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Cultivation and Conservation in Ngorongoro Conservation Area, Tanzania

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Abstract Ngorongoro Conservation Area (NCA), Tanzania, contains renowned wildlife, an expanding human population, and cultivation by Maasai agro-pastoralists and non-Maasai agriculturalists. We used integrated assessments to explore some effects of cultivation on livestock, resident wildlife, and people. Using a Landsat image from 2000, we mapped 3,967 ha [9,803 acres (ac)] of cultivation within NCA, or 39.7 km^2 of the 8,283 km^2 conservation area. Using integrative ecosystem (Savanna) and household (PHEWS) models, we assessed effects of: up to 50,000 ac (20,234 ha) of cultivation; cultivation concentrated into two blocks totaling 10,000 ac (4,047 ha) and 20,000 ac (8,094 ha) that may be more palatable to tourists; and human population growth. Simulations with from 10,000 to 50,000 ac in cultivation showed no large changes in ungulate populations relative to there being no cultivation. When cultivation was altered to be in two blocks, some wildlife populations changed (≤15%) and ungulate biomass remained the same. When cultivation was increased linearly with human population, poor households needed 25% of their diets to come from relief as populations tripled, because livestock could not increase significantly. Our results indicate that having <1% of NCA in cultivation, in its current distribution, is not overly detrimental to wildlife or livestock populations, and is important to Maasai well-being.

Key words Ngorongoro Conservation Area · cultivation · ungulates · wildlife · livestock · Maasai.

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Introduction

Throughout the pastoral semi-arid and arid lands of Africa, land use is intensifying. Human populations are increasing, and pastoral societies that have been reliant upon dairy and meat products are exploiting relatively stable or even declining livestock populations (Kijazi *et al*., 1997; McCabe *et al*., 1997a; Lynn 2000). Decreasing food security has forced pastoralists to diversify their livelihood sources, by selling handicrafts, herding for others, finding employment outside their communities, or by other means (BurnSilver *et al*., 2003). Cultivation has become a dominant means of diversifying, converting many pastoral groups into agro-pastoral communities (Neumann 1998). Intensified land use, and cultivation in particular, has concerned conservationists, with general declines in wildlife documented across regions (de Leeuw *et al*., 1998) and specific declines tied to cultivation (e.g., Serneels and Lambin, 2001). In practice, landscapes have gravitated toward polarized uses: livestock raising and agriculture, or wildlife conservation in park settings. In East Africa only one large conservation area, Ngorongoro Conservation Area (NCA), is managed specifically to balance multiple land use demands (Perkin, 1995), and can provide insights into management of many semi-arid and arid areas of Africa, including buffer zones surrounding more traditional wildlife conservation areas.

Ngorongoro Conservation Area (8,283 km^2) borders Loliondo Game Controlled Area (LGCA) to the north, Serengeti National Park to the west, and agricultural communities on the southeastern border (Fig. 1). NCA was gazetted in 1959 following hardships for Maasai who had been excluded from a precursor to the Serengeti that was larger than the current national park (Neumann, 2000). NCA was created, and Serengeti reduced in size, as a compromise measure. Through that compromise, a unique long-term experiment was mandated—NCA was to be managed considering wildlife conservation *and* the needs of resident Maasai (reviewed in Thompson, 1997). NCA has been designated a Biosphere

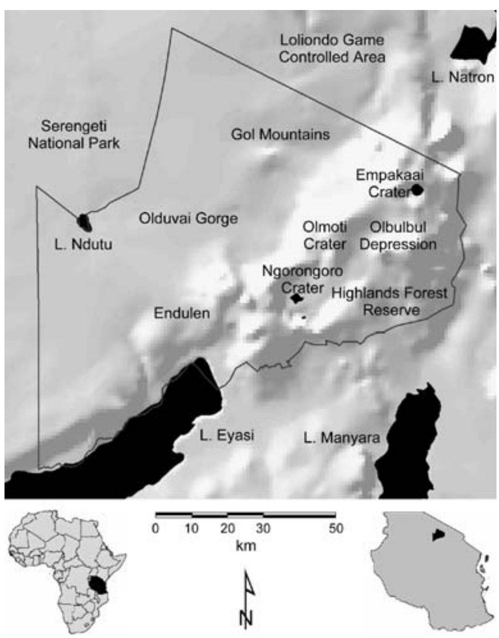

Fig. 1 Ngorongoro Conservation Area, with *shading* showing topography, lakes or basins in *black*, and selected sites labeled. The location of NCA within Tanzania and Africa is shown in insets.

Reserve and World Heritage Site (UNESCO, 2000), designations that are highly valued by NCA managers. Ngorongoro Crater is a world-renowned wildlife viewing area, providing the opportunity to view free ranging black rhinos (*Diceros bicornis*), and important archeological sites are within the conservation area, with evidence of early humans, including many in the world famous Olduvai Gorge.

By several measures, this 'great experiment' was successful for perhaps 30 years (Perkin, 1995): wildlife populations had not declined dramatically (Runyoro *et al*., 1995 provides evidence for Ngorongoro Crater), except for those that were poached in the 1970s and 1980s; livestock had been fairly stable (NCAA, 1999); and tropical livestock units (TLUs, i.e., 250 kg of body mass) per person were above 6 (Kijazi *et al*., 1997; NCAA, 1999), a value that suggests a successful pastoral lifestyle (Brown, 1973). However, since the early 1990s human population growth associated with improved health care and immigration has placed increasing stress on the ecosystem, reflected in a rapid decline in TLUs per person—less than 3 in 1999 among livestock-owning families (NCAA, 1999; Lynn, 2000). In contrast, Maasai in LGCA to the north still had more than ten TLUs per person (Lynn, 2000).

Cultivation of maize, beans, potatoes, and other crops had augmented the livestock-based diet of Maasai for decades. However, concerns about degrading the wildlife conservation value of NCA led the Tanzanian government to ban cultivation in 1975 (McCabe *et al*., 1997b and citations therein), although illegal cultivation still took place (Perkin, 1995). The well-being of the Maasai subsequently declined to the point that, in 1991, the government passed an emergency measure that allowed temporary, limited cultivation in NCA. Women in households could each cultivate 1 acre (ac) using hand tools (McCabe *et al*., 1997b; Galvin *et al*., 2000). The return of cultivation improved Maasai well-being markedly, and crops from households' own plots now contribute about 16% to their diets (Galvin *et al*., 2000), but the Maasai of NCA still cultivate a fraction of the acreage of Maasai in LGCA, about 0.12 ha per person in NCA versus 0.30 ha per person in LGCA (Lynn, 2000). Many non-Maasai emigrated into NCA following the legalization of cultivation in the early 1990s (Kijazi, 1997). Cultivation is the dominate method of livelihood for these families, with livestock raising a secondary activity. In a 1993 study, plots by non-Maasai were the dominant form of cultivation in NCA and are larger than for Maasai cultivators, with more than 50% of the cultivated area in less than 3% of patches cultivated (Kijazi, 1997 and citations therein). Although non-Maasai cultivate more land than Maasai, their plots are rarely worked with machines and the products are consumed by the families, or sold to other families within NCA (Galvin *et al*., 2000).

International and national environmental interests have expressed strong concern over cultivation in NCA, believing that cultivation is not compatible with the conservation goals of the area (IUCN, 1996). Business and governmental interests that profit from tourism are concerned as well, believing that agricultural patches detract from tourists' experiences. Concerns also follow from intensifying land use related to human population growth, including immigration. The population in NCA grows about 3.5% annually (Kijazi *et al*., 1997), so that the population that was about 35,000 in 1992 (NCAA, 1999) was 52,000 in 1999, and 60,000 in 2002 (V. Runyoro, NCAA, personal communication).

Cultivation is perhaps the most contentious land-use in NCA, and remains in bitter dispute among stakeholders. In an earlier integrated modeling effort (Boone *et al*., 2002), one of 16 scenarios explored suggested that increasing cultivation did not severely impact ecosystem functions to the degree people fear. Using integrative modeling to assess issues important in policy making was helpful, however, a map of cultivation was not used in that modeling effort, and modeling methods have since improved considerably. We were therefore asked by the Conservator of NCA to more carefully assess potential effects of cultivation on wildlife, livestock, and people in the NCA. To do so required that we map cultivation within NCA, creating the first high resolution map of cultivation for the area, then use an integrative model to compare ecosystem properties under no cultivation, the current area in cultivation, and increased levels of cultivation. Our results may be used by decision makers in Ngorongoro District, but have implications elsewhere where land use is intensifying because of human population growth, expanding agriculture, and the need to conserve wildlife.

Materials and Methods

Mapping Cultivation

An Enhanced Thematic Mapper+ Landsat scene from February 12, 2000 was used with a hybrid classification method (Hepinstall *et al*., 1999) in a test of methods to map cultivation. Known areas of cultivation were selected as training sites (30,607 pixels, 689 ha), using the georectified Landsat scene as a guide. The Serengeti Plains, where cultivation was known not to occur, were removed from the images, and a 5 km buffer around the southern boundary of NCA was included. Bands 1–7, 8, and ratios 4/5 and 4/3 were standardized to 0–255, resampled to a uniform 15 m pixel resolution, and assigned to 233 clusters using a maximum likelihood classification (ARC/INFO V. 8.3, Environmental Sciences Research Institute, Redlands, California, USA). A map was drawn for each cluster where the cluster was in a highly contrasting color, and inspected. In general, mapping based on cluster analysis worked reasonably well for the extensive cultivated areas to the southeast of NCA, but within NCA, the small patches of cultivation were spectrally confused with shrublands and other habitats. An alternative method of identifying cultivation within NCA was therefore used.

The primary method used to map cultivation within NCA was on-screen digitizing from the panchromatic band 8 (0.52 to 0.90 μm) of the Landsat 7 image. In the contrast-stretched image, cultivation was generally evident. In the northern part of NCA, cultivation showed as dark patches that contrasted sharply with the surrounding grasslands (Fig. 2a). Cultivated patches on the forested slopes of Olmoti Crater (Fig. 2b) were identified by changes in shading and texture. Patches in central NCA were somewhat more challenging to identify, being within a matrix dominated by darker shrubs (Fig. 2c). Cultivation was evident along the southeastern boundary of NCA, where tropical forests abut cultivated lands (Fig. 2d). Other dark patches such as cloud shadows or fire scars that had irregular edges were not mapped as cultivation. Multi-spectral band combinations were inspected in some cases to aid in mapping. In some areas where small patches of cultivation may exist, such as around Olbulbul Depression and along the shores of Lake Eyasi, we could not discern differences in the image. Patches of cultivation in a georectified image (GeoTiff, ©Adobe Corp., San Jose, California, USA) were identified using an image editor (Paint Shop Pro 5, Jasc Software, Inc., Minneapolis, Minnesota, USA) that delineated patches of pixels with similar shades of gray. A parameter in the software was adjusted until a given patch of cultivation was selected, but not surrounding vegetation. The cultivation was then painted a contrasting color. When digitizing was complete, the image was imported into the GIS package and the areas of contrasting color were moved into another layer, representing cultivation in NCA at 15 m resolution. A formal assessment of the accuracy of the resulting map was beyond the scope of our project, but the map was subjected to extensive expert review. More importantly, the ease

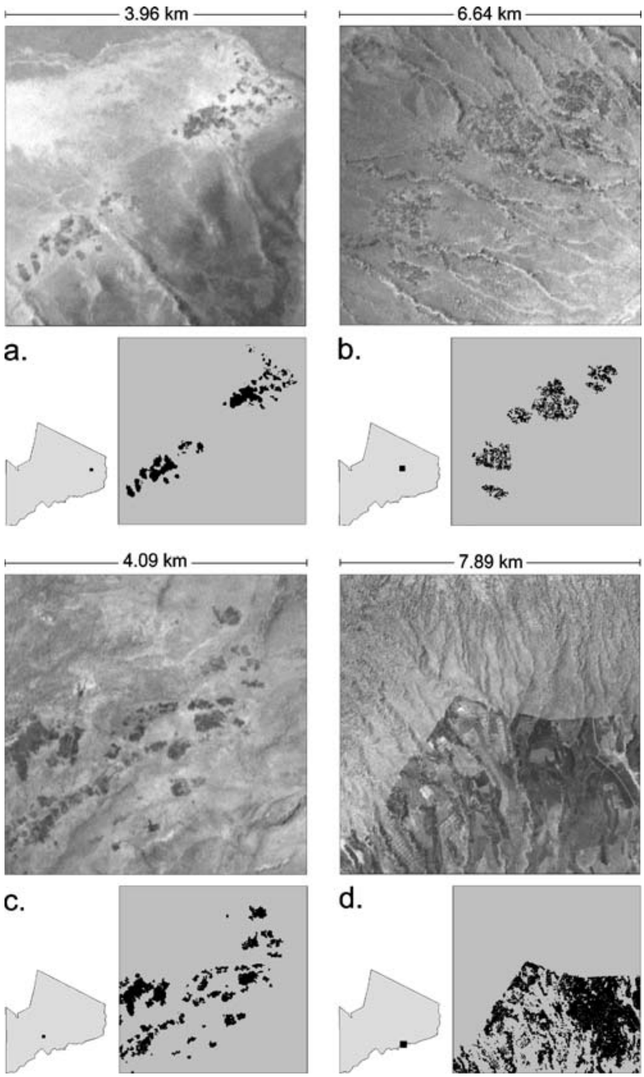

Fig. 2 Examples of cultivation as it appeared in band 8 of a Landsat ETM+ satellite image from NCA. Areas shown include: (a) grasslands within Olbulbul Depression, (b) the forested slopes northwest of Olmoti Crater, (c) drier grasslands and shrublands near Endulen, and (d) extensive cultivation along the southeast boundary of NCA. Areas mapped as cultivation and the location of the example site are shown in insets.

with which most cultivation within NCA could be identified within the satellite image (e.g., Fig. 2) bolstered our belief that the accuracy of the map was adequate for our needs.

Ecosystem and Socioeconomic Modeling

To evaluate ecosystem and social responses to changing levels of cultivation, we used the Savanna Modeling System, merged with the PHEWS model (Pastoral Household Economic Welfare Simulator). Initial development of Savanna began in the Turkana District of Kenya (Coughenour, 1985), and improvements to the model were made in subsequent applications (e.g., Coughenour, 1992; Buckley *et al*., 1993; Boone *et al*., 2002; Boone *et al*., 2005; reviewed in Ellis and Coughenour, 1998). PHEWS was created specifically to model Maasai household decision making in NCA (Thornton *et al*., 2003).

Savanna is a series of interconnected FORTRAN computer programs that model primary ecosystem interactions in arid and semi-arid landscapes, simulating functional groups for plants and animals (e.g., perennial and annual grasses, cattle, grazing antelope). Savanna is spatially explicit and represents landscapes by dividing them into a system of square cells. Savanna reads computerized maps that include, for example, the elevation, aspect, and soil type of each cell. The model predicts water and nitrogen availability to plants, for each of the cells. Based upon water, light, and nutrient availability, quantities of photosynthate are calculated for plant functional groups, using process-based methods. Photosynthate is allocated to leaves, stems, and roots using plant allometrics, yielding estimates of primary production. Changes in plant populations are derived from reproduction related to primary production. At each weekly time-step plants may, for example: produce seeds that become established, grow into older age classes, out-compete other plant functional groups, or die.

A habitat suitability index is calculated for each cell in the landscape, at weekly intervals and for each animal functional group, based upon forage quality and quantity, slope, elevation, cover, and the density of ungulates. Individuals in the population are distributed on the landscape based upon these indices. Animals will feed upon the available vegetation, depending upon dietary preferences and consumption rates. The energy gained is reduced by energy costs associated with basal metabolism, gestation, and lactation. Net energy remaining causes weight change, with weights reflected in condition indices. Charts and maps of the status of vegetation, ungulates and climate are produced at monthly intervals. For more detail about Savanna, see Boone (2000).

The PHEWS model simulates decision making in Maasai households. A rule-based modeling approach was used, because of its simplicity and rapid development, plus more complex economic models would not appropriately describe the weak link between Maasai agro-pastoralism and the market economy (Galvin *et al*., 2000). A series of rules were incorporated that are based on the observed decision making strategies of Maasai in NCA, gleaned from interviews and published sources. Based on our interpretation of interview responses, in the model families seek to meet their caloric needs, while simultaneously seeking to maintain livestock (TLUs per person) and monetary holdings (a ‘cashbox’). TLU targets varied by wealth category (i.e., poor, moderate, and rich), and were parameterized to emulate the TLUs per person observed on NCA. Monetary holdings were weighed against TLUs per person, and if possible, animals were sold or purchased to approach the desired TLUs (Galvin *et al*., 2000). In simulations, energy flow is modeled through PHEWS in a step-wise fashion, representing a hierarchical decision making scheme. Calories are gained from milk, crops raised by the family, from livestock slaughtered due to disease or for occasional ceremonies, and from sugar in tea (a significant energy source for Maasai families). If there remains a caloric deficit and the family has money, maize and other crops are purchased. Finally, if a deficit still remains, the families’ needs are met through supplemental food, such as from friends, relatives, or from international agencies. Concurrently, if the family owns more livestock than observed in reality, animals may be sold (small stock if the deviation is small, large stock or both if the deviation is large). If the family has sufficient funds and TLUs are below the target, livestock are purchased. Galvin *et al*., (2000), Galvin *et al*., (2002), and Thornton *et al*., (2003) provide more detail about PHEWS.

The PHEWS model is tightly linked to Savanna. For example, as each week is simulated, Savanna reports to PHEWS the amount of cultivation in each cell simulated, as well as the livestock populations for that week, including lactating cattle. From these, PHEWS estimates milk and maize availability to families. In turn, PHEWS reports numbers of livestock slaughtered or sold back to Savanna, so that livestock population dynamics may be modeled.

Adapting Savanna and PHEWS to NCA

Functional Groups

Plant and animal functional groups must be defined for an area prior to adapting the Savanna model, based upon the questions to be addressed, balancing the need for detail in responses and the costs of model parameterization and execution. Here, an existing version of Savanna (version 4e) applied to NCA (Boone *et al*., 2002) was modified (yielding version 4Lc). The seven vegetation functional groups remained as in Boone *et al*., (2002), and were: palatable grasses, palatable forbs, unpalatable herbs, palatable and unpalatable shrubs, evergreen forests, and deciduous woods. Eleven animal functional groups were defined. Wild ungulate functional groups included three migratory species: 1) wildebeests (*Connochaetes taurinus*), 2) zebras (*Equus burchellii*), and 3) grazing antelopes (Thomson's gazelle, *Gazella thomsoni*), and resident populations of 4) zebras and 5) grazing antelopes (almost all resident wildebeest inhabit Ngorongoro Crater, which was modeled separately and not discussed here). Three other resident wildlife populations were modeled: 6) browsing antelope, 7) African buffalo (*Syncerus caffer*), and 8) elephants (*Loxodonta africana*). Lastly, 9) cattle, 10) goat, and 11) sheep groups represented the livestock in the NCA. Our model did not include the full geographic range of migratory populations, which range northwest into Serengeti National Park and into Kenya, and so population dynamics of those groups were not modeled. In simulations, appropriate numbers moved onto and off of NCA each year so that forage use was represented fairly, but the total population sizes of migrants were static across years.

Parameterizing the Model

The Savanna model uses geographic layers describing elevation, slope, aspect, vegetation, soils, and water sources to model the growth of plants and distributions of animals. Elevation, slope, and aspect were derived from a digital elevation model produced by the US Geological Survey and acquired from the African Data Dissemination Service (ADDS, 2001). Land cover was mapped by M. Kalkhan (Colorado State University, USA) using a Landsat 5 satellite image from 1991 and existing vegetation maps (e.g., Herlocker and Dirschl, 1972). Soils were from a Food and Agriculture Organization map that was recoded (USDA, 2003). Water sources are mainly from Aikman and Cobb (1997). Maps, called 'force maps,' were created for livestock and elephants, which Savanna uses to limit the distribution of ungulates due to relationships unrelated to habitat. For example, livestock may use Ngorongoro Crater only to take water, and cannot graze extensively. Therefore, the force map for cattle was scored so as to prevent their use of the crater. All geographic data were generalized to 5 × 5 and 2.5 × 2.5 km blocks. Model assessments were conducted at the finest spatial resolution. However, results reported here are based on 360 simulations, so the coarse-resolution model was used to speed program execution.

Weather data from 55 stations within the region were available from 1963 to 1992. Note however that the data on ungulate abundances, human populations, and household attributes are from ca. 2000; the weather data provided a typical response only, and the base model emulates, to the degree possible, conditions in 2000. Savanna uses a focal weather station for detailed information (e.g., relative humidity, wind speed, CO_2 concentration, active radiation); we used the station at the research center in Seronera, Serengeti National Park, which is outside the NCA but has a very complete weather data record.

Parameters were set in the model based upon a literature review, previous Savanna applications (Coughenour, 1992; Kiker, 1998; Boone *et al*., 2002; Boone *et al*., 2004), field work associated with the project (e.g., Galvin *et al*., 2000; Maskini and Kidunda, 2000), and expert opinion. Individual parameters are too numerous to cite, but examples may be classified within groups of ecological processes: plant phenology and biomass (e.g., Ndawula-Senyimba, 1972; McNaughton, 1985; O'Connor and Pickett, 1992; Seagle and McNaughton, 1993; Satorre *et al*., 1996), plant allometrics and growth (e.g., Fourie and Roberts, 1977; Hodgkinson *et al*., 1989; Coughenour *et al*., 1990; Tewari, 1996), ungulate energetics and growth (e.g., Stafford Smith *et al*., 1985; Murray, 1995), wildlife and livestock populations (e.g., Campbell and Borner, 1995; Boshe, 1997; Kijazi *et al*., 1997; NCAA, 1999), habitat relationships (e.g., Sinclair and Gwynne, 1972; Western, 1975; Boshe, 1997), grazing and climatic effects (e.g., Mwalyosi, 1992; O'Connor, 1994; Gowda, 1997; Tapson, 1997; Norton-Griffiths, 1979), and pastoralist status and decision making (e.g., Homewood *et al*., 1987; Bekure *et al*., 1991; Homewood and Rodgers, 1991; McCabe, 1997; McCabe *et al*., 1997b; Galvin *et al*., 2000).

Specific Model Adjustments & Assessment

NCA ungulates outside Ngorongoro Crater are thought to be below some long-term forage-based carrying capacity (Society of Range Management, 1989) due to livestock diseases (Rwambo *et al*., 1999). To incorporate that relationship in the model, disease was incorporated by emulating the main source of disease in reality, tick-borne diseases such as East Coast fever. In the simulation, losses of livestock from disease were greater if animals inhabited higher elevations, if rainfall was greater, or if livestock densities were high. To maintain herbivore populations below carrying capacity, wildlife were modeled to avoid livestock, using an adjustable avoidance parameter associated with the densities of the functional groups. That allowed livestock losses from disease to be modeled without having wildlife populations increase in a density-dependent way, maintaining ungulates below carrying capacity. Livestock and wildlife will use products from agricultural lands to varying degrees (Bayer and Waters-Bayer, 1994). However, to simplify modeling and to have our results show the most extreme effects of cultivation that were feasible, we excluded ungulates from cultivated patches entirely and ungulates did not benefit from crop residues.

Assessing a model as integrative as Savanna can be challenging. The overall structure of the model has been validated extensively in a variety of contexts (e.g., Kiker, 1998; Boone *et al*., 2002; Weisberg *et al*., 2002), and the component algorithms were validated by the original authors. Here, modeled vegetation biomass was compared in a spatial and non-spatial way to biomass data collected by the Ngorongoro Ecological Monitoring Program (Runyoro, 1998) and to greenness data in Normalized Difference Vegetation Indices (NDVI) calculated from satellite images, produced by the Vegetation Programme, part of the Earth Observation System of the Centre National d'Etudes Spatiales of France, in cooperation with Sweden and Belgium (VITO, 2002). Spatially, vegetation green biomass averaged over all years modeled compared well with the average greenness pattern observed from space (Fig. 3; Spearman's ρ = 0.76). Comparisons with greenness data

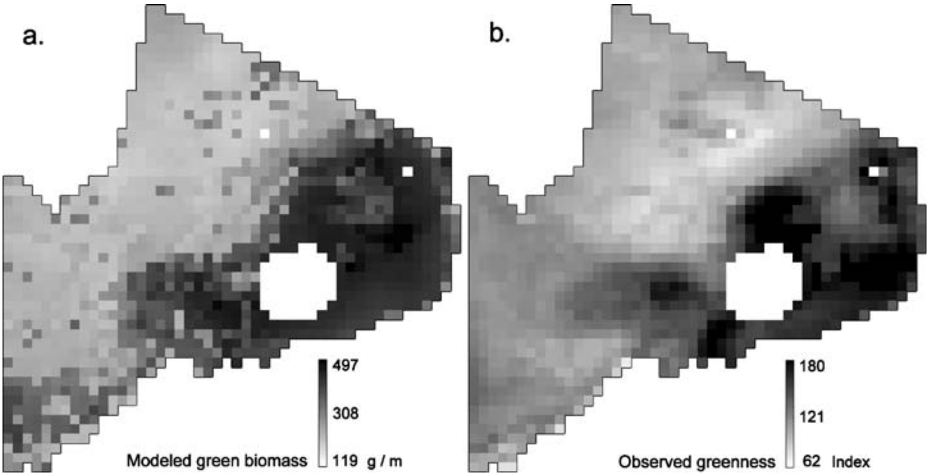

Fig. 3 A comparison of (a) modeled mean monthly green biomass and (b) observed greenness from VEGETATION satellite data. *Shades* were distributed linearly, with the extremes defined based on the mean value, plus and minus two times the standard deviation of the values.

collected on the ground showed that plant phenology was being represented reasonably well (Spearman's ρ = 0.81). Also, more than 20 experts in range science and livestock production in NCA saw our results during workshops, with favorable feedback, what Rykiel (1996) calls face validity.

Queries of Interest

The general goal of our modeling was straightforward; to simulate different levels of cultivation and changes in ecosystem status, focusing upon ungulate populations and human welfare. In practice, we modeled no cultivation, the current level of cultivation, and up to five times the current level of cultivation. Mapped cultivation was used as a guide to generate the GIS layer used in modeling current conditions, and as a guide where less or more cultivation was modeled. The same distribution was used to model lower levels of cultivation, but with fewer hectares per modeled cell in agriculture. Little of each cell with cultivation was actually in cultivation (i.e., mean <1%, maximum 23%), but identified general areas where cultivation was practiced. Therefore, greater areas of cultivation were modeled by increasing the proportion of cultivation in each cell already with cultivation. For the highest level of cultivation, a few cells neighboring those with cultivation and in appropriate habitat were assigned some cultivation. In another scenario, we changed the distribution of cultivation in NCA into two large blocks placed where cultivation is now most dense, to assess potential ecosystem effects from moving cultivation to what may be a more acceptable distribution in the eyes of the tourist trade and local authorities. Specifically, changes in livestock or wildlife populations, or their distributions, were of interest. Lastly, because human population growth is an important ecosystem stressor in East Africa, we modeled human populations at 35,000, 50,000, 100,000, and 150,000 people.

Savanna integrates many sources of information, sometimes leading to complex responses. Results from individual model runs are sensitive to the observed climatic pattern, including any temporal autocorrelation in weather. That pattern and its effect on the ecosystem are not of interest here, so 20 simulations 15-years long of each scenario were run using yearly rainfall patterns selected randomly from the 30 year history cited, with small (≤1°C; ≤1 mm rainfall) variations added. Summarizing results from 20 simulations yielded precise estimates of mean responses (e.g., standard errors <1.3% of mean populations), and allowed standard deviations of populations to be calculated. We discarded the first five years of simulation results in each case while results were stabilizing, so that the results shown summarize the final 10 years of simulated ecosystem responses.

Two types of simulations were conducted—with and without livestock sales. Livestock are an important component of ungulates within NCA; livestock comprise about 80% of ungulates in NCA in the dry season, 21% during the wet season, when migratory animals from the Serengeti (wildebeest, zebra, and Thomson's gazelle) are present (Boone and BurnSilver, 2002) (note here that resident wildlife population changes were modeled, but not migratory population changes, because only a portion of their annual range was included in our study area, NCA). We sought to assess effects of cultivation on livestock and resident wildlife populations, without results being confounded by sales or purchases by Maasai. In some analyses, therefore, household modeling was disabled. In analyses where household status was a response of interest, the full modeling system was used.

Results

We mapped 3,967 ha (9,803 ac) in cultivation within NCA in 2000 (Fig. 4, and not including cultivation shown outside the boundary, which is conducted by non-Maasai agriculturalists). This is a 73% increase in cultivation from that surveyed in 1993, after cultivation was re-instated in 1991 (reviewed in McCabe *et al.*, 1997b). The extent of cultivation to the southeast did not agree spatially with the mapped boundary; that boundary is being re-surveyed on the ground (V. Runyoro, NCAA, pers. comm.). It appears, however, that a significant area of forest within NCA has been converted due to encroaching cultivation (Fig. 4, extreme southeast). Other areas with significant cultivation were Naiyobi, which is northeast of Empakaai Crater, and areas around Endulen, to the south. Based on these results, and given that English units are commonly used in the region (Table I includes metric values), we assessed cultivation at seven levels: 10,000 ac (current conditions); 5,000; 7,000; 20,000; 30,000 and 50,000 ac, and no cultivation (0 ac).

A series of simulations with livestock sales disabled showed few effects of cultivation on livestock and wildlife populations. A slight decline for cattle may be deduced (Fig. 5), and resident zebra do decline in simulations (Table I). In general, however, the integrative nature of Savanna yielded idiosyncratic responses to the different areas in cultivation, which appeared to add more variability than the increase in cultivation itself. Variation within the 20 simulations at each level of cultivation was large (although precise estimates of mean responses were generated). As yearly weather was determined randomly, a series of wet or dry years may favor a given animal functional group. As a given population increased, others declined, yielding large deviations.

The modeling scenario that segregated cultivated areas into two large blocks (Fig. 6) less obtrusive to tourists led to moderate changes in ungulate populations (Table II), versus the current distribution. Changes ≥7.5% were a 15% decline in grazing antelope when 10,000 ac of cultivation were blocked, and a 12–13% increase in browsing antelope and buffalo in the same simulation. Blocked-cultivation at 20,000 ac led to an 8% decline in elephants, and 7.5% increase in grazing antelope. Whether these changes are because of redistributed cultivation or populations changing through integrative responses we cannot say. That said, the overall biomass of ungulates varied less than 2% between scenarios.

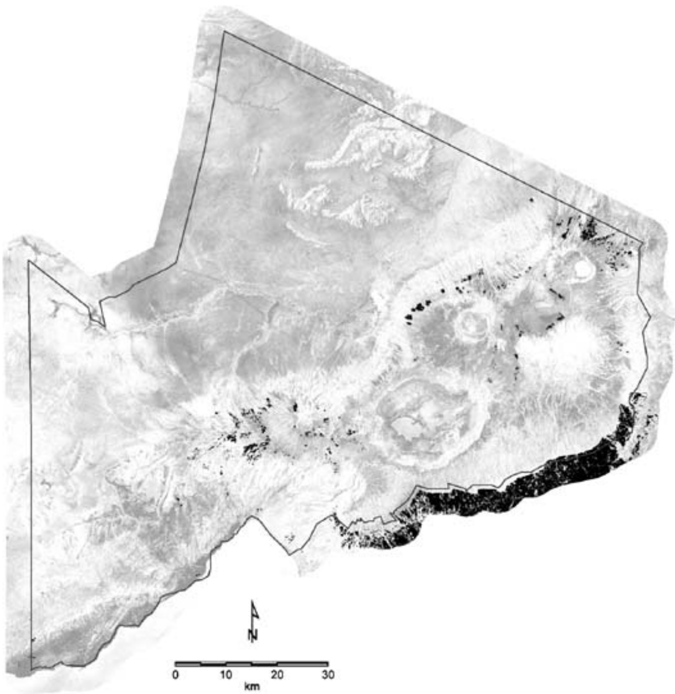

Fig. 4 Cultivated areas within NCA, and a 5 km buffer around the boundary for context, are shown in black. We estimated 3,967 ha (9,803 ac) of cultivation within NCA in February 2000.

Table I Wildlife Population[a] Changes in Response to Areas in Cultivation in NCA

Species or group	Area in cultivation						
	0 ac 0 ha	5,000 ac 2,023 ha	7,000 ac 2,833 ha	10,000 ac 4,047 ha	20,000 ac 8,094 ha	30,000 ac 12,140ha	50,000 ac 20,234 ha
Resident zebra	4,303 (1,619)	4,178 (1,269)	4,410 (1,257)	4,410 (1,035)	4,667 (1,380)	3,812 (1,214)	2,918 (1,862)
Resident grazing antelope	13,153 (3,749)	12,482 (5,124)	13,034 (4,067)	13,927 (5,200)	12,160 (4,325)	11,679 (3,764)	12,820 (4,342)
Browsing antelope	3,103 (889)	2,836 (700)	3,388 (1,016)	2,844 (706)	3,079 (829)	3,049 (840)	3,260 (818)
Buffalo	2,142 (677)	2,069 (920)	2,638 (1,033)	2,079 (768)	2,210 (751)	2,094 (732)	2,016 (909)
Elephant	385 (99)	362 (85)	329 (77)	386 (101)	347 (77)	360 (78)	347 (60)

Results summarize the last 10 years of 15-year simulations, where household modeling, including livestock sales, was disabled. Values in parentheses are standard deviations from 20 simulations with annual weather generated randomly based on historic patterns.

[a] Populations exclude animals within Ngorongoro Crater.

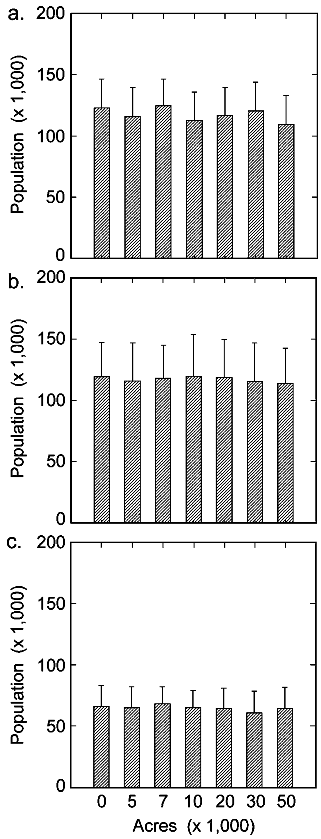

Fig. 5 Livestock populations under different areas in cultivation, with: (a) cattle, (b) goat, and (c) sheep populations shown. *Error bars* show the standard deviation of populations across 20 simulations using randomly assigned yearly weather patterns. See Table I for metric areal units.

Simulations with Maasai households modeled confirmed that human population growth is a dominant motivator or cause of land use intensification and an indirect source of food insecurity. In past analyses (Galvin *et al.*, 2000), the amount of cultivation was changed while the human population was constant. Here we increased cultivation linearly with human populations, but livestock populations were modeled dynamically, and stayed relatively stable as they have been for decades. In four analyses with human populations from 35,000 to 150,000, food insecurity increased dramatically due to declining TLUs per person. For example, in simulations moderately wealthy families had 2.82 TLUs/person with 35,000 people, but 0.67 TLUs/person with 150,000 people in NCA—NCA cannot support enough livestock to meet the needs of 150,000 pastoralists. With 35,000 people, as in 1992, poor and moderately wealthy households required <5% of supplements to their diet (Fig. 7), and rich households require no supplements at all. The need for supplemental foods increased, until with the population at 150,000 people, poor households are needing supplements to fulfill 25% of their diets, and even rich households are requiring supplements for a significant component of their diets.

Discussion

Cultivation has been a point of heated dispute between managers and residents in NCA for more than 15 years (e.g., McCabe *et al.*, 1997b). We have used a complex integrative model to demonstrate that resident ungulate populations do not show marked population changes relative to an absence of cultivation, given the current area and distribution of cultivation. No large population declines were observed with cultivation up to 50,000 ac. Ten thousand acres in cultivation represents 0.49% of NCA (8,280 km^2); or, if only the Pastoralist Development Management Zone is considered (NCAA, 1996; see Boone and BurnSilver, 2002), 10,000 ac in cultivation represents 1.1% of the zone. The model results seem reasonable; levels of cultivation such as this would have minor effect upon ungulates. If cultivation were distributed differently, such as surrounding the northwest rim of Ngorongoro Crater (Runyoro *et al*., 1995) or dominating the grasslands of Olbulbul Depression, effects might be greater. Wildlife movements and migration corridors are not well documented in NCA, except for movements on the plains (Runyoro *et al*., 1995; Boshe 1997), and the version of the Savanna model used did not include explicit modeling

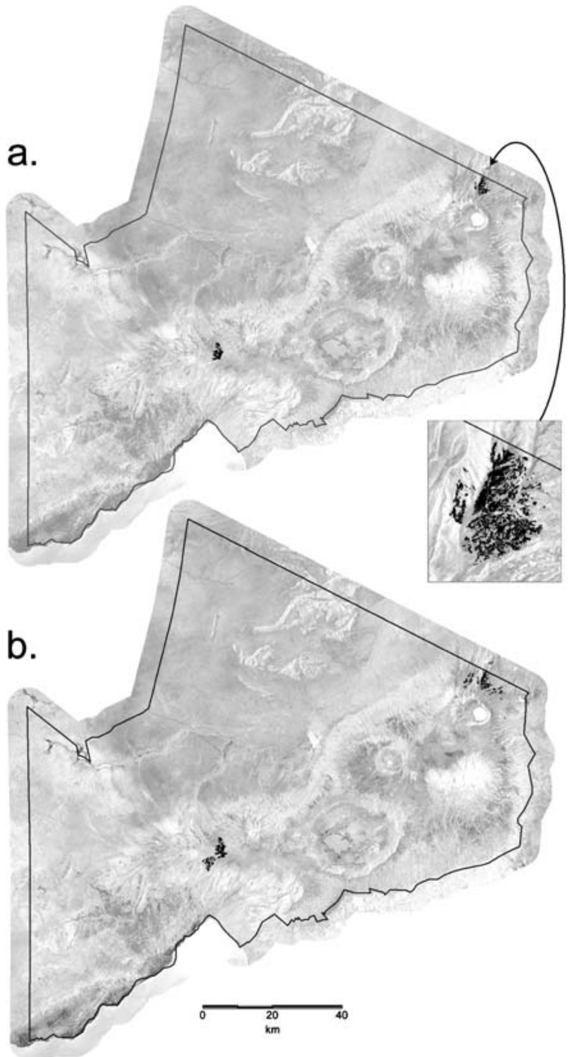

Fig. 6 Cultivation within NCA redistributed into two large blocks. Simulations included: (a) 10,000 ac in cultivation, shown in *black*, and (b) 20,000 ac. The *inset with arrow* shows that cultivation within these blocks is dense, but not continuous. See Table I for metric areal units.

Table II Ungulate Population[a] Changes Under the Observed Distribution of Cultivation[b], and Cultivation Placed into Two Large Blocks (Fig. 6)

Species or group	Distribution of cultivation			
	Current 10,000 ac	Blocked	Current 20,000 ac	Blocked
Cattle	112,540 (23,234)	116,159 (20,514)	116,941 (22,542)	116,573 (24,644)
Goat	120,511 (35,667)	112,582 (33,632)	119,573 (32,674)	118,859 (37,056)
Sheep	65,744 (14,041)	68,135 (17,431)	65,675 (16,707)	62,126 (19,927)
Resident zebra	4,409 (1,035)	4,256 (1,542)	4,668 (1,380)	4,319 (1,319)
Resident grazing antelope	13,927 (5,200)	11,882 (3,482)	12,160 (4,325)	13,077 (4,610)
Browsing antelope	2,844 (705)	3,225 (891)	3,080 (829)	3,141 (879)
Buffalo	2,078 (768)	2,344 (714)	2,210 (751)	2,264 (1,093)
Elephant	386 (101)	364 (87)	347 (78)	318 (74)

Results summarize the last 10 years of 15-year simulations, where household modeling, including livestock sales, was disabled. Values in parentheses are standard deviations from 20 simulations with weather generated randomly based on historic patterns.

[a] Populations exclude animals within Ngorongoro Crater.

[b] For hectares in cultivation, see Table I.

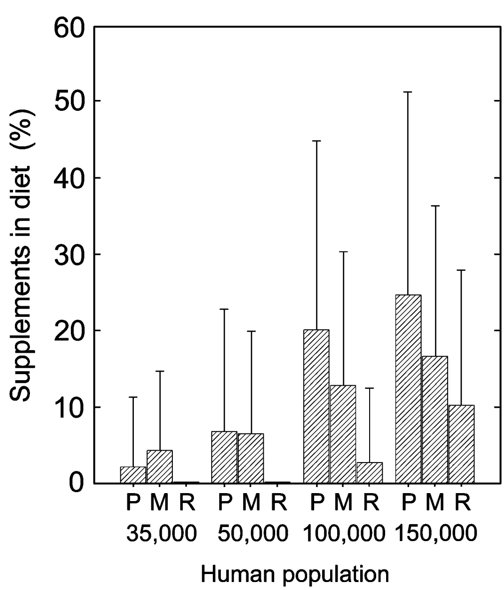

Fig. 7 The percentage of Maasai diets composed of supplemental or relief foods, for poor (*P*), moderate (*M*), and rich (*R*) households with human population at 35,000 to 150,000 people. *Error bars* show the standard deviation of populations across 20 simulations using randomly assigned yearly weather patterns.

of animal movements. Regardless, in its current configuration, cultivation appears to have only minor effects on resident ungulate populations.

Maasai in general, and especially the community in NCA, are faced with increasingly difficult challenges (Galvin *et al*., 2002), but these challenges appear to be manifesting themselves as decreased food security associated with human population growth, not in marked declines in wildlife or livestock populations (Kijazi *et al*., 1997). We have assessed effects of cultivation from its current level to five times its current level, with few changes in resident ungulate populations. However, the decrease in TLUs per person under increased human population and livestock remaining below carrying capacity led to far greater needs for supplemental foods to be provided to NCA Maasai (Fig. 7). In past analyses we found that the benefits to NCA Maasai from cultivation permitted in 1991 were essentially negated by the year 2000, due to increased growth and immigration (Galvin *et al*., 2000). In time, the need for supplemental provisions may exceed what friends, relatives and the national and international aid communities can provide.

Our models include relatively simple effects of cultivation on ungulates and households. Our results are not intended to provide predictions as to actual ungulate population levels or human relief needs 15 years hence, but rather are intended to provide general directions and magnitudes of change. For example, an ongoing Danish-supported pastoral development project within NCA is increasing livestock populations through restocking and improved veterinary care (Bourn, 2002), which may alter the trajectories of ungulate populations. Our models are intended to capture the main effects upon the ecosystem and households, and to compare results from a baseline simulation to results from simulations where only one variable (e.g., cultivated area) has been changed. In brief, ungulates were unable to use areas in cultivation, but that simple restriction may lead to complex cascading responses in Savanna, as in reality. For example, animals unable to use an area will loose access to the forage that area provides, seek alternative foraging areas, disrupt the distributions of other ungulates that were using the alternative areas, and perhaps alter the distribution of migratory species and the biomass of vegetation on which they feed. We did not address other costs associated with cultivation, such as water use, the potential to truncate wildlife corridors, or animals disturbed or killed to protect crops (McCabe *et al*., 1997b), although few wildlife are killed in NCA. Some resident wildlife populations increased under higher levels of cultivation in our integrative modeling (Table I). Competition for forage by ungulates in Savanna yielded declines in some species as cultivation increased and they were excluded from a favored forage area, and compensatory increases in other ungulate populations. Overall, however, these changes are idiosyncratic to the particular scenarios, and the biomass of resident wildlife did not change. We did not assess whether crop production would be harmed or benefit from the change in distribution we modeled, or if other locations would be better or worse than the locations we selected. It may be that cultivation in two larger blocks is more susceptible to climatic variation than its current, diffuse distribution. In general, however, our results using blocked-cultivation appear reasonable. For example, cattle show somewhat more sensitivity to cultivation than do goats or sheep, which is reasonable given their annual movements. During the bulk of the growing season, cattle cannot use the plains because of the risk of contracting malignant catarrhal fever, which is spread by young wildebeest (Boone *et al*., 2002). Cattle are herded to the midland slopes of NCA, where cultivation occurs. Goats and sheep are not at risk from malignant catarrhal fever, and are less constrained in their habitat use. Lastly, we presented our suite of results, but in different formats, to NCA stakeholders, including research scientists, land managers, policy makers, and Maasai agro-pastoralists (Rykiel, 1996). In general, the information we presented agreed with the perceptions of the stakeholders.

Several proposals have been discussed by NCAA and others to address national and international conservation concerns regarding cultivation. The proposal being acted upon now is to exclude larger scale cultivation around Endulen and north of Empakaai Crater from NCA. Large-scale cultivators are typically non-Maasai who have immigrated into NCA following what was to be a temporary reprieve on the ban on cultivation. Tourists and others are often more comfortable with small agricultural plots associated with households than with visible large-scale fields in cultivation, and the removal of large fields may ease many concerns. We could not differentiate between Maasai and non-Maasai cultivation based on satellite images to aid in this decision making (e.g., we believe relying solely on cultivated patch size to suggest Maasai and non-Maasai cultivation would be misleading). Complex family histories, such as plural marriages between Maasai and non-Maasai, residence by non-Maasai for generations (McCabe *et al.*, 1997b), and little record-keeping has made identification of Maasai that are bona fide residents of NCA difficult and contentious (V. Runyoro, NCAA, pers. comm.). The current proposal being implemented by NCAA is to shift all cultivation from NCA to LGCA over a number of years (V. Runyoro, pers. comm.). An area within LGCA has been designated for use by NCA cultivators to raise crops, which will require that families emigrate to LGCA, move annually back and forth between the areas, separate to allow some family members to raise crops in LGCA while others raise livestock in NCA, or stop cultivating. In interviews, a variant of this approach proved unpopular with Maasai in the mid-1990s (McCabe *et al.*, 1997b). Regardless of cultivation in the mid-slopes of NCA, cultivation encroaching into the Northern Highland Forest Reserve from the southeast is unlikely to be by resident Maasai. Given the importance of the reserve as a water catchment, that cultivation should be removed and forest regenerated.

In climatically variable systems such as NCA, it is difficult to quantify how much dietary energy a cultivated area may produce, but general estimates have been made. Our data, analyses, and analyses by others suggest that currently, between 15 and 30% of the energy needs of the Maasai in NCA are met through cultivation, including crops sold to purchase grains grown outside NCA. If cultivation were removed from NCA, it would leave a large deficit in Maasai dietary needs, one that will only become more extreme as human population increases.

Wildlife conservation is a critical component of the great experiment that is NCA. However, international and national observers must avoid reflexive conservation concerns unsupported by evidence, or worse, views that seek to maintain Maasai “as human beings in their primitive state” (notes cited in Neumann, 2000, pp. 124–125). If the NCA experiment is to continue to inform multiple-use land management throughout East Africa, the mix of land uses should remain fairly representative of traditional uses. Cultivation improves diets and likely increases human population growth, further stressing ecosystem services, but denying cultivation to slow growth cannot form a socially acceptable foundation for policy. Maasai in NCA have cultivated for decades (McCabe *et al.*, 1997a), and small scale agriculture has traditionally been part of African pastoralism where ever such cultivation is possible (Neumann, 1998). It is not a culturally aberrant practice inappropriate to the status of NCA as a World Heritage Site, and appears to be ecologically compatible with the other purposes of NCA. Large scale agriculture, either by Maasai or others, is more problematic. Conversion of land to such uses is common in East Africa and may be an unavoidable consequence of modernization, monetization, and human population growth. Its suitability within NCA, however, is questionable, and the most recent estimate available, although now dated, indicates that it may compose more than 50% of cultivation in NCA (Kijazi 1997). Challenges abound in managing NCA, especially in response to human population growth and the control of immigration into multiple-use areas, but based upon integrative modeling and the caveats we cite, we believe that having <1% of NCA in cultivation, in its current distribution, is not overly detrimental to wildlife or livestock populations, and is very important to Maasai well-being.

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