

Reintroducing a large herbivore: a remote sensing and agent-based modeling technique to determine the mountain bongo's (Tragelaphus eurycerus isaaci) past and present critical habitat

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Executive Summary

An initiative is underway to reintroduce captive-bred mountain bongo antelope (*Tragelaphus eurycerus isaaci*) to their native habitat on the Mount Kenya World Heritage Site. The bongo, a charismatic and endangered sub-species that serves as a flagship for the rich and threatened Afromontane forests, is now extinct on Mount Kenya. A small population of these animals remains on the nearby Aberdares Mountains. Reintroducing the bongo to Mount Kenya will be an important contribution to conserving this endangered sub-species, and will also enhance conservation for the globally important Mount Kenya and Aberdares ecosystems.

The mountain bongo is poorly understood, and few detailed data exist on this animal or its habitat. In order to successfully reintroduce this animal, it will be crucial to understand its ecological requirements and locate where its critical habitat is found on Mount Kenya. It will also be important to understand how this habitat may have changed over time. A remote sensing-based approach will be employed to map the spatio-temporal distribution of the crucial habitat variables, which will be determined through a field data collection campaign in the Aberdares. Habitat variables will be recorded in areas where bongo activity is found and in randomly sampled plots. Multivariate statistical analysis will be used to determine the most important variables influencing the bongo's distribution. The current and historical distribution of these variables will be determined using remotely-sensed data. In order to strengthen the subsequent modeling exercise, habitat selection data will also be recorded and analyzed for several more common, related herbivores. A Kenyan graduate student will play an important role in collecting and analyzing this data.

Critical habitat variables may not be usable by animals if they do not have a certain spatial configuration. A modeling approach will be used in order to understand how the variables important to the bongo (and other studied herbivores) are configured. Since it is unclear how much information is required to understand this problem, three models of increasing complexity will be developed and assessed: 1) a binomial generalized linear model; 2) a simple agent-based model; 3) a stochastic, demographic agent-based model. These models will be developed and tested for the Aberdares landscape, using half of the field data. The other half of the data will be employed as the independent validation dataset. The most successful modeling technique will be applied to the Mount Kenya ecosystem.

This research has larger significance to the field of conservation and ecology, in that it will:

- Improve understanding of the role of spatial configuration and complexity in habitat selection;
- Highlight the amount of ecological detail required to understand megaherbivory in a forest environment;
- Identify the most useful remote sensing and modeling techniques for solving this conservation biology problem;
- Enhance understanding of the effects of changing habitats configurations on organisms;
- Result in a technique that can be applied to reintroduction and management programs for other species and ecosystems;
- Attract further research and conservation attention to these two important ecosystems.

Introduction

Human population growth and related habitat transformation threaten to deplete biological capital and disrupt ecological processes [1]. An estimated 30,000 species are extinguished annually by tropical deforestation [1], and populations of many extant species have so declined [2] that nearly 3000 vertebrate taxa face extinction, and may only be saved through conservation breeding [3]. Captive breeding, reintroduction, and translocation programs are thus becoming increasingly important conservation tools [3,4], although there are two important obstacles to re-establishing species: 1) understanding the fundamental ecological requirements and life histories of species of concern [5]; 2) identifying appropriate areas for reintroduction or restoration, recognizing that degradation or modification can render native habitats unsuitable [6,7]. Evolving reintroduction methodologies therefore demand greater scientific input.

Conservation biology techniques, such as Population Habitat and Viability Assessment (PHVA) [8], usually require detailed life history and habitat information. Unfortunately, such data do not exist for most species, particularly endangered taxa [5], and the cost of collecting it by conventional methods can be prohibitive. Remote sensing techniques are a relatively inexpensive, efficient alternative for habitat classification and quantification [9], particularly over large areas of difficult access. Modeling is a tool that affords insight into rare species' ecological interactions that would be difficult or impossible to obtain from field observations, especially where habitats have been altered [10]. The modeling approach is exceptionally effective for determining how a collection of suitable habitat patches must be spatio-temporally configured to create a sustainable environment for an organism. Modeling is also useful for determining the most essential factors controlling an ecosystem [11], and thus the amount of information that must be collected to understand the system. Together, remote sensing and modeling allow ecological issues to be examined over large areas and over long times, and thus may be crucial to the long-term success of reintroduction programs.

An initiative is underway to reintroduce captive-bred mountain bongo antelope (*Tragelaphus eurycerus isaaci*) to their native montane forests of Kenya—specifically the Mount Kenya World Heritage Site [12]. Endemic to Kenya, the mountain bongo is an endangered subspecies [13] with a wild population of less than 100 individuals [12] now confined to the nearby Aberdares mountains. Biologically rich montane forests cover only three percent of Kenya, and are threatened by the country's densest and fastest growing human populations (up to 800 people/km²) and most intensive agriculture [14,15]. A rapid intensification of land use in the Mount Kenya-Aberdares area over the last 50 years has resulted in increased encroachment and resource extraction in the protected mountain forest reserves [15-17]. Shifts in vegetation communities consistent with a warming climate have also occurred [7]. These factors indicate that the bongo's habitat has changed during this time period. Bongo have concurrently declined throughout their range [18], and the last Mount Kenya bongo was seen in 1994 [12]. Detailed habitat information for Mount Kenya and the Aberdares is largely lacking; thus, the only way to compare these sites' past and present environments is with remotely-sensed data.

The charisma and endangered status of the mountain bongo make it an ideal "flagship species" [12], capable of attracting public concern and support for research and conservation efforts [19]. Furthermore, the bongo's large range and dependence on a diverse habitat mosaic [13,20] may qualify it as an "umbrella species," whose habitat needs encompass (and, if conserved, would protect) those of the entire community [19]. Successfully reintroducing the bongo can greatly enhance biodiversity conservation efforts for the Mount Kenya World Heritage Site *en toto*. Determining a wide-ranging species' habitat distribution, and how this might have shifted, can also provide valuable insight into the wider impacts of ecosystem change.

The reintroduction program aims to reestablish a viable free-ranging population on Mount Kenya by sustainably releasing the habituated descendants of an *in situ* managed breeding herd. However, reintroduction strategies hinge upon reliable ecological information. The few existing studies on the bongo [e.g. 21,22,23] pertain to the lowland subspecies (*Tragelaphus eurycerus eurycerus*), which occupies different rainforest habitats in Central and West Africa. My role in this project, in conjunction with the Kenya Wildlife Service (KWS) and the Rare Species Conservatory Foundation (RSCF), is to investigate the ecological requirements for re-establishing a free-ranging bongo population. The success of this endeavor depends on answering the key questions:

- Where and what is the preferred habitat of bongo, and how is it configured?
- Has this habitat changed over time?

I will use remote sensing and modeling techniques to address these ecological issues in a data-poor environment, which will enable me to answer several further questions:

- Can the habitat variables controlling the distribution of a large herbivore in a densely forested landscape be successfully quantified using remotely-sensed data?
- How much detail is required to successfully simulate the studied system? (I.e. what are the essential ecological factors?)
- What is the most effective modeling technique to apply to this situation?

I therefore propose to use a range of spatially-explicit models of varying complexity—from a simple generalized linear model to a demographic agent-based model (ABM)—to determine the bongo's past and present critical habitat within the study area, which will be represented by a landscape composed of key environmental variables quantified with remotely-sensed data. I will strengthen this approach by also applying it to several related and more abundant herbivores.

This research will be essential to determining the feasibility of reestablishing a wild Mount Kenya population, and will provide insight into the drivers of the bongo's decline. It will also provide management recommendations for the forest ecosystems, and will pave the way for broader research into ecological change on the Mount Kenya and Aberdares ecosystems.

Background Information

The project will be undertaken on Mount Kenya and the Aberdares, which are both equatorial mountains separated by approximately 30 kilometers of plains. The two montane ecosystems are biologically diverse [24], with a range of habitats including closed-canopy Afromontane forest, moorland, rock, snow, and ice [14,25,26]. These moisture-trapping massifs are humid islands in a generally arid country, and thus provide a crucial service as water catchments [15,25,26]. This climatic feature, combined with rich volcanic soils, make these areas well suited for agriculture, with the result that heavy settlement and transformation around the mountain perimeters has occurred [14,15]. The forests' extent has dwindled steadily due to illegal incursions and official forest reserve excisions made by both the colonial and post-independence governments [14]. As populations continue to grow, the threat will undoubtedly increase.

The threat to these habitats has long been recognized, and a variety of conservation actions have been taken. Mount Kenya is a designated World Heritage Site whose upper reaches enjoy National Park status, while the lower encircling forests have recently been proclaimed National Forest land. Forest custody now falls under the Kenya Wildlife Service, which has made impressive strides in curbing the rampant illegal logging, cultivation, and settlement that took place in the forests towards the end of the 20th century [16,27].

The protected status of the Aberdares mountains is similar to that of Mount Kenya: the upper mountains fall within a National Park, while the Afromontane forest zone is protected to a lesser extent. A fencing project that encloses the National Park and parts of the forest land has been undertaken as recommended by Butynski [28]. In order to prevent unnatural predation on the bongo and other large herbivores, a culling program was enacted to eradicate a large population of introduced lions, which is believed to have eliminated all but a few remaining individuals [29].

Specific bongo conservation efforts have recently been set in motion. In the Aberdares, a newly completed survey has yielded an estimate of up to 60 remaining animals, divided between 5 separate breeding herds, as well as an unknown number of adult males [30]. In January of this year, 18 bongo were repatriated from captive-bred North American populations to the Mount Kenya area, as the first phase of a long-term project to reestablish a free-ranging population on the Mountain [31]. The research proposed here will form part of the second phase of the reintroduction effort [32].

A large amount of research has been conducted on Mount Kenya and, to a lesser extent, the Aberdares. The vegetation of both mountain areas has been classified by various authors. The phytosociology of Mount Kenya's forests was described by Bussmann [25], while Young made in-depth studies of the Afroalpine zone [e.g. 33,34]. Schmitt [26] classified both the moorlands and forests of the Aberdares National Park. The Kenya Indigenous Forest

Conservation program commissioned several unpublished reports detailing the composition and structure of Mount Kenya and Aberdares forest reserves. The same project also resulted in a mammal survey of Mount Kenya. Mount Kenya's position astride the equator has also made it of interest to researchers studying the effects of climate change (e.g. Shugart et al. [7]).

Little work has been done on the mountain bongo themselves. While the lowland bongo (*Tragelaphus eurycerus eurycerus*) of Central and West Africa has been studied enough to understand its diet selection, habitat associations, and group composition [21-23,35-38], almost nothing is known about the mountain bongo of East Africa. Kingdon's [20] chapter on the subspecies, which draws heavily on the published observations of earlier hunters and explorers [e.g. 39,40,41], field records from the Aberdares, and his own findings, offers the most comprehensive reference. Beyond this work no detailed ecological studies of the mountain bongo have been published. In fact, few comprehensive studies of forest-dwelling African herbivores exist, particularly of those which reside in Afromontane habitats. Plumptre [42,43] has looked at niche overlap and browse selection in large herbivores in the Virunga mountains, while Hart [44] has studied the range and feeding behavior of the okapi. The proposed project, therefore, will help fill an important knowledge gap that has ramifications for a broader community of forest-dwelling large mammals.

The causes for the mountain bongo's decline are uncertain, and speculation has touched on a number of possibilities. The most widely held view attributes the decline to illegal hunting with dogs, which is an easy way to kill bongo since their inclination is to stand and face their pursuers [13,20,45,46]. This form of hunting, together with habitat alteration, was cited as one of the main causes for the bongo's decline in the Cherangani Hills in the 1950s [41]. Predation by lions introduced into the Aberdares has also been blamed [18,29,47] as an important contributor to the bongo's decline, although this explanation cannot account for the Mount Kenya extirpation. Another suggestion is that episodic toxicity in a favored bongo browse plant, the climber *Mimulopsis solmsii*, is responsible [20,40], but the presumably long coexistence of the two species raises doubts about the significance of this factor. A more likely culprit is rinderpest [47], which struck herbivore populations, particularly eland and buffalo, in this part of Kenya in the 1980s and 90s [48]. However, it is more probable that a combination of several factors has caused the bongo's decline. The dramatic human population increase in Kenya's fertile mountain regions is the root cause of increased habitat destruction, hunting, and other threats to the bongo's survival. Increased contact with domestic stock would also increase the risk of. Bongo populations are probably less likely to rebound following disease events than are other herbivores, due to their susceptibility to hound-assisted hunting and their dependence on a diminishing Afromontane forest environment.

Methods

Collection of parameters

In my initial research I will determine the habitat selection, demographic, and physiological data that are important in controlling the distribution of bongo and sympatric related herbivores. I will draw on published literature [e.g. 23,49,50,51] and the knowledge of zoological parks and wildlife experts, including parks staff, hunters, and researchers. The primary means for obtaining these parameters will be field collection, as few data on Afromontane herbivores exist.

Since the recent Aberdares survey work has uncovered a small surviving bongo population [52], data collection efforts will be focused in these mountains. I will use a combination of random and focused surveys to collect distributional and habitat selection data for all the studied species. Employing expert trackers, I will search for track, dung, and feeding signs of bongo in known localities. Important microhabitat factors related to vegetation structure will be assessed using a modified habitat "complexity score", based on cover estimates of each canopy layer and litter abundance [53]. I will record the dominant species in each canopy layer, noting any showing signs of feeding, as well as micro-topographical variables and basal diameters of woody plants. These data will also be collected where the other studied herbivores are found. In addition, I will gather evidence of human activity, as this has an important influence on bongo habitat selection [20,45]. To form a picture of avoided habitat, I will also site random plots, stratified according to defined vegetation types [25,54]. I will sample these as encountered while on focused surveys, and will undertake separate expeditions to collect data from more distant plots.

The plot data will serve as ground-truth for the subsequent remote sensing assessment. Fieldwork will take place during the rainy and dry seasons to capture any altitudinal migration of the herbivores [20]. I will use multivariate

statistical techniques to determine the crucial habitat variables, including discriminant function analysis, principal components analysis, and generalized linear models (GLIM).

Pending the initial results of field data collection, I intend to set up a network of 15 to 20 camera traps to collect supplementary habitat-use information, provided that the conditions of serviceability, safety from theft, and likelihood of sufficient data collection are met. Traps will be replicated within each main habitat type (e.g. forest glade/mineral lick, secondary forest, mature forest, bamboo zone) in proportion to its abundance [55] in a larger area that surveys identify as the likely home range of a breeding herd. The total extent of this area may be definable by natural boundaries as also indicated by the concentration and diffusion of bongo sign, and is expected to be 5000-10,000 hectares or less. Although Kingdon [20] estimates that range size may be between 12,000-30,000 hectares, this figure encompasses both dry and wet season habitat. The current census suggests that bongo range size may be even smaller, as they are now found in remote areas not frequented by humans [52].

Within each sampled habitat type, sites will be placed where there is prior evidence of bongo activity, and where repeat observations are more likely (i.e. on or near a trail) [56,57]. Camera traps will be placed close enough together ($\leq \sim 2$ km)—terrain permitting—to maximize the chances that all home range residents are recorded [56,57]. The primary measure of interest will be the rate at which bongo (and other herbivores) are photographed per habitat type, which will provide information about habitat selection [55]. This survey technique will also yield data on activity patterns and demographic structure. Since the bongo are likely to shift their range seasonally, camera trapping will be repeated in both wet and dry seasons, with locations determined by the first surveys to find bongo sign in each season. The ruggedness of the terrain and remoteness of bongo populations [52] will dictate that cameras requiring less frequent servicing be used in this study.

In order to maximize data collection and provide in-country academic opportunity, I will recruit a Kenyan MS level student to undertake data collection. After a period of calibration, this student will lead a second survey team in the Aberdares. Mount Kenya will not be field surveyed.

Remote sensing

Habitat mapping has been an important focus of ecology [58], as patch size and location heavily influence a species' ability to occupy a given environment [59,60]. The bongo is believed to require a complex mosaic of mature forest, secondary forest, and grassland [20]; therefore, understanding the spatial configuration of habitat resources is requisite to determining available range. Remotely-sensed data are increasingly applied to studies of habitat structure and suitability [9,58,61,62], and are indispensable in data-poor and inaccessible environments. I intend to use satellite and aerial imagery to map the current and historical distribution of important habitat variables for the bongo and related antelopes.

Literature suggests that vegetation structure and composition and topographical features such as slope are important in controlling antelope habitat selection [45,49-51]. Soil nutrient distribution also appears to be a significant factor for forest herbivores [21,22,63], as does temporal variation in forage quality, evidenced by seasonal shifts in bongo distribution [20]. I will use available Landsat, MODIS, ASTER, and digital terrain data to quantify these and other important variables within the Aberdares and Mount Kenya.

I will classify forest communities using the phytosociologies of Bussmann [25] and Schmitt [54]. Initial results from maximum likelihood classifications of Mount Kenya's forests have resulted in a 70% overall classification accuracy. I will improve results with the Sun-Canopy-Sensor correction for topographical effects [64], which has been found to substantially improve classification accuracy [65]. If results are still unsatisfactory, newly developed alternative classification methodologies may be used [e.g. 66,67,68]. The Aberdares will be classified using Schmitt's [54] phytosociological groupings and sample points. The resulting vegetation community maps will form the "matrix" within which other habitat variables are defined. I will undertake these classifications with available Landsat 5 imagery taken contemporaneously with the forest classifications (1985 for the Aberdares, 1994 for Mount Kenya). The results will be compared with recent images (as well as a 1985 image in the case of Mount Kenya) to determine the extent of change to forest communities.

The most important ecological factors for the herbivores are likely to be found within vegetation structure. For instance, the link between browse availability and leaf height is surely a prime reason for the bongo's dependence on

secondary forest [20,21,23]. Forest glades are important for grazing and mineral supplementation [20,21,35], and may well serve as home range anchor points [21]. Fieldwork will determine the importance of these and other structural features. Forest structure will be determined using linear spectral mixture modeling, which assumes that the contribution of a feature to a pixel's reflectance is proportional to its abundance [e.g. 69,70,71]. In this study, four constituents, or endmembers, will be important: green vegetation, non-photosynthetic vegetation (NPV), shade, and soil. I will obtain endmember spectra from available libraries, and may treat these in two ways: 1) averaging all available spectra per endmember; 2) using a look-up table to select the best spectrum of several per endmember [e.g. 71,72]. The proportion of each constituent will help to explain structural differences in the forests. For instance, a high proportion of shade should indicate tall primary forest, while low shade and high green vegetation speaks of low, dense secondary growth. A similar combination with higher soil values will relate to forest clearings, which I will further define using high-pass filters for edge detection between glades and surrounding forest. I will use ASTER data recorded during the field research to quantify forest structural feature, and repeat the method using earlier images contemporaneous with Landsat imagery. The features detected within ASTER will be correlated to the Landsat imagery, which I will then use to determine habitat structural changes over the past 20 years.

To track seasonal variation in forage quality, I will use satellite-derived vegetation indices, such as the normalized difference water index (NDWI), and the normalized difference vegetation index (NDVI) [73], which respectively provide a measure of leaf water content (LWC) and greenness. As LWC, greenness, and leaf nutrient levels are positively correlated [74,75], rainfall-related fluctuations in these variables will provide information on seasonal browse quality distribution. I will investigate this issue using a time series of MODIS 16-day composite reflectance data and available Tropical Rainfall Measuring Mission (TRMM) 3B43 monthly rainfall and ground station data. Having determined the most useful index for detecting precipitation-linked browse quality shifts within the forest, I will map the seasonal extrema of the best measure to show the likely yearly variance in antelope range.

The derived habitat maps for the Aberdares will be verified with the field collected data. I will use high resolution multispectral satellite (e.g. Spot Image) and airborne digital images as supplementary groundtruth for the Aberdares, and the sole source of groundtruth for Mount Kenya. These data will reveal visible structural features such as forest clearings, while the multispectral images will be used to correlate spectral features to the coarser resolution of ASTER imagery.

Models

Large mobile animals generally depend on an array of different landscape-level resources. In the case of the bongo, a seasonally shifting mosaic of various habitat patches is required [20]. The fieldwork and remote sensing components of this study will seek to determine and locate the important habitat variables. The remaining question will be: must the required habitat patches be specifically arranged to provide a suitable overall habitat? The answer is almost certainly yes, given that behavioral, physiological, or exogenous physical constraints influence habitat selection. For instance, a probable habitat patch might be unusable if it is too far from other required resources. Modeling is an efficient method for addressing this question of configuration, but it raises another question: how much additional information is necessary to determine habitat arrangement?

In order to address the issues of configuration and data requirements, I will develop three models covering a range of complexity, which will further enable determination of the most useful model to apply to this situation. The available field data will require the models to be developed for the Aberdares landscape. Ground data will be divided to provide one set for model development and verification, and an independent validation set. The most successful method will be extrapolated to Mount Kenya, where the results will be subject to long-term validation as part of the larger reintroduction project. The effects of habitat change on the studied species will also be assessed by applying the environmental variables derived from the earliest available satellite imagery to simulations with the most appropriate model.

The following models are proposed:

Statistical model of predicted versus actual distribution: The verification dataset will be used to develop a binomial generalized linear model [76] of presence/absence probability for the bongo and other herbivores across the Aberdares landscape [e.g. 77]. The satellite-derived habitat data will serve as independent variables. The model's validity will be measured by how well it predicts the animal distributions recorded in the independent dataset.

Agent-based models: Spatially-explicit, individual-based models (IBMs) are powerful tools for determining how organisms utilize a heterogeneous landscape, particularly for hard-to-study animals [10,78]. Agent-based models (ABMs) allow a richer examination of behavioral ecology than IBMs [79], in that their combination of artificial intelligence and object-oriented programming reveals the emergent behavior of independent and interacting decision-making entities (the agents) in relation to conditions in their simulated environment [79,80]. I will create two different ABMs, which I will validate using the independent dataset. I will use existing software (e.g. SWARM [81] and MOAB [82]) to minimize programming time.

Simple physiological-based ABM: The habitat utilization patterns of a single animal “object” within a grid-based environment (composed of the important remotely-sensed habitat variables) will be modeled in this hybrid approach, which is appropriate for individual-based (or agent-based) models in which a continuous representation of the environment is required [83]. The environmental representation could take a form (depending on field data results) in which browse quantity and quality is derived from seasonal palatability and vegetation structure and composition data, which will provide an energy value per grid cell. Soil nutrient availability could also prove to be an important factor [21], with utilizable concentrations being located at licks in forest openings. The agent will be modeled using a simple state and transition concept [e.g. 10,84], with the state being governed by the animal’s internal energy and nutrient reserves, acquired through feeding and licking. At each time step, the agent will assess its energy and nutrient reserves, and the availability of these in the occupied environment [e.g. 85]. If browse is available, the animal will continue the default behavior of feeding and add to its energy reserves. Should any reserve fall below a given level, or if browse is depleted, the agent will assess neighboring cells, and the agent will move towards a cell with suitable resources, or in a random fashion until it finds adequate resources beyond a defined perception distance [e.g. 84]. Energy will be expended through movement, with death occurring if energy or nutrient levels reach zero [85]. The agent will thus behave in a way that minimizes energy expenditure (following empirically derived metabolic rates), and the spatial configuration of habitat will be determined by how efficiently the agent can meet its energetic and mineral supplementation requirements.

Stochastic demographic ABM: The same environmental representation used in the previous approach will be employed in this version, with the addition of factors related to human activity that affect agent behavior and persistence. The human component will be incorporated in the landscape as a function of distance from sources of human activities, and will influence the agent’s ability to persist. The agent component of the model will add the dimension of population dynamics, which will result in suitable habitat configuration being defined by the ability to sustain a viable herd. An extra component of the model—a population manager [84]—will govern the multiple agents representing individuals of both sexes and several age classes. Each agent will be governed by an increased number of states and behaviors related to life history and interspecific interactions, such as breeding condition [e.g. 10,84]. The stochastic component of the model will relate to human proximity, wherein an agent will have a probability of dying that is inversely related to distance from human source. The human distance function will also serve to bias agent movement away from areas of increasing likelihood of contact.

Other Project Components

This project will provide a dissertation research opportunity for a Kenyan Master’s student. The study requires extensive field survey work, thus the Kenyan student will lead one of two survey teams in the Aberdares, and will be able to use the data collected towards earning a Master’s degree. Contact has been made with Professors at the University of Nairobi, where a newly established conservation biology Master’s degree program may provide a well-qualified candidate. Other institutions, such as the East African Wildlife Society, the Rhino Ark Foundation, the Laikipia Wildlife Forum, and Mpala Ranch, will also be contacted. Participation by a Kenyan national at the academic level in this research project will ensure that expertise pertaining to the bongo and its habitat is developed and retained within the country.

The field work component of the project will require a number of support staff. Chief among these will be accomplished trackers, who will be essential to interpreting animal behavior from signs—a vital aspect of determining habitat utilization. Sightings of the target species will be rare in such dense forest, particularly of the notably shy and scarce bongo, therefore it will be crucial to have the services of at least two master trackers (one for each survey team). If not available within KWS’ ranks, these experts will be recruited from local communities. KWS rangers must also be retained as a matter of policy and safety, and the services of one porter and field assistant per study area will be required. Where possible, all individuals will be drawn from local communities.

My dissertation will take the form of a series of peer-reviewed publications, thus the results will be available as a matter of priority to the scientific community. Selected results will also be presented at academic and conservation management symposia. Additionally, I intend to convert these results into a herbivore habitat and land use management plan in conjunction with the Kenya Wildlife Service. I will also strive to produce popular articles for the Kenyan and American environmental press, particularly for publications such as the East African Wildlife Society's journal *Swara* and for National Geographic Kids magazine. I would also like to share my work with school groups in both countries, as well as present to special-interest societies in which I have an interest, such as the Washington DC Botanical Society and the Nelspruit, South Africa branch of the Plant Specialist Group.

Post project follow-up

The findings of this research will be crucial to determining where and if bongo can be successfully reestablished on Mount Kenya, and what measures should be taken to secure and grow the existing free-ranging Aberdares and the captive Mount Kenya populations. As such, this work is considered to be part of the second phase of the reintroduction project, the third phase of which aims to manage a contained breeding population from which sustained releases of bongo into the Mount Kenya forests may ultimately be made. It will thus be necessary to assess the findings of this work following the possible reestablishment of a free-ranging population [32]. A key question to answer will be: do the bongo indeed utilize habitat in those areas and in the manner predicted by the study? An additional round of field surveys will be necessary for this work, preferably assisted by radio- and GPS-collared animals. The answer to this question will be a measure of the study's success. However, this research project provides a more rapidly verifiable method for determining bongo habitat distribution on Mount Kenya. If the model proves valid for the suite of herbivores studied in the Aberdares, including the bongo, the confidence with which it can be applied to Mount Kenya may be measured by how well it predicts habitat for the same herbivores (minus the bongo) on Mount Kenya.

This research project, together with the larger reintroduction project, are the cornerstones upon which wider efforts to conserve these vital Afrotropical habitats can be built. The project has the potential to attract significant national and international interest, which should be parlayed directly into project generation and support. Chief among these should be to improve KWS's manpower and equipment for undertaking increased law enforcement to prevent poaching and further forest destruction. The development of a larger and coordinated applied-research program focused on mountain ecosystems is also an important step to take.

The approach envisioned for this project has the potential to be applied elsewhere. As satellite imagery provides a cost-effective and global medium for deriving ecological information [9,67], this research will be relevant to species conservation projects throughout the world. This idea is particularly appealing given the absence of habitat and life history data in many priority conservation areas. The method proposed here will be directly relevant to mountain bongo conservation projects throughout its former range, such as the Virunga National Park in the Democratic Republic of the Congo [86] and the Mau Escarpment in Kenya. On a broader scale, since the terrestrial response to climate change is poorly understood [87], this technique could be further developed into a tool for understanding the reaction of non-plant taxa to environmental change. A standardized model that determines habitat requirements for an array of species using remotely-sensed environmental factors could be a powerful tool for studying ecological change at the landscape scale.

This technique not only has the potential to be useful in ecological forecasting, but could also be vital for endangered species reintroduction and restoration, an emerging conservation biology discipline. A uniform technique for determining habitat requirements and dynamics could also be used to identify probable invasive taxa.

Anticipated project outcomes

This real-time, applied research program will provide scientific support for a regionally important conservation project, and significantly contribute to the fields of conservation biology and landscape ecology.

In terms of the study's significance to the bongo project, this modeling-based approach will serve to:

- Delineate suitable habitat for the bongo (and several related herbivores), and provide the scientific underpinnings for the long-term reintroduction project;

- Identify the most appropriate management actions necessary to conserve the Aberdares population and to create conditions for a viable wild Mount Kenya population.

The larger significance of this research will be to:

- Improve understanding of the role of spatial configuration and complexity in habitat selection;
- Highlight the amount of ecological detail required to understand megaherbivory in a forest environment;
- Identify the most useful remote sensing and modeling techniques for solving this conservation biology problem;
- Enhance understanding of the effects of changing habitat configurations on organisms;
- Result in a technique that can be applied to reintroduction and management programs for other species and ecosystems;
- Attract further research and conservation attention to these two important ecosystems.

Timetable

Fall, 2004	Complete required coursework
January, 2005	Take comprehensive examinations
May, 2005	Defend research proposal before academic advisory committee
June, 2005	Organize logistical aspects of study in Kenya: source vehicle, project headquarters, interview and train Kenyan Master’s student and staff
July-August, 2005	Dry season field surveys, Aberdares
September-October, 2005	Satellite imagery analysis and development of habitat probability maps
November-December, 2005	Wet season field surveys, Aberdares
January-February, 2006	Continue satellite imagery analysis
March-April, 2006	Additional rainy season field surveys, as needed
May-July, 2006	Commence model development
August-September, 2006	Additional dry season field surveys, as needed
October, 2006-January, 2007	Finalize satellite analysis, complete models, analyze results
February-June, 2007	Write-up and defend thesis, graduate

Budget

Category	Year	Total Period/ Number	Description	Rate	Amount	Funder
Personnel	2005	5 mo. (17 days/mo.)	KWS rangers and trackers	\$15/day	\$8,100.00	Other
	2005	5 mo. (22 days/mo.)	Graduate student	\$15/day	\$1,650.00	Other
	2005	5 mo. (17 days/mo.)	Field assistants & Porters	\$15/day	\$5,100.00	Other
	2006	6 mo. (17 days/mo.)	KWS rangers and trackers	\$15/day	\$9,180.00	Other
	2006	6 mo. (22 days/mo.)	Graduate student	\$15/day	\$1,980.00	Other
	2006	6 mo. (17 days/mo.)	Field assistants & Porters	\$15/day	\$6,120.00	Other
					Sub-total	\$32,130.00
Research fees	2005-2006	3 years	Research permit		\$300.00	U. Virginia
				Sub-total	\$300.00	

Travel and accommodation	2005-2006	4	Airfare: US-Kenya	\$2,000.00	\$8,000.00	Other
	2005-2006	7 months	Research quarters	\$30.00	\$5,700.00	Other
				Sub-total	\$13,700.00	
Equipment and materials	2005-2006	N/A	4wd project vehicle	N/A	\$15,000.00	Other
	2005-2006	TBD	Running costs	\$0.24	\$6,240.00	Other
	2005-2006	20	Camera trap equipment	\$350.00	\$7,000.00	WCS
	2005-2006	2	GPS Units	\$250.00	\$500.00	WCS
	2005-2006	N/A	Camping equipment for 7 X 2 people	\$2,000.00	\$2,000.00	WCS
	2005-2006	N/A	Data supplies (tape measure, rainproof notebooks, etc.)	\$500.00	\$500.00	WCS
	2005-2006	4	Handheld radios	\$250.00	\$1,000.00	WCS
	2005	2	High resolution satellite images (SPOT/IKONOS)	\$6,500.00	\$13,000	WCS
	2005	10 hours	KWS aircraft costs for aerial digital imagery	\$100.00	\$1,000.00	WCS
				Sub-total	\$46,240.00	
Special requirements	2005-2006	To be determined	Plant sample identification (herbarium fees), soil samples, etc.		\$2,000.00	Other
				Sub-total	\$2,000.00	
				Total	\$94,370.00	WCS

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