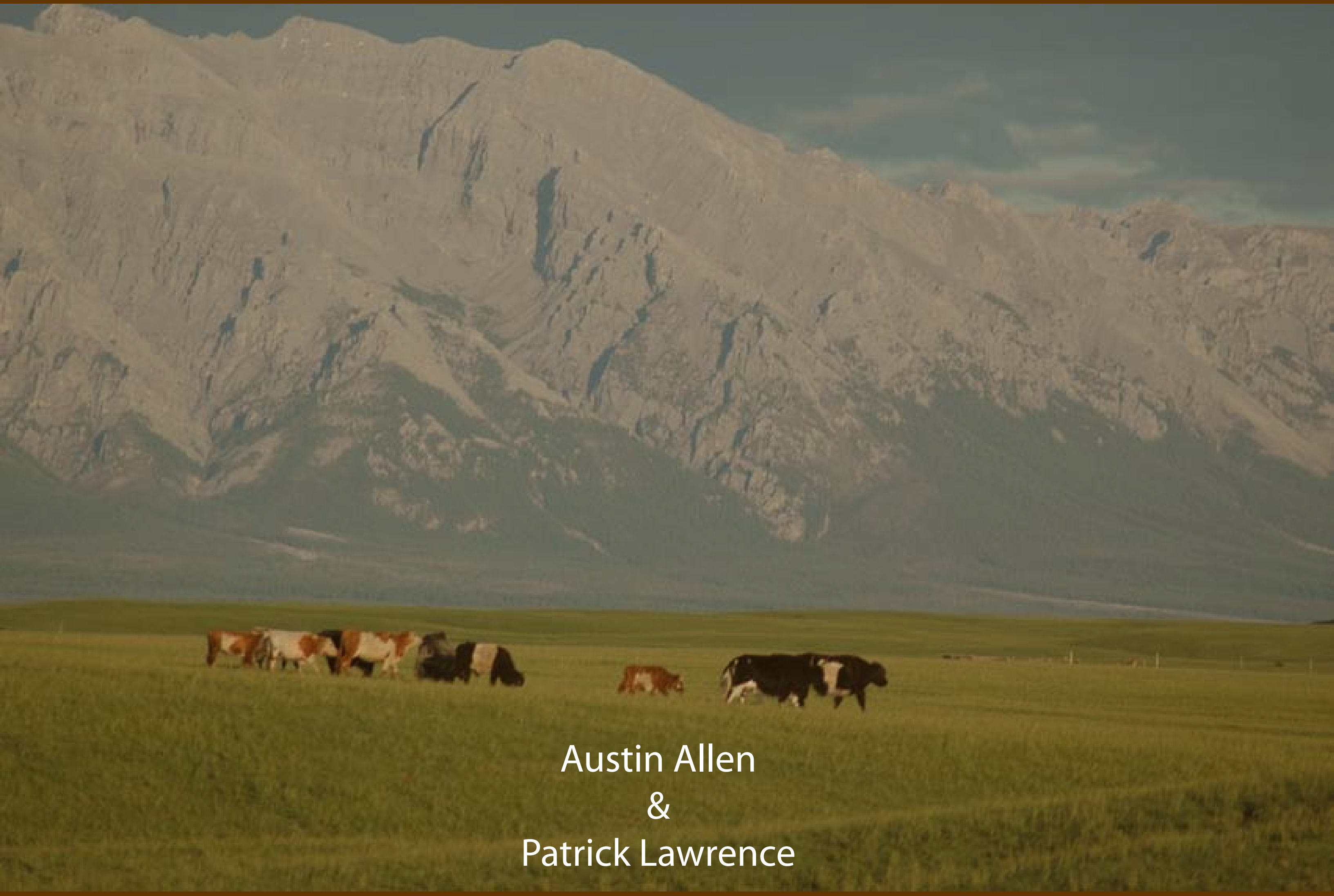
Erosion, Sand Dune Movement and Pasture Fertility in the Darhad Valley, Northern Mongolia



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&
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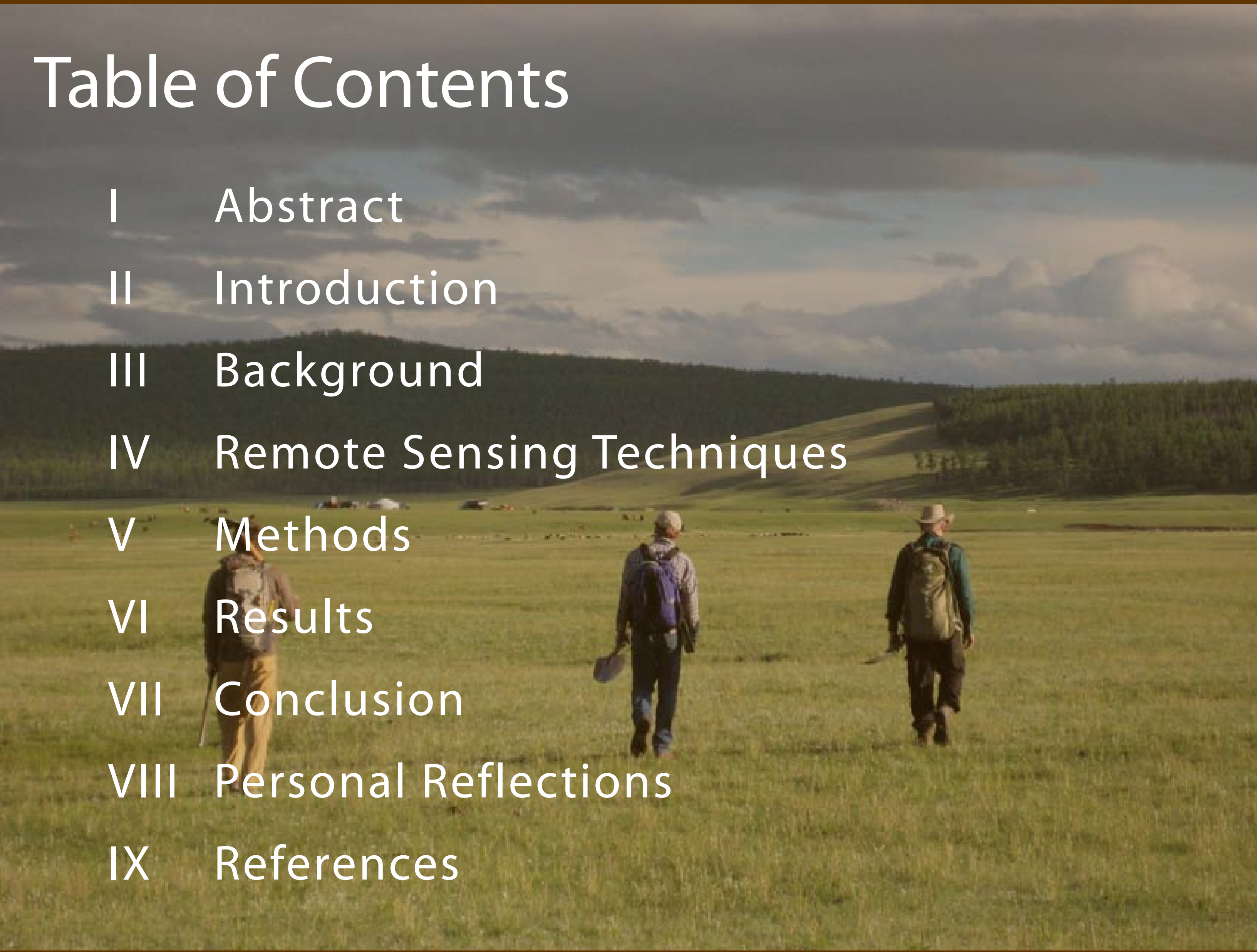
Summer 2007 Field Season

With Support From:

BioRegions International
The American Center for Mongolian Studies (ACMS)
Council of American Overseas Research Centers (CAORC)
US State Department Educational and Cultural Affairs Bureau



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Abstract

In response to community concerns about pasture fertility in the Darhad Valley, Mongolia, we initiated a 3 to 5-year research project beginning in Summer 2007. Primary topics under investigation are erosion, community grazing practices and long-term environmental sustainability.

The study area is at New Spring, a region approximately 15 km Northwest of Rinchinlhumbe Soum, a concentrated area of sand dunes and eroding soils. As of September 2007, preliminary data have been collected and analyzed for sand dune spatial extents and expansion, plant species richness and abundance, range production capacity, soil properties, and local attitudes towards degradation.

Results have shown that dunes occupy an area of 55147 m^2, but poor correlations to remotely sensed satellite imagery have prevented an analysis of temporal changes in percent bare ground. However, important baseline data were collected, indicating that the species campanula glomerata, potentilla rivera, potentilla acaulis and lentopodium leutopodeides could be useful stabilizers of currently eroding soil. Anecdotal surveys have shown that herders consider loss of pasture land to be a significant concern, and would relocate their camps if forage were to decrease. However, most do not seem to consider overgrazing to be a potential cause of the degradation.

Sand dunes have periodically moved across the Darhad landscape for hundreds, if not thousands of years, as indicated by the depth and development of buried topsoil horizons. Production appears to be naturally low, but could potentially be improved with rotational grazing practices. Increasing the health of the rangeland is largely a human problem, thus future efforts of this project should devote a significant amount of time towards engaging herders to find practical, economical and sustainable solutions.

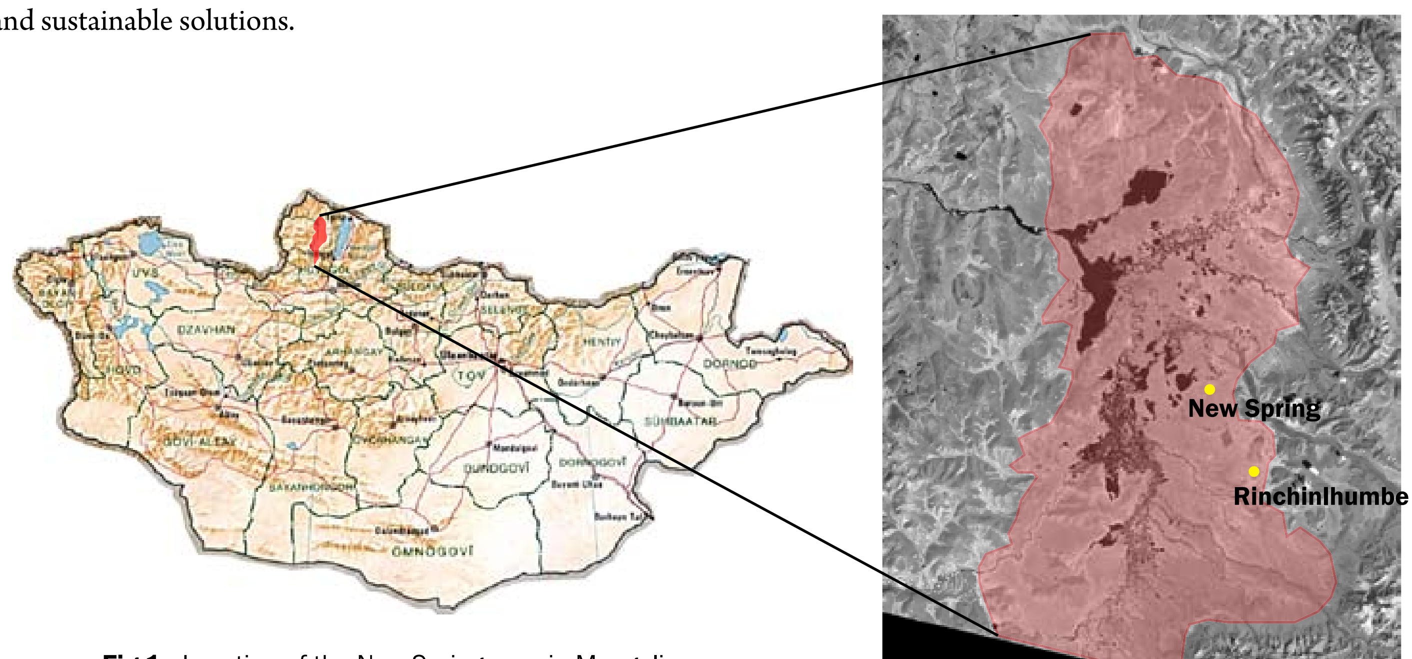

Fig 1. Location of the New Spring area in Mongolia

Introduction II

Livestock grazing has been a cornerstone of Mongolian life for thousands of years, and remains the primary source of livelihood into the 21st century. It provides the nourishment for countless families and remains the common thread uniting Mongolians nation-wide. Unfortunately, over the last century, changes in grazing practices have prompted serious concerns about long-term pasture fertility. An increasing population base and the switch to a capitalist economic system have arguably resulted in more heavily used rangelands. Climate change, overgrazing, and other anthropogenic pressures are often blamed for the loss of vegetation cover (Hein 2006, Meyer 2006, Wang 2006, Geist & Lambin 2004). However, quantification of negative changes is generally lacking and anecdotal at best. The confounding influences of climate and other environmental variables have made the picture much less clear. The intent of this project is to assess vegetation changes in a small study area and devise ways to counter negative trends. These solutions would ideally be inexpensive or even profitable, environmentally sustainable and culturally sensitive.

Background III

Walking around the sand dunes for a number of days, Austin and I noticed some interesting patterns in the way the goats, sheep and yaks moved. They would generally stay in a loose clump, slowly shifting over the landscape like a primitive amoeba. We would often see the same herd pass over the same section of ground multiple times in one day, slowly picking their way to the next palatable section of ground. Selectively eating those plants that were greenest and tender, they would exert pressure upon certain species rather than eating everything under their hooves. This presumably resulted in some plants being grazed more than once in a short period of time, reducing their ability to regenerate. It didn't take a stretch of the imagination to picture less palatable species taking their place, and vegetation heading for a general decline.

This pattern of grazing was witnessed throughout the valley, and speaks volumes about Mongolia's recent past. During Soviet times, the grazing system was collectivized and animal numbers were strictly controlled. Information about how this was implemented is difficult to obtain, but anecdotal evidence points towards a generally lower number of animals per acre. Regardless of what happened before 1990, it now seems that numbers are increasing drastically as the capitalist system becomes more widely adopted. With tangible economic benefits to having a larger herd, more and more herders are trying to squeeze the most out of their land. Using rotational grazing systems, a larger number of animals can create a healthier landscape (Savory 1999), but without controls, animals could potentially increase bare ground - just what Austin and I had witnessed.

To initiate the first phase of this project, we focused on historical image analysis with concurrent mapping, surveys and vegetation collection. Remote sensing has been used in other regions of the world to detect temporal changes in cover. Small-scale research has primarily focused upon Normalized Differential Vegetation Index (NDVI)-related indices available from the NOAA AVHRR and USGS Landsat satellites. NDVI is a widely-used surrogate for vegetation growth (Al-Bakri & Taylor 2002, Schmidt & Karnieli 2000, Anyamba & Tucker 2005). We used Landsat images for its finer spatial resolution and wide temporal coverage.

Out of all the vegetation indices, NDVI and the Transformed Soil Adjusted Vegetation Index (TSAVI) have the strongest correlation to Leaf-Area Index (LAI) and biomass in Central Asia (Purevdorj 1998). This was determined by using second-order polynomials to compare biomass and LAI to various vegetation indices (Table 1). These indices were calculated using ground spectral measurements, so there may be some discrepancy between them and concurrent satellite images, which would be affected by the atmosphere. The small differences between the indices' r^2 values are likely due to sampling error, but even in areas with low vegetation cover TSAVI/NDVI perform no worse than the soil-adjusted indices, and are more widely used (Lawrence and Ripple 1998, Li et al 2002, Anyamba and Tucker 2005). However, TSAVI is not widely used for most remote sensing applications; therefore NDVI was chosen for this study. Problems with the use of NDVI arise with the effects of plant senescence and soil background reflectance when vegetation amounts are low (Purevdorj 1998). This can be ameliorated by choosing study sites with sufficient vegetation cover during maximum green-up.

Index	r^2 (avg)
NDVI	0.92
TSAVI	0.92
SAVI	0.89
MSAVI	0.89

Table 1. Summary of R2 values generated between various vegetation indices and biomass/LAI (Purevdorj 1998)

Following the acquisition of a NDVI composite time-series, spectral change analysis is typically performed, which may be preceded by classification. A dense seasonal and inter-annual collection of images is usually preferred for change analysis to more accurately explore trends and patterns. Unfortunately, the use of such a dataset is very time consuming and impractical (Runnstrom 2003). In this study, it was also holistically impractical, as the cost of one Landsat image could easily fund basic education for three children, much less 20 or more images. Therefore, we were constrained to two images which were available free-of-charge. For this study, images were not classified for change analysis due to lack of training data and the complexity of implementing a multi-temporal categorical analysis.

To investigate changes of vegetation through time, a variety of methods have been used (Lu et al 2004). The easiest and most direct is simple differencing, which subtracts one image from another. This method is straightforward, but is less adept at discerning more nuanced temporal patterns (Young and Wang 2001, Lu et al 2004). It can simply be performed on two images, or between the average of images from successive years, which reduces climatic effects (ex: difference between (81+82)/2 and (91+92)/2) (Young and Wang 2001). Other studies have used Principal Components Analysis (PCA), linear regressions of NDVI, change curve detection, coefficients of variation, and other techniques (Al-Bakri and Taylor 2003, Houtondjii 2006, Bradley 2007, Lawrence and Ripple 1999, Li et al 2003, Weiss et al2001). Principal Components Analysis excels at discerning discreet trends, but is dependent upon heuristic interpretation of each component (Al-Bakri and Taylor 2003). It has been used in conjunction with several other techniques by performing PCA on temporal change vectors of Temperature/NDVI arctangents (arctan used since T/NDVI goes to infinity when NDVI goes to 0). This enables the creation of normalized change vector magnitude and direction maps, but they must be interpreted locally. In addition, trajectories are hard to analyze, and are limited by NDVI saturation (Lambin and Ehrlich 1997, Lu et al 2004). Most importantly, PCA in any form cannot be used for predictions, which was the goal of this study. This lack of prediction capabilities was also the drawback for coefficient of variation approaches (Weiss et al. 2001).

One approach that does enable predictions is the use of change curves (Lawrence and Ripple 1999). This is an approach that fits a polynomial to the means of pixel clusters determined using an unsupervised ISODATA procedure. Given a sufficient quantity of values and the proper regression algorithm, it can successfully model temporal changes and extract desired change parameters. Regressions can also be used for prediction on a pixel-by-pixel basis without clustering. The drawbacks of this approach are difficulties in obtaining a temporally dense sequence of images, finding statistically significant differences between individual pixel values and cluster means, and the aforementioned prohibitive costs.

Many of the reviewed articles dealt with the correlation between NDVI and precipitation. If the goal of a study is to examine human-induced vegetation changes, then the confounding effect of precipitation on NDVI needs to be decoupled. One method to accomplish this is to gather climatic data from the time period and look for correlations between precipitation and NDVI such as NDVI = a + b (Rainfall) (Archer 2004, Houtondjii 2006). This approach assumes that the residuals are human induced (Geerken 2004). Growing season NDVI values can also be averaged and anomalies detected against the multi-year mean, which helps minimize the effects of variable precipitation (Anyamba and Tucker 2005). An alternative site-specific approach is to use visual analysis to examine precipitation and vegetation trends, examining the data subjectively for correlation (Lu et al 2004). Similar approaches are sometimes taken with temperature, which is an indirect measure of the energy available for plant growth (Li et al 2002, Lambin and Ehrlich 1997). Unfortunately, precipitation data is unavailable for much of Mongolia, so decoupling it from NDVI responses is extremely difficult.

One final issue concerning NDVI arises when precipitation is below 250 mm or above 1100 mm (site-specific), due to the behavior of NDVI at these extremes. At very high values, NDVI saturates and levels off, and the same happens if it is very low (Archer 2004). Fortunately, the proposed study site falls within these bounds.

In summary, NDVI or band wise change analysis appears to be a valid approach to detecting temporal vegetation changes in Mongolia, but it needs to be used with care. Effects of precipitation on NDVI should not be ignored, and should be decoupled or reduced when possible (though in our case it was impossible). Change analysis can be performed with many techniques, the best of which should be chosen according to the question asked. For this study, it would take the form of a multiple regression of bare ground against NDVI/single band values followed by simple differencing.

Methods V

Our data collection consisted of five phases: mapping the spatial extent of the sand dunes, conducting an informal survey of local herders, collecting bare ground and species data, establishing exclosures to estimate annual production, and analyzing adjacent soil pits. Photos of sampling procedures follow this section.

Sand dune mapping

Using a Trimble GeoXT GPS mapping unit with a corresponding base station set up in Rinchinlhumbe, we traced the outlines of sand dunes, deflation areas, deposition areas and current exclosures of our organization and others. Dune edges were easy to follow, but deposition areas were much more difficult. A dividing line between deposition areas and surrounding pastureland was decided at approximately 40% sand cover. For deflation areas, we used a 30% sand cover amount.

Herder Survey

To involve local herders, listen to their concerns and hear their ideas, we conducted an informal survey of families near the sand dunes. Questions asked pertained to their history in the area, thoughts about the sand dunes, ideas for mitigation, their knowledge of our work and to what extent they would like to participate in possible solutions.

Bare Ground and Species Data

Bare ground data was designed to correlate with Landsat satellite imagery, thus was designed for 30 by 30 meter pixels. We used a point-intercept method (**Figure 3**), and averaged our measurements for each pixel to obtain percent bare ground measurements. This was completed for 10 points on 5 transects, chosen to best represent a range of bare ground values. For each point at which we noted presence or absence of bare ground, we also noted the dominant species and cataloged our findings. These were later identified by Mongolian scientists at the Agriculture Sciences University in Ulaanbaatar.

Annual Production Estimates

Using local labor, we engaged several families to build four 4 by 4 meter exclosures to obtain estimates of the rate of for-

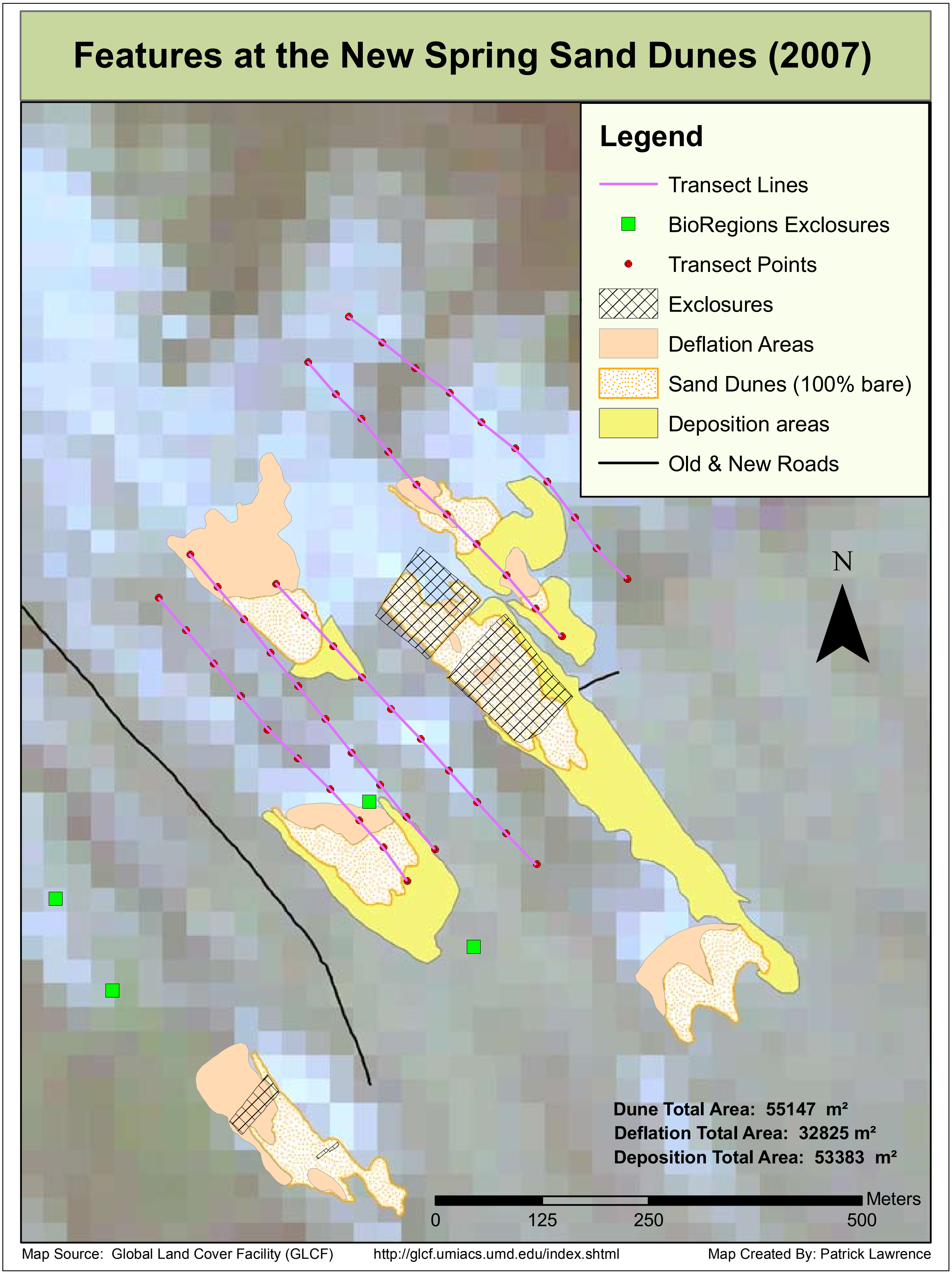

Fig 2. Current dune features, exclosures and transect points at the New Spring sand dunes.

age production. Their locations were heuristically selected to best represent production on similar soils that had not been degraded by erosion. Exclosures were erected on June 20 and left until July 13, the height of the growing season. Logistics prevented a longer period to let the vegetation grow. Six 0.25 m^2 squares were randomly chosen for clipping within a 2 by 2 meter square in the center of each exclosure. This reduced edge effects such as shading or lack of moisture. Vegetation was dried, weighed, then averaged for an per-square-meter production estimate.

Remotely Sensed Data Analysis

Two Landsat images from 2001 and 1986 were acquired from the Global Land Cover Facility (GLCF) at the University of Maryland. Both were scaled to exoatmospheric radiance using USGS equations (USGS Landsat Project Website), and the 1986 image was georegistered to the 2000 image (less than 1/2 pixel RMSE). Band data corresponding to the transect points were regressed against percent cover measurements using Bands 1, 2, 3, and 4 combined , then NDVI and the individual bands separately. Linear and logarithmic regressions were performed, but the lack of significance prevented further analysis.

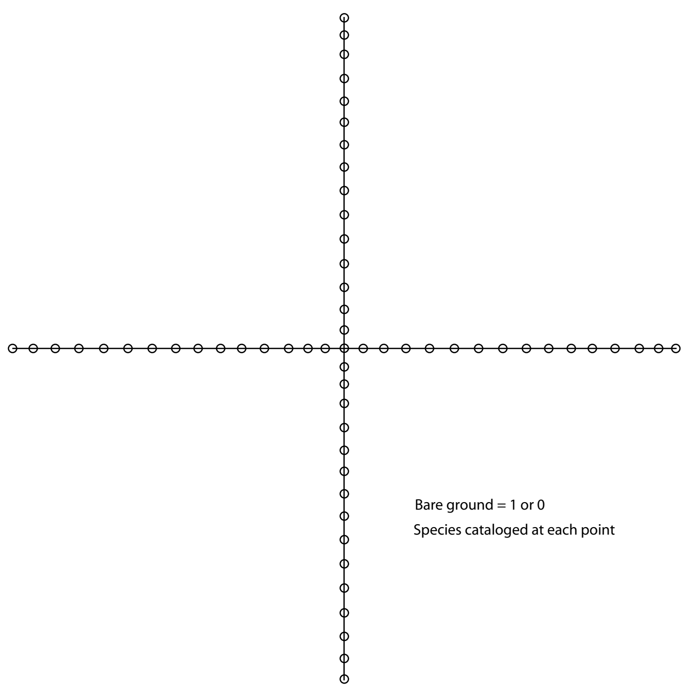

Figure 3. Point-intercept sampling strategy used at each transect point.

Fieldwork Photos


Crafting the exclosures


Previous Exclosures


Austin and Patrick digging soil pits


Local Mongolians helping clip vegetation


A classic barchan sand dune at New Spring


Soil pit near an exclosure


Point-intercept bare ground and vegetation sampling

Results VI

Sand dunes, deposition and deflation areas were successfully mapped, with 76% of the features at less than 1m of accuracy. The total dune area was found to be 55,147 square meters while the deflation and deposition areas were 32,825 and 53,383 square meters, respectively (**Fig 2**).

The herder survey found that as a whole, herders were very concerned about the potential loss of pasturelands and supported any efforts to mitigate erosion. However, most were uninformed about current projects underway near their gers and did not have any specific ideas to contribute. For most, their grazing strategy consists of letting their animals roam freely while keeping abreast of their movements. This does not seem to encompass moving the animals to any specific place for a specific time period, which confirmed our expectations. Overall, herders seemed to have the most faith in exclosures to reduce sand movements.

The bare ground measurements did not have any discernible correlations to the red or near-infrared Landsat bands, nor to NDVI in 2000 or 1986 (**Fig 4**, **Fig 5**, **Fig 6**). Our bare ground measurements were evenly distributed between 0 and 100%, but p-values were far above the 0.10 threshold. Therefore, change detection analysis was not performed as the results would not be significant.

Campanula glomerata, potentilla rivera, potentilla acaulis and lentopodium leutopodeides were the most abundant species at New Spring (**Fig 7**). Overall, a total of 36 distinct species were found during sampling, most of which are seen in **Figure 8**.

Rates of biomass growth near the sand dunes ranged from 3.7 to 6.1 g/m2/day (**Fig 9**). Interpretation of these results will commence before the next field season. Soil pit results are displayed in **Figure 10**.

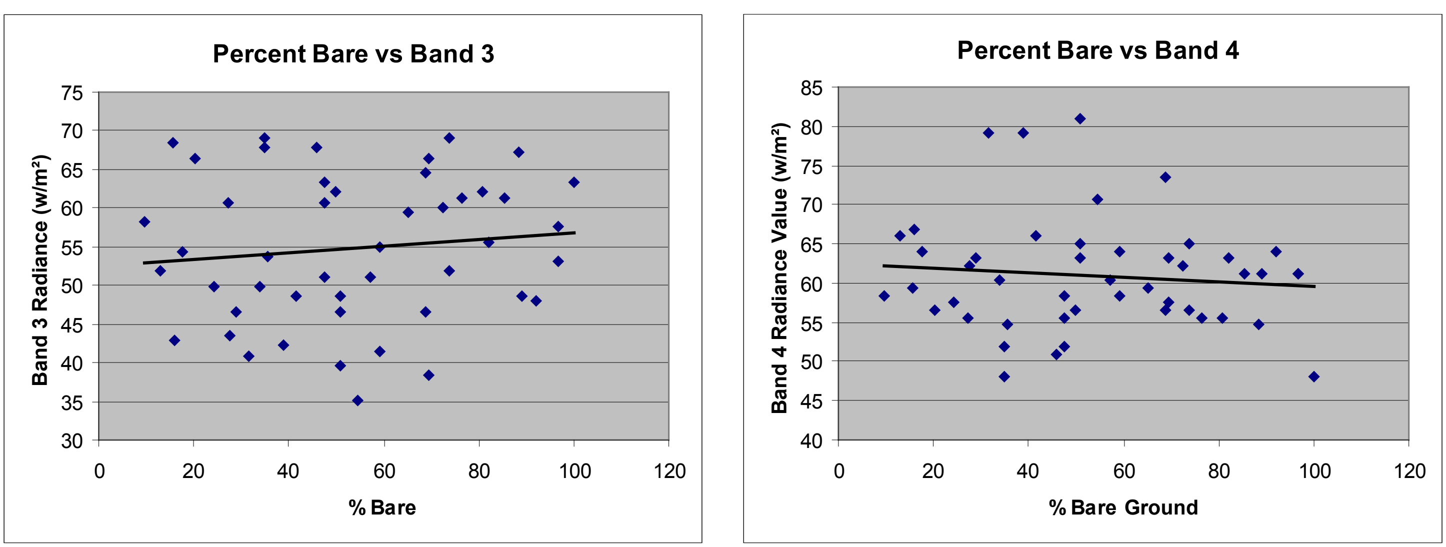

Fig 4. Percent bare ground regressed against Band 3 (red) and Band 4 (near-infrared)

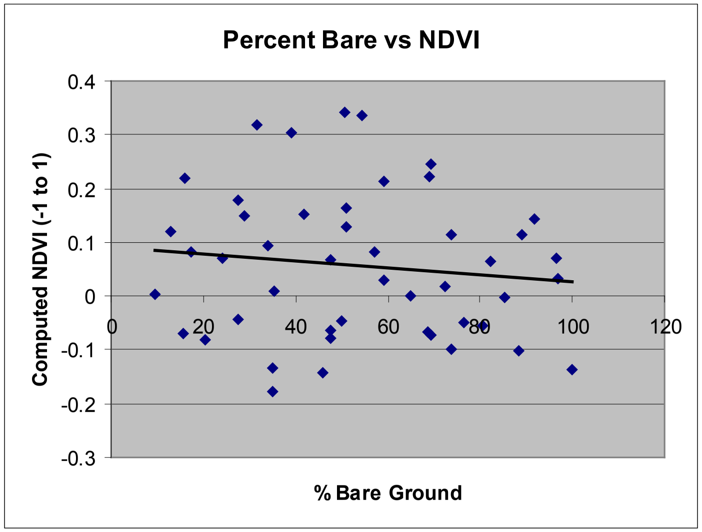

Fig 5. Percent bare ground regressed against NDVI

Regression	p-value	r-squared
Bare vs. NDVI	0.4259	0.01414
Bare vs. Band 3	0.4344	0.01364
Bare vs. Band 4	0.4858	0.01086

Fig 6. Statistical results from figures 4 and 5

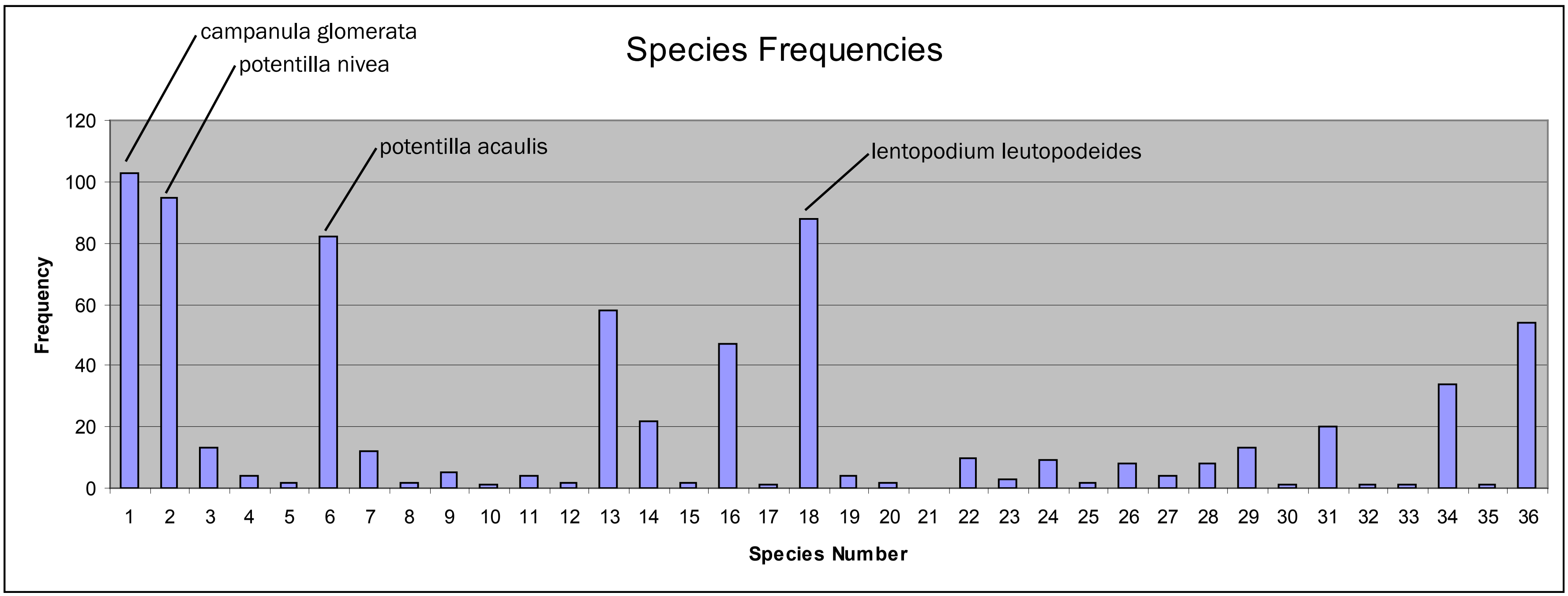

Fig 7. Frequency of species found during the point-intersect sampling.

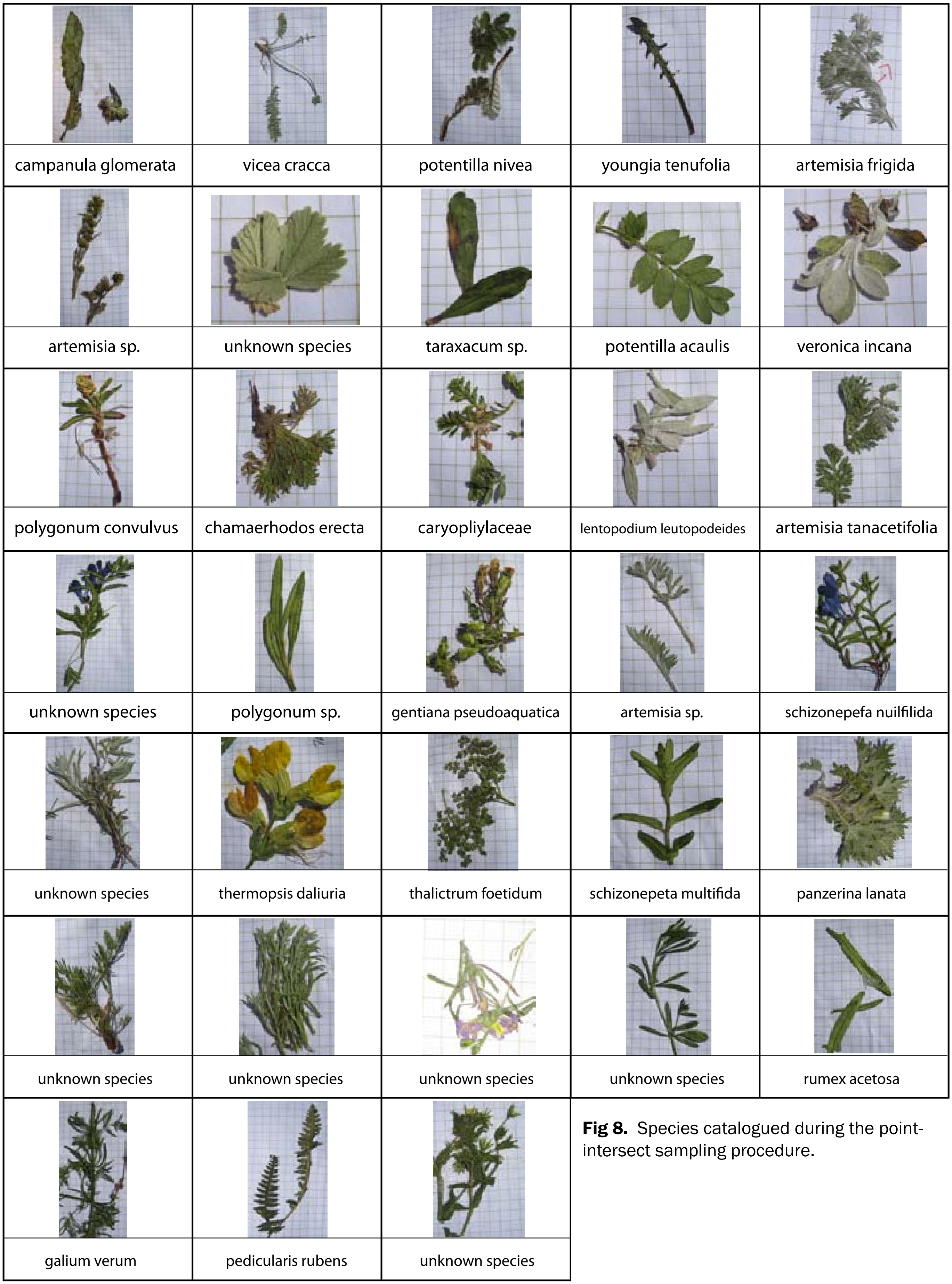

Fig 8. Species catalogued during the point-intersect sampling procedure.

Exclosure	Dry Weight Total (g/m^2)	Standard Deviation	Avg Rate of Growth (g/m^2/day)
1	84.0	4.1	3.7
2	140.0	4.7	6.1
3	98.7	3.7	4.3
4	93.3	1.6	4.1

Fig 9. Dried biomass weights from the exclosures (per meter-squared) and average rates of growth.

Horizon	Depth (cm)	Texture	Structure	pH	Color (moist)	HCl
Site 1 (east side of barchan dune)						
A	0-12	sandy clay loam	med. Moderate granular to s.g.	7.3	7.5YR 2.5/1	y, slightly
Bw	12-28	sandy loam	med. Weak subangular blocky	7.5	7.5YR 4/1	y, slightly
C	28+	loamy sand	single grain	8.1	2.5 Y 5/3	y, moderately
Site 2 (deflation grass behind barchan)						
A	0-15	sandy clay	med. Weak Subangular blocky	7.5	10YR 2/1	y, slightly - mod
C	15+	loamy sand	single grain	8	2.5 YR 5/4	y, slightly
** Buried weak A horizon at 27-32 cm						
Site 3 (east exclosures south of active area)						
A	0-15	sandy loam	med. Weak subangular blocky	?	2.5Y 4/2	y, slightly - mod
Bw	15-50	sandy loam	single grain	?	2.5 Y 5/2	y, slightly - mod
Ab	50-65	sandy clay loam	med. Moderate subangular blocky	?	10 Yr 3/1	y, slightly - mod
C	65+	sandy loam	med. Moderate subangular blocky	?	10 Yr 5/3	y, mod - strongly
Site 4 (West, most southerly location in active area)						
A	0-12	sandy loam	med. Weak subangular blocky	7.3	2.5 Y 4/3	y, slightly
Bw	12-32	sandy loam	med. Weak subangular blocky	8	2.5 Y 5/4	y, slightly
Ab	32-37	sandy clay loam	fine weak subangular blocky	8	10 YR 3/2	y, slightly - mod
C	37+	loamy sand	single grain	7.3	10 YR 5/3	y, slightly

Fig 10. Results from soil pits located next to the exclosures. Buried A horizons indicate a historical regularity in sand dune movements

Conclusion VII

The poor correlation results for the remote sensing analysis may be due to several factors. First, the image we used was from 2001, which may not accurately represent the bare ground spatial distribution of 2007. Secondly, the source (GLCF), while reputable, appears to have possibly had issues with geometric correction. Areas of higher band 3/lower band 4 reflectance appear to be offset by approximately 60 meters. This could be corrected by purchasing a newer image and obtaining a set of ground truth GPS points in summer 2008.

Despite an unfortunate lack of correlation between bare ground measurements and NDVI, there was good success with our other data collection. These results will form the baseline from which the following years of this study can build upon. It is expected that dune features will be mapped again and production sampled, which will give a better sense of changes that are occurring. With more knowledge of the conditions at the sand dunes, future studies can look more in depth at specifics relating to erosion and grazing. Regardless of whether the dynamics of the sand dunes are known, pasture health can still be improved.

From this study, I learned that the mitigation of erosion will have to stem from human action. It has further reinforced my belief that scientific knowledge is ineffective without communication, collective understanding and inclusion of locals. If herders in the area could be engaged on a deeper level, the chances of successfully dealing with erosion would multiply many fold. I personally hope to be involved with this transition in making science more accessible to everyone. Such a step is practical, meaningful and ultimately necessary to make holistic improvements in the Darhad quality of life.

Personal Reflections VIII

Travel in less developed countries always stimulates a welcome change in perspective from the insular life led in much of the US, particularly Bozeman, Montana. I am lucky enough to have visited a variety of places throughout the world, which has broadened my worldview immeasurably. However, past experiences never completely prepare oneself for entry into an unknown culture. I kept this in mind when going to Mongolia, and attempted to erase all expectations. However, there still was some adjusting to do.

There were several significant obstacles to our research activities, which quickly made them known upon arrival in the Darhad Valley. First and foremost, the lack of basic energy infrastructure made the use of electronics (GPS units and computers) tremendously difficult. A string of rainy days could mean a complete loss of productivity and down time. Other projects seemed to quickly fill the void, but prioritizing data collection proved to be difficult. The lack of quick and reliable transportation further complicated the situation. Arranged horses or vans could arrive several hours, or even days late, if they were available at all. These issues are hardly a failing on the part of the Mongolians – merely a cultural difference in concepts of punctuality that must be taken into account.

Being far removed from any significant city also makes changes in research plans difficult to execute. Without complete knowledge of the Darhad environment before we arrived, it was hard to know if our plans were realistic or feasible. Luckily, with some modifications, our designs worked quite well, but a certain level of luck certainly played into this outcome. Ultimately, researchers, particularly environmental scientists, need to be able to improvise and think on their feet if planning on research in the remote areas of Mongolia.

Luckily, strong support from my advisor, Cliff Montagne, helped smooth out many of the kinks and made the whole process much more enjoyable. I have known him for several years, interacting on a regular basis and serving as a teaching assistant in his classes. Working with him to develop an in-depth knowledge of Holistic Management has made my understanding of BioRegions' community development approach much more complete. He also provided many days' worth of advice and assistance before and after the project, making sure that my plans were on track. During the trip, we worked together on a daily basis, both on this assignment and other BioRegions projects, and I feel that our mutual understanding has resulted in a strong friendship. There were undoubtedly times when progress was slow, but we always moved forward in a positive way, with patience and thoughtfulness. I look forward to working with him in the future, whether it is with BioRegions or with other endeavors.

As discussed in the previous section, I feel that a country-wide study of pasture health is long overdue. This could take many forms, but would likely involve a country-wide sampling strategy which could be used to generalize about nationwide trends. Mongolia's environment is its greatest asset and sustains most of its population directly via subsistence. Therefore, monitoring the condition of the grasslands, water and other landscapes is of utmost importance. However, this research necessarily should not exist in a vacuum, as economic and social issues are also of great concern. Just as the economy cannot be boosted at the expense of the environment and health, so the environment cannot be held untouchable at the expense of common peoples' livelihoods. The intersection between these different disciplines is the area that interests me the most, and I hope to be involved with holistic research on it in the future. Ultimately, degradation of communities, human or natural, generally results from human misunderstandings, thus must be dealt with in the human realm.

Whether it deals with this intersection or with more focused research, I have a strong interest in further scientific activities in the Darhad or Mongolian in general. I have a great appreciation for the Mongolian way of life – the culture, the traditions, the hardiness and the respect for nature. I only hope that this can be preserved and enhanced in the face of modernization and future changes to come. The possibility for graduate research looms near, as does a continued commitment with BioRegions. Time will make my connection to Mongolia much clearer in its terms, but I am certain that it will remain in some lasting form.

I would like to thank the ACMS staff in Ulaanbaatar – particularly Brian White and D. Enkhbaatar for their support and willingness to assist myself and others who performed research in the Darhad. Their contacts and personal help have greatly increased the effectiveness of BioRegions' work and our ties to the Mongolian scientific community. ACMS' website also had valuable materials on it such as the links to past research and scientific publications completed in Mongolia. I would suggest more personal contact with ACMS personnel before research activities are initiated and more communication between fellows, but overall my experience with the ACMS has been overwhelmingly positive.

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