

Integrated Assessment Results to Support Policy Decisions in Ngorongoro Conservation Area, Tanzania

POLEYC Project

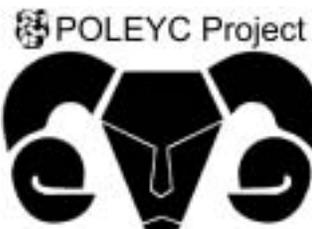
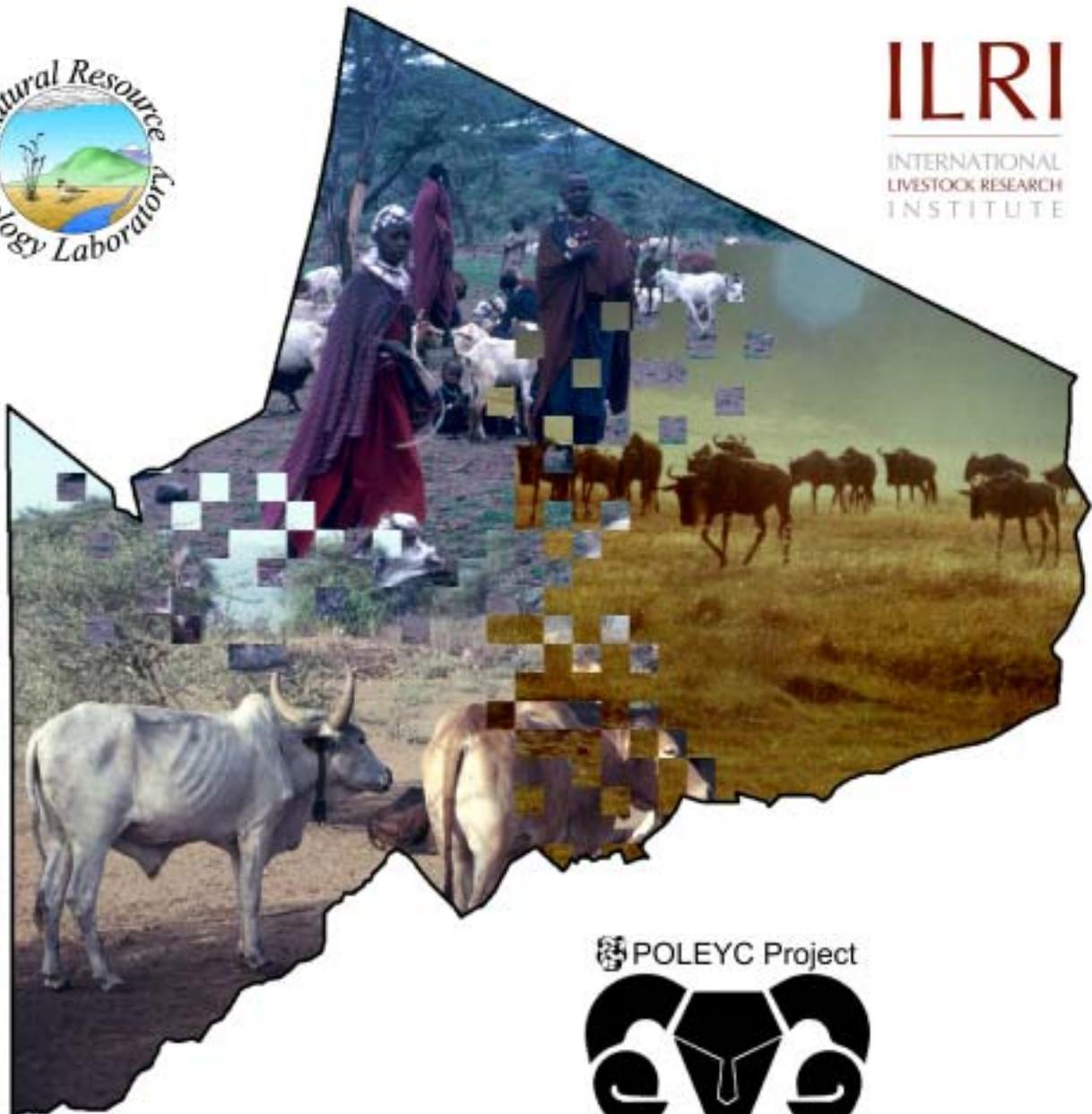
(Policy Options for Livestock-based livelihoods, and EcosYstem Conservation)

Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, Colorado, USA
and the International Livestock Research Institute, Nairobi, Kenya

of the

Global Livestock Collaborative Research Support Program

(GL-CRSP) University of California, Davis



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Front cover photos by Kathy Galvin and Randy Boone, back cover art by Randy Boone, portrait on
this page by Jim DeMartini.

Dedication

This report is dedicated to the memory of Dr. Jim Ellis (October 1938 to March 2002), the architect of the POLEYC project. Jim's vision of people, livestock, and wildlife existing harmoniously in sustainable landscapes continues to guide our work. His ease, skill, and experience were evident whether he was communicating with the world's most recognized ecologists, listening to land managers describe the concerns they must balance, or responding respectfully to a Maasai elder. To learn more about Jim's many contributions, please see <http://nrel.colostate.edu/events/ellis.html>



^a See Appendix A for full titles and institutional associations of project personnel

TABLE OF CONTENTS

Table of Contents	i
Abbreviations	ii
List of Tables	ii
List of Figures	iii
Acknowledgments	iv
Executive summary	v
1. INTRODUCTION	1
2. POLICY QUESTIONS	5
2.1 What is the capacity of NCA to support large herbivores?	5
2.1.1 Annual rainfall	6
2.1.2 Monthly rainfall	8
2.1.3 Management zones	10
2.1.4 Spatial analyses	16
2.1.5 Ecological modeling	17
2.1.6 Limitations	18
2.1.7 Estimates of appropriate stocking evaluated	20
2.2 Where is cultivation in Ngorongoro Conservation Area?	21
2.3 What is the balance between wildlife, livestock, and human populations?	27
2.4 What are potential effects of cultivation in NCA?	30
2.5 What are the effects of controlling livestock disease?	38
3. SUMMARY AND CONCLUSIONS	45
4. LITERATURE CITED	47
Appendix A Team Members and Institutional Participants in POLEYC	51
Appendix B NCA portion of the POLEYC January 2002 trip report	57
Appendix C Handouts used in presentations, with some KiSwahili	62

ABBREVIATIONS

AE - Adult equivalent

ETM - Enhanced Thematic Mapper (Landsat 7 satellite sensor)

GIS - Geographic Information System

GL-CRSP - Global Livestock Collaborative Research Support Program

LHU - Large Herbivore Unit (250 kg of body mass)

NCA - Ngorongoro Conservation Area

NCAA - Ngorongoro Conservation Area Authority

PHEWS - Pastoral Household Economic Welfare Simulator

POLEYC - Policy Options for Livestock-based livelihoods, and EcosYstem Conservation

TLU - Tropical Livestock Unit

UNESCO - United Nations Educational, Scientific, and Cultural Organization

LIST OF TABLES^a

Table 1	Current large herbivore population estimates on NCA.....	6
Table 2	Estimates of appropriate stocking on NCA, based on Coe et al. (1976)	8
Table 3	Estimates of appropriate stocking on NCA, based on McNaughton et al. (1989).....	9
Table 4	Estimates of appropriate stocking on NCA, based on Oosterheld et al. (1992)	10
Table 5	Estimates of appropriate stocking on NCA based on monthly rainfall	12
Table 6	Estimates of appropriate stocking based on management zones	14-15
Table 7	Summary of appropriate stocking estimates	20

^aThe table legends shown are partial or paraphrased versions of the actual tables. Refer to the tables for full legends.

LIST OF FIGURES^a

Figure 1	Ngorongoro Conservation Area and the surrounding area	1
Figure 2	Human and livestock populations, and their ratio	3
Figure 3	Monthly net aboveground primary productivity	11
Figure 4	Monthly estimates of plant productivity and herbivore biomass	11
Figure 5	Management zones within Ngorongoro Conservation Area	13
Figure 6	Summary of estimates of appropriate stocking	19
Figure 7	Example images and cultivation mapping in NCA	23-25
Figure 8	Mapped cultivation in NCA in February 2000	26
Figure 9	Wildlife and livestock populations at different human populations	29
Figure 10	Cultivation maps used in modeling	31
Figure 11	Cultivation maps used in modeling, with cultivation in two blocks	32
Figure 12	Livestock and wildlife biomass with and without cultivation	33
Figure 13	Cattle distributions with and without cultivation	34
Figure 14	Effects of cultivation from 0 to 50,000 ac on livestock and wildlife	34
Figure 15	Supplemental foods required by increasing human populations	35
Figure 16	Cash reserves for rich households with different human populations	36
Figure 17	Livestock biomass with current and blocked cultivation	36
Figure 18	Changes in resident wildlife with current and blocked cultivation	37
Figure 19	Resident wildlife with blocked cultivation at 10,000 and 20,000 ac	37
Figure 20	Cattle population with East Coast fever losses reduced	39

(List of Figures continues)

^aThe figure legends shown are partial or paraphrased versions of the actual figures. Refer to the figures for full legends.

LIST OF FIGURES

Figure 21	Palatable grass biomass when disease in cattle is reduced	40
Figure 22	Cattle population when disease is reduced, and excess animals sold	40
Figure 23	Palatable grass biomass when disease is reduced, and excess livestock sold	41
Figure 24	Cash holdings for rich households, with disease in livestock reduced	41
Figure 25	Cattle populations when juvenile mortality is reduced	43
Figure 26	Resident wildlife biomass when juvenile livestock mortality is reduced	43
Figure 27	Supplements required by Maasai when less juvenile livestock mortality	44
Figure 28	TLUs per adult equivalent when juvenile livestock mortality is reduced	44

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Our thanks go to the members that make up the POLEYC team (listed in *Appendix A*). We thank the Conservator of NCAA, Mr. Emmanuel Chausi, for posing the questions we addressed in this report; it is rewarding to pursue research knowing with certainty that the results will be of use. Special thanks go to Victor Runyoro, of Ngorongoro Conservation Area, for his assistance in designing these assessments, and his help during our outreach efforts. We thank Francis Ikayo and Gaspar Leboy for providing translations in our NCA presentations, and for their other assistance. Denne Reed of State University of New York cooperated in purchasing the satellite image of NCA used in mapping cultivation. We thank the scientists of NCA, members of the Executive Pastoral Coun-

cil, and the pastoralists of Endulen who provided input during our outreach efforts; we believe their insights improved this report.

Our thanks to members of our previous GL-CRSP project, IMAS, for producing results that laid a strong foundation for the analyses under POLEYC. We thank the staff of the Natural Resource Ecology Laboratory for providing the support required to keep an effort of this complexity moving smoothly. Lastly, we thank GL-CRSP, the sponsors of this work, for their recognition of the importance of applying sound integrated assessments to policy decisions. Their kindness and support during recent trying times are particular valued.

EXECUTIVE SUMMARY^a

The Ngorongoro Conservation Area Authority (NCAA) is charged with balancing the needs of Maasai inhabitants and their livestock, as well as the wildlife for which Ngorongoro Conservation Area (NCA) is renowned, and the tourism industry that the wildlife supports. Thus, management of NCA represents a unique and important experiment in balancing multiple uses that has continued for more than 40 years. NCA supports many populations of wildlife, including black rhinoceros, elephant, wildebeest, buffalo, and a suite of predators. Humans have inhabited NCA for eons – the area includes important archeological sites – and the Maasai continue to inhabit the area. Maasai are semi-nomadic pastoralists, sometimes moving great distances to find adequate forage and water for their herds of cattle, goats, and sheep. Owing to its unique combination of wildlife, scenery, and pastoral land use, the NCA has been recognized as a Natural World Heritage Site (1979) and made a Biosphere Reserve (1981) under United Nations UNESCO Man and Biosphere Programme.

Managing NCA has never been straightforward, but an increasing demand for use of the land has made balancing competing interests (e.g., conservation, livestock husbandry, cultivation) extremely challenging. The migratory wildebeest population is now high, relative to when NCA was gazetted, which prevents Maasai from using the plains in the wet season when the wildebeest are on NCA, due to disease risks. Human population growth is high (3.5% to 4.3%, including immigration), but livestock populations have been relatively stable (perhaps with recent increases because of improved veterinary services). When NCA was created, the standardized number of livestock per person was more than 15 TLUs/person. That value had fallen to 8 TLUs/person by 1986, and in 1999, with 51,600 residents, was at 2.77 TLUs/person. These livestock holdings are below what experts believe are required to maintain a purely pastoral lifestyle. Given that, NCAA sought to improve Maasai food security in 1991 by allowing limited cultivation, which had been banned in 1975. Most

Maasai are now agro-pastoralists. Because of conservation concerns expressed to NCAA, in 2001 the Tanzanian government considered banning cultivation once again, but did not make final decisions.

From 1997 to 2000 a team led by Dr. Michael B. Coughenour and supported by the Global Livestock Collaborative Research Support Program (GL-CRSP), addressed potential management questions in NCA in a project known for the method of investigation used, the *Integrated Management and Assessment System*, or IMAS. The overarching goal of the project was to assist policy makers and stakeholders to balance food security for pastoralists, wildlife conservation, and ecosystem integrity. In 2000, results from this work led the Conservator of NCAA to approach us with questions our team was poised to address. To paraphrase, he asked:

- How many animals may be supported in NCA?
 - What is the effect of cultivation on wildlife, livestock, and people in NCA?
 - What are the effects likely to be from improved veterinary care, on livestock populations, wildlife, and people?
- To which we added some questions that needed to be addressed prior to, or in concert with, those listed:
- What are the magnitude of effects of human population growth?
 - Where and how much land is cultivated in NCA?

These basic questions, and often similar questions in three other research sites in which we work, spurred us to propose to the GL-CRSP that we use integrated assessments to assist policy makers and other stakeholders in their decision making, by suggesting potential trade-offs in different management options. The GL-CRSP, in turn supported by the US Agency for International Development, has funded our project entitled *POLEYC*, for *Policy Options for Livestock-based livelihoods, and Ecosystem Conservation*. The following sections summarize our findings.

^aFor brevity, information is not cited in this summary. See the body of the report for citations.

How many animals may be supported in NCA?
(Sections 2.1, 2.3)

The answer to this question is, “It depends upon the ratio of livestock to wildlife, and the method used to estimate the number of animals that may be supported.”

This answer may seem weak, but is the most appropriate response based upon our results. We used a suite of methods that seek to predict appropriate herbivore biomass based on:

- regression techniques, where stocking on sites around a region are statistically related to rainfall or plant production, allowing stocking to be estimated for new sites;
- management and land use, where stocking on other areas was used as a reference, and herbivore stocking (the balance between livestock and wildlife) was assigned to NCA management zones based upon their use;
- spatial analyses, where satellite images were used to estimate plant production, then the amount of forage needed by each animal each day was used to estimate how many animals might be appropriate for the area;
- ecological modeling, where the Savanna ecosystem model was used to integrate many relationships, such as limits on the access of animals and the balance between animal groups, and appropriate stocking was estimated.

These methods yielded 14 estimates of appropriate stocking on NCA, plus our estimate of current stocking. General rules of thumb have been cited, and demonstrated in our results. If a given amount of wildlife biomass may be supported on NCA, about twice that may be supported if both wildlife and livestock were present, and about ten times as much if only livestock were present and the area was managed intensively. Specifically, we estimate based upon many sources that NCA currently contains about 218,865 large herbivore units (LHUs), if averaged over the whole year. That number varies between 488,886 LHUs in the wet season, and 122,019 LHUs in the dry season. Livestock comprise about 21% of the total in the wet season, 80% of the total in the dry season.

We estimated that appropriate stocking for

NCA was between 181,246 LHUs and 541,716 LHUs. More telling, an integrated approach using ecological modeling showed the capacity of NCA to be 250,925 LHUs, slightly higher than the current stocking on NCA. This compares well with the pattern of relatively stable resident livestock and wildlife populations in NCA over decades. However, in modeling, we do not see the ability of NCA to support significantly more livestock, to increase the tropical livestock units (TLUs) per person and allow Maasai to return to a more pastoral lifestyle. Currently Maasai have about 2.77 TLUs per person, which allows them to meet roughly 35% of their household needs through livestock, assuming that 8 TLUs per person is the baseline required to lead a pastoral lifestyle. To bring that to 6 TLUs per person, for example, would require 250,111 cattle and 418,050 small stock on NCA – our modeling indicates that NCA cannot support that many animals. It seems policy makers must search for means of limiting population growth within NCA, encourage emigration, or provide more access to income sources other than through livestock raising.

How much land is cultivated in NCA, and where?
(Section 2.2)

We mapped 3,967 ha or 9,803 ac in cultivation in NCA in February of 2000. The cultivation was mostly around Endulen and on the northern slopes of Empaakai.

We mapped cultivation based upon a satellite image made-up of picture elements representing 15 m x 15 m patches on the ground. With assistance from V. Runyoro, we identified many known cultivated patches, and found that they often had a distinctive appearance in the image. Computer image processing techniques were used to map cultivation outside of NCA. However, most cultivation inside NCA was mapped using an image editing package, where the user pointed to a patch of cultivation, and the computer identified the patches' shape and size automatically, based upon the colors in the image. We believe we have mapped the bulk of cultivation successfully, but small patches were missed, some confusion with

brush lands occurred, and the map has not been assessed using ‘ground-truthed’ information.

There is some disagreement between the NCA boundary available to us and the extent of cultivation in the southeastern part of the area. Encroachment of cultivation into the highland forests to the east appears to be occurring. Forests on the north-western slope of Olmoti have also been converted to cultivation. Areas to the south of Endulen (e.g., Kakesio) appeared to have little cultivation.

What is the effect of cultivation on wildlife, livestock, and people in NCA? (Section 2.4)

Our simulation modeling suggested only modest changes to wildlife and livestock populations under current or increasing cultivation in its current distribution. Under current economic conditions, cultivation is critical for food security for Maasai of NCA.

We used Savanna ecosystem modeling to examine potential effects of current and increasing cultivation on wildlife and livestock. We also examined effects of increasing human population and cultivation (but relatively stable livestock populations) on Maasai food security. The cultivation map already described was recalculated to represent the amount of cultivation in 25 km² blocks that represented NCA. Then simulations were done with and without cultivation, and the results compared. Similarly, simulations were done comparing cultivation at its current level (about 10,000 acres), and at higher levels (20,000 ac, 30,000 ac, 50,000 ac).

The cultivation we mapped, 9,803 ac, represents about 1.1% of the Pastoralist Development Management Zone, excluding Olduvai Gorge (although not all within the zone). In modeling, that level of cultivation led to small changes in livestock and wildlife biomass, compared to no cultivation. We increased cultivation to 50,000 ac, or about 5.5% of the Pastoralists Development Management Zone, and did not see large changes in livestock or wildlife populations. Maasai food security declined markedly when human population and cultivation were increased in concert, because of fewer TLUs/person. In past work we have dem-

onstrated that cultivation is important in maintaining the food security of NCA Maasai. For example, based upon our current estimates, if cultivation were disallowed, requirements for supplements for poor families in NCA would almost double.

What are the effects likely to be from improved veterinary care? (Section 2.5)

A marked increase in livestock populations and potential damage to the ecosystem, unless markets are available. Market sales benefit Maasai.

Again, the Savanna model was used to estimate potential effects from improved veterinary practices. A source of mortality associated with disease was included in the Savanna model, which was used to alter adult livestock mortality. Another setting that controls general survival from year to year was altered to reflect improved survival of juvenile livestock. In general, these changes in care reflected increased vaccinations for East Coast fever and other infectious diseases.

Our modeling suggests that current efforts to reduce losses due to disease have the potential to increase the population growth rate for livestock, especially cattle. In general, reducing juvenile mortality appears to be the investment in veterinary care that yields the largest returns. Cattle populations increased until capacity was reached (although still limited somewhat by disease), and remained stable or declined as vegetation biomass was reduced. When excess animals (relative to current populations) were sold, the ecosystem essentially remained unchanged. If livestock production is to be increased through improved veterinary care, market access must be adequate to allow Maasai to sell excess animals, and market conditions must encourage them to do so.

What are the magnitude of effects of human population growth? (Sections 2.1, 2.3, 2.4)

Profound. Any solutions to food security for today will likely be inadequate in a few years, if current population growth rates continue.

We used methods from simple mathematics to complex ecological and socioeconomic modeling

to assess what the effects of future human population growth rate may be. Using the most conservative recent estimate, the Maasai population within NCA is growing at about 3.5% per year, both due to better health care and to immigration. The population in 1999 of 51,600 is expected to be 100,000 in 2019, and 150,000 in 2030. If livestock populations remain constant, TLUs per person would fall from 2.77 in 2000 to 1.39 in 2019, and to 0.92 in 2030, with a corresponding need to increase supplements to livestock sources to maintain food security. As another example, allowing limited cultivation improved the food security for Maasai in 1992, but by the late 1990s any benefits had been offset by an increased human population.

Given that increasing cultivation is politically difficult and that livestock populations appear to be near the maximum that NCA may support, deficiencies will need be compensated from other sources, such as wage labor, mostly from outside NCA, or a greater contribution to pastoral livelihoods from tourism. Livestock production in NCA

also may be intensified, with animals being raised and sold with more rapid turn-over than today, without a large increase in the number of livestock on NCA. Lastly, relief in the form of food from governmental and non-profit agencies may need to be increased.

Difficulties abound in the management of Ngorongoro Conservation Area, but those struggling with the difficulties – and those living under restrictions the area's status brings – contribute to knowledge about management of semi-arid lands. The issues addressed here, such as stocking rates, encroachment from cultivation, and human population growth, are by no means unique to NCA. In many other places in East Africa and elsewhere, land use intensifies without oversight, often with undesirable results. Ngorongoro is not unique because of the magnitude of its problems, but rather because those problems are being faced, head-on, by policy makers, stakeholders, and community groups.

1. INTRODUCTION

In 1959, the Tanzanian government gazetted Ngorongoro Conservation Area (NCA), to be managed explicitly as a multiple use area by the Ngorongoro Conservation Area Authority (NCAA; the Ngorongoro Conservation Unit prior to 1975). The NCAA was charged with balancing the needs of Maasai inhabitants and their livestock, as well as the wildlife for which NCA is renowned, and the tourism industry that the wildlife supports. Thus, the management of NCA represents a unique and important experiment in balancing multiple uses that has continued for more than 40 years. Balancing competing needs has never been straightforward in NCA, but is becoming more and more difficult as demands for land intensifies.

1.1. The Area

Ngorongoro Conservation Area (Figure 1), is 190 km west of Arusha, Tanzania and bordered by Serengeti National Park to the west and northwest, Loliondo Game Controlled Area to the north, and private and communal lands to the southeast and south. Rift Valley lakes south and east of NCA include Lake Eyasi, Lake Natron, and Lake Manyara, which is bordered by Lake Manyara National Park. NCA is topographically diverse, comprised of nine volcanoes (Oldonyo Lengai remains active), three of which have formed calderas, including Olmoti Crater with its grassy floor, Empakaai Crater dominated by a lake, and the world-renowned Ngorongoro Crater, at 250 km²

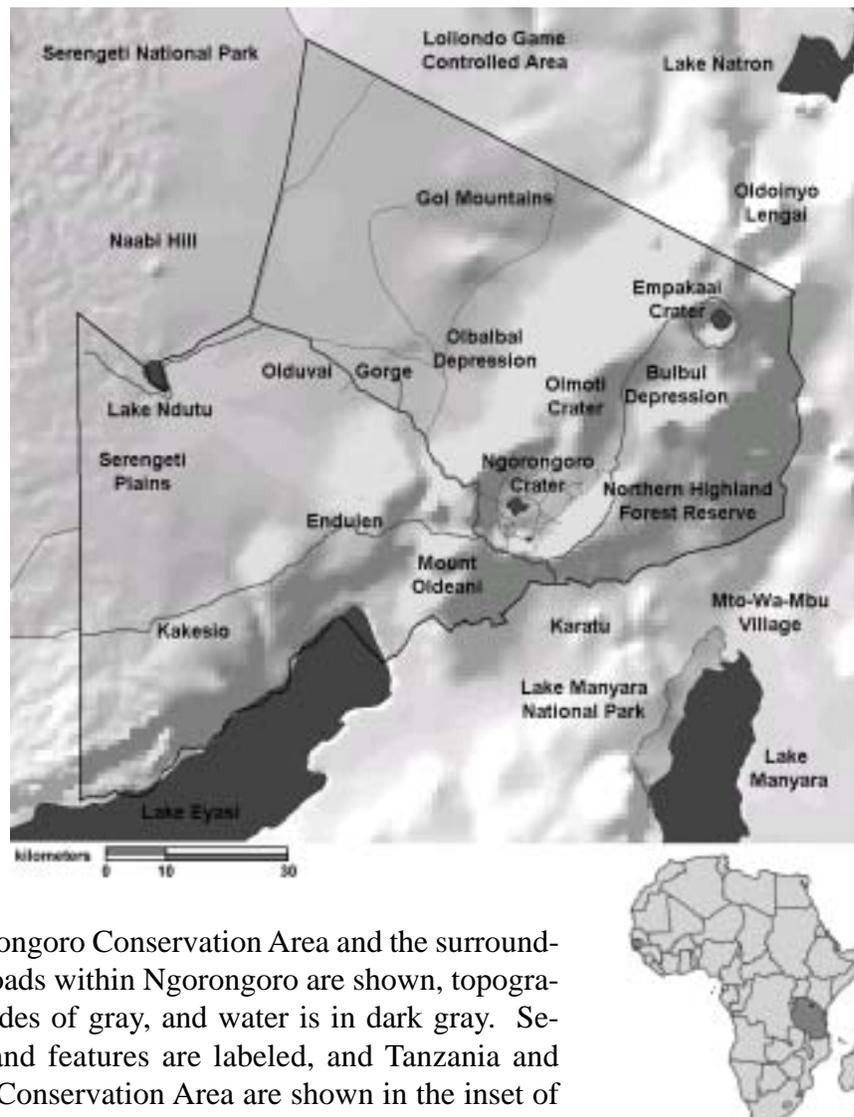


Figure 1. Ngorongoro Conservation Area and the surrounding area. Roads within Ngorongoro are shown, topography is in shades of gray, and water is in dark gray. Selected sites and features are labeled, and Tanzania and Ngorongoro Conservation Area are shown in the inset of Africa.

one of the worlds' largest unbroken, non-flooded calderas.

Ngorongoro is a semi-arid region, and like many such areas, the quantity and timing of rainfall in a given year can vary greatly (Ellis and Galvin 1994). Storms move in from the southeast and the Indian Ocean, and during the short (November and December) and long rains (March through May) precipitation is heavy, especially in the Ngorongoro Highlands. January and February are usually dry, and the long dry season extends from June to October. The highlands of NCA receive the most rainfall in the region, but contribute a strong rain shadow effect, with areas to the northwest such as Olduvai Gorge receiving the lowest rainfall of the region, at about 450 mm annually. Across the entire conservation area, an average of 712 mm of precipitation falls annually, based on our data. That said, there is considerable variation in the amount of rainfall, and rarely does NCA have a 'typical' year.

These rainfall patterns and steep elevational gradients lead to a complex mix of vegetation within NCA. The plains are dominated by low and medium grasses. On the hillsides are tall grasses, sometimes mixed with shorter grasses and exotic species (e.g., *Eleusine jaegeri*). The highlands also contain some large areas of grass, such as Bulbul Depression and grazing areas around Endulen. The lower slopes of NCA are dominated by Acacia shrubs and trees, with Acacia trees scattered throughout the woodland. The highland forest is composed of evergreen trees of many types, as well as heaths and a bamboo forest. Ngorongoro Crater contains Lake Magadi and several swamps, such as Gorigor Swamp to the south. The crater also contains the Lerai Forest, however, the bulk of the crater is grassland, habitat used by wildlife.

NCA supports world-renowned populations of wildlife, including the only free-ranging population of black rhinoceros in East Africa, about 14 animals that inhabit Ngorongoro Crater. Elephant, wildebeest, buffalo, lions, and many other species inhabit the crater as well. Outside the crater, and in the wet season, the migratory herds of wildebeest, zebra, and Thomson's gazelle dominate the plains of Ngorongoro. Smaller resident popula-

tions of these species remain year-round, joined by others such as Grant's gazelle, buffalo, impala, kongoni, and giraffe. Owing to its unique combination of wildlife, scenery, and pastoral land use, the NCA has been recognized as a Natural World Heritage Site (1979) and made a Biosphere Reserve (1981) under United Nations UNESCO Man and Biosphere Programme.

1.2. The People

Humans have inhabited NCA for eons, with discoveries by the Leakeys and others of early human remains in Olduvai Gorge, the Laetoli footprints of early humans, and Nasara rock shelter. Maasai pastoralists are the latest group to have moved into NCA, about 200 years ago – there is general agreement that the culture of the Maasai allowed the wildlife just cited to persist in the region. The Maasai are semi-nomadic pastoralists, sometimes moving great distances to find adequate forage and water for their herds of cattle, goats, and sheep, as well as donkeys that serve as pack animals. Seasonal movements were very important to the Maasai in the past, and remain important today, to a lesser degree. Historically, Maasai moved from the midlands and highlands of NCA down into the plains in the wet season, their herds grazing in the short grasses until water became scarce. They would then return to the midlands and highlands during the late dry season, herding animals amongst the green vegetation at higher elevations, and awaiting the short rains. These movements, combined with the relatively low human population, allowed Maasai to maintain food security. Reduced opportunities for movement and human population growth have changed that, as described below.

1.3. Increasing Demands for Land

Almost all stakeholders in NCA (e.g., conservationists, livestock owners, cultivators) have increased their need for land in NCA in recent decades. The migratory wildebeest population was decimated by the introduction of rinderpest in the late 1800s. Their numbers remained suppressed until the 1960s when rinderpest control within the livestock population reduced disease in wildebeest

(Sinclair 1995). The wildebeest population quickly recovered, from about 250,000 animals in 1961 to a peak of about 1.4 million animals in 1977. Today researchers estimate that there are about 1.2 million migratory wildebeest in the Serengeti Ecosystem. Perhaps half of these animals spend some number of weeks calving and foraging within NCA, during the wet season (February to April). Assuming a similar ratio occupied NCA in the past, there has been almost a five-fold increase in the number of wildebeest supported on the system over the last 40 years.

Intensified use of NCA by wildebeest had a direct effect upon Maasai herders. Wildebeest calves are either born infected with, or soon become infected with, *Alcelaphine herpesvirus 1*, the virus that causes malignant catarrhal fever in cattle. The virus presumably does no harm to wildebeest, but the wildebeest calves spread the disease on foliage through their mucus, and foraging adult cattle that follow and become infected will almost always die. Maasai herders are fully aware of the threat wildebeest calves pose to their cattle. Whereas they would herd their cattle in the short grass plains during the wet season in the past, today they must move out of the plains in the wet season, into the midlands and highlands (McCabe 1995). Cattle are denied access to the nutritious young grasses of the short grass plains, but also must now inhabit the highlands longer and perhaps at higher densities, with greater exposure to ticks and tick-borne diseases, such as East Coast fever. For this, and no doubt other reasons, the numbers of livestock in NCA has been essentially constant for decades, although small stock have increased relative to cattle (Figure 2b).

Livestock populations have been relatively constant, but the human population has not. In 1959, when NCA was gazetted, the population was about 10,000 people. In 1999, the last survey available, the population was estimated at about 51,600 people (Figure 2a, NCAA 2000), and increasing at an annual growth rate of about 4.3% (3.5% overall, from 1954 to 1994; Kijazi 1997). This high growth rate is due in part to improved survival and health care, and also to the immigration of Maasai and non-Maasai people into NCA. There are in-

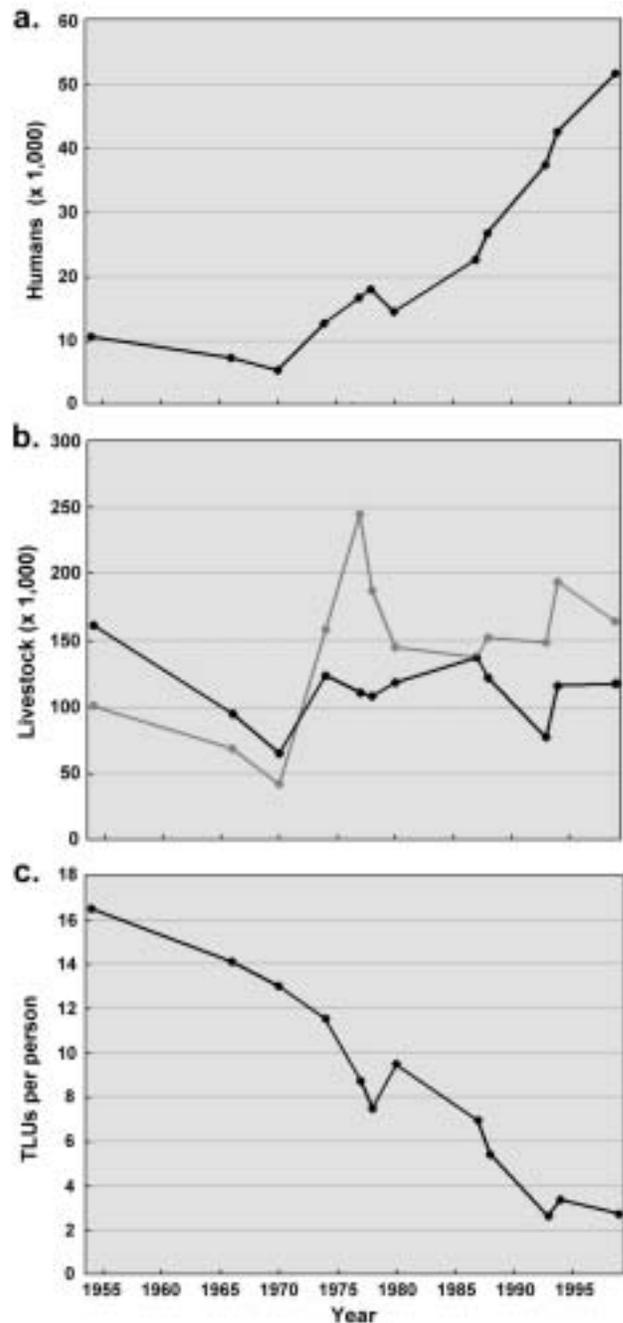


Figure 2. The human population in NCA over the last 45 years has increased steadily (a), whereas cattle (b, black line) and small stock (b, gray line) populations have been relatively stable. When standardized, the number of tropical livestock units (TLUs) per person had declined dramatically (c). Adapted from Kijazi et al. (1997) and NCAA (2000), and using the conversion of livestock units from NCAA (2000) of cattle equal to 1 TLU and small stock equal to 1/7th TLU.

sufficient data to calculate a natural growth rate of the population within NCA (that is, remove effects of immigration), but Kijazi (1997) estimated that the rate is about 2.3% per year. A constant number of livestock and steadily increasing human population bodes poorly for a pastoral society. Specifically, researchers standardize counts of different types of animals (e.g., cattle, sheep, goats) based upon body size to yield tropical livestock units (TLUs). They also standardize people of different ages and sexes to yield adult equivalents (AEs). Researchers studying pastoral societies have judged that at least 6 TLU/AE are required for the members to lead a wholly pastoral lifestyle (Brown 1973; Galvin 1992). The need for spendable income has increased in recent decades (e.g., to pay school fees and purchase food), and so as others have done, in some analyses we will increase this ratio and consider that people may maintain a pastoral lifestyle if, essentially, each adult had eight cattle (8 TLU/AE). Kijazi et al. (1997) and NCAA (2000) report human populations rather than AEs, but taking those as similar, when NCA was created, there were more than 15 TLU/person. By 1986, the ratio had fallen below 8 TLUs/person, and in 1999 was about 2.4 TLUs/person. Recent interviews with members from a sample of households yielded 2.77 TLUs/person (Lynn 2000), similar (2.74) to calculations by NCAA (2000). Theory strongly suggests then that the Maasai of NCA cannot maintain a wholly pastoral lifestyle given their current livestock holdings.

Experiences of NCA Maasai loudly echoed these theoretical suspicions. In 1975 cultivation was banned in NCA, but by 1991 food security for the Maasai was so tenuous that the Tanzanian government temporarily allowed limited cultivation. Most Maasai became agro-pastoralists, doing small-scale subsistence cultivation of mostly maize and beans (Kijazi et al. 1997). Some large-scale cultivators, generally from tribes other than Maasai, have been cultivating in NCA as well, such as around the Endulen area. In 2001 the Tanzanian government planned to once again ban cultivation, but did not make final decisions. At present, the government intends within about 5 years to reinstate the ban, and to shift cultivation from within

NCA to blocks of land in Loliondo Game Controlled Area, to the north of NCA (V. Runyoro, NCAA, pers. comm.).

1.4. GL-CRSP Activities

From 1997 to 2000 a team led by Dr. Michael B. Coughenour and supported by the Global Livestock Collaborative Research Support Program (GL-CRSP), addressed potential management questions in NCA in a project known for the method of investigation used, the *Integrated Management and Assessment System*, or IMAS. The overarching goal of the project was to assist policy makers and stakeholders to balance food security for pastoralists, wildlife conservation, and ecosystem integrity. We reported upon the results from integrated assessments (Boone et al., 2002; Boone and Coughenour 2001), modeling pastoral welfare (Thornton et al., In press; Galvin et al. 2000), effects of climatic variability (e.g., Galvin et al. 2001; Boone et al. 2000), areas of importance and effects of disease (Rwambo et al. 2000), and the compatibility of pastoralism and conservation in the area (Galvin et al., In press). These works, and others listed in Boone and Coughenour (2001), laid a strong foundation for the efforts of our current research team. The results of our work were provided to NCAA personnel through workshops, presentations, and reports.

In 2000, the Conservator of NCAA, Mr. Emmanuel Chausi, approached us with questions our team was poised to address. To paraphrase, he asked:

- How many animals may be supported in NCA?
- What is the effect of cultivation on wildlife, livestock, and people in NCA?
- What are the effects likely to be from improved veterinary care on livestock populations, wildlife, and people?

To which we added some questions that needed to be addressed prior to, or in concert with, those listed:

- What are the magnitude of effects of human population growth?
 - Where and how much land is cultivated in NCA?
- These basic questions, and often similar questions in three other research sites in which we work,

spurred us to propose to the GL-CRSP that we use integrated assessments to assist policy makers and other stakeholders in their decision making, by suggesting potential trade-offs in different management options. The GL-CRSP, in turn supported by the US Agency for International Development, has funded our project entitled *POLEYC*, for *Policy Options for Livestock-based livelihoods, and Ecosystem Conservation*. Our first goal was to address the questions put to us by the Conservator of NCAA, and important to all stakeholders in NCA. This report reviews our results.

2. POLICY QUESTIONS

2.1. What is the Capacity of NCA to Support Large Herbivores?

Although the population of migratory wildebeest has increased greatly in the last 30 years, the large herbivore biomass resident on NCA appears relatively stable – catastrophic declines in wildlife have not occurred, and livestock biomass has been stable (NCAA 2000). Runyoro et al. (1995) provide more rigorous evidence that biomass within Ngorongoro Crater has remained stable over 30 years. Efforts are underway to increase the number of livestock in NCA, and to improve the survival of the pastoral herds (DANIDA 2001). However, the number of large herbivores that may be supported on NCA is unknown. It may be that an increase in livestock populations will have minimal effect upon wildlife, and that forage on NCA remains unused from year to year. Or, increases in livestock populations may lead to decreases in wildlife populations. Our goal is to estimate the large herbivore biomass that may be supported on NCA, based upon forage availability, so that we may begin to predict how changes in herbivore populations may affect the ecosystem as a whole.

Our objective is to use several methods to calculate the capacity of NCA to support large herbivore biomass. The term ‘carrying capacity’ is a confusing and contentious one (Caughley 1980; Dhondt 1988), but important to land managers. The capacity can be defined in many ways (Scarnecchia 1990), such as that set by predation, disease, political realities, or climatic limitations, but here we

focus upon forage-based carrying capacity. Essentially, we ask “How much forage is available for wildlife and livestock in NCA?” We use ‘carrying capacity’ (or simply capacity) as a measure of the large herbivore biomass that may be supported over the long term without degrading the vegetation, following the definition of the Society of Range Management (1989). Although we limit ourselves to forage-based carrying capacity, our objective is to calculate that capacity in the context of climatic variation, limitations to access by animals, and habitats available on NCA. Each of the methods that we will use to calculate capacity has advantages and limitations, which will be reviewed, but taken in-total, they will suggest a range of herbivore biomass that may be supported on the system in a sustainable way. Managers and stakeholders may then examine these capacities, in light of the management goals established for NCA. Large herbivore units (LHU) used to estimate capacity will be calculated in a simple way based upon body mass (using Coe et al. 1976), recognizing that more rigorous methods are available (Scarnecchia 1990). An LHU is 250 kg, so a 200 kg zebra equals 0.8 LHU, and a 1,725 kg elephant equals 6.9 LHUs. Note that LHUs are analogous, but not equal to, TLUs. For example, adult cattle are taken to be equal to 1 TLU, whereas a cattle (averaged across all ages) is considered 180 kg (Coe et al. 1976), or 0.72 LHUs.

The current large herbivore populations on NCA, drawn from a variety of sources, are shown in Table 1. The values shown reflect animal functional groups we have used in past modeling exercises (e.g., ‘grazing antelope’ combine several species), and exclude some herbivores (e.g., ostrich). Using the list of animal masses from Coe et al. (1976), we estimate that at the peak of the wet season, and if all migratory populations (i.e., wildebeest, zebra, Thompson’s gazelle) peaked at the same time (which is typically not the case, but a close approximation), NCA contains 488,886 LHUs. In the dry season, when the migratory animals have moved off NCA, the system contains 122,019 LHUs.

Table 1. Population estimates for large herbivore functional groups (see Boone et al., 2002) in Ngorongoro Conservation Area. Estimates, converted to LHUs, are shown for animals at peak migration (i.e., "wet season"), and when migratory animals have moved off the NCA ("dry season").

Functional group	Population ^a	Body mass ^b kg/animal	LHUs/NCA in wet season ^c	LHUs/NCA in dry season ^c
Cattle	115,468	180	83,137	83,137
Goats	130,000	18	9,360	9,360
Sheep	63,000	18	4,536	4,536
Migratory wildebeest	625,000	123	307,500	0
Migratory zebra	62,959	200	50,367	0
Migratory grazing antelope	150,000	15	9,000	0
Resident wildebeest	9,000	123	4,428	4,428
Resident zebra	7,087	200	5,670	5,670
Resident grazing antelope	13,600	30	1,632	1,632
Buffalo	3,150	450	5,670	5,670
Browsing antelope	2,654	40	425	425
Elephant	300	1,725	2,070	2,070
Rhinoceros	15	816	49	49
Giraffe	1,666	750	4,998	4,998
Warthog	250	45	45	45
Total			488,886	122,019

- a - Functional groups 'Area' and 'Crater' for browsing antelope and buffalo in Boone et al. (2002) are combined here (see Boone et al. 2000 for more detail). One-half of the entire population of migratory wildebeest were estimated to enter NCA (Sinclair, pers. comm.), which is similar to that reported for Thomson's gazelle (42%) and eland (45%), as derived from Campbell and Borner (1995) and Boshe (1997). Populations were drawn from: Estes and Small (1981); Sinclair (1987); Perkin and Campbell (1988); Homewood and Rodgers (1991:120-121); Campbell and Borner (1995); Runyoro et al. (1995); Kijazi et al. (1997); Boshe (1997); Machange (1997, for the ratio of sheep to goats); and NCAA (2000), plus personal communications with K. Campbell, V. Runyoro, and A.R.E. Sinclair.
- b - From Coe et al. (1976), except for functional groups with mixed species (i.e., resident grazing antelope, browsing antelope), which were estimated from the ratio of species and their masses in each group.
- c - LHU (large herbivore unit) may be defined as 250 kg of live-weight of large herbivores, akin to the definition used in tropical livestock units in the region.

In the next five sections, we present a series of estimates of the capacity of NCA to support large herbivores. Our intention in using a wide variety of methods is to demonstrate the diversity of views researchers have about capacity, and to provide a lower and upper estimate of capacity for NCA that we believe is reasonable. For completeness, we present our results in some detail, at the risk of confusing the reader. *To aid in interpretation, these estimates are tabulated and summarized graphi-*

cally in a discussion of this section. The methods used were based upon: annual rainfall, monthly rainfall, management zones, spatial analyses with remotely sensed data, and ecological modeling. Each is reviewed in the following sections.

2.1.1. Annual Rainfall

Ecologists have long recognized that above-ground net primary productivity (here essentially the vegetative mass produced by a plant annually)

in semiarid and arid areas is related to annual precipitation (Krebs 1978). Rosenzweig (1968) plotted a curvilinear relationship between net annual aboveground primary production (NAAP) in vegetation types across the globe and precipitation, and a linear relationship to actual evapotranspiration. Phillipson (1975) used this relationship and observations from Tsavo National Park (East), Kenya to estimate elephant carrying capacity for the park. The relationship between wildlife biomass, production, and rainfall was later explored (Coe et al. 1976) across eastern and southern Africa, and were highly correlated (e.g., $r^2 = 0.92$, $N=20$, $P<0.001$). A similar relationship was found for pastoral ecosystems, with biomass values elevated above ecosystems with wildlife alone (Coe et al. 1976, discussed by Sharkey 1970). In the next decade, the relationships between rainfall, productivity, and herbivore biomass were explored further. For example, Le Houérou et al. (1988) demonstrated that in semiarid and arid areas of the world, annual precipitation was linearly related to annual aboveground primary production, implying that annual production is water-limited. In 1989, McNaughton et al. showed that after log-log transformation, net annual primary production was associated with African large herbivore biomass ($r^2 = 0.58$, $DF=49$, $P<0.001$), consumption, and secondary productivity. The technique was applied specifically to livestock systems in South America (Oosterheld et al. 1992) and a regression with a similar slope was found ($r^2 = 0.80$, $DF=65$, $P<0.001$), although as in Coe et al. (1976), the livestock biomass supported at a given level of NAAP was about an order of magnitude higher than herbivores in natural systems (Sharkey 1970).

We used the regression equations derived by Coe et al. (1976), and those of McNaughton et al. (1989) and Oosterheld et al. (1992), which depend upon Rosenzweig's (1968) calculation of annual NAAP or a similar relationship to estimate large herbivore biomass that may be supported in NCA over the long-term. These authors did regression analyses using stocking on areas as their independent variable. That implies that the results do not necessarily reflect carrying capacity, but rather typical stocking of sites given a broad scale pattern. In

analyses we present that are not forage-intake based, but instead rely upon regression results, we assume that the stocking rate predicted reflects appropriate carrying capacity. This in-turn implies that the populations used by the authors (e.g., McNaughton et al. 1989) were at relative equilibrium, over the long term. Conversions not used by the original authors were used here to yield the same units in each method, as much as possible. Precipitation data from November 1973 to October 1988 were used to estimate mean rainfall over the entire period, interpolated using inverse distance weighted smoothing. Annual rainfall amounts (from November to the following October) were also used to assess the year-to-year variation in large herbivore capacity that may be expected (but see limitations). These estimates of annual rainfall were spatially explicit, but the regression equations will represent production and stocking for NCA as a whole.

From 1974 (i.e., November 1973 to October 1974) to 1988 the NCA had an average annual rainfall of 712 mm (Table 2), with a low of 501 mm in 1976 and a high of 1,031 mm in 1977. In the method of Coe et al. (1976) where they included pastoral and wildlife areas in their regression, a mean of 6,419 kg/km² of larger herbivore biomass was calculated to be supported on NCA over the long term (Table 2), and 212,609 LHUs for all of NCA. Coe et al. (1976) also provided a linear regression equation using 12 areas with only wildlife. When used here (not shown tabulated), an average of 4,981 kg/km² and 164,976 LHUs could be supported long-term. As noted (Coe et al. 1976; Oosterheld et al. 1992), pastoral systems tend to support more biomass than systems with only wildlife. Using Rosenzweig (1968) to calculate NAAP and the biomass formula from McNaughton et al. (1989) yields a mean capacity for NCA of 5,625 kg/km², or 186,315 LHUs for the NCA (Table 3). When a formula developed for livestock systems was used (Oosterheld et al. 1992), 2,709,168 LHUs was estimated to be supported for NCA (Table 4). This is about an order of magnitude larger than predicted for the unmanaged system, as expected (Sharkey 1970; Oosterheld et al. 1992).

Table 2. Large herbivore biomass capacity calculated for Ngorongoro Conservation Area using the method of Coe et al. (1976). In the regression from Coe et al. used here, pastoral and wildlife ecosystems were included.

Year ^a	Herbivore biomass ^b		LHUs in NCA ^c
	Rainfall mm/yr	kg/km ²	
1974	666	5,781	191,480
1975	574	4,590	152,027
1976	501	3,717	123,094
1977	1031	11,391	377,283
1978	855	8,519	282,164
1979	771	7,256	240,325
1980	716	6,469	214,247
1981	764	7,154	236,947
1982	504	3,751	124,240
1983	774	7,300	241,778
1984	614	5,096	168,783
1985	749	6,937	229,766
1986	606	4,993	165,382
1987	817	7,939	262,941
1988	745	6,880	227,865
Average	712	6,419	212,609

a - Defined, for example, as November 1973 to October 1974, and labeled as 1974

b - Large herbivore biomass, where:

$$\log_{10} \text{Biomass} = 1.552 * \log_{10}(\text{Rainfall}) - 0.62, \text{ by Coe et al. (1976).}$$

c - Given that NCA is 8,280 km², and a LHU (large herbivore unit) may be defined as 250 kg of live-weight of large herbivores, then LHUs in NCA are:

$$\text{LHUs} = (\text{biomass (kg/km}^2\text{)} * 8,280) / 250$$

These calculations provide extremes to frame the analyses that follow. Setting-aside the limitations discussed below, if NCA were dedicated solely to wildlife, its forage-based capacity would be 164,976 LHUs. If the NCA were dedicated solely to intensively managed livestock production (e.g., plowing and seeding, fertilizing, use of pesticides), its capacity is estimated at 2,709,168 LHUs. In a regression based on combined wildlife and pastoral ecosystems, the estimated capacity was 212,609 LHUs.

2.1.2. Monthly Rainfall

The migratory herbivores that move on-and-off of NCA may make annual estimates of capac-

ity misleading. Coe et al. (1976) included Ngorongoro Crater and Serengeti National Park in their data set, providing some evidence that areas within the entire ecosystem fell along the regression line as expected. However, comparing estimates of productivity to our estimates of large herbivore biomass by month may be instructive. The regression equations we have been using (Coe et al. 1976; McNaughton et al. 1989; Oesterheld et al. 1992) were not developed based upon months, but there is precedence in modifying them for that use. Phillipson (1975:175) applied a multiplier (i.e., 2.911) to Rosenzweig's (1968) formula for calculating NAAP, which he then used to calculate net monthly aboveground primary productiv-

Table 3. Large herbivore biomass capacity calculated for Ngorongoro Conservation Area using the method of McNaughton et al. (1989).

Year ^a	Rainfall	NAAP ^b	Herbivore biomass ^c	
	mm/yr	kJ/m ² /yr	kg/km ²	LHUs in NCA ^d
1974	666	17,834	4,745	157,160
1975	574	13,934	3,261	108,004
1976	501	11,117	2,314	76,627
1977	1031	36,837	14,293	473,376
1978	855	26,998	8,912	295,181
1979	771	22,740	6,866	227,388
1980	716	20,111	5,696	188,655
1981	764	22,398	6,709	222,215
1982	504	11,228	2,349	77,790
1983	774	22,887	6,933	229,627
1984	614	15,582	3,865	128,014
1985	749	21,673	6,382	211,370
1986	606	15,247	3,739	123,847
1987	817	25,036	7,947	263,191
1988	745	21,481	6,296	208,534
Average	712	19,946	5,625	186,315

a - Defined as in Table 2.

b - NAAP = Net above ground primary productivity, where:

$\log_{10} \text{NAAP} = 1.66 * \log_{10}(\text{Rainfall}) - 1.66$, by Rosenzweig (1968), with rainfall substituted for actual evapotranspiration in this semi-arid area, following Coe et al. (1976) and others. Rosenzweig's formula provides g/m²/yr, and a conversion to kJ (i.e., 16.72 kJ/g) was provided by Golley (1961), as used by Oosterheld et al. (1992).

c - Large herbivore biomass, where:

$\log_{10} \text{Biomass} = 1.52 * \log_{10}(\text{NAAP}) - 4.79$, by McNaughton et al. (1989), and yielding kJ/m². These were converted to kg/km² using 9,900 kJ per kg of livestock fresh weight (Coughenour et al. 1985); i.e., $\text{kg/km}^2 = \text{biomass kJ/m}^2 / 9,900 * (1000*1000)$.

d - Defined as in Table 2.

ity (NMAP) for Tsavo National Park, East, Kenya. As a check, Phillipson (1975) also summed the monthly estimates (NMAP), which compared favorably with the annual estimate (NAAP).

Methods analogous to those used in Section 2.11 were used here, except that Coe et al. (1976), which did not use NAAP as a basis for calculating capacity, was not used here. Following Phillipson (1975), we used a multiplier of NMAP (here 3.62), which when summed over months to yield NAAP compared well with the annual estimates ($r^2 = 0.94$, $n=15$ years, and nearly equal means).

Figure 3 shows the anticipated monthly primary productivity in NCA using the modified method of Rosenzweig (1968). Productivity varies in each year, reaching a peak during the wet season (March or April), and dropping to near zero in the dry season (July, August, and September). The change in productivity through the year mirrors estimates of actual large herbivore biomass on the ecosystem (Figure 4). Large herbivore capacity for the ecosystem is shown for the wettest and driest years, for the period used, in Table 5. Monthly variations in productivity (Figure 4) suggest that the severity and duration of the dry season may limit

Table 4. Large herbivore biomass capacity calculated for Ngorongoro Conservation Area using the method of Oesterheld et al. (1992). Livestock biomass is the focus of Oesterheld et al. (1992).

Year ^a	Rainfall mm/yr	NAAP ^b kJ/m ² /yr	Herbivore biomass ^c kg/km ²	LHUs in NCA ^d
1974	666	17,834	68,368	2,264,350
1975	574	13,934	46,043	1,524,936
1976	501	11,117	32,067	1,062,073
1977	1031	36,837	218,550	7,238,376
1978	855	26,998	132,852	4,400,056
1979	771	22,740	100,910	3,342,132
1980	716	20,111	82,882	2,745,045
1981	764	22,398	98,492	3,262,045
1982	504	11,228	32,581	1,079,070
1983	774	22,887	101,957	3,376,826
1984	614	15,582	55,076	1,824,123
1985	749	21,673	93,433	3,094,490
1986	606	15,247	53,188	1,761,600
1987	817	25,036	117,723	3,898,993
1988	745	21,481	92,112	3,050,737
Average	712	19,946	81,799	2,709,168

a - Defined as in Table 2.

b - Defined as in Table 3. Note that Oesterheld et al. (1992) used a different linear model to predict NAAP (i.e., Lauenroth 1979) than was used here.

c - Large herbivore biomass, where:

$\log_{10} \text{Biomass} = 1.602 * \log_{10}(\text{NAAP}) - 3.98$, by Oesterheld et al. (1992), and yielding kJ/m². These were converted to kg/km² using 9,900 kJ per kg of livestock fresh weight (Coughenour et al. 1985, and used in Oesterheld et al. 1992); i.e., $\text{kg/km}^2 = (\text{biomass, kJ/m}^2) / 9,900 * (1000 * 1000)$.

d - Defined as in Table 2.

large herbivore capacity. However, monthly estimates of large herbivore capacity (e.g., Table 5) are not particularly informative. The capacity of a system to support large herbivores over the long term represents an integration of the available resources over that term. Calculating NMAP (Figure 4) is a sound method of looking at variation within the ecosystem. However, after using NMAP to calculate monthly larger herbivore capacity (e.g., Table 5), we believe that it is an inappropriate way to assess capacity; a monthly assessment approaches an ‘instantaneous carrying capacity,’ which is incongruous with the idea of carrying capacity being applicable over the long-term.

2.1.3. Management Zones

The Ngorongoro Conservation Area Authority has defined five management zones and a subzone (NCAA 1996), used to delimit land uses (Figure 5). The Highland Forest Zone serves as a water catchment area and supports wildlife in its forests and glades. Pastoralists apply for permits to graze livestock in the glades within the forest reserve during droughts. In practice, grazing in the reserve occurs without permits being issued, and pastoralists are periodically removed from the reserve. The Ngorongoro Crater Zone is devoted to wildlife and tourism. Pastoralist herders may enter the Crater to water their animals and for minerals, but they may not linger. The Lake Eyasi Basin

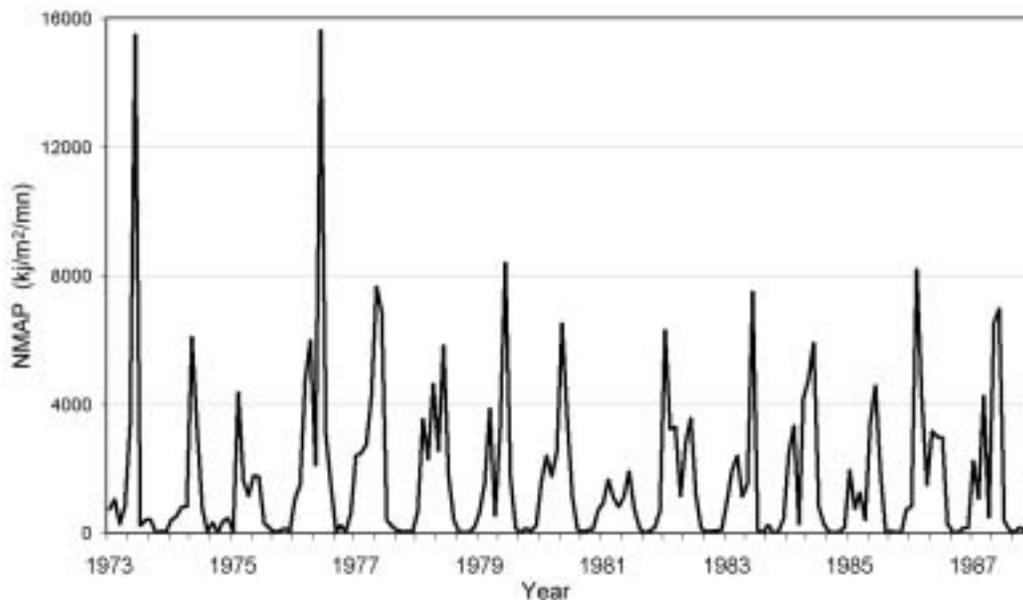


Figure 3. Monthly net aboveground primary productivity on Ngorongoro Conservation Area, calculated using Rosenzweig (1968) and a modification to adjust monthly totals to equal each annual total (Coe et al. 1976).

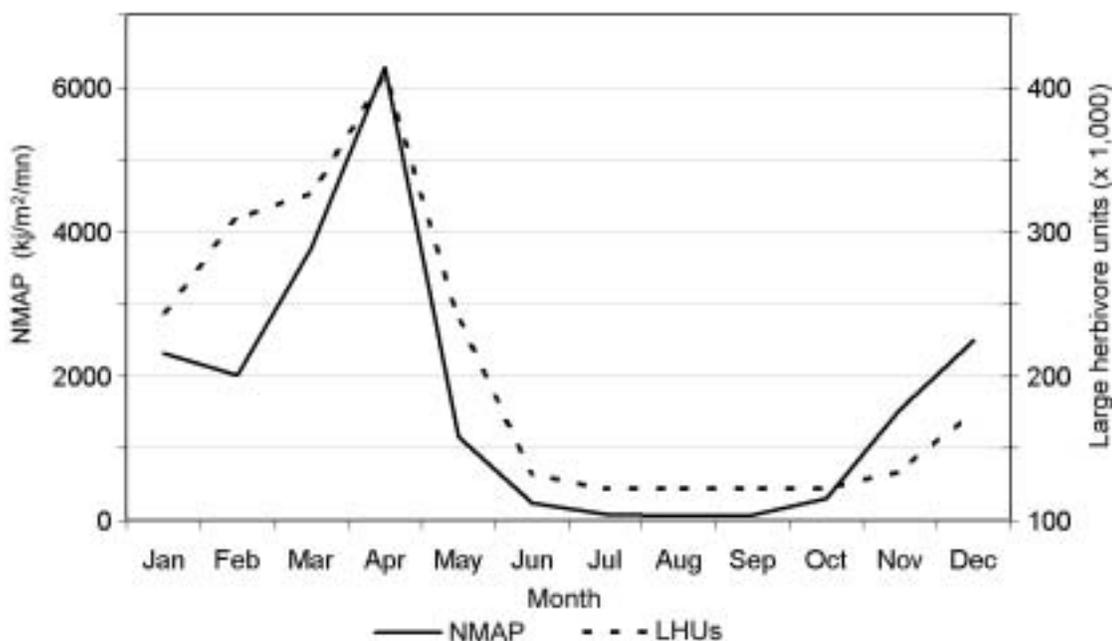


Figure 4. Average monthly estimates of net aboveground primary productivity (NMAP) and large herbivore biomass (in LHUs) currently on NCA.

Zone covers areas of extreme topography. The area is used by pastoralists and, to the south, agriculturalists. The Pastoralist Development Zone is used as a permanent settlement zone and by livestock herders to graze their animals. The area includes

the slopes of the mountains, leading down into the plains, and contains most of the NCA pastoralist households (Lynn 2000). The Pastoralist Development Zone also includes the Gol Mountains to the north, although few pastoralists have perma-

Table 5. Estimated net monthly aboveground primary production (NMAP) and estimates of large herbivore carrying capacity, for 1976, the driest year used, and 1977, the wettest year used.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1976 NMAP^a												
kJ/m ² /mn	25.3	4,352.6	1,626.1	1,132.4	1,773.9	1,716.4	307.8	120.2	21.8	56.7	132.4	49.1
Unmanaged^b												
kg/km ²	0.2	556.2	124.5	71.9	142.1	135.2	9.9	2.4	0.2	0.8	2.8	0.6
LMUs/NCA	7	18,423	4,125	2,380	4,708	4,478	329	79	6	25	91	20
Managed^c												
kg/km ²	1.9	7,139.2	1,474.4	825.8	1,694.8	1,607.8	102.5	22.7	1.5	6.8	26.5	5.4
LMUs/NCA	62	236,449	48,832	27,350	56,133	53,250	3,394	753	49	226	878	179
1977 NMAP												
kJ/m ² /mn	1,049.8	1,476.3	4,744.9	5,969.5	2,088.6	15,639.4	3,040.5	1,440.6	0.3	236.6	33.6	576.0
Unmanaged												
kg/km ²	64.0	107.5	634.2	899.1	182.2	3,886.7	322.4	103.6	0.0	6.7	0.3	25.7
LMUs/NCA	2,121	3,561	21,005	29,777	6,034	128,727	10,679	3,431	0	220	11	852
Managed												
kg/km ²	731.4	1,262.9	8,197.4	11,841.9	2,201.8	55,399.6	4,018.3	1,214.4	0.0	67.2	2.9	279.6
LMUs/NCA	24,225	41,829	271,500	392,204	72,923	1,834,833	133,087	40,222	0	2,226	97	9,262

a - Calculated following Rosenzweig (1968), using monthly rainfall and a multiplier to yield NMAP (Coe et al. 1976; see methods).

b - Regression equation from McNaughton et al. (1989).

c - Regression equation from Oesterheld et al. (1992).

ment households there. The Short Grass Plain Zone is used by migratory wildlife extensively during the wet season, and may be used by pastoralists at other times. Within that zone and the Pastoralist Development Zone, the Olduvai Gorge subzone was delineated, where livestock are not allowed to graze, to protect archeological sites.

This section includes two methods not yet used. First, we use the management zones described to divide NCA into areas with individual forage carrying capacities, based upon whether they support wildlife or livestock. Second, in addition to using estimates of stocking drawn from regression analyses, we use stocking levels drawn from the literature, for areas comparable to NCA. Ngorongoro Crater provides a clear example – the large herbivore biomass of the Crater has been estimated an-

nually for 38 years, and so we use that figure for the Crater in all analyses.

If each of the management zones were dedicated entirely to a single use (i.e., to wildlife conservation and tourism, or to pastoral livestock production), and using the estimates for wildlife and for pastoral communities from Coe et al. (1976) for stocking, we estimate 167,952 LHUs may be supported on NCA (Table 6a). This provides a low estimate of capacity, given the assumptions of Coe et al. (1976). At the other extreme, if the pastoralist areas were managed solely to produce livestock (i.e., perhaps seeding or fertilizing fields) as in the Oesterheld et al. (1992) regression, the total LHUs that could be supported on NCA would be 1,401,300 (Table 6b). If we use biomass on ob-

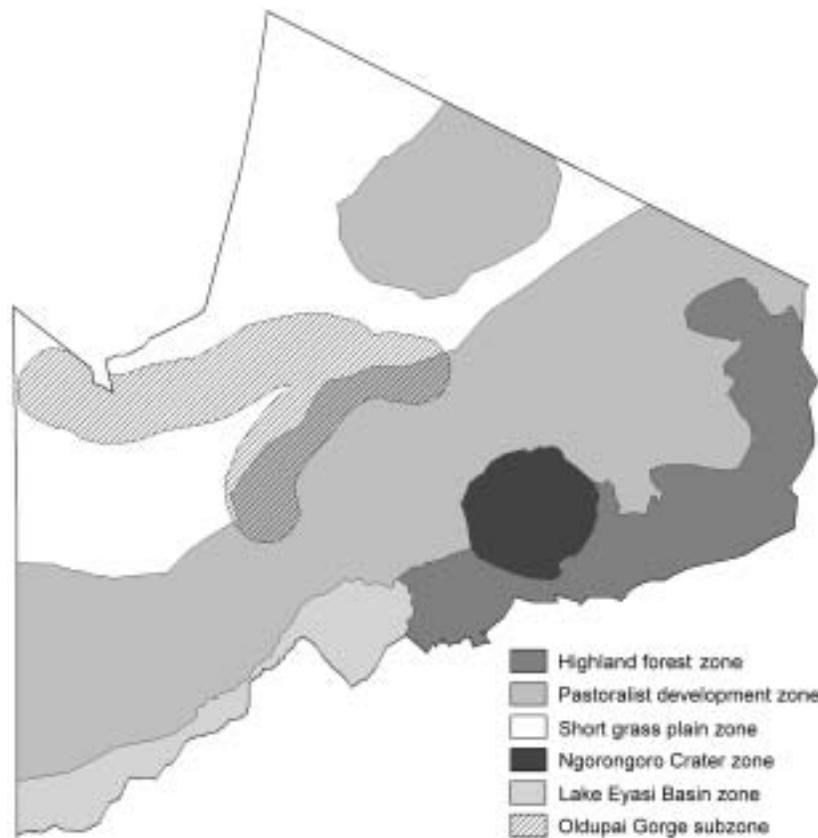


Figure 5. Management zones used by the Ngorongoro Conservation Area Authority (NCAA 1996).

served areas as a guide, we may use Ngorongoro Crater biomass ($10,982 \text{ kg/km}^2$; Runyoro et al. 1995) as a high estimate of biomass for wildlife throughout NCA, and biomass reported for Kaputei District, Kenya ($7,884 \text{ kg/km}^2$; Watson 1972, cited in Coe et al. 1976), which was a pastoral area with similar annual rainfall to NCA (i.e., 710 mm). The biomass supported on Kaputei seems a high estimate as well. As examples, stocking in Loliondo Game Controlled Area, bordering NCA on the north, was $5,423 \text{ kg/km}^2$ in the late 1960s (Watson 1969), in Kajiado District stocking was at $5,625 \text{ kg/km}^2$ in 1977 to 1983 (de Leeuw et al. 1990:16), but Kajiado receives less rainfall than NCA (Ole Katampoi et al. 1990) making the comparison less helpful. A fairer comparison focuses upon Olkarkar Group Ranch in northeastern Kajiado, where rainfall was about 700 mm annually (inferring from nearby Sultan Hamud Group Ranch; de Leeuw 1990:47). In Olkarkar, de Leeuw (1990) estimated that 2 ha/TLU would constitute a ‘safe stocking rate’ in most years, which translates to $5,000 \text{ kg}$

TLU/ km^2 . To convert from TLUs to LHUs to incorporate wildlife, we may add the ratio of domestic (17.5 TLU/km^2) to wildlife herbivores (5.0 TLU/km^2) seen on the district as a whole (de Leeuw et al. 1990), yielding an estimate of $6,111 \text{ LHU/km}^2$.

When stocking rate is calculated using these observed estimates (Table 6c), capacity was estimates at 311,361 LHUs for NCA. In that estimate, wildlife stocking rate ($10,982 \text{ kg/km}^2$) was above pastoral stocking rate ($7,884 \text{ kg/km}^2$), which is unusual. This likely reflects unusually high biomass within Ngorongoro Crater, but to generate a high estimate of capacity, we will assume the pastoral stocking rate is low. Estimates from Coe et al. (1976), although not linear, predict for NCA that stocking in a mixed wildlife/pastoral community would be about twice that of the wildlife community alone (e.g., Table 6a). Doubling the estimate for wildlife stocking yields an estimate for the pastoral community of $21,964 \text{ kg/km}^2$ and an estimate of LHUs for NCA of 541,716 (Table 6d).

Table 6. Capacity of NCA based upon stocking rates in other areas and calculations of capacity, estimated using NCAA management zones. NCA is 8,242 km², using our boundary data.

a. Zones dedicated to a single use, with stocking set by regression relationships

Zones	Area	Community	Stocking	LHUs/Zone	LHUs in NCA
	km ²		kg/km ²		
Highland forest zone	954	Wildlife	3,233	12,340	167,952
Ngorongoro Crater zone	302	Wildlife	10,982	13,244	
Lake Eyasi Basin zone	423	Pastoral	6,413	10,853	
Pastoralist development zone	3,667	Pastoral	6,413	94,063	
+ Oldupai Gorge subzone	257	Wildlife	3,233	3,329	
Short grass plain zone	1,977	Wildlife	3,233	25,567	
+ Oldupai Gorge subzone	662	Wildlife	3,233	8,556	

Notes: Wildlife stocking from regression in Coe et al. (1976), except for the Crater, and pastoral stocking from Coe et al.; a regression with pastoral and wildlife areas (Table 2).

b. Zones dedicated to a single use, with stocking set by regression relationships

Zones	Area	Community	Stocking	LHUs/Zone	LHUs in NCA
	km ²		kg/km ²		
Highland forest zone	954	Wildlife	3,233	12,340	1,401,300
Ngorongoro Crater zone	302	Wildlife	10,982	13,244	
Lake Eyasi Basin zone	423	Managed	81,799	138,437	
Pastoralist development zone	3,667	Managed	81,799	1,199,828	
+ Oldupai Gorge subzone	257	Wildlife	3,233	3,329	
Short grass plain zone	1,977	Wildlife	3,233	25,567	
+ Oldupai Gorge subzone	662	Wildlife	3,233	8,556	

Notes: Wildlife stocking from regression of Coe et al. (1976), managed stocking from regression of Oosterheld et al. (1992), using 712 mm of rainfall. Crater stocking from Runyoro et al. (1995).

c. Zones dedicated to a single use, with stocking set using nearby areas.

Zones	Area	Community	Stocking	LHUs/Zone	LHUs in NCA
	km ²		kg/km ²		
Highland forest zone	954	Wildlife	10,982	41,916	311,361
Ngorongoro Crater zone	302	Wildlife	10,982	13,244	
Lake Eyasi Basin zone	423	Pastoral	7,884	13,343	
Pastoralist development zone	3,667	Pastoral	7,884	115,643	
+ Oldupai Gorge subzone	257	Wildlife	10,982	11,307	
Short grass plain zone	1,977	Wildlife	10,982	86,846	
+ Oldupai Gorge subzone	662	Wildlife	10,982	29,063	

Notes: Wildlife stocking from Ngorongoro Crater (Runyoro et al. 1995), pastoral stocking from Watson (1972), cited in Coe et al. (1976), for Kaputei District, Kenya, with 710 mm annual rain.

(Table 6 continues)

Table 6 (continued)**d. Zones dedicated to a single use, with stocking set by biomass in the Crater**

Zones	Area km ²	Community		Stocking kg/km ²	LHUs/Zone	LHUs in NCA
		Wildlife	Pastoral			
Highland forest zone	954	Wildlife		10,982	41,916	541,716
Ngorongoro Crater zone	302	Wildlife		10,982	13,244	
Lake Eyasi Basin zone	423	Pastoral		21,964	37,172	
Pastoralist development zone	3,667	Pastoral		21,964	322,168	
+ Oldupai Gorge subzone	257	Wildlife		10,982	11,307	
Short grass plain zone	1,977	Wildlife		10,982	86,846	
+ Oldupai Gorge subzone	662	Wildlife		10,982	29,063	

Notes: Wildlife stocking from Ngorongoro Crater (Runyoro et al. 1995), pastoral stocking set at twice the value used for wildlife, inferred from Coe et al. (1976) and Table Xa.

e. Zones dedicated to a multiple uses, with stocking for wildlife set at that predicted by regression (3,233 kg/km²; Coe et al. 1976) and pastoral areas using Kaputei District, Kenya (7,884 kg/km²; Watson 1972), which had 710 mm annual rainfall.

Zones	Area km ²	Community (%)		Stocking kg/km ²	LHUs/Zone	LHUs in NCA
		Wildlife	Pastoral			
Highland forest zone	954	85	15	3,931	15,003	181,246
Ngorongoro Crater zone	302	100	0	10,982	13,244	
Lake Eyasi Basin zone	423	35	65	6,256	10,588	
Pastoralist development zone	3,667	30	70	6,489	95,176	
+ Oldupai Gorge subzone	257	75	25	4,396	4,526	
Short grass plain zone	1,977	80	20	4,163	32,923	
+ Oldupai Gorge subzone	662	90	10	3,698	9,787	

Notes: Community usage was assigned based upon our perceived use in each zone.

f. Zones dedicated to a multiple uses, with stocking for wildlife set at that in Ngorongoro Crater (10,982 kg/km²; Runyoro et al. 1995) and pastoral areas set at twice the value for wildlife alone (21,964 kg/km²).

Zones	Area km ²	Community (%)		Stocking kg/km ²	LHUs/Zone	LHUs in NCA
		Wildlife	Pastoral			
Highland forest zone	954	85	15	12,629	48,204	516,275
Ngorongoro Crater zone	302	100	0	10,982	13,244	
Lake Eyasi Basin zone	423	35	65	18,120	30,667	
Pastoralist development zone	3,667	30	70	18,669	273,843	
+ Oldupai Gorge subzone	257	75	25	13,728	14,134	
Short grass plain zone	1,977	80	20	13,178	104,215	
+ Oldupai Gorge subzone	662	90	10	12,080	31,969	

Notes: Community usage was assigned based upon our perceived use in each zone.

Treating the management zones as dedicated to a given community (i.e., wildlife or pastoralists) simplified results in Table 6a-d. Next we used the same estimates of herbivore stocking rates (e.g., Table 6e is analogous to Table 6a), but partition use of each management zone between the two communities. Our perception of use in the zones are reflected in percentages assigned to each area. For example, the Highland Forest Zone is intended for water catchment and wildlife, but pastoralists do graze animals in the glades, yielding a score from us of 85% wildlife, and 15% pastoral use. When analyzed, a stocking rate of 181,246 LHUs for NCA was calculated (Table 6e). If the higher estimates of 10,982 kg/km² for wildlife (from the Crater; Runyoro et al. 1995) and twice that (21,964 kg/km²) for pastoral areas was used, the estimate for NCA was 516,275 LHUs (Table 6f).

2.1.4. Spatial Analyses

Normalized Difference Vegetation Indices (NDVI) may be created from satellite images gathered by the Advanced Very High Resolution Radiometer, a weather satellite operated by the US National Oceanic and Atmospheric Administration. These images have been shown to correlate with vegetation biomass and vigor (e.g., Tucker et al. 1985; Kogan 1998; Boone et al. 2000). Integrated NDVI images may also be used to estimate annual net primary productivity (e.g., Paruelo et al. 1997). Such estimates require a series of measures of NAAP for calibration, which were not available to us. As an alternative, we returned to Rosenzweig's (1968) use of actual evapotranspiration to estimate NAAP, and Coe et al. (1976) and others use of annual precipitation as a substitute for evapotranspiration. Coe et al. used that relationship for areas with less than 700 mm of rainfall, and so we did the same.

In brief, we: 1) used 8 km resolution NDVI images from 1982 to 1999 (ADDS 2001) calculate 12 mean monthly NDVI images, and from those calculated the integral of NDVI over the entire year, which yielded a single image of average NDVI for the entire 18 year period. 2) A data set showing annual precipitation (Corbett et al. 2001)

was used to identify areas with < 700 mm of rainfall, within a large study area incorporating northern Tanzania and southern and central Kenya. 3) Rainfall was used to estimate NAAP following Rosenzweig (1968) as applied by Coe et al. (1976) and others. 4) From a random sample of 1,000 points within the area with < 700 mm rainfall, we discarded those that were within 200 km of the coast, or fell in water bodies or pure crop land in the Seasonal Land Cover Region database (Loveland et al. 2000), which left 778 points. NDVI for these locations, and their UTM coordinates, were used as independent variables in a regression that predicted NAAP (78% of variation explained). 5) Using the regression results, a spatial layer for NAAP for the entire region was calculated, and one for NCA parsed from that. The resulting map of NAAP for NCA had 129 cells, each 8 km square (i.e., 8,256 km²).

To estimate appropriate stocking for NCA, NAAP within forest canopies, which is unavailable to most large herbivores, had to be quantified. We overlaid the map of NAAP upon an NCA land cover map (M. Kalkhan, NREL, Colorado State University), and reduced NAAP in forests by 75%, in woodland/forest mix by 40%, and in water and barren ground to zero, yielding a map of NAAP available to most herbivores. The number of large herbivores that may be supported on NCA were then calculated based upon vegetation removal, using 10 kg vegetation dry matter for each large herbivore unit each day (i.e., kg dry matter/LHU/day) (de Leeuw 1991). This estimate includes wastage and trampling. The amount of net primary production that could be removed without long-term damage ('proper use factor') used was a conservative 25% (Sloane 1986), a high estimate of 62.5% (de Leeuw 1991), and a widely used 50% (Ellis and Swift 1988; de Leeuw 1991).

Using the methods described, we estimated that average NAAP for NCA was 1,014 g/m², with a low of 745 g/m², and high of 1,458 g/m² (Figure 4). When overstory production was accounted for (and water and barren lands set to zero), the mean NAAP was 721 g/m², or 7.2 tons DM (dry matter)/ha. An LHU is estimated to require 3.6 ton DM/yr

(de Leeuw 1991), and NCA has 824,200 ha. From these, we calculate that if 25% of NAAP was consumed, 407,076 LHU could be supported on NCA. If 50% of NAAP was consumed, 814,153 LHU could be supported, and if 62.5%, 1,017,691 LHU could be supported on NCA. These analyses do not take into account the differences in diets between browsers and grazers, for example. They also do not include restrictions upon the movements of animals, either due to legal requirements (e.g., livestock not able to graze in Ngorongoro Crater) or to habitat requirements (e.g., distance to water, available cover). In the next section, these simplifying assumptions will be removed, using ecosystem modeling.

2.1.5. Ecological Modeling

The methods used in the previous sections to estimate appropriate stocking have the advantage of simplicity, but the NCA ecosystem is not simple. We use an ecosystem model that integrates many of the complexities to estimate appropriate stocking. The Savanna modeling system, written by Michael Coughenour, is a process-based ecosystem model that treats a landscape as small (e.g., 5 x 5 km square) blocks. Savanna reads spatial data sets that describe the blocks (e.g., elevation, slope, vegetation type, soil), and a series of settings that describe how organisms in the ecosystem reproduce and grow. Savanna models the growth of plants and animals on the blocks, estimating conditions each week over a period of 10 to 100 years. Savanna is described in more detail in Boone et al. (2002), Ellis and Coughenour (1998), and Boone (2000).

There are many settings in Savanna that affect the number of simulated herbivores that may be supported. We required some reference to help assign values to those settings – Ngorongoro Crater provided that reference. The long-term stocking rate of Ngorongoro Crater is essentially known from 55 published censuses spanning from 1966 to 1995 (Runyoro et al. 1995; Moehlman et al. 1997), and stocking has not varied markedly (Runyoro et al. 1995). Savanna version 4L was adapted to model Ngorongoro Crater at 1 km resolution, and NCA at 5 km and 2.5 km resolutions,

and initial settings were taken from a previous application in NCA (Boone et al., 2002) and South Africa (Boone et al., In review). The plant functional groups modeled were palatable grasses, palatable forbs, unpalatable herbaceous plants, palatable and unpalatable shrubs, evergreen forests, and deciduous woods. We also added swamps, to represent the wetlands on the crater floor. Animal groups modeled included wildebeest, zebra, buffalo, grazing antelope, browsing antelope, elephants, rhinoceros, and warthogs. After assigning values to parameters to reflect information in the literature, simulations were run and settings adjusted until plants were being modeled reasonably. We then adjusted settings affecting herbivore populations until their populations were relatively stable over a 15 year period, reflecting the stability seen in censuses. The settings required to model large herbivore biomass in Ngorongoro Crater reasonably could then be used when modeling the entire NCA.

The application to the entire NCA, excluding Ngorongoro Crater management zone (Figure 4), had the same vegetation types, except swamps were not included. Eleven animal groups were modeled, including three migratory groups (i.e., wildebeest, zebra, and grazing gazelle), two analogous resident groups (zebra and grazing gazelle; almost all resident wildebeest reside in Ngorongoro Crater, which was not modeled here), and browsing antelope, buffalo, elephant, cattle, goats, and sheep. The Savanna modeling system was modified so that cattle avoided wildebeest, based upon the avoidance of wildebeest by Maasai herders to prevent malignant catarrhal fever. Examples of other restrictions on the distributions of animals incorporated in Savanna were the exclusion of elephants from northern NCA and the Gol Mountains, and for livestock, restrictions on the use of the Northern Highland Forest Reserve, the NCA craters, and reduced livestock grazing in the southeast due to the threat of cattle rustling.

Migratory animal populations were set at their final values (Table 1), and were held constant in all analyses. Populations for the remaining eight animal groups were set at 67% of their current stocking rates, and the parameter values affecting

herbivores were set to be equal to those used in the Ngorongoro Crater application (wildlife) or a previous NCA application (livestock). Holding all animal group populations constant, parameter values were adjusted until plant phenology, biomass, and distributions were being modeled reasonably. We repeated the simulation, allowing the resident wildlife and livestock populations to vary. Adjustments were made to parameters controlling the rates at which herbivore populations change, but not to values affecting capacity, such as their base energy usage. With stocking at 67% of the current rates, populations increased over the 15 years modeled. We therefore increased herbivore populations to the current stocking rate (i.e., 100%, see Table 1) and repeated the simulation. Again small changes were made to parameter files so that all the populations changed in unison, to the degree possible. In these simulations, we found that populations stopped increasing after five years of simulation, and palatable grass biomass declined; these results were plotted in figures for this report. We judged the system to be at capacity just prior to that point.

When the NCA ecosystem was simulated and initial herbivore population sizes were set to their current levels, resident populations of livestock and wildlife increased, in general, in the initial years. In the fourth year, simulated herbivore biomass reached a maximum, and remained relatively stable for the following seven years. However, biomass of herbaceous plant groups began changing in the eighth year of the simulation, suggesting overstocking by some animal groups. Palatable grasses declined and unpalatable herbs and palatable forbs increased. Given that forage degradation may indicate that capacity is being exceeded (Society of Range Management 1989), we judged that populations in the third and fourth years of the simulation were at some upper level of capacity. The peak LHUs supported on NCA during the dry season in these simulations was 173,138 (which includes herbivores from Ngorongoro Crater, based upon the long-term biomass; Runyoro et al. 1995). Stocking during the wet season peaked at 515,067 LHUs. The number of animals that were supported

on the system, averaged over the months of each year, peaked at 250,925 LHUs.

2.1.6. Limitations

Each of the analyses described include some limitations. Taken sequentially, however, later analyses often incorporate complexities that are limitations in earlier analyses. For example, the straightforward assessments using Coe et al. (1976), McNaughton et al. (1989), and Oesterheld et al. (1992) on the entire area ignore the heterogeneous nature of NCA. These habitats are not equally selected by the large herbivores of NCA, nor are all accessible due to legal restrictions, threats from disease, or inadequate water sources. In later analyses, such as those using the management zones, and especially that based upon ecological modeling, these complexities are considered explicitly.

The regression techniques we have used were developed using data of a given range, and should not be extrapolated beyond those ranges without care. Coe et al. (1976) included areas with precipitation from 165 mm/yr to 1,150 mm/yr, which includes the range of rainfall recorded on NCA. However, Coe et al. (1976) limited their use of annual precipitation as a substitute for actual evapotranspiration in Rosenzweig's (1968) formula for NAAP to sites with < 700 mm/yr. Rainfall in NCA exceeded that in about half of the years we used. We do not know the degree to which precipitation > 700 mm/yr is no longer an adequate substitute for evapotranspiration in the Rosenzweig formula. Regardless, with only two years above 800 mm, and one above 1,000 mm of rainfall, the error introduced is likely minor. We used the limitation of Rosenzweig's relationship fitting areas with < 700 mm annual rainfall (Coe et al. 1976), but then assumed the regression results for areas < 700 mm would be appropriate for those with more rainfall. Note that this method does not assume that rainfall and NAAP are linearly correlated > 700 mm, but rather that the saturation in the relationship relating NAAP to rainfall is similar to the relationship relating NAAP to NDVI.

The estimates of stocking based upon nearby areas include an important assumption that rain-

fall is the primary determinant of stocking, and other differences between the sites are secondary (e.g., Coe et al. 1976; McNaughton et al. 1989). Temporal changes in stocking are averaged or ignored as well. This is not important in areas where total biomass is at a long-term equilibrium (e.g., Ngorongoro Crater; Runyoro et al. 1995), but would be for areas that are changing rapidly. The benefit of ecosystem modeling is its ability to integrate many relationships and rules governing ecosystem processes, but the complexity required to do that integration can be a limitation. Some of the parameter values assigned in modeling are published in the literature, but often not from the area of interest. Other parameters must be adjusted based upon the behavior of simulations. The results from simulations are dependent upon the settings, but how those settings interact is not directly tractable. How errors in settings propagate in the model is unknown, although feedbacks prevent

results from becoming extreme. Also, as in any model, simplifications must be made to model landscapes with Savanna. Incorrect assumptions in the model or important effects not modeled (e.g., small mammal herbivory) may bias results. That said, in this application, two attributes reduce the risk of biased responses: 1) large herbivore units rather than individual population trends are the focus, and 2) Ngorongoro Crater provided a guide to how vegetation in the region related to stocking rates.

Some analyses included subjective assignments of values. In the spatial assessments of capacity, the percentage of NAAP to make unavailable due to tree cover was decided subjectively. Field research and literature review may suggest more appropriate values than those we have used. Analyses based upon management zones included subjective percentages assigned representing the use of areas by wildlife and pastoral communities. Fur-

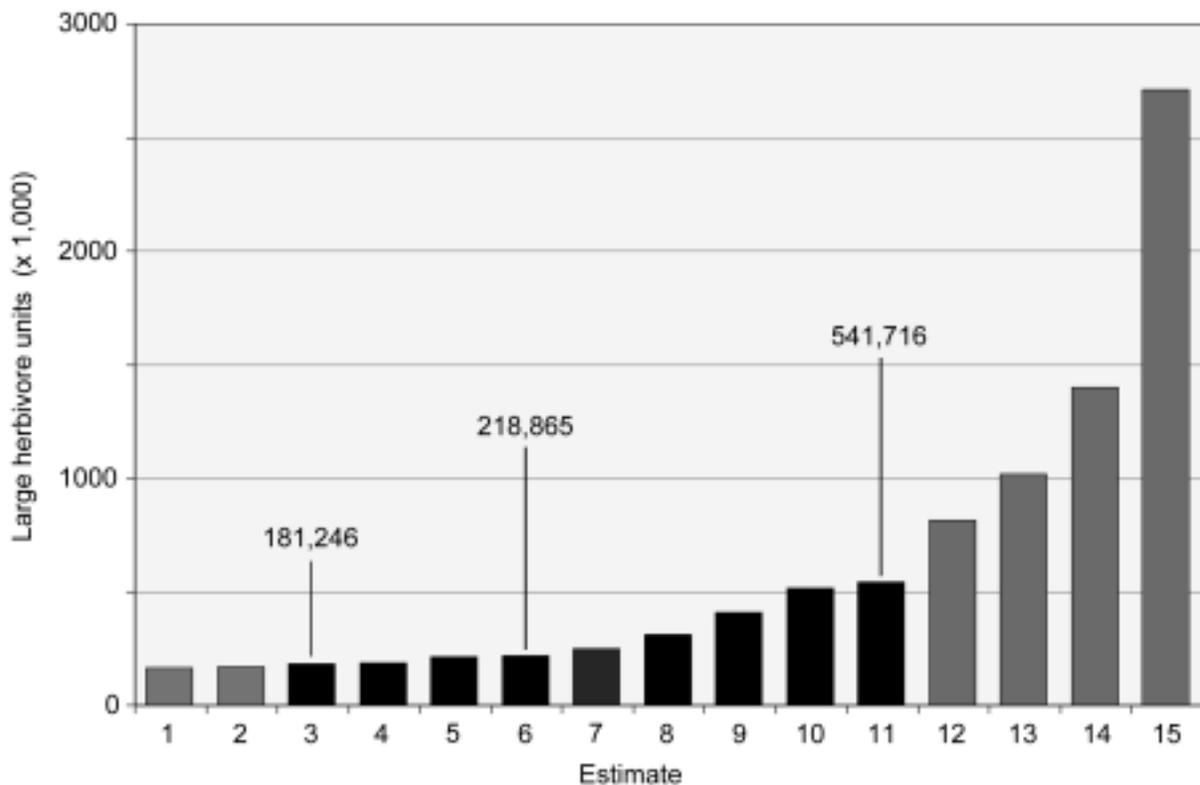


Figure 6. A graph depicting appropriate stocking rates for NCA based upon 15 methods of estimation. The methods were ranked based upon their estimate of capacity, and assigned numbers, 1 to 15. We estimate current stocking at 218,865 LHUs, and based upon the estimates we used, a reasonable range of stocking to be 181,246 to 541,716 LHUs. See Table 7 for more detail.

ther research may be helpful in making those estimates more objective, such as aerial counts of wildlife and livestock in each management zone.

2.1.7. Estimates of Appropriate Stocking Evaluated

The estimates of appropriate stocking rates for Ngorongoro Conservation Area (Figure 6 and Table 7 provide summaries) based upon forage availability and access vary widely (i.e., 164,976 LHUs to 2,709,168 LHUs). This wide range is appropriate; the number of large herbivores that may be supported depends upon management objectives. For example, we know of no ecological reason why

NCA would not support 2.7 million LHUs if intensively solely for livestock production. We recognize that the balance between livestock and wildlife in the NCA large herbivore community is a decision to be made by the NCA Authority, in concert with local stakeholders and other policy makers. We cannot identify the ‘best’ estimate. We simply provide these estimates to support that decision-making process. That said we have gained some insights and noted caveats while generating the estimates shown in Figure 6. Our thoughts on the estimates of appropriate stocking follow, providing one interpretation – one opinion – from a research group not directly involved in policy mak-

Table 7. Summary of estimates of appropriate stocking rate on Ngorongoro Conservation Area, including an estimate of current stocking.

Technique	Comments, and section or table with more detail	Estimate LHUs in NCA
1. Regression	Coe ^a using wildlife areas	164,976
2. Zone-based regression	Coe ^a using wildlife area / Pastoral and wildlife areas	167,952
3. Zone-based, mixed uses	Coe ^a for wildlife areas / Kaputei ^b for pastoral areas	181,246
4. Regression	McNaughton ^c	186,315
5. Regression	Coe ^a using pastoral and wildlife areas	212,609
6. Current conditions	Residents at 122,019 LHU, all peaked ^d at 468,031 LHU	218,865
7. Ecological modeling	Residents peaked at 173,138 LHU, all at 515,067	250,925
8. Zone-based, other sites	Ngorongoro Crater for wildlife areas / Kaputei for pastoral	311,361
9. Spatial analysis	ANPP from NDVI ^d , 25% of forage used	407,076
10. Zone-based, mixed use	Ngor. Crater for wildlife areas, and twice that for pastoral	516,275
11. Zone-based, other sites	Ngor. Crater for wildlife areas, and twice that for pastoral	541,716
12. Spatial analysis	ANPP from NDVI ^d , 50% of forage used	814,153
13. Spatial analysis	ANPP from NDVI ^d , 62.5% of forage used	1,017,691
14. Zone-based, regression	Coe ^a using wildlife areas / Oosterheld ^e for pastoral areas	1,401,300
15. Regression	Oosterheld ^e for all areas	2,709,168

a - Coe et al. (1976), with results for African game parks and for parks and pastoral areas combined.

b - Kaputei District, Kenya, a pastoralist area with rainfall amounts similar to NCA.

c - McNaughton et al. (1989), based upon African game parks and other unmanaged African grasslands.

d - Peak wet season value differs from Table 1; this estimation includes differences in timing of migrations.

e - ANPP is annual net primary production, NDVI is normalized difference vegetation indices.

ing on NCA. NCA policy makers and stakeholders will have additional, unique insights.

The observed and modeled estimates of stocking rate (estimates 6 and 7 in Table 7, i.e., 218,865 and 250,925 LHUs) are an attempt to portray stocking rate as a single value. The technique is convenient, but readers should recall that stocking changes dramatically throughout the year in NCA.

Coe et al. (1976) used Ngorongoro Crater and Serengeti National Park in their regression analyses, but these were single points among many. It may be that their regression results underestimate capacity of the fertile volcanic soils of NCA. The estimates of McNaughton et al. (1989) may have similar difficulties. We also suspect that estimates of annual net primary productivity calculated for NCA using Rosenzweig's (1968) regression relationship overestimates productivity in Ngorongoro grasslands (we know of no measurements of NAAP within NCA, for use in comparisons). For example, the plains near Lake Ndutu receive about 630 mm of rainfall annually (Campbell and Hofer 1995; Corbett et al. 2001) and yields an estimate of NAAP of 970 g/m²/yr, which seems excessive. It is possible that estimates using Rosenzweig's (1968) relationship overestimate NAAP in grasslands and underestimate NAAP in NCA highland forests (4, 9, 12, 13, 14, and 15 in Table 7; Coe et al. (1976) used Rosenzweig (1968) in their analyses, but their results do not require the use of the formula).

Several analyses use the relationship between vegetation and herbivore biomass in Ngorongoro Crater as an indication of appropriate stocking rate in NCA (7, 8, 10, and 11 in Table 7). That includes in a less straightforward way the ecological modeling conducted, where stocking on the system was set using the Crater as a guide. This assumption may be inappropriate, to the degree that Ngorongoro Crater is unique in its relationship between vegetation and large herbivores. Estimates using management zones with mixed usage (3, 10 in Table 7) seem more appropriate than those that assign a single use to each zone (2, 8, 11, 14). The only estimate that explicitly include the dynamics of herbivores migrating into and off NCA, and balancing resident herbivores in-turn, is the estimate that used ecological modeling (7 in Table 7).

In general, we judge the assumptions behind estimates (14, 15 in Table 7) using Oosterheld et al. (1992) (e.g., fertilizing, planting forage, predator control) unlikely to be in agreement with the multiple-use objectives of the conservation area. Also, the estimate (1 in Table 7) based on Coe et al. (1976) using only wildlife areas is likely in conflict with the multiple-use goals of NCA. The mixed uses, zone-based estimate of stocking based upon Coe et al. (1976) and Kaputei District (3 in Table 7) seems a better use of available information (management zones) than estimate 2. Given that estimate 3 is only 18% below the current estimate of stocking (6 in Table 7), we believe that estimate, 181,246 LHUs in NCA, provides a reasonable lower appropriate stocking rate. Estimates progress upward incrementally through 541,716 LHUs in NCA (estimate 11 in Table 7), then jump more than 272,000 to 814,153 LHUs (estimate 12) based upon Rosenzweig (1968) applied to integrated NDVI data. This stocking rate may incorporate an overestimate of NAAP, and is significantly higher than the next lower estimate, so we discount its applicability. The upper limit of stocking appropriate for NCA would then be 541,716 LHUs. Our estimates of appropriate stocking in NCA therefore range from 181,246 to 541,716 LHUs.

In the context of managing NCA, and citing results reported in a section that follows (Section 2.3) that used ecological modeling, we do not see the ability of NCA to support significantly more livestock, to increase the TLUs per person and allow Maasai to return to a more pastoral lifestyle. Ecological modeling that integrated restrictions on animals' access, for example, yielded an estimate in the wet season of 515,067 LHUs, and 173,138 LHUs in the dry season (Table 7). If livestock were double their current population, allowing NCA Maasai to move from 2.77 TLUs/person to 5.54 TLUs/person and a more pastoral lifestyle, stocking would then be 585,919 LHUs in the wet season, and 122,019 in the dry season (based upon Table 1, with livestock populations doubled). The wet season stocking with twice the current livestock would therefore exceed the maximum capacity, estimated using ecological modeling.

2.2. Where is Cultivation in Ngorongoro Conservation Area?

To address the NCA Conservator's queries regarding the effects of cultivation on wildlife, people, and livestock, we first had to have a spatial layer representing cultivation. The most detailed map of cultivation for NCA we are aware of was published in McCabe et al. (1997). This small map lacked the detail we required for our work. Also, the map was created in the early 1990s, soon after cultivation was reinstated. We required a high resolution map that represented the distribution and extent of cultivation in the last few years reasonably.

Creating a high-quality land use map for a large region such as NCA is a large undertaking, beyond the scope of the POLEYC project. Such efforts may include the use of multiple satellite images, extensive collection of training and testing information in the field (i.e., 'ground truth data'), interpretation of aerial photographs or videography, the use of advanced image processing techniques, and expert review and testing of the final map (e.g., Hepinstall et al. 1999). Here, we required a more straightforward and less expensive method, but one that would yield a cultivation map judged accurate by experts.

2.2.1. Methods

From work with collaborators we had available a radiometrically corrected Landsat Enhanced Thematic Mapper satellite image from February 12, 2000. Landsat ETM images actually contain several images or bands, with six images of 30 m resolution (the image is comprised of small elements or cells, with each square cell 30 m on a side) in the visible and near infrared color spectrum. Two coarser bands (60 m resolution) measure in the thermal spectrum, and are not used in our work. The final band has a finer resolution (15 m) and measures reflectance across a broad range of wavelengths (i.e., panchromatic). Preliminary inspection of the image, which was almost cloud free, suggested that it would be useful for mapping cultivation.

Mr. Victor Runyoro of the NCAA visited NREL in October of 2001, and met several times with

POLEYC personnel to plan assessments. During those meetings we visually inspected the satellite image and identified 30,543 cells (687 ha) known to be in cultivation. Samples were identified from all areas of NCA where cultivation is known, and included samples outside the area, to the southeast and west. These patches of cultivation were recorded in a geographic information system (GIS) for later reference.

Typical methods of computerized mapping with Landsat satellite images entail special multivariate clustering methods such as supervised and unsupervised maximum-likelihood classification. We used these methods to rate their utility in mapping cultivation in NCA. In short, mapping based upon clustering methods were not particularly effective within NCA, and will be described without detail.

Initial attempts to map cultivation used all of NCA and areas within 5 km of the boundary. For the area, we used ETM bands 1-5 and 7 (recalculated to be 15 m resolution), and 8, as well as two normalized band ratios, 4/5 and 4/3, which have been shown to be useful in mapping vegetation (e.g., Hepinstall et al. 1999). Supervised classification of the image using the patches identified as cultivation led to too much confusion between NCA shrub lands, brushy areas, and cultivation. Unsupervised classification of the image into 209 types and inspection of the resulting clusters yielded similar confusion. Based upon our knowledge of cultivation patterns in NCA, we then discarded the plains and Ngorongoro Crater from the image, leaving the Pastoralist Development, Highland Forest, and Lake Eyasi Escarpment Management Zones. This remaining area was again clustered using an unsupervised technique (i.e., isocustering), yielding 233 clusters with distinct spectral signatures. We inspected the clusters, highlighting each individually on a map on the computer screen, and recorded types likely to be cultivation. The patches defined visually as cultivation, cited above, were used as reference when mapping other cultivation patches. Any confusion with other types (e.g., shrubs or brush) was also noted. In general, we concluded that this method

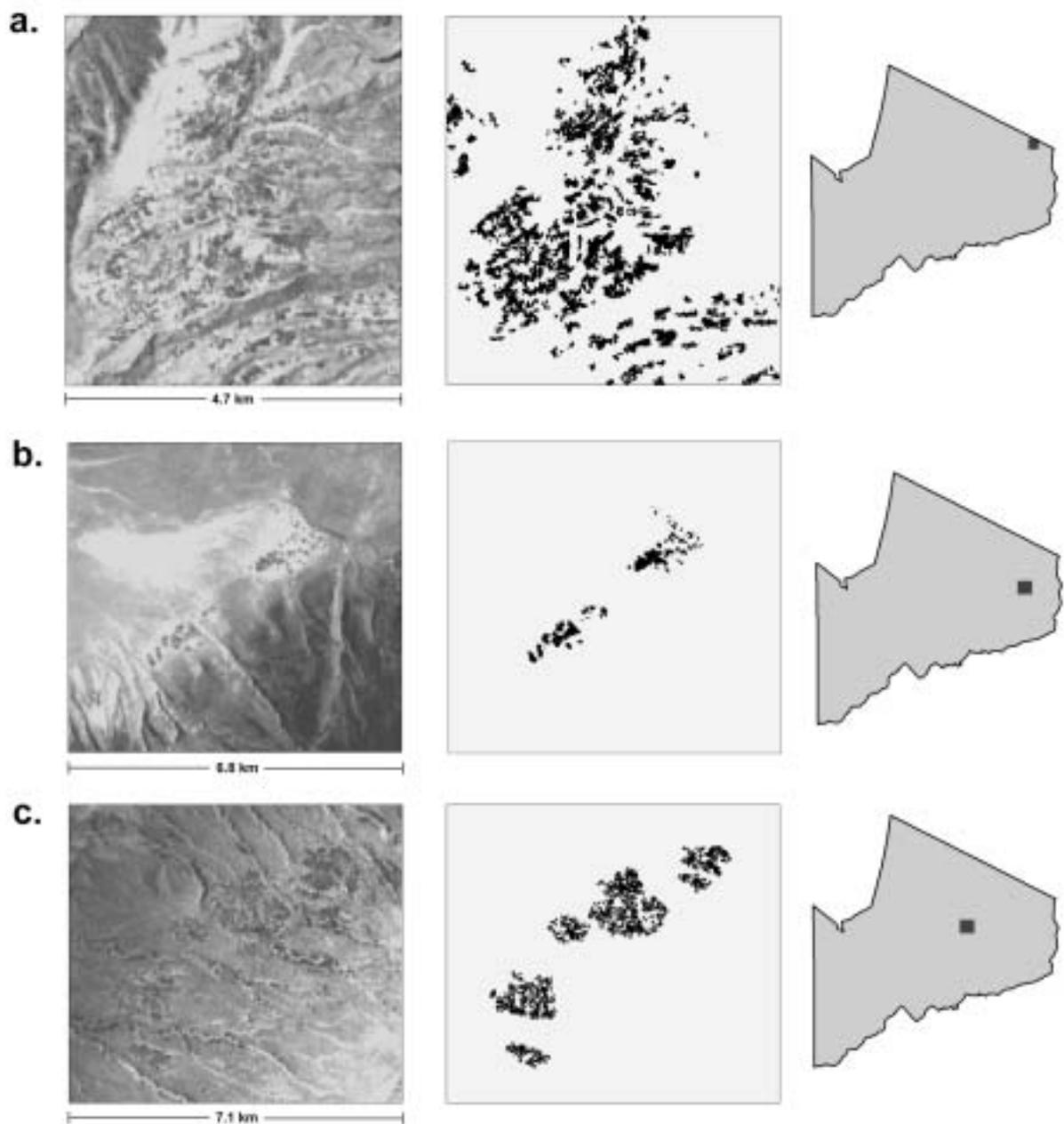


Figure 7. Selected areas within NCA, comparing the panchromatic band from the Landsat ETM satellite image and the final cultivation map, with an inset for each showing the location of each site. In grasslands, such as northeast of Empaki Crater (a) and in Balbal Depression (b) cultivation was relatively easy to identify. Cultivation in the forested slopes of northwest of Olmoti Crater (c) had a unique texture that allowed mapping.

of mapping was successful in areas where cultivation was contiguous, such as outside NCA, along the southeastern border. However, we sought another method of mapping the small patches of cultivation within NCA.

While inspecting the satellite images, we found that cultivation was often clear in the finest reso-

lution, panchromatic band. Regardless, we continued to pursue mapping through image processing because manually outlining patches of cultivation would be extremely time consuming. Revisiting the problem after the marginal success of image processing methods, we noted that in image editing software used in publishing, a fea-

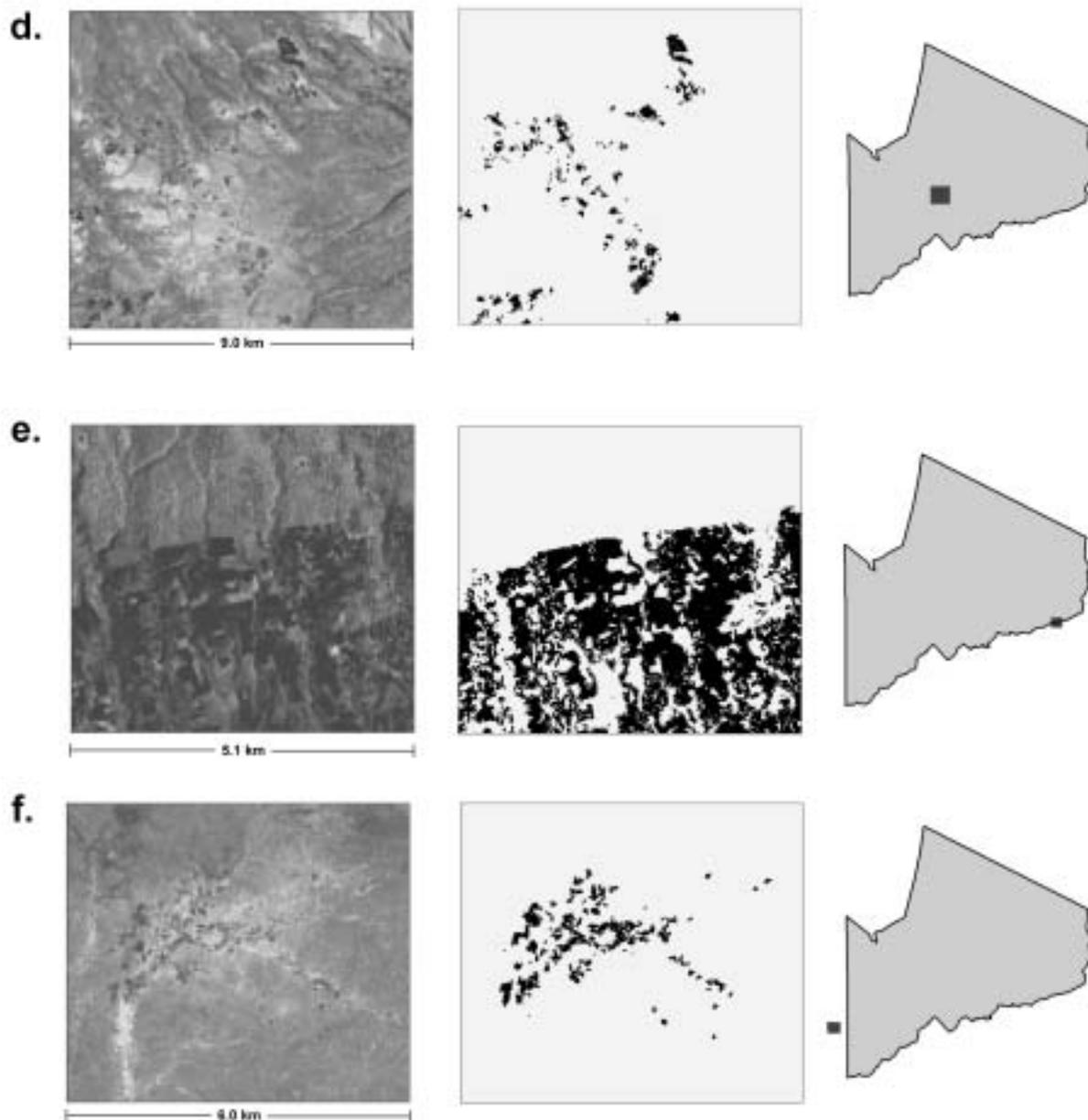


Figure 7. (Continued) Further to the southwest, shrubs and complex drainage patterns made mapping cultivation more difficult, but still possible (d). Extensive cultivated areas mostly outside of NCA (e) were mapped using image processing, although areas west of NCA (f) were mapped by hand, with cultivation easily identified.

ture allows the user to click on a given area, and all the neighboring pixels of similar color (or hue, or brightness) will be selected. *Our main method* of mapping cultivation within NCA was therefore using image editing software (Paint Shop Pro, Jasc Software, Minneapolis, Minnesota, USA) to select areas thought to represent cultivation. The ability of GIS to export layers to images allowed this mapping within an editing tool to retain the precise

geographic locations of picture elements. Again, the patches defined visually as cultivation, cited above, were used as reference areas in this process. In practice, identifying cultivation was straightforward – a pixel within a patch thought to be cultivation was identified in the image editing program, and other neighboring pixels of similar color were automatically selected. The only necessary adjustment made controlled how similar the

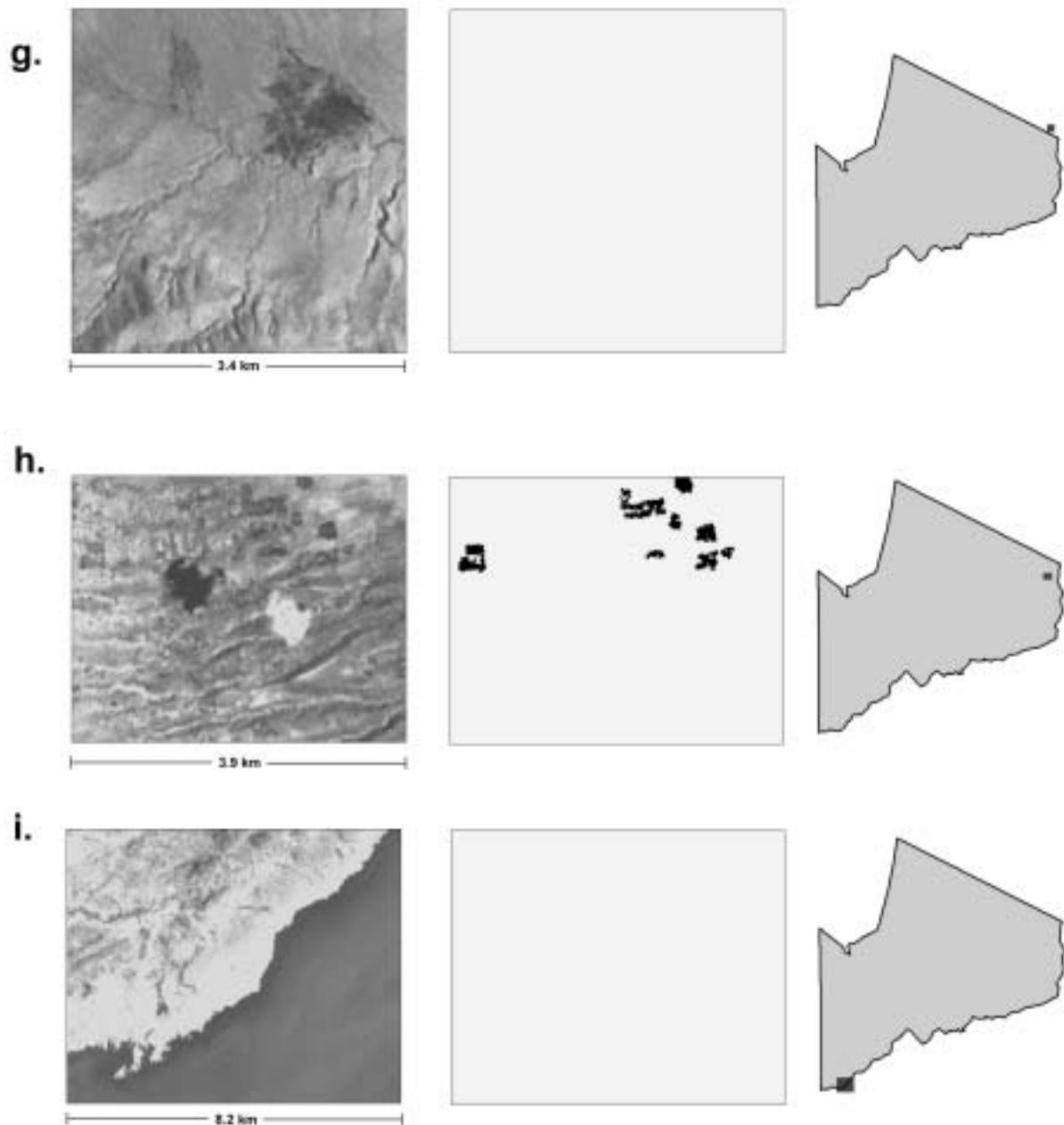


Figure 7. (Continued) Fire scars had a unique, ragged contour that tended to follow topographic features and contain gaps (g), and were not mapped as cultivation. Cloud shadows appear as dark patches similar to cultivation (h), but a corresponding white cloud of the same shape removed any confusion. In some areas, such as along the shores of Lake Eyasi (i), cultivation believed to occur could not be mapped using these methods.

neighboring pixels had to be selected.

2.2.2. Results

Prior to showing the final cultivation map we generated, we will show examples of areas throughout the NCA, and describe any difficulties we encountered. Figure 7a-i show the Landsat satellite

image for a selected area and the cultivation we mapped, along with an indication of the location of the site. (Note that our image viewing tools showed differences in brightness more clearly than the printed images in Figure 7 can.) In general, areas of grassland – especially short grasses – showed cultivation in high enough contrast for us

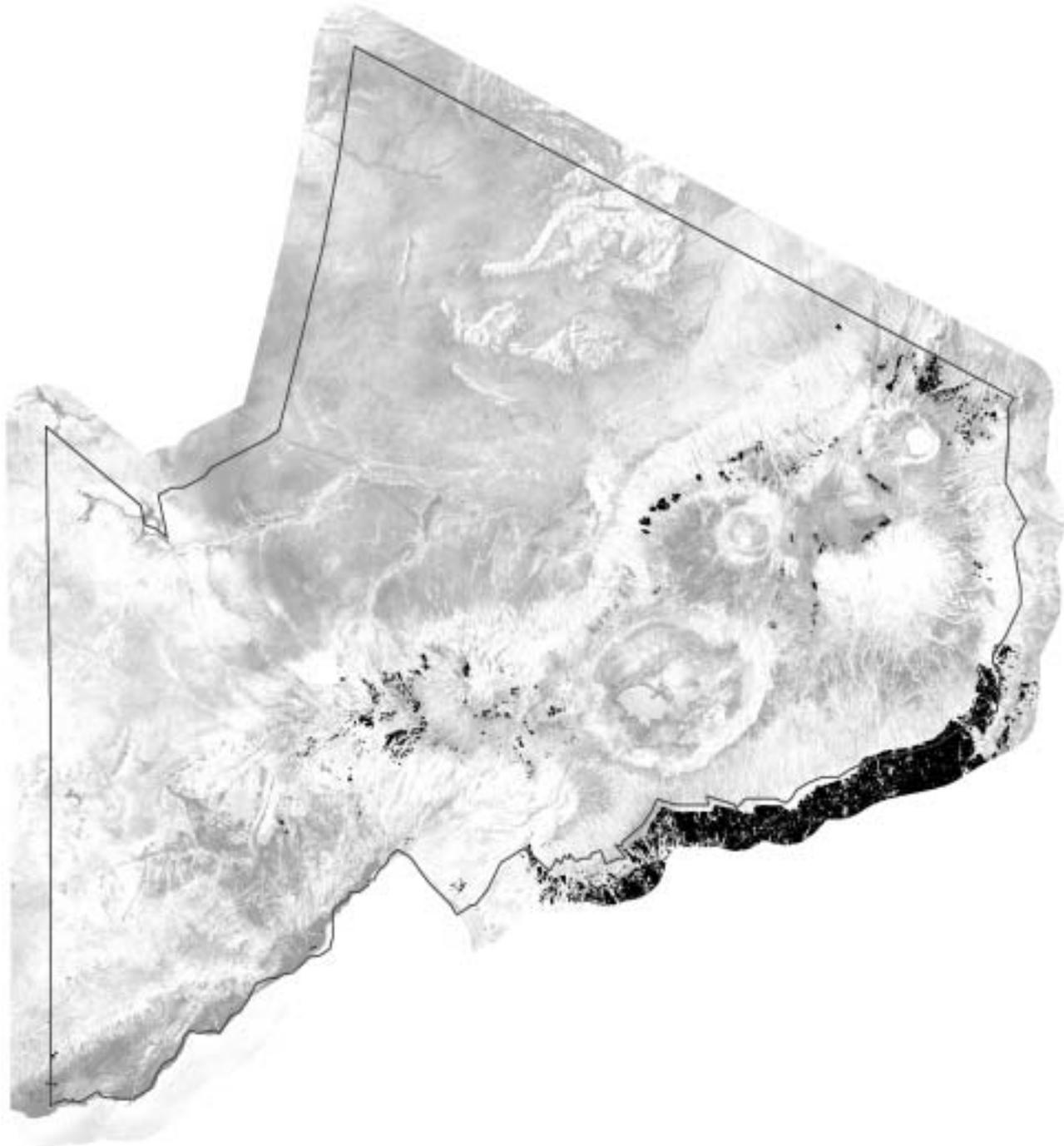


Figure 8. Cultivation in Ngorongoro Conservation Area, shown in black, February 2000. Within NCA, 3,967 ha or 9,803 ac were mapped as cultivation. For context, a 5 km buffer around NCA is also shown.

to be confident that we were mapping it reasonably (e.g., Figure 7a, b). Cultivation in the forested areas along the northwest slopes of Olmoti Crater was evident as well, as a series of patches with a texture different than the surrounding forest (Figure 7c). As mapping continued to the south-

west, identifying cultivation became more difficult, as braided drainage systems and brushy habitats confused the image. Regardless, we believe the cultivated areas around Endulen are mapped reasonably, for example (Figure 7d). The extensive agricultural area to the southeast of NCA was

mapped using image processing techniques (Figure 7e), with some confusion with brushy natural habitats, but sufficient to meet our needs. Other areas outside NCA were also mapped (e.g., Figure 7f) to ensure we could identify cultivation throughout the region. In the case of the area in Figure 7f, the cultivation contrasted well with the surrounding grasslands.

Some patches with high contrast were not mapped as cultivation. Charred fire scars showed as dark patches (e.g., Figure 7g), however they had a distinctive, ragged outline and fire ‘skips’ in their interiors that made them unique in appearance. Clouds made shadows that were dark as well, however the neighboring cloud of the same shape made the distinction with cultivation clear (e.g., Figure 7h). In some cases, we could not identify cultivation based upon the satellite image, despite our understanding that areas were cultivated. Cultivation along the southern shores of Lake Eyasi was difficult to identify (Figure 7i); dark patches occur in the image, but we could not distinguish them from shrubs. Similarly, we understand that areas around Olbalbal Depression are cultivated when water is available for irrigation. We could not identify those areas, however (not shown).

The final cultivation map is shown in Figure 8, which includes areas outside NCA but within a 5 km distance. Note that the resolution of the printed image precludes showing the fine-scale pattern of cultivation shown previously, e.g., the fine-grained patches shown in Figure 7c show as solid patches near the center of Figure 8, on the northwest slopes of Olmoti. Notable patterns include that the agreement between the boundary of NCA and the edge of the main area of cultivation in the southeast is poor. We believe the computer map of the NCA boundary to be of good quality (i.e., based upon Tanzanian 1:50,000 scale maps). There is also an ongoing project to resurvey the boundaries of NCA (V. Runyoro, pers. comm.). It may be that the relatively small errors in boundaries (computer-based or real extents) have led to the pattern we see today. In contrast, we believe that the area to the east well inside the NCA is cultivation encroaching into the area. Other areas of

significant cultivation include the northern slopes of Empaakai, the forested slopes of Olmoti, and areas around Endulen. We estimated that in February 2000 there were 3,967 ha or 9,803 acres of cultivation in NCA. That value excludes cultivation outside NCA but shown in Figure 8, and does not differentiate between cultivation by Maasai and other groups.

2.2.3. Limitations

We have noted that image processing techniques could not differentiate cultivation from shrubs and other land cover types within NCA well. The method was used more successfully along the southeastern boundary of NCA, but some confusion still remains. Identifying cultivation visually within an image editing package proved more successful, but distinguishing cultivation was still sometimes difficult. Some areas actually in cultivation were not mapped, and some areas mapped as cultivation were in natural cover. That said, 80% accuracy in land cover mapping is generally taken as a rule of thumb for a useful effort. Although we do not have the opportunity to formally assess the cultivation map, based solely upon objective impressions from the methods used and expert review, we believe it correctly distinguishes cultivated versus natural land cover with greater than 80% accuracy.

The method used to identify cultivation patches (i.e., identifying contiguous areas of color within image editing software) led to patches that were interconnected, likely to a greater degree than in reality. In Figure 7a, for example, the reader may be able to infer connected patches in the cultivation map. Our estimate of area in cultivation is unbiased by this effect, but we do not report mean cultivated patch area, patch count, or similar measures, since these would be biased.

2.3. What is the Balance between Resident Wildlife, Livestock, and Human Populations?

In our review of methods of estimating the capacity of rangelands to support large herbivores, we cited that wholly wildlife-based herbivore sys-

tems tend to support about half the total the herbivore biomass of pastoral systems (e.g., Coe et al. 1976), and an order of magnitude less biomass than managed livestock systems (e.g., Oesterheld et al. 1992). The answer then to the question, “How many large herbivores may be supported on NCA?” must therefore be, “It depends upon the mix of wildlife and livestock.” It would be inappropriate for us (nor were we asked) to identify a ratio of wildlife to livestock that would be the goal for which the NCAA and pastoralists should strive. Instead, in this section we discuss the trade-offs anticipated if livestock and wildlife numbers were changed over time. In short, we address the following question, “*Given different human population levels and livestock holdings per person, how many wildlife may be supported on NCA?*”

2.3.1. Methods

To assess the effects of different ratios of livestock and wildlife we used the Savanna Modeling System. The complexity of Savanna allowed us to integrate into the assessments changes in access to livestock and wildlife as their populations changed. For example, in Savanna (version 4Lb was used in this report), wildlife avoid livestock to varying degrees (R. Reid, unpublished data). In turn, cattle (in reality their herders) avoid migratory wildebeest, to avoid infection with malignant catarrhal fever. When livestock populations were kept low, more area was available for use by wildlife because of less avoidance.

Some detail about Savanna was provided in the section describing assessments of the capacity of NCA to support herbivores. As mentioned, migratory populations (wildebeest, zebra, Thomson’s gazelle) are not modeled. They are held constant because we do not know what may affect their populations in other parts of their migratory range. That restriction is continued here – decreasing livestock on NCA may allow more migratory animals to inhabit NCA, but we do not know if the Serengeti and Maasai Mara regions used in other times of the year would allow an increase in migratory animal numbers. Also, theoretically, changes in livestock numbers should not affect wildlife within Ngorongoro Crater (except for displacing wildlife

from elsewhere into the crater). These analyses do not include Ngorongoro Crater wildlife populations. We therefore must modify the question just posed, to become “..., *how many resident wildlife may be supported on NCA excluding the crater?*” Results for wildlife from this section pertain only to resident wildlife, and the wildlife biomass within the crater may simply be added to these results if values for all of NCA are needed.

The logic used in these assessments with Savanna was straightforward. The model for NCA was adjusted to yield relatively stable livestock and wildlife populations at their current populations over a 15 year simulation. This modeled (and observed) ratio of livestock and wildlife formed a starting point to which other simulations were compared. Livestock were then added or removed from the simulation, their populations held constant, and wildlife populations increased or decreased until their populations remained relatively stable over a 15 year simulation. The proportion of cattle, goats, and sheep was maintained in all analyses. The balance between wildlife functional groups can be tenuous, and sometimes one population might decline while the others were stable. Regardless, the effect was small, and total biomass of resident wildlife is the measure of interest. At some point there may simply be too many livestock on NCA, and we needed to define when that was the case; livestock populations were held constant in these simulations, and so overstocking wouldn’t appear as population changes. The NCAA mandate says that livestock will not have an adverse effect upon the ecosystem (V. Runyoro, pers. comm.). With that, in simulations, if wildlife populations were dropped to zero, we used steadily declining palatable grass as a cue that the system was overstocked with livestock.

In practice, we assessed expected changes in resident wildlife across five levels of livestock holdings:

- 3 TLUs/person, which approximates closely the current estimate on NCA (2.77 TLUs/person; Lynn 2000);
- 6 TLUs/person, which is the minimum thought to support a wholly pastoral lifestyle (Brown 1973) (Note that elsewhere we sometimes use 8 TLUs/

person as a baseline, given increased costs pastoralists face);

- 10 TLUs/person, the holdings of pastoralists in neighboring Loliondo (Lynn 2000);
- 1.5 TLUs/person, half the current livestock holdings;
- 0 TLUs/person, with livestock removed.

We also included five levels of human population:

- 50,000, approximately the current human population in NCA;
- 100,000, double the current population, and expected in the year 2019 if population growth remains at that reported in 1997, 3.5% (Kijazi 1997);
- 150,000, triple the current population, and expected in the year 2030;
- 35,000, the approximate human population of 1992 (NCAA 2000);
- 0, with humans removed.

We therefore looked at expected resident wildlife populations with livestock LHUs varying from 0 animals (i.e., 0 TLUs per person, or 0 people) to 1,500,000 LHUs (10 TLUs per person with 150,000 people present).

2.3.2. Results

Background information calculated from herbivores in NCA (Table 1) or simple calculations of percentages include that, based upon current population estimates of the species we include in modeling, resident wildlife comprise about 5% of the total herbivore biomass on NCA during the wet season (derived from Table 1). That climbs to 20% of total biomass when the migratory animals move off NCA, essentially June through December. Livestock are 21% of total biomass in the wet season, and 80% of the total in the dry season. Also, with 8 TLUs per person as a baseline required to live a pastoral lifestyle, those with 6 TLUs must meet 25% of their needs through non-livestock sources, such as purchased food, wage labor, or traditional relief. With 3 TLUs (about the current conditions), 62% must be met by other sources, and at 1.5 TLUs, 81% of needs must be met in other ways.

Figure 9 summarizes expected changes in resident wildlife populations as livestock and human populations vary. Values approximating current conditions (3 TLUs/person, 50,000 people) yield

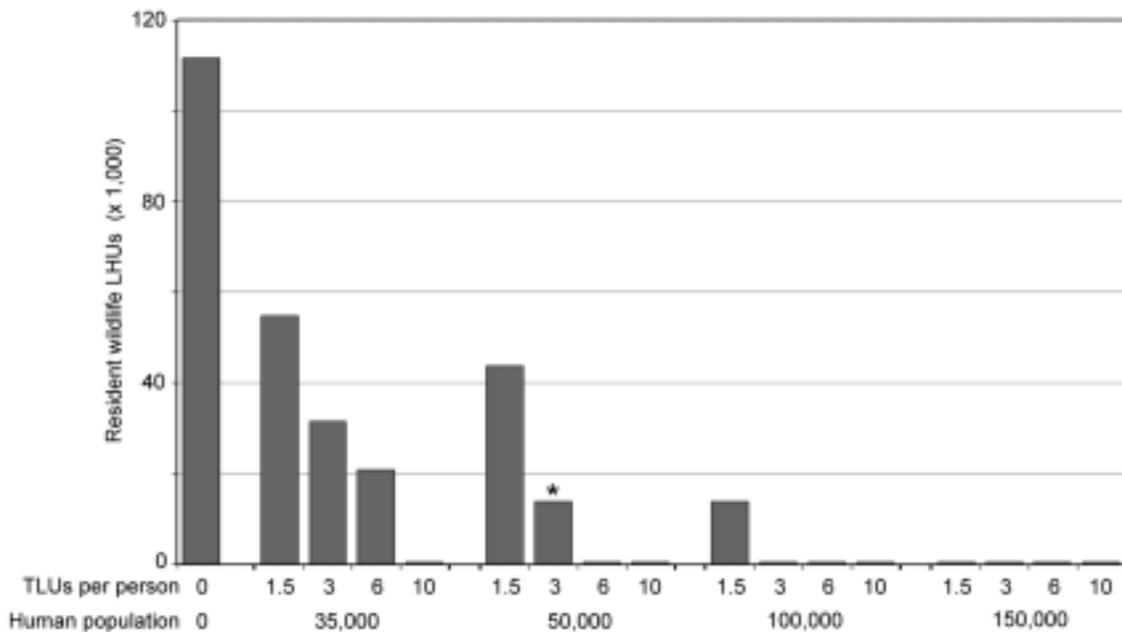


Figure 9. The change in resident wildlife populations of NCA under different levels of human population and livestock holdings per person. The starred bar (3 TLUs per person and 50,000 people) represents current conditions. Bars of zero height have 0 wildlife, and reflect overstocking and degradation of the grasslands.

an estimate of 13,806 LHUs for resident wildlife outside the crater, which compares well with the 15,467 LHUs estimated from current populations (Table 1, including resident zebra and gazelle, buffalo, browsing antelope and elephants; rhinos, giraffe, and warthogs were not modeled in this application, and resident wildebeest are mostly in the Ngorongoro Crater). That result is equivalent to having a future population of 100,000 people each with 1.5 TLUs (Figure 9). Under the current human population, if people owned half as many livestock (1.5 TLUs on average) as they do now, the resident wildlife population would be expected to be 43,627 LHUs, almost a three-fold increase. If the human population on NCA returned to what it was in about 1992, with 35,000 people, the system could maintain 6 TLUs per person (Figure 9), with somewhat more resident wildlife than seen today. If livestock were removed from NCA, eight times more resident wildlife would be expected, as compared to today.

In contrast, our computer simulations indicate that NCA does not have the capacity to allow the current human population (about 50,000 people) to each own the 6 TLUs required to be fully supported as pastoralists, and of course the 8 TLUs used as a more modern benchmark could not be supported either (Figure 9). That would require doubling the number of livestock on NCA, and our modeling indicated that after removing all wildlife, that number of cattle causes declines in range quality. Given that 6 TLUs per person for 50,000 people causes degradation, it also follows that 3 TLUs per person for 100,000 people will cause degradation. Based upon our simulations, if human population growth continues at 3.5%, in the year 2019 individuals could not each own the modest number of cattle that they own today, without leading to declines in wildlife numbers and degraded rangelands.

2.3.3. Considerations

Intensively managed livestock systems support much more herbivore biomass than systems with only wildlife. Our modeling did not incorporate management practices such as improving pastures through planting or predator control. Their absence

is unlikely to be viewed as a limitation, however, given that such management strategies would be in conflict with the mandate that the NCAA has to manage the area.

Readers should note that we have used both LHUs and TLUs, which, as mentioned, are similar but not equal. We have also simplified our methods by using human population numbers in our results, rather than adult equivalent, which are the formal basis for the rules of thumb such as 8 TLUs per AE. In other words, for simplicity, we have not incorporated human sex and age differences in this work.

2.4. What are Potential Effects of Cultivation in NCA?

A primary purpose for NCA and mandate to NCAA is to conserve the world-renowned wildlife of the area (Thompson 1997), in part responsible for the area's status as a Natural World Heritage site and a Biosphere Reserve. The cultivation that has been allowed in NCA since 1991 has been extremely contentious, with conservationists viewing cultivation as incongruent with wildlife conservation. The NCAA also has the mandate to manage the area to ensure the well-being of the Maasai inhabitants (Thompson 1997), and the tenuous food security of Maasai in NCA is likely to deteriorate further, given current socioeconomic conditions. Cultivation has helped greatly to ease the food insecurity of NCA Maasai, but neighboring Maasai in Loliondo Game Controlled Area to the north cultivate more than NCA pastoralists, and are better-off in general (Lynn 2000; Galvin et al., In press). Should cultivation be reduced? ... removed? ... allowed to expand? We must leave the difficult task of balancing the multiple uses of NCA to the Authority and local stakeholders. To aid those making these decisions, we assess a more straightforward query, "*What are the predicted effects of different levels of cultivation on livestock and wildlife populations?*"

In an extension to the queries put to us by the Conservator of NCA, we also assessed potential effects of redistributing cultivation. We asked, "*What are the predicted effects of keeping cultivation at its current level, but distributed in two large*

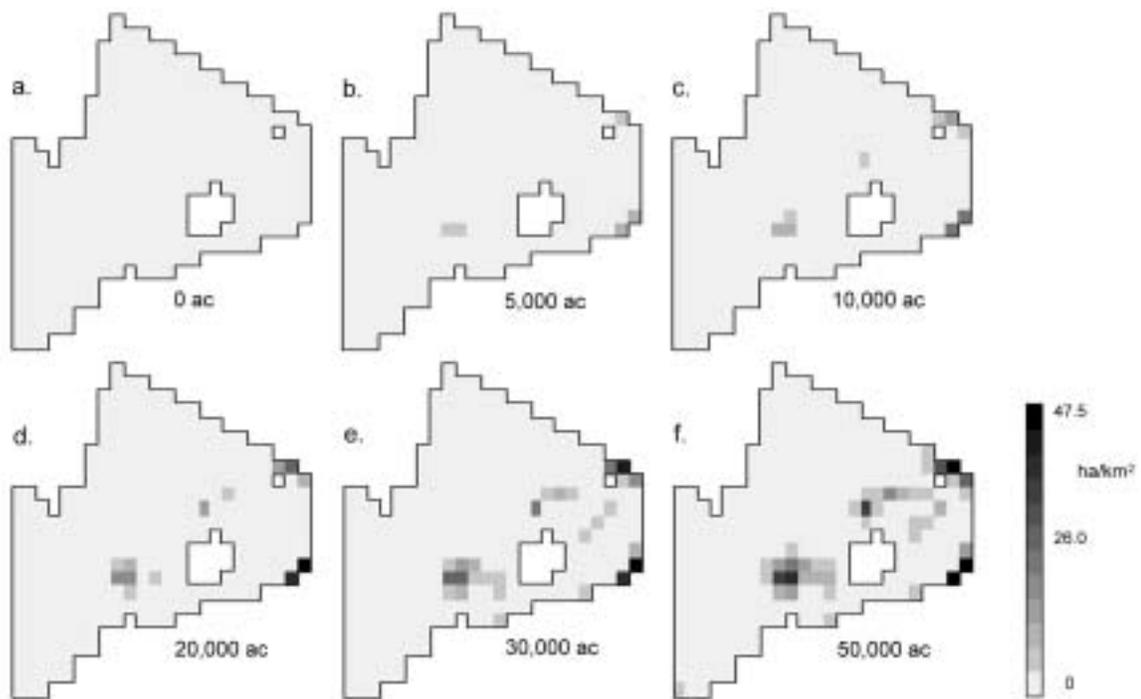


Figure 10. Maps of cultivation used in modeling. The map with 10,000 ac (c) is based upon the cultivation map shown in Figure 7, representing cultivation in the year 2000.

blocks on the landscape?” We also looked at the effect of doubling the current area in cultivation (i.e., 20,000 ac) in two large blocks.

2.4.1. Methods

Again, the Savanna Modeling System was used to assess potential effects of cultivation. The cultivation map already described was used here. Savanna divides a landscape into a grid of square blocks; in this case we used 5 km x 5 km blocks. We therefore calculated cultivation for each square kilometer using the map created, and generalized to 5 km x 5 km blocks. Within NCA, 9,803 ac of cultivation were mapped. To simplify analyses, we rounded that number to 10,000 ac (Figure 10c). We then generated the remaining maps shown in Figure 10 (i.e., 5,000 ac, 20,000 ac, 30,000 ac, 50,000 ac, and 0 ac of cultivation).

Because a primary mandate to the NCAA is to maintain human well-being of the pastoralists of the system, in modeling we merged with Savanna the PHEWS model, created by P. Thornton and K. Galvin. The PHEWS (Pastoral Household Economic Welfare Simulator) models decision mak-

ing and well-being of pastoral household occupants, and has been adapted to NCA. PHEWS uses states of the ecosystem (e.g., number and age/sex classes) passed to it by Savanna to infer decisions pastoralists may make. Decisions are based, in part, upon two main measures of status: 1) the current TLU/AE versus a target TLU/AE, and 2) cash reserves/AE versus a target cash reserve/AE. For families in three wealth categories (poor, moderate, and rich), each month their status is assessed. The energy available to them through drinking milk, eating maize and meat (dead animals or those slaughtered for special occasions), and sugar in tea is calculated. If requirements are met and target TLUs are met, animals may be sold. If requirements have not been met, but cash reserves are in excess, animals and maize may be purchased. Finally, if requirements have not been met but cash is not available, the families’ needs are met by supplements. These supplements may have many sources, such as gifts from family or friends, wage labor earnings, and traditional relief from governmental or non-profit organizations. For more information about PHEWS, see Thornton et al. (In

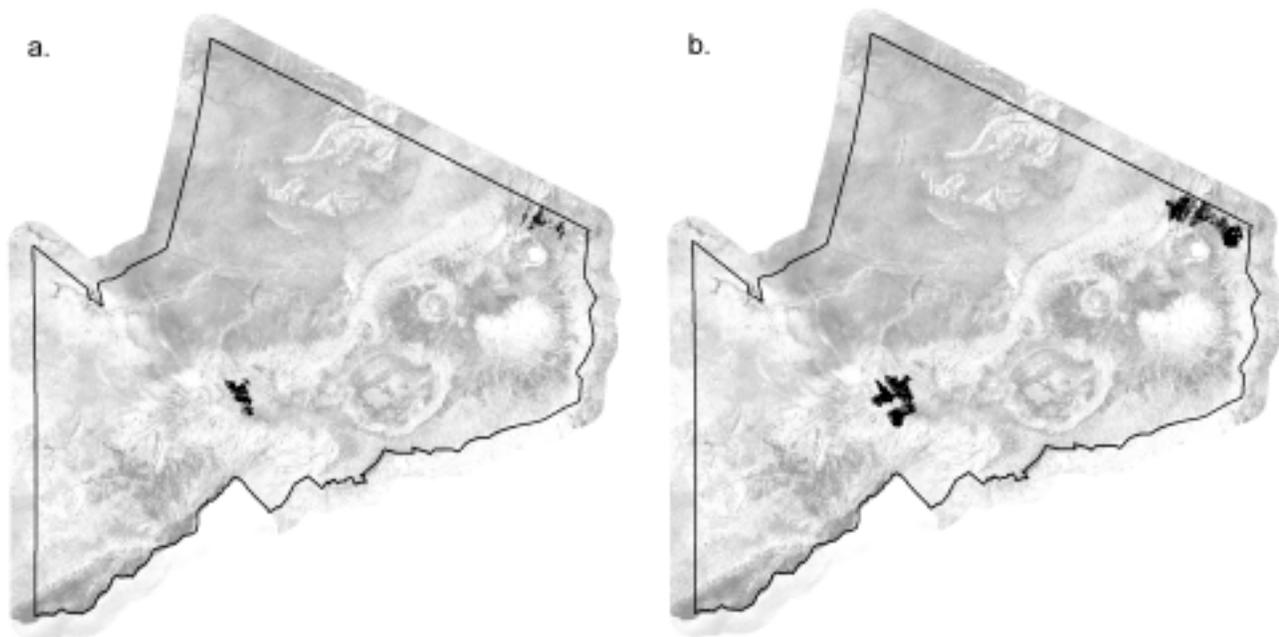


Figure 11. Maps of cultivated areas, where cultivation was redistributed into two blocks, near Endulen and the northern slopes of Empakaai. Cultivated area assessed included 10,000 ac (a) and 20,000 ac (b).

press) and Galvin et al. (2000).

The PHEWS application to NCA required that pastoralists cultivate a given area; we were unable to judge effects of decreasing or increasing cultivation for a given household. Two sets of simulations were run. In one, the effect of cultivation on animals was assessed, with the PHEWS model not used. That allowed us to judge effects of the displacement of wildlife and livestock from cultivated areas. In the other set of analyses, the area currently cultivated by households (0.67 ha/poor household, 0.89 ha/moderate, 1.42 ha/rich; Galvin et al. 2000) was used as a baseline. Then to represent increasing human population (and cultivation), households were added. Effects of different amounts of cultivation on a given household were not evaluated.

The two areas in NCA with concentrations of cultivated fields are in the Endulen west of Ngorongoro Crater, and on the northeastern slopes of Empakaai Crater. Using techniques similar to those used to map cultivation originally, we went to each of those areas, and selected landscape patches in grassland habitats until each area had 5,000 ac of cultivation, or 10,000 ac total. In the

computer map, the other areas of cultivation within NCA were removed, leaving a map with 10,000 ac of cultivation in two blocks (Figure 11a). We continued this same process, selecting another 10,000 ac to be cultivation within the two areas, yielding a map of 20,000 ac in two blocks (Figure 11b).

2.4.2. Results

In simulations run with cultivation (i.e., Figure 10c) and without cultivation (Figure 10a), livestock biomass was similar through time (Figure 12a). Similarly, resident wildlife biomass did not change markedly between the simulations. Savanna results lead us to believe that 10,000 ac in cultivation *in its current spatial configuration*, is not likely to have adverse impacts upon livestock or wildlife populations. These results may be anticipated – if the Pastoralist Development Management Zone, excluding Olduvai Gorge (Figure 5) were used as reference, at 3,667 km² (Table 6), the 3,967 ha currently in cultivation is less than 1.1% of the zone. That said, we saw changes in the distribution of cattle between the two simulations (Figure 13). Cattle densities were higher in the midlands when cultivation was in place than when

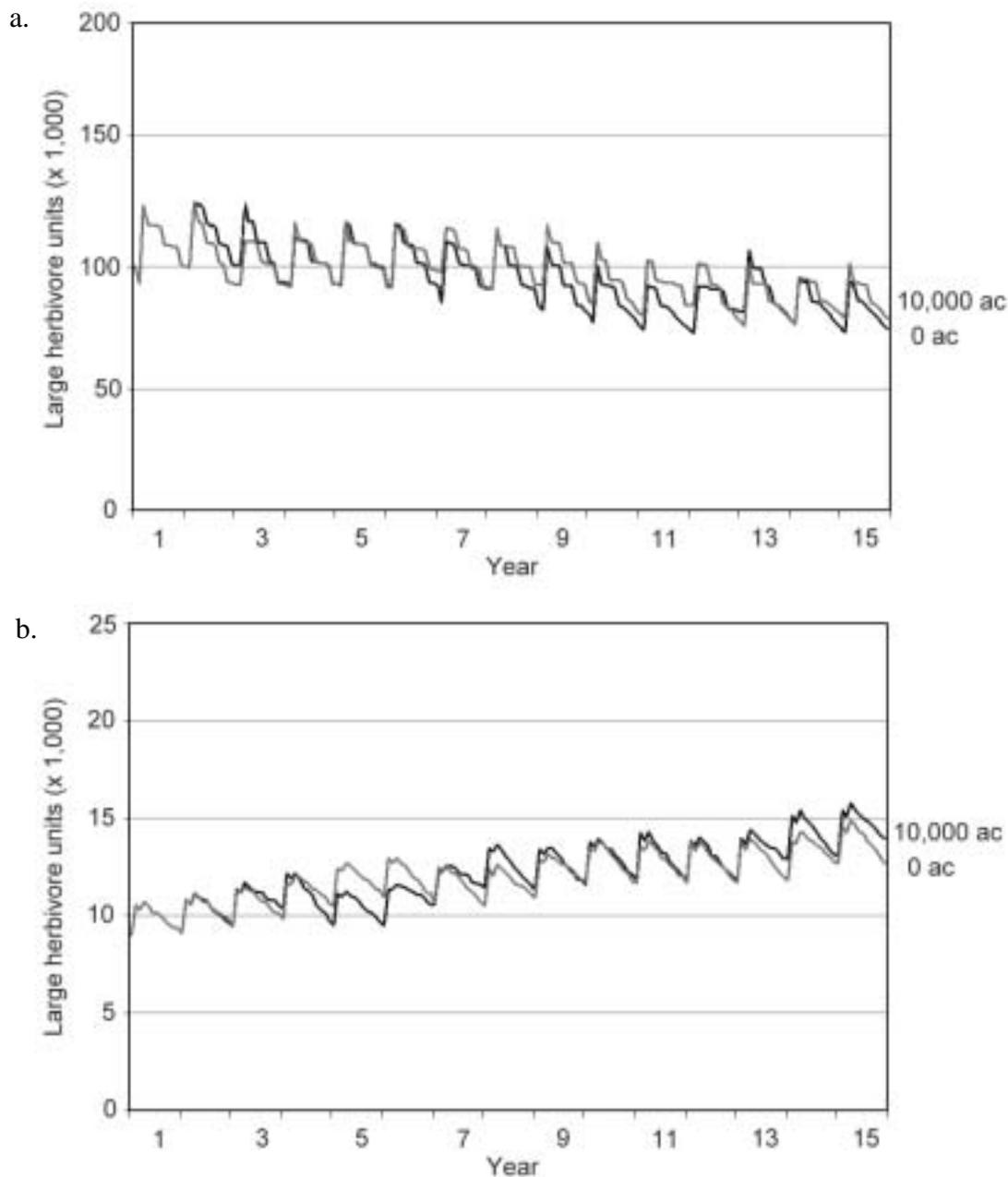


Figure 12. In simulations, livestock biomass (a) and resident wildlife biomass (b) did not change markedly with cultivation in place, compared to no cultivation.

cultivation was not included.

We varied cultivation from 0 ac to 50,000 ac (again, if the Pastoralist Development Zone were the area of interest, about 5.5% would be in cultivation), with its distribution similar to observed cultivation, as shown in Figure 11. Livestock and resident wildlife populations did not change markedly when cultivation was varied from 0 ac to

50,000 ac (Figure 14).

If the area currently cultivated is doubled (20,000 ac) along with human population (100,000 people) or tripled (30,000 ac, 150,000 people), food security for Maasai decreases rapidly. This is due mainly to decreasing TLUs/person as human population increases, but livestock populations stay relatively constant. There is also some loss of livestock

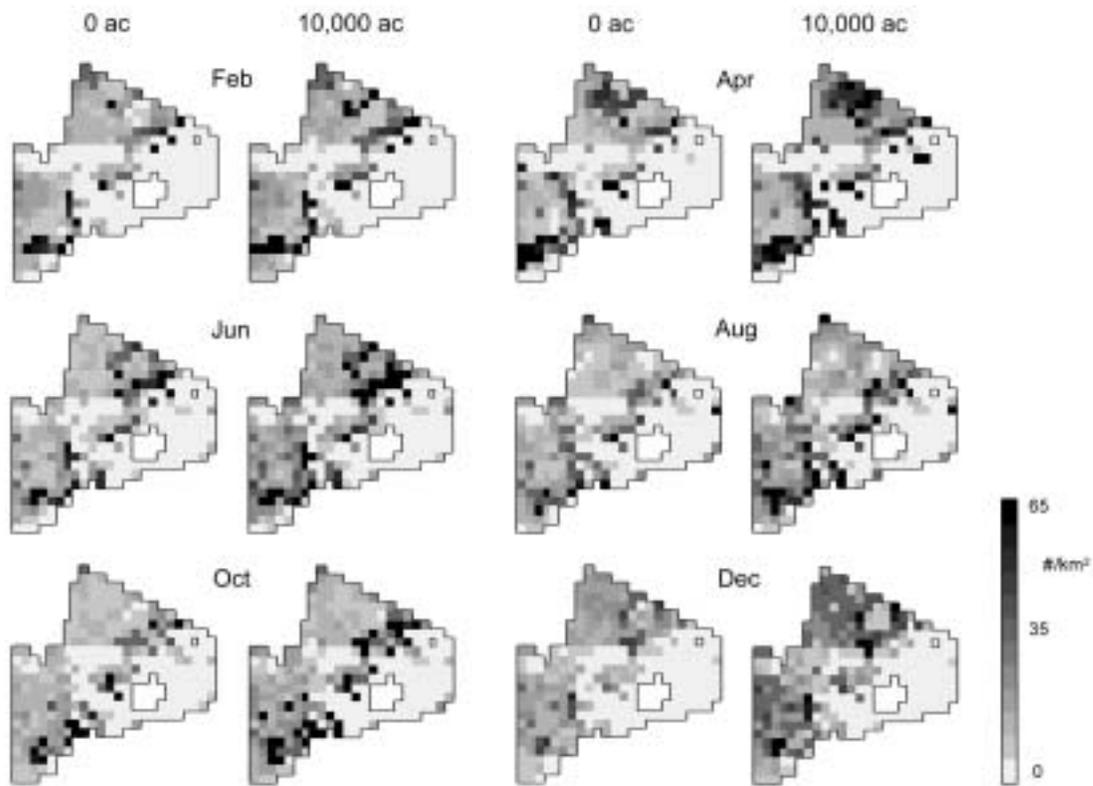


Figure 13. Cattle distributions with (10,000 ac) and without (0 ac) cultivation for selected months in the 12 year of simulations. Distributions change somewhat when cultivation is in place.

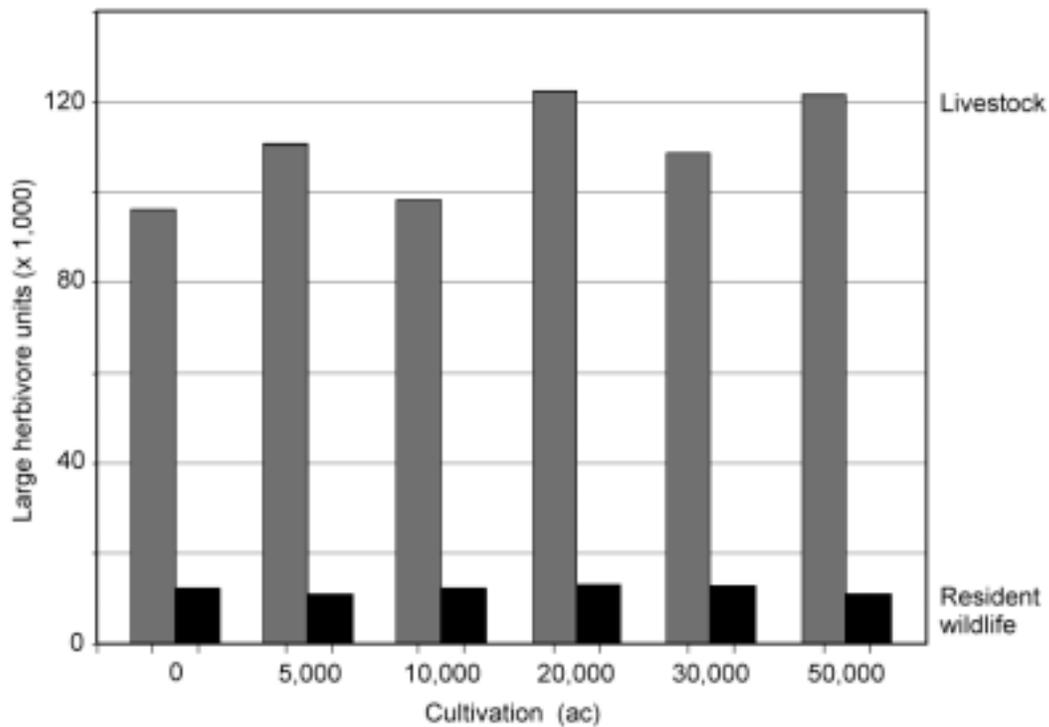


Figure 14. Changes in livestock and resident wildlife populations under different levels of cultivation.

grazing area, although its effect upon livestock was shown to be minor (Figure 14). Overall, we estimate that rich people in NCA currently do not require supplements to their diets (i.e., relief) – with 150,000 people and 30,000 ac of cultivation, even rich families required 10% of their diet be supplemented, and poor families required 24% supplements (Figure 15). In contrast, if 35,000 people inhabited NCA (as in 1990), no households would need more than 5% supplements to their diets. Similarly, cash reserves available to rich families are lower under high human populations, but steadily increase with 35,000 people (Figure 16).

When cultivation was moved from its current distribution to occurring in two larger blocks, livestock populations were at current levels in some years, but appeared less able to take advantage of years of higher rainfall (Figure 17), yielding a more stable population in the simulation. Resident wildlife biomass increased when cultivation was blocked, with a substantial increase in resident grazing antelopes (Figure 18). Resident wildlife

declined initially when cultivation was blocked and at twice its current level (i.e., 20,000 ac), but then recovered to current levels (Figure 19).

Although not directly assessed here (see limitations), in past work we have demonstrated that cultivation at its current level is critical for Maasai in NCA. Without cultivation, poor households would require that almost 25% of their needs be made up by relief or other sources, versus about 13% now. If cultivation were doubled, poor and medium households were shown to benefit greatly (Galvin et al. 2000).

2.4.3. Limitations

To ensure that responses from the Savanna application are sensitive to effects such as drought or changes in cultivation, the animal populations must be carefully balanced. Under experimental settings, we cannot ensure that responses of individual resident wildlife populations are appropriate. However, as an integrative model, if one population increases, another will decline due to

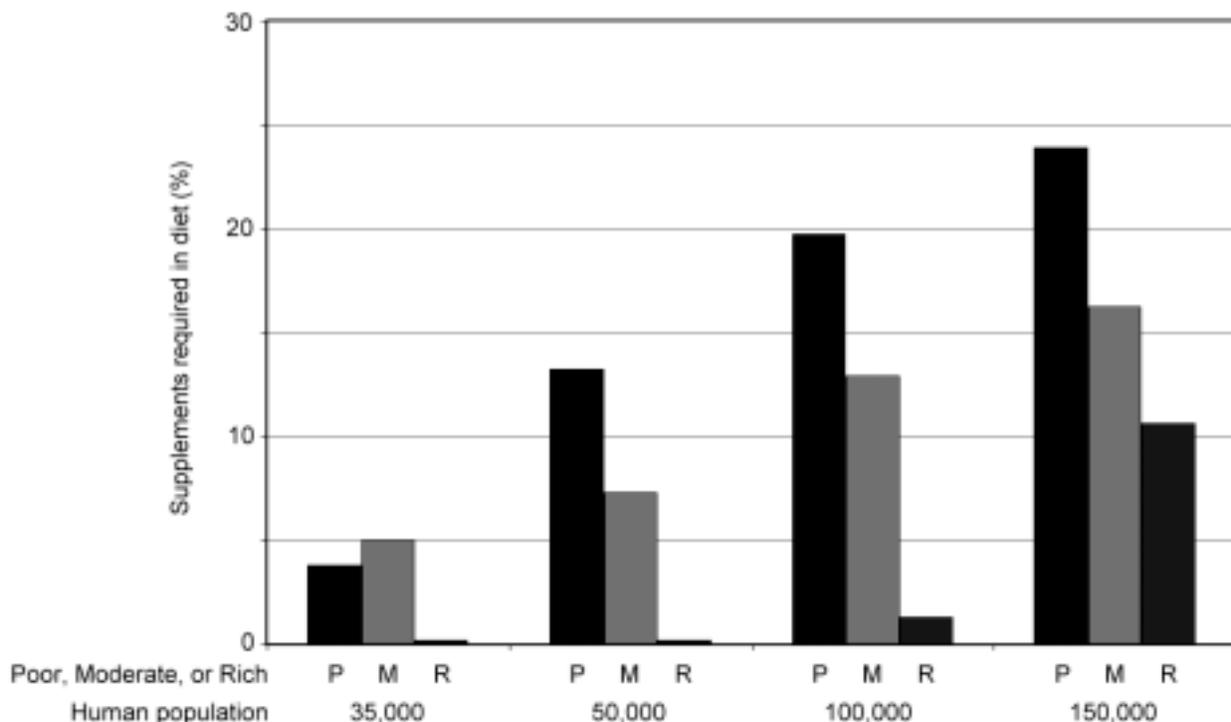


Figure 15. Supplemental foods required in Maasai diets under different human populations and correspondingly increasing cultivation.

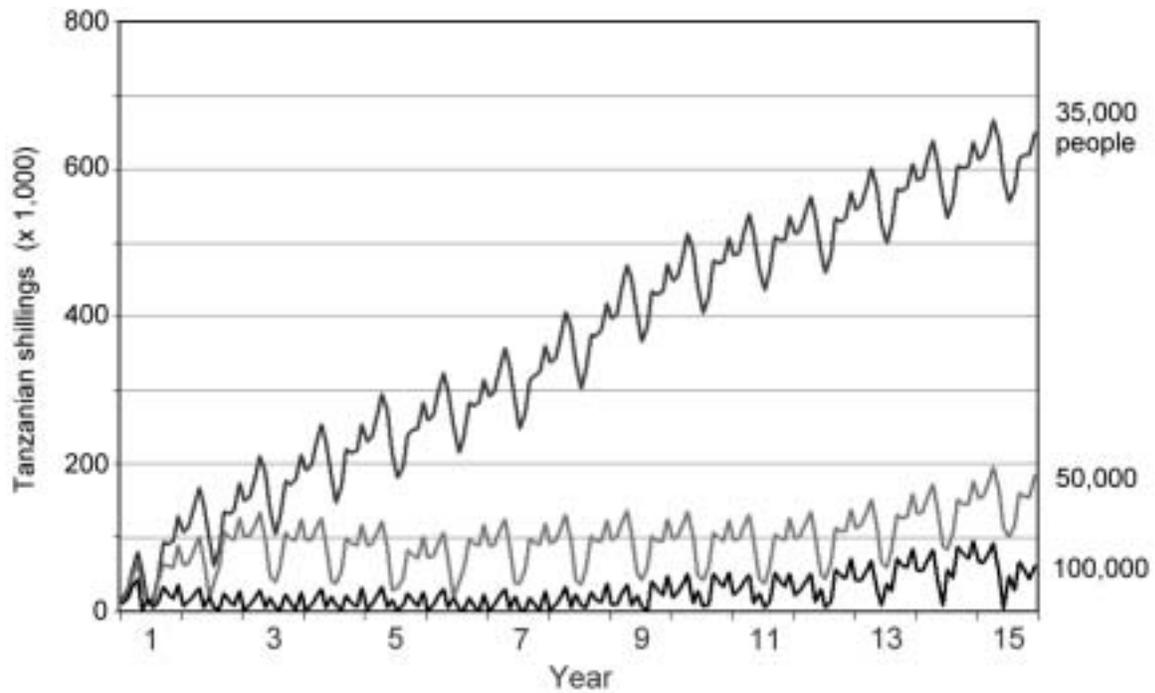


Figure 16. Cash reserves for rich households under different levels of human population.

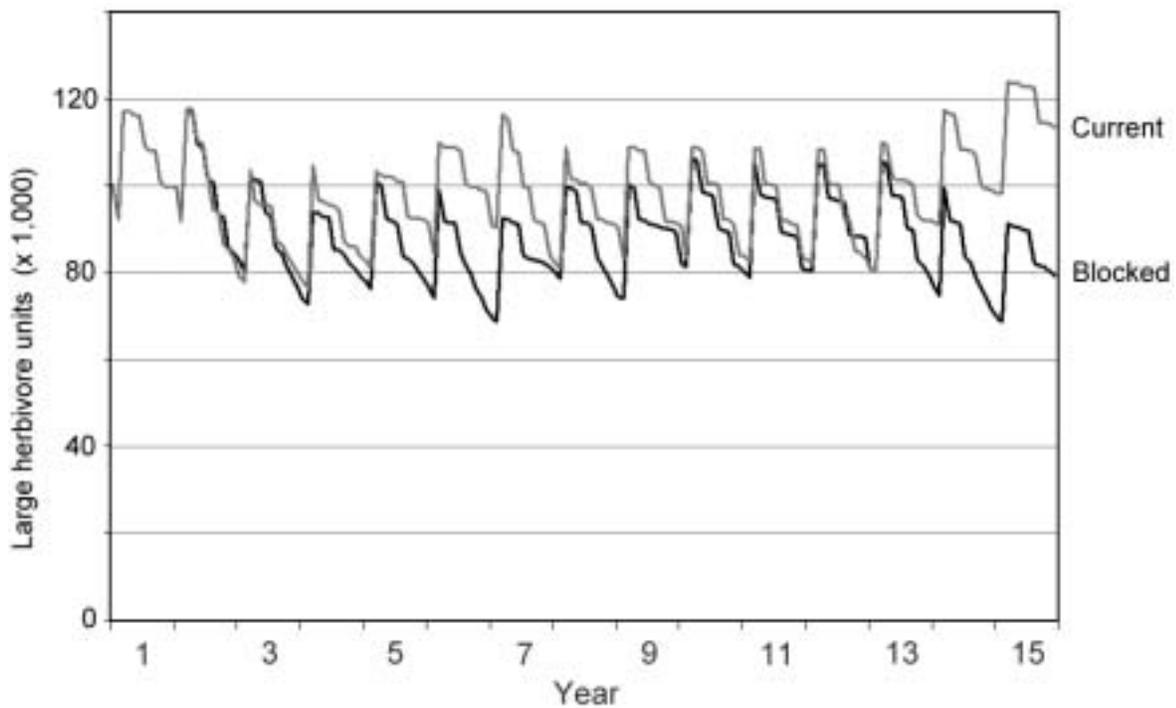


Figure 17. Livestock biomass under cultivation in its current distribution versus a blocked distribution.

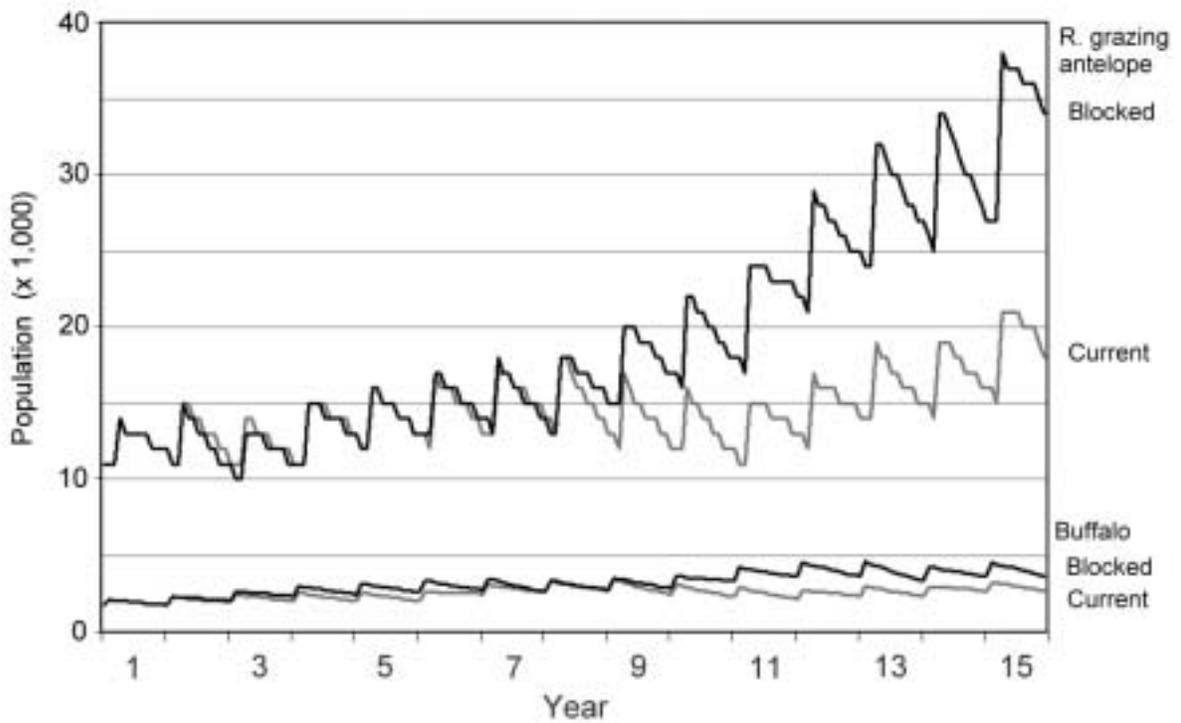


Figure 18. Increases (e.g., resident grazing antelope) or little change (buffalo) in resident wildlife populations when cultivation is in its current distribution versus blocked distribution.

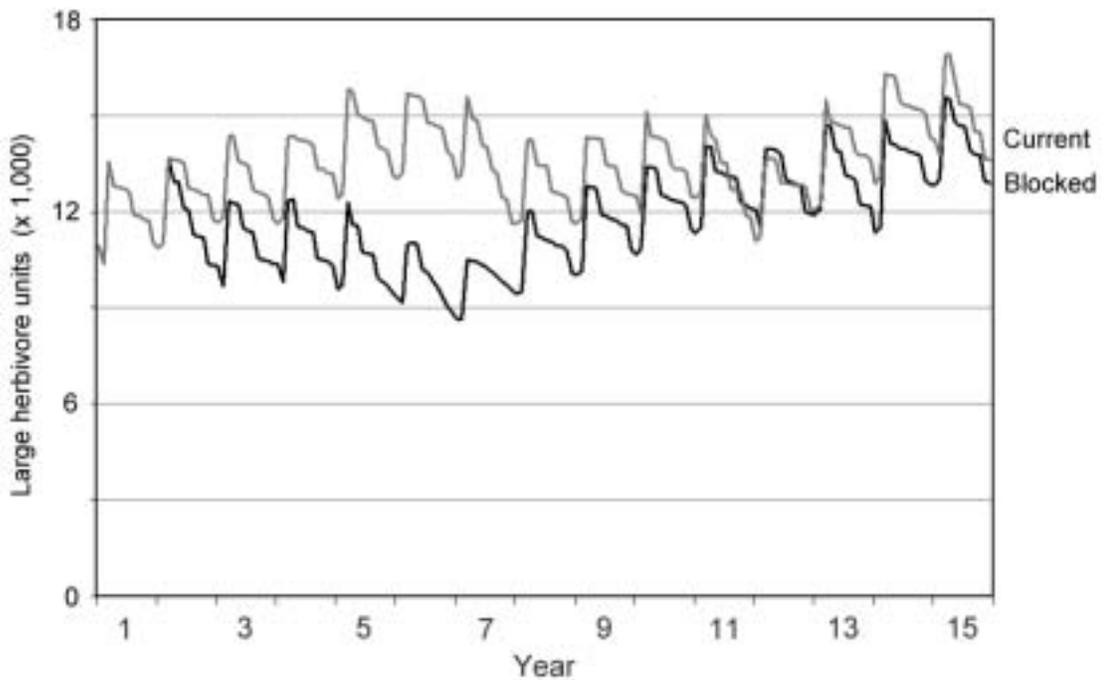


Figure 19. Changes in resident wildlife biomass when cultivation is in its current distribution and at 20,000 ac, versus when blocked, and at 20,000 ac.

competition for forage, for example. Given that our focus is upon changes in large herbivore biomass rather than individual populations, we believe the results reported are reasonable predictions.

The model requirement that cultivation be constant for a given household prevented us from assessing effects of varying cultivated areas on household status. We looked at household status under different population levels and cultivation by increasing cultivation linearly as household numbers increased. Future applications of the PHEWS model will not be constrained in this way.

As cultivation was increased, the livestock biomass may have increased slightly (Figure 14). In Savanna, livestock that inhabit higher, wetter areas are more at risk for becoming infected with East Coast fever or other diseases. As livestock were excluded from high elevation areas used for cultivation, their populations may have benefitted. Although this seems logical, we do not know if such a response would occur in reality, and at this time consider it a modeling artifact.

2.5. What are the Effects of Controlling Livestock Disease?

Losses of livestock to disease in NCA can be extreme – losses to the tick-borne diseases East Coast fever and ornilo were 18% for adult cattle and 52% for calves in a recent survey (Rwambo et al. 2000). Wildebeest migrating onto NCA in the wet season bring with them the virus causing malignant catarrhal fever, causing Maasai herders to move their animals into the midlands and highlands. This concentration of animals increases their exposure to tick-borne and infectious diseases (McCabe 1995; Rwambo et al. 2000). Limited grazing areas increases the risks of wildlife to livestock, and livestock to wildlife, transmission of disease. These threats have increased calls for the development of a disease management program to reduce losses to tick-borne and infectious diseases (e.g., Rwambo et al. 2000). Such a program is underway, under the Ngorongoro pastoralist project *ERETO*, sponsored by the Danish Agency for Development Assistance (DANIDA 2001). *ERETO* sponsors veterinary personnel, working on-the-ground in NCA to reduce livestock losses from

disease. Projects reviews and opinions suggest that the efforts of *ERETO* to improve livestock survival and increase populations (with additions due to the *ERETO* livestock restocking program) are currently successful, although not without challenges. That said, veterinary care remains expensive, and owners must balance benefits from veterinary care versus costs. Marketing remains a challenge as well. Whether Maasai will be able to sell their animals in stable markets at reasonable prices remains a concern.

We addressed two general questions. First, we investigated what the ecological effects may be from improved veterinary care, as requested by the Conservator of NCA. Second, we looked at the expected benefits of the control of losses due to disease on adult livestock, and contrasted that with disease control in juvenile populations. Overall, our results also allow stakeholders to balance benefits to Maasai versus costs, important for when external funding for veterinary care ceases.

2.5.1. Methods

Modifications to the Savanna modeling system for NCA include the addition of a disease component. Livestock that inhabit wetter or higher areas, factors associated with increased tick-borne diseases, are at greater risk of death than those in lower, dryer areas. In practice, balancing an ecosystem in Savanna can be challenging. However, the logic in this case is straightforward. Assessments already described in the section on carrying capacity yielded an application of Savanna to NCA where the livestock and wildlife were presumably at capacity. The number of livestock in that simulation exceeded the long-term populations. Given that livestock are thought to be below capacity in NCA due to disease (see Boone et al. 2002), we added deaths from disease into the application. Losses emulating East Coast fever (cattle) and other infectious diseases (all livestock) were increased until the populations were similar to their long-term levels. (Adjustments were also made controlling wildlife avoidance of Maasai herders and their livestock, so that decreases in livestock were not simply matched by increases in wildlife.) This application, with livestock and wildlife populations

similar to their current levels, was the foundation for our assessments. Two sets of simulations were conducted, one with the PHEWS model disabled, and one with PHEWS enabled and Maasai able to sell excess animals that build-up in the system when diseases losses are reduced.

Savanna includes a second method of incorporating improved veterinary care (Boone and Coughenour 2001). The values describing how animal populations should change include settings that report average annual mortality for each year of the animal's life (these mortalities are modified by animal conditions during simulations, but serve as a baseline). These settings may be modified to reflect changes in levels of veterinary care. For example, potential effects of improving juvenile survival by 25% may be assessed by simply reducing first-year mortality in the model by that amount. The results then allow livestock owners to contrast costs and benefits from improved care.

2.5.2. Results

In simulations, reducing cattle losses due to

East Coast fever by 75% led to a large increase in the cattle population (Figure 20), from about 130,000 to 180,000 animals in 10 years. In the last four years of the simulation, the cattle population remains about the same, suggesting they are at capacity (but with some disease losses still present). Decreases in green biomass for palatable grasses (Figure 21) indicate that NCA was overstocked in later years. If cattle losses due to disease are reduced and opportunities for pastoralists to remove excess animals are not available, pasture quality in NCA will decline.

In contrast, if Maasai had stable markets available to sell excess animals, even a 90% reduction in losses due to East Coast fever did not lead to a change in the cattle population (Figure 22). There also was little change in the availability of green biomass of palatable grass (Figure 23). There are ecological effects due to the more rapid turnover of livestock, such as a small shift in the age class ratios of cattle as excess animals were sold prior to their old-age. The most significant change, however, was in economic benefits to Maasai through

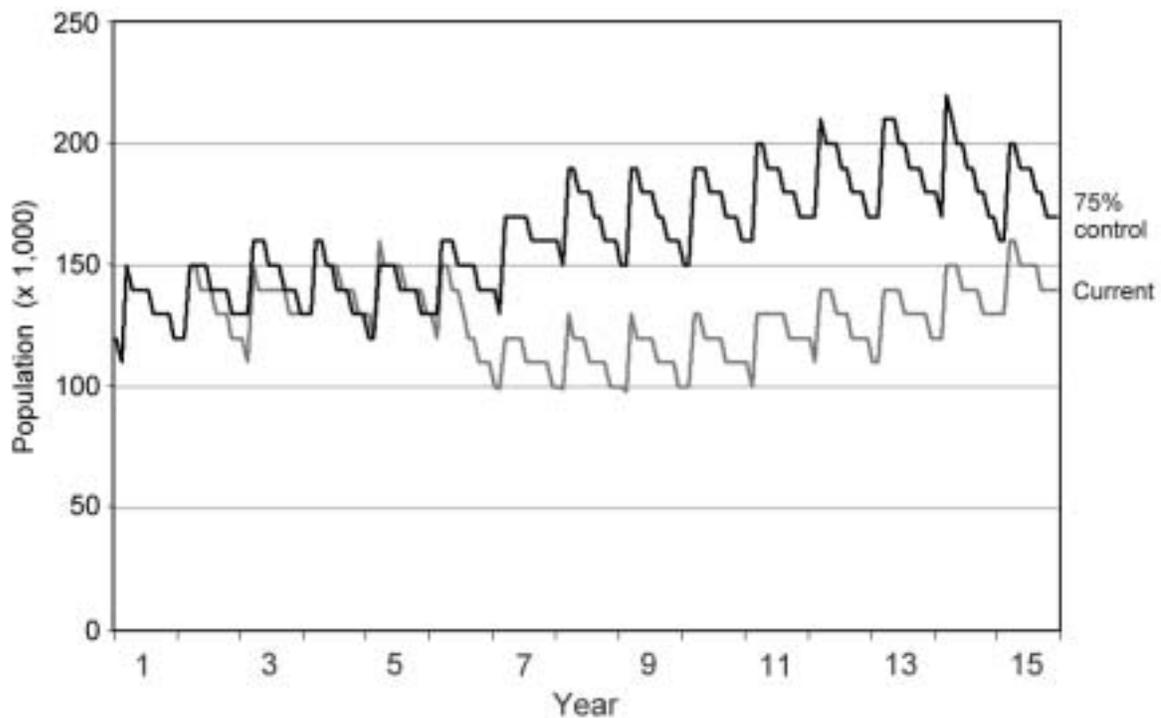


Figure 20. The cattle population when simulated with losses due to East Coast fever reduced by 75%, compared to current conditions.

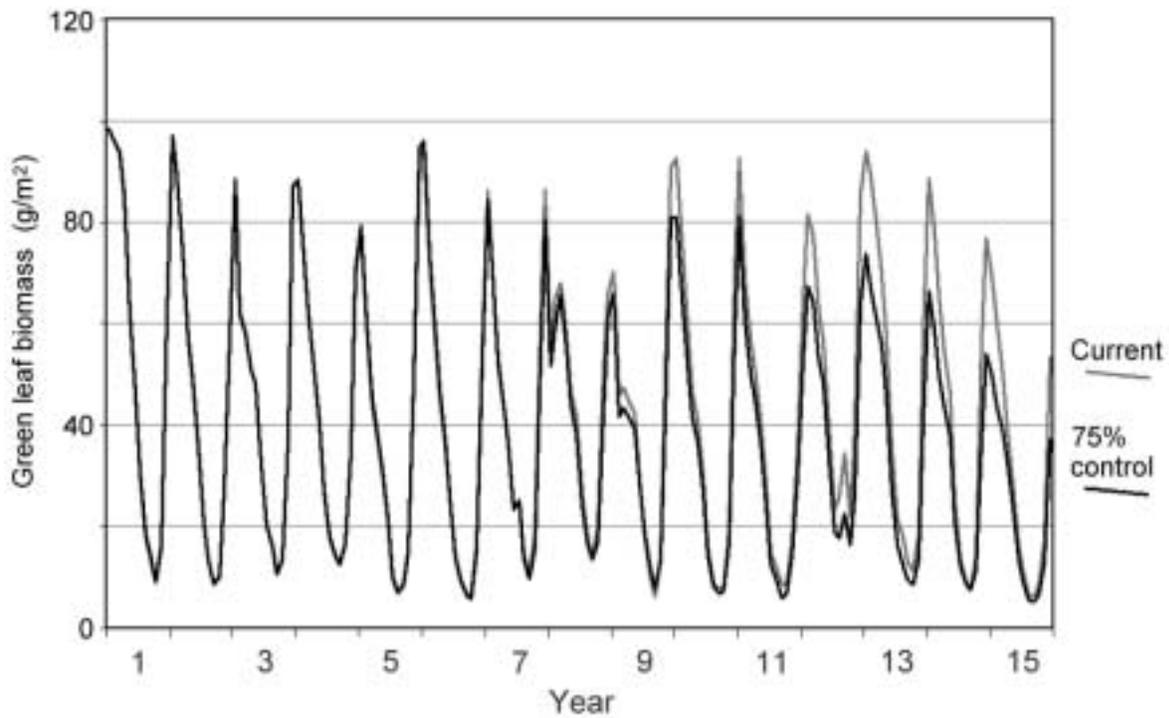


Figure 21. As the cattle population increases due to control of East Coast fever, palatable grass biomass declines relative to current conditions, suggesting overstocking.

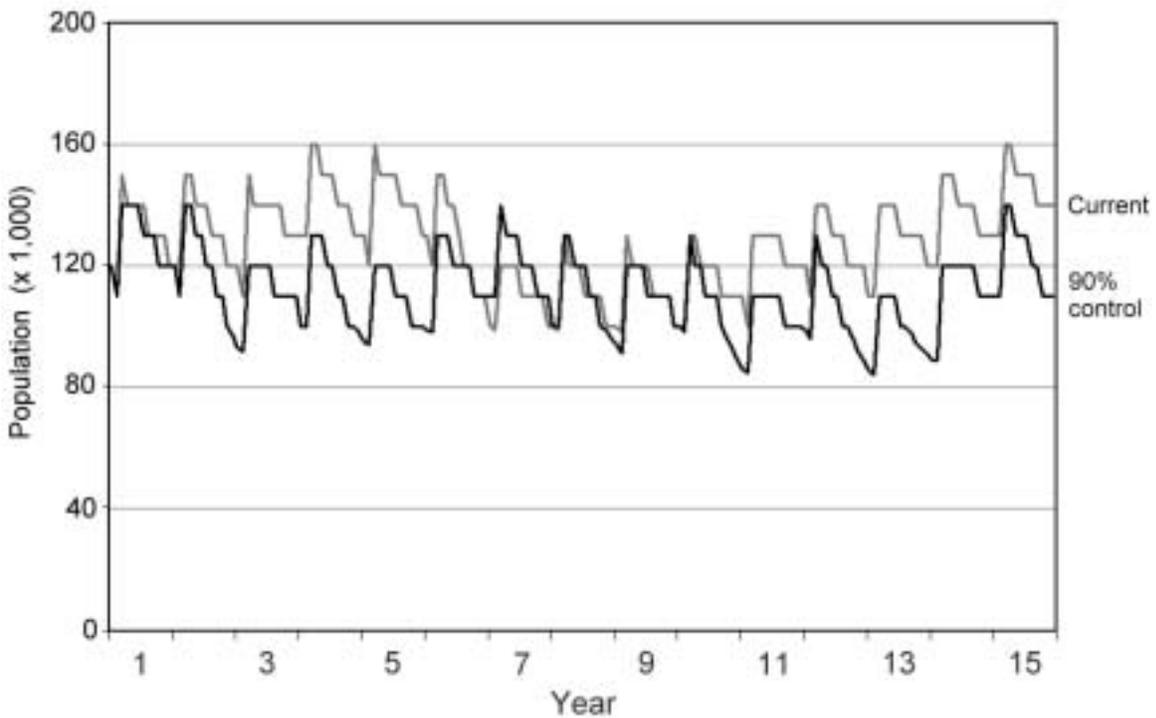


Figure 22. When East Coast fever losses are reduced but excess animals are sold, the cattle population stays similar to that representing current conditions.

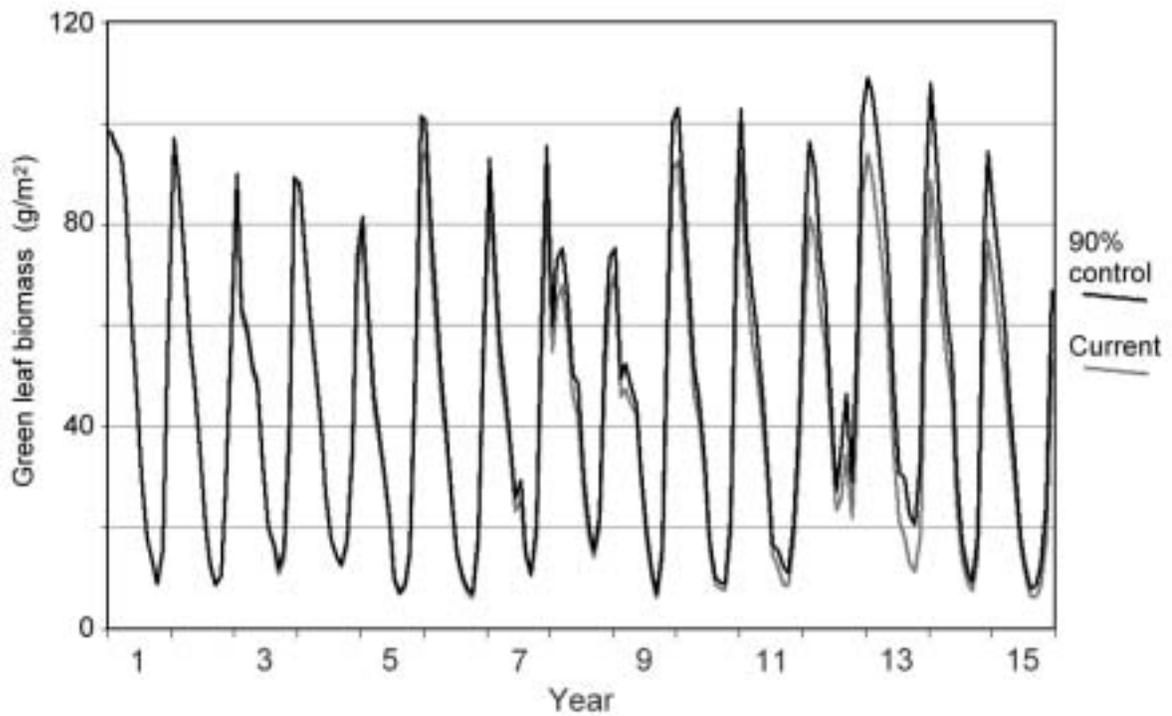


Figure 23. With East Coast fever losses reduced, but additional cattle sold, the green leaf biomass of palatable grass does not change markedly.

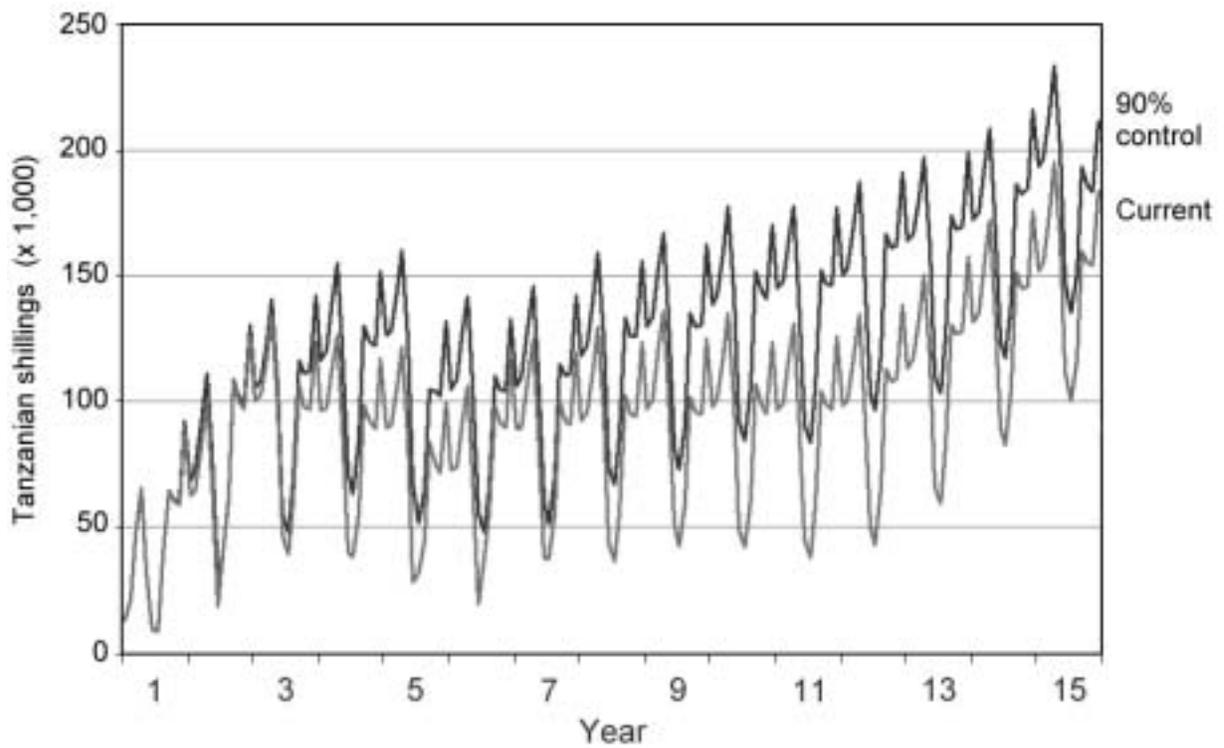


Figure 24. When East Coast fever losses are reduced and surplus animals sold, the cash holdings for rich households increases relative to current conditions.

animal sales. Figure 24 shows increasing cash holdings by rich households, for example, with East Coast fever losses controlled by 90%.

Results were similar, but more extreme, when juvenile survival of cattle, goats, and sheep was reduced by 25% and 50%. A 25% reduction in losses led to a rapid increase in the cattle population (Figure 25), and a 50% reduction caused the population to climb to the degree that in the 10th year of the simulation, the overstocked population declined, to current levels by year 15 (Figure 25). These density dependent responses make interpretation of changes to resident wildlife populations complex, but we saw expected declines in populations early in simulations (Figure 26, e.g., year 7, with “Current” population above the “25% less” population, and “50% less” the lowest level). Later in the simulation with 50% less juvenile mortality for livestock, the cattle population declines, for example. This causes resident wildlife biomass to increase in a density dependent fashion. When the PHEWS model is used in these analyses and excess animals sold, few ecological effects are evident, as in the example of controlling East Coast fever. Benefits to Maasai may exhibit a threshold behavior. For example, supplements required by households was similar whether juvenile mortality was at its current level or reduced by 25% (Figure 27). When mortality was reduced by 50%, households required fewer supplements. We believe this threshold may be a modeling artifact, due to the fine balance between the income expected to households in PHEWS, and the likelihood they will sell small versus large livestock. More cattle were sold when juvenile survival was reduced by 25% than under current conditions, allowing the goat population to increase. With a 50% reduction in mortality, the cattle population grows rapidly and the ratio of small stock to large remains similar to the current conditions. Changes in the proportions of small and large stock sold affect cash holdings (Figure 28).

2.5.3. Considerations

Incorporating PHEWS in these analyses assumes that stable markets accessible to NCA pastoralists exists, and that excess animals will be sold. Research shows that the need for cash by Maasai leads to an increase in the numbers of livestock that they sell (BurnSilver, In prep.).

In PHEWS, the likelihood that Maasai will sell animals, or conversely, hold animals, is related to the target TLUs/AE settings. Those settings (2.2 TLUs/AE for poor households, 3.3 TLUs/AE for moderate households, and 9.0 TLUs/AE for rich households) generate overall stocking rates on NCA similar to current conditions. Thus, our results showing few ecological changes in NCA when excess animals are sold defined “excess animals” relative to current conditions. If economic or social pressures encouraged Maasai to own more animals, we would expect ecological changes to be seen, such as decreases in resident wildlife populations and reduced forage.

In the Savanna application, and in our results, components of mortality due to disease are split into two sections, as described in this section’s methods. This division is helpful to interpret effects of general disease reduction versus reducing mortality in juveniles (or any other age class). However, care must be used when interpreting the results. For example, even though more than 50% of calves have been reported lost in NCA (Rwambo et al. 2000), the mortality shown for female calves (the second source of mortality described in the methods) in Savanna is 30%. In the model, the remaining mortality is associated with disease due to tick-borne disease (the first source of mortality described). In modeling, that means that a 25% reduction in mortality of juveniles is a change from 30% to 22.5%, rather than a larger change, from perhaps 50% to 37.5%.

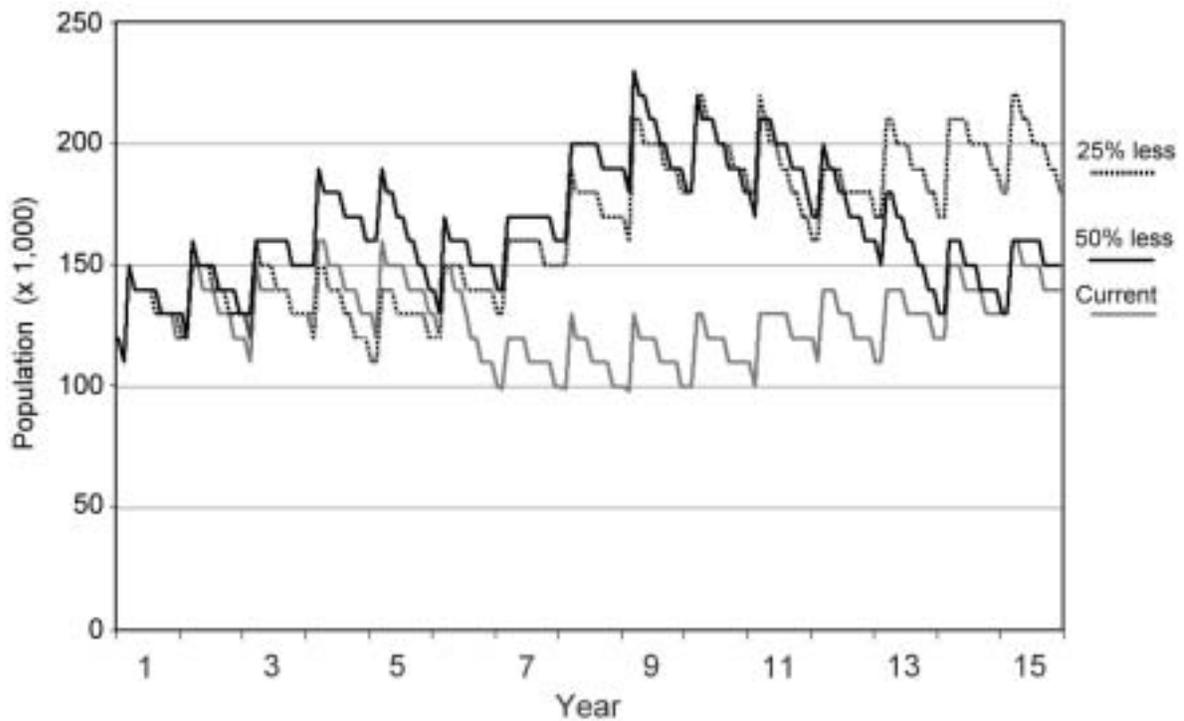


Figure 25. Cattle populations increase dramatically when juvenile mortality is reduced. When mortality is reduced 50%, the cattle population builds to an unsustainable point (years 1-9), then declines (years 10-15).

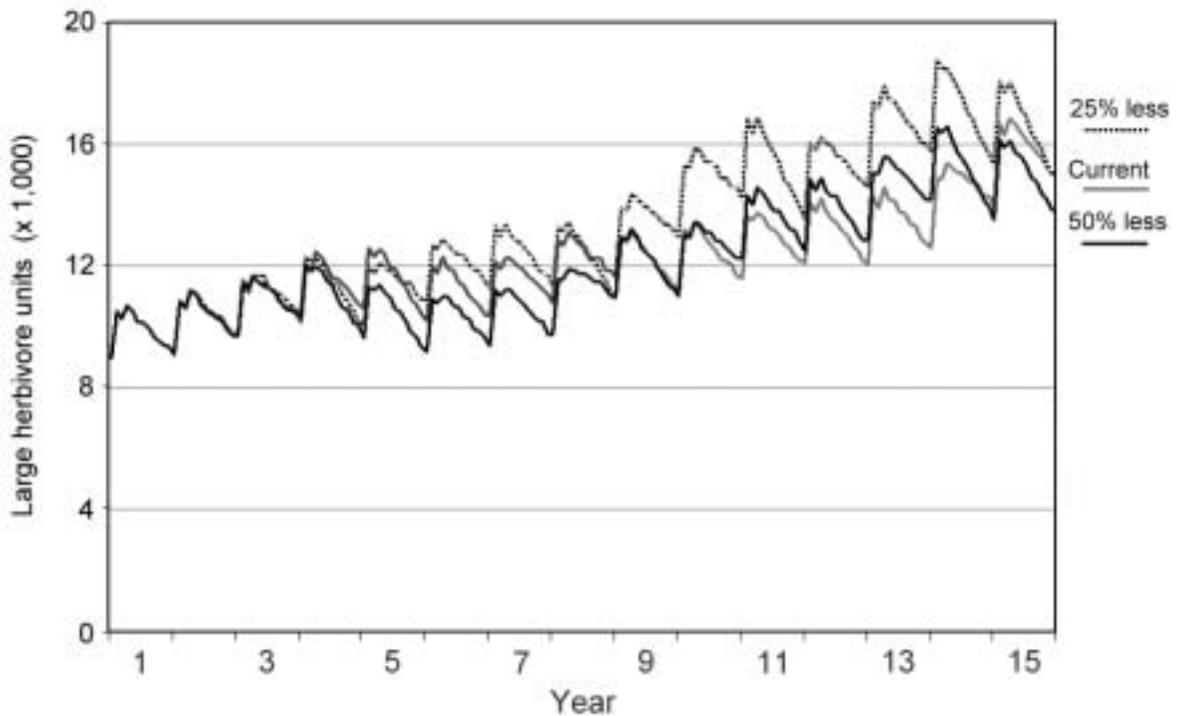


Figure 26. Reducing the juvenile mortality of cattle had a moderately negative effect upon resident wildlife biomass. Interpretation in later years (8-15) is confused because of density dependent responses to overstocking of cattle.

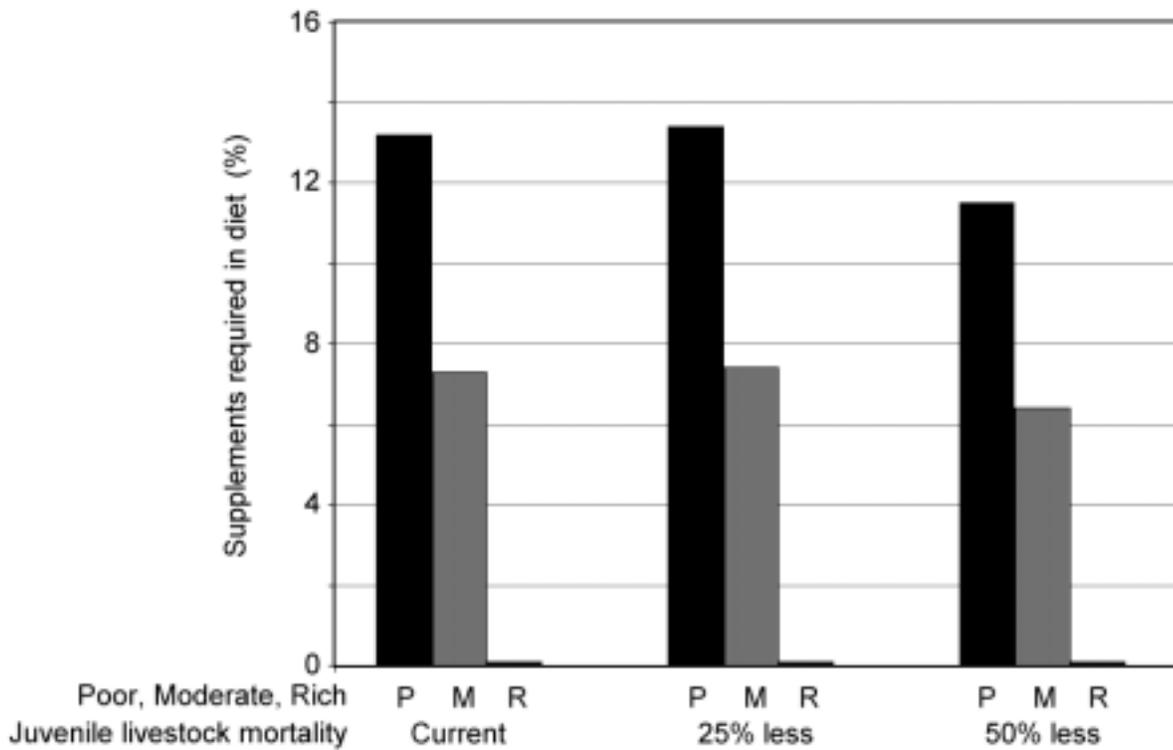


Figure 27. Reducing juvenile mortality for all livestock made a difference in Maasai well-being when decreased by 50%, but not when decreased by 25%, suggesting a threshold effect.

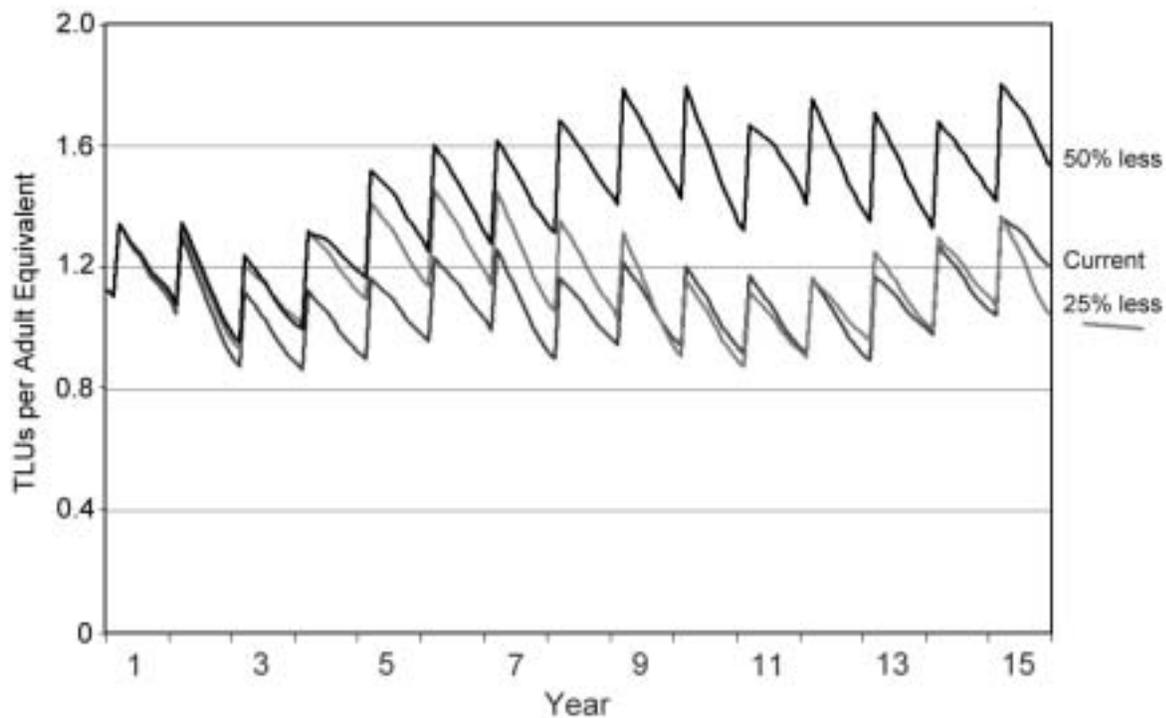


Figure 28. When East Coast fever losses are reduced and surplus animals sold, the livestock holdings for rich households increases relative to current conditions.

3. SUMMARY AND CONCLUSIONS

In this summary, we revisit the Conservator's questions he had originally posed to us. Here we briefly review results, sometimes *excluding important considerations and citations* discussed in the previous sections – an interested reader should refer to the full description in the appropriate section of our results:

3.1. *How many animals may be supported in NCA?*

The answer to this question is, "It depends upon the ratio of livestock to wildlife, and the method used to estimate the number of animals that may be supported."

This answer may seem weak, but is the most appropriate response based upon our results. General rules of thumb have been cited and demonstrated. If a given amount of wildlife biomass may be supported on NCA, about twice that may be supported if both wildlife and livestock were present, and about ten times as much if only livestock were present and the area was managed intensively. Specifically, we estimate based upon many sources that NCA currently contains about 218,865 large herbivore units (LHUs), if averaged over the whole year. That number varies between 488,886 LHUs in the wet season, and 122,019 LHUs in the dry season. Livestock comprise about 21% of the total in the wet season, 80% of the total in the dry season.

We estimated that appropriate stocking for NCA was between 181,246 LHUs and 541,716 LHUs. More telling, an integrated approach using ecological modeling showed the capacity of NCA to be 250,925 LHUs, slightly higher than the current stocking on NCA. This compares well with the pattern of relatively stable resident livestock and wildlife populations in NCA over decades. However, in modeling, we do not see the ability of NCA to support significantly more livestock, to increase the tropical livestock units (TLUs) per person and allow Maasai to return to a more pastoral lifestyle. Currently Maasai have about 2.77 TLUs per person, which allows them to meet roughly 35% of their household needs through live-

stock, assuming that 8 TLUs per person is the baseline required to lead a pastoral lifestyle. To bring that to 6 TLUs per person, for example, would require 250,111 cattle and 418,050 small stock on NCA – our modeling indicates that NCA cannot support that many animals. It seems policy makers must search for means of limiting population growth within NCA, encourage emigration, or provide more access to income sources other than through livestock raising.

3.2. *How much land is cultivated in NCA, and where?*

We mapped 3,967 ha or 9,803 ac in cultivation in NCA in February of 2000. The cultivation was mostly around Endulen and on the northern slopes of Empaakai.

We mapped cultivation based only upon a satellite image made-up of picture elements representing 15 m x 15 m patches on the ground. With assistance from V. Runyoro, we identified many known cultivated patches, and found that they often had a distinctive appearance in the image. We believe we have mapped the bulk of cultivation successfully, but small patches were missed, some confusion with brush lands occurred, and the map (Figure 8) has not been assessed using 'ground-truthed' information.

There is some disagreement between the NCA boundary available to us and the extent of cultivation in the southeastern part of the area. Encroachment of cultivation into the highland forests to the east appears to be occurring. Forests on the northwestern slope of Olmoti have also been converted to cultivation. Areas to the south of Endulen (e.g., Kakesio) appeared to have little cultivation.

3.3. *What is the effect of cultivation on wildlife, livestock, and people in NCA?*

Our simulation modeling suggested only modest changes to wildlife and livestock populations under current or increasing cultivation in its current distribution. Under current economic conditions, cultivation is critical for food security for Maasai of NCA.

Our modeling used the map we created to represent how much of each 5 km x 5 km block within NCA was in cultivation. Areas in cultivation were then excluded from use by livestock and wildlife. The cultivation we mapped, 9,803 ac, represents about 1.1% of the Pastoralist Development Management Zone, excluding Olduvai Gorge (although not all within the zone). In modeling, that level of cultivation led to small changes in livestock and wildlife biomass, compared to no cultivation. We increased cultivation to 50,000 ac, or about 5.5% of the Pastoralists Development Management Zone, and did not see large changes in livestock or wildlife populations. In past work we have demonstrated that cultivation is important in maintaining the food security of NCA Maasai. For example, based upon our current estimates, if cultivation were disallowed, requirements for supplements for poor families in NCA would almost double.

3.4. *What are the effects likely to be from improved veterinary care?*

A marked increase in livestock populations and potential damage to the ecosystem, unless markets are available. Market sales benefit Maasai.

Our modeling suggests that current efforts to reduce losses due to disease have the potential to increase the population growth rate for livestock, especially cattle. In general, reducing juvenile mortality appears to be the investment in veterinary care that yields the largest returns. Cattle populations increased until capacity was reached (although still limited somewhat by disease), and remained stable or declined as vegetation biomass was reduced. When excess animals (relative to current populations) were sold, the ecosystem essentially remained unchanged. If livestock production is to be increased through improved veterinary care, market access must be adequate to allow Maasai to sell excess animals, and market conditions must encourage them to do so.

3.5. *What are the magnitude of effects of human population growth?*

Profound. Any solutions to food security for today will likely be inadequate in a few years, if current population growth rates continue.

Using the most conservative recent estimate, the Maasai population within NCA is growing at about 3.5% per year, both due to better health care and to immigration. The population in 1999 of 51,600 is expected to be 100,000 in 2019, and 150,000 in 2030. If livestock populations remain constant, TLUs per person would fall from 2.77 in 2000 to 1.39 in 2019, and to 0.92 TLUs per person in 2030, with a corresponding need to increase supplements to maintain food security. As another example, allowing limited cultivation improved the food security for Maasai in 1992, but by the late 1990s any benefits had been offset by an increased human population (Galvin et al. 2000).

Given that increasing cultivation is politically difficult and that livestock populations appear to be near the maximum that may be supported, deficiencies will need to come from other sources, such as wage labor, or a greater contribution to pastoral livelihoods from tourism. Livestock production in NCA also may be intensified, where animals are raised and sold with more rapid turn-over than today, without a large increase in the number of livestock on NCA. Lastly, relief in the form of food from governmental and non-profit agencies may need to be increased.

Difficulties abound in the management of Ngorongoro Conservation Area, but those struggling with the difficulties – and those living under restrictions the area's status brings – contribute to knowledge about management of semi-arid lands. The issues addressed here, such as stocking rates, cultivation, and human population growth, are by no means unique to NCA. In many other places in East Africa and elsewhere, land use intensifies without oversight, often with undesirable results. Ngorongoro is not unique because of the magnitude of its problems, but rather because those problems are being faced, head-on, by policy makers, stakeholders, and community groups.

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Appendix A. Personnel and Participants in the POLEYC project of the Global Livestock CRSP.

KENYA		
Name	Title	Affiliation
Atieno, Fred	M.S. student	Department of Range Management, University of Nairobi International Livestock Research Institute
Bagine, Richard	Director of Research	Kenya Wildlife Service (KWS)
Chege-Waruingi, Lucy	GIS Specialist	African Conservation Centre
Cheruiyot, Dr. H.K.	Assistant Director, Range Research	Kenya Agricultural Research Institute
Cowles, Paul	Director	PACT/CORE
Grootenhuis, Jan	Doctor of Veterinarian Medicine	Private Consultant
Jenkins, Mark	Senior Warden Meru National Park	KWS
Ole Kampau, Sitoya	Group Ranch Treasurer POLEYC Representative	Osilalei Group Ranch Kajiado District, Kenya
Kimani, Kimau	Program Assistant	International Livestock Research Institute
Kinyamario, Jenesio	Professor	Department of Range Management, University of Nairobi
Kipkeu, Michael Limo	Senior Warden Amboseli National Park	KWS
Kruska, Russ	Geographic Information Systems Specialist	International Livestock Research Institute
Lekinayia, Jonathan	Community Conservatio Project Officer	African Wildlife Foundation
Likampa, James	Group Ranch Treasurer POLEYC Representative	Imbirikani Group Ranch Kajiado District, Kenya
Mbogoh, Stephen	Professor	Department of Agricultural Economics, University of Nairobi
Mworia, John	M.S. Student	Department of Botany, University of Nairobi
Mulama, Martin	Ecologist	KWS
Mutero, Wycliffe	GIS Specialist	KWS
Njoka, Jesse	Research Scientist	Department of Range Management, University of Nairobi
Nriati, Paul	Kilimanjaro Heartlands Coordinator	African Wildlife Foundation
ole Kamuaru, P.	Assistant to the Director Ph.D student	Natural Environmental Secretariat University of Nairobi
Onyango, Okello	Technical Specialist	International Livestock Research Institute (now at Texas Tech University, Lubbock)

Leonard Partimo	Group Ranch Secretary POLEYC Representative	Olgulului/Lolarashi Group Ranch Kajiado District, Kenya
Reid, Robin	Senior Ecologist	International Livestock Research Institute
Rwambo, Paul	Doctor of Veterinarian Medicine, Resident Scientist	Kenya Agricultural Research Institute
Said, Mohammed	Research Scientist	Department of Resource Surveys and Remote Sensing
Salash, David	Group Ranch Treasurer POLEYC Representative	Eselenkei Group Ranch Kajiado District, Kenya
Thornton, Phillip	Agricultural Economist	International Livestock Research Institute
Wathaka, John	Head of Programs Ecologist	African Conservation Center
Wandera, Jackson	Land Use Planning Coordinator	SARDEP
Western, David	Chairman	African Conservation Centre

TANZANIA

Name	Title	Affiliation
Andreoli, Elena	Veterinarian	OIKOS Project
Banyikwa, Feetham	Adjunct Faculty Research Associate	Department of Botany, University of Dar es Salaam Biological Research Laboratories, Syracuse University
Gereta, Emmanuel	Ecologist	TANAPA
Jones, Clive	Land Use Planner	Private Consultant- GEF/UNDP project
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Lenganasa, Edward	Chief Park Warden Tarangire National Park	TANAPA
Kijazi, Allan	Project Officer Acting Conservator	Biodiversity and Protected Areas, African Wildlife Foundation Ngorongoro Conservation Area
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Moehlman, Patricia	Research Scientist	Tanzania Wildlife Research Institute
Mwalyosi, R.B.B.	Equid Specialist Group Leader Director	The World Conservation Union (IUCN) Institute of Resource Assessment
Mwilawa, Angello	Livestock Research Scientist	Livestock Production Research Institute
Mtalo Elifuraha Gerard	Senior Lecturer	UCLAS University of Dar es Salaam

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Nahonyo, Cuthbert	Professor Dept. of Zoology	University of Dar es Salaam
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Toima, Peter	Director	Maasai Advancement Association
Sorensen, Carole	Project Advisor	ERETO

UGANDA

Name	Title	Affiliation
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UNITED STATES

Name	Title	Affiliation
Boone, Randall	Scientist	Natural Resource Ecology Laboratory, Colorado State University
BurnSilver, Shauna	Research Associate Ph. Student	Natural Resource Ecology Laboratory Graduate Degree Program in Ecology, Colorado State University
Coughenour, Michael	Senior Research Scientist, Associate Professor (Affiliate) Advising Faculty	Natural Resource Ecology Laboratory Rangeland Ecosystem Science Graduate Degree Program in Ecology, Colorado State University
DeMartini, James	Professor	Department of Pathology, Colorado State University
Ellis, James	Senior Research Scientist Associate Professor (Affiliate) Advising Faculty	Natural Resource Ecology Laboratory Department of Rangeland Ecosystem Science Graduate Degree Program in Ecology, Colorado State University
Else, James	Doctor of Veterinarian Medicine,	Tufts University, Massachusetts

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Appendix B.

In January of 2002 a portion of our team (Jim Ellis, Shauna BurnSilver, Randy Boone, Jim DeMartini, Joyce Acen, and Joana Roque de Pinho) traveled to Ngorongoro Conservation Area, Tanzania, to present to scientists and pastoralists the results reported in this document. The portion of our trip report to the Global Livestock Collaborative Research Support Program follows that includes our time in Ngorongoro follows:

Wednesday, January 16th

In the morning, prior to departing for Ngorongoro Conservation Area (NCA), Drs. DeMartini and Boone met with Dr. Leive Lenen, a veterinary pathologist who is working with the Tick-borne Disease Project, Arusha- and leading an effort to reduce tick borne diseases in the region. The goal of this meeting was to discuss issues linked to livestock and wildlife disease as they relate to ongoing CSU/ILRI GL-CRSP disease modelling work in the Ngorongoro and Tarangire project areas. A summary of that meeting follows:

The discussion began with Dr. Lenen pointing out that East Coast Fever (ECF), a tick borne disease caused by *Theileria parva* (*T. parva*) was the most important livestock disease problem in the Ngorongoro Conservation Area (NCA). Problems with ECF began initially when Maasai herders were forced to use the NCA highland forests for grazing instead of the Serengeti plains, especially during the wet season months of February thru May, because of malignant catarrhal fever. ECF is a bigger problem in calves than in adults: Traditional tick control methods consist mainly of picking them off and spraying with acaricide, which does not effectively reach young calves. Adult cattle, nevertheless, experience high mortality rates: approximately 30 % survive exposure to infected ticks and become immune for life. Meanwhile, young calves,

under a few months of age, experience a mean 60% mortality rate in most years; in 1998, it was as high as 90%. This can be reduced to 5-7 % mortality using the infection and treatment method of vaccination using a cocktail vaccine consisting of 3 strains of *T. parva*: Muguga, Kiambu 5, and *T. parva serengeti lawrencei* transformed (to a cattle strain from a buffalo-derived strain). Dr. Lenen's husband has been studying the effectiveness of ECF vaccination in Endulen (Ngorongoro Conservation area) for his PhD dissertation; he found that mortality reached almost 60% in 100 unvaccinated control calves whereas it was on about 5% in 100 vaccinated calves. The vaccine costs \$7.50 per dose, delivered, and is given to calves from 3 wks. of age and older. Maasai are willing to pay for the cost of the vaccine and last year about 16,000 cattle were vaccinated in the N. Tanzania area.

There are insufficient data on tick infection rates in this area, although this is being addressed by ILRI scientists, including Dr. Richard Bishop who is characterizing parasite strains of ticks. There needs to be more study of engorged ticks and the role of buffalo in the epizootiology of ECF. Regarding ECF disease models, Chris O'Callegan is working on a new version of the ECF model with Medley (both epidemiologists at Imperial College, London and ILRI collaborators); it will focus on dairy cattle but will encompass pastoral settings as well. This will be particularly important in Tanzania where 93% of cattle ECF vaccinations take place.

There is some new information regarding the cattle disease the Maasai call "Ormilo." The disease was first recognized in 1982 in Loliondo and by 1993 was commonly recognized in the NCA. When it is first seen in an area, the mortality rate may be 70%, but after a time, it seems to drop and younger

animals may be affected. It is possible that wildebeest may have a role in the epidemiology of ornilo. Ornilo is similar clinically and pathologically to Corridor disease which has been described in South Africa as associated with *T. parva lawrencei*. Dr. Lenen has prepared a manuscript for publication which has been accepted by the Journal of Clinical Microbiology and should be published soon.

Since 1999, 5 rhino deaths have been documented in the Ngorongoro Crater and the overall population has been reduced from about 35 in recent decades to 14 now. The deaths followed a drought and some people thought that drought-associated stress played a major role in the deaths. Dr. Lenen said that a new *Babesia* species, *B. bicornis* had been found in the animals blood, accounting for the anemia. Dr. Lenen believes that it may have been introduced with importation of black rhinos from South Africa a few years ago.

In summary, the information provided by Dr. Leive on ECF incidence (up to 70% in calves in the NCA), the lack of its prevention by conventional methods (tick control), and the remarkable success of the new vaccine approach (16,000 cattle vaccinated in Arusha/NCA area last year, reduction of calf mortality to 5-7%) will be very useful in further developing our an ECF model for integration into Integrated Assessment efforts. The success of the ECF vaccination program also validates inclusion of a modeling scenario in the NCA Integrated Assessment demonstrations which is based on 75 % reduction in calf mortality due to ECF (described below).

-The research team (Ellis, Boone, BurnSilver, DeMartini, Acen, and Roque de Pinho) was joined for dinner at the Ngorongoro wildlife lodge by Victor Runyoro (NCAA- Chief Ecologist).

Thursday, January 17th

- On January 17th, we began a series of three demonstration meetings of Integrated Assessment results from the CSU/ILRI GL-CRSP project with a presentation to NCAA scientific and managerial staff. The meeting also was attended by two representatives of the *Ereto* project (ole Nassei and Leboy). Dr. Alan Kijazi, Acting Conservator of NCA, introduced the CSU research team and described the linkages between the work of the CSU/ILRI GL-CRSP and the management goals of the NCAA. Because of his responsibilities as acting conservator of the NCA, A. Kijazi designated Victor Runyoro, Chief Ecologist of NCAA, to work closely with us during our stay in NCA, and to participate in each of the three integrated assessment demonstrations.

-Twenty members of NCAA attended the meeting, including staff and scientists involved in range and wildlife ecology, forestry, hydrology, information services, and security. Jim Ellis introduced the GL-CRSP project on integrated assessment to the audience, and reviewed background on our efforts. In his introduction, Ellis emphasized that the Mr. Emmanuel Chauis, the Chief Conservator of NCA, had put to the GL-CRSP team specific questions he thought important to address. Specifically, these questions revolved around the effects of cultivation on wildlife and livestock, carrying capacity for herbivores in the NCA, and the effects of increased veterinary interventions on human well-being, herbivore stocking rates and the environment. Additionally, the issue of increasing human population growth in the NCA was added to the Integrated Assessment scenarios. Randy Boone then reviewed the results of Integrated Assessments designed to address those questions.

Boone reviewed methods of estimating appropriate stocking in NCA, and estimated that stocking should be between 181,246 large herbivore units (LHUs) and 541,716 LHUs, with the current stocking of livestock and wildlife at about 219,000 LHUs. Ellis pointed out that at 219,000 LHUs, Maasai within NCA have between 2 and 3 tropical

livestock units per adult equivalent, well below a level required for a wholly pastoral lifestyle. Further, ecological modeling results suggest that NCA cannot support enough livestock to allow the current population (50,000 people) such a lifestyle. Therefore, even if stocking rates were able to increase, additional economic and livelihood options will become increasingly important for NCA pastoralists. Boone demonstrated methods and results of cultivation mapping in Ngorongoro, with 9,800 acres of cultivation in NCA in 2000. After reviewing the Savanna ecosystem model and the PHEWS pastoralists household model, Boone demonstrated that at the current rate of human population growth, the population will be doubled in 2017 (100,000 people), and NCA will no longer be able to support even the current low level of 2-3 TLUs per adult equivalent. We demonstrated that the effects of cultivation as it is currently distributed, on livestock and resident wildlife populations, are likely minimal, and would continue to be if the area in cultivation were doubled or tripled. We also showed that the efforts to improve livestock survival currently underway (improved veterinary efforts and restocking of livestock for poor families- supported by ERETO) may have dramatic positive effects upon livestock populations. Given that our ecosystem modeling suggests NCA may be unable to support significantly higher livestock populations, we stressed that improved livestock survival will likely make access to markets particularly important, so that excess animals may be sold. Improving access to markets for NCA pastoralists was therefore presented as a policy initiative which in order to succeed, would have to be supported by the NCAA and by government intervention at higher levels.

Questions and a discussion followed the demonstration. All comments were welcomed, but as our work in NCA was nearing completion, we asked that comments reflect things participants would like to see included in a report, or suggestions for any future work. Technical and scientific issues were discussed, such as the effects of unpalatable vegetation on our assessments of appropriate stocking rates, and the benefits and costs of livestock

grazing in the Northern Highland Forest Reserve. However, much of the discussion highlighted the differences in views between those balancing wildlife conservation and Maasai needs (NCAA) and those perceived as seeking to improve Maasai well-being (Ereto). Beyond our research results, we believe that the GL-CRSP project on integrated assessment could help to improve communication between these two groups. Integrated assessments suggest the trade-offs inherent in different policy options. Based on these demonstration meetings, both the NCAA and pastoralist groups would be equally aware of the trade-off effects of management and development directions on human well-being, livestock and wildlife in the NCA.

Significant changes or concerns about our work were not expressed, and NCAA requested that we provide them with a draft final report by April 10th of this year, so that they may provide the information to the NCA Board of Directors.

-On the evening of January 17th, prior to our demonstrations to pastoralists, Dr. J. DeMartini was visited by Dr. Harold Wiik, a veterinarian with TAWIRI working in Serengeti National Park. DeMartini was invited to join Dr. Wiik as he traveled to the park. The decision was difficult for Jim DeMartini, given his interest in pastoralists' views on animal diseases, but he joined Dr. Wiik on a two day visit to the Serengeti. A summary of that meeting follows:

Dr. Wiik, a veterinarian from Norway who has been working in the Serengeti N.P. and NCA since 1998, and Dr. DeMartini travelled from the NCA to Seronera in the SNP for a two day visit and discussions. The veterinary laboratory is located in Seronera, is part of the Tanzanian Wildlife Research Institute (TAWIRI) and is supported by the Messerli Foundation of Switzerland. Dr. Wiik and his Tanzanian counterpart Wildlife Veterinary Research Officer, Dr. Robert D. Fyumagwa, have three main objectives in this program: to train Tanzanian veterinarians in wildlife disease research, to perform necropsies on ill and dead animals in the park, and to conduct research. Discussions focused on im-

proving means for establishing diagnosis of disease outbreaks using histopathology, viral isolation and serology. Although there have been substantial improvements in the laboratory and communication links with institutions in developed countries, much remains to be done and it was felt that a compelling case can be made for further expansion of diagnostic capabilities and research activities related to wildlife disease. Dr. Wiik is studying herpesvirus infections in zebras and has been involved in studies describing latent rabies infections in hyenas, results of which have recently been published (East et al, Proc.Nat Acad. Sci., December, 2001). He also is involved in rinderpest surveillance studies sponsored by PACE. On January 19, buffalo in the NCA were immobilized and samples collected for rinderpest serology and a tuberculosis survey, based on gamma-interferon production by cultured blood leukocytes exposed to TB antigens (an assay developed in South Africa). This was a very productive visit in gaining a current perspective on wildlife disease problems and their effect on pastoralists livestock in Ngorongoro and the wider Serengeti-Mara ecosystem.

Friday, January 18th

On January 18th, we presented essentially the same demonstration of the Integrated Assessment results to 9 of 16 members of the Executive Pastoral Council of the NCA. We were joined also by two of the NCA scientific staff in attendance on the 17th. We modified our demonstration of the Integrated Assessment results for this presentation in order to correspond to the language and technical level of the audience. The presentation was in English, with direct translation into KiSwahili (and KiMaa when necessary). Our demonstration included less technical detail, but we communicated to the Pastoral Council the same results provided to the NCAA staff and management. Ellis introduced the Integrated Assessment questions addressed by the CSU/ILRI GL-CRSP, and provided a thorough background on our work. BurnSilver reviewed ecological modelling approaches, and introduced the PHEWS pastoral model. Boone then demon-

strated the results of the Integrated Assessment scenarios. The Pastoral Council discussed the Maasai tradition of wildlife conservation, and the strains that agriculturalists and conservationists from outside the NCA place upon their livelihoods. The importance of access by livestock to areas where they are currently excluded was discussed (e.g., the Highland Forest). Concern was expressed that the CSU/ILRI GL-CRSP effort was responding primarily to the wishes and agenda of the NCAA, but not those of pastoralists. With help from Victor Runyoro, we communicated that our team had been working with pastoralists in NCA for many years, had made efforts to understand the difficulties they face, and had incorporated those concerns in our work. We agreed, however, that more work was required in the future to gather opinions from all stakeholders prior to exploring modelling scenarios using the integrated assessment approach. Like the NCAA, the Pastoral Council was keen on receiving copies of the NCA final report, so that they may review and synthesize the results, and discuss them with their constituents.

Saturday, January 19th

Our demonstration was again modified for presentation to pastoralists at a community gathering in Endulen, south-central NCA, on January 19th. The school room used had no electricity, so Acen and Roque de Pinho redrew computer graphics showing our most important results onto poster paper, for use in the demonstrations. Also, Mr. Runyoro assisted us in translating additional graphics into KiSwahili, which were provided to workshop participants in handout form. About forty-five Maasai elders from the area around Endulen attended the presentation, organized by Mr. Gaspar Leboy of the Ereto pastoral project. The demonstration was translated from English directly into KiMaa. Ellis introduced the GL-CRSP integrated assessment project, BurnSilver introduced computer modelling approaches (a challenge - as most attendees had never seen a computer), and Boone presented the results of modelling scenarios from our work. Questions posed during the demonstration and a

lengthy discussion following echoed the concerns of pastoralists. Attendees spoke of past and continuing protections Maasai provide to wildlife, such as congregating into neighborhood settlement zones to leave grazing areas for livestock, and defacto for wildlife. Attendees also cited the declines in their well-being, compared to the past when “it was like heaven.” Ellis assured participants that, although rebuilding the prior “heavenly” state of NCA was likely impossible, we are all working toward moving it closer to that goal. As in the previous demonstrations, participants expressed concern over the perceived (and to some degree, actual) dominance of NCAA in setting the research agenda; less for GL-CRSP in particular as for all present and prior research efforts in the conservation area. Victor Runyoro helped guide discussions by recognizing that these deficiencies were present, but were improving, and that the current NCAA members were keen on improving the well-being of Maasai pastoralists within the NCA, while maintaining conservation values. We also pointed out that Integrated Assessments under CSU/ILRI GL-CRSP provide information to support discussions amongst stakeholders, rather than dictate policy pathways. A final comment requested that more concrete guidance be provided, with the suggestion that researchers and teachers return, to use research results and help pastoralists make decisions. As in each of the demonstrations, members of the community requested a copy of a report of our work.

In summary, our demonstrations in Ngorongoro Conservation Area were challenging but successful. Responses from NCAA scientists suggest that the issues of concern to the Chief Conservator were indeed most important for us to address, and our own results show that our adding human population growth as an issue was wise. The scientists and managers of NCAA and key personnel of Ereto have heard our results and the methods we use to balance objectives, in integrated assessments. Importantly, members of all the stakeholder groups were brought together, hopefully a step toward

better mutual understanding. Members of the Pastoral Council and pastoralists in the Endulen community have heard our results as well, and although it was a challenge to communicate technical detail effectively, their feedback confirms that our main points were understood. Significant changes to our research were not suggested. Instead, participants at all three meetings stressed the need for improved communication within NCA. As well, pastoralists stressed the importance of researchers including the pastoral community in setting the research agenda and taking the time and effort to report our results to them.

The second phase of the CSU/ILRI GL-CRSP has already made good headway in making the process of Integrated Assessment more “demand driven” in each of its project areas. However, the results of these initial demonstration meetings in the NCA make it clear that more effort expended on outreach (both in increasing the frequency of outreach activities and in improving the materials used in community workshops) will be well spent.

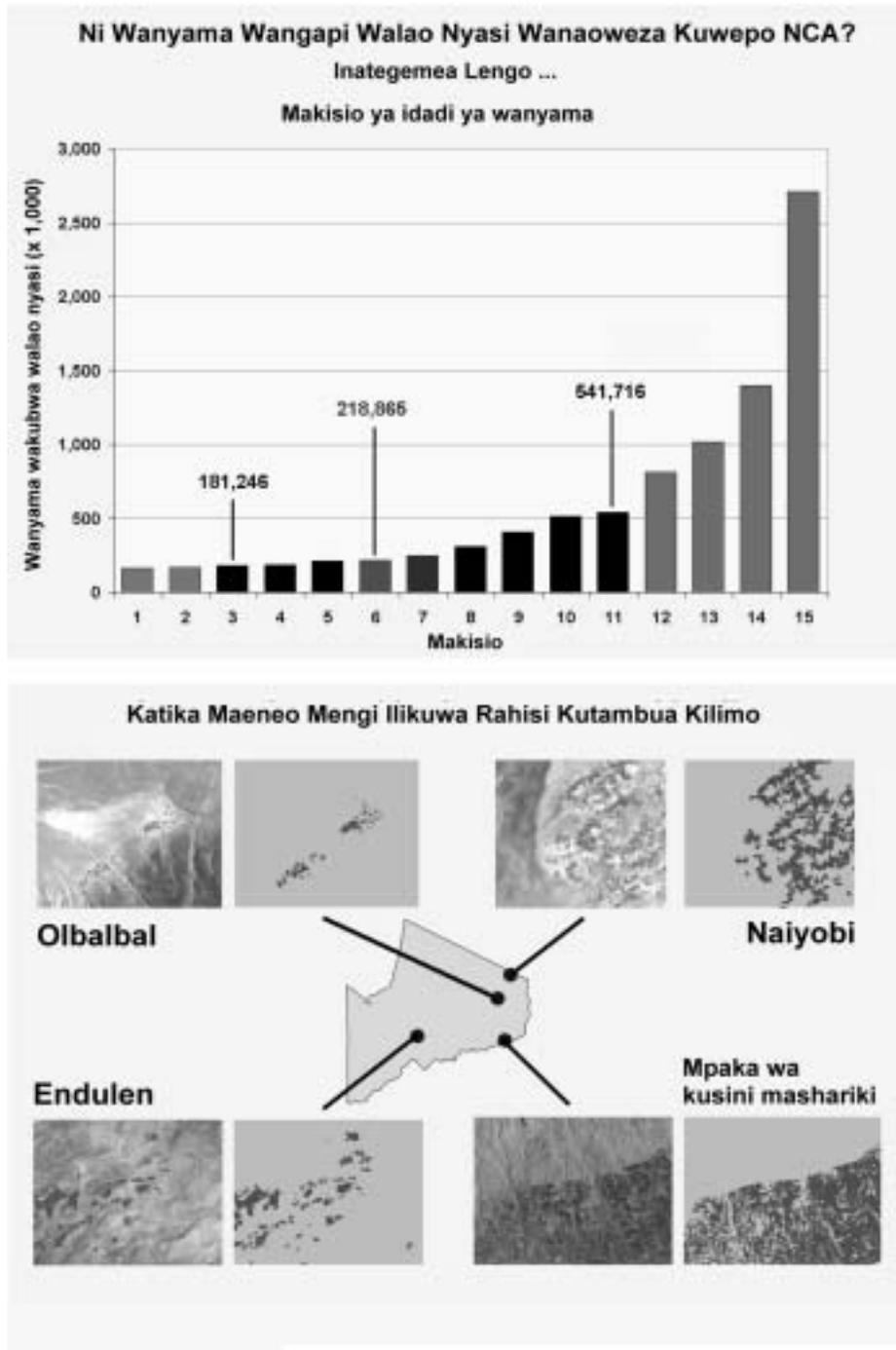
-J. DeMartini rejoined the rest of the GL-CRSP team in the evening of the 19th.

Sunday, January 20st

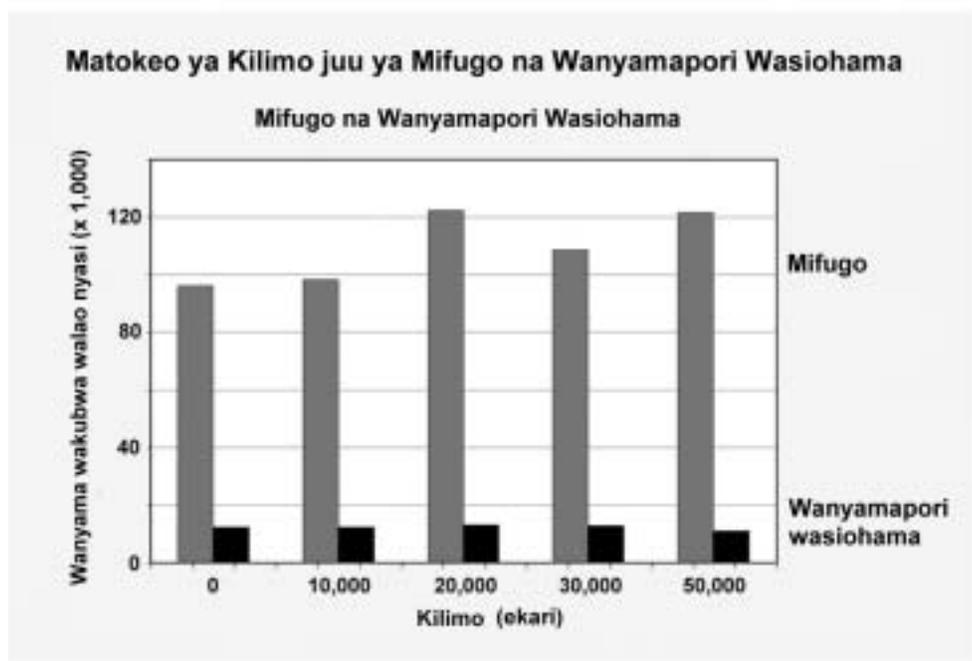
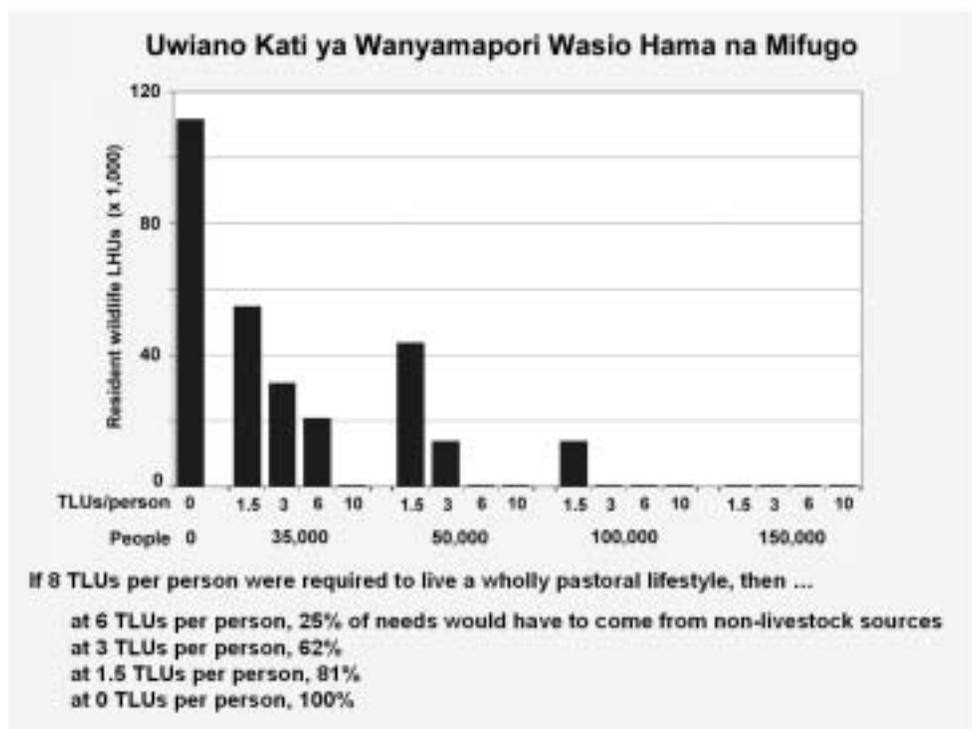
Dr. H. Wiik extended an early morning invitation to the CSU GL-CRSP group to join he and his team while they immobilized and collected blood samples from African buffalo on Ngorongoro Crater floor. The goal of this work was to assess the presence of tuberculosis in the crater buffalo population. Boone and BurnSilver joined DeMartini and Wiik in collecting samples. Ellis, de Pinho and Acen toured the Ngorongoro crater that morning in a separate vehicle. 10 am, the team regrouped, and passed by the NCAA and Ereto offices to thank Victor Runyoro and Ereto staff for their help and collaboration in setting up the three days of meetings and workshops. Subsequently, the team departed for Tarangire National Park.

Appendix C.

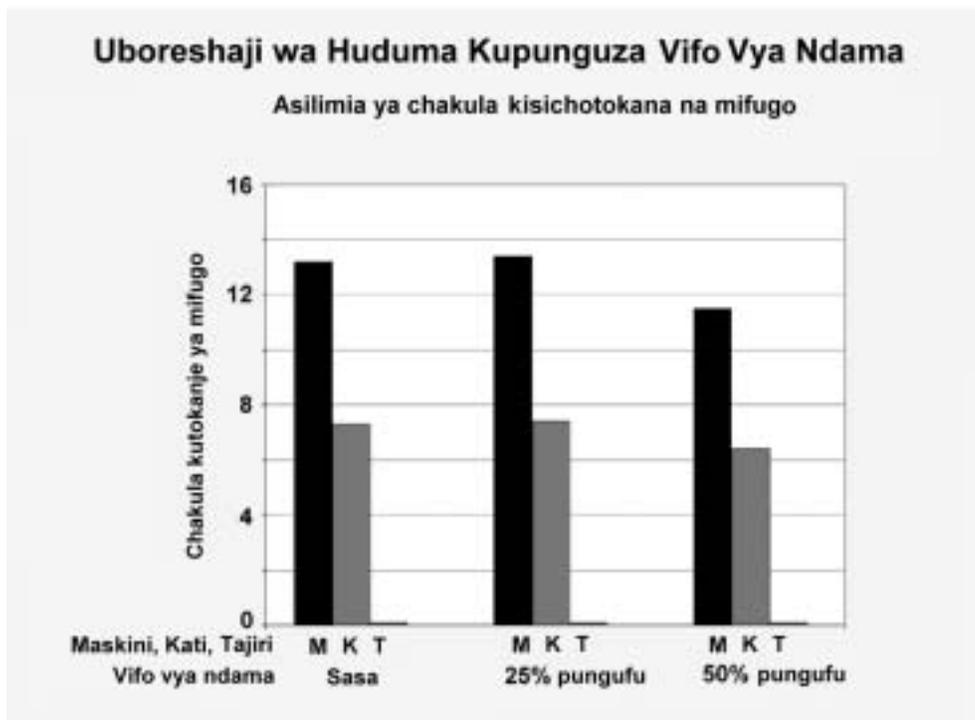
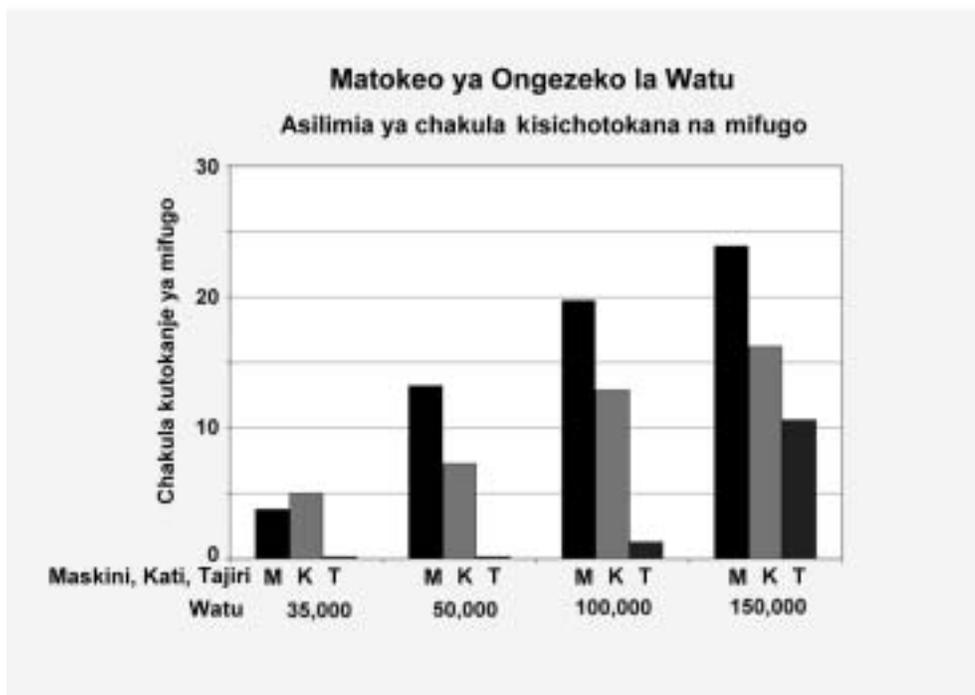
On January 18th, 2002, we presented POLEYC results to Executive Pastoral Council representative, a group representing pastoralists' interests. On the following day, we presented results to pastoralists in Endulen, Ngorongoro (see Appendix B). At these meetings, critical results were provided to participants as handouts, including some information translated into KiSwahili by V. Runyoro. The contents of those handouts are shown here.



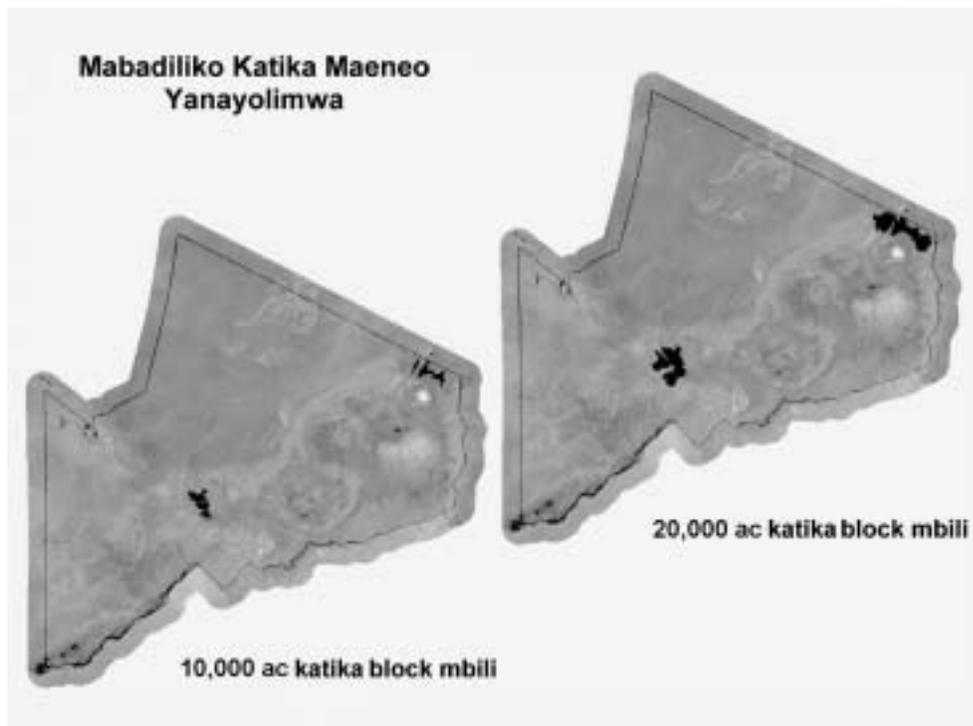
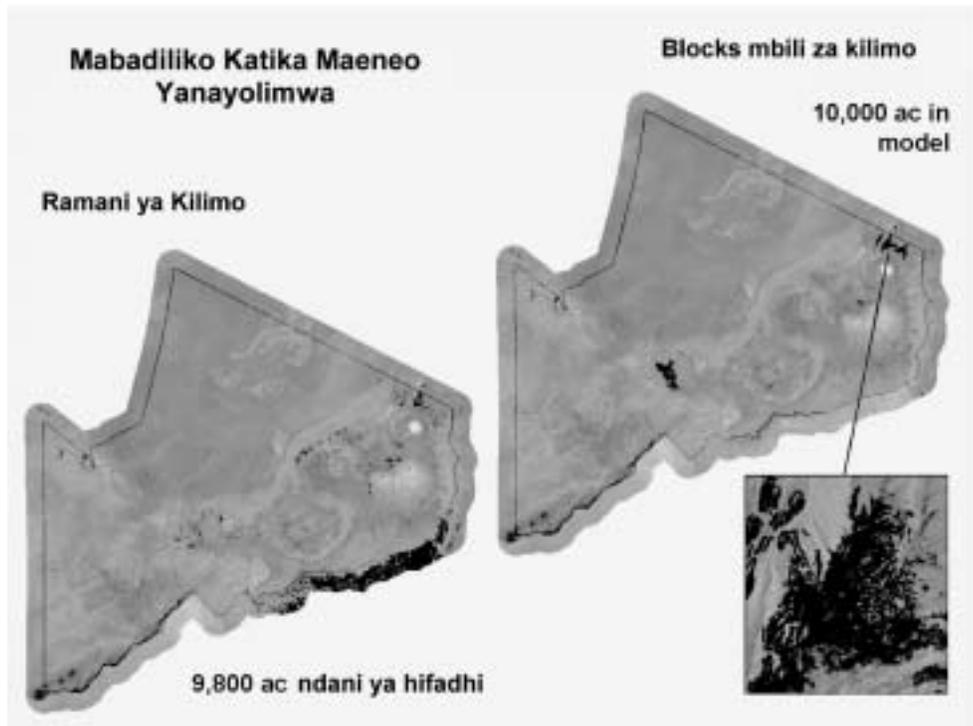
Appendix C-1. A slide used in demonstrations, with selected text translated into KiSwahili. The contents are similar to Figures 6 and 7 of this report. See those legends for more information.



Appendix C-2. A slide used in demonstrations, with selected text translated into KiSwahili. The contents are similar to Figures 9 and 14 of this report. See those legends for more information.



Appendix C-3. A slide used in demonstrations, with selected text translated into KiSwahili. The contents are similar to Figures 15 and 27 of this report. See those legends for more information.



Appendix C-4. A slide used in demonstrations, with selected text translated into KiSwahili. The contents are similar to Figures 8 and 11 of this report. See those legends for more information.



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