

**SCALE Annual Report  
2001-2002**

**PARTICIPANTS**

<b>Participants</b>	<b>Project Role</b>
James E. Ellis	Principal Investigator
N. Thompson Hobbs	Principal Investigator
Roy Behnke	CoPrincipal Investigator
Randall B. Boone	CoPrincipal Investigator
Kathleen Galvin	CoPrincipal Investigator
Robin Reid	CoPrincipal Investigator
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Andrew Ash	Senior personnel
Michael Coughenour	Senior personnel
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Carol Kerven	Senior personnel
Kevin Price	Senior personnel
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**COLLABORATING ORGANIZATIONS**

Macaulay Land Use Research Institute  
 International Livestock Research Institute  
 CSIRO – Sustainable Ecosystems  
 Kansas Applied Remote Sensing Program – University of Kansas  
 Institute of Pasture and Fodder, Almaty, Kazakstan  
 Institute of Botany, Beijing, China  
 Agricultural Research Council, South Africa  
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 Institute of Ecology and Resource Management, University of Edinburgh, Scotland

**ACTIVITIES**

**Introduction**

Biological complexity in arid and semi-arid lands (ASALs) arises from spatially-linked ecological states and processes. Herbivores, humans and other agents integrate distinct spatial units into complex ecosystems by moving among and exploiting these units. Spatial complexity plays a central role in the structure and function of grazed ASAL ecosystems, but modern human land use tends to deplete spatial biocomplexity through ecosystem fragmentation. Ecosystems are simplified by breaking up interdependent

spatial units into separate entities, compartmentalizing ecosystems into isolated sub-units. The result is a reduction in the scale over which complex interactions among environment, large herbivores and human management take place. Ecosystem fragmentation and the reduction of biocomplexity interferes with ecosystem function and reduces system capacity to support ecological communities, social structures and economic activities. As a result, many of the world's ASAL ecosystems are dysfunctional to varying degrees. Dimensions of dysfunction vary from place to place, but include: increasing conflicts between wildlife and humans; wide-spread rangeland degradation in East Asia; increasing levels of poverty among pastoral people in Africa; the decline of rural livelihoods in the rangelands of Australia and the western US; wholesale collapse of grazed systems in Central Asia; and global-scale outbreaks of livestock diseases ('mad-cow,' foot and mouth disease) in confined industrial livestock enterprises. Our team's global research experiences suggest world-wide fragmentation of biocomplexity in ASAL grazing lands caused by a complex, but discordant, set of interactions involving ecosystem spatial properties, economic concepts, and legal-political constraints on land tenure and land use. Improvement of the situation will require, among other things, a much better scientific understanding of complex interactions among ecological, political and economic systems.

We argue that vegetation complexity and spatial scale are crucial to understanding ecosystem function in ASAL's. Our goal is to demonstrate the importance of complexity and costs of fragmentation at sites around the world by linking ecological and socio-economic research, and in the process, create an international network of scientists addressing these issues. Our global objectives are:

1. Develop a framework for analyzing and describing ecosystem spatial complexity and its role in grazed ecosystem function and sustainability, including the movement-mediated responses of herbivores to complexity and fragmentation.
2. Determine the effects of real fragmentation experiments on herbivores, ecosystems, enterprises and people, and use model-simulated fragmentation/consolidation experiments to identify options for ecological and economic sustainability.
3. Characterize patterns of ecosystem fragmentation as they exist under different environmental, political and economic systems; investigate how and if ecological and political-economic factors interact to control the evolution of land use systems.
4. Create a method and modeling approach for assessing the value of natural capital in complex grazed ecosystems, the costs of complexity loss due to fragmentation, and the trade-offs between economic inputs and ecological complexity.
5. Coordinate these analyses in an integrated assessment of complexity and fragmentation.

These objectives would be difficult to achieve under most circumstances. These problems operate over large spatial scales, long time frames and involve a variety of disciplines. But a set of natural experiments in ecosystem fragmentation has been set up (inadvertently) around the world, allowing us to address these relatively intractable problems. Members of our team are now working in, or have completed research in 21 ASAL ecosystems in Asia, Africa, Australia and North America. Sixteen of these ecosystems have undergone fragmentation of one sort or another; five are more or less

intact. These sites/regions form the universe for our proposed research. This situation presents an unusual opportunity: a project of this breadth is feasible only because each of the 21 projects is either partially supported and underway, or recently completed.

Specific objectives flow from the global objectives above. We proposed 13 research objectives (8 field-based, 5 modeling), many of which are being met by work at all 21 sites, others which will be achieved in a sub-set of sites. Here we outline activities pertinent to each research objective during our first year of work

**Research Objective 1: Case Study Synthesis and Comparisons** (All scientists and collaborators)

**Objective:** *Develop a state-of-knowledge publication on complexity, scale and fragmentation.*

**Activities:**

We made plans to convene a workshop of project participants in conjunction with the International Rangeland Congress (IRC) to be held in Durban, South Africa during August of 2003. The purpose of the workshop will be to assemble case studies from sites around the world and to develop integrative, synthetic chapters for a book on effects of fragmentation on arid rangelands, for which we are now seeking a publisher. In addition, the project will host a symposium at the IRC entitled, Fragmentation of Rangelands: Ecological and Economic Implications, A Tribute to James Ellis.

**Research Objective 2: Complexity Framework and Analysis** (Boone, Price, Reid)

**Objectives:** *Develop a framework for complexity analysis, apply to all sites; determine herbivore access to complexity for fragmented and un-fragmented grazing orbits (in conjunction with RO 4).*

**Activities:**

The locations and spatial extents of the 23 study areas included in SCALE are being identified, based upon inputs from project participants knowledgeable about large herbivores and their movements within the areas. In some cases the spatial extent of areas are clear, such as the fenced Baiinxile Farm of Inner Mongolia, China, and the well-defined caldera of Ngorongoro Crater, northern Tanzania. In other cases, the appropriate spatial extent for use in analyses is more subjectively defined. A database has been created that stores (or will store) information about each site, including geographic position, primary contacts, and vegetation and topographic heterogeneity. Queries posed to researchers include the availability of detailed spatial data for their areas (e.g., Landsat satellite images, fine-scale elevation information), for use in heterogeneity analyses, described below.

Normalized Difference Vegetation Indices (NDVI) have proven useful in landscape heterogeneity analyses we have done to date. Spatial and temporal variation in the indices, which correlate with green vegetation biomass, are related to movements pastoralists make with their livestock. We have acquired 1 km resolution NDVI images for many of the 23 study sites and have added them to our geographic information system (GIS), and will complete the set shortly. These data, from the Global Land 1-km AVHRR Project (USGS 2001a) are available globally, for 1992, 1993, 1995, and 1996,

with some images missing. Kansas Applied Remote Sensing (KARS), of the University of Kansas and led by Dr. Kevin Price, have created NDVI images for 1994 and 1997-1999 using the methods developed by the EROS Data Center. These images were created with support from other projects, for central Asia (NSF DEB 9523441) and North America (NASA). Images for SCALE sites on the remaining two continents (Africa and Australia) will be created by KARS with support from this NSF project. In addition, KARS has identified serious discrepancies between NDVI images based upon data from the satellite NOAA 16 versus NOAAs 12 and 15; images from 2001 and 2002 are not comparable to earlier images. KARS have successfully detrended the spatial data in 2001 and 2002 to make comparisons within the North American data set valid, and are applying those fixes to the central Asian data set now. Lastly, we seek to include measures of heterogeneity of forage nutritional value in our analyses. We have held discussions with Dr. Price to collaborate in creating images reflecting forage nutritional content based upon AVHRR satellite images.

Other spatial databases available globally are being compiled into the GIS for the four continents containing our 23 sites. Spatial data in-place include the HYDRO1k database (USGS 2002), a derivative the USGS GTOPO30 global digital elevation model. HYDRO1k includes a hydrologically corrected elevation model, slope, aspect, streams, flow accumulations and basins, and a compound topographic index. GTOPO30 was acquired for Australia, where HYDRO1k is not available. The Global Ecosystems data set from the Global Land Cover Characterization Data Base (USGS 2001b) has been acquired, which includes 100 cover types. More refined products from this source (e.g., Africa seasonal land cover regions, with 197 cover types) have been added to the GIS for the four continents of interest. NDVI images from 1982 to 1999, at 8 km resolution, have been compiled for the African study sites, and will be gathered for the remaining sites. We have located another promising source for global vegetation information, generated in a joint effort by European nations using merged French Spot satellite images, and known as 'Vegetation' (Vegetation Programme 2002).

Research supported by this NSF project, the Global Livestock Collaborative Research Support Program (GL-CRSP), and the National Center for Ecological Analysis and Synthesis (University of California) have advanced methods we will use to create a framework for global comparisons of complexity. Computer programs we have used to conduct spatial and temporal analyses of heterogeneity will be modified for use in this research. Methods developed to conduct cluster analyses to quantify vegetation heterogeneity across Africa will be applied to the 23 sites, as a single integrated analysis.

Dr. Boone and Shauna BurnSilver conducted analyses of greenness profiles from NDVI images in Kajiado District, Kenya. In Kajiado, what used to be large Maasai sections (e.g.,  $4 \times 10^5$  ha) have been divided into smaller group ranches ( $1 \times 10^5$  ha), and the ranches are in the process of being divided further into individual parcels (100 ha). We sought to portray the reduced options available to pastoralists as landscapes are fragmented. Using 36 1-km resolution mean NDVI images, we created greenness profiles of the southern half of the district for an average year in the mid-1990s. Eight km resolution images for each month from 1982 to 1999 were resampled to 1 km resolution, and used to create 18

year greenness profiles. Those profiles were used in analyses, some of which are shown in the section on findings.

In separate analyses by Boone, NDVI greenness profiles throughout the year, and across years from 1982 to 1999, were calculated for all of Africa ( $n=457,747$  pixels), based on 8 km resolution 10-day summaries acquired from ADDS (2001). These data sets were used in hierarchical cluster analyses. Custom software was used to create thousands of images at regular distances within the hierarchical tree, with colors randomly assigned but conserved across maps, which were imported into a geographic information system. The correlation between continent-wide data (e.g., human population density) and the area of clusters within each image was assessed, and the image in highest agreement identified. Animations of images were also prepared.

### **Research Objective 3: Herbivore Selection at the Paddock Scale (Ash, Gross)**

**Objective:** *Determine the effects of pasture size on animal diet quality and performance.*

**Activities:**

The objective of this research is to determine the effects of pasture size on animal diet quality and performance. The key hypothesis of this component of our work is that at similar stocking levels, animal performance is better in large paddocks than small ones due to greater vegetation complexity, allowing greater selectivity and improved diet quality. To test this hypothesis we are examining seasonal diet quality of cattle as a function of paddock size, productivity, and vegetation complexity using pastoral enterprises in north-east Queensland, Australia.

This component of the project requires considerable cooperation from pastoralists in allowing the research team to use their commercial paddocks and for them to help us in sample collection. Therefore, the first stage of this project has been to secure the support of a number of pastoralists in the region to undertake the study. We developed and circulated a concise outline of the project that included sampling requirements and our obligations in providing regular feedback to pastoralists in the region. This was followed up with interviews and to date we have agreements with managers/owners of sixteen enterprises (10,000 – 50,000 ha) to participate in the project (see Figure 1). From these sixteen enterprises we will obtain the proposed twenty “experimental” paddocks to meet year one objectives. It is expected that dung sampling from these 20 paddocks will commence in October.

In addition to the main study area in north-east Queensland we have been fortunate to obtain the cooperation of a large pastoral company in the Northern Territory who are embarking on a large scale intensification study (see Figure 1). This study will offer a number of paddocks varying in size and complexity which will significantly increase our sample size. Remote sensing imagery has been obtained from this study site to begin determining appropriate measures of landscape complexity.

In addition, we have obtained support for a post-doctoral researcher that will focus on developing and refining models that integrate policy, social, economic, and biophysical processes in rangelands. The emphasis in this project is to use highly aggregated models

and new approaches (e.g., agent-based models) that permit learning and evolution of system responses. We have specifically targeted goals for the new position to support this project.

**Research Objective 4: Herbivore Movements in Fragmented vs. Intact Ecosystems**  
(Reid, Behnke)

**Objective:** *Determine effects of fragmentation on herbivore access to ecosystem complexity.*

**Activities:**

We hypothesize that fragmentation of arid and semi-arid lands will reduce the access that both wild and domestic herbivores have to ecosystem complexity. This objective aims to evaluate movements of herbivores and their access to vegetation complexity on properties or grazing areas of various sizes, from a few hectares to several thousand square kilometers. Movements over several small to medium-sized properties are being determined at IMAR, Mongolia (site 1), Kajiado, Kenya (8), Kitengela, Kenya (10), and Victoria Downs, Australia (20). Movements by pastoral herders covering medium to large areas are being determined at Mongolia I (site 2); Balkash, (4) and Moykium (5), Kazakstan; and Mara, Kenya (9). This work is complete in the Ngorongoro Conservation Area (12) and Loliondo Game Control Area (13) in Tanzania. Extant data on wild herbivore movements are available for Moykium (5), Mara (9), Serengeti National Park (14) and Jackson Hole, Wyoming, USA (18). Tempo-spatial patterns of vegetation complexity will be obtained from RO 2. Information on livestock herd movements will be obtained at all sites by interviewing herders (55). Interviews with ~50 herders will be conducted at each site. Herders will be asked to recount seasonal herd movements starting in 1992 through 2002; and to also describe movements during exceptional (i.e., drought, etc.) years. Herd destinations will be located on the ground, described and geo-referenced with a GPS. Herders will be asked to identify kinds and quantities of supplemental feed where applicable. At Sites 1, 5 and 8, year-long herd tracking and GPS plotting will also be conducted. At Site 8 we will evaluate the effects of differential vegetation access among properties of different scale, on livestock diet quality by NIRS fecal analysis as described in RO 3. Livestock condition indices will be estimated four times per year at sites where we have on-site personnel (Sites 4, 8, 9, 10). The effect of fragmentation on wild herbivore abundance and diversity will be investigated at three African sites (9, 10, 16) representing different points on the fragmentation continuum. Variables analyzed will include property size, vegetation complexity patterns (RO 2), livestock herd size, livestock condition index, supplemental feed provided, NIRS diet quality, and other factors collected in RO 8.

In 2001-2002, research on this objective was restricted to the sites in East Africa and Kazakstan. Fieldwork in Kajiado, Kenya and the data are being analyzed and published, funded by another project. Fieldwork in the other two sites in Kenya and in Kazakstan began this year and site selection, sampling protocols and initial data collection were completed.

In all East African sites, studies were designed to reveal effects of fragmentation and vegetation complexity on herd movements of Maasai pastoralists. Study areas include

landscapes differing in vegetation complexity and levels of fragmentation (caused by changes in land tenure and land use). The three sites we are studying represent the range of situations within these rangelands: 1) arid (Kajiado) to sub-humid (Mara), 2) low vegetation complexity (Mara) to moderate complexity (Kitengela and Kajiado), and 3) a mix of private and communal grazing lands and low fragmentation (Mara and Kajiado) to privatized land holdings and higher fragmentation (Kitengela). Fragmentation occurs on these landscapes because of fence building, changes in the patterns of grazing and human use intensity and conversions from grazing land to another type of land use (quarries, settlement, cultivation).

Site selection and design of the work in Kajiado will not be described in detail here because this work is funded under a companion project funded by USAID. Research began in 2002 in the Mara, and will start in 2003 in Kitengela. At each of these sites, several study areas will be selected, similar to the Kajiado site, which represent different levels of vegetation complexity and landscape fragmentation. In the Mara, this includes sites with few to many Maasai settlements and areas with low and moderate vegetation complexity. In Kitengela, we will include sites in open rangelands without fencing, mixed landscapes, and private and fenced holdings. Recent maps of settlements and satellite imagery will be used to select these study areas.

In East Africa, data collection on livestock herd movements was completed at the Kajiado site, and data collection is beginning at the Mara site. In Kajiado, changes in economic strategies, herd size and composition, marketing strategies and spatial movements of livestock were documented through interviews of 5-7 elders from each area for a total of 39 pastoral household heads. This sample was stratified by wealth level (rich, medium, poor). Verbal descriptions of monthly grazing movements for sampled households were also collected for 2 years (1999 and 2000) in the surveys in order to provide a time depth for grazing movements across multiple seasons and years. The team also measured the grazing orbits of livestock herds by following the herds of the small sample of households during the long dry season and right after the short rains. Grazing paths were marked at 30-minute intervals and vegetation data (tree, grass and shrub % cover, greenness and height), and herd behavior was also documented at each time point.

In the Mara, a protocol for herd movements was tested using a hand held GPS units. Two Maasai field assistants were trained to take points and how to program the unit to take waypoints automatically at equal time intervals. We found that the GPS mapping software, MapSource, required too many steps for data download, and solved this problem by switching to OziExplorer, which is simple to use and data can be directly converted into ArcView shape files. This grazing orbit data will be collected over the following year and linked to both AVHRR and Modis satellite data received from RO 2 and a companion NASA-funded project. We will count and locate wildlife herds at the same time as the grazing orbit study so that we can better understand the interaction between livestock movement and wildlife spatial patterns. At the same time, the field team will also complete a set of interviews, similar to those described above for Kajiado.

Finally, we will also collect data on livestock diet quality by collecting dung and analyzing it by near infrared spectrometry (NIRS).

**Research Objective 5: Typology of Actual Land Use Patterns** (Behnke, Kerven, Galvin, Reardon-Anderson, Gross)

**Objective:** *Develop a standard format to differentiate and compare land use patterns and management scales within and across study sites.*

**Research Objective 7: Factors Driving Contemporary Trends in Land Use Change** (Behnke, Galvin, Reardon-Anderson, Kerven, Gross)

**Objective:** *Investigate how ecological, political and socio-economic factors interact to influence individual land use decisions.*

**Activities:**

It was decided at the first PI's meeting that research objective 6 would be excluded from the study in its present form. However, we are including it here because we will still emphasize it to a lesser degree when working on research objective 5 and 7.

Roy Behnke has developed a comprehensive internal discussion paper on pastoral land tenure and land use (see <http://www.nrel.colostate.edu/projects/scale/tenure.htm>). This document will be used by all research teams to develop summaries of land tenure/use systems, and changes to those systems, for all study sites. The paper discusses methods for analyzing pastoral land use and land tenure systems, in order to provide a standard protocol for work on RO5 and RO7. These summaries can then be used to construct a first approximation of a standard protocol that will fit the variable conditions across the SCALE sites. This paper discusses analytical techniques and provides a loose format that should be useful in preparing these initial site summaries.

A conceptual model of the relationship between increasing landscape fragmentation and developmental trajectories has been developed (see Figure 2).

**Research Objective 8: Economic Surveys and Analysis** (Thornton, Stafford Smith)

**Objectives:** *Gather information on household economic performance and the economic dimensions of livestock production systems in relation to scale and resource access.*

**Activities:**

Activities for this objective involve gathering data on household economic performance and the economic dimensions of livestock production in relation to scale and resource access. Survey data and secondary sources will be used to assess household economic viability, spatial resource access patterns and level of material subsidy. Decision trees would be constructed to understand how enterprise scale and access to ecological complexity relates to economic complexity.

Data continued to be collated for the Kajiado case study. In particular, these data are contributing to a typology of households in the area, each with access to different types and amounts of resources, and different levels of agricultural and non-agricultural enterprise diversification. Rules governing the allocation of resources at the household level, and the purchasing and selling of livestock, are being elicited and will form the core of the PHEWS model for Kajiado.



In addition two activities to further these research objectives were initiated in Kazakstan.

### 1. Household income questionnaire

A questionnaire module on household income sources was designed and applied to the 40 sample households in the Desertification and Regeneration: Modeling the impact of market reforms on Central Asian rangelands (DARCA) survey. At the February PI meeting it was agreed that the DARCA household survey data on livestock income and expenditures needed to be supplemented by data on all other sources of income available to the sample households. A more complete picture of household income would then be possible. The questionnaire, attached, will only be applied one time. The income questionnaire interviews were carried out by Aidos Smailov during May and June in Kazakstan. The data is being processed and will be available in several months.

### 2. Survey and study of pastoral seasonal livestock mobility patterns

A small survey and study has started of desert-based pastoral households that continue to move their livestock seasonally to different ecological zones. The households are based in the remote community of Ulan Bel in the Moinkum desert of south-central Kazakstan. This community was formerly a state collective farm for livestock, holding 60,000 sheep, 600 horses, 400 cattle and 200 camels. The human population was 2,000. Mean annual precipitation is 200 mm. The nearest town is 300 km distant.

Currently the human population has stabilized at around 1,500. People have stopped emigrating to the crop growing areas near to larger settlements in the south of the region following the economic crisis of the mid 1990s and the collapse of the state livestock collective farm in 1998. There appears to have been an increase in the smallstock population in the last couple of years, mainly due to increases in the goat population. The villagers now have 12,500 sheep and goats, 493 cattle, 172 horses and 63 camels.

A drop of nearly 80% in the smallstock population since the mid 1990s has reduced the grazing pressure on remoter pastures formerly used by the Ulan Bel collective farm and before that, Kazak nomads.

The system of seasonal livestock movement has however, almost completely disappeared. Formerly, animals were regularly moved in each season away from the villages along the Chu River to pastures with distinct vegetation communities and climates (see Figure 3). In spring, livestock were moved northwards through Betpak Dalla (hungry steppe), a plain north of the Chu River, where they grazed on ephemerals and salty plants. Lambing took place in Betpak Dalla in March. They reached a broad plateau called Sary Arka (yellow spine) some 300 km. north of the Chu River by early summer (May). This area was rented by the Moinkum state farms from neighboring Dhezkazgan Oblast (administrative region). The dominant vegetation is steppe grasses, and the precipitation at 300 mm is higher than in the south. Here the shepherds stayed in yurts around wells. In September animals were moved back towards the Chu River and

grazed south of the river for a month or two, while breeding took place. Reeds and other natural hay were harvested for winter fodder from around the Chu River. By December, shepherds and their flocks were settled into winter grazing sites in the Moinkum desert, at winter houses with attached barns and wells. These winter sites were between 40-100 km. south of the river. Large barns were built to house the animals for winter. The sandy Moinkum desert provided good grazing of semi-shrubs and shrubs, as well as shelter from the dunes, for animals over winter.

The community of Ulan Bel has been visited several times since 1999 as part of the DARCA activities but was not included in the DARCA household sample. In March of this year, Ulan Bel was re-visited. Discussions were held with the village administrator and animal husbandry officer to introduce the objectives of SCALE. They gave their approval to conduct research in the area. Interviews were carried out with 15 pastoralists who keep their animals at pasture sites some distance from the village, in contrast to the majority of villagers who now graze their livestock within the village perimeter. Of the 15 pastoralists interviewed, five still undertake the summer migration of up to 200 km north to Betpak Dalla, and move their animals to the desert sands some 50 km south of the village for the winter. The remaining ten people keep their animals year-round at wells in the desert some 40-50 km south of the village. The pastoralists who move their animals are always those with the largest flocks, though some villagers with fewer animals combine these with relatives who undertake seasonal migrations.

In May, six of this group of 15 pastoralists were included in the DARCA household sample survey, to monitor their economic performance and livestock grazing patterns for SCALE. The survey will continue for at least 3 more quarterly rounds: Sept. 2002, Dec/Jan 2003 and March/April 2003. Further in-depth interviews will also be carried out with these and other pastoralists in Ulan Bel.

**Research Objective 9: PHEWS (Pastoralist Household Economic Welfare Simulator) Model Assessments** (Thornton, Stafford Smith)

**Objective:** *Determine economic-ecological interactions resulting from alternative land use practices.*

**Activities:**

The economic data being collated under RO 8 is being used as key input data to the development of the Pastoralist Household Economic Welfare Simulator (PHEWS) for Kajiado. Together with secondary information and expert input, the rules for classifying pastoral households and for determining the allocation of resources and management decisions such as purchasing and selling, will be determined and programmed into the model. It is expected that a working version of the model, linked to Savanna, will be completed by December 2002 for the Kajiado case study.

A related activity has seen the linking of the Savanna ecosystem model to a mathematical programming package, XPRESS-MP. This involved only a few changes to the code of Savanna, but the entire exercise has been very useful as a “proof of concept”; it means that in the future, it will be possible to use Savanna routinely in resource optimization problems. This is of direct relevance for agro-pastoral systems that are more connected

to the market economy, where there are needs to optimize the use of land, labor and/or capital at both household and community levels. This initial work has involved a very simple household model, but this will be made more complex and realistic in the future.

**Research Objective 11: Spatial Complexity, Temporal Variability and Population Patterns (Hobbs)**

**Objective:** *Develop competing models linking animal populations to spatial complexity.*

**Activities:**

In conjunction with a workshop sponsored by the National Science Foundation Center for Ecological Analysis and Synthesis, we compiled time series of population data for 175 combinations of large herbivore species and study locations from tropical and temperate systems throughout the world. Simultaneously, we have gathered relevant NDVI and weather data for each study site. We are using these data to test the hypothesis that spatial heterogeneity in vegetation as indexed by NDVI (see Research Objective 2) dampens the effects of temporal heterogeneity in weather on herbivore population growth rate.

**Research Objective 12: SAVANNA-PHEWS Complexity-Fragmentation**

**Experiments (Boone, Coughenour, Thornton)**

**Objective:** *Model effects of fragmentation on ecosystems and people.*

**Research Objective 13: Complexity, and Fragmentation in Theoretical Ecosystems**

(Boone, Coughenour, Hobbs, Ellis)

**Objective:** *Study general responses of ASAL ecosystems to fragmentation.*

**Activities:**

Advancing Research Objectives 12 and 13 was not a focus of year 1 of the project. Regardless, progress has been made. Dr. Mike Coughenour has modified the Savanna ecosystem model to make it easier to apply and more flexible. Changes were made to represent hydrologic flow more effectively, model blowing snow, and predict rainfall in topographically diverse regions more appropriately. Drs. Boone and Coughenour have discussed how to explicitly incorporate large herbivore movements in the Savanna model, and initial coding of that modification has begun. Dr. Lindsey Christensen completed analyses in Baiinxile Livestock Farm, Inner Mongolia, in-part addressing effects of fragmentation of the farm on livestock stocking rates (Christensen 2001). Her work, supported by another NSF project, is directly related to SCALE goals and was proposed as a SCALE site, with Savanna work completed (Table 2, SCALE proposal). In work supported by GL-CRSP, Drs. Philip Thornton and Boone updated an adaptation of the PHEWS pastoral household simulator to Ngorongoro Conservation Area, Tanzania, and Dr. Boone used Savanna-PHEWS to address management questions, including fragmentation and loss of grazing habitat due to cultivation. Those findings will augment results generated when Savanna modeling under SCALE begins in earnest. Further, the NCA-Savanna application will be used in analyses for Research Objective 12.

## FINDINGS

### Research Objective 2: Complexity Framework and Analysis (Boone, Price, Reid)

**Objectives:** *Develop a framework for complexity analysis, apply to all sites; determine herbivore access to complexity for fragmented and un-fragmented grazing orbits (in conjunction with RO 4).*

#### Findings:

In work related to Research Objective 2, we have found that *daily* pathways followed by Maasai herders and their livestock were weakly correlated with landscape and vegetation heterogeneity, and their lengths were strongly correlated with parcel area (BurnSilver et al., in press). A weak correlation with heterogeneity may be expected, given that herders may be expected to locate homogeneous patches of green forage on any given day.

Analyses relating *seasonal* grazing areas to landscape and vegetation heterogeneity are pending, and we hypothesize that those correlations will be much stronger. Herders will have needed to maximum access to high quality forage across seasons.

Compiling vegetation greenness profiles for Kajiado District allowed us to portray reduced options available to livestock herded by Maasai, as land was fragmented. In the simplest presentation, used here, the diversity of greenness profiles reflects foraging options available to herders. In the Maasai section Ilkisongo (Figure 4a), a diversity of greenness profiles suggests many options for herders, but in Imbirikani Group Ranch, options are reduced (Figure 4b). In an individual 500 ha parcel within the ranch, alternative grazing areas are not available – if forage in the dry season falls (Figure 4c) below that required to support the herder's livestock, moving to greener pastures is not an option. However, if grazing cooperatives are formed and animals moved between five 100 ha parcels owned by herders, the mean vegetation greenness is higher than for the single farm (Figure 4d).

Clustered images may be thought of as hierarchical biophysical regions (e.g., Krohn et al. 1999), and can guide robust data extrapolation (Boone et al., 2000). Boone found that deserts (e.g., Sudan, Kalahari) had homogeneous NDVI profiles in analyses of within year profiles and profiles across 18 years, with large clusters remaining until well down the hierarchical tree. Equatorial areas yielded small clusters high in the tree when the data set with an annual profile, reflecting diverse NDVI responses. These areas yielded large clusters in the analysis across years, so although annual profiles are diverse, their NDVI patterns across years are similar. Areas east of Lake Victoria (e.g., the Arc Mountains of Tanzania) showed the most complex patterns. The areas of clusters correlated with human population density (LandScan 2000) (Spearman's  $D = -0.64$ ), cattle density (Kruska et al. 1995) ( $D = -0.36$ ), and mammalian species richness (Reid and Kruska, pers. comm.) ( $D = -0.83$ ); e.g., diverse vegetation responses reflect a diversity of niches supporting mammal species, although many theories have explained richness gradients. Humans, for example, also add to the diversity in vegetation responses through cultivation.

**Research Objective 4: Herbivore Movements in Fragmented vs. Intact Ecosystems**  
(Reid, Behnke)

**Objective:** *Determine effects of fragmentation on herbivore access to ecosystem complexity.*

**Findings:**

Preliminary findings are only available for the Kajiado site. Ecosystem complexity indices were developed based on multiple combinations of NDVI, DEM and soils layers for 6 study areas in the region. Pastoral grazing orbits from the wet and dry seasons were overlaid on these complexity indices in order to identify if pastoralists are selecting for areas of high landscape complexity in their grazing movements, and if macro-scale factors like land tenure and economic change are impacting pastoralists' ability to access heterogeneity when necessary. The team found that the scale of herd movements was significantly smaller in areas which had been subdivided and in areas with a high degree of economic sedentarization, compared with areas where fragmentation was not a factor. Additional analyses are ongoing to identify at what temporal scale access to landscape complexity is important for herders; e.g. weekly, monthly or over the course of consecutive seasons.

**Research Objective 8: Economic Surveys and Analysis** (Thornton, Stafford Smith)

**Objectives:** *Gather information on household economic performance and the economic dimensions of livestock production systems in relation to scale and resource access.*

**Findings:**

Preliminary findings are only available for the Kazakstan sites. The state farms imposed in this area of Moinkum, Kazakstan (see activities, RO8) in the late 1940s largely adopted the migratory grazing pattern used by Kazak nomads in the pre-Soviet system. The botany, history, wildlife, landforms and climate of the entire area is well-documented by Soviet scientists. A collection of their monographs is held by Ilya Ilytch Alimaev, one of the collaborators within SCALE. For the purposes of SCALE, both the pre-Soviet and Soviet grazing patterns may be considered *livestock management systems*. The current grazing patterns are evolving quite rapidly, but it is possible to discern several new systems emerging simultaneously. We may take the pre-Soviet grazing pattern as the analytical starting point, if sufficiently well-documented.

The livestock management systems are *heterogeneous*, containing a variety of states in terms of plant cover, species, topographic positions, phenological stages and climates. The cultural system was homogenous, although a few families of different ethnic origin were introduced in the Soviet period.

The systems are also *complex* in that over time, several processes have acted upon the systems, generating interactions between variables within them. Notable among these processes are:

- a) climate variability (long-term records exist) – a driver
- b) land use changes (pre-Soviet, Soviet and post-Soviet) – a function of (c), (d), (e) and (f)
- c) animal movement (see above)- a function of (b) and possibly (a)

- d) animal population numbers (fluctuations due to winter blizzards, droughts and recent economic crisis) – a function of (a), (e) and (f).
- e) external economic forces (changes in the prices of livestock inputs and outputs) – a driver
- f) institutional breakdown (collapse of state managed farms and subsidies) – a driver

The previous Soviet system has become *fragmented* very recently – within the past 5-7 years. Most livestock managers no longer make use of the spatial heterogeneity available in the environment. Fragmentation has not been externally imposed (e.g. because of changes in formal land tenure) but is due to the economic cost of moving between the variety of landscapes. As a result, new scales of operation are being attempted.

One of the interesting effects of fragmentation in this case is likely to be an increase in vegetation heterogeneity on pastures no longer grazed, and a decrease of heterogeneity in peri-village pastures now being heavily used.

## **PUBLICATIONS**

Boone, R.B. and S.B. BurnSilver. In preparation. Assessing effects of landscape fragmentation using normalized difference vegetation indices. Policy Brief by the *Global Livestock Collaborative Research Support Program, University of California, Davis*. (Note: Citing partial support from NSF Scale, pending agreement with GL-CRSP)

BurnSilver, S.B., R.B. Boone, and K.A. Galvin. In press. Linking pastoralists to a heterogeneous landscape: The case of four Maasai Group Ranches in Kajiado District, Kenya. Linking household and remotely sensed data: Methodological and practical problems (Fox, J., V. Mishra, R. Rindfuss, and S. Walsh, eds.). January 2002.

## **PRODUCTS**

SCALE website - <http://www.nrel.colostate.edu/projects/scale/>

## **CONTRIBUTIONS TO EDUCATION AND TRAINING**

*From Philip Thornton*

Philip Thornton had interactions with JoAna de Pinho, graduate student (NREL, Colorado State University).

*From Randy Boone*

In a six-hour training session in July 2002, Dr. Boone trained six participants in the Savanna modeling system, the central tool used in Research Objectives 12 and 13. Dr. Coughenour followed that with an additional 10 hours of training for four participants. Some participants will be using the Savanna model in NSF Biocomplexity research.

Drs. Boone and Hobbs attended a workshop organized by the National Academy of Sciences entitled *Integrating Education in Biocomplexity Research*, in Washington, DC,

April 16-17, 2002. In the workshop, we learned methods to incorporate undergraduate and adult education into biocomplexity research. The value of fully integrating undergraduate students into project research was emphasized.

Boone is cooperating in teaching a graduate course at Colorado State University (EY 592.007), led by Dr. Niall Hanan. The course, entitled “What in the World *is* Biocomplexity?” includes reviews of significant biocomplexity literature, and weekly demonstrations or laboratories exploring biocomplexity issues. When scheduling allows, Boone attends another review series, a weekly discussion group that reviews papers pertaining to SCALE related issues.

*From Robin Reid*

A Ph.D. student from the University of Maryland was mentored (by Reid, Serneels and Kshatriya at ILRI, Kenya) in writing a successful proposal to NASA for additional funding to look at the movement of herbivores in the Serengeti-Mara ecosystem.

*From Tom Hobbs*

Tom Hobbs and Simon Tavener (Math Department, CSU) held a weekly summer reading discussion group to discuss scholarly articles relevant to the project.

## **OUTREACH**

*From Andrew Ash*

The aims and objectives of the project have been explained to pastoralists in the region in the process of getting collaboration. An overview of the project has also been presented to the North Queensland Beef Research Committee, a pastoralist led organization in northern Queensland.

*From Randy Boone*

Boone and other GL-CRSP personnel have presented research addressing landscape fragmentation in Kajiado District to Maasai group ranch members, members of non-governmental organizations, and scientists in East Africa. Effects of habitat loss, for example due to cultivation in Ngorongoro Conservation Area were also presented. These results were generated with support from GL-CRSP, but the results from Kajiado will be important in the context of SCALE analyses at that site.

*From Robin Reid*

A team of Maasai pastoralists was selected and convened for herd-following data collection at the Mara site. A Maasai community meeting was held (funded by a USAID project) in December, 2001, to discuss the project with community members.

## **Presentations**

“Biocomplexity, spatial scale and fragmentation: Implications for arid and semi-arid ecosystems (SCALE)”, Poster presented at *Integrating Education in Biocomplexity Research*, National Academy of Sciences, April 16-17, 2002.

Boone, R.B. 2002. Hierarchical cluster analyses of African satellite imagery. Interactive presentation (Poster), US International Association of Landscape Ecology meeting, Lincoln, Nebraska, April 23-27.

Boone, R.B., S.B. BurnSilver, N.T. Hobbs, and K.A. Galvin. In preparation. Large-scale movements of large herbivores: livestock following seasonal changes in forage supply. Large Herbivores in Fragmented Landscapes (Workshop and volume), January 2003. (Abstract accepted)

Boone, R.B. and N.T. Hobbs. In preparation. Lines around fragments: Effects of fencing on large herbivores. Fragmentation of Rangelands: Ecological and Economic Implications, Special Session, International Rangeland Congress (Symposium and volume), July 2003. (Abstract accepted)

### **OTHER PARTICIPANTS**

*From Andrew Ash*

Andrew Ash, Chris Stokes, John Gross, Brett Abbott and Mike Nicholas - CSIRO Sustainable Ecosystems, Townsville

Mark Stafford Smith - CSIRO Sustainable Ecosystems, Alice Springs

*From Carol Kerven*

Ilya Ilytch Alimaev, Institute of Pasture and Fodder, Almaty, Kazakstan

*From Robin Reid*

This project funds 20% of the time of Joseph Ogutu, a male Kenyan who is an ecosystem modeler and spatial statistician on the project. Joseph is based at the International Livestock Research Institute in Nairobi, Kenya.

### **OTHER COLLABORATIONG ORGANIZATIONS**

*From Andrew Ash*

Cooperation with a large pastoral company in the Northern Territory. This site will offer a number of paddocks varying in size and complexity which will significantly increase our sample size.

*From Robin Reid*

Scientists at the International Livestock Research Institute are leading this research objective. This institute provides waiver of salary and in-kind support for the project. The scientists on the project collaborate with the Kitengela Land Owners Association in Kitengela, Kenya and the Koyiaki Group Ranch in the Mara, Kenya. These organizations provide advice and identify appropriate field assistants for the project.

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- BurnSilver, S.B., R.B. Boone, and K.A. Galvin. In press. Linking pastoralists to a heterogeneous landscape: The case of four Maasai group ranches in Kajiado District, Kenya. In *Linking Household and Remotely Sensed Data: Methodological and Practical Problems* (J. Fox, V. Mishra, R. Rindfuss, and S. Walsh, eds.)
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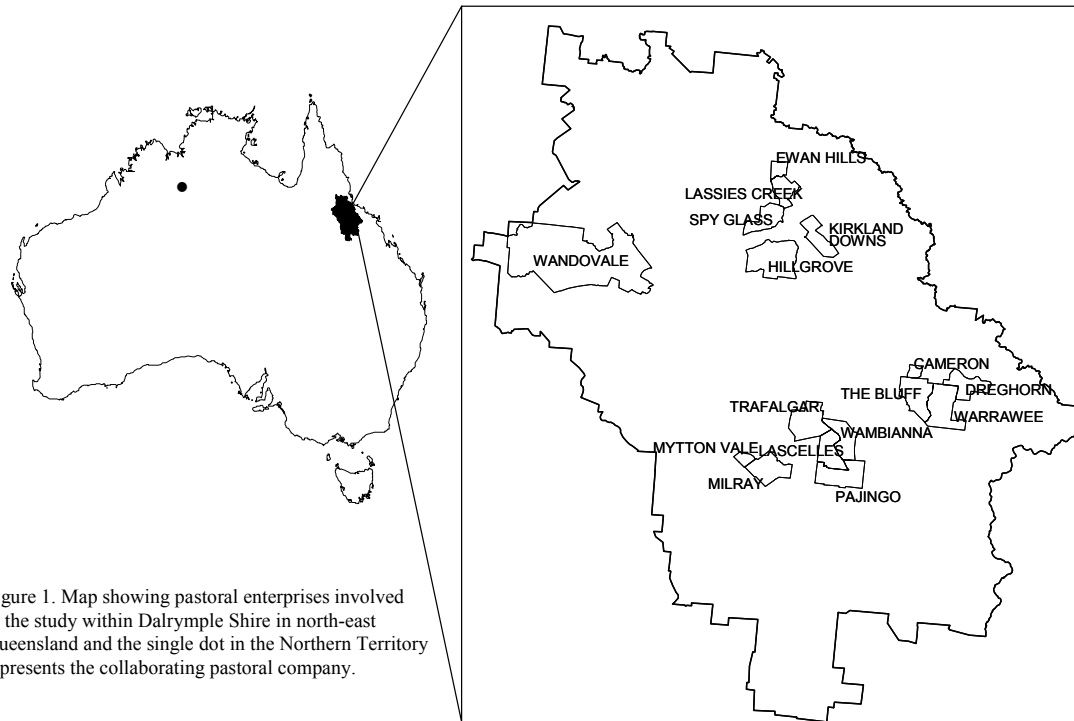


Figure 1. Map showing pastoral enterprises involved in the study within Dalrymple Shire in north-east Queensland and the single dot in the Northern Territory represents the collaborating pastoral company.

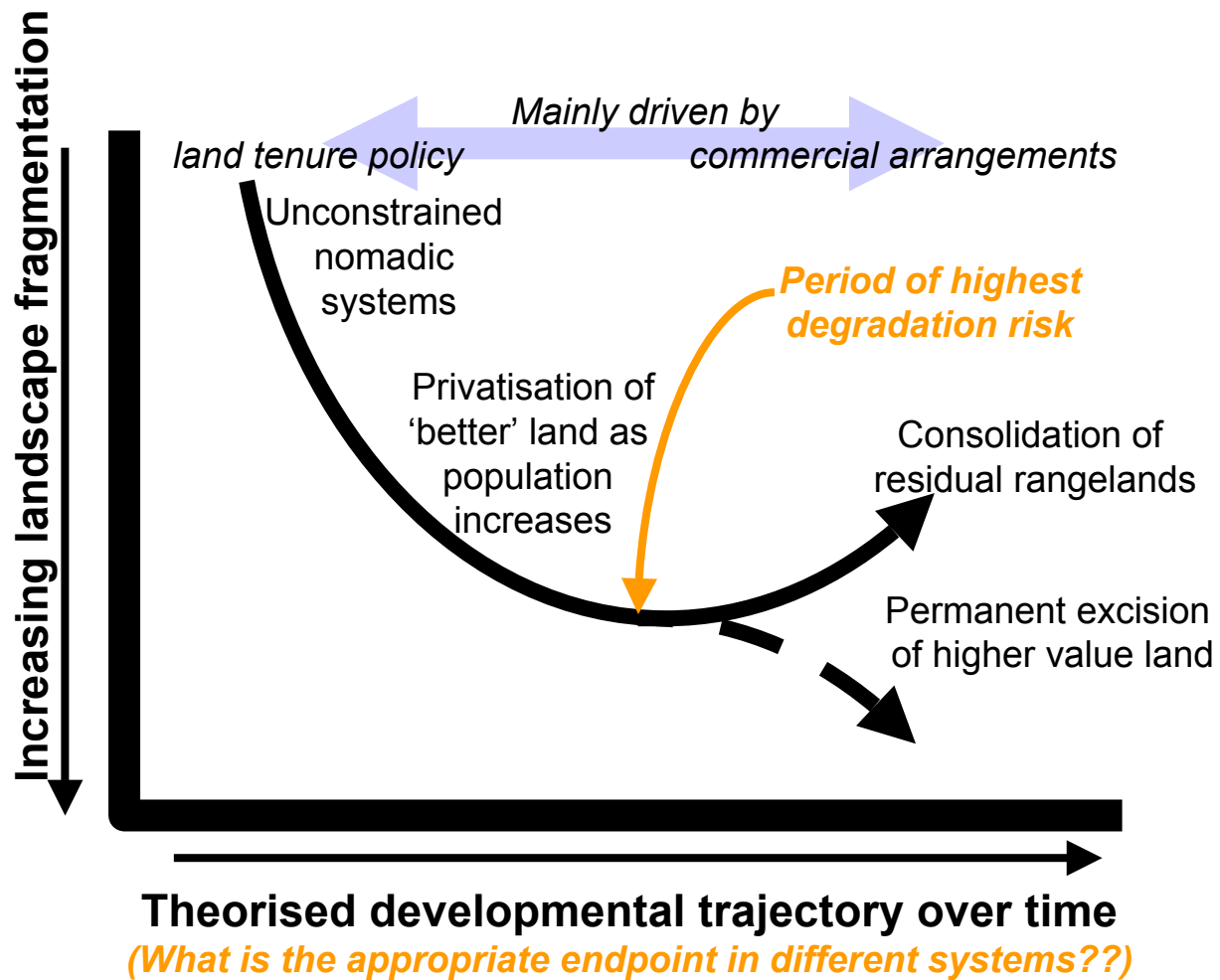
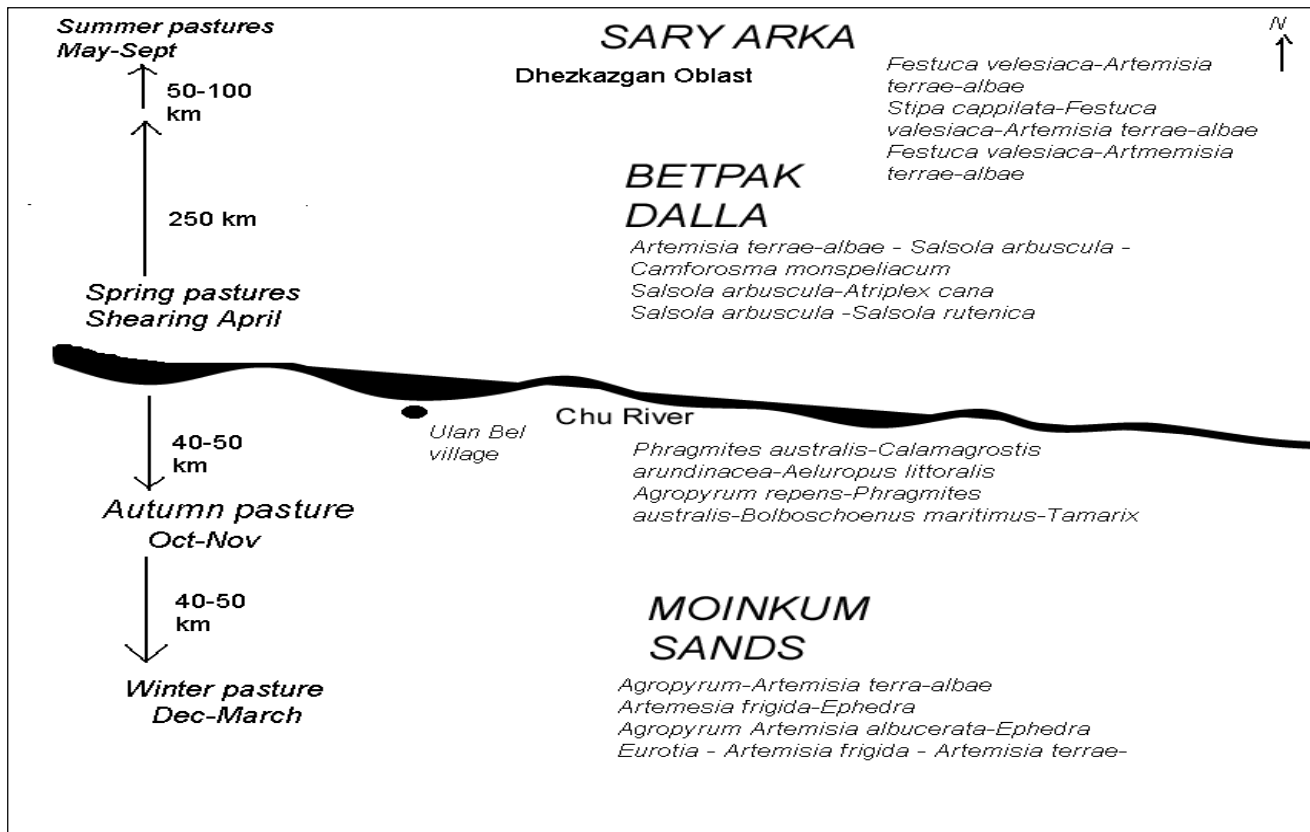


Figure 2



**Figure 3: Migration system of Moinkum livestock in state farms (NOTE: Types of vegetation in each of the zones are provided by Ilya Ilytch Alimaev, Institute of Pasture and Fodder, Almaty, Kazakstan.)**

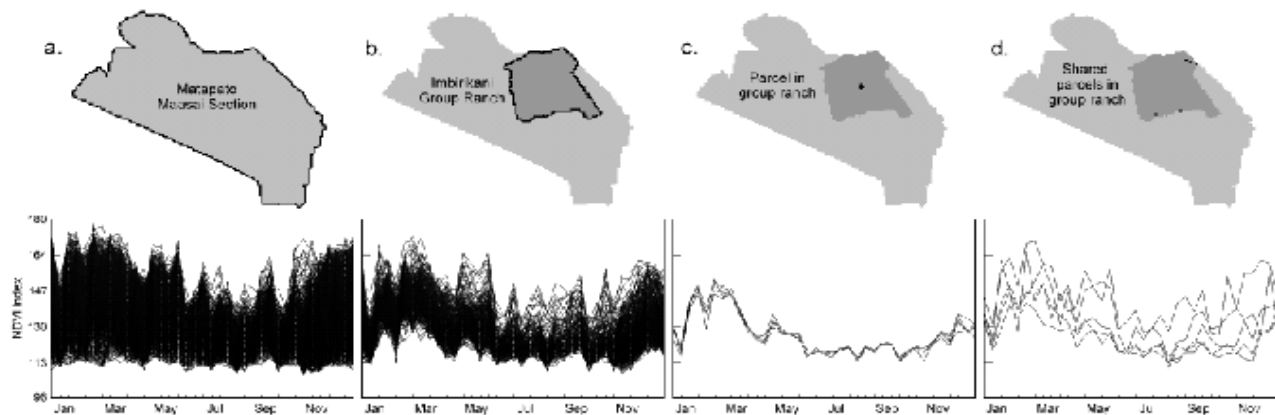


Figure 4. Vegetation heterogeneity is reflected in greenness profiles created for individual pixels based on satellite images. Over all of Matapato Maasai Section of Kajiado District, Kenya (a), grazing options are varied; if one 100 ha patch has low forage availability, another will have high availability. Within the Imbirikani Group Ranch (b), less diversity in vegetation responses are shown, and little variation is shown within a 500 ha parcel within the ranch (c). In contrast, if 5 herders each owning 100 ha cooperate, more options for grazing are available.