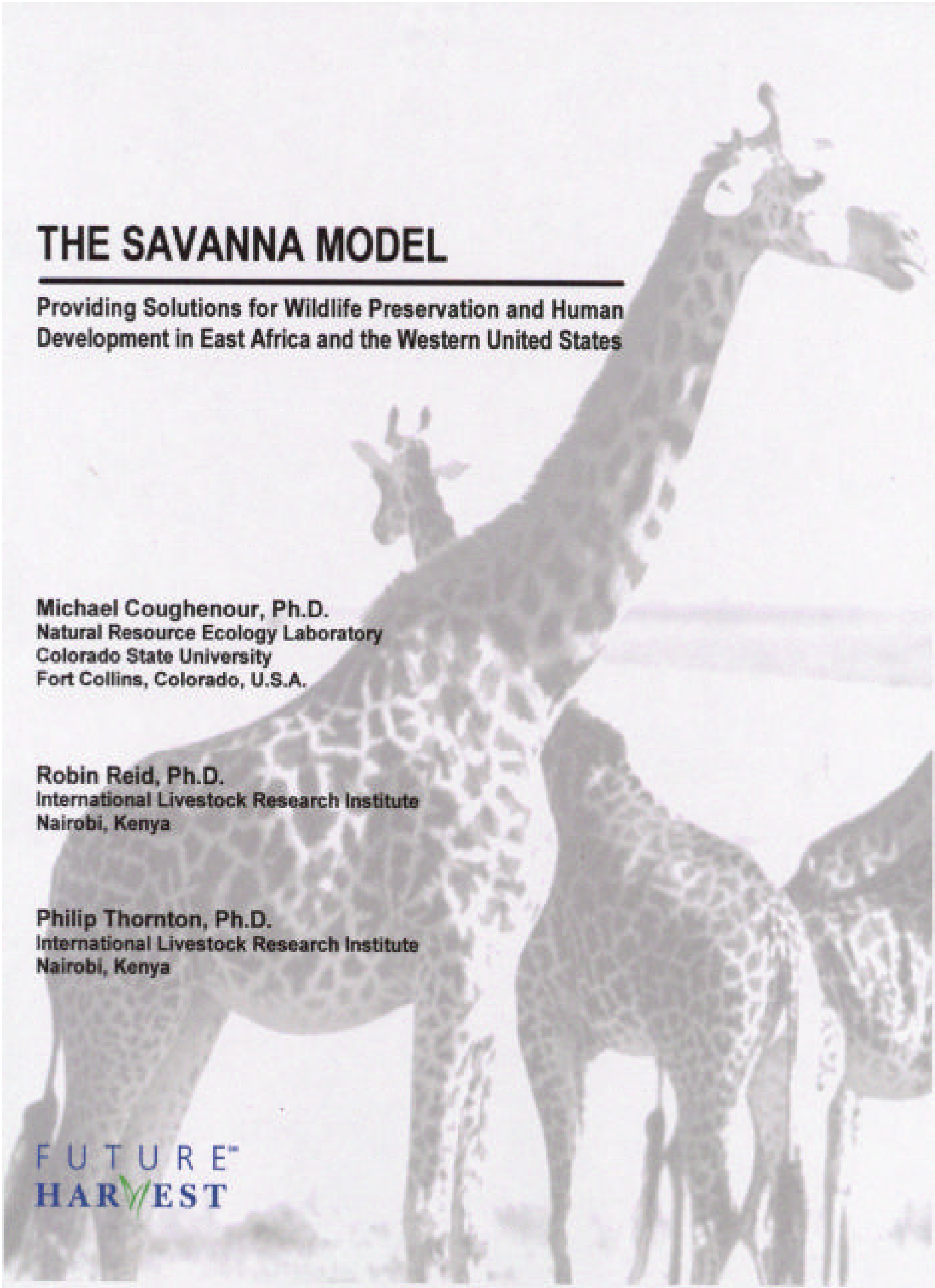

THE SAVANNA MODEL

Providing Solutions for Wildlife Preservation and Human Development in East Africa and the Western United States

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FUTURE HARVEST

The National Resource Ecology Laboratory at Colorado State University has a long tradition of bringing scientists from different disciplines together to examine complicated ecological problems. In addition to focusing on grasslands, research at NREL spans the globe and contributes to the scientific basis for understanding the interactions that sustain our environment locally, regionally, and globally.

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The International Livestock Research Institute (ILRI) is the world's leading research institution addressing sustainable animal agriculture in developing countries. A non-profit organization focused on reducing poverty, hunger, and environmental degradation through livestock research, ILRI scientists are ideally positioned to address the complex human, livestock, and wildlife issues in East Africa.

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INTRODUCTION

As many wildlife species decline in East Africa, a new tool may help to reverse this trend and save wildlife in an area that has been called the jewel of wildlife conservation on Earth. This tool is a computer-based model that has taken 15 years to develop. It could help save elephants and rhinoceros in East Africa and help balance elk and bison populations in the western United States.

The model is being applied in conservation areas in East Africa and the western United States to predict the future of wildlife and to find solutions to the tremendous pressures confronting both wildlife and people in and around conservation areas. SAVANNA simulates the effects of different natural changes, land-use practices, and management strategies, helping stakeholders make critical decisions.

SAVANNA is the first ecological model capable of tackling the full range of land-use options and policies facing protected areas. The model represents the processes that give rise to ecosystem change, such as plant growth, animal population growth, and nutrient recycling by soil microorganisms. By simulating these processes, the model can project ecosystem changes over periods from five to 100 years.

SAVANNA is unique in many ways. Unlike most ecological models, SAVANNA is comprehensive. It not only includes plants, soils, weather, and nutrient cycling, but it also includes animals, adding another layer of complexity. Furthermore, SAVANNA includes both human activity and human welfare, allowing it to model situations in which people initiate and respond to change in the environment. Most models are either static, capturing the state of an ecosystem at only one point in time, or nonspatial, representing the ecosystem as a homogeneous aggregate. SAVANNA is dynamic, showing the interaction of different processes over space and time.

SAVANNA is being applied to critical problems in East Africa and the western United States. In both regions, wildlife and ecosystems face many challenges, including rapidly growing human populations. Although the rate of population increase is slowing in East Africa, Kenya's population has more than tripled since 1960, and is now 29 million. Likewise the Tanzanian population has more than tripled to 32 million during the same period. In parts of the western United States, population is rising even more rapidly. In Colorado, for example, population increased by some 20 percent in the 1990s, and five of the 10 fastest-growing states are in the West, with population increases of up to 45 percent in the 1990s.

While conservation challenges in the United States are the result of affluence, in East Africa conservation challenges are more nearly the result of poverty. In Kenya, per capita income is $270 a year; in Tanzania it is $260. Lack of resources at all levels presents a major challenge to wildlife conservation and management in East Africa.

The region still supports the greatest concentration of large mammals left on Earth—yet their future is uncertain. Many species are rapidly declining. Between 1977 and 1996, Kenyan wildlife declined by one-third. Between 1975 and 1990, Kenya's elephant population dropped by 85 percent, to approximately 20,000, and its rhino population fell by 97 percent, to fewer than 500. Poaching of wildlife has contributed to the declines, as has changing land use.

Human land use can complement or undermine wildlife populations. Today, pastoral people who have traditionally herded cattle for a living are taking up farming. The change is not altogether voluntary. Cattle diseases have diminished herds, forcing pastoralists to look for other sources of food and income. Improved cattle health and productivity would reduce the pressure to farm, which in turn would aid wildlife. While pastoralism is reasonably compatible with wildlife use, farming is largely incompatible. East African pastoralists move their cattle across the range following the rains, in patterns that complement the cycles of the savanna plants and wildlife. Farming, on the other hand, is stationary, monopolizing the resources of an area and presenting an easy target for wildlife that trample farmers' fields and eat their crops.

In East Africa, the areas of greatest large mammal diversity in Africa are also many of the areas of greatest human population increase. SAVANNA modelers are focusing on these areas, including the species-rich, cross-border region of Kenya and Tanzania that holds Kenya's Amboseli National Park and Maasai Mara National Reserve and Tanzania's Ngorongoro Conservation Area and Serengeti National Park.

In Amboseli National Park, wildlife numbers have remained relatively stable over the last 20 years. This stability is threatened, however, by the cultivation of important wetlands that serve as dry-season grazing areas for wildlife and livestock. Researchers and policy makers are using SAVANNA to discover new ways for local people to benefit economically from sustaining wildlife, such as through ecotourism projects. Such projects provide incentive for pastoralists and farmers to conserve wildlife. SAVANNA will be used by local development programs, the Kenya Wildlife Service, and local community conservation groups in the Amboseli region.

In the area around the Maasai Mara National Reserve, human population is growing by 7 percent a year—almost three times the national increase of 2.5 percent annually. Around the Reserve, cultivated land has increased 1,000 percent, from 1 to 10 percent of the area between 1977 and 1997. In his recent work, Wilber Ottichilo, formerly of the Kenyan Wildlife Service, reports that all non-migratory wildlife in and around the Reserve declined by 58 percent during the same period. Researchers in the Mara are priming the SAVANNA model with detailed information on the state of the ecosystem, including data on all large mammal populations, livestock, settlements, and tourism facilities. Local non-governmental organizations and communities are using the model as part of a long-term land-use-planning program focused on the Mara ecosystem.

In the Ngorongoro Conservation Area, where the number of rare black rhinoceros declined from more than 100 in the 1960s to 12 in 1995, researchers are setting up a

SAVANNA station. Pastoral development groups, the Ngorongoro Conservation Area Authority, and local and regional wildlife conservation organizations will use the model to look at the impacts of farming on the number and types of wildlife species that live in the ecosystem.

In the western United States, scientists are using SAVANNA to determine how many large mammals can subsist in conservation areas that are often small or fragmentary. In some cases, human activity has altered the natural dynamics of these areas to the extent that natural regulation of animal populations may no longer be viable. If left alone, for instance, populations of wild horses in Montana's Pryor Mountain Wild Horse Range would grow so large that they would degrade rangeland vegetation. SAVANNA has modeled the carrying capacity of the area and found that it can support between 150 and 200 wild horses. While this determination is more than the Bureau of Land Management estimates of 90 to125 horses, it is considerably lower than the number of horses that would be present if the herd size were to grow unchecked.

In Yellowstone National Park, SAVANNA is modeling the land's bison and elk carrying capacity—the number of animals that the Park can sustain. The model is assessing the impact on bison of changing land use, such as ranching or the plowing of snow-covered roads. Conservationists can use model findings to determine which critical habitats outside the Park boundaries to buy. Last year, conservationists purchased almost 3,237 hectares (8,000 acres) next to the northern edge of the Park. Park managers will be using model results to limit bison contact with cattle, and thus help prevent the spread of brucellosis, a disease that can be fatal to cattle.

In Colorado's Rocky Mountain National Park, the United States Environmental Protection Agency has funded a SAVANNA application to assess the impacts of potential climate change on wildlife, ecosystems, and economics. The program is just getting underway.

In both Africa and the United States, SAVANNA is tackling some of the most complex issues facing conservation.

HOW SAVANNA WORKS AND WHAT MAKES IT DIFFERENT

Unlike most models, which are confined to determining the effects of many variables on a single outcome, SAVANNA produces multiple outcomes. It also incorporates complex systems, such as wildlife and livestock, which no other models are able to do. SAVANNA tracks change in the environment, across space, and over time. SAVANNA's spatial dimension allows interactions among many different points. For instance, during a model run, rainfall in one area prompts the movement of cattle and wildlife in another area. Most models are only capable of taking a snapshot of many different points on a map, and ignore the interactions between different areas. In SAVANNA—as in life—all forms of movement interact to transform the ecosystem in ways both subtle and profound.

SAVANNA is comprehensive. It not only includes plants, soils, weather, and nutrient cycling but also wildlife and livestock. Furthermore, SAVANNA includes both human activity and human welfare, allowing it to create scenarios in which people initiate and respond to change in the environment.

SAVANNA looks at the interactions of all components of the natural world. Whereas most ecosystem models take either a biogeochemical approach or a population approach, SAVANNA incorporates both. Biogeochemical models are typically concerned with the balance of carbon, nitrogen, and water. They model nutrient recycling and simulate things like carbon flow. Most population models consider the number of organisms and project population fluctuations over time, without considering nutrient constraints or other biogeochemical factors.

SAVANNA represents different parts of the landscape independently, rather than averaging values for the landscape as a whole. For example, a typical model would fail to perceive the effects of large changes on a small patch of critical landscape, such as a water source. SAVANNA can tell whether that small patch of land dries up or expands.

SAVANNA accomplishes all this through the use of several interacting submodels. These include submodels to represent plant growth in terms of biomass production and population growth, soil water budgets, nutrient cycling, animal population dynamics, and human ecology, including diet and income.

Researchers must compile the information needed by the model, using field observations, remote sensing, and weather data. For any given environment, the model estimates the available nitrogen, water, light energy, and the numbers and size of plants and animals. In all, the model can use tens to hundreds of variables in each run.

SAVANNA portrays ecosystem processes using boxes and arrows. Boxes represent a state that can only be changed by the flow of materials or energy into or out of the box. The arrows represent these flows. In this approach, neither matter nor energy is created or destroyed. Mathematical equations represent the flow rates as they vary in response to the amounts of matter or energy stored in different states, or in response to inputs of matter or energy from outside the system. The latter are referred to as driving variables, and the foremost of these is weather.

Weather data is the model's most important input. It includes precipitation, temperature, humidity, and wind speed. The model calculates solar radiation from latitude, time, and cloud cover data. Data from numerous weather stations are used to create monthly maps of precipitation and temperature.

A second type of data comes from Geographic Information Systems, or GISs. These data include digital maps of vegetation, soils, elevation, and slope. Descriptive tables accompany the vegetation and soils maps. They describe vegetation in terms of tree cover and height, herbaceous root biomass, and plant species composition. Soil descriptions include water-holding capacity, soil depth, and nutrient content.

Water has a pervasive effect on ecosystem dynamics because it affects plant growth, particularly in dry environments. Thus, the model accounts for soil moisture based on precipitation, and water losses due to plant transpiration, runoff, and drainage.

The plant submodels represent increases and decreases in plant abundance. Sunlight, moisture, temperature, and plant nitrogen content affect photosynthesis, metabolism, and the conversion of atmospheric CO_2 and soil nutrients into plant biomass. The photosynthetic products are allocated to leaves, roots, and stems. Plants die in response to water stress, changes in day length, or low temperatures. In the soil, microorganisms decompose dead plants. Nitrogen released during decomposition is then available for living plants.

The herbivore foraging submodel represents how much forage livestock and wildlife consume. This is affected by the abundance and quality of edible plants. The animal energy balance submodel represents the rate of energy use by animals, relative to their rate of energy intake from forage. When intake exceeds expenditure, animals gain weight; when the opposite occurs, animals lose weight. The condition of the animal is measured in terms of its weight relative to the norm. The animal population models represent birth and death rates, which are affected in turn by animal condition.

The human submodel focuses on the economics of Maasai ranching. It examines the impacts of human activity on wildlife dispersal. The submodel represents rich, medium, and poor households. For each household, the model calculates the interactions of dietary energy flow, cash flow, household sales, cropping decisions, and livestock herding. Researchers continually test the rules used in the model and adapt them to actual human behavior. This submodel also takes into account the location of households, roads, water wells, and other elements of community infrastructure.

SAVANNA displays its results using different formats. In a temporal format, one can see the average number of animals or of plant biomass in different parts of the landscape. In a spatial-temporal format, the spatial distributions of animals and biomass can be viewed as sequential maps, moving backward or forward in time. In tandem with a Geographic Information System, SAVANNA provides highly refined mapped information.

Thus SAVANNA models chains of cause and effect by using complex data on factors that affect plant growth, animal forage intake rates, animal abundance, and human population and activities. Because it is so comprehensive, SAVANNA is a powerful tool for predicting the outcomes of land-use decisions in a crowded and complex world.

WILDLIFE CONSERVATION IN EAST AFRICA

In East Africa, Kenya’s population has tripled since 1960, and is now 29 million. The Tanzanian population tripled over the same period to 31 million. Some of the fastest-growing regions are adjacent to wildlife conservation areas, putting pressure on already stressed ecosystems. Farmers from overcrowded highland areas are moving into rangelands in search of land to grow crops. While many pastoral people would like to continue to herd cattle, they are restricted from important grazing areas. Crowded into smaller areas with inadequate resources, more cattle are falling ill and herds are diminishing. As pastoralists turn to farming, newly sedentary populations near wildlife areas remove land from wildlife use. At the same time, tourists crowd into the relatively few areas with developed infrastructure. If things continue on this course, by the middle of the 21st century, most East African conservation areas will be islands in a sea of humanity.

These threatened areas contain the greatest large mammal diversity in Africa. Chief among them is the cross-border region of Kenya and Tanzania, where the migratory movements of some two million wildebeest, gazelles, and zebras define the Greater Serengeti ecosystem. Lions, jackals, cheetahs, and hyenas shadow the spectacular mass migrations. Elephants and giraffes silhouette the skyline. To many wildlife biologists, this area represents the jewel of wildlife conservation on Earth.

Pastoral people are an important part of East Africa. Pastoralists have herded their cattle in harmony with wildlife for thousands of years. For centuries, the Maasai, the predominant herding people in the region, used livestock management techniques that complement the life cycles of savanna plants and animals. Although colonial administrations, and later national governments, set up protected areas with the goal of conserving wildlife, policies that excluded Maasai from these areas inadvertently created new problems. Forced to abandon vast sweeps of grassland, Maasai cattle herds declined and their poverty deepened. Unable to support themselves through livestock alone, Maasai increasingly turned to farming for survival. Now both Maasai and non-Maasai are converting grazing lands that once supported wildlife and livestock into farm fields.

Many of the newly converted farmlands are adjacent to national parks and reserves. Conflicts between people and wildlife are therefore a daily occurrence in East Africa. Wildlife migrates from parks to surrounding areas, where animals, people, and livestock compete for resources. Wildlife tramples and eats farmer’s crops, transmits diseases to cattle, kills livestock—and sometimes kills people.

Wildlife, too, suffers as growing sedentary communities draw on water, occupy former wildlife habitat, and consume other limited resources; as people sometimes protect their lives and property by killing wildlife; and as tourists crowd into wildlife areas.

Tourism is vital to East African economies, and conservation areas supply a major source of national revenue. In 1998, Tanzania had 326,000 visitors, earning the country US $375 million. By 1987, tourism had become Kenya’s primary source of foreign exchange, surpassing exports of tea and coffee. In 1997, 750,000 tourists visited the country, spending $502 million. But insufficiently regulated tourism strains natural ecosystems and wildlife.

The biggest challenge for wildlife biologists is to manage large mammals in the face of growing human populations, expanding settlements, and increased conversion of land to agriculture. The biggest challenge for many local people is simply meeting the daily food and healthcare needs of their families.

Governments and local groups are working to develop policies that address the needs of people and conserve wildlife. Some policies to discourage poaching rely on local people. Government policies that in the past restricted farming now permit it in some areas. Such changes recognize that most East Africans rely on subsistence farming. In other places, the form of land tenure is changing from land held collectively by group ranches made of several Maasai families to private holdings.

The SAVANNA ecosystem model is examining the impacts of these various policies. It is asking how to conserve ecosystem integrity, balance conservation with food security, and enhance human welfare. Researchers are using the model to look at different policy scenarios, considering questions such as: What if hunting is legalized in an area? What if an entire region becomes cultivated right up to the border of the park? What if group ranches become privatized and land becomes fragmented?

Following are three case studies demonstrating how researchers and their partners are applying SAVANNA to East African ecosystems.

- **Ngorongoro Conservation Area, Tanzania**

Ngorongoro's spectacular landscape encompasses highlands, forests, and grassy plains. Central to the Area is the Ngorongoro Crater, formed by the explosive collapse of an ancient volcano. The 250-square-kilometer (97-square-mile) crater is internationally renowned for its rich wildlife and spectacular scenery and supports one of the last populations of the endangered black rhinoceros in Tanzania. The Conservation Area's short grass plains are the wet-season grazing grounds for much of the Serengeti's migratory herds of wildebeest, gazelle, and zebra. The highlands provide important habitat for rhinoceros, elephant, and buffalo. Ngorongoro is located in the cradle of humankind. Two of the world's most famous archaeological and paleontological sites, Oldupai Gorge and the Laetoli Footprint Site, are in the Conservation Area.

Prior to 1960, Maasai people had free access to the Conservation Area and to the adjacent Serengeti plains. In 1960, they were evicted from the Serengeti, and, in 1974, they were evicted from the Ngorongoro Crater. By 1995, about 42,000 Maasai lived in the Conservation Area, where they continued to graze cattle in non-restricted areas and to farm. The Maasai population, growing at about 3 percent a year, remains largely impoverished, with most households earning less than $10 a month.

The status of wildlife in the Ngorongoro Conservation Area is mixed. The population of black rhinoceros, the most threatened large mammal there, declined from more than 100 in the 1960s to 12 in 1995 and is on the verge of extinction. In response, the Ngorongoro Conservation Area Authority imported two black rhinoceros from South Africa in 1998, with hopes that interbreeding would not only expand the population but also contribute to a more robust gene pool. The lion population also suffers from a lack of genetic diversity that may be harming the animals' health and fertility. Other animal species listed as threatened or endangered by the World Conservation Union include the wild dog, the African elephant, and the cheetah.

On the other hand, the wildebeest population, as well as that of other large herbivores, remains healthy. There are currently about 900,000 wildebeest in the Serengeti migratory herd, up from 240,000 in 1960. About one-third to one-half of these migrate into the Ngorongoro Conservation Area. The wildebeest increase followed the eradication of rinderpest, a disease fatal to wildebeest and cattle. The wildebeest population competes with other wildlife species and cattle for grazing land.

Perhaps the biggest change underway in the Ngorongoro ecosystem is the conversion of rangeland to farmland. In 1992, a ban on cultivation was temporarily lifted. As a result, within three years, 85 percent of Maasai were cultivating small plots of land. Their modest harvests of maize, beans, and potatoes meant fewer households were forced to sell their cattle to survive. The number of reproductive animals sold dropped from 47 percent to 1 percent. People were adopting cultivation as a means of maintaining their cattle and pastoral way of life.

However, Maasai were not the only ones to take advantage of the change in policy. In addition to small-scale farming by Maasai, government and Conservation Area employees, schoolteachers, hospital workers, shopkeepers, and other non-indigenous residents working in the Area also farm. Their farms are larger, averaging about 1.6 hectares (4 acres), and tend to grow crops for sale rather than subsistence. In addition, outsiders are settling in the region exclusively to farm. Their large-scale agriculture is putting more and more land under cultivation.

In 1997, the ban on farming was lifted completely. Now, wildlife managers are struggling to understand how this change will affect conservation.

The SAVANNA model is looking at the impacts of increased farming on the number and types of wildlife species that live in this system. The information from SAVANNA will be used by the Ngorongoro Conservation Area Authority, pastoral development groups, and local and regional wildlife conservation groups.

SAVANNA has already been used to model a number of scenarios regarding people, livestock, and wildlife in the Conservation Area. It has predicted the outcomes of various possible developments, such as:

- more land under cultivation;
- more droughts;
- more livestock;
- more water resources directed to tourist lodges; and
- more people.

Researchers have used SAVANNA to model 14 alternative scenarios for how life might unfold in Ngorongoro. One model run programmed Ngorongoro's Maasai population to grow at its present rate of 3 percent for 15 years, expanding from 4,500 households to 6,800 households of 10 people each. With each new household, an additional small plot of land was converted to farming, removing it from wildlife use. Surprisingly, the net effect on wildlife turned out to be minimal, because in the end only a small fraction of Ngorongoro's total land area came under cultivation.

Researchers are now establishing a SAVANNA modeling center in the nearby town of Arusha, so that stakeholders in the pastoral and wildlife conservation communities can have full access to the model itself and to its products.

- **Amboseli National Park, Kenya**

Amboseli, set at the northern foot of Mt. Kilimanjaro, is Kenya's second most popular tourist attraction. Amboseli was made a reserve in 1948, and in 1974, the central 488 square kilometers (188 square miles) were designated as the Amboseli National Park. Local Maasai and Park management have worked together to resolve ongoing issues of joint resource use, conservation impacts on wildlife and Maasai, and compensation to Maasai for their forfeiture of Park grazing and water.

In the 1980s, Maasai group ranches began to initiate wildlife and tourism projects. At the same time, Maasai were rapidly changing from subsistence pastoralism to an economy of farming, salaried employment, and commercial livestock ranching. Changing land use is currently transforming the entire economy of Amboseli from a mixed wildlife-livestock system to a primarily agriculture-based system.

The proximity of wildlife, farm fields, and ranching is a cause of constant conflict. In 1998, one group ranch reported the deaths of 200 goats, 50 sheep, and 40 cows killed by lions, hyenas, elephants, and cheetahs. Group ranches around Amboseli are being rapidly subdivided into privately owned plots. This fragments not only the land, but also the process of making decisions about land use.

Biodiversity loss, including the loss of plant species, is a major concern in Amboseli. David Western, chair of the African Conservation Center and former director of the Kenyan Wildlife Service, reports that in some parts of Amboseli one-half of the former plant species have been lost. For 32 years, Western has maintained a database on Amboseli's mammals, plants, habitats, and land use.

Western and his colleagues with the African Conservation Center are working with researchers at the ILRI to model future land-use scenarios in Amboseli.

SAVANNA will investigate another crucial and unique aspect of Amboseli: critical swamps outside the Park that wildlife and livestock use for dry-season grazing and watering. Some swamps are accessible mostly to wildlife in the protected areas, while others are being converted to agriculture to meet the demand of urban consumers in Nairobi. The SAVANNA model will be used to look at different options for management of these swamps so that pastoralism, agriculture, and wildlife can continue to co-exist in peace.

ILRI scientists and economists at the University of Nairobi are working together to discover new ways for local people to benefit economically from sustaining wildlife, such as through ecotourism projects. Such projects provide incentive for pastoralists and farmers to conserve wildlife. Local development programs, the Kenya Wildlife Service, and local community conservation groups will be using SAVANNA in the Amboseli region.

- **Maasai Mara National Reserve, Kenya**

At the northern end of the Greater Serengeti Ecosystem, the 1,700-square-kilometer (656-square-mile) Maasai Mara is the most popular wildlife viewing area in East Africa. It draws one-third of all tourists visiting Kenya and generates 8 percent of that nation’s tourism revenue.

In addition to tourists, Maasai Mara has attracted a growing local population. Scientists estimate that between 1959 and 1999, human population around Maasai Mara has increased 7 percent a year, whereas the national population is increasing an average of 2.5 percent a year.

The amount of land under cultivation has also grown, increasing 1,000 percent, to cover from 1 to 10 percent of the surrounding area between 1977 and 1997.

All this development has taken a clear toll on wildlife. In his recent work, Wilber Ottichilo, formerly of the Kenyan Wildlife Service, reports that all non-migratory wildlife species except for elephant, impala, and ostrich declined by 58 percent between 1977 and 1997. Buffalo, giraffe, eland, topi, and waterbuck each declined by more than 70 percent. The smallest decline was in Grant’s gazelle, which still fell by 52 percent. The wildlife declines are probably the result of several factors, including periodic droughts, land-use changes, increased competition for resources, and poaching. Livestock populations of cattle, sheep, and goats have remained stable, although the number of donkeys declined by 67 percent.

In recent years, the National Reserve has suffered from a deterioration of infrastructure and lack of wildlife protection. Two dozen lodges and permanent tented camps are clustered in just two parts of Maasai Mara. Their intensive use causes waste disposal problems and shortages of firewood for cooking. Poor road upkeep contributes to overuse of parts of the Reserve closest to the lodges.

Human population has grown most rapidly in the crucial dispersal areas for wildlife around the Reserve. In November 1999, scientists at ILRI and several partner institutions conducted a first-ever, fine resolution assessment of the state of this system by compiling data on all the large mammals, livestock, settlements, and tourism facilities in the system.

This information is now being incorporated in the SAVANNA model and is being used by local non-governmental organizations and communities in a long-term land-use planning program in the Mara ecosystem. The program will set land-use policy for the Mara system so that people, livestock, and wildlife can continue to co-exist in the face of tremendous pressures to convert this rich ecosystem into farmland.

WILDLIFE CONSERVATION AREAS IN THE WESTERN UNITED STATES

In January 2000, President Clinton set aside 2.7 million acres of federal land in the western United States as national monuments. The act included the addition of 8,000 acres to the California Pinnacles National Monument—while just up the road developers initiated a 1,500-home subdivision. As more than 1.25 billion visitors a year flock to federally protected lands, conservation of land and wildlife has become a balancing act between competing interests. In Yellowstone National Park, some decry and others applaud the reintroduction of the gray wolf. Is the wolf undermining elk herds or is it helping to maintain a healthy balance in the ecosystem? Does it pose an unreasonable threat to ranchers' cattle? A court in Wyoming says yes, a court in Idaho says no. Was last year's executive order that halted new road building on 40 million acres of National Forest land more of a blessing to wildlife or a curse to loggers?

Protected lands everywhere face a host of complicated choices and challenges. The SAVANNA ecosystem model is helping to sort them out. Following are three case studies demonstrating how researchers are applying SAVANNA to wildlife conservation areas in the western United States.

· Yellowstone National Park, Wyoming

Wyoming's 8,806-square-kilometer (3,400-square-mile) Yellowstone National Park is known as much for its bison as for its 200 natural geysers. Approximately 10 million visitors a year visit the Park, admiring its geological and biological diversity.

Behind the scenes, however, wildlife managers are struggling to balance the needs of Park wildlife and nearby ranchers. Managers are currently re-evaluating their plan for managing the Park's bison population, which has grown from fewer than 600 to more than 4,000 in the last 20 years. Every winter, large numbers of bison stray outside Park boundaries. Ranchers on the Park's outskirts fear that bison will infect their cattle with brucellosis, a disease that causes miscarriages, infertility, and sometimes death in cattle. As a result, the Park has directed its personnel to shoot animals that stray outside Yellowstone's borders.

Part of the problem resides with the Park's boundaries, which were originally drawn more for political than ecological reasons, leaving a portion of the winter range of elk and bison outside the Park. Much of this critical land is privately owned. SAVANNA is helping to determine what areas of habitat outside the Park are most essential to wildlife, and this can inform strategies to return private land to the public domain. Last year, the Rocky Mountain Elk Foundation, the Department of the Interior, and the United States Forest Service bought nearly 3,250 hectares (8,000 acres) of private land on the northern edge of Yellowstone.

Furthermore, Park managers need an accurate understanding of the ecosystem's bison carrying capacity (the number of healthy bison that can be sustained on Park resources), to redesign their management strategy. Carrying capacity depends on factors such as food availability, bison movements, climate, and snow cover. For instance, plowing snow-covered Park roads may increase the amount of forage available to bison, which will raise the system's carrying capacity. Snow plowing can also increase bison migration out of the Park.

Using the SAVANNA model, researchers are reassessing the Park's carrying capacity and predicting the influence of human activities, such as snowplowing, on bison population dynamics and movements. The SAVANNA model will simulate plant growth, snow depth, wildlife foraging, and bison population fluctuations and distribution in Yellowstone to improve the Park's wildlife management.

- **Rocky Mountain National Park, Colorado**

Rocky Mountain National Park straddles the continental divide in north central Colorado. The Park's main gateway is on the eastern side, in the town of Estes Park, where suburban subdivisions and golf courses grow apace. Five years ago, the Park's elk management program came under review, along with the realization that even as development encroaches on the Park, the elk population may be growing beyond sustainable limits. SAVANNA was employed to reassess the Park's carrying capacity and elk management strategies. Its report is due later this year.

The elk population in the Park has nearly doubled in the past 30 years, from about 500 to 950 today. Furthermore, there is now a population of elk that lives in and around the town of Estes Park. It has grown from zero to more than 2,000 animals.

The elimination of large predators and the disruption of historic elk migrations by town developments may have caused an over-concentration of elk within the Park's eastern borders. More pavement and houses outside the Park have also curtailed hunting opportunities. The elk population today is therefore higher than 30 years ago, when elk were not only hunted intensively outside the Park but also culled inside. Since 1968, Park policy has prohibited culling, allowing the population to grow to its "natural" limits. But those limits may be more than the vegetation, soil, and streams can support.

Scientists are using the SAVANNA model to determine how many elk are appropriate, and to predict how the ecosystem will change given different sized elk populations. The National Park Service is currently considering alternative management scenarios for elk that would be consistent with management objectives of preserving wilderness.

However, wilderness is itself difficult to define. To approach such a definition, the model is simulating conditions prior to the arrival of Europeans. This task is complicated by the fact that elk were extirpated from the region for decades, during which time vegetation could have changed to a different state. Therefore, to understand the area's "natural" state, the impact of the absence of elk must be accounted for, as well.

Once modeled, these historic conditions could serve as a reference point for evaluating departures from the pristine past, and to disentangle the effects of humans from the effects of climate and intrinsic ecosystem dynamics.

In addition, researchers are using the model to examine the potential impact of climate change on ecosystems, economics, and human land use. The project, funded last year by the United States Environmental Protection Agency, will simulate different climate scenarios that may occur as a result of global warming over the next century. The model will look at the effects of climate change on elk, plants, water systems, as well as the economic impacts on stakeholder communities, particularly in Estes Park.

- **Pryor Mountain Wild Horse Range, Montana**

The Pryor Mountain Wild Horse Range in southern Montana was the first of its kind in the United States. Three herds of wild horses roam across semidesert, shrublands, grasslands, woodlands, and coniferous forests. The approximately 175 horses that make up the herd are descendants of a unique genetic strain of Andalusian mustangs introduced by the Spanish as early as the 16^{th} century.

The United States Bureau of Land Management is charged with maintaining the horse herd at a size that is compatible with the area's natural resources, including its plants, soil, and water resources as well as resident herds of big-horn sheep and mule deer. Furthermore, the horses' home range is a multi-use recreation area that allows hunting and off-road vehicles. Cattle graze in areas adjacent to the horse range.

Since 1970, to prevent range degradation and accommodate other land uses, the Bureau of Land Management has periodically culled the wild horse herd. Many have questioned this practice and the scientific assumptions about the area's carrying capacity that underlie it.

SAVANNA provides a solid foundation upon which to base such management decisions. The traditional approach to evaluating carrying capacity is based on estimates of the land's forage supply and the animals' forage requirements. In contrast, SAVANNA simulates rainfall, plant growth, and forage production over time and over the landscape. From this simulation, the model estimates the amount of forage available to herds of different sizes, the fitness of individual animals, and overall birth and death rates. This thorough approach provides clear answers to the complex questions of resource management in a dynamic and varied landscape.

Scientists at Colorado State University have run the SAVANNA model with various horse densities and weather scenarios. In many scenarios, herds increased to more than 300 and even 400 horses if the animals were not culled. At these population levels, the range was degraded, leaving some areas barren of grass. Herbaceous biomass above and below ground was reduced to less than 20 percent of potential in many areas. Other wildlife suffered, and soil eroded. The horses themselves were in poorer condition, and annual horse mortality was high.

Thus, according to SAVANNA's modeling, the horse population must be managed below its natural limits to meet range management and animal welfare objectives. While the Bureau of Land Management has estimated the Range's carrying capacity to be between 90 and 125 horses, SAVANNA shows it to be between 150 and 200 animals. This number would minimize vegetation loss, while ensuring viability of the horse herd.

The combination of field research and ecosystem modeling that researchers have carried out in the Pryor Mountain Wild Horse Range serves as an example of how SAVANNA can improve the management and conservation of wild horses on United States rangelands and in other regions of the world.

GETTING AND USING THE SAVANNA ECOSYSTEM MODEL

The SAVANNA ecological model addresses the needs of both wildlife and people. It is inclusive by design, relying upon and inviting the participation of stakeholders, from pastoralists to national decisionmakers. ILRI is hosting hands-on SAVANNA training programs for partners in relevant non-governmental organizations, development officers, and researchers in Kenya, Uganda, and Tanzania. The training uses existing model applications in Ngorongoro and Amboseli to demonstrate the range of policy and management scenarios that SAVANNA can tackle.

ILRI and Colorado State University are establishing a SAVANNA Center near the Ngorongoro Conservation Area, and plans are underway for similar centers in other wildlife areas where ILRI researchers will work with community and national policy makers to better manage complicated social and ecological systems.

If your organization is interested in using the SAVANNA model, contact Michael Coughenour at Colorado State University or Robin Reid at the International Livestock Research Institute:

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In Africa, several regional and local nongovernmental organizations, national research institutes, and private enterprises contribute financial and human resources to this project. In Kenya, community organizations include Narok County Council, Lemek and Koyiaki Group Ranches, and the Koyiaki/Lemek Wildlife Trust in the Maasai Mara, and the Oguliului, Mbirikani and Selengai Group Ranches in Amboseli; NGOs include African Conservation Centre (ACC), African Wildlife Foundation (AWF), World Wide Fund for Nature (WWF), the Olelepo Landowners Conservation Company Ltd., and Campfire Conservation Limited; national research institutes include the Department of Resource Surveys and Remote Sensing (DRSRS), Kenya Agricultural Research Institute (KARI), University of Nairobi, and the Kenya Wildlife Service (KWS); and private enterprises include Bush Homes of East Africa, Rekero, Kerr, and Downey, and Explore Mara Ltd. In Tanzania, important contributions were made by the Tanzanian National Parks (TANAPA), the Ministry of Agriculture, the Tanzanian Wildlife Research Institute (TAWIRI), the Ngorongoro Conservation Area Authority, AIGWANAK Trust, and the University of Dar es Salaam. Ugandan contributors included the Ugandan Wildlife Authority (UWA) and Makerere University.

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