Research Note

Designing a Conservation Landscape for Tigers in Human-Dominated Environments

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Abstract: *Wildlife populations in small, isolated reserves face genetic and demographic threats to their survival. To increase the probability of long-term persistence, biologists promote metapopulation management, in which breeding subpopulations are protected as source pools. Animals that disperse from the source pools increase the probability of persistence of the metapopulation across the greater landscape. We used a geographic information system (GIS)-based, cost-distance model to design a conservation landscape along the Himalayan foothills for managing a metapopulation of Asia's largest predator, the tiger (*Panthera tigris*). The model is based on data from 30 years of field research on tigers, recent satellite imagery, and a decade of buffer-zone restoration in this region. We used the model to (1) identify potential dispersal corridors for tigers; (2) identify strategic transit refuges; and (3) make recommendations for off-reserve land management and restoration to enhance the potential of corridors for tigers. This tool can aid the design of conservation landscapes for other endangered, wide-ranging species in human-dominated environments.*

Key Words: conservation landscapes, dispersal, metapopulation management, Terai, tigers

Diseño de un Paisaje de Conservación para Tigres en Ambientes Dominados por Humanos

Resumen: *La supervivencia de poblaciones de vida silvestre en reservas pequeñas y aisladas enfrenta amenazas genéticas y demográficas. Para incrementar la probabilidad de persistencia a largo plazo, los biólogos promueven el manejo metapoblacional, en el que las subpoblaciones reproductivas son protegidas como fuentes. Los animales que se dispersan desde la fuente incrementan la probabilidad de persistencia de la metapoblación en el paisaje extendido. Utilizamos un modelo de costo-distancia, basado en SIG, para diseñar un paisaje de conservación en las estribaciones de los Himalaya para manejar una metapoblación del mayor depredador de Asia, el tigre (*Panthera tigris*). El modelo se basa en datos de 30 años de investigaciones de campo, imágenes de satélite recientes y una década de restauración de la zona de amortiguamiento en esta región. Utilizamos el modelo para (1) identificar potenciales corredores de dispersión para tigres; (2) identificar refugios de tránsito estratégicos y (3) hacer recomendaciones para el manejo y la restauración de tierras afuera de la reserva para promover el potencial de los corredores para tigres. Esta herramienta puede auxiliar en el diseño de paisajes de conservación para otras especies en peligro y de amplio rango de distribución en ambientes dominados por humanos.*

Palabras Clave: dispersión, manejo de metapoblaciones, paisajes de conservación, Terai, tigres

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Introduction

Conservation of endangered large vertebrates in fragmented landscapes has become a central issue for conservation biologists. As conversion of natural habitat continues, the protected areas established to conserve these species become insular and interspersed within matrices of human land uses. In Asia, as elsewhere on Earth, many

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of these protected areas are too small to support viable populations of large mammals over the long term, and isolated populations of large vertebrates in such refuges have a high probability of local extinction (Hanski 1994; Noss et al. 1996; Wikramanayake et al. 1998). In response, conservation biologists are promoting the concept of metapopulation management to conserve large, wide-ranging species (McCullough 1996; Noss et al. 1996; Margules & Pressey 2000; Mech & Hallett 2001). The objective is to protect breeding populations as source pools and provide dispersal opportunities by linking habitat patches across the landscape mosaic to maintain a larger population.

The Terai Arc Landscape, located along the Himalayan foothills, attempts to implement this new paradigm in conservation. Here we present a least-cost pathway model and use it to identify a system of potential dispersal corridors for managing a metapopulation of tigers (*Panthera tigris*) in the landscape. The model is based on ecological and behavioral parameters of tigers collected during 30 years of field research (Sunquist 1981; Smith & McDougal 1991; Smith 1993), recent satellite imagery, and experience in buffer-zone restoration during the past decade (Dinerstein 2003).

The probability of successful dispersal decreases with corridor length (Gustafson & Gardner 1996), but strategically located stepping stones can provide temporary refuge and increase dispersal success (Newmark 1993; Sweanor et al. 2000; Kautz & Cox 2001). Nepal has an effective community forestry program in which degraded forestlands are leased to local community-based user groups. If these are managed to allow natural regeneration—an accepted management practice—they have the potential to become refuges for dispersing tigers. Therefore, we also used the model to identify strategic stepping-stone refuges that can improve the dispersal potential of corridors and to make recommendations for off-reserve land management and corridor restoration. These land-management strategies are important because corridors span and include areas of human land use and help manage and restore of habitat used for dispersal where connectivity has been lost or severely degraded.

This model is already helping advance tiger conservation in lowland Nepal and northwestern India, moving rapidly from a theoretical construct of metapopulation management to landscape planning and implementation in the Terai Arc. The lessons learned in designing and implementing this conservation landscape can be applied across the subcontinent and beyond for large-mammal conservation.

Methods

Remote Sensing and GIS

We first performed an unsupervised classification in Erdas Imagine of the five Landsat 7 ETM satellite images that spanned the Terai Arc Landscape. The images (Image 141-41, acquisition date 4 November 1999; 142-41, 13 December 1999; 143-41, 25 March 2000; 144-40, 9 November 1999; 145-40, 15 October 1999) were obtained from the Global Land Cover Facility at the University of Maryland, College Park, http://glcf.umiacs.umd.edu. We ran 15 iterations of 30 classes grouped into eight habitat categories: 1, good forest; 2, degraded forest; 3, grassland; 4, water; 5, sand/dry riverbed; 6, bareground; 7, agriculture type A (sugar cane fields); 8, agriculture type B. Tigers are known to disperse through sugar cane fields (a tall grassland analog) in northern India, so we distinguished between sugar cane and other agriculture. Using the eliminate function, stratified by the eight habitat types, we removed clusters of <11 pixels (i.e., approximately 1 ha).

We used our knowledge of the area to reclassify ambiguous grid cells in ArcView 3.2/Spatial Analyst. We drew polygons around known forest, grassland, agriculture, and riverbeds and reclassified aberrant grid cells within large polygons. For example, grid cells classified as "agriculture" within large polygons of "good forest" were reclassified as bare ground because they are likely not agriculture. The five reclassified images were then merged to create an image of the entire Terai Arc Landscape.

To identify large, intact blocks of "good habitat," we buffered 1 km—considered an area of high human influence—around clusters of agriculture and population centers. We used the best available settlement data (ESRI 1993) for India and Village Development Committee maps (VDC) for Nepal (HMG 1996) to identify population centers. Land use in India is clearly divided between agriculture and associated villages and protected areas (including forest reserves). Thus, finer-scale settlement data, even if available, would likely not affect the size of the intact habitat blocks. We grouped the resulting grid by habitat type to reflect suitability for dispersal. Blocks of <11 pixels were merged with surrounding habitats.

Creating the Cost Grid

We assigned each cell in the classified grid a value ranging from 1, good, to 5, poor, for each of three parameters: block size, habitat type, and elevation (Table 1). These values reflect a judgment of the biological cost of dispersal and likelihood of use by tigers. The three values for each grid cell were then combined to form a single metric to rank grid cells relative to one another.

We assumed that large blocks of good forest in lowland habitats are more likely to be used during dispersal than small blocks of good habitat in high elevations because of lower disturbance levels associated with large blocks and the higher densities of the prey base in low-elevation forests. Tigers face a higher biological cost when traversing large areas of poor habitat than when traversing small areas; thus, a grid cell in a large block of poor habitat

Table 1. Values of grid cells based on habitat type, block size and elevation, and in human-affected buffered areas.

	Value	*Block size (km^2)*	*Value*	*Elevation (m)*	*Value*
Habitat type					
forest/grassland	1	>20	1	<300	1
	1	5–20	3	300–500	2
	1	<5	5	>500	4
degraded	2	>20	5	<300	1
	2	5–20	3	300–500	2
	2	<5	1	>500	4
water or bare ground	3	>20	5	<300	1
	3	5–20	3	300–500	2
	3	<5	1	>500	4
Land cover in buffered areas					
forests and grasslands	4				
water and riverbeds	4				
degraded or grazed	7				
agriculture type A	15				
agriculture type B	25				

received a higher cost value. For example, a grid cell in a block of intact, lowland forest that is >20 km^2 has a dispersal cost of 3, whereas the cost assigned to a grid cell in a large, high-elevation bare patch is 12 (Table 1). All grid cells within protected areas were assigned a cost value of 1 for block size and habitat type.

We did not give the agricultural areas and buffered grid cells separate values for each parameter. Instead, because of their proximity to anthropogenic influences, we assigned them a single cost value approximating their cost relative to that of the intact areas (Table 1).

We treated protected areas and other intact habitat blocks known to harbor breeding tigers as "sources." We used the cost-distance function in ArcInfo/Grid to create dispersal cost grids from these sources. The cost value for grid cells within a source was considered to be zero. Using the corridor function, we created corridors between pairs of source areas, which we then combined to create a map of the entire landscape by retaining the lowest scores assigned for each grid cell during the pairwise analyses. We then used the minimum-cost grid cells to depict dispersal corridors between source populations across the landscape (Fig. 1).

The algorithm includes a distance function so that the dispersal cost increases with corridor length. Thus, potential corridors between protected areas that are farther apart have greater costs than corridors between refuges that are closer together, which is not readily apparent from the landscape cost grid (Fig. 1). Therefore, to identify the corridors with the lowest cost values, we created dispersal "cost contours." First, we removed the core areas from the grid map and then selected the 10% (level 1 corridors), 20% (level 2 corridors), and 30% (corridor buffers) of grid cells with the lowest cost values of all source pairs to create three cost contours (Fig. 2a). The 10% threshold contour (level 1 corridors) holds the best potential for tiger dispersal.

Modeling Corridor Restoration

There are two areas of tenuous connectivity between Chitwan National Park and Bardia National Park, one in Lamahi and one on either side of Butwal City where human encroachment extends into the Churia Hills (Fig. 2b). These areas represent bottlenecks in the potential corridors, but several forests have been handed over as community forests to local user groups. Therefore, we redid the analysis, treating these community forests as good habitat, to see whether the corridor potential would improve if these community forests were managed to allow natural regeneration.

To create a corridor between Bardia National Park and Sukla Phanta Wildlife Sanctuary, we determined the range of grid-cell values for areas outside protected areas that are known to harbor resident tigers. We then extracted the grid cells between Bardia and Sukla Phanta with cost-distance values that fall within that range, chose the cells within intact forest patches, and reanalyzed the data (Fig. 2b). These small patches are meant to represent centroids for larger stepping-stone refuges.

Results

Our model identified three tiger subpopulations across the Terai Arc Landscape (Figs. 1 & 2a). The first was comprised of the tigers in and between Corbett and Dudwa Tiger Reserves, including Kishanpur Wildlife Sanctuary in India and Sukla Phanta Wildlife Sanctuary in Nepal. The second consisted of tigers in Katerniaghat Tiger Reserve and Sohelwa Wildlife Sanctuary in India and Bardia National Park in Nepal in a landscape that extends across the Rapti River valley to include the inner and outer Churia Hills (Fig. 2a). Establishing transit refuges between Sukla Phanta and Bardia improves the potential of the corridor between the Bardia-Katerniaghat complex and Sukla Phanta-Dudhwa complex, via the Basanta forest, from a level 2 to a level 1 corridor, thus potentially uniting these two subpopulations. The transit refuges also established a level 2 corridor between Sukla Phanta and Bardia along the Churia Hill range (Fig. 2b).

The third tiger subpopulation, centered on Chitwan National Park, was isolated from the subpopulations in the west, primarily as a result of the bottleneck created by Butwal and habitat degradation in the Lamahi area. However, community forests could potentially restore the link between Chitwan and the western refuges, albeit with a level 2 corridor. These community forests also created potential corridors between the inner and outer Churia ranges, across the Rapti River valley.

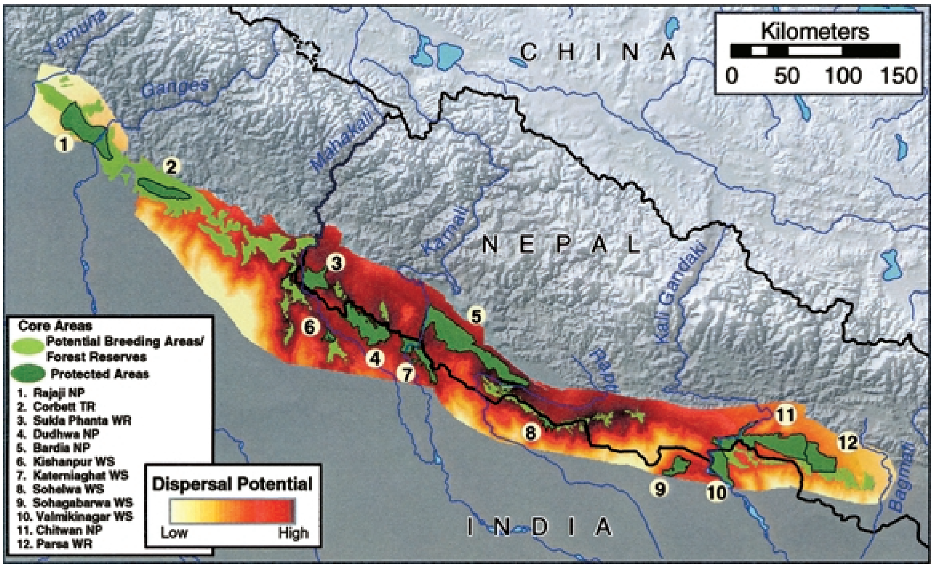


Figure 1. Potential tiger dispersal corridors in the Terai Arc Landscape based on the least-cost pathway model. The darker reds represent potential corridors with the lowest biological costs for dispersal; the yellows represent areas with higher biological costs. Core areas include protected areas, forest reserves, and large, intact habitat blocks that can support resident tigers. NP = National Park; TR = Tiger Reserve; WR = Wildlife Reserve; WS = Wildlife Sanctuary.

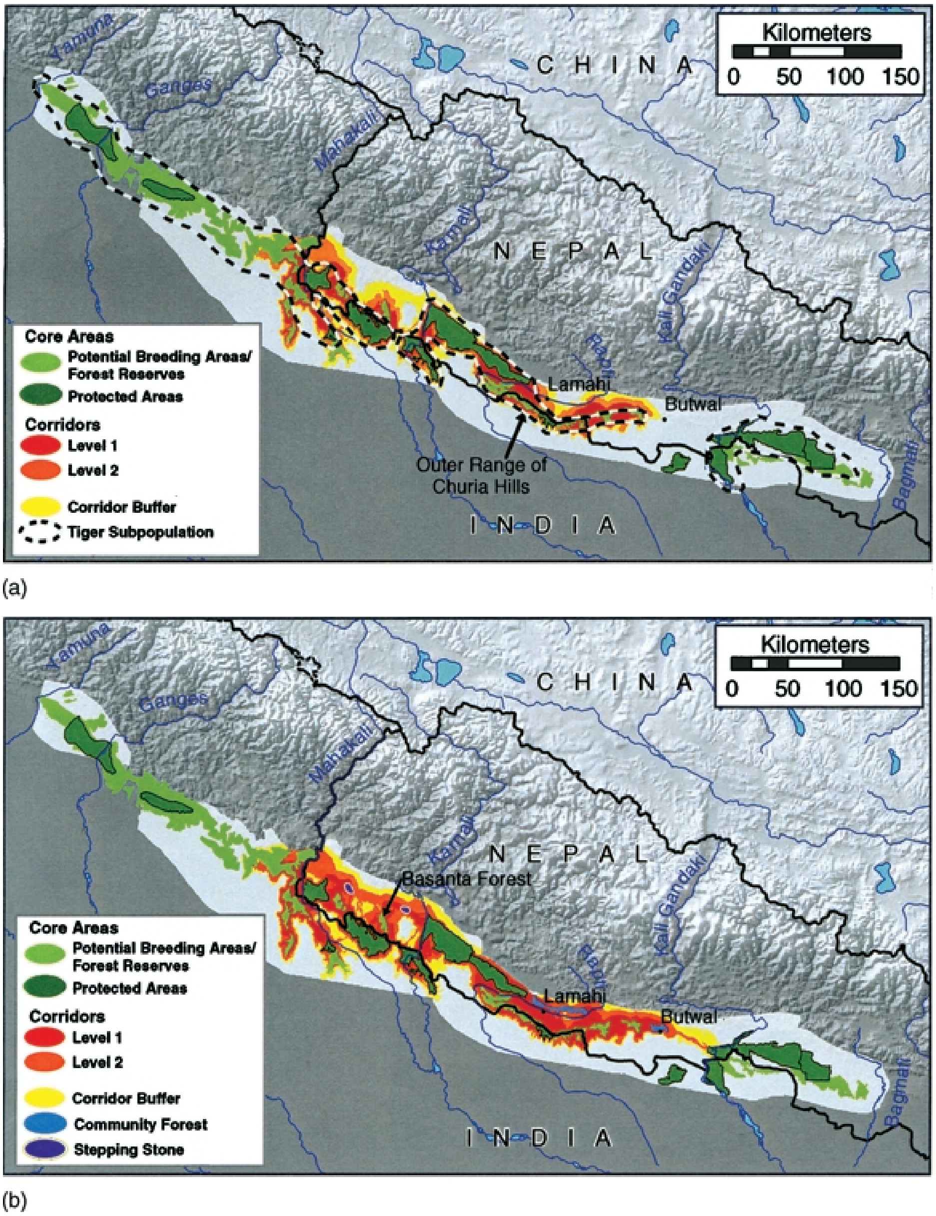
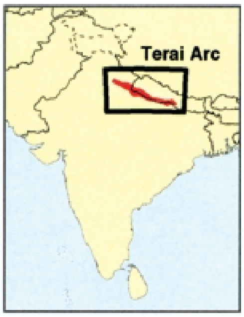


Figure 2. (a) Potential tiger dispersal corridors based on the "dispersal cost contours." Level 1 corridors represent the best pathways for dispersal, and are defined by the lowest 10% of cost values (10% threshold). Level 2 corridors are represented by the contours created by the next 10% of low-cost grid cells (20% threshold). The Corridor Buffers are represented by the contours created by the 30% threshold. Existing tiger subpopulations are delineated by the dashed line (see text for details). (b) The corridor analysis expanded to include strategically placed stepping stones and community forests that would restore habitat and improve dispersal potential of corridors.



Discussion

Corridors in the Terai Arc

The continuous belt of grassland and subtropical forest that once extended across the Himalayan foothills is now highly fragmented, and, along with it, the resident tiger population. Smith et al. (1998) identified four populations across the Terai that are hypothesized to be separated by dispersal barriers, identified on the basis of visual interpretation of satellite images and short field surveys to confirm tiger presence. However, potential corridors for focal species can often be difficult to detect through visual assessments of structural landscape features and habitat configurations and are better revealed by simulation models (Gustafson & Gardner 1996).

The results of our initial analysis show that two of the four populations identified by Smith et al. (1998) are currently linked and that potential dispersal corridors for tigers exist or can be restored between all protected areas and other core habitat. Establishing transit refuges or restoring degraded habitat through strategic land-use planning can potentially link the other populations.

Wildlife populations that are isolated or have a probability of exchanging fewer than one individual per generation are vulnerable to inbreeding depression (Mills & Allendorf 1996), calling into question conservation strategies that manage populations as isolated units. Although tigers occur at high densities in prime habitat within the protected areas of the Terai Arc Landscape, these refuges are fast becoming insular, and there are indications of inbreeding depression in populations isolated within reserves (Smith & McDougal 1991). In a simulation of cougar populations, Beier (1993) showed that the addition of one to four immigrants over a decade into a small population can significantly increase its persistence. Similarly, the persistence of tiger populations within protected areas can be enhanced if these populations can be managed as a metapopulation.

Most of the remaining large, intact habitats in the Terai are now within protected areas. Although it is essential that these refuges are given effective protection, off-reserve land-use and management strategies such as community forestry can be used to restore and maintain corridors to facilitate dispersal and genetic exchange between tiger populations in the core areas. Tigers are habitat generalists and disperse through secondary habitat (Smith 1993), so the corridors we identified are likely to be effective. This assumption is supported by field studies of radio-collared cougars (Beier 1995; Sweanor et al. 2000) and lynx (Palomares et al. 2000), both of which will disperse through low-quality corridors. Corridors of secondary habitats will not be effective for habitat specialists or poor dispersers, however, because these corridors will become population sinks. Thus, conservation of habitat specialists requires managing corridors with land-use strategies that create and maintain good-quality habitat.

We note that the model does not provide absolute cost thresholds for dispersal, but only an indication of pathways with the lowest relative costs and those that include the most suitable ecological conditions for dispersing tigers. In our application of the least-cost pathway model, we tried to identify broad corridors with the highest potential for allowing dispersal between core areas that contained the grid cells with the lowest costs—within the 30% threshold—by assessing each grid cell in the landscape relative to the others. These corridors are well suited for conservation landscape planning because they are not demarcated as narrow, continuous conduits connecting two points, but as landscape features with various land-use and land-cover conditions that can support and facilitate dispersal. We also note, however, that dispersing tigers could potentially use other pathways.

Beyond Tigers and the Terai Arc

Habitat fragmentation and conversion are rapid throughout the ranges of large carnivores and have been widely acknowledged as a significant cause of their population declines (Terborgh 1999). Thus, conservation landscape design must include pathways for these wide-ranging endangered species to thread their way through human-dominated matrices (Dinerstein 2003). Our geographic information system (GIS)–based model for the Terai Arc shows how the ecological and habitat parameters of the tiger were used to design such a conservation landscape. We present this model as a tool for designing conservation landscapes to manage metapopulations of large carnivores beyond the shadow of the Himalayas.

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