspective of the humanist current, place-based education calls for "using a school's surroundings and community as a framework within which students can construct their own learning, guided by teachers and administrators using proven educational practices." (Lieberman and Hoody 1998: 16). Yet, while we consistently established Namib Sand Sea as a framework for learning, we do not include the community in the same, comprehensive way. By siloing interaction with the Topnaar community into just one Module, separate from the presentation of information about World Heritage and the Namib Sand Sea, we also do little to reconceptualize the Namib Sand Sea as a cultural landscape, a fundamental part of the ethnographic current.

One reason we were not able to weave culture throughout our curriculum was due to the specifications of the FLC Grant based on the World Heritage site inscription. The grant requires that J.P. Brand students learn about why the Namib Sand Sea is a World Heritage Site. The UNESCO World Heritage inscription recognizes the Namib Sand Sea for its unique geologic processes, flora and fauna, endemic species and natural beauty. It does not, however, emphasize the culture of the Topnaar people. World Heritage Sites are created in order to preserve and protect natural and cultural heritage around the world, but there is no acknowledgement of any aspects of local Topnaar culture in the current World Heritage inscription. From a postcolonial lens, this lack of incorporation of Topnaar culture into the very definition of this World Heritage Site is an oversight that maintains hegemonic colonial relations that undervalue indigenous culture. This again, is an issue of neglecting to acknowledge the Namib Sand Sea for its cultural importance and heritage by UNESCO and Gobabeb because it is easier to successfully inscribe a World Heritage Site for ecological features, rather than cultural ones.

Gobabeb was given the responsibility of helping manage the Namib Sand Sea as a World Heritage Site. As a research and training center, specializing in desert ecology, its focus is not on local communities or Topnaar culture. By nature of Gobabeb's work, there is a lesser emphasis on incorporating social sciences and concepts like postcolonial theory into environmental education. Failing to address postcolonial criticism of their educational initiatives is by no means an oversight by Gobabeb staff. Gobabeb's long-term focus is on scientific research rather than in anthropologic studies, social sciences, or related disciplines. There is no social scientist currently on staff at Gobabeb to address issues like multicultural understanding in Gobabeb's education initiatives. This lack of attention to social sciences serves to broaden the divide between the scientific and cultural aspects of the Namib Sand Sea. Furthermore, through interviews with Gillian, we gleaned her hesitation to reach out beyond Gobabeb staff as part of the curriculum. In this process, we observed that many of the dynamics between Gobabeb and the community discussed in the Dartmouth Africa Foreign Study Program report from 2013 exist to this day. According to this report "Gobabeb explains its main objective as pursuing a future of greater environmental sustainability and thus centers its activities on science research." (Megrue, Williamson, and Oszkinis 2013: 6).

However, when our curriculum is solely taught by Gobabeb staff members who are not part of the Topnaar community, our curriculum plays into some of the criticisms of postcolonial education that we tried to avoid. Authors Coombes and Brah highlight one such criticism: "with the assistance of early scientific taxonomic discourses, knowledge about the other was produced, and ultimately passed back through Western lenses to the colonized themselves" (2000; cited in Carter 2004). In many ways, our curriculum passes indigenous knowledge through a Western lens to students by presenting the Namib Sand Sea as a World Heritage Site solely based on natural processes. In addition, we look at the extent to which we have subscribed to the postcolonial criticism that: "The value assigned to the knowledge/culture depends upon its

translatability, that is, its removal from its original historical and cultural context, and ease of integration" (Carter 2004: 872) when reflecting on our attempt to include discussion with Topnaar community members in Module 5. Rather than create a separate module, we could have integrated elements of Topnaar culture throughout the curriculum.

Overall, the postcolonial criticisms of our own curriculum go beyond this unique situation and complicate one of the fundamental bases of education in Namibia: Learner-Centered Education (LCE). In our curriculum, we embraced LCE as the dominant learning style because it is specifically identified as the optimal method of teaching and learning in the Namibian curriculum. However, in diverse, multicultural settings, there are many limitations to the application of LCE. The emergence of LCE in Namibia in the early 1990's was directly tied to the emergence of the idea of "education for all". In theory, LCE and "education for all" would solve the issues with education in Namibia by allowing a greater and more diverse range students have access to education and allow students to learn for themselves, ultimately benefitting more than they would from other teaching methods. However, recent studies have pointed to the flaws in this theory, criticizing the fact that there is a large under-estimation of what resources are needed to successfully implement LCE (O' Sullivan 2003).

In one comprehensive 2003 study of education in Namibia, there were four major issues found with LCE in Namibia (O'Sullivan 2003). The first was that teachers themselves had trouble understanding what LCE was, and therefore could not properly implement it. In addition, teacher training is often inadequate and insufficient, so even students who are able to attend school are not gaining the knowledge they need or receiving enough attention to learn from a learner centered approach (Dahlstrom & Nyambe 2014). Second, LCE is most successful in very specific classroom environments, usually with small class sizes, lots of space to work and an abundance of resource and materials, which is often lacking in Namibian schools. Third, learners themselves had not been exposed to the type of learning that LCE utilizes, having been taught with a very structured, traditional learning style, making it difficult for students to adjust to the new teaching style. Finally and most importantly, LCE is not completely effective in Namibia because LCE is a western teaching and learning technique that focuses on western culture and ideals. Where students growing up in a western education system have been encouraged to question, challenge, experiment, etc., students in other parts of the world, such as Namibia, have been raised to respect elders and not question what they have been taught (O'Sullivan 2003). Overall, this calls into question whether even LCE as a teaching strategy can effectively address the diverse cultural context of Namibia.

Recommendations

Addressing culture in Environmental Education

Based on the difficulty in applying both humanistic and ethnographic currents in our modules, we suggest that Gobabeb put a greater emphasis on including culture in its educational initiatives. However, another important step in this process would be to update the World Heritage Inscription for the Namib Sand Sea to include Topnaar culture. We acknowledge that one of the reasons this may not have happened yet is because of lack of managerial capacity for the cultural inscription. In order to have an inscription for certain criteria, there has to be an organization or representative accountable for managing that criteria. We recommend that Gobabeb work with the Ministry of Culture to add to the inscription of the World Heritage Site aspects from the cultural importance of the area. Furthermore, we recommend that Gobabeb considers having a specialized social scientist on staff or as a consultant, especially if the Namib Sand Sea World Heritage site is culturally inscribed. Even if the inscription cannot be changed, it is worthwhile to encourage youth to reflect on both heritage and culture throughout their 5-day visit to Gobabeb. Overall, we encourage Gobabeb to consider the post-colonial criticisms presented in this report when creating curriculum material for the future.

Pursue Teacher Training

Part of the FLC grant included training of Namibian teachers to help them achieve a higher standard of teaching. Because the Namibian Education system has been partially influenced by outside stakeholders, and although the method may have success in these actors' respective home countries, it has not had the same effect in Namibia. It is an issue of improving the understanding of environmental education as a whole and better implementing LCE. Therefore, until teachers have access to proper environmental education training and learn how to understand and teach LCE, Namibia's post-apartheid education system will struggle to be effective and successful. We therefore suggest that Gobabeb expand upon the FLC grant's section on teacher training in addition to its work with primary school students. Even training a few local grade 7 teachers will have impacts on quality of teaching and therefore learning in primary schools. LCE has potential to be a successful learning method, but further steps are needed before we will see its effects. Therefore, Gobabeb should increase its focus on teacher training. Without support from teachers within the classroom, the 5-day program will have less effect on learners.

Community Based Projects

Based on our research on place-based learning and our inability to prominently feature it in our curriculum, we believe it is worthwhile for Gobabeb to explore incorporating community into its curriculum. Creating more student and community interaction would benefit the learner through place-based learning, and again strengthen the understanding of the Namib Sand Sea and the local community. We suggest that Gobabeb reach out to local Topnaar communities and see if

they would be willing to work with Gobabeb to create community-based projects where students from local schools can work within the community on projects having to do with environmental protection and sustainable development.

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Module 1: World Heritage Criteria

Objectives:
- Encourage students to reflect on their notions of nature and culture
- Have students identify the criteria of World Heritage Sites
- Teach students about the importance of the Namib Sand Sea (NSS), why World Heritage Sites (WHS) exist and why the NSS is a WHS

Content:
What is the purpose of a WHS?
- A WHS is a place that is listed by the United Nations Educational Scientific and Cultural Organization (UNESCO) as being of special cultural or physical importance. WHSs belong to all people of the world, no matter where they are located. Therefore, it is up to the international community to take care of and preserve each site.

Why is the NSS a WHS?[2,3]
1. Outstanding natural beauty of the NSS
2. Active geological processes of global significance
   - Two superimposed dune systems
   - Three contrasting, ongoing sedimentary 'conveyor belt systems'
3. Ongoing natural ecological dynamics that drive the evolution and interaction among NSS fauna and flora
   - Adaptations to fog-dependent ecosystem
   - " continuously adapting to life in a hyper arid environment"[4]
4. Many diverse endemic species live in dunes
   - Adaptations to harvest fog
   - Extraordinary diversity of endemic species of special significance to science and environmental understanding

Why should we care about the NSS?
- Important to preserve the natural beauty of the desert
- Reduce the threat of human impact on the NSS
- Archaeological and historical remains can tell us stories about the past

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[2] http://www.worldwildlife.org/ecoregions/at1315

[3] http://whc.unesco.org/en/list/1430

[4] http://whc.unesco.org/en/list/1430

- Scientists can learn about past, present and future conditions from studying the NSS, such as climate, dune formation, wildlife, etc.
- We can learn about the unique weather patterns/climate of the NSS
- Protect the several species of plants and animals that live in the NSS
- The Topnaar people live in this area of the NSS

Activity 1: Personal Nature and Culture[5]

Overview: Students will be guided to reflect on their own conceptions of nature and culture.

Materials:
- 1-2 Gobabeb Staff to facilitate
- Paper for each student
- Markers for each student

Instructions: Make sure each student has their own piece of paper and some access to markers. Have students create a t-chart on their page with "nature" written on one side and "culture" on the other. Ask students to work individually at first and be prepared to clarify what "culture" could potentially mean. For example: "*What are some things that are important to your own family?", "What things are important to people in your community at home?"*. Clarifying questions for nature: *"What things in the environment are important to you?", "What do you like to do outside in nature?"* Instruct them to write or draw things to do with culture on the "culture" side and things to do with nature on the "nature" side. Tell them that things can be written on one or both sides. After a few minutes of writing, get students back into groups and prompt them to talk about what they drew or write. Use this activity as a way to transition into the short World Heritage Site lecture in the next activity, reflecting on students' own ideas of nature and culture.

Activity 2: Namib Sand Sea Dune Walk and Card Game

Overview: Using what they learned about the criteria of a WHS, students will observe and classify aspects of the NSS into the 4 categories.

Materials:
- 2-3 Gobabeb Staff to facilitate
- 4 large, colored notecards per student (for 40 students, 160 notecards)
- Pens and colored pencils
- Hole punch
- String

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[5] FLC NSS Booklet used as inspiration for activity

- Scissors
- Whiteboard or chalkboard and markers or chalk (if available)

Instructions:
1. **Before the dune walk**, give a short lecture (10 minutes) on the NSS as a WHS. Abbreviated content above is suggested for the lecture. Be sure to connect this lecture to the previous activity about personal nature and culture. After the lecture, give each child 4 large note cards with one of the NSS WHS criteria on the front of each card. In the presentation, the four criteria for the WHS can be abbreviated as follows to match up with the cards.
   a. Natural Beauty
   b. Ecological Dynamics
   c. Geologic Processes
   d. Diverse and Endemic Species
2. **Throughout the dune walk**, the person leading it will prompt students to hold up the card they deem most relevant to the information being presented at the time. For example, when talking about golden moles on the dune (an endemic species) ask them to hold up the card that fits best with this information.
   a. Note that information that will be presented on the dune walk has already been compiled by Gobabeb intern Meg, as shown on the schedule in Appendix II
   b. The focus of the dune walk is on discussing and observing NSS flora and fauna as well as geologic processes of the dunes
3. **After the dune walk,** (see Dune Walk Card Game on schedule in Appendix II) students will break up into small groups and the facilitator will give discussion questions for each group and ask student to write down reasons why the NSS is a WHS.
   a. Prompt students to list the different WHS criteria and write them on a whiteboard if available (*"Who can tell me one of the categories for a WHS that we looked at today?"*)
   b. Facilitate discussion of each category one at a time; encourage groups of students to come up with their own questions, write things down:
      i. Natural Beauty: *"What did you find beautiful about the dunes?" "What is special about this place?"*
      ii. Ecological Dynamics: *"What do animals do in this environment?" "What does the dune ant look like and why?"*
      iii. Geologic Processes: *"How is fog important to this desert?", "What are other interesting things about the weather in this desert?"*
      iv. Diverse & Endemic Species: *"What are some species that you can only find here?" "What are some of the species we talked about on the dune walk?"*

c. After students write down examples on the cards, they can use colored pencils to decorate each card. Cards can be turned into a take-home mobile by hole punching the top and bottom of the card and tying string between each of the cards and coming out the top of the connected strand of cards. These mobiles can be hung up back in their school classroom.

Table of Information for Each Criteria[6]

Natural Beauty: dunes (color, size, texture), open sky, stars, plants, animals, clouds, sunrise, sunset, desert storms	**Geologic Processes:** world's only desert with dunes this big influenced by fog, dunes and their movement, sand transport by wind, river gyand ocean current; gravel plains, rocky hills, river beds
Ecological Adaptations: sand swimming and diving invertebrates, reptiles and mammals; loose sand, changing winds and fog; Ex. beetles flattened bodies for swimming, lizards shovel-like snouts, insects swimming movements	**Diverse & Endemic Species:** plants (dune grasslands, shrubs, !nara, ostrich grass, welwitschia, bushman-grass, etc) animals (beetles, spiders, birds, antelopes, small mammals, etc)

Module 2: Namib Sand Sea Flora and Fauna

Objectives:
- Have students identify NSS plants and animals
- Teach students the definition and importance of endemic species, and how plant and animal communities are constantly adapting to survive in the NSS
- Provide students with the necessary knowledge to be able to compare/contrast plants & animals found in the NSS to those found at home

Content[7]**:**
What are the important species found in the NSS?
- Plants
    - !Nara - Keystone species
    - Ostrich Grass (*Cladoraphis spinosa)*
    - Namib Dune Bushman-grass (*Stipagrostis Sabulicola)*
    - The Welwitschia plant
- Animals (Insects, spiders, scorpions, reptiles, birds, mammals)
    - Fog-Basking Beetle (*Onymacris unguicularis)*
    - Flying saucer trench beetle (*Lepidochora discoidalis*)
    - Racing Darkling Beetle (*Onymacris plana)*

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[6] All information sourced from Seeley, M., & Pallet, J. (2008). *Namib secrets of a desert uncovered.* Windhoek: Venture Publications.

[7] All information sourced from Seeley, M., & Pallet, J. (2008). *Namib secrets of a desert uncovered.* Windhoek: Venture Publications.

- ○ Namib Dune Ant (*Camponotus detritus)*
- ○ Dancing White Lady Spider (*Leucorchestris arenicola)*
- ○ Sidewinding Adder (*Bitis peringueyi)*
- ○ Wedge-snouted Lizard (*Meroles cuneirostris)*
- ○ Namib Dune Gecko (*Pachydactylus rangei)*
- ○ Ostrich (*Struthio camelus)*
- ○ Dune Lark (*Calendulauda erythrochalamys)*
- ○ Oryx (*Oryx gazelle*)
- ○ Grant's Golden Mole (*Eremitalpa granti namibensis*)
- ○ Cape Fox (*Vulpes chama*)

What is an endemic species?
- ● A species that exists only in one specific area and nowhere else
- ● Provide researchers with information about the history and special geological processes of the area
- ● Are very adaptable and have evolved to survive in their geographic location, usually one that is hard to live in for most plants and animals
- ● Eight species of plant (53% of the sand sea total), 37 arachnids (84%), 108 insects (52%), 8 reptiles (44%), a bird (11%) and two mammals (17%) are known only from NSS habitats
- ● Examples: golden mole, dune gerbil, dune lark, sand sea endemics, !nara

Adaptations to surviving in NSS[8]
- ● The NSS is a very unique environment:
  - ○ hyper arid environment
  - ○ fog serves as the primary source of water- life out here gets five times as much moisture from fog as from rain
  - ○ the tops of dunes are constantly reforming due to changing winds.
- ● This unique combination of loose sand, variable winds and fog creates an ever-changing variety of microhabitats that forces plants and animals to adapt to survive.
- ● Adaptations:
  - ○ provide heat tolerance
  - ○ prevent water loss
  - ○ allow movement through the dune sands, etc.
- ● Adaptations can be behavioral, structural or physiological.

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[8] http://www.landscapesnamibia.org/sossusvlei-namib/

Activity 1: Animal Interview Game

Overview: This activity will help students learn about the most important and coolest endemic species to the Namib Sand Sea.

Materials:
- 1-2 Gobabeb staff to facilitate
- Cards with important NSS plants/animals
    - Photos, facts, unique features
- Score keeping method

Instructions:
1. Using a set of cards with a photo of the animal, key habitat/behavioral facts, and unique features, allow students to spend time looking at the different plant and wildlife of the NSS. *Throughout this, remind students that these species are endemic to the NSS, and review the different adaptations and survival techniques that each plant/animal uses to live in the NSS.*
2. Split the group into two teams. Select a student from one team to stand in front of the class and pick one of the plant/animal cards. The student keeps his/her card a secret, and is ''acting'' as that animal for his/her turn.
3. Students from that team may then ask 5 ''interview'' questions as a group to the student who is representing the animal.
    a. Questions may include: *What do you eat? How many legs do you have? Can you fly?*
    b. Students may not ask specific questions such as "Are you a type of beetle?''
4. After asking 5 questions, the team must come up with 1 guess for what they think the plant/animal is. If they guess correctly, they get 1 point for their team. If they guess incorrectly, the other team (who has not asked any questions yet) gets to guess the animal, and if they are correct, get 1 point.
5. A student from the other team then goes and picks another card, and the game continues.
6. The team with the most points at the end of the game wins.

Module 3: Scientific Process/Method

Objectives:
- Teach students about scientific method through interactive process
- Expose students to three different soil types in NSS
- Promote student ownership of project with student data collection
- Familiarize students with soil properties

Content:

What are the steps of the scientific process?

1. Choosing a problem to solve
2. Selecting a hypothesis
3. Some preliminary research
4. Developing a plan
5. Carrying out the procedure
6. Analyzing the results

What causes fluctuations in soil temperature?

- Heat is both absorbed and lost from the surface of the soil.

What factors influence soil temperature?

- amount, intensity, and distribution of precipitation;
- daily and monthly fluctuations in air temperature;
- type, amount, and persistence of vegetation;
- soil color, slope, elevation, and availability of groundwater

Activity 1: Intro to Soil Project

Materials:

- 1-2 Gobabeb Staff to facilitate
- Worksheet to record information (Appendix IV)

Instructions:

1. This activity would be introduced on the first day and would give students some basic information regarding the gravel plains, riverbed and dunes.
2. This activity would include a quick walking visit to each of the areas (gravel plains, riverbed and dunes). The lecturer will point out relevant plants and animals as seen on the gravel plains, riverbed and dunes. Students will be encouraged to ask questions and take observations on the soil. Students will be encouraged to dig in soil, pick up soil to feel it.
3. After the walk together, split students up into three groups and assign each group a location (gravel plain, riverbed and dune) to collect the soil temperature three times a day (8:00am, 2:00pm, or 7:00pm) for two days. Additionally, explain that students make notes about the weather when they record the soil temperature at these locations. Encourage students to think about how weather might affect soil temperature.
4. In the three groups, facilitate discussion on what they observed at the weather station earlier and of the soil
   a. *Describe soil- what colors is it? What does it feel like? Where do we find it?*
   b. *Is this soil familiar to you?*
   c. *What do you already know about soil?*
   d. *What do you think will affect how hot the soil is?*
   e. *Do you think the soil is warmer in one place over another?*

> *f. What do you remember about weather from earlier today?*
5. Have students write down one question they want to think about on their worksheet relating to soil temperature at different times of day or under different weather conditions.
6. Instructor will give a short lecture on the scientific process, explaining how the soil temperature experiment will let students go through this process. Content above can be used at instructor discretion.

Activity 2: Data Collection

Overview: This activity will let students collect data on soil at their assigned location. In this process, students will learn how to take measurements and ask hypothesis building questions

Materials:
- 3 Gobabeb Staff to Facilitate
- Thermometers for use in soil (We recommend at least eight thermometers total. The student to thermometer ratio for the J.P. Brand group will be 5:1)
- Worksheet to record information (Appendix IV)

Instructions: Each of the three groups (gravel plains group, riverbed group and dune group) will go out with a facilitator to collect data at their location three times a day for two days. Students will be instructed on how to take measurements of soil temperature with the thermometer and accurately record these measurements on their worksheet. Each student should use the thermometer to record their own data. Acknowledge that students may have slightly different data. At each time of day, encourage students to make additional notes on the weather at that time, especially emphasizing if there are any changes in weather.

Activity 3: Data Compilation

Overview: Students will compile their soil data in small groups to design a poster and present their findings.

Materials:
- 3 Gobabeb Staff to facilitate
- 8 large poster boards
- Markers
- Rulers

Instructions: On the last day of the program, all the students will be brought together. Take two students from each location group and pair them with two students from each of the other

location groups (six students a group for seven or eight groups). Have the two students from the same location average each of their data points (help them with this; see "Average Data" Table in Appendix IV). Students will share their data and can graph the change in temperature over the course of two days at each location (three graphs total). Have more advanced groups graph their data for the gravel plains, riverbed and dunes all on the same graph (have them fill out the "Summary of Data (Advanced Worksheet)" in Appendix IV) Thus, each group of six students will have three graphs: one for gravel plains, one for river bed, one for sand dune.

The groups of six students each will use the time on the last day to make a poster summarizing their findings about soil temperature and weather observations over the course of two days. In the process of poster making, students can be guided through organizing their poster according to the elements of the scientific method that fit into Grade 7 Namibian curriculum. The following should be included on student posters:
- Initial Student Questions: Each student can write their own question or students can combine questions
- Initial Soil Observations: Students should be encourage to discuss their initial observations
- Weather Observations: Have them write or draw the weather on each day
- Three Graphs (example from Gravel Plains shown below)

Encourage students to organize and synthesize their information:
- *Did anyone have similar questions to start?*
- *How did the weather observations relate to the soil temperature?*
- *Did the weather change over the course of the day?*
- *Were soil temperatures different in different location? Why do you think so?*

After the posters are prepared, students will begin a poster session (like a small science fair). Each student group will briefly present their poster and then students will be able to discuss their findings in smaller groups.

Module 4: Climate Change/Energy

Objectives:
- Give students a background on the human impact of carbon emissions on the environment
- Encourage reflections on how human behavior contributes to climate change
- Discuss the effects of climate change on the NSS?

Content:

What is Global Warming?[9]

- Earth is getting slightly warmer year by year as a result of human activity. Global warming is caused by the greenhouse effect, called so because the earth's atmosphere acts like a giant greenhouse and traps in heat. When the Sun's radiation enters our atmosphere, it heats our planet. Earth gives off some of its heat as radiation of its own. Some of this radiation passes straight through the atmosphere and disappears off into space, but some is reflected back again by the "blanket" of greenhouse gases in the atmosphere. The more greenhouse gases, such as CO_2 or methane, there are, the more heat is trapped and the hotter Earth becomes.
- The greenhouse effect is good! Without it, our planet would be too cold to live on. However, humans have negatively been contributing to this greenhouse effect. Burning fossil fuels give off carbon dioxide, which increases the greenhouse effect and heats the planet. This is often described as an anthropogenic process, which simply means "humans caused it."

What is climate change?[10]

- Climate change is not new to our planet; earth's climate has been changing for hundreds of millions of years. The climate change we talk about today is different. While traditional climate change makes Earth as a whole either hotter or cooler, modern climate change makes climate more sporadic and extreme—hotter in some places, cooler in others; drier in some places; wetter elsewhere.
- This can have negative impacts on plants, animals and ecosystems. Sea levels will rise, our poles will melt, temperatures will increase- which can disturb species habitats and ways of life.

How can we stop global warming?

- We need to reduce the amount of carbon dioxide that we emit into the atmosphere. This means using less energy or using it more efficiently. Use renewable energy, such as solar or wind when possible. Turn off the lights when you leave a room, limit electronic use, don't burn trash.

Activity 1: Climate Change Game (Note: this activity should be done after a tour of Gobabeb where the solar panels are shown to the students and after the fog screen activity where the facilitator will talk about how climate change can impact this fog and how many species are dependent on the fog)

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[9] http://www3.epa.gov/climatechange/basics/

[10] http://www3.epa.gov/climatechange/basics/

Overview: Students will be acting out/simulating the process of global warming by playing a tag game.

Materials:
- Cards that assign and explain roles
- Chair(s) to designate
- Open area that is safe for running
- 2-3 Gobabeb Staff (one of which is main facilitator)

Instructions:
In the first phase of the game, students will simulate how greenhouse gas emissions from power plants and burning trash lead to climate change. The facilitator should give a brief overview of what a greenhouse gas is and some of the content behind climate change while explaining the activity. Climate change should be emphasized as a problem the group will be simulating. Material can be presented as a lecture with a larger group or in more of a group discussion with a smaller group. In both cases, encourage student questions about material and incorporate visual diagrams (on chalkboard, paper or in a presentation) where possible. (One possible question after the short lecture or discussion is: *Have you ever heard anything about global warming or climate change? Discuss with a partner.)* After this, students will play the first part of the game. Then, the facilitator pauses the game to lead a discussion about what is happening here, encouraging students to contribute what they already know about climate change and global warming. The instructor will review the content they have already presented an incorporate any content that was not already discussed. Then, students can play the second phase of the game. The second phase of the game adds complexity to the game and prompts children to consider alternative energy sources.

Each student is given a card with one of the following roles on it:
- Coal Power Plant
- Burning Garbage
- Sun Rays
- Trees- Just second round
- Solar panels- Just second round

Rules of First Round of the Game:
1. Give out cards to students, making sure there is an even split between the number of suns and then the number of coal power plants and burning garbage combined (ex: 20 suns, 10 coal power plants, 10 burning garbage)
2. Start the game and release all of the suns. Explain to them that they run back and forth between one wall or side of the area (labeled as space) and the other wall/side (labeled earth)

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3. Have the coal power plants and the burning garbage students form two lines on the earth side. Release the students two at a time (one from each line) as the game goes on. The coal power plant and garbage students try to tag a sunray. Each power plant or garbage can only tag one sun ray (that sun ray then sits down because they have been caught). The purpose of this is to show what happens when more coal is burned in power plants and more trash is burned.
4. Stop the game play after most of the sunrays have been caught. Prompt students to answer questions:
    a. *"What caused the sun rays to get caught?*
    b. *"When there were fewer coal power plants burning and fewer people burning garbage (in the beginning), was it harder to trap the sun rays?*
    c. *"What happened as there were more coal power plants burning goal and more people burning trash"*
    d. *"Sun generates heat, if there is more heat trapped on earth, what do you think will happen?"*
    e. *"How do you think this would affect the desert where there is already only fog that brings water to the plants and animals here? (Suggest drought and potentially less fog if students don't think of this)*
    f. *How would less fog affect animals?* (make suggestions such as how the fog would affect Head-stander Beetle (Onymacris unguicularis) or alike)
    g. *How could more droughts affect the people who live here in the Namib Sand Sea?*

Rules for Second Round of the Game (this round is more advanced and complex):
1. Give out cards to students but substitute half of the power plants/burning garbage students with trees and solar panels (Ex: 20 suns, 5 coal power plants, 5 burning garbage, 5 trees and 5 solar panels)
2. The rules for power plants, suns and burning garbage is still the same, but the job of trees is that whenever a sun gets tagged and sits down, the trees can go tag those suns and they are back in the game (no longer trapped) and can run back and forth again
3. The solar panels can tag the coal power plants and get them out (simulating that solar power can replace coal power)
4. Release all the suns at once and then release each of the other categories one at a time
5. Stop the game play after a sufficient amount of time (once students start to tire or get bored, after ten minutes or so) Prompt students to talk about these questions, now in small groups
    a. *"How was this version of the game different than the first round"*
    b. *"Was it harder to trap the sun rays when there were more trees?*
    c. *"For the coal power students, was it harder to catch the sun rays when the solar power was chasing you*

d. Advanced: Have paper and pencil available for students and guide them through drawing the game on paper with arrows for what is contributing to greenhouse gasses (coal and burning trash) and what is taking in greenhouse gases (the trees). Discuss how solar power is a substitute for coal power. Discuss how solar power is what powers Gobabeb. Discuss the difference between solar and coal power.

Module 5: Environment and Topnaar Culture

Objectives:
● Familiarize students with Topnaar culture, tradition and ways of life

Potential Content:
Who are the Topnaar?[11]
● Oldest inhabitants in Namibia, 13 villages, 300-400 people
● Settled along the Kuiseb River in the Erongo Region of Namibia
What is the importance of !nara and livestock to these communities?
● The desert is normally an inhospitable place to live, and a community is usually not able to be successful in this environment. The !nara plant and livestock allow Topnaar people to have a resource to rely on, and they are able to sustain their community. When they introduced livestock, they no longer had to rely on hunting and gathering. The endemic !nara plant also provides a sustainable resource, for both community and commercial purposes. Both of these give the Topnaar people a secure source of food as well.

Activity 1: Topnaar Story

Overview: This activity allows students to interact with and listen to a Topnaar community member to help better understand the Topnaar people and culture.

Materials:
● Gobabeb staff member or member from Topnaar community

Instructions:
Have students listen to a local Topnaar community member talk about the history of the community, traditions, culture, etc. There is no formal structure necessary for this activity. Students will have the chance to listen, learn about the community and ask questions.

Another suggestion we have is to also create a short film about the Topnaar people, working with local communities, the chief and alike, that can be shown to many school groups. According to

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[11] Information sourced from Seeley, M., & Pallet, J. (2008). *Namib secrets of a desert uncovered.* Windhoek: Venture Publications.

Gillian, a Brazilian filmmaker will be coming sometime in the next year and could make this movie. This movie could be used if a Topnaar staff member is not able to spend the time with the students to tell a story.

Appendix II: Sample 5-day Schedule of J.P. Brand Visit to Gobabeb

	Day 1 (Arrival)	Day 2	Day 3	Day 4	Day 5	
8:00		Breakfast	Breakfast	Breakfast	Evaluations & Quiz Game	
8:30						
9:00		Soil Project Data Collection	Soil Project Data Collection	Collect Fog-Screens and Pitfall Traps and Discuss	Departure	
9:30						
10:00	Arrival	Personal Nature and Culture	Fog-Plant Exercise	Compile Data into Final Project		
10:30		Namib Sand Sea Dune Walk				
11:00	Intro to Gobabeb					
11:30	Tour of Gobabeb and Weather Station					
12:00			Topnaar Story/!Nara Movie/ !Nara Song			
12:30	Break					
13:00	Lunch	Lunch	Lunch	Lunch		Has been designed by Gobabeb Staff
13:30						Designed/ Suggested by Dartmouth
14:00	Intro to Soil Project	Soil Project Data Collection	Soil Project Data Collection	Final Project Worktime		Will be designed by Meg/someone else
14:30						
15:00		Dune Walk Card Game	Fog-Screen Designing			
15:30						
16:00	Set Pitfall Traps to Collect Insects	Climate Change Game and Discussion	Make-Your-Own Fog Screen	Soil Project Presentations		
16:30						
17:00						
17:30	Break	Break	Break			
18:00	Dinner	Dinner	Dinner	Sundowners		
18:30						
19:00	Game/Movie	Soil Project Data Collection	Soil Project Data Collection	Dinner		
19:30						
20:00		Animal Interview Game	Dune-Night Walk	Scorpion Hunt		
20:30						
21:00						

Appendix III: Semi-structured Interview Questions

Semi-Structured Interview Questions for Chief Kooitjie

1. What is the significance of the Namib Sand Sea to the Topnaar people?
2. Are there any stories in Topnaar culture involving the animals or plants of the Sand Sea?
   a. Any stories about the weather, the dunes, the river?
   b. What do you think would be good things to talk to people about regarding?
3. The Namib Sand Sea has recently been declared a World Heritage Site (2013)?
   a. How do you feel about this?
   b. Has anything changed since then?
   c. Do you think this is important?
4. The relationship of the Topnaar people to the !Nara?
   a. Why is the !Nara important?
5. What do you wish the Topnaar people knew about their environment?
6. How important is education to you and your people?
   a. Is high school education important?
   b. Do you see a value to education for your people?
7. Is there anything that Gobabeb should be teaching people outside of the area (Namib Sand Sea) about your people?

Questions for Principal and Teachers, J.P. Brand School visit on 11.5.15

Demographics (for principal)
1. How many students attend school?
2. How many boarders? How many day students?
3. What different grades are in the school?
4. What is student to teacher ratio?
5. Male to female ratio?
6. Where are students from?
   a. Urban vs. rural?
7. How many students are from Topnaar community?
   a. Urban vs. rural?
8. What other ethnic groups do children come from?
9. What is dropout rate?
   a. When do students drop out most frequently?
10. What is the language of instruction at the school?
11. What language do most students speak?
12. Are any other languages taught?
13. What are the biggest problems facing the school?

Environmental Education

1. Do you teach students about the environment?
2. How do you teach them?
3. What, in your opinion, are the most effective ways to teach about the environment?
4. What materials/curriculum are used to teach?
5. Are there hands on ways that students learn about the environment?
6. Do you encourage students to take care of the environment (don't litter)?
7. What are some of the challenges you have with addressing the environmental education curriculum?
8. (Principal) Are teachers knowledgeable about the environment?
9. (Teacher) Is environmental education a priority in school?
10. (Teacher) Are you familiar with the term climate change?
    a. If yes, do you teach students about climate change in school?
11. Are you familiar with what Gobabeb is?
12. Have any students, to your knowledge, visited Gobabeb before?
13. We are working on creating a 5 day experience for Grade 7 students at Gobabeb, is this something the school would be interested in?
14. Do you think we should be targeting grade 7 learners?

Namib Sand Sea and Topnaar
1. How important is teaching about the Namib Sand Sea and the local environment?
2. How important is teaching environmental protection of these areas?
3. How often do students "get outside" the classroom to learn about the NSS?
4. Are you aware that the NSS is a World Heritage Site?
    a. What is the importance of this?
5. Is there any interaction between the school and local Topnaar community?
6. Is there any cultural education?
    a. Do students learn about local Topnaar communities and cultures?
    b. Are there other cultures that are taught? How?

Questions for Students, J.P. Brand School visit on 11.5.15
General Questions
1. What is your name?
2. How old are you?
3. Where are you from?
    a. Urban, rural?
4. What are some of your favourite things to learn about?
5. What are some of you favourite activities?
Environmental Education/Culture
1. Have you learned about the environment in school?
2. What have you learned about the environment?

3. How do your teachers teach you about the environment (games, homework, etc.)
4. Do you like learning about the environment?
5. Is it hard to understand about the environment?
6. How important is the environment to you?
7. Do you spend time outside at home?
8. Do you spend time outside at school?
9. Do you think protecting the environment is important?
10. How do you protect the environment?
11. Have you heard of climate change?
    a. If yes, what do you know about it?

Semi Structured Interview with Gillian

1. What motivated Gobabeb to apply for the FLC Grant?
2. Has Gobabeb received funds from the Finnish Embassy before?
3. What are you hoping to see from the grant?
4. How does it fit into the long term goals of Gobabeb?
5. What are the long term education goals of Gobabeb?
6. Does Gobabeb plan to continue any primary education programs in the future?
7. Does Gobabeb plan on continuing the Youth Environmental Summit (YES) program?
8. Is Gobabeb interested in maintaining a relationship with J.P. Brand in the long term, past the duration of the grant?
9. What has been discussed regarding curriculum strategy in the past?
10. Is there anyone who is Topnaar on the staff who would be willing to talk to us?
11. If we have expenses that we want to include items that require budget expenses, is that okay? Should we keep track of that?
12. Who will be facilitating the curriculum here at Gobabeb?
13. Could the teachers help facilitate parts of the curriculum?
14. Have J.P. Brand teachers who come to Gobabeb been involved in the past to help facilitate discussion and work on activities with the kids?

Appendix IV: Soil Temperature Activity

Name:_____

Group Location:_____

Date of Soil Observations: _____   Dates of Soil Temperature

Observation:_____, _____

Instructions: For soil observation, make notes on the color, feel and texture of the soil. For "My Data", students will record the soil temperature at each time of day at their location. For "Average Data" students will average their data with a partner in their group.

Soil Question:

_____

_____

_____

_____

Soil

Observations:_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

My Data

	9:00	14:00	19:00	Weather Notes
Day 1				
Day 2				

Average Data

	9:00	14:00	19:00
Day 1	(____+____)/2 = _____	(____+____)/2 = _____	(____+____)/2 = _____
Day 2	(____+____)/2 = _____	(____+____)/2 = _____	(____+____)/2 = _____

Instructions: When students come together, have them record all of the averages from different locations at different times into the same table for comparison.

Summary of Data (Advanced Worksheet)

	Time of Day	Gravel Plain	Riverbed	Sand Dune
Day 1	9:00			
	14:00			
	19:00			
Day 2	9:00			
	14:00			
	19:00			

Sample Graph of Soil Temperature in Gravel Plain

| 9am | 2pm | 7pm | 9am | 2pm | 7pm |
| DAY ONE | | | DAY TWO | | |

Temp

Time
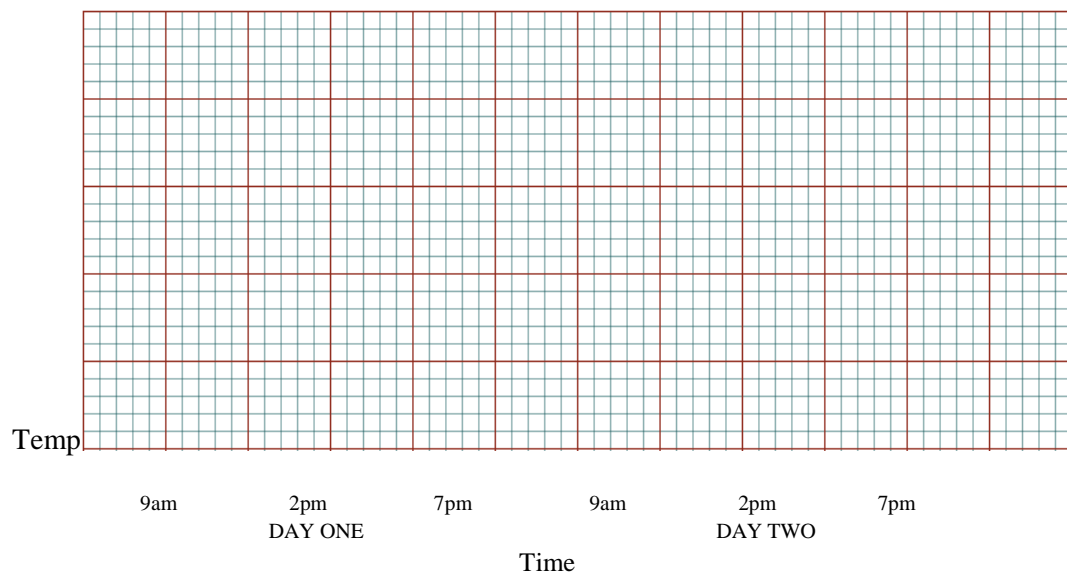
Long Term Study of the !Nara Plant Year III: A Continuation and Expansion of Monitoring Methods

November 14, 2015

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Introduction

Much research is being done on global climate change and the impacts that these environmental shifts will have on global systems. Less is known about climate change impacts on a more regional level, because its impact will vary geographically (Dirkx et al, 2008). Namibia, for example, which already experiences extreme weather such as flooding and drought due to its arid environment, is predicted to be much more vulnerable to climate change impacts than more temperate areas (Turpie et al. 2010). The entire country is expected to experience increases in temperature and evapotranspiration rates, with decreased amounts of and increased variability in rainfall (Turpie et al. 2010, Schneider et al. 2015). These changes are predicted to be less intense along coastal areas, and the extreme climates of the hyper-arid Namib desert and its surrounding areas are predicted to be particularly exacerbated by these climatic changes (Midgley et al. 2005, Schneider et al. 2015).

These environmental shifts have the potential to impact biodiversity. Namibia is a country of remarkable biodiversity with over 4500 plant taxa, 700 of which are endemic to the country, not including 275 Namib Desert endemics shared with Angola (Midgley et al. 2005). In the Midgley et al. (2005) research models of plant vulnerability to climate change, 30-40% of the plants in Namibia modeled were projected to become critically endangered or extinct by 2080, with endemic species projected as slightly less vulnerable. These impacts on biodiversity have implications for humans, too: subsistence livelihoods, based on a reliance on the land and biodiversity, sustain up to 70% of the Namibian population (Midgley et al. 2005). These people could have their livelihoods disrupted by plant extinctions, shortages, or range migrations.

As Midgley et al. (2005) argue, "a full assessment of vulnerability to climate change in the biodiversity sector requires knowledge of the interaction between potential impacts of climate change on biodiversity, and the ability of conservation efforts to adapt to or mitigate these" (11). In order to begin to comprehend this interaction between climate change and biodiversity, the long-term monitoring of species is first necessary in order to develop baseline data on the health and population trends of a species within an ecosystem. Once this baseline is established, factors affecting the health of the species can be identified, thus informing conservation efforts and management strategies to combat those threats to biodiversity (McLaughlin et al. 2013). Long-term monitoring efforts should be as comprehensive and non-invasive as possible in order to best inform monitoring decisions (McLaughlin et al. 2013). It could be particularly important to establish long term monitoring plans for species that perform a key role in their ecosystem and for human livelihoods, because of the significance of that species in its environment.

The !Nara (Ecology and Background)

The *Acanthosicyos horridus*, or !nara, is an important species for long-term monitoring of growth and reaction to climate change for the reasons listed above. The !nara is endemic

to the Namib Desert, an arid but fog-fed desert characterized by low levels of rainfall and high potential evapotranspiration. Evidence suggests that the !nara has existed along the coast of Namibia for over 40 million years (Berry 1991, Ito 2005). As such, the !nara is well adapted to this arid environment; a spiny, dioecious plant of the Cucurbitaceae family, it grows in tangled bushes of greenish branches, conducting photosynthesis through its 2-3 cm long thorns and its stem (Dongol et al. 2014, Ito 2005).

As sand builds up around the roots of !nara seedlings, the plant continues growing above the sand, with the roots and older plant growth form the interior structure of small sand dunes known as hummocks (Berry 1991, Ito 2005). The !nara and its hummocks provide a crucial habitat and food source for countless other species of the Namib desert, including insects, reptiles, mammals, and birds (Henschel and Moser 2004). Additionally, the !nara plays an essential role in the livelihoods of the local Topnaar people, who have been harvesting the fruit for approximately 6000-8000 years as a source of both food and income (Henschel et al. 2004).

Research Objectives
The importance of the !nara within its environment, non-invasive monitoring, and the relationship between hummock size and plant health informed three objectives of this research, which is a continuation of the long-term monitoring of the !nara near Gobabeb Training and Research Center.

First, we want to use established monitoring methodology to assess annual changes. As an endemic plant with a very important role in the lives of animals and the Topnaar, the !nara and !nara hummocks are worthy of year-to-year and longer term monitoring. If the health and population of the !nara is threatened, so are the lives and livelihoods of the animals and humans that rely on the plant. The importance of the !nara prompted us to assess changes happening from 2014 to 2015 using previously established methodology.

Second, we want to broaden and improve long-term monitoring through incorporation of the unmanned aerial vehicles (UAVs). Long-term monitoring efforts of the !nara should be as comprehensive as possible while also taking the fragility of the !nara and the ecosystem that it supports into account. As previously stated, there are many small creatures that depend on the !nara and its hummock: the examination of one plant over 8 weeks uncovered over 2000 tenebrionid beetles of ten different species in addition to many other small insects and lizards (Berry 1991). High-impact, invasive monitoring efforts risk harming these animals directly or indirectly through accidental damage to the !nara or its hummock; indeed, both prior long-term study groups of the !nara at Gobabeb mentioned that minimizing damage to the !nara and its hummock should be a priority (McLaughlin et al. 2013, Beitler et al. 2014).

UAVs can provide a less invasive method for biodiversity monitoring of plants like the !nara. Aerial monitoring can be performed remotely through the imagery produced by UAVs, providing details that could be very time-consuming or destructive if collected on foot (Handwerk 2013). In the case of the !nara, the UAV can also provide information

about areas that are more difficult to access, especially in an environment as fragile as the Namib Sand Sea. These possible benefits of noninvasive monitoring techniques in this area informed our emphasis on broadening and improving long-term monitoring potential through incorporation of the UAV.

Finally, we want to use the data collected from the UAV to examine !nara plant health. The monitoring of the relationship between hummock size and !nara health will become even more important in the face of a drier, hotter climate. Like all desert plants, the !nara is limited in its growth by its access to water . In order for germination to occur, seedlings require temporarily sufficient surface water; furthermore, research has shown that the !nara needs to be connected to a permanent source of groundwater in order to survive in these areas of rare precipitation (Henschel and Moser 2004, Moser 2004, Pfeifer 1979, Dongol et al. 2014). This connection to groundwater is enabled by the !nara's long taproots, which are presumed to extend up to 50m deep (Henschel and Moser 2004).

Despite this dependence on water and the relative scarcity of water resources in the Namib, the !nara is surprisingly water inefficient, trading high transpiration "water waste" for the maintenance of high levels of biomass and slow growth year round. This unusual strategy allows for a huge boost of carbon uptake with a doubled or tripled net assimilation rate when water resources are plentiful (Hebeler et al. 2004). Furthermore, while the root growth rate of most desert plants is in excess of 2mm/day, the !nara root only grows at 0.613 mm/day (Ito 2005, Dongol et al. 2014). Because of this, even remote interdune !nara fields are assumed to be situated above relatively shallow groundwater, making them vulnerable to factors that reduce the water table (Henschel and Moser 2004, Dongol et al. 2014, Shilomboleni 1998).

The water inefficiency of the !nara could put it at risk in a changing climate. Some authors argue that conditions for !nara growth and crop yields for the Topnaar have already deteriorated in recent years (Shilomboleni 1998). Long-term information on hummock size and !nara plant health will help Gobabeb identify the vulnerability of !nara to climate change, thus informing conservation management decisions. This informed our emphasis on using UAV data to add to our baseline data on assessing !nara health.

The combined use of the established "wagon wheel methodology" and UAV image analysis allows us to assess changes from 2014 to 2015 and compare hummock size and !nara health. Furthermore, the introduction of the UAV allows for less-invasive monitoring techniques that can broaden the scope of the !nara long-term monitoring plan and data collection, potentially allowing for predictions about climate change impacts in the future. Our objectives and rationale discussed above (and outlined with Roman numerals below) have informed the following guiding questions and hypotheses:

<u>I. Use Established monitoring methodology in order to assess annual changes.</u>

What is the change in hummock size and total plant volume measured by the "wagon wheel" method (described below) from 2014 to 2015?
- Hummock size is predicted to stay the same using this method.
- Plant volume of !nara plant is predicted to slightly decrease from 2014 to 2015.

<u>II. Broaden and improve long-term monitoring potential through incorporation of the UAV.</u>

How does data collected on the !nara and its hummock from the UAV compare to that of the "wagon wheel?"
- Hummock surface area collected from a 2-dimensional UAV image is predicted to be the smallest measurement, the 3-dimensional model created from the UAV data is predicted to be the largest measurement, and the "wagon wheel" surface area is predicted to fall in between these two.
- Measures of !nara plant volume and coverage of the hummock are predicted to be consistent between the two methods.

<u>III. Use the data collected from the UAV to examine !nara plant health.</u>

Is there a relationship between hummock size and plant health?
- Larger hummocks are predicted to support more healthy !nara plants as measured by plant volume.
- Larger hummocks are predicted to support more healthy !nara plants as measured by the portion of !nara that is alive, or live fraction.

Methods

This study took place from November 2 to November 9, 2015 and was based out of Gobabeb Training and Research Center in Namib-Naukluft National Park. It was a continuation of the long-term monitoring study put in place to assess !nara health and productivity over time by two previous Dartmouth College groups at Gobabeb (McLaughlin et al, 2013; Beitler et al. 2014). Our study continued this monitoring and broadened its data scope by using the established "wagon wheel methodology" and introducing UAV imagery into the monitoring plan. This was made possible by the Dartmouth College donation of an IRIS+ unmanned aerial vehicle (UAV) to Gobabeb TRC as a part of their ongoing relationship to build capacity at the Center for monitoring and increased research potential.

Site Selection

The study took place in the Gobabeb Interdune Valley and at the Kuiseb Delta near Gobabeb Training and Research Center. The Gobabeb Valley (GV) was selected in order to gather data that could be compared to the 2014 study (Beitler et al 2014). Sites 1 and 3 of GV were accessible by foot and car. We did not include Site 2, which was a part of the studies in 2013 and 2014, due to time constraints. The Kuiseb Delta, accessible by car, was selected in consultation with Gobabeb Training and Research Center as a site that is convenient and important for future monitoring. See Appendices 1a & 1b.

Hummock Selection and Identification

For the first part of our study, we used the same hummocks at Sites 1 and 3 as the Beitler et al study in 2014. There were 6 hummocks at Site 1 and 5 hummocks at Site 3 for a total of 11. For the second part of our study, we used 10 hummocks at each site, including the same ones that had been used in the part one. We re-named the GPS codes for hummocks from previous years in order to streamline this system and eliminate confusion. An example of this new classification system follows:
GV103= Gobabeb Valley, Site 1, Hummock #3

Wagon Wheel Transect Method

In 2013, McLaughlin et al. applied the line-intercept method, a long-standing technique for estimating percent plant cover, as a means of monitoring !nara plants; they renamed it the "Wagon Wheel Transect" methodology and used it to measure approximate hummock size and determine cover class (live !nara, dead !nara, other shrub, and bare soil) and height of live plants (McLaughlin et al. 2013) (Appendix 2) . Use of this method was continued in 2014 by Beitler et al, 2014. To address our first research objective of assessing changes happening from year to year, we used this method in the Gobabeb Valley at Sites 1 and 3 to obtain data that can be compared to past year's studies.

Following the methods of McLaughlin et al. (2013), we collected the heights of live !nara patches, percentages of live !nara, dead !nara, and sand along transect lines, and the total lengths of the eight transect lines at every 45 degrees, starting at true north and rotating in a clockwise direction. Heights were measured with a meter stick from the approximate root of a live plant to the top of the bush. Using this information, we calculated average hummock surface area, the percentage of the hummock covered in the various classes of vegetation, and live above-ground !nara volume. McLaughlin et al. (2013) developed a formula to calculate what they referred to as "biomass," which we used; however, we are referring to this value more accurately as aboveground live plant volume (hereafter "plant volume"). We calculated hummock surface area using the following formula:

$$Surface\ Area = 0.5 * \sin(45°) * \left[\left(\sum_{i=1}^{7} T_i * T_{i+1} \right) + (T_8 * T_1) \right]$$

where T= transect length

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We calculated class cover by the percent of transect of that class divided by the total transect lengths. The following formula is the percent live cover, and dead cover and sand cover were calculated with the same formula:

$$Percent\ Live\ Cover = \left(\frac{\sum_{i=1}^{8} L_i}{\sum_{i=1}^{8} T_i}\right)$$

where L= total length of live nara on transect

We calculated live plant volume by multiplying the average of the heights recorded on the hummocks and total hummock surface area and percent of live !nara coverage on the hummock.

$$Live\ Volume = SA * LC * H$$

where SA= total hummock surface area, LC= percent live cover, and H= average height of living plants

Statistical t-tests were performed for this data using JUMP software on the relationship between 2014 and 2015 surface area, plant volume, height, and live cover on the !nara hummock. This enabled us to test our hypotheses from our first research objective that hummock size would remain the same from 2014 to 2015 and that plant volume would increase slightly from 2014 to 2015.

Unmanned Aerial Vehicle

The UAV used in this study was a multi-rotor vehicle that uses lithium polymer batteries (5100mAh 3S) and a Canon S100 camera that was programmed to take 1 photo every 3 seconds as well as collect GPS data. A flight plan was designed using Mission Planner 1.3.32 software to cover the desired study area and take pictures of particular !nara plants. Flights lasted approximately 12 to 15 minutes and ranged in altitude from 40-70m with speeds between 3m/s and 5 m/s. We conducted flights at all 3 sites.

Analysis of UAV Data

Several programs were used to analyze the data collected by the UAV to gain different measurements to address our second and third research objectives. The photos and the automatic GPS locations of the hummocks were loaded into AgiSoft PhotoScan Pro and used to create a digital elevation method (DEM) as well as a stitched together mesh of images (orthophoto) to create one accurate model of each hummock in our study. A 3D representation of each hummock was created by laying this orthophoto on top of the DEM (Appendix 3). In AgiSoft PhotoScan Pro, we calculated the total surface area and volume measurements for the hummocks, which included sand, live and dead !nara and any other material that might be on the surface.

We used this same orthophoto in ArcGIS as a 2-dimensional representation of the hummock which we georeferenced onto a Pansharp satellite image of the surrounding

area (Appendices 4a & 4b). We used this 2D representation to calculate surface area and used an image classification tool in ArcGIS (Appendix 4c) to calculate the percent of the !nara occupied by the different cover categories (live !nara, dead !nara, sand) to address our hypothesis that the plant coverage on the !nara hummock would be consistent between methods. The surface area measurements acquired from this software was compared to the "wagon wheel" and PhotoScan measurements after a t-test was performed to determine the significance of these correlations. This addressed our hypotheses that hummock surface area from the 2D model would be the smallest measurement and that the 3D surface area would be the largest. Under objective three, we hypothesized that larger hummocks would support more healthy !nara plants as measured by both plant volume and live fraction of plants on the hummock, and used the above strategies to inform our conclusions. See Appendix 8 for a more detailed description of software methods.

Results

Research Objective 1: Use Established monitoring methodology in order to assess annual changes

From 2014 to 2015, hummock size from the wagon wheels, indicated by surface area, showed a strong positive correlation between the two years (Fig 1; $r= 0.9929$, $n=11$, $p<0.0001$) and decreased by an average of 3.19% ($t_{10}=-2.87948$, $p=0.0164$). However, the plant volume, which was calculated using the heights, surface area, and live coverage did not change significantly over this time period ($t_{10}= -1.68417$, $p=.1231$). As mentioned above, the surface area decreased slightly, whereas the heights of plants were consistently higher in the 2015 measurements, increasing by an average of 21.94 % (Fig 2; mean_14=0.55, stdev=0.17; mean_15= 0.64m, stdev=0.18). Finally, there was no consistent difference in the percent of live cover on the hummock, ($t_{10} = -1.24$, $p=0.24$, $n=11$) and live plant cover was not highly correlated between years ($r= 0.4426$; $p= 0.1728$; $n=11$). See Appendix 5 for more information.
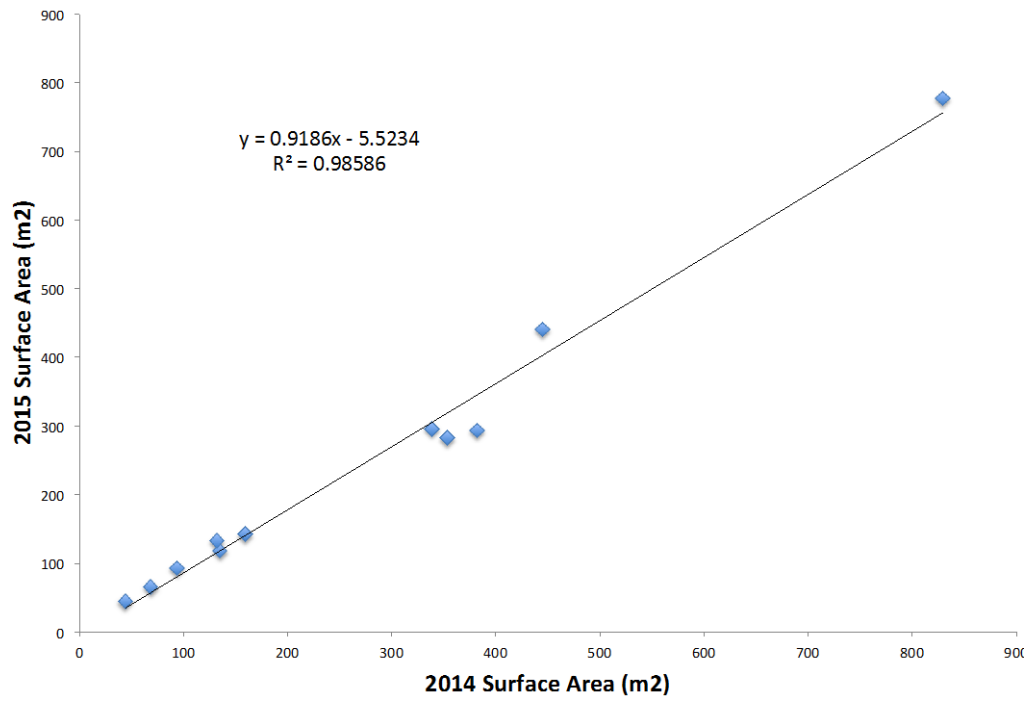
Figure 1. 2014 surface area is strongly correlated with 2015 surface area
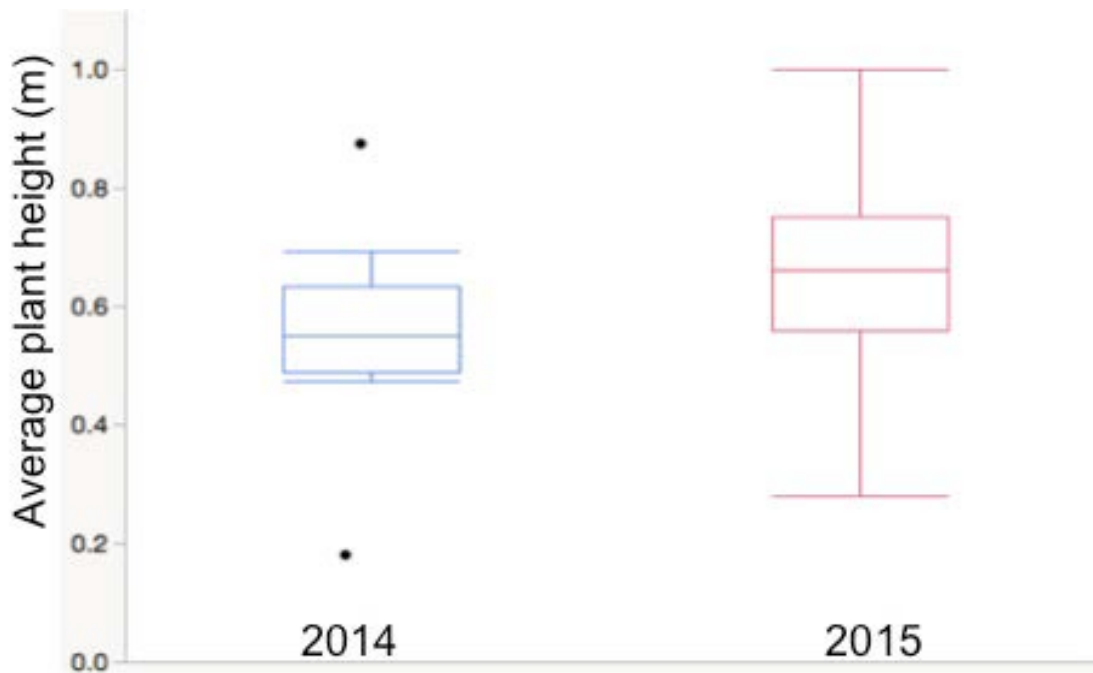

Figure 2. The mean average plant height in 2015 was higher than the mean in 2014

Research Objective 2: Broaden and improve long-term monitoring potential through incorporation of the UAV.

Surface area measurements were collected in three different ways: by hand using the wagon wheel method, in AgiSoft PhotoScan from the 3D hummock model, and in ArcGIS from the aerial image of the hummock. Our prediction was that the smallest surface area would be the one from ArcGIS, which is only aerial and therefore is closer to the footprint of the hummock than total surface area; the second smallest would be the wagon wheel method, which incorporates 3D aspects of the mound but is an estimate; and the largest would be the surface area from PhotoScan, which includes all 3D aspects of the mound, plus any small elevation changes on the hummock from plants or sand.

Surface area estimates from the wagon wheel, ArcGIS and PhotoScan were highly correlated with each other (Table 1, correlations) but PhotoScan areas were approximately two times more than the ArcGIS and wagon wheel estimates. ArcGIS and the wagon wheel estimates were not statistically different (Fig 3; Table 1, t-test). We found that there was no significant correlation between any estimates of type of cover class (live !nara, dead !nara, sand) from wagon wheel and ArcGIS and the estimates were quite varied (Appendix 6a). The three cover percentages calculated in ArcGIS were significantly correlated between each other but only weakly, as to be expected for three percentage measurements that all add up to 100% (Appendices 6a & 6b). Finally, plant volume measurements from the wagon wheel and UAV data were not statistically different (t_6=-1.82992, p=0.117) and were significantly highly positively correlated with each other (r=0.9456, p=0.0004, n=7).
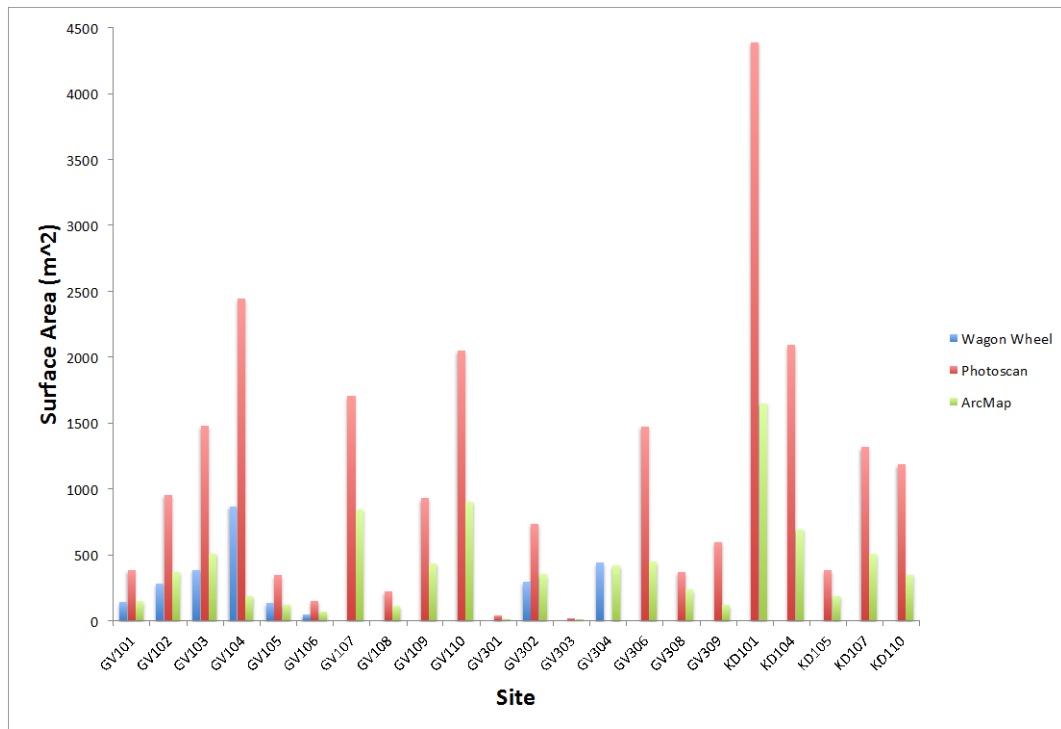
Figure 3. For all sites with multiple surface area calculations, PhotoScan was an average of two times larger than any other method

Research Objective 3: Use the data collected from the UAV to examine !nara plant health

Using the UAV data, hummock "size" was estimated with both surface area and volume. We compared the PhotoScan 3D surface area, the 2D ArcGIS surface area, the 3D PhotoScan hummock volume and the plant volume calculation. As expected, all were significantly correlated (Table 1, correlation). When the same tests were run with fraction of live !nara on the hummocks, no significant correlations were found relating the hummock size measurements to live fraction (Table 1, correlation).

Table 1. Correlation and Paired t-test results

Relationship	Correlation			Paired t-Test	
	r value	p value	n value	t ratio	p value
PhotoScan and Wagon Wheel Surface Area	0.8261	0.0115	6	t_5= 3.0587	0.0141
PhotoScan and ArcGIS Surface Area	0.9699	<.0001	20	t_{19}= -4.42281	0.0001
ArcGIS and Wagon Wheel Surface Area	0.9329	0.0007	6	t_5=1.9242	0.1027
ArcGIS Dead and Live Cover	-0.5435	0.0089	7		
ArcGIS Sand and Live Cover	-0.861	<0.001	7		
PhotoScan Surface Area and Plant volume	0.6175	0.0037	20		
ArcGIS Surface Area and Plant volume	0.6973	0.0003	22		
PhotoScan Volume and Plant volume	0.6348	0.0026,	20	t_{19}=-3.4344	0.0028

IV. Discussion

Research Objective 1: Use Established monitoring methodology in order to assess annual changes

Our use of the "wagon wheel" method as established by McLaughlin et al (2013) allowed us to continue the work of previous Dartmouth groups on the !nara and observe changes in the Gobabeb Valley between 2014 and 2015. A comparison of satellite images from 1972 and 2010 showed that many !nara hummocks were almost exactly the same shape and size over this 38 year period (See Appendices 7a & 7b), which informed our hypothesis that hummock size would not change between years; however, the decrease in surface areas of the hummocks counters this hypothesis (see Figure 1).

The strong correlation in surface areas between 2014 and 2015 indicates that the wagon wheel, even when it is being performed by different people, is a reliable method to use for determining surface area over time. However, the magnitude of this change is not enough to definitively say that there is a downward trend in !nara hummock size, especially over the course of only one year. This trend should continue to be observed over a longer period of time before being used to inform management decisions.

Plant volume did not consistently change, contradicting both our hypothesis and the findings of Beitler et al. that plant volume would decrease over time (2014). Beitler et al (2014) found a 56% decrease in plant volume between 2013 and 2014 in a neighboring valley, so any trend regarding this data has yet to be established and will require a longer

study period. The increase in height was consistent across all plants, indicating that the plants grew over the course of the year, though heights should continue to be a part of the long-term monitoring strategy to understand larger trends in !nara growth. !Nara grow at a slow pace so it is difficult to see change in just one year, further emphasizing the importance of establishing a population baseline. (Henschel et al, 2004).

Research Objective 2: Broaden and improve long-term monitoring potential through incorporation of the UAV.

Because ArcGIS and "wagon wheel" measurements of surface area did not differ and PhotoScan was higher than those estimates, we are unable to distinguish a superior method for determining surface area. The difference between ArcGIS and PhotoScan may be due to calculation details in PhotoScan, so the methods should be re-examined for accuracy. These methods were all highly correlated, however, so in the future, monitoring (either of the same hummocks or entirely new plants) could potentially rely on only one method or a combination of hand and UAV measurements. Data from two different kinds of methods cannot be directly related, but using the information from the T-tests, it would be possible to make predictions for another method, allowing a comparison of data. We recommend using UAV data for this, however, due to the disruptive effects of performing wagon wheels on the fragile hummock ecosystem as noted by us and previous research groups (McLaughlin et al, 2013 and Beitler et al, 2014).

Our hypothesis that measures of !nara plant volume and coverage of the hummock would be consistent between the two methods is partially supported by the lack of difference in the plant volume measurements between the two methods. This makes sense because each calculation depended on identical height measurements and similar surface areas. The only potential for major variation is the difference between class cover percentages from one method to another, which were not correlated. Furthermore, this lack of strong correlation between the percent covers is the biggest inconsistency between the two methods. Every calculation of !nara attributes depends on these numbers, but there was no consistency between methods. This could be due to a number of things, including errors in the training for the image classification tool, inconsistencies in plant classification on the transects and the possibility that transects did not bisect a representative amount of each category of ground cover.

Research Objective 3: Use the data collected from the UAV to examine !nara plant health

As predicted, our forms of measuring hummock size, surface area, and volume were significantly correlated to plant volume; this supports our hypothesis that larger hummocks support more healthy !nara plants as measured by plant volume. This is not surprising because both surface area measurements are related to plant volume calculations directly (2D ArcGIS surface area is used to calculate plant volume) or indirectly (3D PhotoScan surface area is correlated with the 2D ArcGIS surface area). Because of these results and McLaughlin et al. (2013)'s suggestion that plant volume and

hummock volume are both indicators of !nara vitality, these variables and the relationships between them should continue to be monitored in the future.

Our hypothesis that larger hummocks would support more healthy !nara plants (as measured by the portion of !nara that is alive) was disproven by the lack of relationship between hummock size measurements and live fraction. This means that there was no correlation between the hummock size and the percent of !nara on that hummock that is alive. This result was surprising because other studies have suggested that a hummock could become too large for plant growth to occur; !nara roots extend slowly and sand accumulation might make it difficult for these roots to reach groundwater and survive (Ito 2005). This highlights the importance of monitoring !nara of a variety of sizes over a long period of time.

Water availability could also have implications for hummock size and survival of individual plants. For example, Ito (2005) measured !nara hummocks at two sites, one with reduced flooding due to the construction of a flood wall. This decreased the amount of water available to the !nara while also allowing for a buildup of sand on hummocks. Ito found that hummocks in that site had an average larger area (in m^2), but also an average individual plant withering rate of almost two times that of the hummocks at the other site. While we did not find that larger hummocks had a higher percentage of dead !nara, this is a time-dependent trend that could be monitored on !nara and hummock imagery from the UAV in the future.

V. Recommendations and Conclusion

Our first and second objectives allowed us to assess the different contributions of each method of monitoring !nara. Each method has different advantages and disadvantages and can provide a variety of information that can stand alone or be combined with other research to make conclusions about the future of the !nara. Tables 2 and 3 summarize the benefits and drawbacks that we found with each method during our research. We recommend that in future long term monitoring, researchers evaluate the pros and cons of these two methods carefully to decide which method best serves their purposes.

Table 2. Pros and cons of wagon wheel method

Pros of Monitoring with the "Wagon Wheel" Methodology	Cons of Monitoring with the "Wagon Wheel" Methodology
+ Allows for close-up observation and interaction with the !nara and hummocks	- Invasive and high-impact for !nara, hummock, and other animals that rely on it
+ Accessible method that is easy to teach and replicate	- Time-intensive and physically taxing method
+ Low cost	- Potentially difficult to repeat accurately over time by different groups
+ Simple technology	- Cannot survey areas that are protected or difficult to access
+ Established line-intercept method for monitoring plant volume	

Table 3. Pros and cons of using a UAV (Gallacher et al. 2015, Handwerk 2013)

Pros of Monitoring with the UAV Imagery	Cons of Monitoring with the UAV Imagery
+ Low-impact, non-invasive monitoring method	- Technologically complex, often requiring established knowledge
+ Can monitor areas that are difficult to access	- Complex and time consuming post-flight image analysis
+ Can produce an easily replicable flight plan	- Increased transport costs and inconvenience; may require permits or governmental permissions
+ Lower labor costs	- High initial cost investment
+ Less labor intensive, with the potential to reduce time in the field	- Time in field constrained by battery life
+ Can produce everything from 3D models at a small scale to large-scale maps of plant distribution	- Rapid depreciation in value due to continuous advances in technological capacity of commercial options
+ Flight patterns, speed, and photo rate can be calibrated to match the needs of the monitoring project	

According to the developers of the Environmental Long-Term Observatories Network of Southern Africa (ELTOSA), in order to address environmental questions, we need to create accessible data archives to "build up a legacy of information" (Henschel et al., 2003:100). Future research done on the !nara need to consider past studies that have been

done as well as other data about climate and the Namib desert ecosystem. Water availability to !nara is one of the most important variables to be added in to the long-term monitoring established by this and earlier research, because water availability is an vital resource for desert organisms and one threatened by climate change (Midgley et al. 2005). As Aushiku et al. (2015) have found, for example, natural variation in rainfall in the Namib Sand Sea directly impacts the biomass of local flora like the !nara. These findings emphasize the importance of incorporating long-term weather data into monitoring of !nara hummock health and size in the future. It is also important to consider differences in different !nara monitoring sites because these sites will likely be impacted by climate change in different ways (Lindesay and Tyson, 1990).

It is likely that the water inefficiency of the !nara will put it at risk to the climatic changes predicted for Namibia, which include more variable precipitation and increased evapotranspiration rates. As mentioned in the introduction, the !nara makes a strategic choice to constantly increase its biomass, even in times of drought. This excess biomass allows the plant to greatly increase its carbon uptake ability in times of water abundance. At the same time, however, this strategy of "water waste" makes it vulnerable in times of extreme water scarcity (Hebeler et al. 2004). An examination of how these variables change over time in conjunction with changes in temperature, moisture, and water table levels would be useful for examining whether the !nara is threatened by these shifts in climatic conditions or if it is adapting its strategy of high levels of biomass in favor of a more water efficient strategy.

Our research provides the foundation for the expansion of the long-term !nara monitoring project by Gobabeb with new methods. The use of the UAV opens up many new areas for monitoring, providing images that can be used to create a database of information that can be referred back to in future study. While the UAV was a good addition to this program, the wagon wheel method enables the researcher to view !nara up close and observe changes from an important perspective; its use should always be considered as an option and should be evaluated based on the goals of future research. Our research also reemphasizes the importance of continuous monitoring of the !nara, and particularly of the relationship between !nara health and hummock size over time. It is important that any !nara monitoring take the life cycle of the !nara into account so that measurements of various plant aspects can be compared from year to year. Furthermore, these results, combined with other research about other measures of !nara vitality, have potential implications for improving the sustainability of !nara harvests (Anderson et al. 2015). Future studies could monitor these variables to see whether female plants are more at risk than males due to the harvesting of their fruits, providing long-term information about !nara health and thus informing harvesting practices. If data is collected at least once a year, it will continue to help establish a knowledge base about the !nara population, allowing for an evaluation of this endemic plant's potential vulnerability to climate change and informing conservation management decisions in the future.

Acknowledgements

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Appendix 1a: Map of lower Kuiseb. Gobabeb Valley sites are in lower left and delta site is on the coast in top right.

Appendix 2: Bird's eye view of transects on a hummock (McLaughlin et al 2013).
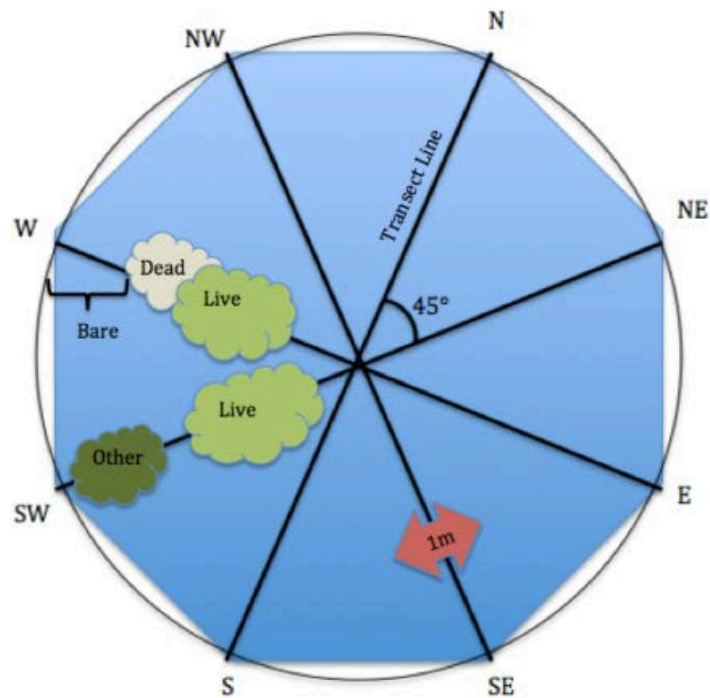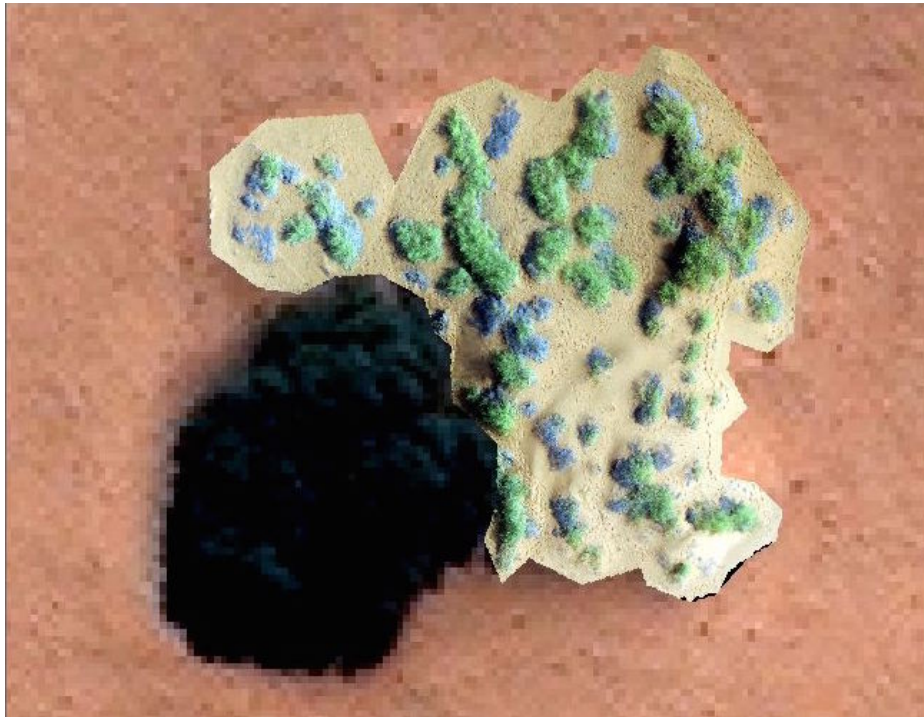
Appendix 3: Screengrab of DEM with orthophoto layer on top from PhotoScan (plant GV104).
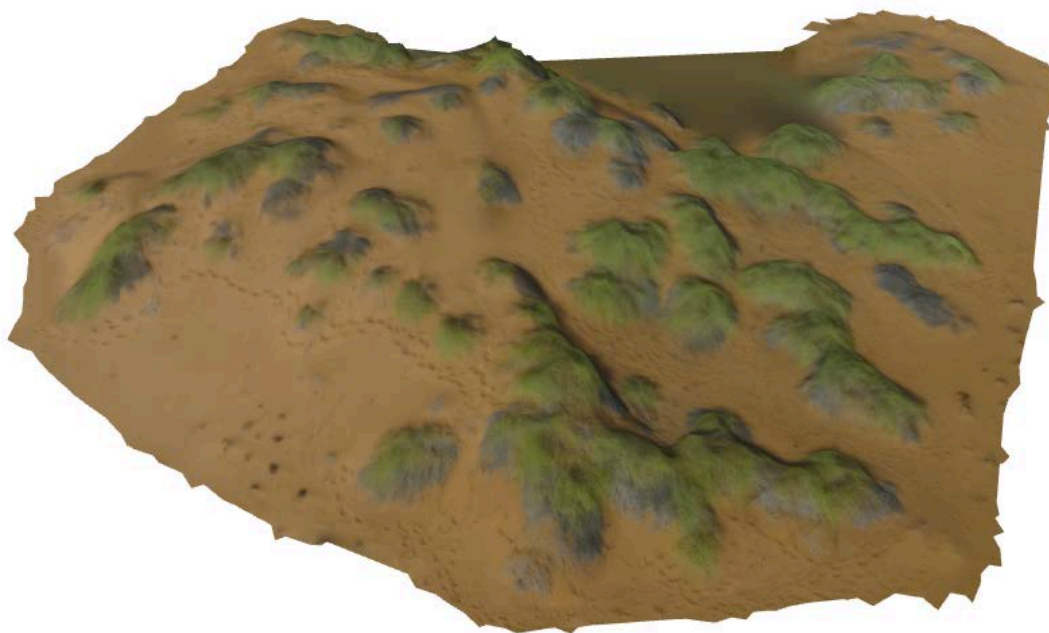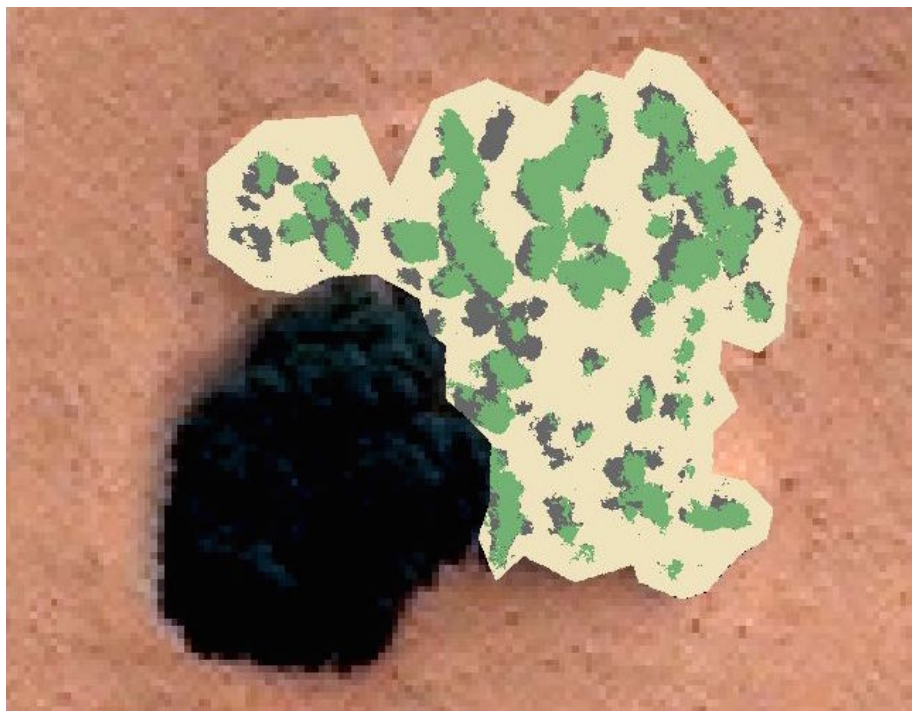

Appendix 4a: Pansharp satellite image of plant GV104, taken in 2010 at best possible resolution.

Appendix 4b: UAV imagery geroreference and overlaid on Pansharp satellite image of plant GV104.

Appendix 4c: Orthophoto of plant GV104 after cover classification type analysis. Tan indicates sand, green indicates live !nara and grey is dead !nara.

Appendix 5: Year to year differences for each plant using wagon wheel method.

|	Total SA (m^2)		Live Cover		Average Height (m)		Live Volume (m^3)	
	2014	2015	2014	2015	2014	2015	2014	2015
Site								
GV101	159.50	141.70	38.6%	20.4%	0.874	1.00	124.10	28.97
GV102	353.91	282.32	29.5%	29.7%	0.489	0.60	82.44	50.10
GV103a	135.41	117.63	27.0%	41.5%	0.55	0.67	43.51	32.83
GV103b	382.47	293.05	21.8%	14.8%	0.692	0.45	91.25	19.50
GV104a	829.66	776.53	65.6%	32.8%	0.567	0.78	343.94	199.00
GV104b	93.82	92.67	32.2%	23.6%	0.512	0.75	35.58	16.41
GV105	132.38	132.29	39.7%	38.9%	0.561	0.64	47.50	32.91
GV106	44.41	44.11	7.1%	8.4%	0.18	0.28	2.18	1.02
GV302	338.79	295.45	23.5%	13.4%	0.473	0.66	92.58	26.29
GV304	445.26	439.79	47.6%	26.5%	0.49	0.56	119.87	64.72
GV305	68.76	65.11	34.4%	54.2%	0.633	0.68	28.16	24.11

Appendix 6a: Class cover correlations from JUMP (H is wagon wheel and GIS is from ArcGIS). The only correlations are between the three measurements from ArcGIS.

	% Live-H	% Dead-H	% Sand-H	% Live -GIS	% Dead GIS	% Sand GIS
% Live-H	1.0000	-0.6273	-0.7752	0.1782	-0.0152	-0.2029
% Dead-H	-0.6273	1.0000	-0.0057	-0.5191	0.5389	0.2914
% Sand-H	-0.7752	-0.0057	1.0000	0.1921	-0.4176	0.0244
% Live -GIS	0.1782	-0.5191	0.1921	1.0000	-0.5435	-0.8610
% Dead GIS	-0.0152	0.5389	-0.4176	-0.5435	1.0000	0.0411
% Sand GIS	-0.2029	0.2914	0.0244	-0.8610	0.0411	1.0000

Appendix 6b: Class cover p values for the correlations above.

	% Live-H	% Dead-H	% Sand-H	% Live -GIS	% Dead GIS	% Sand GIS
% Live-H	<.0001	0.0960	0.0238	0.6729	0.9714	0.6299
% Dead-H	0.0960	<.0001	0.9892	0.1874	0.1681	0.4838
% Sand-H	0.0238	0.9892	<.0001	0.6486	0.3033	0.9543
% Live -GIS	0.6729	0.1874	0.6486	<.0001	0.0089	<.0001
% Dead GIS	0.9714	0.1681	0.3033	0.0089	<.0001	0.8559
% Sand GIS	0.6299	0.4838	0.9543	<.0001	0.8559	<.0001

Appendix 7a: 1972 satellite image showing site 1 in Gobabeb Valley.
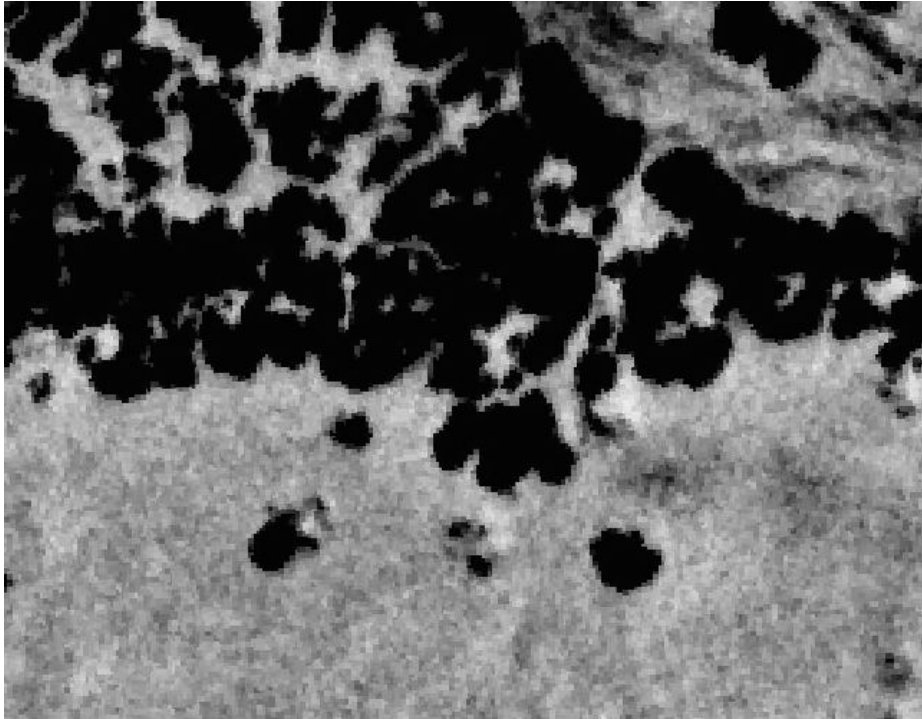
Appendix 7b: 2010 satellite image showing same site 1 in Gobabeb Valley. Note similarities between the two images.

Appendix 8: PhotoScan and ArcGIS work flow.

AgiSoft Photoscan

1. Add photos (view flight plan in mission planner and photos in order taken to select subset).
2. Align Photos (low; pair preselection disabled)
3. Build Dense Cloud (medium, aggressive depth filtering)
4. Build mesh (on dense cloud for !nara, on sparse cloud for trees, face count med)
5. Build texture—to help see image
6. Select clipping tool and outline area of interest (!nara hummock), crop to desired size.
7. Mesh → close holes (100%), then calculate area and volume.
8. Save Photoscan project
9. Export orthophoto and DEM

ArcMap

GEOREFERENCING
1. Add image to be referenced (orthophoto)- sets datum
2. Add map to use for georeferencing
3. Georeferencing tool → Add control points (tab to right of menu) with your orthophoto selected in menu
4. Click on sets of matching points, first on image, then on map. Repeat at least 4-5 times
5. Georeferencing → update georeferencing (save in correct folder); this pins it to map layer
6. Rt. Click on georeferenced layer to Export raster data → save as e.g. GB1_orthoGR (update bits=no)
7. View Link Table (to right of georef menu); save link file (e.g. GB1_GRlink)
8. Apply link file to DEM: search for "warp from file" and select input file=DEM, output file= e.g., GB1_DEMGR, link file= saved above; executing here will save this georeferenced DEM

LAND COVER CLASSIFICATION
1. Classification tool: select orthophoto layer in menu
2. Open training sample manager by clicking on small box in Classification toolbar
3. Select polygon tool
4. Choose several (at least 3) polygon samples for first cover category (e.g. LiveNara), selecting a range of polygons that covers the range of dark-light and color or texture variation for that category. When satisfied, highlight all samples in training manager and use menu button to merge samples. Rename the merged set, e.g. "LiveNara"
5. Repeat for each cover classification (LiveNara, DeadNara, Other, NA)
6. Create signature file for this training set (far right on menu); save e.g. GB1_sig

7. Classification toolbar (with orthophoto selected in menu)→ Maximum Likelihood Classification (select output location, enter output file name, e.g. GB1_Class1, select signature file you just saved) → Click OK and let it run
8. Rt. Click on classified layer → Data → Export Data (save e.g. GB1_Classified)

CALCULATING LAND COVER AREA
1. Open new project
2. Open Pansharp image first (to set datum)
3. Add classified layer e.g. GB1_Classified and Rt. Click to zoom to layer
4. Properties → Source (to check and record cell size, (x,y), these units are in km so e.g. 2.01x10E-7 corresponds to 2.01cm)
5. Rt click to open Attributes table for class, record cell numbers for each class of interest

Vegetation Distribution and Livestock Resource Use in the Lower Kuiseb River

November 14, 2015

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Introduction

Livestock management practices have become increasingly important in recent years as implications of climate change have begun manifesting themselves in ecosystem processes. Changing temperature and precipitation rates incite responses from the vegetation upon which livestock populations depend as vital sources of food. As such, livestock management techniques must consider various means of adaptation that best suit these new climatic paradigms. This is especially true in the warm and dry parts of the world, as well as within developing countries. As the driest country in southern Africa, Namibia is forced to cope with a new changing climate—and those depending on livestock agriculture are no exception. Unfortunately, many of these unprecedented climatic trends are poorly understood, placing restrictions on livestock management practices in regards to climate change. In order to better understand the management adaptations that should be undertaken by livestock agriculturalists, this paper addresses some of the impacts of climate change on vegetation and livestock in Namibia. A primary goal includes derivation of practical knowledge that can be used to advise livestock managers not only in Namibia, but also within other countries sharing similar problems or circumstances.

Livestock in Namibia

Agriculture has shaped the landscape and human history of Namibia for the past 11,000 years (Mendelsohn 2006). Formalized farmlands began with German administration in 1892, and then transitioning to South African influence in the 1920s. From 1990 onwards, Namibian farmers and industries have adopted and produced their own market following Independence. Today, four major farming systems have been implemented across Namibia– small-scale cereals and livestock, cattle ranching, small stock farming and intensive agriculture (Mendelsohn 2006). Namibia's rapidly changing resource use is influenced by internal policies, external forces, social and economic factors, and as important, environmental conditions. Environmental conditions have serious implications for livestock production in arid regions, and knowledge and innovation is required for the current and future viability of Namibian agriculture.

The majority of Namibian farmers keep livestock, and it is the main agricultural focus in 70% of the country, representing around 89% of the agriculture sector's contribution to GDP (Desert Research Foundation of Namibia 2015). Farming livestock is an essential source of income for a majority of communities, and many of who are vulnerable to climate change (Desert Research Foundation of Namibia 2015).

History of Livestock Management Practices in Namibia

Livestock farming was first introduced into Namibia's western catchments from northern parts of Africa, and this resulted in the development of subsistence patterns which were modeled off of nomadic pastoralism (Jacobson 1995). Historically, Namibian livestock farmers were not sedentary, rather nomadic pastoralists seasonally migrated to take

advantage of seasonal and spatial variability in climate as well as natural resource distribution across the landscape. Their movements between temporary settlements were dictated by the seasonal changes in water and forage availability for their livestock (Jacobson 1995). Traditionally, livestock farmers moved due to climate emergencies that may hinder grazing availability and overall survival (Desert Research Foundation of Namibia 2015). Nomadic pastoralism, however, began to disappear in the nineteenth century following the beginning of colonialism in Namibia (Jacobson 1995). Land tenure laws introduced by the colonial government allocated the most productive rangelands to white colonists, by relocating large populations of indigenous people from these lands to less productive areas. These lands had previously been occupied only on a seasonal basis (Desert Research Foundation of Namibia 2015). Today, unrestricted migration is now extremely limited due to the increasing human population, exclusion from conservation areas and freehold farms, and international borders (Desert Research Foundation of Namibia 2015).

Threats to livestock

Climate change has major impacts on vegetation quantity and quality in grazing systems (Mendelsohn 2006). Plants require an optimum temperature range, as rising temperatures dehydrate the plant, while growing rates drop with colder temperatures and frost events. A rise in precipitation allows forage increase, however, water logging and fungal incidence occurs with too much precipitation (Mendelsohn 2006). With increased temperatures and atmospheric carbon dioxide, growth patterns may be altered, and grasses may be outcompeted by legumes. Dry matter yields may also increase, as nitrogen and water soluble carbohydrates are limited due to increasing drought incidences. With variable rainfall at high intensities, the landscape is more prone to nitrogen leaching (Thornton 2009).

Certain plant species adapt to climate change more successfully than others, and the biodiversity of vegetation in grasslands may experience major losses due to bush encroachment. According to the International Panel on Climate Change (IPCC), a 2.5°C increase in global temperatures above the pre-industrial levels may cause biodiversity losses, including 41-51% of endemic plants in southern Africa; many of which (20-30%) are at high risk of extinction due to increasing temperatures (Thornton 2009).

Transhumance, or the seasonal migration of livestock for the exploitation of resources, is one communal grazing method used by many farmers to cope with grassland instability. This system is entirely dependent on climate shifts as livestock are moved on a seasonal basis in order to exploit resources. Transhumance allows maximum forage across the landscape, and livestock can take advantage from ecosystem responses, such as triggers that increase vegetation in previously underutilized areas (O'Farrell 2009). This knowledge related to historical practices that were implemented by nomadic pastoralists and were perhaps passed down through generations.

However, when movement is restricted due to droughts or geographic and social

limitations, farmers need to adapt appropriately. For instance, biomass harvest may be required by chopping down branches or trees where livestock are unable to access forage. Farmers may buy or produce fodder as means of coping. Also, they may plant drought resistant crops or water efficient feeds, utilize agro-forestry; and/or, plant certain species that are ruminant stimulants and enable livestock to digest alternative, less palatable plant species (O'Farrell 2009).

Health risks associated with climate change are given limited attention, and further research is needed to better understand livestock disease vectors (midges, flies, ticks, tsetse and mosquitoes). However, it is known that the rate of development of pathogens or parasites on the animal host has the potential to increase due to rising temperatures. Precipitation, wind, atmospheric composition, and temperature shifts will alter disease and disease vectors, and these transitions may also cause drastic changes in livestock health (Thornton 2009).

History of Topnaar Livestock Management

Namibia's Topnaar communities contain a unique history of livestock farming; they have been raising livestock under extreme desert conditions for hundreds of years without migrating to other areas (Desert Research Foundation of Namibia 2015). According to historical reports and archaeological findings, Topnaars have been pastoralists living along the lower Kuiseb River for around 800 years, primarily farming cattle (Desert Research Foundation of Namibia 2015). Despite livestock numbers in the Lower Kuiseb steadily increasing over the past two decades, this rise has occurred "without major discernible impacts on the rangelands and riparian vegetation utilized by their livestock" (Desert Research Foundation of Namibia 2015). Although traditional coping mechanisms are poorly understood, Topnaars' insignificant impacts on natural vegetation distribution and their long-term success in such harsh environments suggests their resilience in the face of extreme climate variations (Desert Research Foundation of Namibia 2015). Because of this, the Climate Change Adaptation Proposal created by the Gobabeb Research and Training Center suggests that Topnaar livestock management techniques and local knowledge could act as a "potential foundation for adaptation" for livestock farmers throughout Namibia that are burdened with the "increasing uncertainties and extremes of climate change" (Desert Research Foundation of Namibia 2015).

Role of Livestock in Topnaar Communities

Livestock farming is a major source of livelihood for Topnaar people (Desert Research Foundation of Namibia 2015). Livestock census data from 2014 reflected that farmers in this region kept a combined total of 540 cattle, 269 donkeys and horses, 2,219 goats and 148 sheep (Desert Research Foundation of Namibia 2015). About 59% of farmers in this region keep cattle and 51% keep goats, while the average size of regional cattle herds is double that of goat herds (Desert Research Foundation of Namibia 2015). The census also recorded Topnaar ownership of small numbers of horses, donkeys, pigs and sheep. Very few farmers owned large herds of livestock, as only 6% owned herds of 50 or more

cattle, and the average number of animals per household varied spatially. Households living deeper in the interior, on the other hand, owned more than twice the number of cattle and goats than households along the Kuiseb River (Desert Research Foundation of Namibia 2015).

Livestock contribute to many Topnaar households, as they serve as forms of nutrition, income, and food security. In many households, milk, meat, blood, dung, and skins are critical resources from cattle, goats, and sheep (Jacobson 1995). Donkeys and horses, on the other hand, are mainly used for transportation (Desert Research Foundation of Namibia 2015). Livestock serve as long-term investments of labor, and many Topnaar households rear livestock as a main source of income (Desert Research Foundation of Namibia 2015). Typically, Topnaar farmers do not depend on small-scale livestock farming alone due to the region's harsh climate and arid soil conditions. As a result, farmers utilize other natural resources such as !Nara fruits (Desert Research Foundation of Namibia 2015).

Climate in the Namib Desert

The climatic conditions of desert ecosystems like that of the Lower Kuiseb River are not naturally feasible environments for large livestock farming. The Adaptatio Fund Proposal states that this is due to four main reasons: "(i) very poor availability of grazing, mostly none at all; (ii) the perceived adverse impact of cattle on desert ecosystems; (iii) the limited availability of water at very few locations; (iv) and poor production due to the physiological stress that high temperatures impose on cattle" (Desert Research Foundation of Namibia 2015).

The majority of the rural members of the Topnaar community live in settlements along the Lower Kuiseb River, an ephemeral river that only flows for brief periods during particularly wet years. Climate patterns in this region are largely unpredictable and highly variable, both seasonally and annually. For example, mean annual rainfall varies between <20 mm and <50 mm, and most years little to no precipitation occurs. Daytime temperatures range from the low forties and drop to less than 10°C at night during the months of September to November and March to April (Desert Research Foundation of Namibia 2015). Due to these extreme and unpredictable seasonal variations, adequate grazing is only available during exceptionally wet years. Most of the sparse grasses on rangeland adjacent to Topnaar settlements dry out very rapidly following the end of the brief wet season, February to April (Desert Research Foundation of Namibia 2015). Even during the years that this rare transformation from the desert plains to a lush grassland does occur, most of these grasslands are not accessible to small-scale Topnaar livestock producers. The lack of available graze throughout the majority of the year forces livestock to utilize the trees and shrubs along the river banks (Desert Research Foundation of Namibia 2015). A major threat to Topnaar livestock are the variabilities in rainfall patterns and temperature in the region, and as a result more extreme weather events occur.

Floods and droughts complexly affect Topnaar livestock and the vegetation they depend on in numerous ways. Flood events – defined as days when surface water is flowing in the Kuiseb, tend to wash tree pods that livestock depend upon downstream away from communities where they're most needed for fodder (Gobabeb, 2015). Additionally, exceedingly high volume flood events have been known to drown vegetation, and sometimes even livestock. Arriving with little notice and dire implications, floods are considered by farmers to be among the most significant climate hazards (Gobabeb, 2015). These high volume flood events have increased in prevalence in recent years; 4 out of the 5 years when flood water made it all the way to the Atlantic since monitoring began in 1960 have occurred in the past 15 years (Grodek et al. 2013). However, floods also provide many integral services to the ecosystem upon which Topnaar livestock depend. In addition to dispersing seeds to downstream locations, flood events displace accumulated sand deposition that can bury and suffocate tree species. Dunes from the Namib Sand Sea to the south of the Kuiseb can encroach into the riverbed by as much as 120-145mm per year, killing many trees, such as the *F. albida*
 and acacia erioloba, that are vital food sources for Topnaar livestock (Mizuno and Yamagata, 2005). Additionally, flood events recharge subterranean water aquifers, which are put under high stress by livestock management practices (Morin et al. 2009).

Droughts are also significant in the health and survival of Kuiseb ephemeral river ecosystem vegetation, as without adequate precipitation or fog events, plant life, and thus livestock and human life, is unable to survive (Mizuno and Yamagata, 2005). Drought at the eastern head of the Kuiseb most significantly influences processes throughout the entire river, and in recent years they have become more common. Average yearly precipitation in Windhoek, the easternmost head of the Kuiseb, only exceeded its 100-year mean (272mm/year) in two years between 1981 and 1996 (Mizuno & Yamagata 2005). As a result, average flood days per year at the Gobabeb Research Center, located 75km from the Atlantic coast, steeply decreased from 33 days per year between 1962 and 1975 down to only 9.2 days per year between 1976 and 2001 (Mizuno 2005). These droughts have led to a water table decline from -3m below ground level to-12m in 2006 at the Rooibank monitoring center, along the Kuiseb River between Gobabeb and the Atlantic coast (Morin et al. 2006). The implications of rising temperatures and increased drought prevalence are numerous for the Topnaar people and their livestock; droughts negatively affect livestock health and productivity, inevitably resulting in lower market prices for their livestock sales (Desert Research Foundation of Namibia 2015).

Overall, Topnaar have employed the same general risk management strategies in order to minimize the risks to their livestock that result from the effects of unpredictable, extreme, and inconsistent climate patterns on the distribution of natural vegetation on which their livestock depend. Topnaar livestock owners often lend their animals to family members in other areas to spatially distribute their animals and minimize their risks of loss due to droughts, disease, attacks by predators, and other potential outside disturbances. To make up for shortages of forage availability, in particular *Acacia erioloba* and *Faidherbia albida* species of pods, livestock owners may harvest or sell pods from trees or surrounding area in order to provide sufficient food for their livestock. Many farmers also

try to keep as many young female animals as possible in order to increase herd resilience and easily produce dairy products (Desert Research Foundation of Namibia 2015).

Based on the limited literature surrounding livestock diet in the Lower Kuiseb River catchment, further research can yield important insights. The questions this study addressed include: how do Topnaar people adapt livestock management practices to the variable climate of the hyperarid Kuiseb ecosystem? What determines livestock selection of forage in the riverbed (i.e. the spatial distribution of vegetation, species preferences, nutrient content, etc.)? What is the relationship between riparian tree species, *F. albida* and *A. erioloba* pod distribution, and livestock foraging across the landscape of the Kuiseb River?

Through a combination of community interviews, livestock observations, vegetation mapping, cattle-plant interaction, pod distribution, and livestock dung analysis, this study addressed these questions in an attempt to elucidate the importance of cattle-ecosystem relations. The main objectives of this study were: 1) to develop an understanding of cattle behaviors and dietary sources and preferences in the lower Kuiseb River basin; 2) to map and analyze vegetation distribution in the riverbed; and 3) to understand cattle resource use patterns, and the relationship of cattle dietary habits to the dynamic Kuiseb ecosystem.

Methods

Community interviews

In order to explore the current Topnaar community knowledge regarding livestock resource use patterns, livestock management techniques, and the impacts of climate change on vegetation and livestock, short, semi-structured interviews of Topnaar livestock owners were conducted. The questions fell under four different categories: personal livestock ownership, livestock management techniques, livestock resource use patterns, and weather patterns and climate change (see Appendix I).

Initial plans included interviews with at least ten community members, but due to time constraints and difficulty coordinating meetings, only two interviews were conducted with Topnaar livestock owners, both of whom are employed by Gobabeb.

Livestock Observations

Activity Budgets were conducted as a means of studying resource use patterns, particularly where and what vegetation livestock tend to prefer. For one morning and one afternoon over a two-day span, cattle herds roaming the lower Kuiseb River were observed and their activities recorded. These logs of cattle behavior were recorded to formulate a general idea of the natural resource use patterns of cattle in the area. These pilot Activity Budgets were undertaken in the late afternoon between 15:48 and 17:25 on Day 1, and during the late morning period from 9:18 to 11:12 on Day 2. Due to a lack of

cattle downstream from Gobabeb, Activity Budgets were conducted within a 10km range upstream on both days. Animals were observed from a vehicle at a considerable distance away so as to minimize the impact of human presence on the animals' natural behavior.

After consulting literature on activity budgets, a list of potential actions that cattle could be engaged in was generated: foraging, standing (shade), standing (sun), ruminating (shade), ruminating (sun), lying (shade), lying (sun), and other (grooming, drinking, etc.) (see Appendix II). For foraging animals, specific records were kept about what plant species were eaten, which parts of the plants they consumed, and to what intensity they were consuming these resources. To estimate the intensity of individual consumption of each resource, a simplified categorical scale was used: L for low intensity of consumption (one bite or nibbling at the plant), M for medium intensity consumption (intermittent foraging or partial consumption of food resources), and H for high intensity consumption (consuming entire pods or leaves and continuing to consume resources at a fast rate). Data were collected by scanning each herd of cattle from left to right at five-minute intervals. For each herd, rough counts of males, females, and calves were done to get a sense of herd composition. Activity Budget data were analyzed separately for each of the observation periods in order to account for variations that may be related to the times of day these observations were recorded (i.e. afternoon or late morning).

As a means of estimating the approximate health and productivity of livestock, Body Condition Scores (BCS) were recorded for individuals in each herd based on the template (see Appendix III). The BCS roughly estimates cattle health and productivity, and was included in order to explore how natural resource use patterns of cattle might affect these important variables. Individuals that were resting in a supine position were not included in data, as these individuals may appear to have a different BCS than they would if they had been in an upright posture. Calves were also included from this process as the BCS scale used may not be accurate to estimate the general health of maturing animals. A total of twenty individuals were scored over both days of observation.

Vegetation Mapping

A transect of the lower Kuiseb River was surveyed to determine the spatial distribution of the six major tree species: *Faidherbia albida* (Ana tree), *Acacia erioloba* (camel-thorn), *Tamarix usneoides* (wild tamarisk), *Salvadora persica* (mustard bush), *Nicotiana glauca* (wild tobacco), and *Euclea pseudebenus* (wild ebony). A brief description of each plant is given below.

A. Faidherbia albida

One of the largest tree species occurring in Namibia, *F. albida* can reach heights of 30m (Palgrave 2003). Similar in appearance to the *A. erioloba*, the two trees are easily confused—*F. albida*'s shorter thorns and unique pods are two distinguishing features of *F. albida*. The pods of *F. albida* occur year round, but peak in September and October. They are a valuable food source for livestock and are often harvested illegally in the

Kuiseb River for sale as fodder (Palgrave 2003). *F. albida* pods are distinguishable from others by their long and narrower shape that generally twists into a spiral.

B. Acacia erioloba

The most widespread tree species in Namibia, *A. erioloba* is an extremely important source of nourishment for livestock, as well as firewood and building material (Palgrave 2003). With roots as deep as 40m, *A. erioloba* thrives in desert environments, where it ranges in height from 3-8m tall (Palgrave 2003). Its bright green-gray pods provide excellent livestock fodder, and generally appear year round, particularly in the months between July and September (Palgrave 2003). Because of their relatively low recruitment—but high survival post germination—rates in the Kuiseb River, they are often outcompeted by *S. persica* bushes on riverbanks (Mizuno & Yamagata 2005).

C. Tamarix usneoides

Found almost exclusively along dry riverbeds, especially with saline soils, *T. usneoides* is usually a shrub or small tree reaching up to 3m in height (70%), but has been known to grow as tall as 8m in rare instances (Palgrave 2003). Effective at absorbing fog moisture, *T. usneoides* thrives in arid riparian environments (Palgrave 2003). The plant's fruit provides a valuable source of fodder for livestock, making it an important source of nutrition where little else can subsist (Palgrave 2003).

D. Salvadora persica

A bush often found at low altitudes usually less than 3m tall (75% of the time), *S. persica* can also grow inside of other already established trees, allowing it to reach 8m in height (Palgrave 2003). *S. persica* has a very fine but densely packed root system ranging from 20cm to over 1m in length, allowing it to often outcompete *A. erioloba* and *F. albida* in successional growth (Mizuno & Yamagata 2005). Flowers and fruit appear mostly between September and February, and the fruit is often consumed by livestock and birds (Palgrave 2003). Its thicket arrangement is known to accumulate deposited sand, thereby often creating dunes at *S. persica* bases.

E. Nicotiana glauca

While the wood of mature plants is somewhat useful as firewood and construction material, *N. glauca* is an alien and invasive species to Namibia (Henschel & Parr 2010). However, it thrives in the lower Kuiseb River riparian ecosystem and has recently increased its abundant in the area. Although it is browsed by livestock, it isn't favored and is toxic if consumed in high quantities (Henschel & Parr 2010). Each of its small pods often contains over 1,000 seeds each, and old plants can have as many as 2,400 pods; furthermore, recruitment and growth rates are much higher than native Kuiseb River vegetation, further contributing to *N. glauca*'s success in the region (Henschel & Parr 2010). This makes *N. glauca* something of a threat to native plant species incapable of

outcompeting the invasive species, and given its lack of significant economic value, its populations should be controlled and restricted from spreading further.

F. Euclea pseudebenus

Usually smaller in height than *A. erioloba* or *F. albida*, *E. pseudebenus* is usually under 10m in height. Given its name for resemblance to ebony trees, *E. pseudebenus* has a beautiful hardwood trunk often used for firewood or construction (Palgrave 2003). While it does grow fruit edible to cattle and livestock, it occurs far less numerously than *A. erioloba* or *F. albida* pods, and isn't generally sought after as fodder (Palgrave 2003).

The pilot study area was chosen because it was known to have an ample population of both *F. albida* and *A. erioloba*. Using a Global Positioning System (GPS), coordinates of 109 trees or clumps of vegetation were recorded and their species identified by visual recognition in November 2015.

These coordinates were then mapped on two overlapping aerial images of the study area. The images were obtained on 6 and 8 November 2015 via an Iris+ Unmanned Aerial Vehicle (UAV) using a Canon S100 camera (See Appendix IV for detailed flight information).

Sampling Spatial Heterogeneity in Transects (SSHIT) Method

To supplement the Activity Budgets and gather additional information about the interactions between resource distribution, livestock migration, and cattle diet, approximately 20km of the lower Kuiseb riverbed was divided into transects for assessment of vegetation distribution and livestock fecal matter using the Sampling Spatial Heterogeneity in Transects (SSHIT) method. The SSHIT method was designed to draw correlations between cattle and donkey dung counts, canopy cover, vegetation cover, pod and seed counts and distributions, and dietary analysis through dung dissection.

The river was divided into increments of roughly 1km. At each of the nineteen points along the lower Kuiseb River, two transects were studied on each bank of the river (see Figure 1). Data were collected from a 50×1m transect of the river bed behind the first tree line (A), and a parallel 50×1m transect located 20m farther from the center of the river (B). Thus, for each cross-section of the river, four transects were studied: North A, North B, South A, and South B. This system creates cross sections of portions of the lower Kuiseb River, and the multiple transects can be combined to show distribution data over a larger area (see Appendix V). Figure 2 shows a model of one cross-section of the river.

Figure 1. Map of the study region with SSHIT method cross-sections of the Kuiseb River. The points where transects were studied on each side of the river for all 19 stops are shown. The downstream-most point is located farthest west.
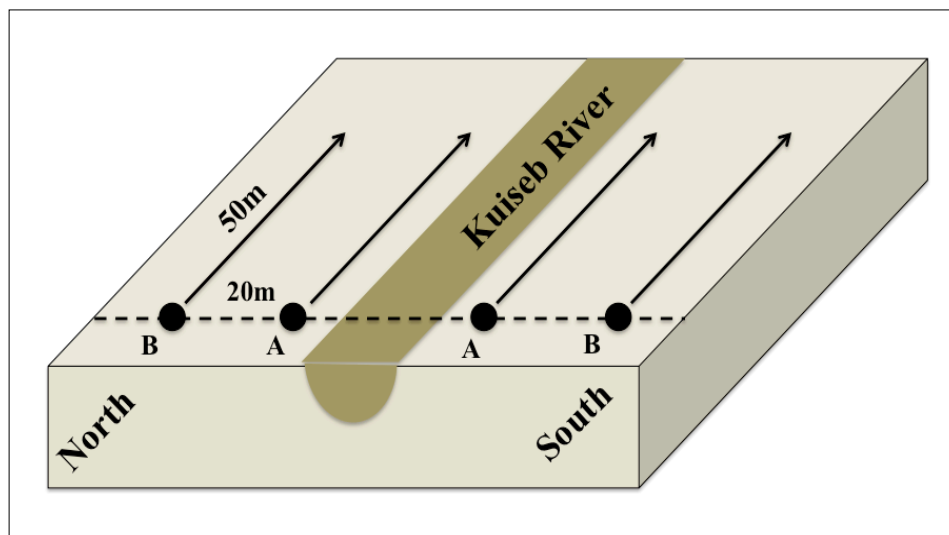

Figure 2. Diagram of a Kuiseb River cross-section as divided by the SSHIT method. Transects A are located behind the first line of trees, and Transects B are located 20m farther outside of the riverbed.

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Along each transect, the total numbers of cattle dung deposits, donkey dung deposits, *F. albida* pods and *A erioloba* pods were counted. When present, four donkey dung deposit samples and a 500cm^3 sample of cattle dung were collected at the starting points, in addition to a single pod of each species. These pods were collected in order to calculate the average number of seeds per pod.

On each side of the river, the total canopy cover was estimated and given a score of 0 to 6. This score corresponds to a percentage, as shown in Table 1. Similar scores were given to each tree species: *F. albida, A erioloba, T. usneoides, S. persica, N. glauca, and E. pseudebenus.*

Score	Percent Cover
0	0 %
1	0 to 20 %
2	20 to 40 %
3	40 to 60 %
4	60 to 80 %
5	80 to 100 %
6	100 %

Table 1. Scale and scoring method for estimating overall and percent species by cover.

Further analysis of the cattle and donkey dung samples were conducted. Dung were soaked in water and separated using sifters. All recognizable pieces of *F. albida* or *A. erioloba* seeds were set aside based on initial collection location, excluding broken or missing shells. These seeds were then sorted into their respective species.

The data collected via the SSHIT method were compiled and Stata 12 was used to create a correlation matrix containing all of the variables. This was done to determine statistically significant relationships using a p-value of $p < 0.05$. Additionally, two-way ANOVA tests were run on the categorical spatial variables for variable *x*.

Finally, the locations of settlements along the Kuiseb in the study area were mapped using ArcGIS 10.2. Using the midpoints between north and south coordinates for each SSHIT stop, a buffer region with a 1km radius was created around each site. These buffers were then overlayed onto an October 2015 satellite image of the study area. Structures were then identified and counted to determine the amount of structures within each 1km buffer region. "Structures" were defined to be any living space located in and around settlement locations. Gobabeb buildings were excluded from this definition. A correlation matrix was then run in Stata 12 to determine the relationships between density of households and amount of dung deposits, pod density, and numbers of seeds in the dung samples.

Results

Community interviews

Two Topnaar livestock owners were interviewed, both of whom were also employees at Gobabeb, in order to better understand the role of livestock in Topnaar communities, Topnaar livestock management techniques, the resource use patterns of these livestock, and the influence of weather patterns and climate change on each of these topics.

Although livestock management techniques vary from owner to owner, it was found that goats generally return to kraals at night, and sometimes herded by dogs. Cattle and donkeys, however, spend their nights in the riverbed—with few, if any, large natural predators along the lower Kuiseb River, and incentives of keeping them in kraals nightly are few. Given the lack of surface water for the majority of the year, animals are watered from communal boreholes. Interviewees believed that donkeys and cattle will eat nearly any type of vegetation in the area, generally without any specific preference save for !nara and dune grasses (particularly after rains), which they will sometimes venture longer distances to find. Small stock and young cattle/donkeys are fed supplemental fodder, however little is known of its nutritional value/success of the practice. Livestock are predominantly used for milk and meat harvesting, and donkeys exclusively for transportation. Interestingly, none of the interviewees have observed any changes in weather patterns in recent years, and do not think that any changes will be experienced in the foreseeable future.

Livestock observations

A. Body Condition Scores (BCS)
The BCS for twenty individual cattle from various herds were recorded over two days in order to estimate the health and productivity of Topnaar cattle. The BCS of individuals were highly variable within and between herds; the lowest observed BCS was 1 and the maximum was 4. The average BCS was 2.63 (sd=0.69).

B. Cattle Activity Budgets
The Activity Budgets were used to determine the behavior of cattle and other livestock throughout the day. During Day 1 (late afternoon), cattle spent most of their time doing "other" activities (52%), lying in the shade (18%), standing in the shade (12%), and foraging (12%); they also spent time ruminating in the shade (5%) and standing in the sun (1%) (Figure 3a). During Day 2 (late morning), cattle spent most of their time lying in the shade (42%), foraging (25%), and standing in the shade (14%). These cattle also spent time drinking water (7%), standing in the sun (6%), lying in the sun (3%), and doing "other activities" (1%) (Figure 3b). This variation in cattle behavior at different times of day was particularly apparent since there were more observations recorded of cattle lying in the shade during the late morning (42%) than during the late afternoon (18%), as shown in Figure 3. Variations in the "other" category also varied considerably between the two days—52% on Day 1 and 7% on Day 2 (see Tables 2 and 3). This may

have resulted because walking, either in the shade or the sun, was not included as a possibility on the Activity Budget and was thus, recorded in the other category. Considerable numbers of livestock were observed walking, both in the shade and in the sun, during the first day and this activity made up a large part of the "other" section for this day. Furthermore, the frequency of foraging behavior may be skewed because the vehicle often stopped for longer periods to observe cattle that appeared to be foraging and due to this these observations may have been recorded more frequently than observations of other behaviors.

Through the Activity Budgets, interesting observations of cattle water use and herd sizes were made: on Day 1, no cattle were observed drinking water, whereas a large gathering of cattle was recorded drinking from the community water point on the Day 2. Multiple different herds of cattle appeared to congregate around this same water point, a drinking trough that was located right next to a community settlement. The sizes of cattle herds that were observed also varied widely: from individual cattle to fourteen individuals.
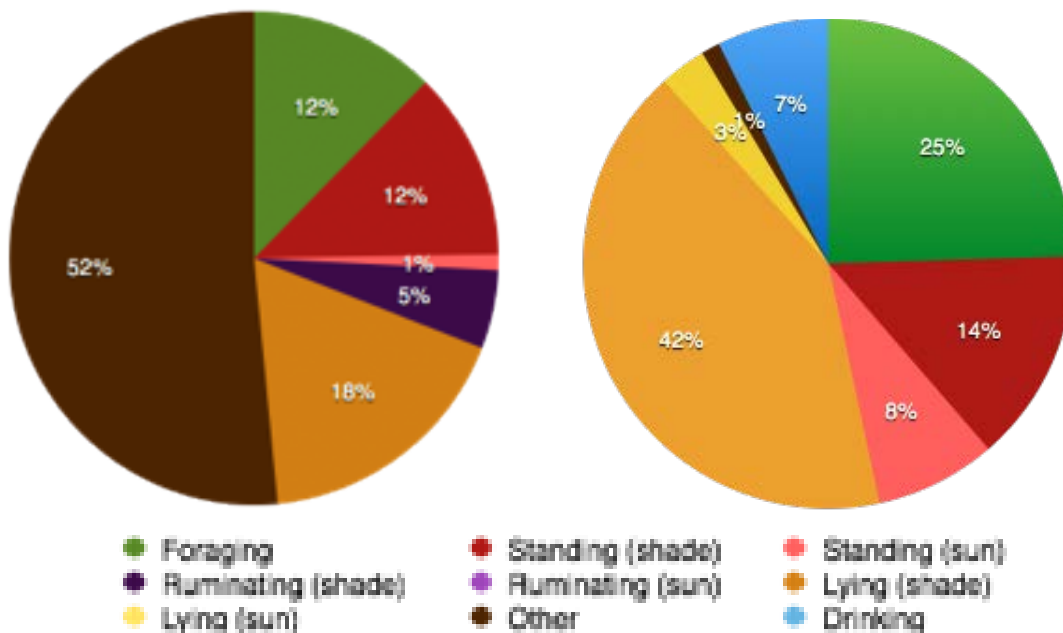
Figure 3. Activity breakdown of all herds from Day 1 (a) and Day 2 (b).

	Herd 1	Herd 2	Herd 3	TOTAL OVERALL
Foraging	0.15	0	0.18	0.12
Standing (shade)	0.06	0.10	0.55	0.12
Standing (sun)	0	0	0.09	0.01
Ruminating (shade)	0.02	0.14	0.09	0.05
Ruminating (sun)	0	0	0	0
Lying (shade)	0.02	0.71	0.09	0.18
Lying (sun)	0	0	0	0
Other	0.75	0.05	0	0.52
Drinking	0	0	0	0

Table 2. Cattle Activity Budget for Day 1 showing proportions of time spent on each activity.

	Herd 1	Lone Bull 1	Lone Cow 1	Herd 2	Herd 3	Herd 4	Herd 5	Herd 6	TOTAL OVERALL
Foraging	0	0	0	1	0.27	0	0.24	0.40	0.25
Standing (shade)	0	1	0	0	0.18	0	0.38	0.11	0.14
Standing (sun)	0.06	0	0	0	0	0.48	0	0	0.08
Ruminating (shade)	0	0	0	0	0	0	0	0	0
Ruminating (sun)	0	0	0	0	0	0	0	0	0
Lying (shade)	0.67	0	0	0	0.55	0	0.38	0.49	0.42
Lying (sun)	0.28	0	0	0	0	0	0	0	0.03
Other	0	0	1	0	0	0.04	0	0	0.01
Drinking	0	0	0	0	0	0.48	0	0	0.07

Table 3. Cattle Activity Budget for Day 2 showing proportions of time spent on each activity.

C. Forage Patterns

Cattle consumption of *F. albida* pods from the ground made up the majority of foraging observed (see Figure 4). Furthermore, the foraging of *F. albida* pods and other forage were usually mutually exclusive. Herds of cattle consuming these pods were not usually observed consuming other "food sources" (see Tables 4 and 5). In contrast, cattle that were observed consuming resources other than *F. albida* pods were observed foraging on a variety of different resources, e.g. fallen branches, *A. erioloba* pods, *S. persica*, *N. glauca,* etc. It was also observed that *A. erioloba* pods took more effort for cattle to chew than did *F. albida* pods.
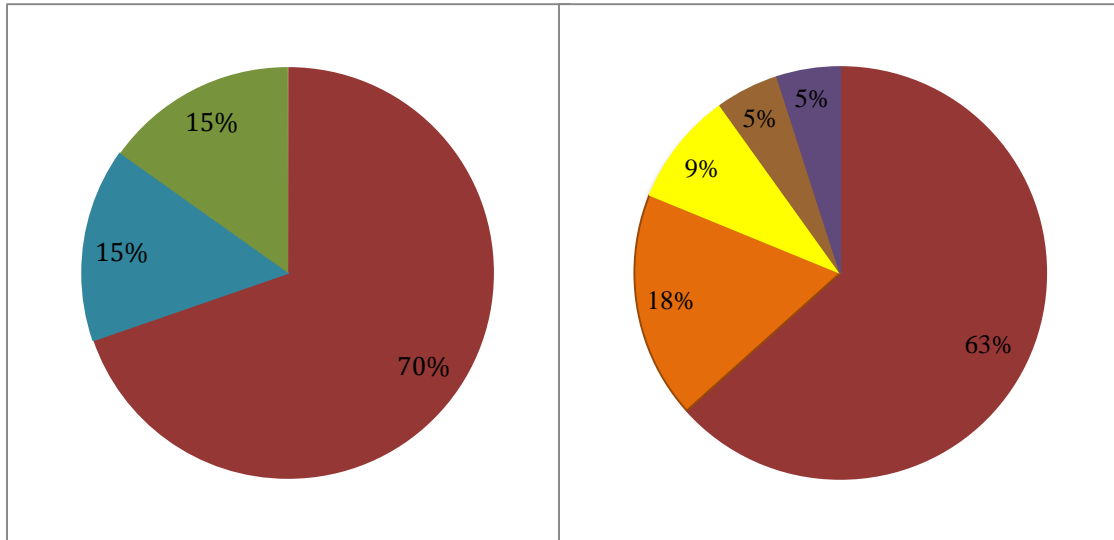
Figure 4. Day 1 (a) and Day 2 (b) foraging proportions of cattle. *F. albida* pods are shown in red, *A. erioloba* pods in blue, *S. persica* leaves in green, fallen branches in orange, *N. glauca* in yellow, dune grass in brown, and unknown plants in purple.

	Herd 1	Herd 3	TOTAL
F. albida **pods (ground)**	9/9	0/4	9/13
S. persica **Leaves**	0/9	2/4	2/13
A. erioloba **pods (ground)**	0/9	2/4	2/13

Table 4. Day 1 foraging proportions of observations.

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	Herd 2	Herd 3	Herd 5	Herd 6	TOTAL
F. albida pods (ground)	4/6	19/19	5/5	0/14	28/44
Unknown	2/6	0/19	0/5	0/14	2/44
N. glauca	0/6	0/19	0/5	4/14	4/44
Fallen Branches	0/6	0/19	0/5	8/14	8/44
Dune grass	0/6	0/19	0/5	2/14	2/44

Table 5. Day 2 foraging proportions of observations.

Measurements of forage intensity varied across sites and forage intensity from low to high, but no consistent patterns were observed.

D. Other Livestock
Goats and donkeys were also encountered during these observations, but Activity Budgets only recorded the actions of cattle. All of the goat herds that were observed included more individuals than any of the cattle herds. Goats were reported eating *F. albida* pods in multiple locations. Additional notes taken while gathering Activity Budget data documented a group of donkeys eating *F. albida* leaves from the ground. Overall, there was little spatial overlap seen among goats, cattle, and donkeys in areas where data was recorded.

Vegetation mapping
109 trees or tree clumps in the lower Kuiseb River were surveyed, and with additional identification using aerial imagery, a total of 639 trees were mapped (see Figure 5).

The percentage of each tree species mapped is shown in Table 6. More than twice as many *T. usneoides* trees compared to any other species are present in the study area, particularly dense in the southwestern corner, which was recently affected by flooding. There were slightly more *F. albida* trees than *A. erioloba*, and both were found to be largely clustered with their own species.

Tree species	Percent of total vegetation
T. usneoides	39.75%
F. albida	19.25%
A. erioloba	17.84%
S. persica	16.59%
N. glauca	4.38%
E. pseudebenus	1.72%
Other	0.47%

Table 6. Percentage of vegetation by tree species in the Kuiseb River study area.

Within the two species that produce pods, 51.90% of the trees are *F. albida* and 48.10% *A. erioloba.* Assuming this ratio is representative of the vegetation throughout the Lower Kuiseb River, it can be applied to the amount of seeds from each species found in the cattle dung. Across individual cattle, the average percentage of *F. albida* was 51.67% and the average percentage of *A. erioloba* was 48.33%, which are similar to the ratio of pod producing trees in the river.
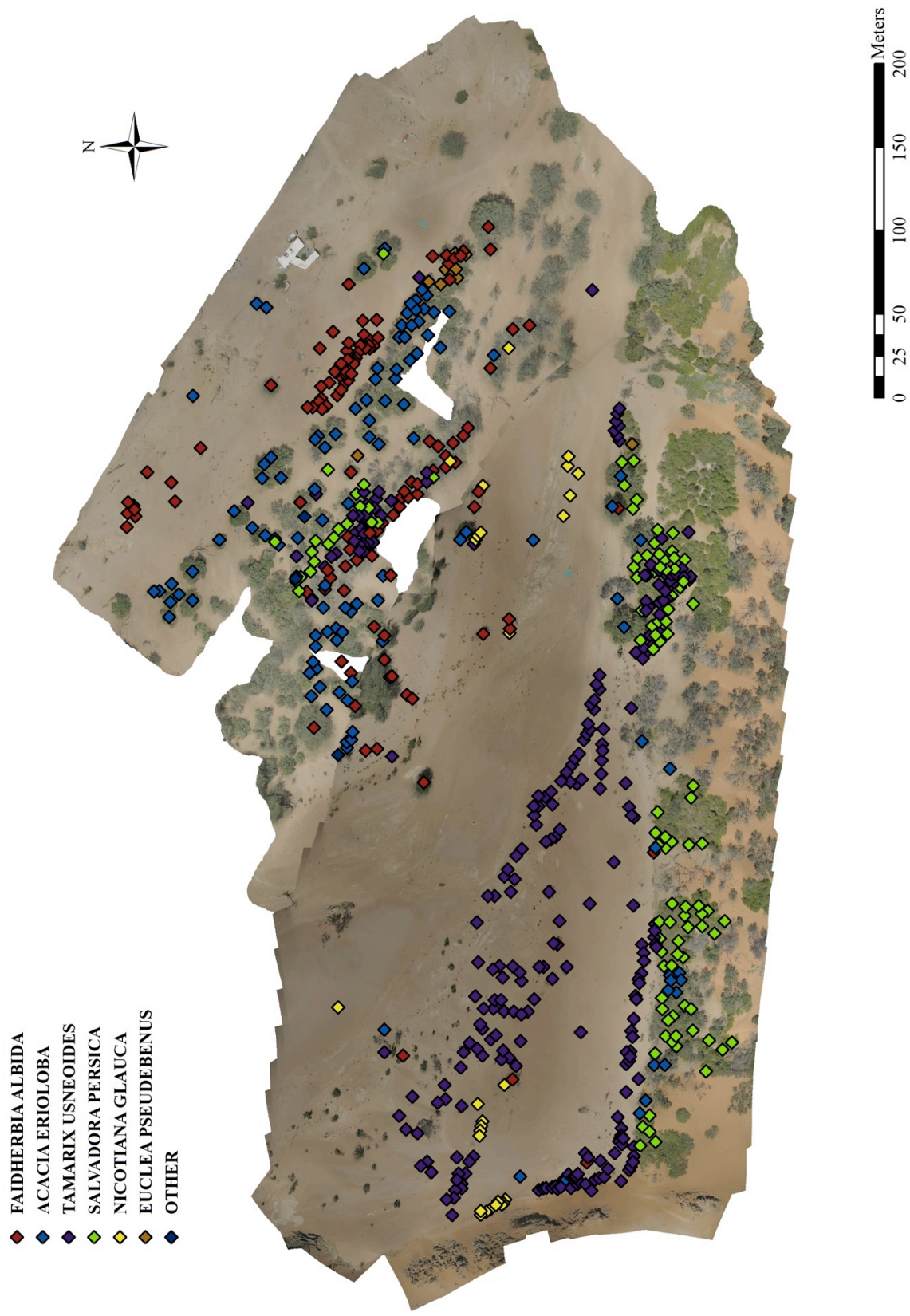
Figure 5. Map of the vegetation distribution in the Kuiseb River near Gobabeb Research and Training Centre.

River Transects

As expected, there was a negative relationship between distribution of *F. albida* and *A. erioloba*, *T. usneoides, S. persica,* and *N. glauca*. Furthermore, there was a negative correlation between density of *S. persica* and *A. erioloba*, and between *S. persica* and *T. usneoides* (see Appendix VI). There was a significant positive correlation between overall canopy cover and both *S. persica* and *E. pseudebenus* vegetation, which makes sense given the tendency of both species to grow in more densely forested parts of the river. Conversely, there was a negative correlation between overall cover and *N. glauca*, a plant that prefers to grow in sparse areas.

There was a moderate negative correlation between tree density and distance upstream for *A. erioloba* (see Figure 6).
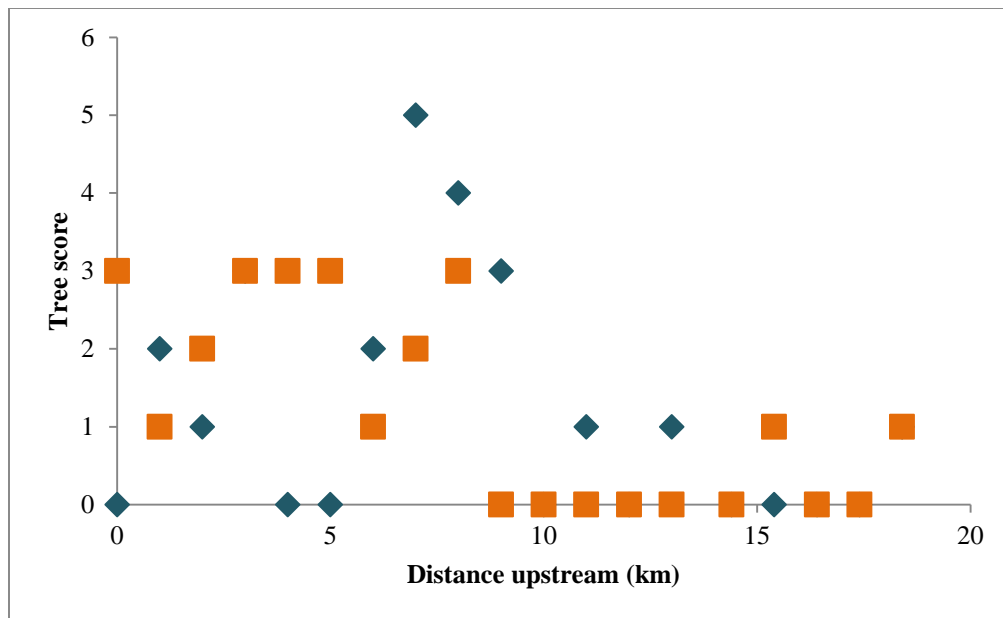
Figure 6. Relationship of *A. erioloba* and distance upstream along the study area. "North" points are designated by blue diamonds, and "South" points by orange squares. There is a statistically significant moderate negative correlation between *A. erioloba* density and distance along the river ($r = -0.4680$, $df = 74$, and $p = 0.0001$).

Overall, there were greater numbers of *F. albida* pods along the inner transects than along the outer ones (see Figure 7). There was no significant relationship between distance along the river and pod distribution, nor between pods and the cover of their respective species.
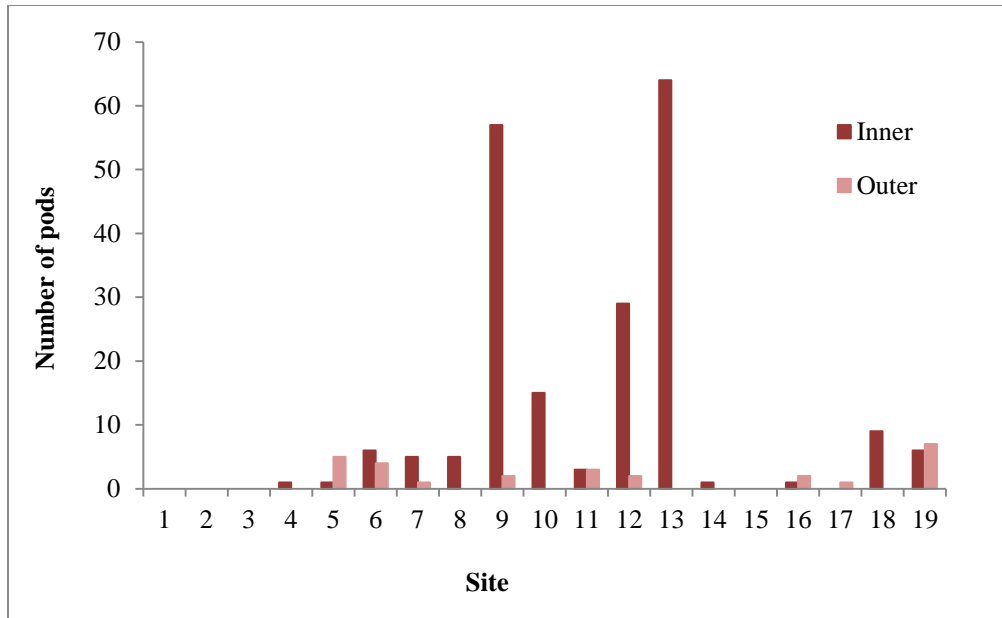
Figure 7. *F. albida* pod counts at each river cross-section site. Results of the ANOVA test showed a statistically significant difference in pod distribution between inner and outer transects ($F = 6.02$, $df = 3$, 72, $p = 0.0166$).

There was a weak negative correlation between cattle dung density and *N. glauca* cover score, but no relationship between number of cattle dung deposits and cover of either of the pod species. However, the density of donkey dung deposits moderately increased with increasing *A. erioloba* cover score (see Figure 8).
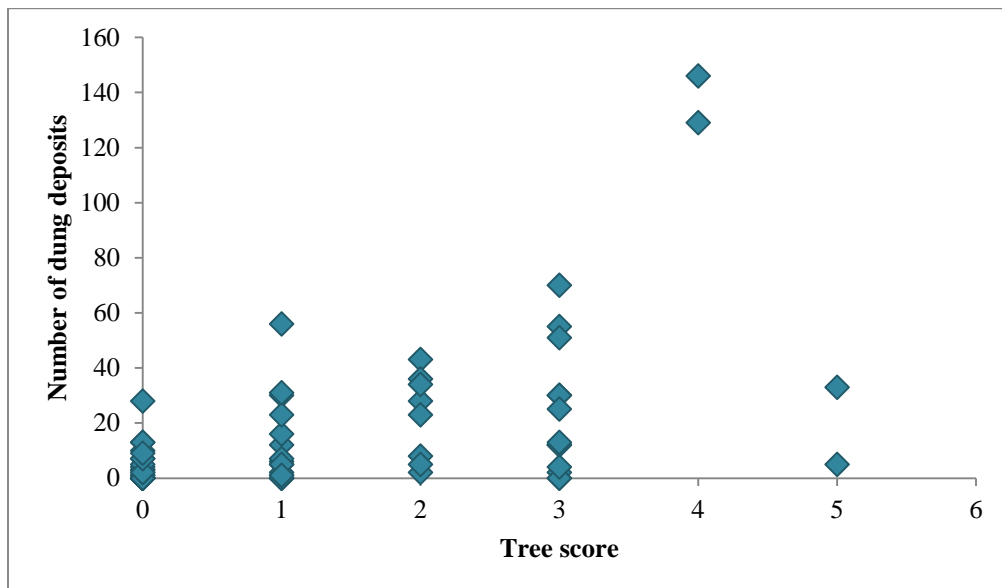
Figure 8. Relationship between *A. erioloba* and number of donkey dung deposits. As can be seen, with increasing *A. erioloba* cover score, there is a statistically significant, moderate increase in amount of donkey dung deposits ($r = 0.5369$, $df = 72$, and $p < 0.0001$).

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With respect to pods, the density of cattle dung deposits was positively correlated with the amount of *F. albida* pods along the transects (see Figure 9). There was no relationship between cattle dung and *A. erioloba* pod amounts.
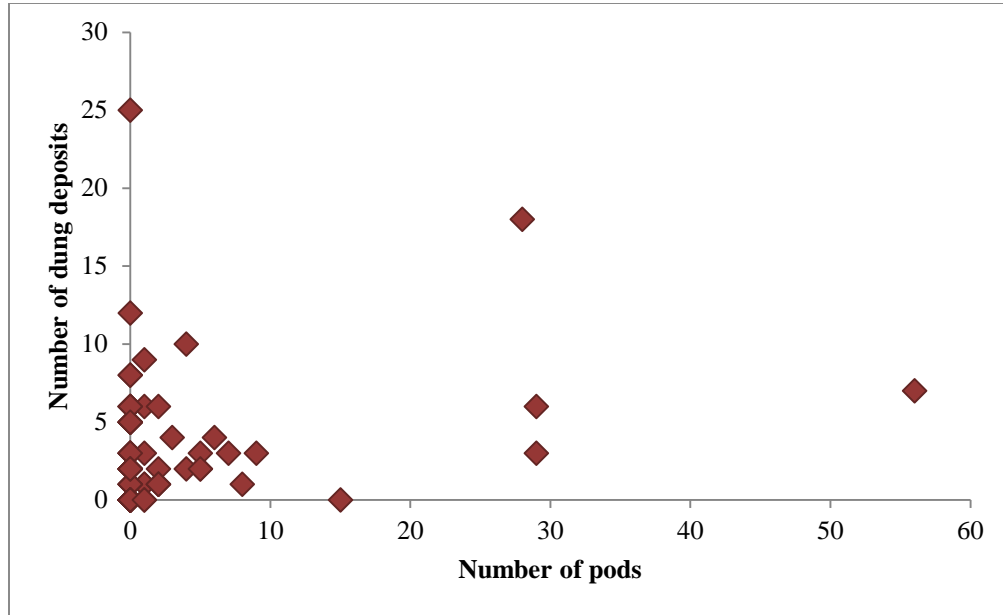
Figure 9. Relationship between *F. albida* pods and number of cattle dung deposits. As can be seen, as the number of pods increases, there is a significant, weak, positive increase in the number of cattle dung deposits ($r = 0.2397$, $df = 72$, and $p = 0.0397$).

There were two locations of high concentrations of structures, one upstream, and another downstream (see Figure 10). A total of 174 settlement structures were identified. Surprisingly, there was found to be a negative correlation between number of structures and density of cattle dung deposits ($r = -0.2638$, $df = 17$, $p < 0.05$). There was no significant relationship between settlement structures and pod density or numbers of seeds in cattle dung samples.

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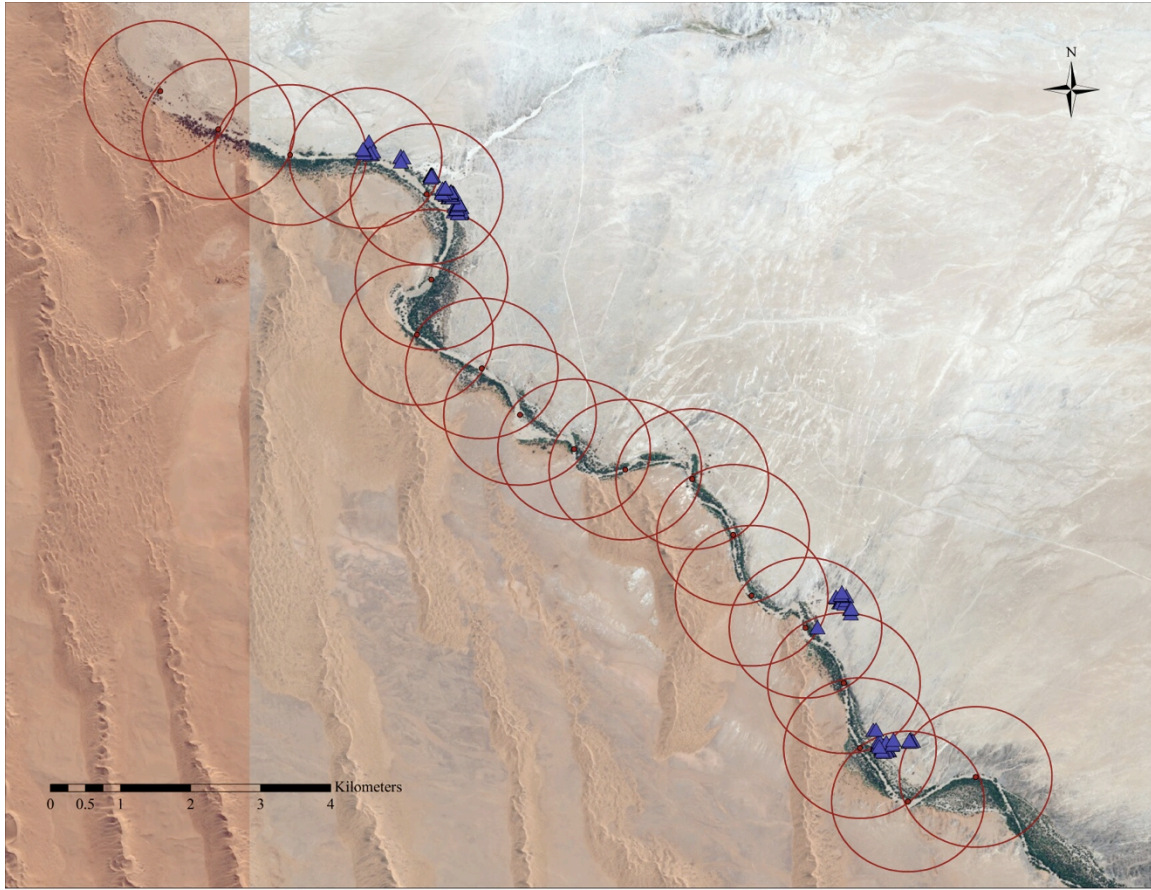
Figure 10. Map of settlement structures lying within buffer regions. Settlement structures are designated by purple triangles. The red points designate the midpoints between northern and southern coordinates for each of the 19 locations. The red circles show the 1km buffer regions used to assess settlement density.

There was found to be a difference between the northern and southern transects with respect to the total number of seeds found in cattle dung samples, though there was no difference between these categories for the individual pod species. For nearly all sites, the total seed counts in cattle dung collected on the north side of the river were higher than those from dung collected on the south side (see Figure 11).
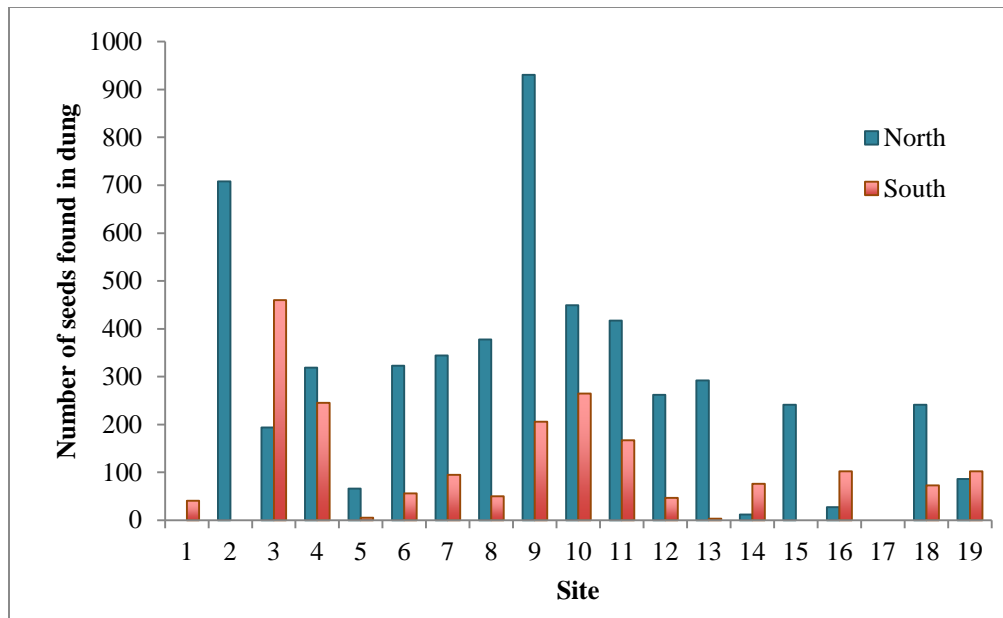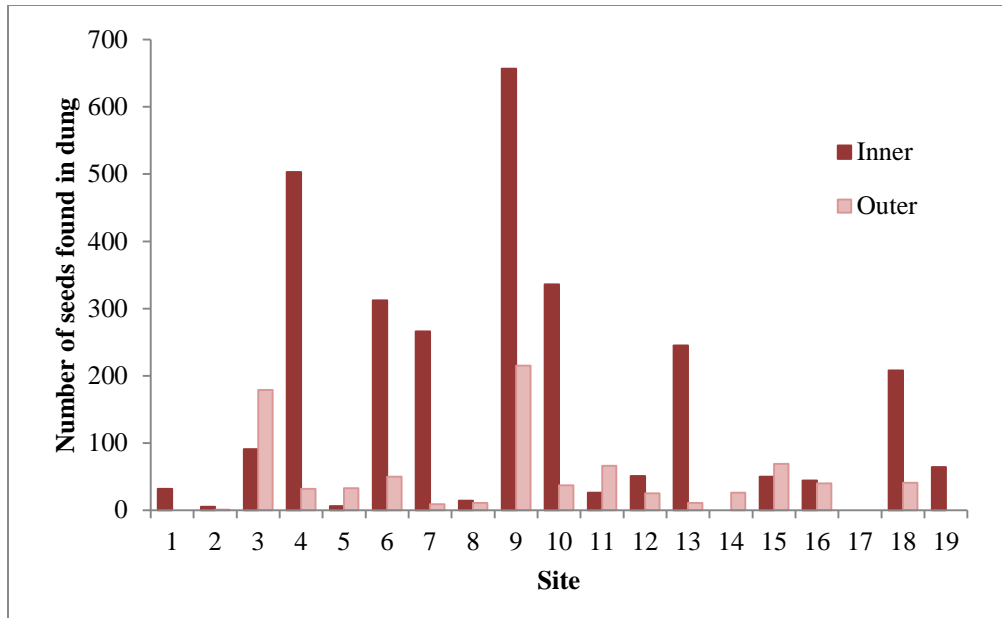
Figure 11. Total seed counts for cattle dung samples collected at each river cross-section site. Results of the ANOVA test showed a statistically significant difference in seed amounts between northern and southern banks of the river ($F = 5.56$, $df = 3, 56$, $p = 0.0219$).

Interestingly, there were differences between the amounts of seeds found in cattle dung collected from the inner versus outer portion of the river. Cattle dung collected from the inner transects of the river tended to have higher numbers of *F. albida* seeds, and lower numbers of *A. erioloba* seeds, whereas samples collected from the outer transects tended to have lower numbers of *F. albida* seeds and higher numbers *A. erioloba* seeds (see Figures 12 and 13).

Figure 12. *F. albida* seed counts in cattle dung samples collected at each river cross-section site. Results of the ANOVA test showed a statistically significant difference in seed amounts between inner and outer transects ($F = 6.05$, $df = 3, 56$, $p = 0.0170$).
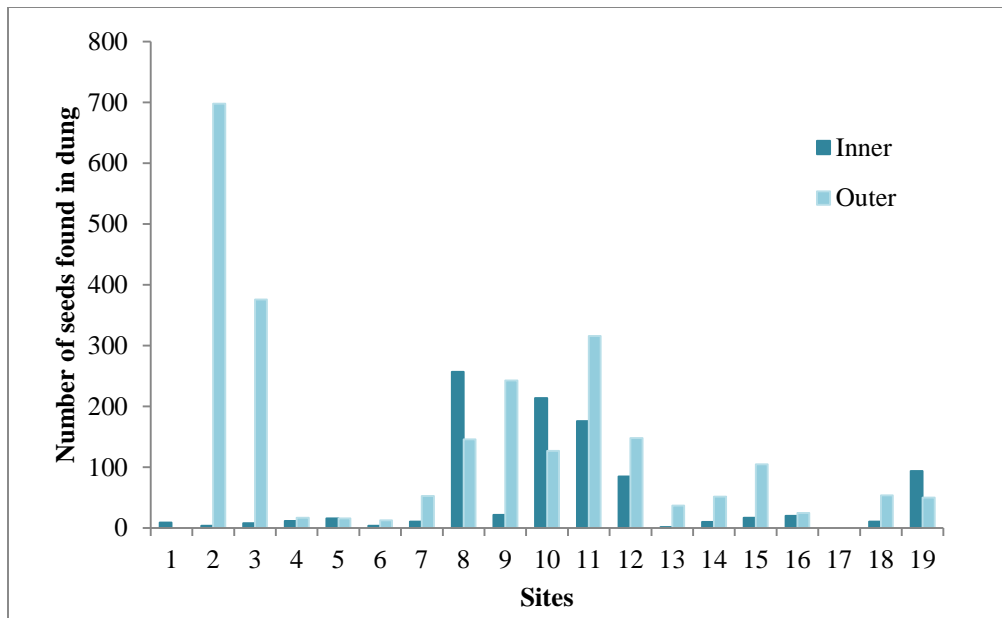

Figure 13. *A. erioloba* seed counts in cattle dung samples collected at each river cross-section site. Results of the ANOVA test showed a borderline statistically significant difference in seed amounts between inner and outer transects ($F = 3.75$, $df = 3, 56$, $p = 0.0580$.).

Discussion

Vegetation Distribution

The density of *A. erioloba* trees decreased upstream along the river, which suggests that the nature of these upstream locations is less conducive to *A. erioloba* growth. The Namib Sand Sea sits along the southern side of the lower Kuiseb River in these areas and according to Mizuno (2005), dune sand deposition buries *A. erioloba* tree roots, limiting oxygen supply, and creating conditions that are less than optimal for *A. erioloba* growth. Conversely, abundance of *E. pseudebenus* displayed the opposite trend. The positive relationship between *E. pseudebenus* trees and upstream locations may be attributed to its ability to grow in stony and sandy desert conditions (Mizuno and Yamagata 2005).

The negative correlations between several pairs of tree species highlights competition for space in the same area. Furthermore, where *F. albida* is concerned, the specific conditions required for tree growth may also be responsible for competition between this species and others, such as *S. persica.* This is partly due to the fact that the roots of the *S. persica* shrub are densely packed and accumulate sand deposition, which stifles oxygen supply to roots of the pod producing species, *F. albida* and *A. erioloba* (Mizuno and Yamagata 2005).

The weak positive correlation between *S. persica* and *E. pseudebenus* growth and overall canopy cover can be explained by the relatively large canopy of these species compared with other trees in the river. Both trees are short in canopy height relative to neighboring pod species. Furthermore, *S. persica* utilizes other nearby trees as structures upon which to grow, so its presence fills in canopy gaps that may not be covered otherwise (Curtis & Mannheimer 2005). The sweeping canopy of the *E. pseudebenus* also covers larger areas than the pod producing species, and does not compete with them in the upper tree level.

In contrast, the weak, negative relationship between total canopy cover and *N. glauca* cover corroborated field observations that suggested this plant tended to grow in more sparsely vegetated areas of the riverbed. Due to the large quantity of seed production of *N. glauca*, it is able to successfully grow and reproduce in areas to which other species have been unable to disperse (Curtis & Mannheimer 2005). Thus, these areas may contain lower canopy cover due to poor resource availability or recent disturbance.

Finally, one of the very important discoveries resulting from the combination of UAV imagery and on-the-ground visual identification is the ability to distinguish between tree species from high-resolution aerial images. Not only were obvious plants such as *S. persica* able to be identified, but via ground-truthing before and verification after aerial identification, *F. albida* and *A. erioloba* trees were able to be differentiated from one another on the vegetation maps. This newfound capability will allow for much easier large-scale vegetation mapping and monitoring in the Kuiseb River.

Cattle resource use patterns

No relationship between cattle activity and vegetation distribution was found, contrary to initial hypotheses. It was expected that there would be a higher concentration of cattle dung in regions with greater *F. albida* and *A. erioloba* cover, as pods from these species of trees were observed as an essential component of cattle diet (Palgrave 1981). The weak, negative correlation between cattle dung deposits and *N. glauca* cover was also unexpected due to the detrimental effects of *N. glauca* consumption on animal health (Palgrave 1981). The *N. glauca* plant contains the toxins anabasine and nicotine, both of which can "cause death or act as teratogens when ingested" (Plumlee et al. 1993). Cattle grazing patterns show that these negative health impacts likely result in reduced likelihood of cattle to forage from these plants, since "large herbivores can develop a conditioned aversion to novel food paired with a toxin" (Bailey et al. 1996).

The positive correlation between upstream locations and number of total seeds found in dung dissections is interesting, as dung deposits are responsible for seed dispersal. Cattle migration routes may play a critical role in this process, as well as relocation after consumption; upstream seed dispersal is a result of such cattle behavior. There was not, however, a higher incidence of pods at the upstream sites. One factor that may explain this result is the possible harvest of *F. albida* and *A. erioloba* pods along certain segments of the river. Harvest of pods is one method utilized by local residents for production and sale of fodder; this removal of pods from the riverbed may partially explain the increased seed counts in areas without higher pod amounts, although more studies are required.

Cattle dung analysis yielded new insights on dietary preferences of the animals. It was expected that there would be a positive relationship between cattle dung incidence and density of *F. albida* and/or *A. erioloba* pods due to knowledge of cattle foraging. Analysis of data collected concludes that there is a weak, but statistically significant positive relationship between cattle dung density and *F. albida* pod density. These results corroborate information found in the literature that claims that *F. albida* pods are the main source of diet for cattle (Desert Research Foundation of Namibia 2015). These observations are further supported by the fact that the majority of foraging cattle were found to be consuming *F. albida* pods from the ground (see Figure 3). Cattle may seasonally prefer *F. albida* pods to other vegetation due to their high nutritional value, making them more palatable. Other studies have demonstrated the high nutrient content of this species of pods, as their seeds and pulp both serve as good sources of protein and minerals for cattle (Hassan et al. 2007). Such characteristics may explain why BCS are slightly below average in this area despite the harsh conditions of the variable, arid climate. The consumption patterns of *F. albida* pods by cattle seem to reflect this dietary preference: *F. albida* pods are consumed as the preferred food source in areas until they are no longer available.

Another potential reason for the positive correlation between cattle dung and *F. ablbida* pod density among analyzed transects could be related to the distribution of *F. albida* trees themselves, and their increased densities along riverbeds due to their short taproot

systems. Though cover in the inner and outer transects was not differentiated, there were greater amounts of both *F. albida* pods and *F. albida* seeds in the dung samples in the inner transects than those 20m outside. Cattle most likely follow the riverbeds during the majority of the time they spend foraging and likely avoiding sloped areas. Studies have shown that "animals probably recognize changes in slope and use that information to remain on contours or to minimize changes in elevation while foraging" (Bailey et al. 1996). Due to this, "several large herbivores such as cattle generally avoid grazing slopes over 10%" (Bailey et al. 1996). As a result, cattle are more likely to forage in areas of the riverbed that are more densely vegetated with *F. albida*.

Data from the cattle Activity Budgets found herds of cattle eating *F. albida* pods exclusively in some areas, while foraging cattle herds observed consuming other vegetation did not limit themselves to just one species. For example, on Day 1 of cattle observations, cattle in Herd 3 were found eating *A. erioloba* pods from the ground and *S. persica* leaves from a bush roughly 10km from Gobabeb. Vegetation mapping from data collected in this area showed generally equal distributions of *F. albida*, *A. erioloba*, *T. usneoides*, *S. persica*, and *N. glauca* species. Although several *A. erioloba* pods were found on the ground where these cattle were foraging, no *F. albida* pods were found on the ground. In another case, cattle from Herd 6 on Day 2 were recorded browsing on dune grass on the slope of a sand dune, *N. glauca* leaves, and fallen branches at browse height that appeared to be dead.

The unusual foraging behaviors of this Herd 6 from Day 2 are likely due to the lack of *F. albida* pods available to them in this area. Although vegetation mapping of this area indicates a 40-60% occurrence of *F. albida* trees, there was an absence of both *F. ablbida* and *A. erioloba* pods. This lack of *F. albida* pods is likely because it is within 0.25km of a settlement, and a relationship between settlement locations and pod density for either species was observed. Regardless, the results suggest that *F. albida* pods are a significant component of cattle diet.

Though cattle were not often observed eating *A. erioloba* pods, these seeds were also found in high concentrations in cattle dung samples, which suggests that this species of pod is also consumed regularly. *A. erioloba* seeds were generally higher in number in the dung samples collected from the outer transects and *F. albida* seeds were higher in those collected from behind the first tree line. Therefore, it is possible that foraging of *A. erioloba* pods occurs largely on the outer banks of the river. Furthermore, Figure 4 shows that while both pod species are roughly equal in abundance, *F. albida* are clustered in the middle of the river, while *A. erioloba* grow in outer areas of the lower Kuiseb River. Thus, the fact that cattle were not found eating these pods during the study could be due the fact that Activity Budget observations were conducted predominately within the riverbed.

Relationships between livestock

Results indicate that the presence of cattle or donkey in a given area does not affect the presence of the other. The negligible amount of seeds extracted from donkey dung samples supports the conclusion that dietary preferences of donkey and cattle differ. Though the animals may occasionally consume the same plant species, they likely eat different parts of these plants. This reduces the pressure on the natural resources consumed by livestock. This is further supported by observations that donkeys and goats contain a more varied, generalist diet in comparison to cattle. There was, however a positive correlation between donkey dung and *A. erioloba* trees, which should be explored further by utilizing GPS collars, observations and Activity Budgets, and vegetation maps in the study area.

Conclusions and further research

This study indicates that livestock in the lower Kuiseb River catchment forage on both *F. albida* and *A. erioloba* pods in high amounts. Because these species of trees are clustered in different parts of the riverbed, their vulnerability to extreme weather events, such as floods, is not necessarily equal. Thus, recent weather patterns indicate changes in temperature and precipitation, as well as drought and flood tendencies in the region are likely to have different impacts on these and the other four species of trees, which will in turn both directly and indirectly affect local livestock.

A number of variables influence vegetation health and distributions, particularly processes occurring upstream along the Kuiseb River. Temperature has been gradually increasing upstream in the Kuiseb River over the past 65 years of monitoring, and precipitation has been on the decline, thus significantly affecting downstream vegetation (Mizuno and Yamagata, 2005). The effects of such changes include: shifting of the water table downstream in the Kuiseb River, increase in flood size and decreases in flood frequency, heat stress inflicted upon livestock and plants, and influxes in sand dune encroachment on the Kuiseb riverbed (Mizuno 2005, Grodek et al. 2013, Morin et al. 2009).

These climactic changes will inevitably disrupt natural ecological processes, significantly impacting vegetation and livestock along the Kuiseb River. This may incite lower vegetation productivity, including growth and pod production, as well as the introduction of invasive species which have tended to thrive under such conditions. Examples of this in the Kuiseb River include *S. persica* and *N. glauca*, which often outcompete native tree and plant species. Because these species compete with popular livestock forage plants, such as *F. albida* and *A. erioloba*, an increase in their overall dispersal will likely adversely affect livestock. Therefore, mitigation of these significant climatic changes should be considered a high priority by communities living along the river. Unless these implications are comprehensively monitored and curtailed, impacts will likely be magnified in the future, negatively influencing the ephemeral Kuiseb River ecosystem and the vegetation and livestock therein.

Such efforts should include more extensive dung collection and analysis along longer transects of the river that span a greater range. In addition, the SSHIT method should be expanded to include counts of pods on the trees themselves, in addition to those on the ground. Furthermore, usage of livestock collaring initiated by Dartmouth College in partnership with Gobabeb and increased Activity Budget observations will contribute to a better understanding of migration patterns, habitat and forage species preference, and energy expenditure throughout the seasons of the year. Further exploration on locations of pod harvest is necessary for understanding the dispersal of seeds in cattle dung across the landscape. A final important implication of this study is the ability to identify tree species from aerial imagery. With this insight, UAVs can be used in combination with on-the-ground tree identification to map larger portions of the river. Particular attention should be paid to the distribution of *F. albida* and *A. erioloba* trees, as these provide significant benefits for community members, both directly in the form of harvesting for income, and indirectly through livestock foraging.

Acknowledgements

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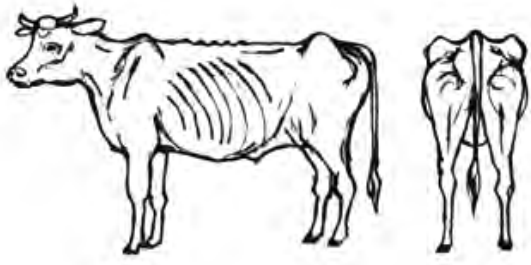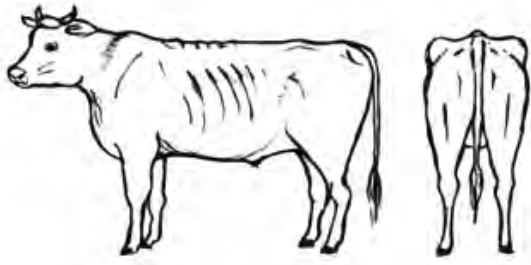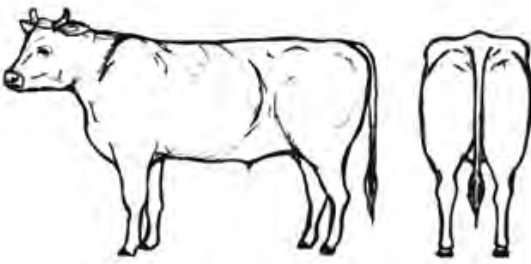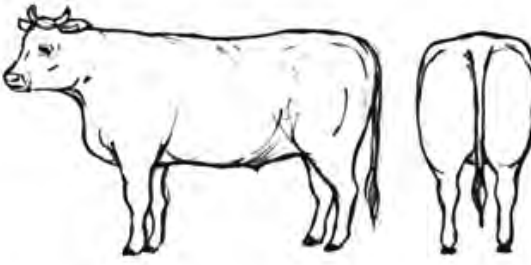# Appendices

Appendix I: Community Interview Questions

1. Do you own livestock? Why or why not?
2. How long have you owned livestock?
    a. What is the history of livestock in your community? (family/culture?)
    b. How long have people in your community owned livestock?
3. What types of livestock do you own? (cattle/goats/donkeys/sheep/horses)
    a. How many animals do you own?
    b. What breeds are they?
    c. What do you use them for? (investment, food, livelihood?)
    d. Which animal do you think is most important? Culturally? Economically?
4. How do you manage your livestock?
5. What are some of the mgmt. techniques that you use?
6. Do you herd your animals? If so, how often?
7. Do you keep your animals in a boma or kraal at night?
8. How/where do the animals get water?
    a. Do you use wells or boreholes? If so, how long have you had them?
    b. Do your animals ever drink from natural water sources? Are there natural water sources available in this area?
9. What do your livestock eat?
10. Where do your animals get their food?
11. What times of day do your animals eat?
12. How much do your animals eat?
13. Do you ever help your animals access food sources or feed them (supplements?) at home?
    a. Collect pods and store them? Knock pods off trees so livestock can eat them?
14. What has the weather been like over the past few years? (floods? Droughts? Different in different areas?)
15. How has the recent weather affected you?
16. How has it affected others in your community?
17. How has it affected your livestock?
18. Have you changed your livestock management practices b/c of the weather?
19. After an extreme weather event (drought, floods, etc.), what do your animals eat?
20. What do you think the weather will be like in the next few years?
21. Are there any tools or ideas that you think could help people in your community with managing their livestock in response to weather changes?
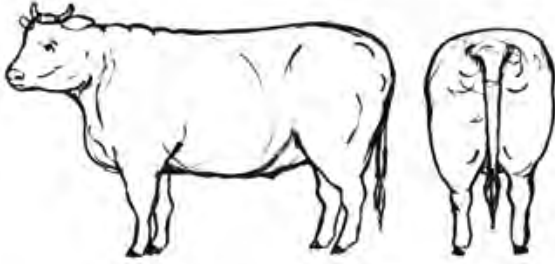
Appendix II: Activity Budget Observations Template

Livestock: Sex: Condition: Date: Time:

Foraging	
Standing (shade)	
Standing (sun	
Ruminating (shade)	
Ruminating (sun)	
Lying (shade)	
Lying (sun)	
Other e.g. sex, grooming, drinking*	
What are they eating? (Consumption- L, M, H)	*F. albida* leaves- *F. albida* pods (tree)- *F. albida* pods (ground)- *A. erioloba* leaves- *A. erioloba* pods (tree)- *A. erioloba* pods (ground)- *T. usneoides*- *S. persica*- *N. glauca*- Other-
Notes:	

Appendix III: Body Condition Score Table

	Condition score 1
	Backbone prominent
	Hips and shoulder bones prominent
	Ribs clearly visible
	Tail-head area recessed
	Skeletal body outline
	Condition score 2
	Backbone visible
	Hip and shoulder bones visible
	Ribs visible faintly
	Tail-head area slightly recessed
	Body outline bony
	Condition score 3
	Hip bones visible faintly
	Ribs generally not visible
	Tail-head area not recessed
	Body outline almost smooth
	Condition score 4
	Hip bones not visible
	Ribs well covered
	Tail-head area slightly lumpy
	Body outline rounded

	Condition score 5 Hip bones showing fat deposit Ribs very well covered Tail-head area very lumpy Body outline bulging due to fat

Appendix IV: UAV Flight Information

Flight #1:
Date: 6 November 2015
Altitude: 70m
Speed: 5 m/s
Flight Time: 10:27
Flight Length: 2600m
Takeoff Coordinates: -23.561775, 15.037620

Flight #2:
Date: 6 November 2015
Altitude: 70m
Speed: 5m/s
Flight Time: 6:01
Flight Length: 1601m
Takeoff Coordinates: -23.562749, 15.036805

Flight #3:
Date: 8 November 2015
Altitude: 70m
Speed: 5 m/s
Flight Time: 6:16
Flight Length: 1555m
Takeoff Coordinates: -23.562559, 15.035736

Appendix V: SSHIT Method

Part 1: Preparation

After looking at maps, we felt that studying an area that included the settlement located upstream of Gobabeb as well as the two settlements located downstream of Gobabeb would adequately address the relationship between livestock, the community, and the ecosystem. These settlements are located approximately 4km upstream and downstream of Gobabeb, and we wanted to travel an additional 5km to show whether changes in the landscape occurred beyond human influence.

We originally planned on studying 18km along the Kuiseb, stopping every kilometer to do the four transects. However, because transects were within close proximity to peoples' homes, we felt that we should extend some distance between transects. This occurred once during our downstream data collection, and as a result our intended 9km downstream study became 9.5km. Additionally, at one location we were unable to run one of the four transects due to close proximity to households. Finally, when travelling upstream of Gobabeb to collect data, we felt that the vegetation had been changing, and so we judged that an additional transect site would be beneficial. As a result, our initial plan transformed throughout the process, and we compiled data from 19.5km along the Kuiseb rather than 18km.

Part 2: Data collection

We dedicated one day to data collection upstream and another day to data collection downstream. For the process, there were four total bodies, whereby two people in one group collected data on the southern portion of the Kuiseb while the other group of two people collected data on the northern portion of the Kuiseb. This process was efficient as one person was able to count pods while the other person was able to count dung.

Before collecting data, we carefully labeled each bag with a specific code that indicated the location with which samples originated. This code included: site number, north or south, and A or B. The A or B represents proximity to the Kuiseb River. As shown in Figure 1, transects labeled A run next to the riverbed and behind the first tree line. Transects labeled B are located 20m due north of northern transects or 20m due south of southern transects. This system creates cross sections of portions of the Kuiseb River. As a result, group 1 collected data from North A and B, while group 2 collected data from South A and South B. In total, each stop required four bags- one for each transect.

At each site, the two groups would disperse and take a GPS coordinate at the start of their transect A. Next, they would walk a 50m transect and count the number of Faidherbia and Acacia pods as well as the number of cattle and donkey dung within a 1m width of their path. Additionally, we found that one person should count pods while the other counts dung. Along the way, the group will collect one cattle dung, donkey dung, Faidherbia pod, and Acacia pod in their carefully labeled bag for further analysis. After

walking the 50m transect, the group turned and walked 20m away from transect A to start transect B. During transect B, the same process of data collection and sampling was implemented.

After both transect A and B was walked, we analyzed the total percent canopy cover as well as species canopy cover. This scale and scoring method is shown in Table 1.

Part 2: Dung Dissection and Seed Counts

Before dissection dung, the same labeling system for the sample bags was used to label the petri dishes. We found that cattle dung was easily dissected after being soaked in water, while donkey dung was easily dissected dry.

Seeds were placed in their respective petri dishes, and counted after all dissections. Additional petri dishes were used once Faidherbia and Acacia seeds were separated, and numbers were then recorded for further analysis.

Appendix VI: Correlation Matrix for Dung Transects

	DISTANCE	CANOPY COVER	F. ALBIDA	A. ERIOLOBA	T. USNEOIDES	S. PERSICA	N. GLAUCA
DISTANCE	1.0000						
CANOPY COVER	0.0577	1.0000					
F. ALBIDA	-0.1881	0.1515	1.0000				
A. ERIOLOBA	**-0.4680**	-0.0363	**-0.2797**	1.0000			
T. USNEOIDES	0.1650	0.0924	**-0.2397**	0.0353	1.0000		
S. PERSICA	0.2055	**0.3003**	**-0.2269**	**-0.2809**	**-0.2690**	1.0000	
N. GLAUCA	0.2065	**-0.3711**	**-0.2845**	-0.1707	-0.0491	0.0809	1.0000
E. PSEUDEBENUS	**0.2851**	**0.2416**	-0.0789	-0.1217	-0.0481	**0.2902**	-0.1127
F. ALBIDA PODS	-0.0827	0.2141	0.0769	-0.0744	0.1967	0.1011	-0.1307
A. ERIOLOBA PODS	-0.0764	0.1807	-0.0379	0.1939	-0.0166	0.0042	-0.1198
CATTLE DUNG	-0.1320	-0.0513	0.0258	0.1643	-0.1042	-0.0738	**-0.2284**
DONKEY DUNG	-0.2141	0.2240	0.1267	**0.5397**	0.0923	-0.1770	-0.1827
F SEEDS IN DUNG	0.1826	0.1583	0.1128	-0.2146	-0.1309	0.1304	-0.1649
A SEEDS IN DUNG	0.2030	0.1093	-0.1005	0.0764	0.1886	-0.1311	-0.0159
TOTAL SEEDS	**0.2892**	0.1977	-0.0011	-0.0893	0.0584	-0.0131	-0.1280

	E. PSEUDEBENUS	F. ALBIDA PODS	A. ERIOLOBA PODS	CATTLE DUNG	DONKEY DUNG
DISTANCE					
CANOPY COVER					
F. ALBIDA					
A. ERIOLOBA					
T. USNEOIDES					
S. PERSICA					
N. GLAUCA					
E. PSEUDEBENUS	1.0000				
F. ALBIDA PODS	0.0863	1.0000			
A. ERIOLOBA PODS	0.0582	0.0403	1.0000		
CATTLE DUNG	0.0563	**0.2448**	0.2102	1.0000	
DONKEY DUNG	0.0337	0.1351	0.1335	0.0902	1.0000
F SEEDS IN DUNG	-0.1554	0.2453	-0.1083	0.0012	-0.2368
A SEEDS IN DUNG	-0.1742	-0.1351	0.0032	-0.0056	0.0804
TOTAL SEEDS	-0.2472	0.0641	-0.0732	-0.0036	-0.1017