CHAPTER 12

Tiger range collapse and recovery at the base of the Himalayas

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An adult tigress needs nearly 3000 kg of meat-on-the-hoof each year; feeding cubs requires an additional 50%. Tigers meet this demand by killing large, hoofed mammals—large deer, wild pigs, and wild cattle. © John Seidensticker.

The tiger's (*Panthera tigris*; Fig. 12.1) threatened status became widely appreciated 40 years ago. Since then, the human population has doubled in South and Southeast Asia (UN 2007), contributing to massive land-use change across most of the tiger's once extensive range. All signs point to an impending range collapse: (1) tigers now occupy only 7% of their historic range (Sanderson *et al.* 2006); (2) tiger geographic range has declined by 40% in only 10 years (Dinerstein *et al.* 2007); and (3) tiger numbers in India are down to ~1410 individuals >1.5 years of age (Jhala *et al.* 2008), about half the number reported in the 2001–02 national estimate (Government of India 2005). More

comprehensive surveys and studies across the shrinking range confirm that we are learning more about fewer tigers.

The overall gloomy trend masks positive results in the recovery of tiger populations in a few selected landscapes. In this chapter, we report on one such effort centred in the Terai zone of southern Nepal and adjacent northern India (Fig. 12.2). These remaining forests and tall-grass savannas skirt the southern foothills of the Himalayas and contain the highest densities of tigers on earth. After providing a brief primer on Terai ecology, we summarize advances in tiger biology—many originating from

Figure 12.1 Smithsonian-Nepal Tiger Ecology Project Tigress 101 (January 1974), the first tiger captured and fitted with a radio transmitter collar. She was subsequently tracked by foot, from trained elephants, and from tree platforms (from which this photo was taken), as she lived and reared her cubs in the riverine savanna/grassland and *sal* forest in eastern Chitwan National Park, Nepal. Her territory abutted farmland with villages nearby but she did not venture beyond the natural vegetation cover in the park. She produced at least four litters. Her first territory was eventually taken over by one of her daughters and she subsequently established a new one in lower quality habitat. Tigress 101 lived to be at least 12 years old before she was poisoned by villagers. © John Seidensticker.

studies conducted in Terai reserves—that inform conservation efforts in the Terai and elsewhere. The results of these field studies have expanded the conservation focus from protecting increasingly isolated core reserves to designing conservation landscapes that can sustain wild tigers as meta-populations. Finally, we show how socio-economic interventions, in the form of community-managed forestry programmes, have provided the underpinning of landscape-scale conservation. The ambitious, overriding goal of this restoration programme, called the Terai Arc Landscape (TAL; Joshi *et al.* 2002), is to facilitate

recovery of wild tiger and prey populations and to ensure that species and habitat conservation becomes mainstreamed into the rural development agenda.

Nearly 10 years since its inception, the TAL experiment illustrates how critical tiger dispersal and breeding habitat can be restored, while enhancing local livelihoods. The importance of bottom-up habitat restoration efforts, such as TAL, complement top-down, trans-national strategies and enforcement to combat the illegal trade in tiger parts, key elements required to spark a range-wide recovery of tigers.

Tigers in the Terai

Terai: an ecological primer

Unlike the mid-elevation forests of the Himalayas, the Terai forests at the foot of the mountains on the northern edge of the Ganges Plain were sparsely settled until the early 1950s. 'The Terai ... was commonly invoked as a region almost defined by death. This tract was considered so deadly as to be impassable for Indians and Europeans alike ...' in the early nineteenth century (Arnold 2006, p.49). A deadly strain of malaria precluded extensive farming of the flood plain. The Nepalese Terai was considered a biological barrier to military campaigns emanating from colonial India and remained largely intact until the late 1950s and early 1960s. Widespread use of dichlorodiphenyltrichloroethane (DDT) eradicated malaria and opened the Terai as an agricultural frontier (Rose 1971).

Fanning out from the southernmost Himalayan foothills, the Terai incorporates the gravelly Bhabar and sandy areas formed from the alluvium deposited from the high mountains and the adjacent, parallel Sivalik range (in India) and Churia Hills (in Nepal; Fig. 12.3a). We refer to the low hills and flood plains collectively as the Terai. The hot, humid, monsoon (June–September) is marked by heavy rains and flooding, the latter being the major structuring force in this ecological community. Winter temperatures are occasionally near freezing in the misty, early mornings. The water table, a critical variable in determining distributions of tigers, lies 5–37 m deep. A high water table creates marshy areas that are drained by numerous southeasterly flowing rivers (Shukla and Bora 2003), and these areas attract tigers and their prey. An 'inner' Terai zone is
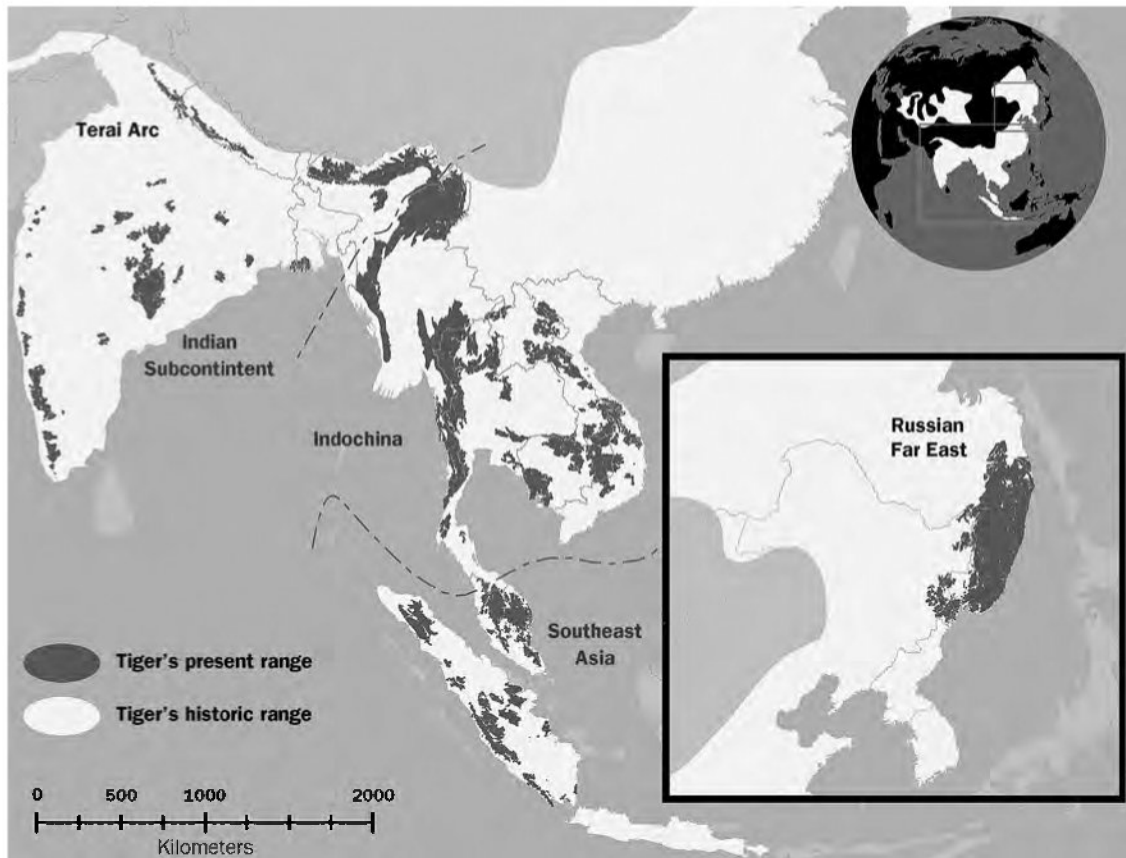
Figure 12.2 Historic (*c.* 1850) and present distribution of tigers. Tigers inhabit only 7% of their historic range today. The Terai Arc Tiger Conservation Landscape (TAL) is located in northern India and Nepal in the forests at the base of the Himalayas. Map courtesy of World Wildlife Fund-US, Wildlife Conservation Society, and Smithsonian Institution.

composed of several broad river or 'dun' valleys—the most famous being Dehra Dun in India and Chitwan in Nepal—lying between the Sivalik/Churia Hills and the outer range of the Himalayas (Kimura 1999).

Some of the world's tallest grass species occur on these flood plains and create the world's tallest grasslands, a globally rare phenomenon (Lehmkuhl 1989, Wikramanayake *et al.* 2002). Today, most of the fertile areas have been converted to agriculture, with sugar cane and rice grown widely.

A quintessential tiger landscape

In the first half of the twentieth century, chroniclers of the great hunts described an abundant tiger popu-lation in the Terai. These royal 'shikars' were staged when the threat of malaria abated during the 2-month winter season. For example, the ruling Rana family of Nepal and their guests shot 41 tigers during the 1933 winter hunt and 120 tigers during the 2-month 1937–38 season (December–January) in the Chitwan Valley (Smythies 1942). Tiger enthusiasts learned of the Terai and the adjacent Himalayan foothills from the books of F. W. Champion, who pioneered the use of flash camera traps in Asia. His classic accounts, *The Jungle in Sunlight and Shadow* (1925) and *With a Camera in Tiger-Land* (1927), offered the first outsider's glimpse of this remarkable jungle. The western Terai foothills came to life in Jim Corbett's hunting stories (1946). After World War II, forest de-partments of India and Nepal (after Nepal opened to

outsiders in 1954) encouraged tiger hunting to generate revenue; this practice continued until the enactment of protective legislation in India in 1972 and Nepal in 1973. Before the ban, wealthy American hunters stalked tigers in the Terai and in 1968, near India's border with western Nepal, shot what some consider the largest example on record. This specimen is on permanent display in the Smithsonian's National Museum of Natural History.

Today, the 11 major protected areas (Table 12.1) established along the Terai provide snapshots of the former glory of this entire zone (Fig. 12.3b). Healthy populations of five species of cervids—barking deer (*Muntiacus muntjak*), hog deer (*Axis porcinus*), spotted deer (*Axis axis*), sambar (*Rusa unicolor*), and swamp deer (*Rucervus duvauceli*) share the flood plain with wild boar (*Sus scrofa*), gaur (*Bos frontalis*), wild water buffalo (*Bubalus bubalis*; now extirpated), nilgai (*Boselaphus tragocamelus*), and blackbuck (*Antilope cervicapra*). The steep slopes of the Sivaliks and Churias support serow (*Capricornis thar*) and goral (*Naemorhedus goral*). All serve as prey for the tiger and sympatric predators, dhole (*Cuon alpinus*) and leopard (*Panthera pardus*). Tigers also take the young calves of Asian elephants (*Elephas maximus*) and greater one-horned rhinoceros (*Rhinoceros unicornis*).

Tiger populations on the Chitwan flood plain could quickly recover from the intensive hunts of the 1930s because the grasslands and forests thriving on rich alluvium supported extraordinary prey densities. The large mammal assemblage, even with the loss of large herds of wild water buffalo and swamp deer across the lowlands, rivalled the ungulate biomass of the most productive African rift valleys (Seidensticker 1976b). Consequently, tiger densities in the protected flood plains in the Terai rank among the highest recorded (>15 tigers over 1 year of age/100 km²; Carbone *et al.* 2001).

The flagship national parks of India and Nepal anchor the TAL from west to east. Corbett National Park was established as India's first national park in 1936 and Chitwan as Nepal's first park in 1973, both of which are now World Heritage Sites. The other core areas in the Terai were gazetted after 1972, although the Nepalese core-protected areas served as royal hunting reserves in the previous decades.

All of the protected areas contained villages that have since been relocated.

There are extensive blocks of recovering, selectively logged *sal* forests in the ~1000 km long conservation corridor of the TAL, extending from the Yamuna River in India to the Bagmati River in Nepal. Development pressures in the TAL are intense. Most of the larger rivers are dammed where they emerge from the Sivalik and Churia Hills to store water for irrigation and power generation for the cities of the Gangetic Plain. Five of 12 Terai forest divisions overlapping with the TAL in India hold large-scale plantations of exotic softwoods (Johnsingh and Negi 2003). The highly productive, tall-grass savannah and riverine forests that previously characterized the sandy areas of the Terai have been largely reduced to those included within the major protected areas.

Conservation science challenge

Restoration of tiger populations across their range poses one of the greatest challenges in conservation biology. The few remaining populations survive in mostly fragmented forest landscapes and recovery entails creating large spaces with abundant prey that are free of intensive human disturbance (Seidensticker *et al.* 1999). In the TAL specifically, the 11 reserves nest within a human-dominated landscape of extreme poverty and many landless people. Thus, tiger conservation faces the added challenge of addressing land tenure issues, local rights, and the legitimate economic aspirations of the rural poor (Tharoor 2007). At the other end of the economic spectrum, a rising Asian middle class has created economic conditions and markets that drive rampant poaching and illegal trade in tiger parts (Dinerstein *et al.* 2007; Damania *et al.* 2008).

Conservation efforts in any tiger landscape, whether in the TAL, the Russian Far East (RFE), or the Sundarbans in the Gangetic delta of India and Bangladesh, must address two fundamental questions: what controls tiger population numbers, and what factors affect the probability of population persistence? These questions concern the tiger's ecology and the mix of ecology and human values. Years of experience tells us
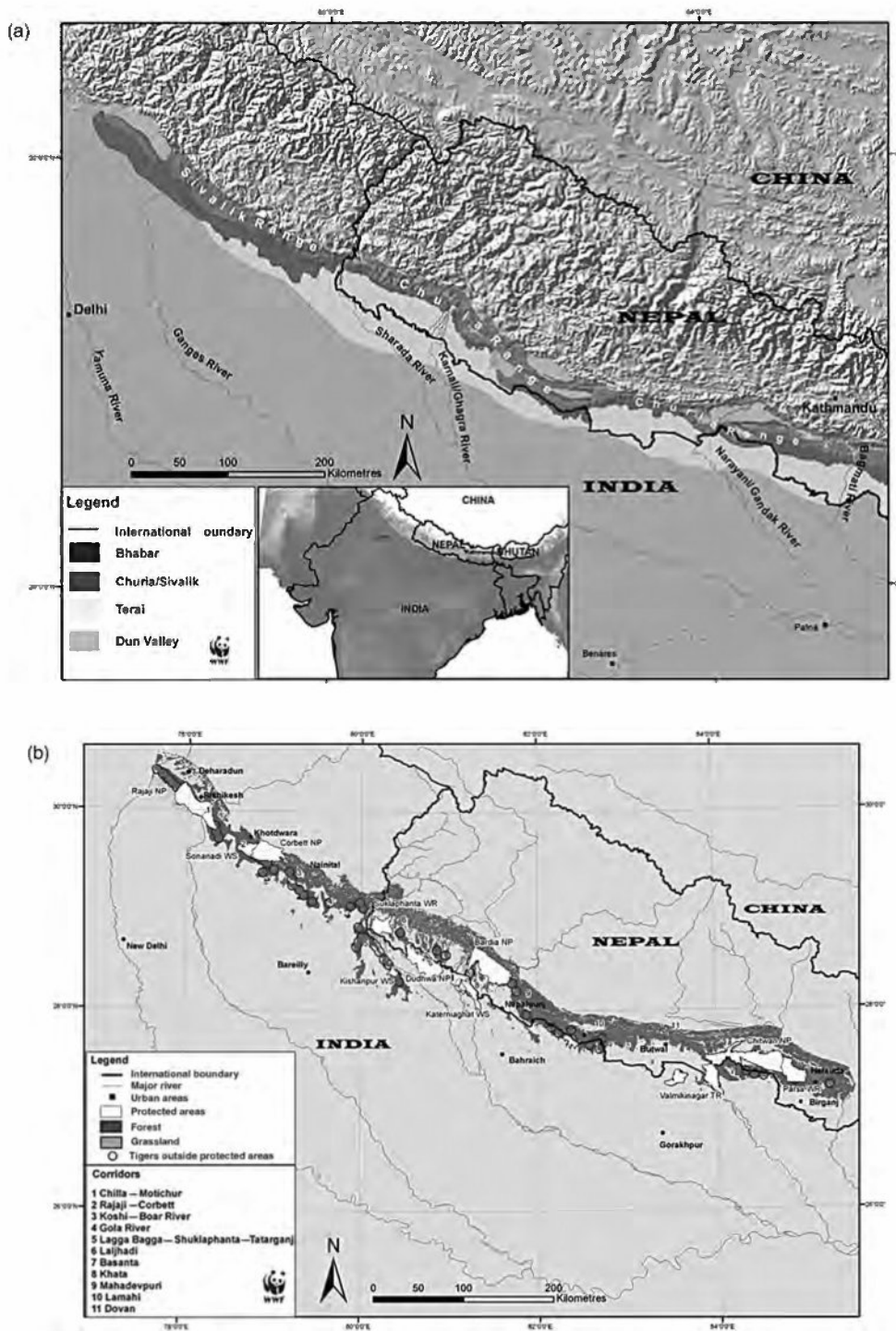
Figure 12.3 Features of the Terai Arc Tiger Conservation Landscape (TAL). (a) We refer to the low hills and flood plains at the base of the outermost ranges of the Himalayas collectively as the Terai. The Terai incorporates the gravelly *Bhabar*, sandy river flood plains, the parallel Sivalik range (in India) and Churia Hills (in Nepal), and the 'inner' Terai zone composed of several broad river or 'dun' valleys lying between the Sivalik/Churia Hills and the outer range of the Himalayas. (b) TAL land cover, protected areas, locations of tigers found living outside the protected areas, and key bottlenecks that must be maintained as connecting corridors to enable the dispersal of tigers and other large mammals across the landscape.

Table 12.1 Protected areas in the Terai Arc Landscape (TAL).

Major protected areas: east to west	Date established	Size (km²) (additional buffer)
Parsa Wildlife Reserve, Nepal[a]	1984	499 (298)
Chitwan National Park, Nepal[a]	1973	932 (750)
Valmiki National Park, India[a]	1989	336 (348)
Sohelwa Wildlife Sanctuary, India	1988	453
Bardia National Park, Nepal[a]	1977	968 (327)
Katarniaghat Wildlife Sanctuary, India	1976	551
Dudhwa National Park, India[a]	1958	490 (124)
Kishanpur Wildlife Sanctuary, India	1972	227
Suklaphanta Wildife Reserve, Nepal[a]	1975	305 (243)
Corbett Tiger Reserve incorporating Corbett National Park and Sonanadi Wildlife Sanctuary, India[a]	1936	1288
Rajaji National Park, India[a]	1983	821
Total		6870

[a] Core tiger-breeding areas.

that tiger populations can be restored by (1) stopping the killing of tigers; (2) reducing anthropogenic impacts on the core tiger-breeding areas; (3) increasing the number of core-breeding areas; (4) reconnecting the cores through forest corridors; (5) ensuring adequate prey populations in cores and connectors; (6) creating the institutional arrangements to support these interventions; and (7) practising adaptive management and innovation in designing field conservation efforts. These measures in whole, or in part, are being implemented within the TAL today.

The proximate challenges of maintaining tigers, even at the local level of protected areas, are daunting. Insular reserves, the strongholds of tiger conservation efforts in South Asia, are rarely large enough to ensure the conservation of ecologically, demographically, and genetically secure tiger populations that are resilient to disturbance events (Woodroffe and Ginsberg 1998; Soulé and Terborgh 1999; Wikramanayake et al. 2004; Ranganathan et al. 2008. Not only must tigers be able to disperse among the reserves, but conservation interventions must also seek to expand tiger populations in all core areas and encourage breeding between core areas through habitat recovery. These principles underpin the TAL programme.

Science-based tiger conservation in the Terai: a short history

Tiger field research has its roots in the Terai jungles, and in Chitwan National Park in particular. Science-based work on tigers began there in 1972, catalysed by the innovation of radio-telemetry. Following collared or known individuals, Seidensticker (1976a), McDougal (1977), Sunquist (1981), and Smith (1993) followed collared or known individuals and focused on quantifying tiger life history. Baseline knowledge on mating, rearing, foraging, dispersal, and refuging (after Eisenberg [1981]) emerged. In addition, ecological responses to differences in prey density, prey species composition, and habitat associations were revealed.

Field investigations need to adapt to local circumstances. The first scientists in Chitwan assumed their site would be a remote, pristine wilderness in which to study free-ranging tigers. Their naiveté ended abruptly during the reconnaissance phase: Chitwan's tigers inhabited a small island (~1000 km²) in the middle of a human-dominated landscape (Seidensticker et al. 1999). This situation proved typical across many South Asian wildlands, where dynamic land-use change was already underway. Accordingly,

field research refocused on the numerical and beha- vioural responses of tigers, leopards, and their large ungulate prey at the park–village interface as a criti- cal step in understanding the persistence and extir- pation of large mammals in Asian landscapes.

In 1972, McDougal and colleagues began the lon- gest running longitudinal study of tigers that con- tinues to this day. McDougal's study linked closely with the Smithsonian-Nepal Tiger Ecology Project founded in 1973 by H. Mishra, J. Seidensticker, R. Simons, and K. M. Tamang, and was followed in subsequent years by M. Sunquist, J. L. D. Smith, and E. Dinerstein (2003). Dinerstein (1979a, 1979b, 1980) first investigated tiger ecology on the flood plains of Nepal's Karnali River in 1975, work that was continued by P. Wegge and associates (2004) beginning in 1992. D. Smith, M. Shrestha, B. Gur- ung, and E. Wikramanayake (Smith *et al.* 1999; Wikramanayake *et al.* 2004; Gurung *et al.* 2006b) investigated tiger occupancy along the length of the Nepalese Terai to describe tiger meta-population structure.

Less progress was made in understanding tiger ecology in the Indian Terai until the Wildlife Institute of India (WII) was formed in Dehra Dun, adjacent to Rajaji National Park, in 1982. A. J. T. Johnsingh and associates documented tiger occu- pancy and breaks in forest connectivity along the length of the Indian Terai (Johnsingh and Negi 2003; Johnsingh *et al.* 2004). A. Harihar, A. J. Kurien, B. Pandav, and S. P. Goyal (Harihar *et al.* 2007) from WII documented the recovery of tiger and prey populations in the Chilla Range within Rajaji National Park following the voluntary resettlement of graziers out of the areas in 2002.

Deconstructing the resilience of the Terai Arc Landscape

As noted by one of the earliest Terai researchers, being a tiger biologist requires one to become an ungulate biologist (M. Sunquist, personal communication), because ungulate distributions hold the key to under- standing tiger ecology. Through a series of studies (Chitwan: Seidensticker 1976b; Mishra and Wemmer 1987; Suklaphanta: Schaaf 1978; Bardia: Dinerstein

1979a, 1979b, 1980) a better comprehension of pop- ulation dynamics, habitat preference, and life history of tiger prey emerged. The impacts of human distur- bance on the forests in the western Sivaliks and the manifestation of these impacts on ungulate densities and, ultimately, on tiger densities were reported by Harihar *et al.* (2007). Dinerstein (1987) took Sun- quist's argument one step further: to be a tiger or ungulate biologist, we needed to be plant ecologists, because understanding successional patterns and the natural disturbance factors that shape the vegetation is key to tiger and prey population dynamics, habitat preference, and recovery. The resilience of the Terai ecosystem, as it turns out, is linked to how dominant plant species respond to habitat disturbance through annual fires and monsoon flooding.

To this end, we discuss critical elements of ecosys- tem resilience and the potential to conserve a viable tiger meta-population in the TAL. First, we briefly describe natural disturbance regimes and vegetation dynamics. Second, we illustrate how the distribution of plant communities and prey distributions influ- ence tiger behavioural systems and life history char- acteristics (work done primarily in Chitwan). Third, we assess tiger range collapse in the Terai and the potential for recovery. Finally, we document res- ponses by tigers to newly available habitats regener- ated by interventions through community forestry programmes in the Nepalese TAL.

Plant succession in Terai forests and grasslands

Plant succession and vegetation responses to distur- bance regimes in the Terai were initially modelled by Dinerstein (1987). The major vegetation types along the riverbanks are tall grass, riverine forest, and derived savanna grasslands. Away from the rivers, *sal* (*Shorea robusta*) forest is dominant, often in pure stands or mixed with other tree species. Tall-grass areas and early riverine forests are generally flooded during the monsoon. Moist-mixed riverine forest is more common where flooding is less severe but where the soil remains waterlogged during the mon- soon. Secondary open mixed forest is common along rivers, where soils are deeper and better drained than

in riverine forest. This type often abuts mature *sal* forest with shrub and grass understories that grows in dryer soils away from the rivers. Open *sal* forest occurs on the dry, steep, south-facing slopes of the Churia and Sivalik Hills.

Key to restoring prey and tiger populations is conservation of the earliest successional stage of the flood plain ecosystem. The riverbeds are dominated by near mono-specific stands of the grass *Saccharum spontaneum*, a wild sugar cane, and support the highest ungulate biomass and highest density of breeding tigers in Asia. This dominant association is adapted to annual, severe disturbance events: monsoon floods. *Saccharum spontaneum* sprouts new shoots soon after inundation by floods, and also after cutting, grazing, or burning. Because it remains green all year long, it is a major food plant for large ungulates.

Without human interference, the successional sequence is from short grass to tall grass and from diverse successional forests to continuous mature forests. The shift from short grass and intermediate-sized *Imperata cylindrica* to tall elephant grasses results in lower deer densities, particularly spotted deer because the grasses become less palatable and unreachable as they mature. Areas of the tall-grass *Narenga porphyracoma* and *Themeda* spp. support the lowest ungulate biomass among grassland types.

Burning, cutting, and domestic livestock grazing alter community structure of *sal* forest, early riverine forest, moist-mixed riverine forest, and secondary open mixed hardwood forest. The result is a derived savannah grassland type favourable to deer and other ungulates. *Sal* is fire resistant and its seedlings are much less palatable to deer and other ungulates than other tree species, which may explain its emergence as the dominant vegetation type. But where *sal* forest has been cleared, derived savannahs can be maintained through annual burning. The intermediate-sized *Imperata* grass, used locally for thatch, dominates old village sites for a number of years depending on the grazing pressure and water table. Where there is a high water table and low grazing pressure, *Imperata* grassland is eventually replaced by tall grasses such as *Narenga porphyracoma*. Heavy grazing pressures by domestic livestock combine with annual fires to arrest grassland succession; when protected from these pressures, these tall grasslands recover rapidly.

Spotted deer mostly frequent derived savannah grasslands and early riverine and moist, mixed riverine forests, whereas swamp deer and hog deer prefer short or tall grasslands. Sambar frequent mature *sal* forest and riverine forest. Nilgai and black-buck survive only in short grasslands and are quickly killed by tigers in tall grass. Wild boar, rhinoceros, and water buffalo also prefer *Saccharum spontaneum* grassland and secondary forest to mature *sal* forest.

The predominant invasive species that reduce the carrying capacity of Terai habitats are *Lantana camara, Chromolaena odorata, Cannabis sativa,* and *Mikania micrantha*. *Mikania* first appeared in Chitwan in the late 1990s and has taken over large areas of riverine forest and grasslands; wild ungulates avoid it. *Lantana*, with little forage value, is found across the Terai, especially in sandy soils near river banks heavily overgrazed by domestic livestock. *Cannabis* grows naturally in many areas but has also escaped from cultivated lands and encroached into the grassland of some protected areas (e.g. Corbett Tiger Reserve), where managers expend great energy and resources trying to remove it (J. Seidensticker, personal observation). The threat of invasion of *Saccharum spontaneum* grasslands by exotic species combined with land clearing and overgrazing by domestic livestock suggest that the most critical habitat for tiger restoration in the TAL is also the most threatened.

Variation in the tiger's behavioural and life history traits in response to resource distribution

We summarize the modal characteristics of the tiger behavioural systems and life history strategy in Table 12.2, based largely on data from Chitwan.

Feeding ecology

Tigers are the largest obligate meat-eaters in Asian wildlands, with population density limited by available large ungulate biomass. Therefore, prey density is the principal driver of tiger density in systems largely unaffected by poaching of either tigers or prey. Karanth *et al.* (2004c) developed a model that

Table 12.2 Modal tiger life history and behavioural systems.

Body size	Males (235 kg, 200–261) 169% > females (140 kg, 116–164)	Sunquist and Sunquist (2002)
General activity	Usually active and moving between sunset and sunrise although they sometime hunt during the day	Sunquist (1981)
Social system	Dispersed; Eisenberg social complexity rating: 2 lowest out of 20	Sunquist (1981); Smith *et al.* (1987)
	Females defend stable home ranges or territories and are intolerant of conspecifics except dependent offspring and during sexual receptivity; females do relinquish portions of their exclusive home ranges or territories to mature daughters, after which there is no persistent association. Female territory size tracks available prey biomass	
	Breeding males defend territories that overlap those of several breeding females. Size is dependent on the assertiveness of adjacent males	
	The transient portion of the population is composed of post-dispersal, non-breeding adult animals that move through in their search for open territories	
Mating	Polygynous; little or no synchrony of reproduction among females; individual males establish and maintain territories over a number of years; male defence of a mate is transitory but he excludes other adult breeding males from his territory, which is large enough to overlap a number of female territories. This restricts a female's chance to breed with males other than the resident territorial male, unless her territory is overlapped by two males. Females maintain individual stable territories that may be subsequently subdivided among female offspring	Sunquist (1981); Smith *et al.* (1987); Smith and McDougal (1991); Barlow *et al.* (2009)
Rearing	Gestation is 103 days; lactation is 90 days. Single adult female lives on a stable territory and raises her young alone; no direct male care, but territorial males exclude other males, resulting in increased cub survival; females mobility is restricted during the first months of her cubs' life; the females begins to move with cubs when they are 2 months of age	Eisenberg (1981); Sunquist (1981); Smith (1993)
Dispersal	Tigers disperse at 23 months (19–28) of age, 1.6 months after a new litter is born. Males disperse further than females and settle in poorer habitat. There is a tendency towards female-biased philopatry by offspring, resulting in female kin clustering with a mean degree of relatedness between females of 0.35	Smith *et al.* (1987); Smith and McDougal (1991); Smith (1993)

(Continued)

Table 12.2 (Continued)

Foraging	Low seasonal flux in the food base that may be highly predictable in some habitats and unpredictable in others; solitary staking and ambush hunting style; high defence of resources: territorial males and female hunt alone (or with their larger offspring) in their exclusive areas; the resident territorial male areas overlap those of the females. No cooperative hunting between adults; females with large offspring may show some cooperation when hunting very large prey; food sharing between females and cubs, even non-reproducing subadults sharing her territory; males dominate over the females at kills	Sunquist (1981); Seidensticker and McDougal (1993)
Refuging	Both males and females 'lie up', resting during the day in thick cover, sometimes in pools of water during very hot periods; females conceal their very young cubs in sheltered areas but move them to new sites frequently	Seidensticker (1976a); Sunquist (1981)
Anti-predatory behaviour	Individualistic; cubs are vulnerable to newly established territorial male tigers, perhaps dhole packs, and fires set by people to burn them out	Sunquist (1981); Smith and McDougal (1991)

predicts tiger densities based on prey densities. Their key finding was that prey densities in alluvium, such as in the Kaziranga National Park in the Brahmaputra River Valley of India, supported among the highest tiger densities recorded (16.76 > 1 year of age/100 km^2). Kaziranga is similar in vegetation to the marshy areas of the Terai flood plains.

Tiger prey items span a wide range in body mass (20 to ~1000 kg) but, on average, tigers kill ungulates in the ~100 kg size class (Seidensticker 1976a, Seidensticker and McDougal 1993). Although tigers kill prey as encountered when hunting, they selectively seek and kill large-bodied ungulate prey, thereby gaining access to considerable portions of the ungulate biomass attributed to a relatively few individuals. The average kill rate is ~50 ungulates/adult tiger/year, while a tigress with large cubs kills 60–73 ungulates/year. They remove about ~10% of the standing ungulate biomass annually (Sunquist 1981). However, tigers are frequently deprived of kills by humans. This kleptoparasitism is a significant factor (e.g. 10 tiger kills were taken by people in an 8-month period in Sunquist's study area) that

determines kill rates and food availability both inside and outside protected areas (Sunquist 1981; A. J. T. Johnsingh and E. Dinerstein, personal observation).

Across South Asia, ungulate biomass varies with water availability, soil type, vegetation cover, accessibility to crops, urbanization, and protection (Eisenberg and Seidensticker 1976). Wild ungulate biomass in Chitwan, and across the Terai, follows a gradient, with highest densities and biomass in riverine forest and tall/short-grass mosaic grazing areas on newly recovering flooded sites (67 individuals/1 km^2, 2800 kg biomass/1 km^2). This contrasts to lower densities and biomass found in *sal* forest-clad hills but near permanent water (18 individuals/1 km^2, 1300 kg biomass/km^2; Seidensticker 1976b). Radio-collared tigers on the flood plain avoided open farmlands, and only occasionally visited adjacent *sal* forests (Sunquist 1981; Smith 1993). In Chitwan, the numerical response to this habitat gradient for resident adult-breeding tigers was dramatic: the density of tigers living in tall-grass savannah/gallery forest was 7/100 km^2, while in mixed riverine/tall-grassland savannah and low elevation *sal* forest it was

5/100 km^2, and dropped to 2.7/100 km^2 in upland *sal* forest.

Tiger sociality

Briefly, the resident-breeding tiger population in Chitwan lived in exclusive home ranges (or territories), while the transients were those unable to establish territories (Table 12.2). Tiger territories averaged 23 (13–51) km^2 for females and 68 (33–151) km^2 for males and were defended both directly and indirectly against other same-sex adults (Sunquist 1981; Smith *et al.* 1989), but with substantial overlap between opposite sexes. Territory size for males were as large as 151 km^2 to as small as 33 km^2 over time, depending on the number of resident males that were living on the park's flood plain (Smith *et al.* 1999). Sunquist (1981) found that a single male territory overlapped those of as many as five breeding female territories and Smith (1993) found one resident male territory overlapped those of seven breeding females. Typically, one male's range overlapped three or four female territories (Table 12.2). Breeding males attempted to mate with as many females as possible, and performed no parental activities.

The area occupied by breeding adults also contained non-breeding adults, which formed ~20% of the population. In 1976, for example, Sunquist (1981) and Smith (1993) found that in their flood plain study area in Chitwan there were 15 resident adults, 14 pre-dispersal offspring, and 3 post-dispersal transient tigers. Karanth *et al.* (2006) estimated the transient portion of the tiger population to be 18% in Nagarahole National Park, India. These were usually young (2–4 years of age), post-dispersal individuals, or uncommonly, old tigers, usually females, displaced from their territories.

Breeding system and tiger lifetime reproductive success

Lifetime reproductive success of multiple females in the population has yet to be documented. But the tigress Chuchchi in Chitwan produced, over 15 years, 5 litters and a total of 16 cubs, 11 of which

survived to dispersal age (McDougal 1991). Chuchchi's three daughters settled locally, all producing cubs; one in the territory of an adjacent female following her death, a second daughter claimed the northern portion of her mother's range, and the third dispossessed her then 14-year-old mother of the southern portion of her range. Chuchchi then roamed widely outside her regular home range, although the actual extent of these movements was uncharted. Eventually, she was killed by a young male, the son of an unrelated neighbouring tigress, when she returned to her former territory. Three sequential territorial males whose ranges overlapped hers sired her five litters and four others may have bred or attempted to breed with her but those litters perished (McDougal 1991). Sunquist (1981) estimated optimal lifetime production for a tigress living in this habitat as 13–18 cubs, with about half that number reaching adulthood. In the RFE, optimal lifetime production for a tigress was 12.1 cubs but only 6.5–7.3 cubs reached 1 year of age (D. Miquelle, personal communication).

Impact of prey density on tiger density and reproductive success

Over the past decade, monitoring programmes have demonstrated that naturally occurring tiger densities vary by a factor of 30, from <0.5/100 km^2 (tigers 1 year of age and older) in the temperate forests of the RFE to 15+/100 km^2 in the flood plain tall-grassland savannah and riverine forests of the Terai. The number of potential prey animals varies from <2/km^2 (<400 kg/km^2) in the RFE to >60 individuals/km^2 (2800 kg/km^2) in the high productivity habitats in India and Nepal. Low prey density translates to lower encounter rates with prey, greater search time, and higher energy expenditures per kill and ultimately, less total energy in the ecosystem to support top carnivores (Sunquist and Sunquist 2001).

In the harsh environmental conditions of the RFE, mean litter size was 2.4, but decreased to 1.3 at 1 year (Kerley *et al.* 2003). In contrast, in a high prey density area like Chitwan, mean litter size was 2.98 (variance 0.48), decreasing to 2.45 (variance 0.62) by year one, and 2.22 (variance 0.51) by year two (Table 12.3).

Table 12.3 Reproductive parameters of tigers living in high- (Chitwan) and low-density Russian Far East (RFE) habitats.

Study site	Age at first reproduction females (years)	Mean litter size	Inter-birth interval (months)	Mean dispersal age (months)	Litters per lifetime
RFE	3.5–4.5	2.5	21.8	18.8	5
Chitwan	3.4	2.98	21.6	23	4–5

Sources: RFE—Kerley et al. (2003) and Dale Miquelle (personal communication, 2008); Chitwan—Smith and McDougal (1991) and Smith (1993).

The mean lifetime production of breeding offspring by female tigers in Chitwan was 2.0 (variance 3.26; Smith and McDougal 1991).

A major source of cub mortality is infanticide, which occurs when a resident-breeding male is usurped by another (Smith and McDougal 1991). Also, when young cubs are born during the dry season, their refuge sites in tall grass are subjected to human-caused fires that contribute to cub mortality. Finally, when a tigress is poached, cubs younger than ~15 months perish when left on their own (Smith 1993).

Karanth and Stith (1999) created a life-stage-based stochastic model to show that prey depletion has a strong negative impact on tiger populations by decreasing cub survival, reducing the carrying capacity for breeding adults, and decreasing population size. The exact ages of tigers in any wild tiger population is unknown, so they used a model with four life-stages for both sexes: breeder, transient, juvenile, and cub. Breeding female tigers were assumed to have stable, exclusive home ranges and their densities positively correlated with densities of ungulates. To reflect the size of actual Indian subcontinent tiger reserves, they set the carrying capacity (*K*) for tigresses from a high of 24 to a low of 3. Based on this range of tigress-carrying capacities, they modelled the possible effects of tiger poaching and prey depletions by depressing survival rates of the affected tiger's demographic stage. From this model, they found that the persistence of tiger populations is a function of the high reproductive potential of tigers.

More recent work by Damania *et al.* (2008) shows that even in high-density prey areas, modest-sized tiger populations (~30 breeding individuals) are fragile, unstable, and vulnerable to extinction and can be expected to crash with a 2% mortality rate; larger populations (>80 breeding adults) can withstand a 10% mortality rate. Prey-deprived tiger populations collapse rapidly with a very small increase in poaching because the carrying capacity for breeding females is depressed, cub survival drops, and tiger numbers decline rapidly, mainly due to additional effects of lowered cub survival. Thus, prey depletion may significantly constrain tiger recovery.

The pattern is clear: where prey densities are low, as in the RFE, the result is low tiger reproductive output and a greatly diminished resilience in the tiger meta-population. The resilience of the Terai landscape to sustain a tiger meta-population is greatly reduced when and where prey populations are depleted through poaching. At present, resilience in the Terai landscape is now dependent on the few secure areas where prey densities are high enough for a tigress to support litters. The recovery of prey populations is a prerequisite for tiger population recovery.

Dispersal system

Understanding tiger dispersal was greatly facilitated by the use of light aircraft to follow radio-collared tigers. In Chitwan, Smith (1993) found that subadults dispersed when they reached 19–28 months of age, ~45 days after the birth of their mother's new litter. Males dispersed on average 33 km (greatest distance = 71 km) and females ~10 km (greatest distance = 43 km). Tigers avoided open farmland; indeed, none of 7000 locations of radio-collared tigers recorded by Smith (1993) occurred in cultivation or villages. Young adult females remained within their mother's home range in better quality habitats;

a total of 16 of 25 females tracked settled near their mothers (Smith 1993). These young females took another year to establish exclusive breeding territories with intensively marked boundaries. One young female that left her natal area shifted localities 13 times over 8 months before settling 33 km west of her natal area. In contrast, only 6 of 32 (19%) subadult males settled near or within their natal area and only 40% of males survived to become established breeders. Dispersing males occupied marginal habitats and temporary post-dispersal territories ranging from 17 to 70 km^2 until able to evict established adult males from prime habitats (Smith 1993).

Intra-guild interactions

Tigers, leopards, and dholes typically coexisted in the riverine forest and tall-grass vegetation of the Terai. Dholes now occur in Chitwan but are absent from the other TAL reserves. Tigers are behaviourally dominant to leopards and dholes (Karanth and Sunquist 2000). The two large cats differ in modal body size by a factor of about four and in average size of prey killed (leopards ~25 kg and tigers ~100 kg). However, they prey on different size classes of the same species. Leopards differed from tigers in their activity periods and in their microhabitat use (Seidensticker 1976a).

High tiger density appears to depress leopard density in Chitwan and in Rajaji (McDougal 1988; Harihar et al. 2007). For example, when the density of resident-breeding tigers occupying prime tall-grass savannah/riverine forest in western Chitwan increased to 8/100 km^2 in 1987, six leopards were killed by tigers over a 21-month period (McDougal 1988). Leopards avoided areas where tiger density was high, instead residing at the peripheries of the park between the high-density tiger areas and croplands. Where tigers have been extirpated in the tall-grass Indian Terai, leopards have recolonized (Johnsingh et al. 2004). India's Nagarahole National Park offers a contrast to Chitwan, where both leopard and tiger abundance was facilitated by abundant prey in a wider range of size classes (Karanth and Sunquist 2000). Wild ungulate prey outside the park is often quite low, so both tigers and leopards subsist on domestic ungulates—goats and calves of

cattle and domestic water buffalo—and for leopards, domestic dogs (Seidensticker et al. 1990).

Tiger genetics and small population size

Smith and McDougal (1991) modelled the rate of inbreeding in the Chitwan population and postulated that it increased by 2% per generation. Kenney et al. (1995) warned that even if a relatively low level of poaching continued over time, the probability of extinction increases sigmoidally because as the duration of poaching increases, the probability of extinction increases rapidly. At lower levels of poaching pressure, a small incremental increase has little effect, but there is a critical zone of poaching pressure in which a small incremental increase greatly increases the probability of extinction in a population the size of that living in Chitwan—and this is one of the largest tiger populations on the Indian subcontinent. At any particular level of poaching pressure, the probability of extinction varies with the duration of poaching. But even if a tiger population survives a period of poaching and fully recovers to pre-poaching population levels, loss of genetic variability due to the rapid population decline during poaching creates a bottleneck effect. This, in turn, creates conditions where the coefficient of inbreeding will increase rapidly in tiger subpopulations.

Tiger numbers in the Terai are depressed because tigers are subjected to depressed prey populations, increased mortality imposed by poaching, and substantial habitat fragmentation, degradation, and loss. The risks to tiger subpopulation viability because of the loss of genetic diversity were initially thought to be of concern but not to pose the substantial and immediate additive threat that the modelling by Kenney et al. (1995) suggests.

Insights from field studies for the design and management of the Terai Arc Landscape

The TAL design builds on insights derived from over three decades of field work on tigers and their prey.

The TAL has three key goals: (1) to restore connectivity for tigers across the 11 protected areas embedded in a 1000 km long landscape; (2) to increase the breeding population of tigers to at least 500 by 2020; and (3) to harmonize location of tiger-breeding areas and dispersal corridors between reserves with the rural development agenda.

Restoring connectivity for tigers

The key insight gleaned from our studies of tiger demography and conservation genetics is that small reserves alone are inadequate to restore tiger populations; resilience and recovery will require a landscape-scale approach. Yet, to reassemble the TAL, we must first understand the extent, locations, and rate of its fracturing.

Half a century ago, before malaria was eradicated in the TAL, tigers probably formed a single inter-breeding population. About 15 years after eradication, the first Director of Project Tiger interviewed forest officers in the Terai in order to map the tiger population (Sankhala 1977). His map, created in 1972, identified three subpopulations: (1) the westernmost component extending from the Yamuna River in the west—spanning Rajaji, Corbett, and Dudhwa National Parks in India and the Suklaphanta Wildlife Sanctuary, Nepal—to the Karnali River in the east, forming the western boundary of Bardia National Park, Nepal; (2) a spatially distinct population occupying the Sivalik/Churia Hills along the India–Nepal border between the Karnali and the Narayani (Gandak in India) rivers; and (3) a segregated population in the Chitwan Valley and the adjacent Parsa Wildlife Reserve in Nepal and Valmiki National Park in India (Fig. 12.3b). Although Sankhala's map depicts three distinct populations, contiguous forest cover in 1972 probably allowed tigers to disperse between them.

The tiger's vulnerability to even moderate habitat fragmentation and dispersal barriers created by roads and other infrastructure became apparent during the 1980s through the work of Seidensticker (1986) and Smith (1993) and this vulnerability was confirmed by Kerley et al. (2002) working in the RFE. The rapid expansion of agriculture and subsequent clearing of forest reduced connectivity, as did the growth of

villages and towns along the Terai rivers. Road networks in rural areas grew from dirt tracks crossable by tigers to asphalt highways with truck and car traffic. Hydroelectric and irrigation projects, which are substantial barriers for tigers, appeared on all the major rivers emerging from the Himalayas, excepting the Karnali. Improved irrigation along the base of the mountains attracted new settlers from the hills and the Gangetic Plain. Human population density in the Terai grew dramatically to reach very high levels for a rural landscape ($\sim$500 people/km^2 in India, about half that in Nepal).

Taken together, these pressures resulted in massive land-use change and increasing insularization of tiger reserves. Geographic information system (GIS) tools allowed Dinerstein et al. (1997) to assess the impact on connectivity and meta-population function. They hypothesized, based on forest cover, infrastructure, and natural barriers that by 1995 tigers had been further divided into at least seven subpopulations in the Terai, which they called Tiger Conservation Units. Smith et al. (1999) hypothesized four subpopulations of tigers living along the Nepalese Terai, based on land-cover maps used to assess the extent and quality of tiger habitat, differential dispersal ability through a given habitat, and ground surveys. Relying on similar land-cover data and occupancy surveys, Johnsingh et al. (2004) hypothesized only two tiger-breeding units in the Nepal Terai and three in the Indian Terai from the western Nepal–India border to the Yamuna River in the far west. They did not report on occurrence of tiger breeding outside reserves, but found that tiger occurrence was 'patchy and variable, influenced by prey availability, cover and disturbance levels' (Johnsingh et al. 2004, p. 54). They also identified 18 sites where the habitat was either highly degraded or constricted, threatening connectivity and restricting tiger movement across the TAL. In the most recent assessment of landscape connectivity, Sanderson et al. (2006) delineated seven tiger subpopulations in the TAL utilizing the most recent land-cover data available, human influence data, tiger dispersal distance, area of tiger presence, and minimum core/area stepping stone size (Table 12.4).

These studies depicted the 'landscape pathology' of this once healthy, intact tiger landscape. The study by Wikramanayake et al. (2004) provided a scientific

Table 12.4 Terai Tiger Conservation Landscape (TCL) spatial and land-cover parameters. Protected areas and buffer zones (Table 12.1) comprise ~35% of the total area identified as TCLs.

TCL name	Total area (km^2)	Habitat area (km^2)	Largest patch (km^2)	Habitat as percentage of landscape area
Chitwan	4055	1257	560	31
Bardia South	499	206	83	41
Bardia	6777	3272	740	48
Suklaphanta	1144	467	300	41
Corbett	5996	1758	250	29
Rajaji	1044	301	172	29
Yamuna	322	120	82	37
Total	19,837	7,381		37

Sources: Dinerstein et al. (2006) and Sanderson et al. (2006).

framework for landscape recovery for tigers and became the blueprint for the TAL. Their model identified potential dispersal corridors and strategic transit habitat for tigers, and made recommendations for land management and restoration beyond reserve boundaries to enhance dispersal. Relying on Landsat satellite images, they used an ArcView-based cost-distance model to establish a grid (1 ha) and scored each grid with a 'dispersal cost' based on habitat parameters and the probability of tigers using those habitats. Combining these metrics, they identified and classified corridors into one of three classes reflecting the probability of use depending on the dispersal cost. The corridor analysis was expanded to include strategically placed 'stepping stones' and community forests that would restore and improve dispersal value of corridors (Fig. 12.4).

Adoption of the model by the Nepal government and donor agencies allowed field workers to target corridor restoration in critical bottlenecks. Initial results have been quite promising. Within 5 years of the forest restoration efforts, tigers were detected in four of the five corridors, including a tigress with cubs in the Basanta forest corridor that connects the Churia Hills in Nepal with the Dudhwa Tiger Reserve in India, indicating that tigers may actually be resident in these linkages. The Khata corridor is a second transnational corridor where tigers have been confirmed following restoration efforts. This corridor connects Nepal's Bardia National Park with Katerniaghat Wildlife Sanctuary in India (Fig. 12.4; Wikramanayake et al.

2010). So far in the Nepalese Terai, six bottlenecks to tiger dispersal were identified for restoration and 200 local Community User Groups re-established 220 km^2 of forest corridors. Gurung et al. (2006b, personal observation) found evidence of tigers breeding outside protected areas in eight locations in the Nepalese Terai. This latter finding helps validate a major assumption of the TAL, that breeding populations can exist outside the 11 gazetted tiger reserves.

The least-cost model and, most importantly, its successful implementation show that GIS-based models can be useful tools to gain government support and to identify tiger conservation landscapes and corridors for recovery. A major issue that remains, however, is monitoring occupancy and meta-population structure across a 1000 km conservation landscape.

Increasing the breeding population of tigers to at least 500 by 2020

Population recovery in the TAL is anchored by seven core protected areas or contiguous protected areas (Table 12.1) supporting abundant prey that are relatively free from human disturbance. In these refugia, tigresses rear cubs that will eventually disperse to other areas through stepping stone or continuous habitat corridors. These subpopulations with breeding tigers are from west to east: Rajaji, Corbett, Suklaphanta, Dudhwa, Bardia, Katerniaghat, and Chitwan/Parsa/Valmiki (Fig 12.3b). The forested
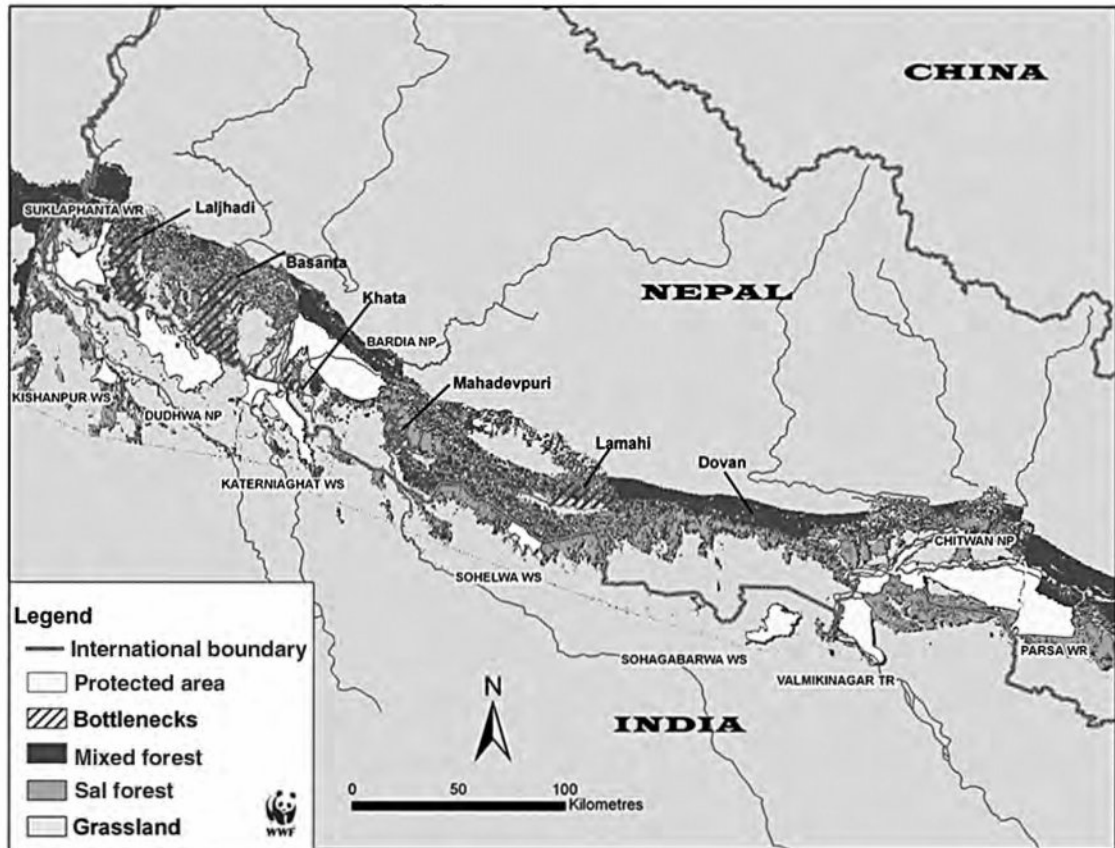
Figure 12.4 Western Nepal Terai corridors and connections: community forestry projects used to harmonize tiger-breeding areas and dispersal corridors between reserves with the rural development agenda. Community forests have resulted in a net increase in forest cover in Nepal, earned local community support for conservation, and expanded conservation efforts far beyond protected areas.

areas between these core areas act largely as dispersal routes rather than as tiger-breeding habitat. To achieve the 2020 goal of 500 breeding tigers will obviously require expanding the number of breeders beyond these core areas to buffer zones and other potential breeding areas nested in the landscape.

Three local issues could prevent the TAL programme from reaching its numeric goal. First, heightened exposure to organized poachers, reduced wild-prey biomass, and human–tiger conflict in non-reserve areas could continue to depress tiger numbers.

Second, the remaining habitat outside reserves offers an unpromising ratio for recovery of tigers: ~85% of remaining vegetation in the Terai is *sal* forest that offers poor forage quality for tiger prey, constituting what one tiger researcher has termed a 'green desert'

(B. Pandav, personal communication). These flat *sal* forests and hill *sal* forests also typically lack permanent surface water during the 8-month dry season. Dinerstein (1987) found that deer seldom use habitats >2 km from available surface water, thus these *sal* forests are occupied by tigers only in the monsoon.

The third constraint is human encroachment. The Nepalese Terai attracts many landless people both from the hills to the north and from across the Indian border. Encroachment into the Basanta Corridor (Fig 12.4) has become a serious issue, in part generated by the landless poor, and compounded by the resettlement of former combatants from the Maoist insurgency. Conservationists have about a 10-year window in which to secure the pathways through major dispersal bottlenecks and potential

tiger-breeding areas along alluvial stretches in the corridors, after which such interventions will be too costly or impossible because of settlement pressures.

Balancing these proximate threats is an ecological maxim: the Terai is a forgiving landscape. If tigers are given reasonable protection and wild prey is sufficient, they and their most preferred habitat rebound rapidly. *Saccharum spontaneum* grasslands can recover from intense overgrazing by domestic stock in <2 years to support tigers again. We cite two episodes of recovery. First, tigers and prey increased in number when protection was effectively established for Chitwan, when it became a national park in 1973. The number of adult tigers occupying prime tallgrass savannah riverine forest in the western end of the park doubled from 4 to 8/100 km^2 between 1976 and 1987 (McDougal 1988), with the same increase in tiger density thought to have occurred through the rest of the park's flood plain.

Second, tigers were absent from the Baghmara and Kumrose areas in the Chitwan Buffer Zone at the eastern end of the park in 1993. A locally managed regeneration project began in 1994 to restore heavily overgrazed areas adjacent to high-density tiger habitats. By 1996, five tigers, including a tigress and cub, were regularly using these formerly degraded areas. Significantly, poaching incidents that had occurred near the regeneration areas ceased after the locally managed buffer zones began to recover in 1994, largely because tigers generated tourist revenue for local residents, providing an incentive to protect rather than poison tigers (Dinerstein *et al.* 1999, Dinerstein 2003).

A change in attitude regarding voluntary resettlement and equitable land transfer programmes has opened up new possibilities for landscape management. Once viewed as pariah projects, new resettlement programmes, initiated by local villagers who want to shift from remote areas closer to towns and population centres, are underway. Two examples are worth noting.

Tigers and prey recovered after pastoralists were voluntarily resettled from the Chilla Range (148 km^2), a series of three small dun valleys at the western end of the TAL in Rajaji National Park, in 2002. By 2006, the valley supported >70 individual ungulates/km^2 and the resident tiger density had climbed from 0 to 2.5/100 km^2, including breeding females. This prey density could potentially support ~14 tigers/100 km^2. The source population for this recovery is presumably Corbett Tiger Reserve, 40 km to the east, which is connected through a forested corridor (Harihar *et al.* 2007). The resettlement of the pastoralists created space for a new tiger source population and also 'unblocked' an adjacent 2-km riverine forest corridor and stepping stone islands where the Ganges River divides the Rajaji National Park. This allowed the first known attempt by tigers to cross the Ganges in the two decades that A. J. T. Johnsingh monitored this crossing (Seidensticker and Lumpkin 2006).

The recently completed land transfer of the Padampur enclave in eastern Chitwan offers another ideal opportunity to study a citizen-initiated land transfer in the Terai. About 14,000 villagers were shifted over a 10-year period to New Padampur, a site ~20 km from the former park enclave and much closer to the town of Narayanghat. Similarly, the increase in critical habitat for tigers and endangered greater one-horned rhinoceros in eastern Chitwan is being studied by K. Thapa and N. Dhakal (personal communication). These examples are beginning to show that win–win situations are possible in areas where benefits to tiger conservation and improving rural livelihoods may be achieved simultaneously.

Harmonizing location of tiger-breeding areas and dispersal corridors between reserves with the rural development agenda

A wise field biologist once said, 'Conservation is ten percent science and 90 percent negotiation' (R. Cowling, personal communication). The past decade of addressing the human dimensions of the TAL can best be characterized as a protracted, yet fruitful, negotiation. Based on the best science available, conservationists have advocated for tigers and people. Seidensticker (2002) and Dinerstein (2003) describe how Chitwan's managers were sensitized to addressing the needs of local people who lost access to the resources now protected by the parks. Bouts of poaching made it clear that local people would have to become part of the protection of those resources.

They would have to experience the park not as a no-trespassing zone that belongs to outsiders and tourists but as a source of non-consumptively generated revenues. In 1993, new legislation in Nepal permitted managers and local communities to negotiate an arrangement whereby local communities received a substantial share of the tourist revenues generated by the park. These revenues were invested through newly empowered local committees to improve livelihoods through better training, education, and health facilities.

That legislation conserved the buffer zones of the Nepalese tiger reserves, but not the corridors between them. The second law, enacted in 1978, allowed village user group committees to take control of government forests and the land to be 'handed over' after completion of a management plan; this act changed the course of conservation in the Nepalese Terai (Dinerstein 2003). This second act allowed Nepalese communities far from protected areas to benefit directly from community forestry. Most of the people in the Terai are still dependent on forest resources to augment daily livelihoods and to survive times of food insecurity with food, fodder, fuel wood, and medicinal plants harvested from the forest. Therefore community-based management and *usufruct* rights to these forests are welcomed. Community forests have actually resulted in a net increase in forest cover in Nepal, earned local community support for conservation, and expanded conservation efforts far beyond protected areas (Wikramanayake *et al.* 2010; Fig. 12.4). These programmes have been maintained even through the recently ended 10-year insurgency in the Nepalese Terai.

Future of the TAL and its tiger population

At the base of the Himalayas, one of the important chapters in the recovery of wild tigers is currently being written. How it will end depends on continually adjusting to the changing situation, being opportunistic, and incorporating new knowledge.

The first piece of new information is derived from the science: the ecological recovery of the TAL requires restoring and expanding vital *Saccharum spontaneum* grasslands and associated riverine forest, the prime breeding sites for tigers. These habitats must be strategically targeted even if it means diverting attention from *sal* forest corridors. Securing these vital habitats along river courses must be a conservation imperative if the TAL is to reach its ambitious target of 500 breeding tigers.

The second aspect of conservation in the TAL is a critical need for innovations to finance habitat restoration. These can range from carbon credit programmes to introduction of hybrid, stall-fed cattle, and/or methane gas digesters. Additionally, new types of trust funds to meet the recurrent costs of restoration or some other types of user payments must be explored.

As the density of tigers living in prime habitat in protected areas increases, an increasing number of subordinate, post-dispersal tigers move out and begin to use the margins of protected areas. Conflict with the people using these habitats is inevitable. Gurung *et al.* (2006a) reported that a total of 37 tigers have killed 88 people around Chitwan in the past 30 years, with an average of 1.5/year from 1978, when the first human death was recorded, to 1998, and 8.25/year from 1999 to 2006. Half of the victims were cutting grass, which required them to bend down or sit, dramatically altering the physical profile presented to a tiger (Seidensticker and McDougal 1993). Ten of the 17 tigers removed were subordinates living in marginal habitats; 9 of these were judged to be impaired due to fights with other tigers, old age, or gunshot wounds. Appropriate conservation schemes are required to address this confounding problem.

The illegal demand for tiger parts and products could overwhelm local efforts in the TAL. This market originates far beyond the boundaries of the parks and even beyond India and Nepal, and could undermine tiger protection measures everywhere. This generic problem can only be countered with international cooperation and interventions (Dinerstein *et al.* 2007).

Coda

The Terai wildlife sanctuaries are pearls set in a thin green necklace strung along the base of the Indian and Nepal Himalayas. The conservation story of these wildlands informs the region and the world that we can sustain tigers and other large mammals

in the face of massive land-use change and an intensifying human footprint. The science we report here is but the first phase, the engineering segment, in the conservation system required to sustain these habitats and their wildlife. The second, larger phase is implementing a compelling vision intertwining society and this ecosystem, realized through the life work and dedication of many conservation practitioners too numerous to thank here for their efforts.

Attempting the impossible is often foolhardy but it is the occupation of visionaries. All of us draw inspiration from the examples of two such visionaries, the late Dr T.M. Maskey, the first warden of Nepal's Chitwan National Park, and Billy Arjan Singh, who remains unbowed in his fight to create and sustain India's Dudhwa National Park. The zeal for conserving the foundations of the Terai-Arc trace back to their unequalled dedication. And so we dedicate this chapter to them.