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Habitat selection by a rare forest antelope: A multi-scale approach combining field data and imagery from three sensors

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Abstract

It can be difficult to further scientific understanding of rare or endangered species that live in inaccessible habitat using traditional methods, such as probabilistic modeling based on field data collection. Remote sensing (RS) can be an important source of information for the study of these animals. A key advantage of RS is its ability to provide information over an animal's complete range, but models incorporating RS data are limited by RS's ability to detect important habitat features. In this study, we focus on the rare, poorly-understood mountain bongo antelope (*Tragelaphus euryceros isaaci*) which survives in the wild in isolated pockets of montane forest in Kenya. We hypothesize that mountain bongo habitat is multi-scaled. We analyzed field and RS data (derived from SPOT, ASTER, and MODIS) ranging in scale from 0.02–85.93 ha to test our hypothesis. Important microhabitat features were identified through logistic regression models of vegetation structure data collected in plots (0.04 ha) of bongo presence ($n=36$) and absence ($n=90$). Models were selected using an information theoretic approach. We analyzed the correlations between microhabitat (four canopy and four understorey structure measures) and RS variables derived using spectral mixture (SMA) and texture analysis; most ASTER and SPOT variables were significantly related with canopy structure variables (max$|r|=0.56$), but correlations between understorey structure and all but two RS variables were insignificant. Further logistic regression modeling showed that combining field microhabitat (primarily understorey structure variables) and larger-scaled RS measures (ASTER spectral mixture analysis variables aggregated to 450 m (20.25 ha)) provided superior models of bongo habitat selection than those based on field or RS data only. The results demonstrate that: 1) forest canopy characteristics at scales of ~20 ha and understorey structural conditions at the micro-scale of 0.04 ha were the most important features influencing bongo habitat selection; 2) models for predicting bongo habitat distribution must incorporate both micro- and macro-habitat variables; 3) optical RS data may characterize important micro-scale canopy variables with reasonable accuracy, but are ineffective for detecting understorey features (unless alternative techniques such as forest structural indices can be successfully applied); 4) RS and field data are both essential for understanding bongo habitat selection. The technique employed here for understanding this rare antelope's habitat selection may also be applied in studies of other large herbivores.

Keywords: SPOT; ASTER; MODIS; Spectral mixture analysis; Texture analysis; Topographic correction; Habitat selection; Herbivore; Forest structure; Scale; Field data; Rare species; Mountain bongo; Logistic regression; Akaike's information criterion

1. Introduction

Rare species are a preeminent concern of conservation biology, which is the "biology of scarcity" (Soule, 1986, pg. 10). Successfully conserving a rare species depends on understanding interactions between the organism and its environment. Spatially-explicit, probabilistic distribution models are important tools for

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examining this relationship, which is central to ecology (Guisan & Zimmermann, 2000). Such models are increasingly used to map species' actual and potential distributions, and to understand the factors influencing these (Guisan & Zimmermann, 2000; Rushton et al., 2004). However, the insight drawn from such models depends on the quality and quantity of input data. Collecting a dataset that is adequate in both senses is difficult when species are rare (Rushton et al., 2004), thus habitat modeling studies are skewed towards more abundant organisms (Guisan et al., 2006).

Rare species pose logistical (cost) and statistical (sample size, independence) problems for distribution modeling studies (Guisan & Zimmermann, 2000; Rushton et al., 2004). Furthermore, predicted distribution patterns and the factors influencing them can vary according to the scale of investigation, as most organisms' habitats are determined by features defined at different scales (Brown, 1995; Wiens, 1989). Choosing appropriate sampling scales is difficult for rare organisms, whose ecological requirements are often poorly-understood (Rushton et al., 2004).

Remote sensing (hereafter RS) is increasingly used in habitat modeling studies to overcome the problems of sample size and scale; RS provides the most efficient technique for collecting large quantities of habitat data over extensive areas at multiple spatial scales (Kerr & Ostrovsky, 2003; Rushton et al., 2004; Turner et al., 2003; Wulder et al., 2004). Modern sensors offer the ability to collect information throughout the electromagnetic spectrum at sub-meter to multi-kilometer resolutions, and can be directly related to a number of field-based ecological measures (Turner et al., 2003). The advances in sensor technology and related analytical techniques have facilitated the increasing use of spatial distribution models in ecological and conservation applications, as high quality data can be collected and meaningfully interpreted in habitats where field surveys are technically or financially impractical (Rushton et al., 2004; Wulder et al., 2004).

Despite this trend, many ecologists and biologists remain skeptical that RS data are suitable for fine-scale ecological studies (Turner et al., 2003). Furthermore, since most sensors are not designed to provide input for distribution models, the ability of RS to detect important habitat features varies according to the characteristics of a species and its ecosystem; these determine whether RS measurements describe the driving habitat variables or their proxies (Rushton et al., 2004; Turner et al., 2003). For instance, high resolution RS data may detect shrubs browsed by an antelope in an open savanna woodland, but would fail to do so if these shrubs were located under closed-canopy forest. In the latter case, the RS data might correlate with a proxy variable, such as canopy cover.

Many RS-based habitat modeling studies rely on such proxies, which are often categorical variables that describe land cover or vegetation types (e.g. Debinski et al., 1999; Saveraid et al., 2001; Schadt et al., 2002). Categorical variables can be poor predictors of the species-habitat relationship, since they cannot account for within-class variability and struggle to distinguish ecotones (St-Louis et al., 2006). More informative proxy variables can be established by developing continuous relationships between RS data and relevant habitat features, such as vegetation structure (Rushton et al., 2004; St-Louis et al., 2006; Turner et al., 2003). The use of continuous, RS-derived proxies is growing in habitat modeling studies (e.g. Gibson et al., 2004; Jeganathan et al., 2004), but ecologists have yet to embrace many of the techniques developed for quantifying such variables (Turner et al., 2003). For instance, the RS literature contains many studies in which RS is used to measure forest structural variables (Hansen et al., 2001; Hudak et al., 2002; Peddle et al., 2001; Scarth et al., 2001; Wulder et al., 1998; Wulder et al., 2004). These methods could be profitably applied in habitat modeling studies of forest-dwelling species.

The subject of this study is the mountain bongo (*Tragelaphus euryceros isaaci*), a large, elusive antelope endemic to a handful of high mountain forests in Kenya. The mountain bongo (hereafter bongo), a distinctive sub-species of Central and West Africa's lowland bongo (*Tragelaphus euryceros euryceros*), was once abundant in the isolated montane forest patches (see Fig. 1A) that represent the limits of its potential habitat. In the past several decades, however, the number of bongos has declined precipitously. Causes are uncertain, but probably stem from a combination of rampant poaching, human encroachment into Kenya's relatively small forest estate, and diseases such as rinderpest (Gathaara, 1999; Imbernon, 1999; Kock et al., 1999; Lambrechts et al., 2003). Less than 100 individuals are believed to remain in the wild (Prettejohn, 2004; Reillo, 2002), the majority of which are confined to the Aberdare Mountains (Fig. 1B). An international reintroduction and conservation project is now underway, which aims to recover the extant sub-populations and re-establish a viable bongo population on Mount Kenya (Fig. 1B), where one of the largest sub-populations used to be found.

This study is part of the ecological research being conducted to support this broader conservation project, which is crucial because of the near-absence of information on bongo ecology. A primary objective is to determine bongo habitat selection and distribution throughout its range using spatial distribution models. However, obtaining the necessary data for developing these models is extremely difficult given the bongo's rarity; the Aberdares' bongo sub-population is the only one with sufficient numbers to study, yet even this herd's density is low relative to the Aberdares' extensive, rugged forest estate. These conditions make it impractical to obtain the sort of fully-stratified, multi-scale field survey data needed for successful distribution models (Vaughan & Ormerod, 2003), as collecting just one observation requires significant investments in time, money, and labor. Furthermore, choosing appropriate sampling scales is difficult in the absence of prior knowledge, while the high costs of field work preclude exploratory investigations. These factors indicate that the necessary habitat information must be provided by RS data trained with a relatively small field dataset. Unfortunately, montane forests challenge the capabilities of optical RS data (the kind most readily available to conservation ecologists), as forest reflectance received by the sensor is confounded by the variable illumination that results from extreme topography (Gu & Gillespie, 1998).

Existing information on the bongo indicates that it is primarily a browser of forest edge and understorey plants, and its preferred habitat appears to be a mosaic of open glades,