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Study of Biodiversity Areas for Conservation in India

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ABSTRACT
Three broadly accepted claims in conservation biology are that the world's developing tropical countries will see the largest declines in biodiversity in the near future, that these regions are among the least studied globally, and that local community support is particularly important for protection in these regions. In assessing India's protected areas, we evaluate these generalizations. Most ecoregions in India are covered by the 5% of the country that is officially protected, and protected areas have played a significant role in the country's lack of reported species extinctions over the last 70 years. Future chances are improved by India's robust conservation-friendly laws, government investment in its 50 Tiger Reserves, and compensation programs that boost local support. However, connectivity and species utilization in buffer zones are important since many protected areas are too small to support a complete complement of species. The success and difficulties of conservation differ across regions based on their level of development. Protected areas with the greatest biodiversity are found in less developed regions, most notably the biodiverse northeast Himalaya, and are the product of localized efforts by committed individuals. We show that there is much potential for ecotourism to boost local income all around India. Our analysis validates the relevance of local support, growing dangers, and a deficiency of data. Particularly needed are studies on biodiversity in buffer zones, long-term monitoring plans, and an evaluation of the financial and environmental benefits of tourism. The creation of monitoring plans for "eco-sensitive zones" surrounding protected areas and a strong focus on maintaining already-established protected areas should be the two key objectives for policymakers.

Keywords: biodiversity, environmental, national park, northeast area, protection

I. INTRODUCTION

Assessments at the global and regional level have indicated the most effective places to put protected areas in order to conserve biodiversity, as well as locations that are relatively under-protected. Other works focus on the state of biodiversity in general (Pimm et al., 2014; Newbold et al., 2015) including evaluations of the extent to which protected areas succeed in maintaining species (Gray et al., 2016; Newbold et al., 2015). These assessments rely on remote sensing (Venter et al., 2016), a few global datasets (e.g. the world database on protected areas, www. iucn.org), literature reviews that contrast biodiversity patterns across space (Gray et al., 2016) or time (Dornelas et al., 2014; Newbold et al., 2015), and contributions to public online databases. While informative, results from these studies raise two major issues that we need to address if conservation prospects are to improve. The first is the quality and quantity of the data. Data may be especially lacking in exactly those regions where biodiversity will be most threatened in the coming years (tropical, rapidly developing areas with high human population growth; Pimm et al., 2014; Tilman et al., 2017). The second is that biodiversity conservation is largely at the provenance of national, state, and local levels, creating large variation in the success of protected areas both between and within countries. We can gain much by studying individual cases, rather than global averages or generalities, because experience across multiple case studies can be tailored to the unique situations encountered in any one location.

India exemplifies the challenges of conservation in developing tropical countries. It is the world's second most populous country and may overtake China within a decade. Its population has more than doubled since the late 1970s, is growing by 15,000 people a day, and has a current density of ~330/km2. It falls in the bottom third of countries ranked by per capita GDP, but with an additional US $50 billion entering the economy annually, it is transforming rapidly: people across all economic classes are consuming more. India has an exceptional number of plant (Joppa et al., 2013) and animal (Jenkins et al., 2013) species facing these increased pressures. For example, 888 species of birds regularly breed within India's boundaries,>8% of the world's total (based on maps compiled by birdlife.org).

While approximately 15% of global land is protected, India officially protects 5% of its area (Dinerstein et al., 2017). However, India's conservation challenge differs from that of other large countries, such as the USA, Brazil, and China. In these countries, large protected areas are situated in sparsely populated regions, which in the USA and China are also of relatively low biodiversity value (Pimm et al., 2018). Instead, in India, many millions of people live within a few kilometres of protected areas and perhaps 4 million reside within them (Narain et al., 2005), although the figure is

uncertain, with no updates this century. This creates major challenges for those who manage India's biodiversity, both because the protected areas are used to some degree, and because major targets of conservation efforts, including elephants (Elephas maximus), tigers (Panthera tigris), leopards (Panthera pardus), bears (Melursus ursinus), wolves (Canis lupus), snow leopards (Panthera uncia) and prey species such as wild pigs (Sus scrofa), nilgai (Boselaphus tragocamelus), chital (Axis axis) and sambar (Rusa unicolor) pose threats to humans, livestock and crops. Such challenges are likely to become more pressing and more widespread across the world, as populations and wealth increase in the tropics.

In this paper, we review and summarize what is known about the success and future prospects for protected areas in India. In Section 2 we describe the status of protected areas, including coverage, area, quality, external threats and connectivity. In Section 3 we consider means of protection, including legislation, government financial support, ecotourism, and local initiatives. We conclude with a general discussion of the status of protected areas in India, and the kinds of key data and policies that are required to improve conservation prospects.

II. BIODIVERSITY CONSERVATION

When we conserve and protect the whole ecosystem, its biodiversity at all levels is protected - we save the entire forest to save the tiger. This approach is called in situ (on site) conservation. However, when there are situations where an animal or plant is endangered or threatened and needs urgent measures to save it from extinction, ex situ (off site) conservation is the desirable approach.

2.1 In Situ Conservation

Protection of Habitat: In India, ecologically unique and biodiversity-rich regions are legally protected as biosphere reserves, national parks and sanctuaries. India now has 13 biosphere reserves, 96 national parks and 500 wildlife sanctuaries, twenty-seven Tiger Reserves and eleven Elephant Reserves covering an area of 15.67 million hectares or 4.7 % of the geographical area of the country. India has also a history of religious and cultural traditions that emphasised protection of nature. In many cultures, tracts of forest were set aside, and all the trees and wildlife within were venerated and given total protection. Such sacred groves are found in Khasi and Jaintia Hills in Meghalaya, Aravalli Hills of Rajasthan, Western Ghat regions of Karnataka and Maharashtra and the Sarguja, Chanda and Bastar areas of Madhya Pradesh. Twenty-one wetlands, thirty mangrove areas and four coral reef areas have been identified for intensive conservation and management purposes by the Ministry of Environment and Forests, Govt. of India.

National Parks and Sanctuaries: India's national parks and wildlife sanctuaries (including bird sanctuaries) are situated Ladakh in Himalayas to Southern tip of Tamil Nadu with its rich bio-diversity and heritage. Wildlife sanctuaries in India attract people from all over the world as the rarest of rare species are found here. With 96 national parks and over 500 wildlife sanctuaries, the range and diversity of India's wildlife heritage is unique.

Biosphere Reserves: These are representative parts of natural and cultural landscapes extending over large areas of terrestrial or coastal/marine ecosystems which are internationally recognized within UNESCO's Man and the Biosphere Programme Thirteen biodiversity- rich representative ecosystems , largely within the forest land (total area – 53,000 sq. km.) have been designated as Biosphere Reserves in India.

Sacred Forests and Sacred Lakes: A traditional strategyfor the protection of biodiversity has been practiced in India in the form of sacred forests. These are small forestpatches protected by tribal communities due to religious sanctity. These have been free from all disturbances.Sacred forests are located in several parts of India i.e. Karnataka, Maharashtra, Kerala, Meghalaya, Similarly,several water bodies for example, Khecheopalri lake in Sikkim, have been declared sacred by the people, leadingto protection of aquatic flora and fauna.

Species-Oriented projects: Certain species have beenidentified as needing a concerted and specifically directed protection effort. Project Tiger, Project Elephant and Projectcrocodile are examples of focusing on single species throughconserving their habitats.

2.2 Ex-situ Conservation

Botanical Gardens, Zoos: Ex-situ conservation is beingundertaken through setting up botanical gardens, zoos, medicinal plant parks, etc by various agencies. The IndianBotanical Garden in Howrah (West Bengal) is over 200 years old. Other important botanical gardens are in Ooty,Bangalore and Lucknow. The most recent one is The Botanical Garden of Indian Republic established at NOIDA, near Delhi in April, 2002. A number of zoos have been developed in the country.These zoological parks have been looked upon essentially as centres of education about animal species and recreation.They have also played an important role in the conservation of endangered animal species such as the Manipur ThaminDeer (Cerus eldi eldi) and the White winged Wood Duck (Cairina scutulata). Notable successful examples of captive4breeding are those of Gangetic gharial (Gavialis gangeticus), turtles and the white tiger.

Gene Banks: Ex-situ collection and preservation of geneticresources is done through gene banks and seed banks. The National Bureau of Plant Genetic Resources (NBPGR), New Delhi preserves seeds of wild relatives of crop plants as well as cultivated varieties; the National Bureau of Animal Genetic Resources at Karnal, Haryana maintains the genetic material for domesticated animals, and the National Bureau of Fish Genetic Resources, Lucknow for fishes.

Cryopreservation: Freeze preservation is particularly useful for conserving vegetative propagated crops [13]. Cryopreservation is the storage of material at ultra-low temperature of liquid nitrogen (-1960C) and essentially involves suspension of all metabolic processes and activities. Cryopreservation has been successfully applied to meristems, zygotic and somatic embryos, pollen, protoplasts cells and suspension cultures of a number of plant species.

Conservation at Molecular Level (DNA Level): In addition to above, germplasm conservation at molecular level is now feasible and attracting attention. Cloned DNA and material having DNA in its native state can all be used for genetic conservation. Furthermore, non-viable material representing valuable genotypes stored in gene banks can all be used as sources of DNA libraries from where a relevant gene or a combination of genes can be recovered.

Legal Measures: Market demand for some body parts like bones of tiger, rhino horns, furs, ivory, skins, musk, peacock feathers, etc results in killing the wild animals. The Wildlife Protection Act (1972) contain provisions for penalties or punishment to prevent poaching and illegal trade. India is also a signatory to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The Convention entered into force on 1st July, 1975. In addition to this, India is also a signatory to Convention on Biological Diversity (CBD), which it signed on 29th December, 1993 at Rio de Janeiro during the Earth Summit [14]. Government of India have also passed the Biological Diversity Act, 2002, the details of this acts is given in lesson 23. World Wide Fund for Nature (WWF) and World Conservation Union supports projects to promote conservation and appropriate development of Biosphere Reserves.

III. STATUS OF PROTECTED AREAS IN INDIA

India designated its first National Park, presently named Corbett National Park, in 1936. To date, officially protected areas in India now consist of 104 National Parks and 551 Wildlife Sanctuaries (www. wiienvis.nic.in); however, 5 National Parks and 79 Sanctuaries are< 1 km2 (many are islands) and are not considered further in this paper. National Parks enjoy the highest protection, being legally free from human intervention (International Union for the Conservation of Nature (IUCN), Category II, see www.iucn.org). Wildlife Sanctuaries fall into IUCN category IV, which allows for limited use. India introduced two additional legal categories for its protected areas in 2002. Conservation Reserves, on public land, and Community Reserves, on private land (IUCN Categories V and VI, respectively) are established mainly on the basis of approved management plans. Of 214 such reserves established by 2019 (4811 km2 in total),>70% are in just three states (122 Community Reserves are in Meghalaya and Nagaland, and 34 Conservation Reserves in Jammu & Kashmir). The Convention for Biological Diversity in 2011 set the well-known Aichi Biodiversity Targets, including the goal that protected areas across the earth's land surface should increase from 13% to 17%. Recent guidelines developed by the International Union for the Conservation of Nature's World Commission on Protected Areas now admits Conservation and Community Reserves as contributing to that goal, but at present these two categories comprise only 0.15% of India's surface area (IUCN WCPA, 2018). However, government-owned reserved forests, which local communities sometimes participate in managing, cover 13.2% of India and often contribute to buffers and corridors for protected areas. To the extent that these are managed in a way that leads to positive biodiversity conservation outcomes, they may also contribute to the Aichi targets. They are certainly subject to legal restrictions on resource exploitation, but are not well monitored to assess the enforcement of protection and status of biodiversity, which are requirements of the current guidelines (IUCN WCPA, 2018).

No bird or mammal is known to have been lost from India since the cheetah (Acinonyx jubatus) was extirpated in the mid-20th century. Protected areas have clearly played an important role in this success. For example,>85% of the world's one-horned rhinos (Rhinoceros unicornis) >70% of the world's tigers live in India, largely a consequence of the efficient functioning of India's Tiger Reserves). For birds, protected areas provide major refuges for many species in low numbers. The three Gyps vulture species, after experiencing a 97% population decline in total due to veterinary use of the drug diclofenac, are now largely found inside or near National Parks. The Jerdon's courser (Rhinoptilus bitorquatus), a critically endangered species last seen in 2009 is most likely to persist in the Sri Lankamaleswara Wildlife Sanctuary (www.iucnredlist.org). Conversely, the low number of protected areas in certain ecoregions such as the Gangetic Plain (Fig. 1) is surely contributing to the endangered status of several species. Grasslands have been converted to agriculture, pasture and plantations throughout India. Threats to grassland birds are exemplified by the Great Indian bustard (Ardeotis nigriceps), which now numbers<250 individuals.

Within India's protected areas, only a few censuses of animal and plant populations have been published to assess their effectiveness at maintaining biodiversity. The global survey of Dornelas et al. (2014) lists just one study of trees from India, with no appreciable change in diversity over time. The Living Planet index, which records censuses between 1970 and 2014, gives only three studies with>5 years of data (http://www.livingplanetindex.org).

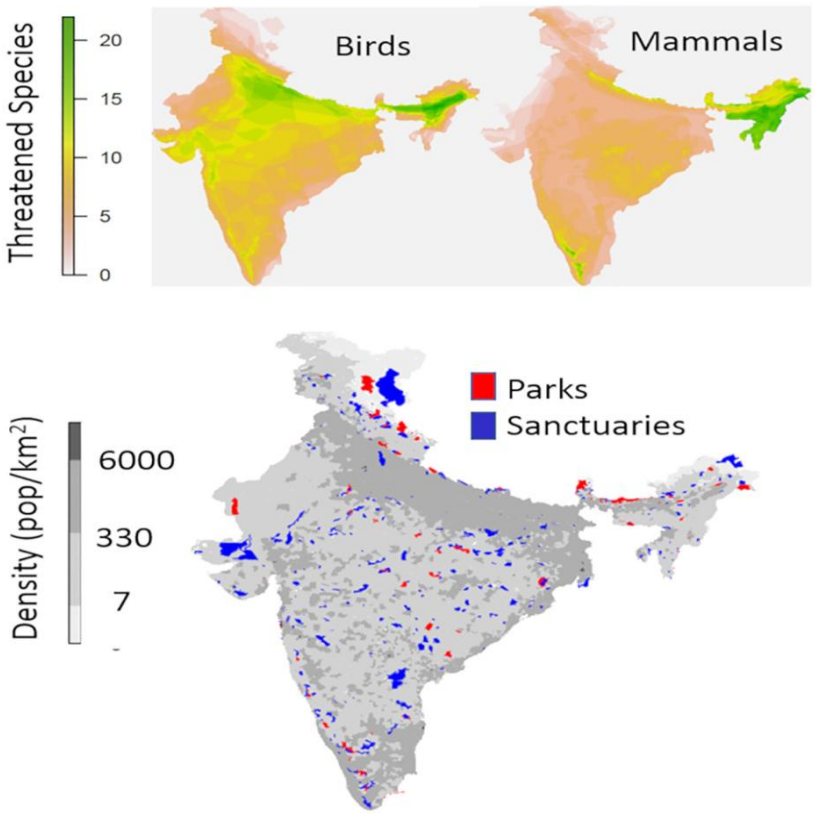

Figure 1: Top left: Heat maps of vulnerable species of birds and mammals

They are the one-horned rhinoceros in two National Parks from Assam leopard, striped hyena (Hyaena hyaena) and chital in the Gir forest and Gyps vultures from Bharatpur (Prakash, 1999). While vultures have declined, all the mammals appear to have increased. Overall, data on the success of protected areas in India are clearly in short supply, and future studies are needed to thoroughly evaluate their efficacy.

3.1 Protected Area Coverage

Rodgers and Panwar (1988) used principles of biogeography and distribution of biomes across India to develop a plan for a protected area network that guided both National and State Institutions. Presently, Sanctuaries and National Parks cover the 28 forested ecoregions of India at a median level of 5.5% of their area. However, 6 ecoregions have<2% coverage (Dinerstein et al., 2017). The map in Fig. 1 also implies that heavily populated regions, such as in the Gangetic Plain, have relatively few protected areas. Considerations of biome and ecoregion coverage do not address how many species are actually present in the protected areas. To assess species coverage, we overlaid India's 888 breeding species of birds (from birdlife.org), as the best known group, on delimited Sanctuaries and National Parks (Fig. 1). These are clearly lower bounds on species numbers, because trimming maps to include factors such as habitat, elevation, and park fragmentation excludes many species (Li and Pimm, 2016; Ocampo-Peñuela et al., 2016). According to this analysis, only three bird species with substantial breeding populations in India are not present in any protected area (White-capped bunting Emberiza stewarti, Glossy Ibis Plegadis falcinellus and Maroon-backed accentor Prunella immaculata), all of which have large populations in other countries (the Glossy ibis appears to have recently started breeding in south India, in a small sanctuary (Venkatraman, 2009)). However, the conclusion of thorough coverage is qualified because 82 species are only found in protected areas smaller than 500 km2, and 160 are found in four or fewer Protected areas (Supplemental Fig. 1). Finally, when we restricted the analysis to Tiger Reserves, which are the focus of much of India's conservation effort (see below), we found that 28% of all bird species do not overlap with any reserve. The figure increases to 33% if we exclude the Tiger Reserves in Arunachal Pradesh, which are less well protected than elsewhere (see below). One reason for the absence of many bird species and associated ecoregions from Tiger Reserves is that east Himalayan elevations above 1500m contain the highest bird species richness of anywhere in India (Price et al., 2011).

Northeast India is exceptional in its richness of species, many of which are threatened (Fig. 1). It is also one of the most biodiverse places in the world (Price, 2012; Jenkins et al., 2013). In the analysis associated with Fig. 1, we found that 25 protected areas intersect the ranges of>300 breeding bird species, all of which are in the forested regions of northeast India and the eastern Himalaya. They include National Parks that are both small (e.g., Phawngpui Blue Mountain in Mizoram, 55 km2 and Keibul-Lamjao in Manipur, 39 km2) and large (Khangchendzonga, Sikkim, 1784 km2).

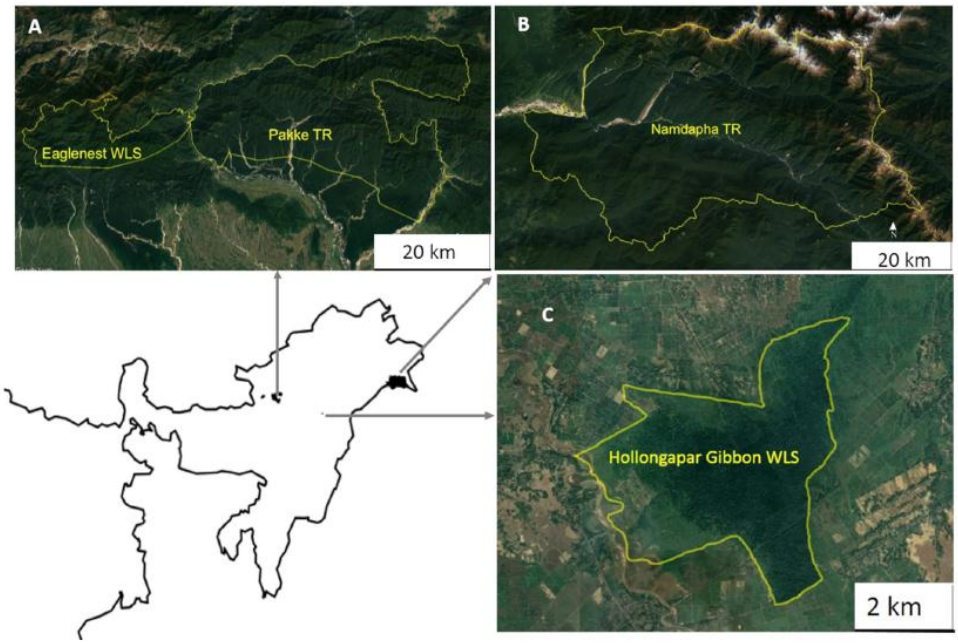

Figure 2: Four northeastern Indian protected areas (overlaid on Google Earth pictures)

Despite the biological importance of northeast India, recent reviews of conservation and development in India barely mention this region (Shahabuddin, 2010; Bindra, 2017; Bhagwat, 2018; see Price, 2019). Therefore, in certain sections below we describe four protected areas in the northeast (as indicated by letters in Fig. 1, right and mapped in Fig. 2). These four examples are chosen to illustrate topics of general concern, but for which no summary dataset is available.

3.2 Protected Area Size

Based on global studies, estimates of bird species loss suggest that isolated tropical fragments 10 km2 in area will lose their first species within 7 years, while one the size of 500 km2 will lose its first species within 40 years (Newmark et al., 2017). However, it takes about 300 and 3000 years, respectively, for 50% of the original avifauna to be lost from these fragments. In India, areas smaller than 700 km2 have historically experienced a 50% probability of losing dholes (Cuon alpinus) and areas smaller than 135 km2 a 50% probability of losing tigers (Woodroffe and Ginsberg, 1998), exemplified by the more recent loss of tigers from Sariska National Park (in 2005, the Park covers 270km2) and Panna National Park (in 2008, 540 km2; Chundawat et al., 2016; Gopal et al., 2010; Shahabuddin, 2010). These two parks have since been repopulated with tigers through translocation of individuals (Jhala et al., 2015). Elsewhere in the world, much larger protected areas have lost large mammal species. Six parks smaller than 5000 km2 in Ghana lost at least 25% of their large mammals in 30 years (Brashares et al., 2001). Eighty-eight percent (14/16) of protected areas smaller than 10,000 km2 across Tanzania and western North America lost at least one species over timespans of 50–80 years (Newmark, 1995, 1996). Additional negative effects of small areas in India include reduced genetic diversity (golden langur [Trachypithecus geei], Ram et al., 2016; tiger, Natesh et al., 2017) and higher load of gastrointestinal parasites in multiple mammal species (Chakraborty et al., 2015). Twenty-nine parks and Sanctuaries in India are larger than 1000km2 and just two are larger than 5000km2 (one in the desert, and another above treeline; Fig. 1). However, India's Tiger Reserves are generally a composite of National Parks and Sanctuaries (these two categories cover ~40% of Tiger Reserve area), plus reserved forest or other governmental land, which effectively increases the area of suitable habitat (Jhala et al., 2015). Maintenance of this land importantly contributes to protection (Wikramanayake et al., 2011; Chanchani et al., 2016).

3.3 Protected Area Habitat Quality

At present, the biodiversity of individual protected areas with respect to a pristine state is uncertain, but clearly varies substantially from one place to another. Many protected areas are lower in quality than they otherwise could be. First, industrial monocultures such as rubber, coffee and teak have historically formed significant areas of National Parks and Sanctuaries, due to colonial emphasis on commercial forest use. Such monocultures harbour only a small proportion of the native fauna (Kumar et al., 2011). Second, forest fragmentation has been documented in some protected areas (e.g. Nameri Tiger Reserve, Saikia et al., 2013). Fragments are generally smaller and farther apart towards the park periphery, and they are more numerous in smaller rather than larger protected areas (e.g., Rajasthan, Krishna et al., 2014). Third, people live inside many protected areas. Narain et al. (2005) suggest that 56% of the National Parks and 72% of the Sanctuaries had some people living in them (but they also note a great deal of uncertainty in these figures). Fourth, even in those protected areas without human habitation, local people (Datta, 2007; Narain et al., 2005; Shahabuddin, 2010), tourist

enterprises (Karanth et al., 2012) and developers (Bindra, 2017; Bhagwat, 2018) use resources inside the protected area. In some cases, this is legal, especially when local rights allowing limited use of Sanctuaries were retained from previous local rights held prior to designation as a Sanctuary. In many other cases, legal restrictions are ignored. For example, according to Bindra (2017, p. 114) 200,000 cattle graze in, or close to, Sariska Tiger Reserve, and the small Hollongapur Gibbon Sanctuary in Assam contains heavily degraded land on one side used for cattle grazing (Fig. 2c).

Given observations such as these, Bhagwat (2018) suggests that many protected areas have recently suffered from "downgrading, downsizing, and degazettement", which would surely affect long term conservation goals. However, available data imply relatively modest losses (7 downsizes, 5 downgrades, and 2 degazettes, http://www.padddtracker.org/view-paddd, ~1100 km2 in total downsized between 1990 and 2010). These have been more than compensated by recent additions to the protected area system (24 Sanctuaries added ~5200 km2 between 2010 and 2015, www.wiienvis.nic.in). This is not to say that downgrading is not occurring, but that changes in protected area quality are poorly documented.

Effects of size and quality can be countered by directed management programs that alter and improve prospects for targeted species in dangerously low numbers (Butchart et al., 2006, 2016). As we noted, in India, population sizes of one horned rhinoceros and tiger are explicitly a result of protected area management and protection, specifically focused on these species.

3.4 Hunting in Protected Areas

Hunting is another understudied threat (Velho et al., 2012). Hunting pressure clearly varies across regions and taxa, but is particularly intense in northeast India. India's wildlife laws entirely prohibit hunting of wildlife in these forests, but enforcement is weak. Tribal communities have a strong tradition of hunting—for meat, medicine, ritual customs, recreation, and increasingly for income (Aiyadurai et al., 2010). Improved technologies like guns and snares along with access to markets have resulted in large vertebrates becoming extremely rare or locally extirpated in many parts of Arunachal Pradesh (Datta et al., 2008a). In one study of 51 villages, 33 mammal species were hunted, of which 20 are listed as threatened on the IUCN Red List (Aiyadurai et al., 2010). Beyond tigers, the primary targets are hornbills, ungulates, pheasants, bears, and primates (Aiyadurai et al., 2010; Datta et al., 2008a), although other groups such as squirrels and small carnivores are also hunted (Datta et al., 2008b; Dollo et al., 2010). Given the functional importance of these faunal groups as prey species for large carnivores or as frugivores and seed dispersers, their decline is likely to have myriad ecological consequences (Naniwadekar et al., 2014). Despite the imperfections of law enforcement and the prevalence of hunting, protected areas still provide a greater level of security to wildlife than Community and reserved forests.

One such protected area threatened by hunting in the northeast is Namdapha Tiger Reserve in the east Himalaya (1985 km2, Fig. 1, Fig. 2, Datta, 2007; Datta et al., 2008a; Narain et al., 2005). At the time of park declaration in 1983, a community claimed prior residence and disputed the boundary demarcation on the eastern fringe. In the late 1990s, partly prompted by loss of agricultural lands to erosion, and partly to claim land in the park, local people established several villages inside the park. Their population has since grown. Subsistence hunting and commercial poaching of bears and tigers have gone largely unchecked (Datta et al., 2008a). Reserve management has been inadequate for many years.. A conservation organization started community-based initiatives that included education, health care, alternate energy, and other welfare initiatives over eight years in an effort to reduce hunting and win the community's support for conservation (Datta, 2007). This was accompanied by efforts at dialogue between the community and the government at local, state, and national levels. Land was identified for resettlement but the community refused to leave, citing their dissatisfaction with the resettlement package. A stalemate continues. Nevertheless, hornbills and other species are at higher densities inside Namdapha than outside (Naniwadekar et al., 2015).

3.5 Fragmentation and Connectivity

According to Reddy et al. (2013), India is losing forest area at the rate of 0.2% per year, and>90% of remaining forest fragments are less than 1km2 in size. Global assessments indicate that habitat fragmentation in India is extensive (Crooks et al., 2017). Beyond forest loss, fragmentation prevents movement in arboreal animals, such as the western hoolock gibbon Hoolock hoolock (Vasudev and Fletcher Jr, 2015). Isolation of fragments has resulted in increased human-elephant conflicts (Baskaran et al., 2013), reduced gene flow among populations of tigers (Natesh et al., 2017) and forest understory birds (Robin et al., 2015), and altered species composition in mixed foraging bird flocks (Sridhar and Sankar, 2008). Negative consequences of fragmentation may be reduced if fragments are connected, enabling the movement of organisms between them (Crooks and Sanjayan, 2006). The tiger has been the main focus of connectivity studies (Qureshi, 2014), but ease of transit across the landscape varies across species and interacts with the particular obstacle encountered. Small understory birds are less likely to cross large open gaps than large, more mobile species (Robin et al., 2015). For example, a landscape genetics study in Central India shows that roads with high traffic and urban areas strongly affect connectivity for the tiger (Thatte et al., 2018, Fig. 3B). But for the jungle cat (Felis chaus) a similar analysis implies roads are relatively stronger obstacle than land use and all non-forest areas (linear infrastructure and other land use)
impede movement and connectivity for the sloth bear (Melursus ursinus) (Thatte, 2019). Maintaining connectivity in the face of development pressures across India will be an outstanding difficulty (Chanchani et al., 2016; Harihar et al., 2018;

Thatte et al., 2018; Bhagwat, 2018). This is exemplified in Uttarakhand, where suitable tiger habitat has been cut-off by development (Fig. 3A) and contains many fewer tigers than it could support.

3.6 Other Threats

Beyond habitat degradation, fragmentation, and hunting, other threats to conservation of biodiversity in protected areas include climate change, invasive species, and interactions between all threats. The richest locations for biodiversity in the east Himalaya should be relatively resistant to warming, given low anticipated climate change velocities (km/degree/year), facilitating tracking by flora and fauna. However, invasive plants are expected to be particularly adept at climate tracking, with presumed impacts on native flora (Mungi et al., 2018; Thapa et al., 2018). Manish et al. (2016) concluded that native plant species at higher elevations were most at risk from warming. This may perhaps be ameliorated because these are the elevations with the most protected area coverage (Elsen et al., 2018).

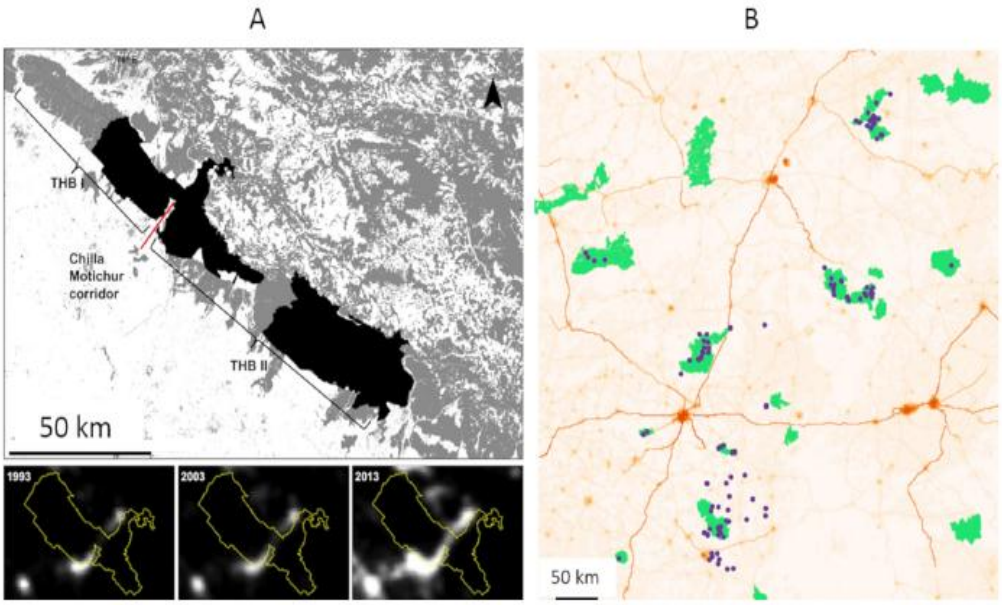

Figure 3: Two case studies demonstrating cross-tiger landscape functional connectedness.

In the plains of India, high climate velocities in addition to the fragmented forested landscape may combine to accentuate threats from habitat loss and invasive species, and further intensify connectivity issues. Predictions are difficult and confounded by precipitation. The Intergovernmental Panel for Climate Change (https://gisclimatechange.ucar.edu/gis-data-ar5) predicts that much of India will become drier than the 1986–2005 average, with only the currently wettest regions, i.e. the Western Ghats and the eastern Himalaya, becoming substantially wetter (Supplemental Fig. 2).

IV. PROTECTION MEASURES

The previous sections summarized what is known about the status of protected areas in India. Conservation of species within these areas is likely to be essential to the persistence of a large fraction of India's biodiversity. We now turn to ask how India is addressing protected area maintenance, considering legislation, national investment, contributions from ecotourism, local community initiatives, and possibilities for edge habitat restoration.

4.1 Legislation

The Constitution of India lays down parameters of governance, that is, the fundamental rights, duties, legislative fields, and powers of the Central and State Governments. Article 21 of the Constitution establishes the right to a clean environment and imposes an obligation on Governments to protect the environment. It is against this background that we should understand statutory enactments. For example, the Wildlife (Protection) Act of 1972 established a list of threatened species of India in the form of Schedules, which accord species certain levels of protection, and defined the categories of National Parks and Sanctuaries. The Supreme Court has leveraged this act and invoked the Indian Constitution to make several important rulings protecting nature. Some of the more remarkable illustrations include a ban on treefelling in natural areas, albeit with provisions for exceptions (TN Godavarman Thirumulkpad versus Union of India, 1996), the creation of the National Green Tribunal and a Central Empowered Committee to hear and oversee implementation of Supreme Court orders regarding environmental cases (Dutta, 2005), a temporary ban on tourists from visiting core areas of some Tiger Reserves (2012), and enforcement of a mine closure after Kudremukh in the Western Ghats was elevated to the status of a National Park. The Supreme Court also affirmed the importance of up to 10 km eco-sensitive zones bordering

National Parks and Sanctuaries, within which development and other activities need to consider the goals of the protected area. At the meeting of the Indian Board of Wildlife in January 2002, a 'Wildlife Conservation Strategy' was adopted wherein "lands falling within 10 km of the boundaries of National Parks and Wildlife Sanctuaries should be notified under as ecofragile zones". This order was revised in 2011 by the National Board for Wildlife, setting delineation and legal control of eco-sensitive zones at a distance that is site-specific (http://www.indiaenvironmentportal.org. in).

Finally, the passage of the Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forests Rights) Act in 2006 made it possible to confer land rights to people unofficially settled and cultivating forest lands (including protected areas) based on land tenure. While the Act provides an opportunity to formally recognize the role of these traditional forest-dwellers as allies in conservation, it also recognizes the need for inviolate areas for biodiversity conservation, from where people could be excluded upon just "settlement of rights" and after free prior informed consent is obtained (GOI, 2006).

4.2 Government Investment

The flagship national conservation program is that of Project Tiger, started in 1973. Government funding under this program has been primarily focused on the 50 designated Tiger Reserves, covering an area of ~71,000 km2 (2% of India's land area). Federal funds earmarked for Tiger Reserves in the fiscal year 2016–2017 (US$54.2 million) were over twice the amount allocated for conservation of biodiversity in other schemes ($23.6 million; see the Integrated Development of Wildlife Habitats scheme in the Union budget, http://www. indiabudget.gov.in/). Each Tiger Reserve annually receives direct grants based on requests made ($48,000 - $12 million per Reserve in 2016–2017) from the Central Government plus additional funds from the relevant State Government. The stated goal for Tiger Reserves is the maintenance of a functioning ecosystem, rather than tiger conservation per se. Focusing on the tiger appears to be an effective conservation tactic because it engenders public support and attracts tourists (Verissimo et al., 2011), it delivers broad biodiversity benefits given that tiger's habitat requirements inevitably result in the protection of other species (Sergio et al., 2006; Thornton et al., 2016), and top predators in general have a disproportionate effect on ecosystem stability (Cristoffer and Peres, 2003; Estes et al., 2011).

Despite the benefits gained from a focus on the tiger, several issues complicate the efficacy of tigers as a panacea for conservation. First, as noted above, the most species-rich locations for birds lie above 1500m in the east Himalaya, and many bird species are not found in any Tiger Reserve. Second, habitats most favourable for tigers are not necessarily suitable for other species. Karanth et al. (2009) estimate that rainforests and tropical evergreen forests, which are particularly species-rich (Gibson et al., 2011), support tigers at lower densities (1–2 tigers/ 100 km2), than do alluvial grasslands (15 tigers/100 km2) or deciduous forests (10 tigers/100 km2). Third, some management practices that enhance habitats for tigers or their prey, such as the burning of grasslands, may harm other species, such as the critically endangered pygmy hog (Porcula salvania) (Narayan and Deka, 2002).

4.3 Government Compensation

Government-facilitated resettlement of communities is one ingredient of protected area policy. At least 100,000 people were relocated between 1970 and 2008 (Lascorgeix and Kothari, 2009). This is only 2%–3% of Narain et al.'s (2005) suggestion for how many people continue to live in protected areas, but they have been focused on protected areas with relatively sparse populations (Karanth et al., 2018a). Resettlements continue (Karanth et al., 2018a), but require considerable investment, and have historically been controversial owing to negative outcomes for displaced communities (Shahabuddin and Bhamidipati, 2014; Karanth et al., 2018a). However, presently local people voluntarily move out of parks in return for new land and associated increases in living standards (e.g. Bhadra Tiger Reserve [Karanth, 2007]), and indeed many people are now on waiting lists (Karanth et al., 2018a). Resettlements have demonstrably led to improvements for wildlife; reproductive performance of prey and density of tigers increased significantly within three years of pastoralists resettling out of Rajaji National Park (Harihar et al., 2009).

Whether or not protected areas have people living inside them, all protected areas have people living nearby. In some locations, people living on a reserve's edge have come to tolerate the presence of a reserve as essentially someone else's property (Badola, 1999; Wilshusen et al., 2002). This tolerance is severely tested when animals stray out of protected areas and encounter humans and settlements on the edge. Tigers, leopards, elephants, and bears often inflict considerable costs on nearby inhabitants, including human casualties, property damage, and depredation of livestock or crops, all of which generally affects economically stressed communities (Karanth et al., 2013). Inevitably, this leads to increased animosity as well as the retaliatory killing of animals (Dickman et al., 2011; Harihar et al., 2014). Increasingly, compensation schemes are addressing this issue (Karanth et al., 2018b). In some cases, Non-Governmental Organizations (NGOs) offer a suite of benefits to offset livestock losses. One example from Spiti valley is the communityrun insurance schemes and livestock protection measures against snow leopard and wolf depredation (Mishra et al., 2003). While certainly helping, these are limited in scale and funding. Now NGO initiatives are more focused on facilitating government pay-outs. For example, Project Wild Seve (wildseve.org) works around Bandipur and Nagarahole Tiger Reserves in the southern state of Karnataka. Between 2015 and 2018, they helped expedite $230,000 of government compensation for 5339 families (K K Karanth, unpublished data).

4.4 Local Community Investment

The rapid increase in the number of Community Reserves and Conservation Reserves has potential for communities to benefit economically while conserving nature (Shahabuddin and Thadani, 2018). To illustrate this potential, we again draw on an example from northeast India. Eaglenest Wildlife Sanctuary (103 km2), lies in the western part of Arunachal Pradesh. It is an important Sanctuary, ranging from the plains up to 3000m and containing a huge diversity of species (Price, 2012, Figs. 1, 2a). The Eaglenest Biodiversity Project started in 2003 in partnership with the local Bugun tribe (Mohan and Athreya, 2011). The project has met with some success. Most notably, local people currently manage ecotourism. For 8 months of the year, ecotourism employs about 25 people and supports several businesses. While large mammals appear to be more abundant inside the Sanctuary than outside it (Velho et al., 2016), there have been no studies of change in extraction activities by local people. However, in 2016, the Buguns of Singchung village set aside 16 km2 of village forest adjacent to Eaglenest as a Community Reserve, thereby restricting its exploitation. The success of the Eaglenest project so far depends on an interplay of factors including few external pressures, linking local socio-economic benefits to the integrity of the wilderness through ecotourism, influential individuals who brought together stakeholders, and a comprehensive biodiversity inventory. Furthermore, a Supreme Court litigation that helped relocate a proposed road outside its boundaries, helped in conveying to the local community a sense of the global importance of its biodiversity.

4.5 Local Champions

Exceptional individuals — "conservation champions" — have been known to be vital to the success of Tiger Reserves despite various odds against them (Post and Pandav, 2013). These are individuals dedicated to the locality and integrated into the community. The relatively young Pakke Tiger Reserve (Fig. 2a, 862 km2) in western Arunachal Pradesh has performed much better than Namdapha, which we considered in an earlier section. One reason for this is the presence of dedicated forest officers, resulting in greater participation of local communities, in conjunction with strong leadership and law enforcement. Importantly, from 1999 onwards, a local officer from the Nyishi community engaged the community living on the south-eastern boundary. After 2006, new leadership provided by another Nyishi officer strengthened law enforcement and developed initiatives to build local institutions to support conservation (A. Datta, pers. obs.). Tigers, ungulates, and primates all appear to have increased in numbers (Jhala et al., 2015; Selvan et al., 2014). Besides local personalities, Pakke has probably been more successful than Namdapha because it is more accessible than Namdapha and the community that surrounds Pakke is a dominant tribe in the state with political power. The community around Namdapha remains a largely marginalized, little-known tribe.

4.6 Ecotourism

A promising way to gain local support for a park is through increased income. Most obviously, nature-based tourism can provide economic benefits (Karanth et al., 2012). More than 3 million visits to National Parks were recorded in 2015, greater than a threefold increase since 2005 (Karanth et al., 2017). We consider economic benefits to local people from the presence of protected areas. Data are generally scarce, but a recent governmentcommissioned assessment of six Tiger Reserves generated some figures of park-derived local income (Verma et al., 2015). Local workers employed by the Forest Department at the Sundarbans receive $500,000 annually. For Periyar, patrolling by locals with accompanying tourists garnered $250,000 per year. In some protected areas, part of the gate fees goes to communities living on the park edge for development schemes—estimated at $50,000 for Sundarbans. For Corbett, employment of (daily wage) workers and guides generated approximately $1.3 million in wages annually. These amounts are relatively small when considering the size of surrounding populations. Furthermore, around Corbett, the purchasing of land by external hoteliers has led to local disillusionment and conflicts, partly stemming from the fact that little of the revenue stays locally (Rastogi et al., 2015). However, estimates of economic benefits from parks ignore many other indirect sources of revenue, including from tourists who stay locally. In 2006–2007, at Kaziranga, tourists were estimated to have spent $5 million, of which about $1.6 million went to local enterprises (Hussain et al., 2012). The extent to which this income stayed in the surrounding community is not known. Karanth and DeFries (2011) studied hotels and homestays near 10 Tiger Reserves. From their data, assuming an occupancy rate of 50%, we estimated an average monthly inflow of $9000–$48,000 in room fees (depending on the park), with just 2%–6% of this going to salaries for local employees. Again, this ignores many other benefits flowing to communities, but the information available suggests relatively limited local benefits. Overall, these findings imply considerable opportunities for improvement in local income generated by protected areas. For example, studies based on travel costs invariably find that entrance fees could be raised as a means to increase revenue (Guha and Ghosh, 2009; Badola et al., 2010). Any measures taken to improve local profits require appropriate reforms to ensure equitability in the distribution of benefits, and greater local involvement in ecosystem management and protection activities (Rastogi et al., 2010).

4.7 Local Benefits from Expansion

Global reviews show that degradation of habitat adjacent to reserves has considerable impact on reserve health (Laurance et al., 2012). Thus, an additional strategy for increasing the success of protected areas could be to improve edge habitat. This should be possible to do with local economic benefits. Restoration efforts can be through both single-owner private land (e.g. tea estates, Mudappa et al., 2014) or community-based efforts in reserved forest (e.g. for hornbills [Rane

and Datta, 2015]). Small but valuable interventions include encouraging surrounding coffee plantations to be organic, shade, and wildlife friendly, with associated consumer certification (Anand et al., 2008; Bose et al., 2016; Chang et al., 2018). More extreme interventions transform lands to private reserves, which are particularly effective when adjacent to protected areas (Karanth and Karanth, 2012). At present, India has only a few private reserves (e.g. Jabarkhet Nature Reserve in Uttarakhand and Sai Wildlife Sanctuary in Karnataka). The idea of private reserves remains controversial because benefits to local communities require co-operation among many small landholders (Karanth and Karanth, 2012), with the alternative again being land annexures by powerful interests (Rai, 2012). Nevertheless, when applied fairly, after careful social impact assessment and in participation with local communities to ensure equitable returns, private reserves have potential. Finally, public lands next to protected areas could be better developed for conservation and associated ecotourism. For example, we obtained records from the Uttarakhand Forest Department, which show that visits to Corbett National Park increased from 62,600 in the year 2000 up to 280,000 tourists in 2015, but remained capped at about that number in 2016 and 2017. Associated with both the increase and the limit, more tourists started to visit adjoining Ramnagar reserved forest (Supplemental Fig. 3). Approximately 60 km2 of the reserved forest were designated as Pawalgarh Conservation Reserve in 2012, where tourism is regulated and comes with entry fees, further heping to promote regulated eco-tourism. The number of tourists visiting Pawalgarh now rivals that visiting Corbett (Supplemental Fig. 3).

V. CONCLUSION

Many assessments of the success of protected areas are based on global datasets. Here, we have extended such analyses to consider protection at the national and local level in one of the world's most biodiverse countries, India. A renewed emphasis on lessons learned from case studies is exemplified by Pringle's (2017) review of two protected areas, one in Costa Rica and the other in Mozambique. Both of these cases have been facilitated by public-private partnerships, with a number of dedicated local citizens and international collaboration. That is one particular model; it may not generalize to all locations. As Pringle notes, there is no "one-size-fits-all recipe". However, there is consensus that success relies on local support, and that benefits to both people and wildlife are essential for long-term conservation.

Protected areas vary considerably in their conservation outcomes (Oldekop et al., 2016). In India, factors affecting success vary with the degree to which the region is developed. For example, well-developed institutional infrastructure in Corbett makes management of tourists and economic opportunities for local people the critical issues (Rastogi et al., 2010). In contrast, the remoteness of parks in Arunachal Pradesh in northeast India results in major threats from deforestation and hunting (Aiyadurai et al., 2010; Datta et al., 2008a; Pandit et al., 2007; Velho et al., 2012). Within Arunachal Pradesh, effectiveness of protection also varies greatly. This is due largely to the lack of strong institutional mechanisms in the Government (mainly the Forest Department), unlike in most other parts of the country. Hence, local factors become even more important in determining success. These differences are likely to apply to other developing countries as well, where the most pristine areas may experience the highest variance in conservation successes.

Strong legal backing and enforcement help preserve protected areas, but an emerging theme is that conservation requires the support of local communities. One promising way to garner such support is to provide nature-based economic benefits. Economic benefits are two-pronged: monetary compensation for losses caused by wildlife, and revenue generated, particularly by tourism. Both schemes are currently in place in India, and they have considerable potential to provide income and resources to people living near protected areas. In several states, these schemes could be considerably improved in terms of delivery and distribution (Karanth et al., 2018b). The case studies presented here illustrate that in India, best practices vary among individual protected areas. Managers must operate with regard to each area's level of development, socio-economic standing, and political context, along with the customs, needs, and constraints of tribal and indigenous communities. We anticipate that similar principles apply to other countries.

A major message from our assessment is the lack of data, and prompts one to ask what should be the important priorities for research. We identified three particular needs. First, more study of the landscape matrix in which protected areas are embedded would be exceptionally valuable, especially as many protected areas are relatively small and connectivity is a major issue. For example, in Uttar Pradesh some Tiger Reserves actually have a lower density of tigers than does the surrounding reserved rorest (Chanchani et al., 2016). We need a greater understanding of what factors drive this, how other species are doing in reserved forests, and how biodiversity prospects could be improved without detriment to human uses of the forest. Second, very little longterm monitoring of populations in protected areas is happening in India. Apart from tigers, this is not co-ordinated centrally, unlike the missions of many societies in the US and Europe (e.g. the British Trust for Ornithology in the UK). Third, a much better understanding of cash benefits of protected areas, particularly from tourism, is required (Karanth et al., 2017). We suspect that they are larger than currently appreciated. With respect to practical efforts, especially for NGOs involved in conservation, our review emphasizes the importance of individuals and organizations investing energy intensively at single sites rather than in a more diffuse manner, and interactively with local populations. For policy makers, we have two recommendations. First, management of surrounding reserved forests to include scientific monitoring and management in collaboration with local communities would be an effective way forward; legal backing is already in place given the Supreme Court order that up to 10 km from a protected area can be considered an eco-sensitive zone. Through these measures, India can endeavour to get reserved forests designated as IUCN Category VI protected areas, which will lend support to the country's claim of having already

exceeded the Aichi target (17%) in terms of area under protection (Pande and Arora, 2014). Second, we echo the arguments of Bindra (2017) that it is critical to focus on the protected areas we have, with development and denotifications allowed only under exceptional circumstances. The 5% of land currently designated as protected is essential to the conservation of India's biodiversity, not only through targeted efforts for threatened species, but to maintain populations of less-threatened species.

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