Landscape Analysis of Tiger Distribution and Habitat Quality in Nepal

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Abstract: *Despite more than two decades of conservation efforts, only limited information is available on the metapopulation structure of the tiger (*Panthera tigris*). We report on the geographic distribution of tigers in Nepal in relation to habitat quality and describe an inventory and monitoring system that can be applied across the entire range of the species. Using information from previous studies, interviews with local people, and digital thematic mapper satellite data, we identified four populations of tigers; three occur primarily within the borders of Nepal, and a fourth is across the border in India. We estimate that there are 153 breeding tigers in these four populations. In the Chitwan population, 77% of breeding tigers live in three protected areas; the rest occupy national forests. Tigers in all four populations survive in isolated forest remnants of what was once a continuous subtropical forest zone lying south of the Himalayas. Within central Nepal the ratio of good- to poor-quality tiger habitat ranged from 16% to 86% across seven forest districts. The four areas with the highest ratio of good-quality habitat (>54%) supported breeding populations, one area with a marginal ratio of good-quality habitat (46%) was used only occasionally, and the two areas with the lowest ratio of good-quality habitat (<26%) were not used by tigers. We suggest that when the ratio of good to poor habitat drops below approximately 50%, tigers no longer breed; when it drops below 30%, tigers no longer occur in an area. Estimates of potential tiger habitat and data on habitat used by tigers demonstrate the need to expand current management beyond parks to encompass the entire land base supporting these fragmented populations so that small tiger populations can be managed as ecosystem or tiger management units rather than as portions of populations within protected areas.*

Análisis de Paisaje de la Distribución de Tigres y Calidad del Hábitat en Nepal

Resumen: *A pesar de mas de dos décadas de esfuerzos de conservación, la información sobre la estructura metapoblacional del tigre* Panthera tigris *es viable únicamente en forma limitada. Reportamos la distribución geográfica de tigres del Nepal en relación a la calidad del hábitat y describimos un inventario y un sistema de monitoreo que puede ser aplicado a lo largo del rango de distribución total de la especie. Usando información de estudios previos, entrevistas con pobladores del lugar y datos de mapeadores digitales temáticos, identificamos cuatro poblaciones de tigres; tres de las cuales ocurren principalmente dentro de los límites de Nepal y una cuarta población se encuentra mas allá de la frontera con India. Estimamos que existen 153 tigres reproductores en estas cuatro poblaciones. En la población de Chitwan, 77% de los tigres reproductores viven en áreas protegidas; el resto ocupa bosques nacionales. Los tigres de las cuatro poblaciones sobreviven en bosques remanentes aislados de lo que alguna vez fué un bosque subtropical continuo del Sur de los Himalayas. Dentro de la región central de Nepal y a lo largo de siete distritos forestales, la proporción de tigres en buena y mala condición varía entre 16% y 86%. Las cuatro áreas con la tasa mas alta de calidad de hábitat (>54%) soporta poblaciones reproductoras; un área con una tasa marginal de buena calidad de hábitat (46%) fueron usadas por los tigres únicamente en ocasiones y las otras dos áreas con la tasa más baja (<26%) no fueron usadas. Sugerimos que los tigres no se reproducen si la tasa entre hábitat bueno y malo es*

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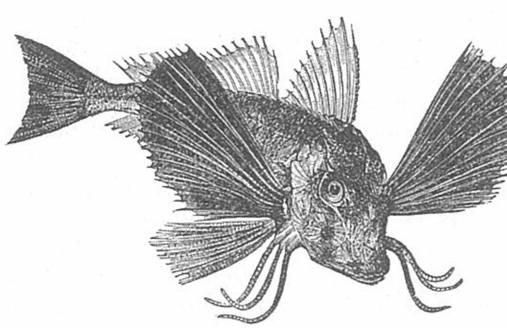

más baja de un 50%; si baja más de un 30%, los tigres no se encuentran en el área. Estimaciones de hábitat potencial para tigres y datos de hábitat usado por tigres demuestran la necesidad de expander el manejo actual más allá de los parques y abarcar la totalidad de las tierras que soportan estas poblaciones fragmentadas, de tal manera que puedan ser manejadas como ecosistema o como unidades de manejo para tigres, y no como porciones de poblaciones dentro de áreas protegidas.

Introduction

Tigers (*Panthera tigris*) were once widely distributed across the riverine grasslands and forests of Asia. As human populations converted the rich alluvial plains to agricultural lands, tigers gradually became confined to the forests of the region. There were, however, still an estimated 40,000 tigers on the Indian subcontinent in the early 1900s (Gee 1964). After World War II, clearing of forest lands accelerated forest loss and fragmentation. As a result, tiger populations now occur only in small, isolated forest sanctuaries. Throughout the species' range population sizes are estimated to vary from less than 20 to less than 200 breeding animals (Jackson 1993). At this range of population sizes, stochastic genetic, demographic, and ecological events can have a strong effect on population dynamics (Shaffer 1981; Frankel & Soulé 1981).

Present tiger distribution extends from a population near the Pacific coast of Russia to southern India and peninsular Malaysia and Sumatra. Outside Nepal, however, there is little information on the size and degree of gene flow among tiger populations, despite more than two decades of conservation efforts. For example, in India there have been four national tiger censuses since 1972, but none has provided information on metapopulation structure, which is defined by the spatial pattern, size, and connectedness of populations (Levins 1969) and determined by the geography of tiger habitat, the size of habitat units, and the extent to which cover types act as dispersal barriers. Furthermore, these censuses do not provide demographic information that defines who was counted (e.g., all individuals from cubs to adults; subadults, dispersers, and adults; or only breeding resident adults) or supply information on the number of tigers in discrete populations. Similarly a recent estimate of tiger numbers in Sumatra does not clearly define where one population ends and another begins (Faust 1994; Tilson et al. 1994). Although estimates of numbers remain extremely crude, throughout the tiger's range there are probably only three to four populations with more than 100 breeding individuals.

Beginning in 1846, tiger habitat in Nepal was protected from development by royal policy that discouraged settlement and agriculture in the lowlands (Terai) to maintain a malarial barrier to invading armies. In the 1950s, however, overpopulation in the middle hills resulted in a reversal of this policy; settlement in the Terai was encouraged, and a massive malaria eradication program led to a rapid increase in the human population due primarily to emigration. These changes resulted in loss of tiger habitat and fragmentation, which continued until the National Park Act of 1973 established several protected areas. Although the act created a network of protected areas, it did not halt degradation of critical tiger habitat outside reserves. Since 1990 an additional factor, the significant Asia-wide increase in tiger poaching (Jackson 1993; Miquelle et al. 1993), has seriously threatened the survival of already small populations (Kenney et al. 1995).

Many scientists believe that extinction of smaller tiger populations is likely to be a common event in the near future (Jackson 1993) because (1) populations are small and isolated, (2) populations often span multiple jurisdictional units, which complicates management decisions, and (3) the new threat of poaching is widespread and significant. Any strategy to prevent the extinction of the tiger must also include a management plan for each tiger population. The first step in developing such plans is to define the geographic extent of each tiger population in relation to habitat quality (e.g., land cover and human land use) (Smith et al. 1987*a*; Ahearn et al. 1990). This will allow identification of critical areas where changing land use may result in further habitat fragmentation and reduction in population size. Once distribution data are known, this information can be used to (1) devise land-use strategies, (2) calculate population size, (3) predict changes in tiger distribution, and (4) devise ecosystem- and landscape-scale biodiversity strategies. We report on the metapopulation structure of tigers in Nepal and describe an inventory and monitoring system that can easily be applied across the entire species range so that small tiger populations can be managed as ecosystem (Grumbine 1994) or tiger management units (Dinerstein et al. 1996) rather than as portions of populations within protected areas.

Geography of Potential Tiger Habitat in the Terai

In the 1930s, tiger habitat in the foothills of the Himalayas was continuous for over 1800 km, from west of Corbet National Park, India, through the lowlands of Nepal, Sikim, and Bhutan to eastern India (Smythies 1942). In Nepal tigers have been confined largely to the lowland habitat (below 1000 m elevation) for over a century because intensive human settlement patterns in the middle hills reduced cover and prey to the extent that tigers were extirpated from that region. Presently, tigers exist in the Terai in the forests on the slopes of the Siwalik Range and in the rich alluvial grasslands and riverine forests in a series of valleys called "duns." Ample rainfall and the rich alluvial soils of the duns support diverse vegetation characterized as tropical-moist deciduous, riverine, and upland forest, interspersed with tall grasses (Stainton 1972). This mosaic of habitat in the duns has resulted in a rich large-mammal fauna that historically has included some of the highest densities of tigers on the Indian subcontinent (Smythies 1942). Today this belt of lowland forest still runs the entire length of Nepal, but it has become highly fragmented. Expanding human populations, increased development, and road construction have resulted in isolation of the major dun valleys, creating an increasingly isolated metapopulation structure of tigers.

Methods

To determine the metapopulation structure of tiger populations, we needed to define potential tiger habitat so that we would know where to survey. Data from over 14,000 locations of 46 radio-collared tigers (Smith 1993) and visual sightings reported by local people throughout the country were used to determine potential tiger habitat. The only records of tigers ever reported from agricultural or urban areas were of injured and emaciated animals that occasionally wandered into villages when they could no longer hunt wild prey (C.M. & J.L.D.S., unpublished data). Therefore, we defined potential tiger habitat as all other lands (e.g., forest, grass, and shrub lands) below 1000 m in elevation. By visual interpretation of 1:250,000 false color composite satellite maps (Institute of Applied Geosciences, Offenbach, Germany, 1986) we digitized polygons of all potential tiger habitat (Davis et al. 1990). Cover types included Siwalik forest, which consists of rugged hills with steep slopes and deeply eroded streams, and low-elevation forest and grasslands, which consist of alluvial plain and sloping benches that rise to the base of the Siwaliks. These cover types were then classified as relatively undisturbed or degraded to highly degraded, producing four categories of cover-type quality.

Potential tiger habitat was then surveyed throughout Nepal and adjacent habitat in India (1987, 1991, 1993, 1994, 1995). J.D.S., C.M., and two to four Nepalese teams of research technicians surveyed the Terai, often dividing into two smaller teams of two to three persons. At each survey site we spent a few hours to half a day and surveyed one to two sites per day. To make our approach as efficient as possible, we used knowledge of tiger biology based on a long-term study in Royal Chitwan National Park (RCNP; McDougal 1977; Sunquist 1981; Smith et al. 1987*a*, 1987*b*; Smith et al. 1989; Smith & McDougal 1991; Smith 1993) and relied on local people's knowledge of where tigers occur to shorten our search time. We also analyzed remote sensing data to devise a rapid assessment strategy that minimized the time and effort required for field survey. At each survey site we interviewed local people to ascertain if there has been recent tiger sign (e.g., tracks, livestock kills). We learned to distinguish between village-bound "experts" and people who spent considerable time in the forest and were likely to have encountered and could recognize tiger sign. If people reported they had recently observed tiger sign, we asked to be taken to the spot to verify that the sign was produced by a tiger and to determine the sex and age class of the animal (McDougal 1977). When there was no information from local villagers, we searched likely tiger travel routes such as forest roads, human and animal trails, dry streambeds, and ridge tops (Smith 1984; Smith et al. 1987*b*). We determined the sex and age class of tracks based on our experience monitoring radio-collared tigers or those viewed or photographed (C.M. & J.L.D.S., unpublished data). Where the substrate was too hard to leave tracks, we confirmed the presence of tigers by sniffing trees that were likely to have been scent-marked by tigers. On a number of occasions we were able to detect the distinct odor of tiger scent marks (Smith et al. 1989).

Once tiger presence was confirmed, we questioned local villagers to determine if tigers lived there throughout the year. We classified an area as breeding habitat from reports of sightings of cubs or their tracks at any time during the year or from observations of adult tracks or kills throughout the year, indicating to us that tigers were resident. The area was classified as dispersal or buffer habitat if sign was observed only occasionally during the year. We often returned to a site in different seasons and subsequent years to verify that tigers were resident in the area. We made two assumptions about survey sites classified as breeding habitat: at a minimum one male and one female tiger were resident in the area, and the home range of these two animals was approximated by a 6-km radius that included all habitat similar to that found at the site (Smith et al. 1987*a*).

Survey sites were spaced 3–15 km apart, depending on spatial patterns and homogeneity of forest cover and condition. We searched for gaps in survey coverage by visually inspecting the relationship between potential tiger habitat and probable home ranges. We interpreted 1:50,000 black-and-white aerial photographs and 1:250,000 satellite maps and made site visits to determine if forest cover was similar in surveyed and unsurveyed areas. Where this was the case, we extrapolated breeding distribution to the entire block of habitat that occurred between two surveyed areas. When adjacent survey sites were classified as breeding and nonbreeding habitat, we manually interpreted the demarcation of tiger habitat based on natural features or distinct changes in habitat quality; when that was impossible, we demarcated tiger habitat as extending half the distance between sites.

Once tiger breeding habitat was delineated, we used a geographic information system to calculate statistics on the size and distance among areas occupied by tigers. Population size was then estimated based on the total area occupied by a population of breeding tigers, and information on the density of tigers was obtained as part of behavioral and ecological studies at RCNP (Sunquist 1981; Smith 1984; Smith et al. 1987*a*; C.M., unpublished data).

To resolve qualitative differences within our visual interpretation of satellite maps and to better estimate the gradient between habitat that supported resident breeding tigers with habitat that did not, a Landsat Thematic Mapper™ scene of central Nepal (row 151, path 41, March 1988) was classified into categories of forest condition and cover type. An unsupervised classification procedure, a type of cluster analysis (Lillesand & Kiefer 1994), was used to establish 30 spectral classes that were then assigned to a total of 11 vegetation classes. Assignment was done through the interpretation of 1:50,000 aerial photographs and by conducting ground surveys. The 11 vegetation classes were then grouped into classes of either good- or poor-quality habitat, based on ground sampling of each information class that provided data on the density of horizontal cover, the amount of human use, and the relative abundance of prey (including livestock), estimated by the number of pellet groups or dung piles per 10-m^2 plots (Smith 1984). Poor-quality habitat had less than 0.5 deer pellet groups per 10 m^2 (Smith 1984). To relate information on the occurrence of breeding or transient tigers or the absence of tigers to habitat quality in each of the seven administrative units, we calculated the ratio of good to poor habitat for each unit.

Results

Lowland and Siwalik forest cover forms a belt of potential tiger habitat that extends across the lowlands of Nepal; it is increasingly fragmented from west to east (Fig. 1a). South of this belt of forest is the almost totally deforested Gangetic Plain in the states of Bihar and Uthar Pradesh, India. To the north are the densely settled middle hills of Nepal. In over 20 years we have never heard reliable reports by foresters, hunters, or local people of tigers living in the middle hills of Nepal. Barriers to east-west dispersal occur at A, B, C, and D in Fig. 1b. At A and B, cultivation extends from the Gangetic Plain north into the middle hills, creating barriers to tiger dispersal; a weaker dispersal barrier occurs at C; and at D a 2-km strip of densely settled habitat separates the Dudwa Tiger Reserve in India from potential tiger habitat in Nepal. These four barriers divide tigers in the region into four populations: (1) Chitwan, (2) Bardia, (3) Sukla Phanta, and (4) Dudwa.

Chitwan Population

The Chitwan population is the largest tiger population in the region: its habitat encompasses an area of 2543 km^2 and includes the largest area of prime lowland forest in Nepal (Table 1; Smith et al. 1987*a*). This population also has the largest amount of tiger habitat within protected areas (1921 km^2). It extends 165 km east to west, lies in the central zone of the Nepalese lowlands, and includes Royal Chitwan National Park, Parsa Wildlife Reserve, Valmiki Tiger Reserve (India), and the Bara forest block. To the west, the Chitwan population is isolated from the Bardia population not only by a strong dispersal barrier at the city of Butwal (Fig. 1b, point B), but also by a weaker barrier of highly degraded habitat that extends 250 km between the eastern extent of the Bardia population and the western extent of the Chitwan population. To the east, Chitwan has a dispersal barrier at the Bagmati River gorge where cultivation extends from the Gangetic Plain to the base of the Siwalik Hills. East and west of this gorge the hills are highly degraded and heavily settled. There were tigers further east at Kosi Tappu Wildlife Reserve and Trijuga Forest (Fig. 1b) in the early 1970s (J.L.D.S. & C.M., unpublished data), but no tigers or tiger sign have been observed in Kosi since the mid-1970s. In Trijuga there may still be a few remnant individuals, but during surveys of the area in 1994 no tigers were documented there.

Bardia Population

The core of the Bardia population is in Royal Bardia National Park (RBNP). In 1987 the addition of the Babai Valley to the park nearly doubled its size (Fig. 1b). When we surveyed Babai Valley in 1987 there were tiger tracks only in the western part of the valley adjacent to RBNP. By 1994 tigers occupied the entire valley. Tigers are found another 93 km east of the park, but in this area habitat degradation, especially along the periphery of the forest, is resulting in the gradual reduction of tiger distribution. For example, in an area south of the western Rapti River (Fig. 1b, point B) where C.M. recorded tigers in 1968 and 1978, we still found tigers during our 1987 survey, but in 1994 cattle use of the forest had increased and there was no sign of tiger or its prey.

To the west of Bardia the population extends to within about 15 km of the Sukla Phanta population, but this thin belt of forest along the base of the Siwaliks is under in-

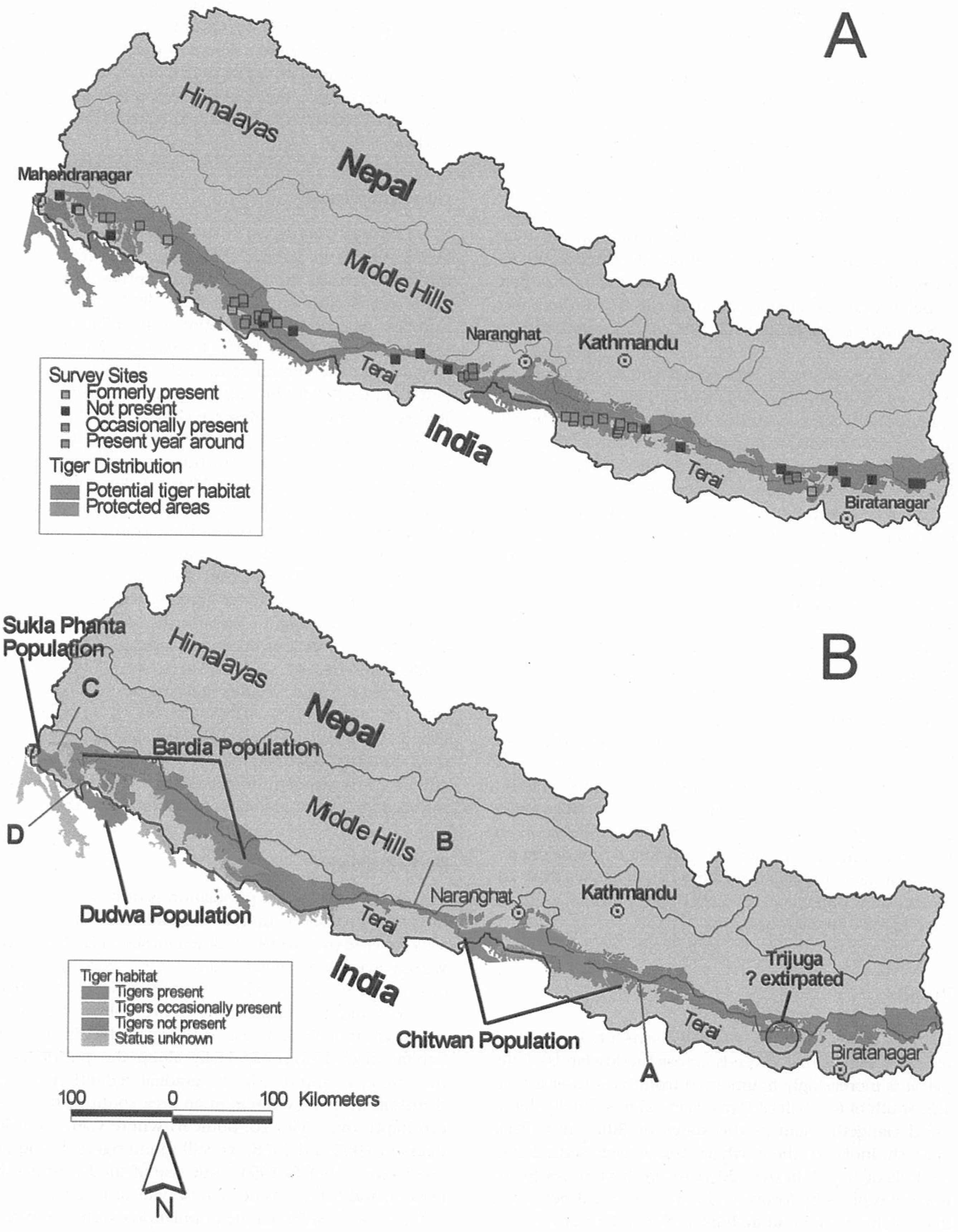

Figure 1. Survey sites and tiger distribution in Nepal in relation to potential habitat and protected areas (a) and extent of three tiger populations in Nepal (Sukla Phanta, Bardia, Chitwan) and an adjacent population in India (Dudwa) (b). (Letters A, B, C, D indicate dispersal barriers.)

Table 1. Population estimates of breeding tigers based on density estimates and area of distribution.

*Population**	*Total area*	*Area in reserves*	*Estimated breeding tigers*	*Estimated breeding in reserves*	*Estimated total population*
Chitwan	2543	1921	69	50	196
Bardia	1840	938	50	25	143
Sukla Phanta	320	320	16	16	46
Dudwa	674	674	18	18	53

* *The Chitwan, Bardia, and Dudwa populations are estimated to have a density of one tiger per 37 km^2; Sukla Phanta is estimated at one tiger per 20 km^2 (Smith et al. 1987a). We used a ratio of 2.8 cubs and subadult tigers per breeding adult to calculate the total number of tigers.*

creasing human pressure. Nepal's only east-west highway, which has just been completed, runs along the southern edge of this forest strip. Furthermore, the habitat west of the Karnali River is in the process of becoming isolated from RBNP because of habitat degradation. In 1987 we found tiger sign 14 km west of RBNP, but in 1993 we could not document the presence of tigers within 14 km of the Karnali River after an extensive 10-day field survey, which included interviews with local people who graze cattle and collect biomass in the forests. In 1987 we found tiger sign at five sites in the forest along the base of the Siwalik Hills, but none in the large fingers of forest that extend south of the east-west highway. During a 7-day survey in 1994 we obtained reports of tigers at only three of the five sites where tigers occurred in 1987.

Sukla Phanta and Dudwa Populations

The Sukla Phanta population occurs within Sukla Phanta National Park (SPNP; Fig. 1b); it is the smallest population in Nepal. The area is entirely lowland forest and grasslands and supports a high density of ungulates, including a population of more than 1000 swamp deer (*Cervus duvauceli*). Because the area is entirely lowland forest, we used a density estimate of one tiger per 20 km^2, which is the density estimate for a similar lowland area of RCNP (Smith et al. 1987*a*). The area south of Sukla Phanta in India was not surveyed; it is possible that tigers occur there along the Sarda River. Satellite imagery indicates that the potential habitat corridor between Sukla Phanta and India is about 1–2 km wide.

We have no information on the density of tigers in Dudwa; there is very little grassland habitat, however, so we do not expect that it is any higher than in RCNP or RBNP in Nepal. We calculated the number of breeding tigers in Dudwa using the same density estimate that we used for these parks.

Habitat Quality

Thirty spectral classes were assigned to a total of 11 vegetation classes. Seven vegetation classes constituted good-quality habitat, including open Sal forest, tall grass, mixed grasslands, upper bench Sal, mixed deciduous forest, Siwalik hills, and dry river courses; the remaining 4 vegetation classes constituted poor-quality habitat, including degraded deciduous forest, denuded hills, degraded Sal forest, and agricultural fields and pasture (Fig. 2). The ratio of good- to poor-quality habitat ranges from 86% to 16% across the seven forest units we classified (Fig. 3). The four areas with the highest ratio of good-quality habitat supported breeding tigers, one area with a marginal ratio of good habitat was used only occasionally, and two areas with low ratios of good habitat were not used by tigers (Fig. 3). Examination of ratios of good to poor habitat suggests that when the ratio drops below approximately 50%, breeding tigers no longer occur; when it drops below 30%, tigers are not found in the area.

Discussion

Metapopulation Structure of Nepal's Tiger Populations

Remote sensing, geographic information systems, and rapid assessment techniques to determine the presence of tigers and the abundance of tiger prey are critical tools for analysis and planning at landscape- and population-level scales. These technologies provide a means of (1) mapping the distribution of tigers at a resolution needed to determine the extent of individual tiger populations and (2) monitoring these populations to evaluate the success of conservation efforts. Dinerstein et al. (1996) made an excellent start at landscape-level planning by mapping the distribution of tigers at the landscape scale. Establishment of tiger conservation units was important for regional planning and identifying priorities, but the extent of these units was not verified in the field. We have focused on a complex of tiger conservation units in Nepal and adjacent forests in India and have conducted field surveys to determine the extent of populations and barriers to dispersal. We also verified—on the ground and from satellite data—the undocumented forest cover data from the World Conservation Monitoring Center (WCMC) that Dinerstein et al. (1996) used. We defined the metapopulation structure of tigers in Nepal and in adjacent areas in India, and we explored the use of remote sensing data to monitor the quality of tiger habitat.

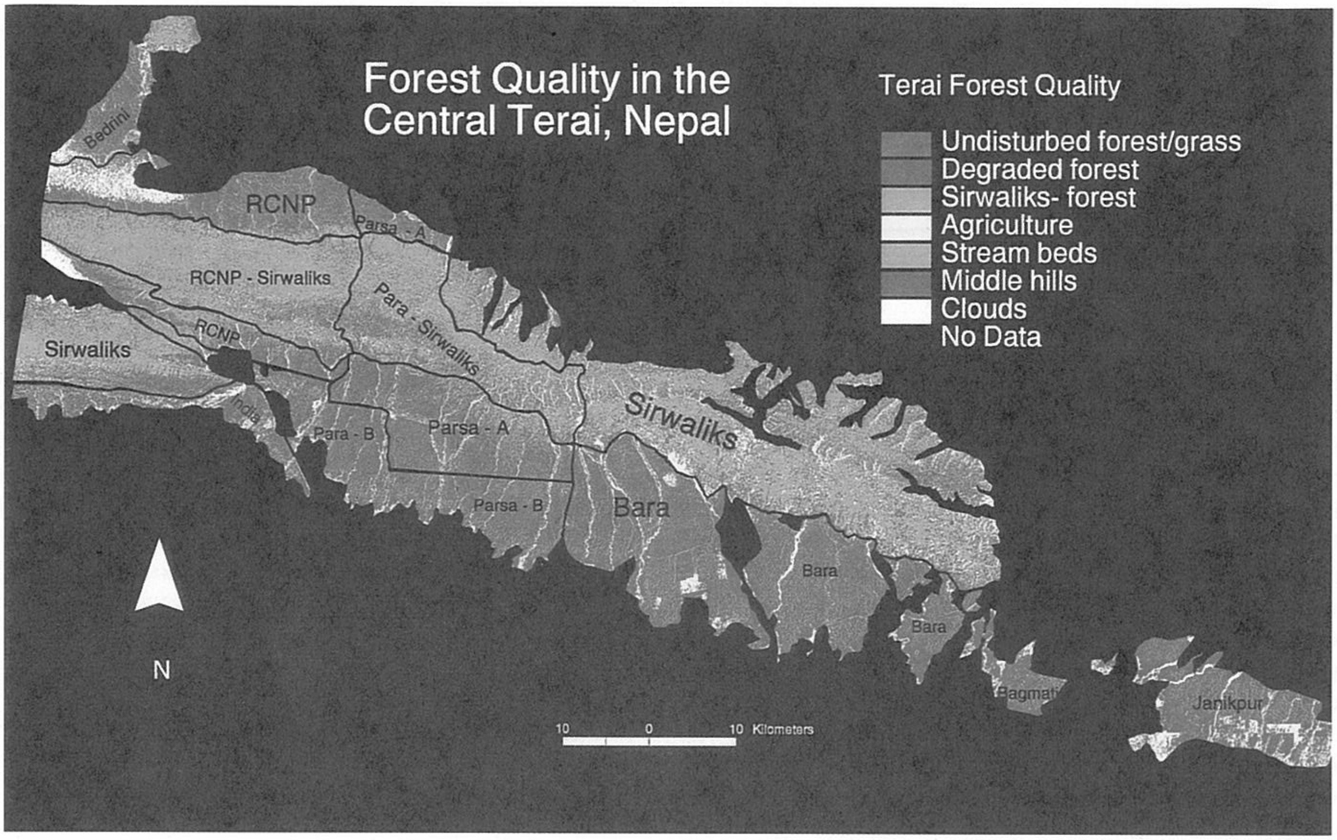

Figure 2. Forest quality in the central Terai, Nepal, based on thematic mapper classification.

Four tiger populations were identified. Our data on the extent of tiger habitat both within and outside of reserves demonstrates the need to expand current management beyond the parks to encompass the entire land base that supports these populations. Approximately one-third and one-half of the land occupied by the Chitwan and Bardia tiger populations is outside the respective parks. Both our calculated estimates of 37 and 28 breeding tigers and recent field censuses of 43 and 28 breeding tigers for Chitwan/Parsa and Bardia reserves, respectively, are in close agreement (C.M., unpublished data) and are in the range of population sizes where stochastic processes can lead to rapid extinction (Soulé 1980; Kenney et al. 1995). Based on our calculations, approximately 25% and 46% of the breeding animals of the Chitwan and Bardia populations, respectively, live outside reserves. It is not possible to conserve such small tiger populations if they continue to be subdivided into even smaller management units. As Miquelle et al. (1993) suggested, there should be a global goal of no further decline in tiger numbers. One of the keys to achieving this goal is to establish landscape-scale planning so that protected areas, national forests, community forests, and other lands be managed to maximize tiger habitat while still providing for the needs of local people.

Monitoring Habitat Quality

Defining the extent of tiger populations and securing the land base to support tigers through establishment of protected areas or through conservation zoning is not enough. We must also ensure that the land continues to support tigers. Habitat degradation and prey poaching are widespread and have reduced the prey base needed to support tigers. The condition of tiger habitat needs to be monitored to prioritize areas for conservation action and to measure the effectiveness of management efforts. For example, we found that there is a small difference in the ratio of good to poor habitat that distinguishes between areas where tigers live and breed year-round and areas that are used only occasionally by tigers. As a result we hypothesized that there may be a threshold in the distribution of good to poor habitat that reflects an overall reduction in the prey base, below which breeding does not occur (Fig. 3). An important objective of future research will be to determine the variance for these thresholds by examining a number of other regions. Once these thresholds and their variances are established, analysis of temporal sequences of satellite images would make it possible to track changes in forest condition and predict the ability of an ecosystem to continue to support tigers. For example,

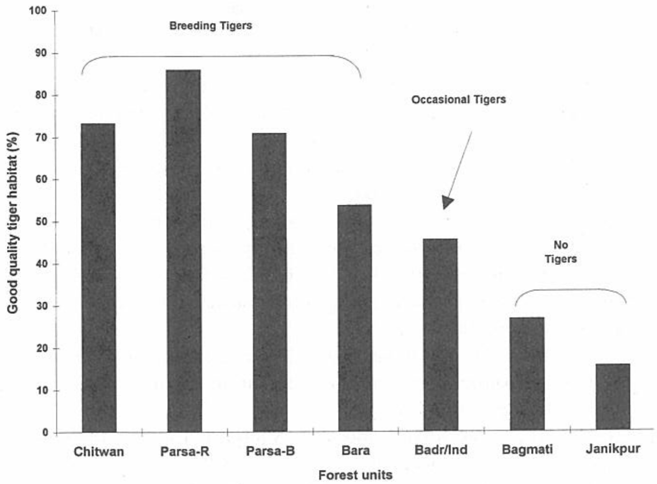

Figure 3. The ratio of good to poor tiger habitat across seven forest units in central Nepal (Parsa-R, Parsa Reserve; Parsa-B, Parsa Buffer; Badr/Ind, Bhadrini).

the relatively small difference in ratios of good and poor habitat at Bara where tigers breed and at Bhadrini where they do not (Fig. 3) suggests that any deterioration of habitat quality in Bara could lead to a major range contraction of the Chitwan tiger population.

Remote sensing is a critical, objective tool for monitoring the quality of forest cover. But to use it to monitor the quality of tiger habitat, the relationship between radiation reflectances, habitat quality, and prey abundance must be established. This relationship needs to be continually examined and refined because intensive poaching of tiger prey may result in floristically intact tiger habitat that simply does not have the prey base to support tigers (Rabinowitz 1993; U. Karanth, personal communication). Thus, remote sensing must be used in conjunction with a prey monitoring system to be an effective monitor of tiger habitat quality.

Beginning in 1986 the government of Nepal tacitly began implementing ecosystem-scale management for the Chitwan tiger population. In that year, Parsa Wildlife Reserve was established to the east of RCNP to expand the total area of tiger habitat under the highest level of protection (Smith 1984). Protected tiger habitat was again increased in 1989, when the government of Bihar, at the urging of the Nepalese government, created Valmiki Tiger Reserve adjacent to RCNP. These additions expanded the protected area component of the Chitwan tiger population to 75% of the population's entire distribution (2543 km^2) and created a potential multi-jurisdictional tiger management unit. The agencies managing these units in India and Nepal are beginning to coordinate their activities in this transboundary region. A fourth administrative unit in this ecosystem is the Bara forest to the east of Parsa. It supports approximately six additional breeding animals but is not presently managed to contribute to the larger ecosystem or regional biodiversity conservation goals.

Managing at the Population Level

The Nepalese Department of National Parks and Wildlife Conservation is considering a similar, multi-jurisdictional tiger management unit for Bardia that will encompass much of the remaining tiger habitat to the east of Bardia. The Bardia tiger population extends 180 km from east to west. Royal Bardia National Park, located in the center of this population, makes up about 50% of the population's range. To the west of RBNP, a narrow habitat peninsula ranging from 3 km to 8 km wide extends 93 km long. It is under increased human pressure as a result of the completion in 1991 of the highway from the Karnali River west to Mahendranagar. Before the road was built, villagers typically gathered a single load of wood that they carried home for their own use. Now, with the new road, villagers gather several bundles of wood daily to sell to passing truck drivers before returning to their homes with their own bundle. This increased harvest of forest biomass accelerates forest degradation, decreases ungulate biomass, and may explain the recent extirpation of tigers at two of the five sites where they were previously documented in 1987.

Changes are occurring in Nepal, however, and there is potential for ecological restoration of tiger habitat. In the late 1980s a new land ethic began to emerge across the lowlands. Agroforestry increased on privately owned lands, and local user groups increasingly established community forests on degraded public land. Simultaneously, the Department of National Parks and Wildlife Conservation began shifting its management efforts to the interface between parks and people. In 1993 an amendment embracing buffer-zone management was added to the National Parks and Wildlife Conservation Act 2029, which allocates 30–50% of park revenues for buffer-zone management and community development in the periphery of protected areas. This act provides a means for local people to meet their resource needs and at the same time to participate in landscape-scale plans that can restore the extent and connectivity of tiger habitat in the Terai. Ultimately, tiger conservation will depend on the local people's ability to establish sustainable relationships with the forest ecosystems of the Terai.

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