

## Protected areas and biodiversity conservation in India

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## 1 **Abstract**

2 Three well-supported generalizations in conservation biology are that developing tropical  
3 countries will experience the greatest biodiversity declines in the near future, they are some of  
4 the least studied areas in the world, and in these regions especially, protection requires local  
5 community support. We assess these generalizations in an evaluation of protected areas in India.  
6 The 5% of India officially protected covers most ecoregions and protected areas have been an  
7 important reason why India has suffered no documented species extinctions in the past 70 years.  
8 India has strong legislation favouring conservation, government investment focused on 50 Tiger  
9 Reserves, and government compensation schemes that facilitate local support, all of which  
10 brighten future prospects. However, many protected areas are too small to maintain a full  
11 complement of species, making connectivity and species use of buffer zones a crucial issue.  
12 Conservation success and challenges vary across regions according to their development status.  
13 In less developed areas, notably the biodiverse northeast Himalaya, protected areas maintaining  
14 the highest biodiversity result from locally-focused efforts by dedicated individuals. Across  
15 India, we demonstrate considerable opportunities to increase local income through ecotourism.  
16 Our evaluation confirms a lack of data, increasing threats, and the importance of local support.  
17 Research on biodiversity in buffer zones, development of long-term monitoring schemes, and  
18 assessment of cash and conservation benefits from tourism are in particular need. For policy  
19 makers two main goals should be the development of monitoring plans for 'eco-sensitive zones'  
20 around protected areas, and a strong emphasis on preserving established protected areas.

21

22 **Keywords:** biodiversity, ecotourism, edge expansion, local community, northeast India, Tiger  
23 Reserves

## 24 **1. Introduction**

25 Assessments at the global and regional level have indicated the most effective places to put  
26 protected areas in order to conserve biodiversity, as well as locations that are relatively under-  
27 protected (Myers et al., 2000; Ocampo-Penuela et al. 2016; Newmark et al. 2017; Pollock et al.,  
28 2017; Elsen et al., 2018; Pimm et al. 2018). Other works focus on the state of biodiversity in  
29 general (Pimm et al., 2014; Newbold et al., 2015) including evaluations of the extent to which  
30 protected areas succeed in maintaining species (Gray et al., 2016; Newbold et al., 2015). These  
31 assessments rely on remote sensing (Venter et al., 2016), a few global datasets (e.g. the world  
32 database on protected areas, [www.iucn.org](http://www.iucn.org)), literature reviews that contrast biodiversity patterns  
33 across space (Gray et al., 2016) or time (Dornelas et al. 2014; Newbold et al., 2015), and  
34 contributions to public online databases. While informative, results from these studies raise two  
35 major issues that we need to address if conservation prospects are to improve. The first is the  
36 quality and quantity of the data. Data may be especially lacking in exactly those regions where  
37 biodiversity will be most threatened in the coming years (tropical, rapidly developing areas with  
38 high human population growth; Pimm et al., 2014; Tilman et al., 2017). The second is that  
39 biodiversity conservation is largely at the provenance of national, state, and local levels, creating  
40 large variation in the success of protected areas both between and within countries. We can gain  
41 much by studying individual cases, rather than global averages or generalities, because  
42 experience across multiple case studies can be tailored to the unique situations encountered in  
43 any one location.

44

45 India exemplifies the challenges of conservation in developing tropical countries. It is the  
46 world's second most populous country and may overtake China within a decade. Its population

47 has more than doubled since the late 1970s, is growing by 15,000 people a day, and has a current  
48 density of ~330/km<sup>2</sup>. It falls in the bottom third of countries ranked by *per capita* GDP, but with  
49 an additional US \$50 billion entering the economy annually, it is transforming rapidly: people  
50 across all economic classes are consuming more. India has an exceptional number of plant  
51 (Joppa et al., 2013) and animal (Jenkins et al., 2013) species facing these increased pressures.  
52 For example, 888 species of birds regularly breed within India's boundaries, more than 8% of the  
53 world's total (based on maps compiled by birdlife.org).

54

55 While approximately 15% of global land is protected, India officially protects 5% of its  
56 area (Dinerstein et al. 2017). However, India's conservation challenge differs from that of other  
57 large countries, such as the USA, Brazil, and China. In these countries, large protected areas are  
58 situated in sparsely populated regions, which in the USA and China are also of relatively low  
59 biodiversity (Pimm et al. 2018). Instead, in India, many millions of people live within a few  
60 kilometres of protected areas and perhaps 4 million reside within them (Narain et al. 2005),  
61 although the figure is uncertain, with no updates this century. This creates major challenges for  
62 those who manage India's biodiversity, both because the protected areas are used to some  
63 degree, and because major targets of conservation efforts, including elephants (*Elephas*  
64 *maximus*), tigers (*Panthera tigris*), leopards (*Panthera pardus*), bears (*Melursus ursinus*), wolves  
65 (*Canis lupus*), snow leopards (*Panthera uncia*) and prey species such as wild pigs (*Sus scrofa*),  
66 nilgai (*Boselaphus tragocamelus*), chital (*Axis axis*) and sambar (*Rusa unicolor*) pose threats to  
67 humans, livestock and crops. Such challenges are likely to become more pressing and more  
68 widespread across the world, as populations and wealth increase in the tropics.

69

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

77 .

## 78 **2. Status of Protected areas in India**

79 India designated its first National Park, presently named Corbett National Park, in 1936. To date,  
80 officially protected areas in India now consist of 104 National Parks and 551 Wildlife  
81 Sanctuaries ([www.wiienvis.nic.in](http://www.wiienvis.nic.in)); however, 5 National Parks and 79 Sanctuaries are less than 1  
82 km<sup>2</sup> (many are islands), and are not considered further in this paper. National Parks enjoy the  
83 highest protection, being legally free from human intervention (International Union for the  
84 Conservation of Nature (IUCN), Category II, see [www.iucn.org](http://www.iucn.org)). Wildlife Sanctuaries fall into  
85 IUCN category IV, which allows for limited use. India introduced two additional legal categories  
86 for its protected areas in 2002 (Saigal et al., 2018). Conservation Reserves, on public land, and  
87 Community Reserves, on private land (IUCN Categories V and VI, respectively) are established  
88 mainly on the basis of approved management plans. Of 214 such reserves established by 2019  
89 (4,811 km<sup>2</sup> in total), more than 70% are in just three states (122 Community Reserves are in  
90 Meghalaya and Nagaland, and 34 Conservation Reserves in Jammu & Kashmir). The  
91 Convention for Biological Diversity in 2011 set the well-known Aichi Biodiversity Targets,  
92 including the goal that protected areas across the earth's land surface should increase from 13%

93 to 17%. Recent guidelines developed by the International Union for the Conservation of Nature's  
94 World Commission on Protected Areas now admits Conservation and Community Reserves as  
95 contributing to that goal, but at present these two categories comprise only 0.15% of India's  
96 surface area (IUCN WCPA, 2018). However, government-owned reserved forests, which local  
97 communities sometimes participate in managing, cover 13.2% of India and often contribute to  
98 buffers and corridors for protected areas ([www.fsi.nic.in](http://www.fsi.nic.in); Shahabuddin and Thadani, 2018). To  
99 the extent that these are managed in a way that leads to positive biodiversity conservation  
100 outcomes, they may also contribute to the Aichi targets. They are certainly subject to legal  
101 restrictions on resource exploitation, but are not well monitored to assess the enforcement of  
102 protection and status of biodiversity, which are requirements of the current guidelines (IUCN  
103 WCPA, 2018).

#### 104 *2.1 Protected area contributions to conservation*

105 No bird or mammal is known to have been lost from India since the cheetah (*Acinonyx jubatus*)  
106 was extirpated in the mid-20th century (Divyabhanusinh, 1999). Protected areas have clearly  
107 played an important role in this success (Karanth et al., 2010; Walston et al., 2016). For example,  
108 more than 85% of the world's one-horned rhinos (*Rhinoceros unicornis*) and more than 70% of  
109 the world's tigers live in India, largely a consequence of the efficient functioning of India's Tiger  
110 Reserves (Jhala et al., 2015; Talukdar et al., 2008; Walston et al., 2016). For birds, protected  
111 areas provide major refuges for many species in low numbers. The three *Gyps* vulture species,  
112 after experiencing a 97% population decline in total due to veterinary use of the drug diclofenac,  
113 are now largely found inside or near National Parks (Prakash et al., 2017). The Jerdon's courser  
114 (*Rhinoptilus bitorquatus*), a critically endangered species last seen in 2009 is most likely to  
115 persist in the Sri Lankamaleswara Wildlife Sanctuary ([www.iucnredlist.org](http://www.iucnredlist.org)). Conversely, the

116 low number of protected areas in certain ecoregions such as the Gangetic Plain (Fig. 1) is surely  
117 contributing to the endangered status of several species. Grasslands have been converted to  
118 agriculture, pasture and plantations throughout India (Arasumani et al., 2018; Rahmani, 2012).  
119 Threats to grassland birds are exemplified by the Great Indian bustard (*Ardeotis nigriceps*),  
120 which now numbers <250 individuals (Dutta et al., 2016).

121

122         Within India's protected areas, only a few censuses of animal and plant populations have  
123 been published to assess their effectiveness at maintaining biodiversity. The global survey of  
124 Dornelas et al. (2014) lists just one study of trees from India, with no appreciable change in  
125 diversity over time. The Living Planet index, which records censuses between 1970 and 2014,  
126 gives only three studies with more than 5 years of data (<http://www.livingplanetindex.org>). They  
127 are the one-horned rhinoceros in two National Parks from Assam (Syangden et al., 2008), lion  
128 (*Panthera leo*), leopard, striped hyena (*Hyaena hyaena*) and chital in the Gir forest (Singh and  
129 Gibson, 2011) and *Gyps* vultures from Bharatpur (Prakash, 1999). While vultures have declined,  
130 all the mammals appear to have increased. Overall, data on the success of protected areas in  
131 India are clearly in short supply, and future studies are needed to thoroughly evaluate their  
132 efficacy.

133

## 134 2.2 Protected area coverage

135 Rodgers and Panwar (1988) used principles of biogeography and distribution of biomes across  
136 India to develop a plan for a protected area network that guided both National and State  
137 Institutions. Presently, Sanctuaries and National Parks cover the 28 forested ecoregions of India  
138 at a median level of 5.5% of their area. However, 6 ecoregions have less than 2% coverage



139 (Dinerstein et al. 2017). The map in Fig. 1 also implies that heavily populated regions, such as in  
140 the Gangetic Plain, have relatively few protected areas. Considerations of biome and ecoregion  
141 coverage do not address how many species are actually present in the protected areas. To assess  
142 species coverage, we overlaid India's 888 breeding species of birds (from birdlife.org), as the  
143 best-known group, on delimited Sanctuaries and National Parks (Fig. 1). These are clearly lower  
144 bounds on species numbers, because trimming maps to include factors such as habitat, elevation,  
145 and park fragmentation excludes many species (Li and Pimm, 2016; Ocampo-Peñuela et al.,  
146 2016). According to this analysis, only three bird species with substantial breeding populations  
147 in India are not present in any protected area (White-capped bunting *Emberiza stewarti*, Glossy  
148 Ibis *Plegadis falcinellus* and Maroon-backed accentor *Prunella immaculata*), all of which have  
149 large populations in other countries (the Glossy ibis appears to have recently started breeding in  
150 south India, in a small sanctuary (Venkatraman 2009)). However, the conclusion of thorough  
151 coverage is qualified because 82 species are only found in protected areas smaller than 500 km<sup>2</sup>,  
152 and 160 are found in four or fewer Protected areas (Supplemental Fig. 1). Finally, when we  
153 restricted the analysis to Tiger Reserves, which are the focus of much of India's conservation  
154 effort (see below), we found that 28% of all bird species do not overlap with any reserve. The  
155 figure increases to 33% if we exclude the Tiger Reserves in Arunachal Pradesh, which are less  
156 well protected than elsewhere (see below). One reason for the absence of many bird species and  
157 associated ecoregions from Tiger Reserves is that east Himalayan elevations above 1500m  
158 contain the highest bird species richness of anywhere in India (Price et al., 2011).

159

160 Northeast India is exceptional in its richness of species, many of which are threatened  
161 (Fig. 1). It is also one of the most biodiverse places in the world (Price, 2012; Jenkins et al.,

162 2013). In the analysis associated with Figure 1, we found that 25 protected areas intersect the  
163 ranges of >300 breeding bird species, all of which are in the forested regions of Northeast India  
164 and the eastern Himalaya. They include National Parks that are both small (e.g., Phawngpui Blue  
165 Mountain in Mizoram, 55 km<sup>2</sup> and Keibul-Lamjao in Manipur, 39 km<sup>2</sup>) and large  
166 (Khangchendzonga, Sikkim, 1784 km<sup>2</sup>). Despite the biological importance of northeast India,  
167 recent reviews of conservation and development in India barely mention this region  
168 (Shahabuddin, 2010; Bindra, 2017; Bhagwat, 2018; see Price, 2018). Therefore, in certain  
169 sections below we describe four protected areas in the northeast (as indicated by letters in Fig. 1,  
170 right and mapped in Fig. 2). These four examples are chosen to illustrate topics of general  
171 concern, but for which no summary dataset is available.

172

### 173 *2.3 Protected area size*

174 Based on global studies, estimates of bird species loss suggest isolated tropical fragments 10 km<sup>2</sup>  
175 in area will lose their first species within 7 years, while one the size of 500 km<sup>2</sup> will lose its first  
176 species within 40 years (Newmark et al. 2017). However, it takes about 300 and 3,000 years  
177 respectively for 50% of the original avifauna to be lost from these fragments. In India, areas  
178 smaller than 700 km<sup>2</sup> have historically experienced a 50% probability of losing dholes (*Cuon*  
179 *alpinus*) and areas smaller than 135 km<sup>2</sup> a 50% probability of losing tigers (Woodroffe and  
180 Ginsberg 1998), exemplified by the more recent loss of tigers from Sariska National Park (in  
181 2005, the Park covers 270km<sup>2</sup>) and Panna National Park (in 2008, 540 km<sup>2</sup>; Chundawat et al.,  
182 2016; Gopal et al., 2010; Shahabuddin, 2010). These two parks have since been repopulated  
183 with tigers through translocation of individuals (Jhala et al. 2015). Elsewhere in the world, much  
184 larger protected areas have lost large mammal species. Six parks smaller than 5,000 km<sup>2</sup> in

185 Ghana lost at least 25% of their large mammals in 30 years (Brashares et al. 2001). Eighty-eight  
186 percent (14/16) of protected areas smaller than 10,000 km<sup>2</sup> across Tanzania and western North  
187 America lost at least one species over timespans of 50-80 years (Newmark 1995, 1996).  
188 Additional negative effects of small areas in India include reduced genetic diversity (golden  
189 langur [*Trachypithecus geei*], Ram et al. 2016; tiger, Natesh et al. 2017) and higher load of  
190 gastrointestinal parasites in multiple mammal species (Chakraborty et al. 2015).

191 Twenty-nine parks and Sanctuaries in India are larger than 1,000km<sup>2</sup> and just two are  
192 larger than 5,000km<sup>2</sup> (one in the desert, and another above treeline; Fig. 1). However, India's  
193 Tiger Reserves are generally a composite of National Parks and Sanctuaries (these two  
194 categories cover ~40% of Tiger Reserve area), plus reserved forest or other governmental land,  
195 which effectively increases the area of suitable habitat (Jhala et al., 2015). Maintenance of this  
196 land importantly contributes to protection (Wikramanayake et al., 2011; Chanchani et al., 2016).  
197

#### 198 *2.4 Protected area habitat quality*

199 At present, the biodiversity of individual protected areas with respect to a pristine state is  
200 uncertain, but clearly varies substantially from one place to another. Many protected areas are  
201 lower in quality than they otherwise could be. First, industrial monocultures such as rubber,  
202 coffee and teak have historically formed significant areas of National Parks and Sanctuaries, due  
203 to colonial emphasis on commercial forest use. Such monocultures harbour only a small  
204 proportion of the native fauna (Kumar et al., 2011). Second, forest fragmentation has been  
205 documented in some protected areas (e.g. Nameri Tiger Reserve, Saikia et al. 2013). Fragments  
206 are generally smaller and farther apart towards the park periphery (e.g. Tadoba Andhari Tiger  
207 Reserve, Nagendra et al. 2006), and they are more numerous in smaller rather than larger

208 protected areas (e.g., in protected areas of Rajasthan, Krishna et al. 2014). Third, people live  
209 inside many protected areas. Narain et al. (2005) suggest that 56% of the National Parks and  
210 72% of the Sanctuaries had some people living in them (but they also note a great deal of  
211 uncertainty in these figures). Fourth, even in those protected areas without human habitation,  
212 local people (Datta, 2007; Narain et al., 2005; Shahabuddin, 2010), tourist enterprises (Karanth  
213 et al., 2012), and developers (Bindra, 2017; Bhagwat, 2018) use resources inside the protected  
214 area. In some cases, this is legal, especially when local rights allowing limited use of Sanctuaries  
215 were retained from previous local rights held prior to designation as a Sanctuary. In many other  
216 cases, legal restrictions are ignored. For example, according to Bindra (2017, p.114) 200,000  
217 cattle graze in, or close to, Sariska Tiger Reserve, and the small Hollongapur Gibbon Sanctuary  
218 in Assam contains heavily degraded land on one side used for cattle grazing (Fig. 2c).

219

220           Given observations such as these, Bhagwat (2018) suggests that many protected areas  
221 have recently suffered from “downgrading, downsizing, and degazettement”, which would surely  
222 affect long term conservation goals. However, available data imply relatively modest losses (7  
223 downsizes, 5 downgrades, and 2 degazettes, <http://www.paddtracker.org/view-padd>, ~1,100  
224 km<sup>2</sup> in total downsized between 1990 and 2010). These have been more than compensated by  
225 recent additions to the protected area system (24 Sanctuaries added ~5,200 km<sup>2</sup> between 2010  
226 and 2015, [www.wiienviis.nic.in](http://www.wiienviis.nic.in)). This is not to say that downgrading is not occurring, but that  
227 changes in protected area quality are poorly documented.

228

229           Effects of size and quality can be countered by directed management programs that alter  
230 and improve prospects for targeted species in dangerously low numbers (Butchart et al., 2006,

231 2016). As we noted, in India, population sizes of one horned rhinoceros and tiger are explicitly a  
232 result of protected area management and protection, specifically focused on these species.

233

### 234 *2.5 Hunting in protected areas*

235 Hunting is another understudied threat (Velho et al. 2012). Hunting pressure clearly varies across  
236 regions and taxa, but is particularly intense in the northeast India (Aiyadurai et al., 2010; Datta et  
237 al., 2008a; Velho et al., 2012). India's wildlife laws entirely prohibit hunting of wildlife in these  
238 forests, but enforcement is weak. Tribal communities have a strong tradition of hunting—for  
239 meat, medicine, ritual customs, recreation, and increasingly for income (Aiyadurai et al., 2010).  
240 Improved technologies like guns and snares along with access to markets have resulted in large  
241 vertebrates being extremely rare or locally extirpated in many parts of Arunachal Pradesh (Datta  
242 et al., 2008a). In one study of 51 villages, 33 mammal species were hunted, of which 20 are  
243 listed as threatened on the IUCN Red List (Aiyadurai et al., 2010). Beyond tigers, the primary  
244 targets are hornbills, ungulates, pheasants, bears, and primates (Aiyadurai et al., 2010; Datta et  
245 al., 2008a), although other groups such as squirrels and small carnivores are also hunted (Datta et  
246 al., 2008b; Dollo et al., 2010). Given the functional importance of these faunal groups as prey  
247 species for large carnivores or as frugivores and seed dispersers, their decline is likely to have  
248 myriad ecological consequences (Naniwadekar et al., 2014). Despite the imperfections of law  
249 enforcement and the prevalence of hunting, protected areas still provide a greater level of  
250 security to wildlife than Community and Reserved Forests (Naniwadekar et al., 2015; Velho et  
251 al., 2016).

252 One such protected area threatened by hunting in the northeast is Namdapha Tiger  
253 Reserve in the east Himalaya (1985 km<sup>2</sup>, Fig. 1, Fig. 2, Datta, 2007; Datta et al., 2008a; Narain et

254 al., 2005). At the time of park declaration in 1983, a community claimed prior residence and  
255 disputed the boundary demarcation on the eastern fringe. In the late 1990s, partly prompted by  
256 loss of agricultural lands to erosion, and partly to claim land in the park, local people established  
257 several villages inside the park. Their population has since grown. Subsistence hunting and  
258 commercial poaching of bears and tigers have gone largely unchecked (Datta et al., 2008a).  
259 Reserve management has been largely absent, with no director for 10 years. A conservation  
260 organization started community-based initiatives that included education, health care, alternate  
261 energy, and other welfare initiatives over eight years in an effort to reduce hunting and win the  
262 community's support for conservation (Datta, 2007). This was accompanied by efforts at  
263 dialogue between the community and the government at local, state, and national levels. Land  
264 was identified for resettlement but the community refused to leave, citing their dissatisfaction  
265 with the resettlement package. A stalemate continues. Nevertheless, hornbills and other species  
266 are at higher densities inside Namdapha than outside (Naniwadekar et al., 2015).

267

## 268 *2.6 Fragmentation and connectivity*

269 According to Reddy et al. (2013), India is losing forest area at the rate of 0.2% per year, and  
270 more than 90% of remaining forest fragments are less than 1km<sup>2</sup> in size and global assessments  
271 indicate that habitat fragmentation in India is extensive (Crooks et al., 2017). Beyond forest loss,  
272 fragmentation prevents movement in arboreal animals, such as the western hoolock gibbon  
273 *Hoolock hoolock* (Vasudev et al., 2015). Isolation of fragments has resulted in increased human-  
274 elephant conflicts (Baskaran et al., 2013), reduced gene flow among populations of tigers  
275 (Natesh et al., 2017) and forest understory birds (Robin et al., 2015), and altered species  
276 composition in mixed foraging bird flocks (Sridhar and Sankar, 2008).

277

278           Negative consequences of fragmentation may be reduced if fragments are connected,  
279 enabling the movement of organisms between them (Crooks and Sanjayan, 2006). The tiger has  
280 been the main focus of connectivity studies (Qureshi, 2014), but ease of transit across the  
281 landscape varies across species and interacts with the particular obstacle encountered. Small  
282 understory birds are less likely to cross large open gaps than large, more mobile species (Robin  
283 et al., 2015). For example, a landscape genetics study in Central India shows that roads with high  
284 traffic and urban areas strongly affect connectivity for the tiger (Thatte et al. 2018, Fig. 3A). The  
285 tiger has been the main focus of connectivity studies (Qureshi, 2014), but for the jungle cat (*Felis*  
286 *chaus*) a similar analysis implies roads are relatively stronger obstacle than land use (Thatte et  
287 al., 2019). For the sloth bear (*Melursus ursinus*) a similar analysis implies all non-forest areas  
288 (linear infrastructure and other land use) impede movement and connectivity (Thatte et  
289 al., 2019). Maintaining connectivity in the face of development pressures across India will be an  
290 outstanding difficulty (Chanchani et al., 2016; Harihar et al., 2018; Thatte et al., 2018; Bhagwat,  
291 2018). This is exemplified in Uttarakhand, where suitable tiger habitat has been cut-off by  
292 development (Fig. 3B) and contains many fewer tigers than it could support.

293

#### 294 *2.7 Other threats*

295 Beyond habitat degradation, fragmentation, and hunting, other threats to conservation of  
296 biodiversity in protected areas include climate change, invasive species, and interactions between  
297 all threats. The richest locations for biodiversity in the east Himalaya should be relatively  
298 resistant to warming, given low anticipated climate change velocities (km/degree/year),  
299 facilitating tracking by flora and fauna. However, invasive plants are expected to be particularly

300 adept at climate tracking, with presumed impacts on native flora (Mungi et al., 2018; Thapa et  
301 al., 2018). Manish et al. (2016) concluded that native plant species at higher elevations were  
302 most at risk from warming. This may perhaps be ameliorated because these are the elevations  
303 with the most protected area coverage (Elsen et al., 2018). In the plains of India, high climate  
304 velocities in addition to the fragmented forested landscape may combine to accentuate threats  
305 from habitat loss and invasive species, and further intensify connectivity issues. Predictions are  
306 difficult and confounded by precipitation. The Intergovernmental Panel for Climate Change  
307 (<https://gisclimatechange.ucar.edu/gis-data-ar5>) predicts that much of India will become drier  
308 than the 1986-2005 average, with only the currently wettest regions, i.e. the Western Ghats and  
309 the eastern Himalaya, becoming substantially wetter (Supplemental Fig. 2).

310

### 311 **3. Protection measures**

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

317

#### 318 *3.1 Legislation*

319 The Constitution of India lays down parameters of governance, that is, the fundamental rights,  
320 duties, legislative fields, and powers of the Central and State Governments. Article 21 of the  
321 Constitution establishes the right to a clean environment and imposes an obligation on  
322 Governments to protect the environment. It is against this background that we should understand



323 statutory enactments. For example, the Wildlife (Protection) Act of 1972 established a list of  
324 threatened species of India in the form of Schedules, which accord species certain levels of  
325 protection, and defined the categories of National Parks and Sanctuaries. The Supreme Court has  
326 leveraged this act and invoked the Indian Constitution to make several important rulings  
327 protecting nature. Some of the more remarkable illustrations include a ban on tree-felling in  
328 natural areas, albeit with provisions for exceptions (TN Godavarman Thirumulkpad versus  
329 Union of India, 1996), the creation of the National Green Tribunal and a Central Empowered  
330 Committee to hear and oversee implementation of Supreme Court orders regarding  
331 environmental cases (Dutta, 2005), a temporary ban on tourists from visiting core areas of some  
332 Tiger Reserves (2012), and enforcement of a mine closure after Kudremukh in the Western  
333 Ghats was elevated to the status of a National Park. The Supreme Court also affirmed the  
334 importance of up to 10 km eco-sensitive zones bordering National Parks and Sanctuaries, within  
335 which development and other activities need to consider the goals of the protected area. At the  
336 meeting of the Indian Board of Wildlife in January 2002, a 'Wildlife Conservation Strategy' was  
337 adopted wherein 'lands falling within 10 km of the boundaries of National Parks and Wildlife  
338 Sanctuaries should be notified under as eco-fragile zones'. This order was revised in 2011 by the  
339 National Board for Wildlife, setting delineation and legal control eco-sensitive zones at a  
340 distance that is site-specific (<http://www.indiaenvironmentportal.org.in>).

341

342 Finally, the passage of the Scheduled Tribes and Other Traditional Forest Dwellers  
343 (Recognition of Forests Rights) Act in 2006 made it possible to confer land rights to people  
344 unofficially settled and cultivating forest lands (including protected areas) based on land tenure.  
345 While the Act provides an opportunity to formally recognize the role of these traditional forest-

346 dwellers as allies in conservation, it also recognizes the need for inviolate areas for biodiversity  
347 conservation, from where people could be excluded upon just “settlement of rights” and after  
348 free prior informed consent is obtained (GOI, 2006).

349

### 350 *3.2 Government investment*

351 The flagship national conservation program is that of Project Tiger, started in 1973. Government  
352 funding under this program has been primarily focused on the 50 designated Tiger Reserves,  
353 covering an area of ~71,000 km<sup>2</sup> (2% of India’s land area). Federal funds earmarked for Tiger  
354 Reserves in the fiscal year 2016-2017 (US\$54.2 million) were over twice the amount allocated  
355 for conservation of biodiversity in other schemes (\$23.6 million; see the Integrated Development  
356 of Wildlife Habitats scheme in the Union budget, <http://www.indiabudget.gov.in/>). Each Tiger  
357 Reserve annually receives direct grants based on requests made (\$48,000 - \$12 million per  
358 Reserve in 2016-2017) from the Central Government plus additional funds from the relevant  
359 State Government. The stated goal for Tiger Reserves is the maintenance of a functioning  
360 ecosystem, rather than tiger conservation *per se*. Focusing on the tiger appears to be an effective  
361 conservation tactic because it engenders public support and attracts tourists (Verissimo et al.,  
362 2011), it delivers broad biodiversity benefits given that its habitat requirements inevitably result  
363 in the protection of other species (Sergio et al., 2006; Thornton et al., 2016), and top predators in  
364 general have a disproportionate effect on ecosystem stability (Cristoffer and Peres, 2003; Estes et  
365 al., 2011).

366

367 Despite the benefits gained from a focus on the tiger, several issues complicate the  
368 efficacy of tigers as a panacea for conservation. First, as noted above, the most species-rich

369 locations for birds lie above 1500m in the east Himalaya, and many bird species are not found in  
370 any Tiger Reserve. Second, habitats most favourable for tigers are not necessarily suitable for  
371 other species. Karanth et al. (2009) estimate that rainforests and tropical evergreen forests, which  
372 are particularly species-rich (Gibson et al., 2011), support tigers at lower densities (1-2 tigers/100  
373 km<sup>2</sup>), than do alluvial grasslands (15 tigers/100 km<sup>2</sup>) or deciduous forests (10 tigers/100 km<sup>2</sup>).  
374 Third, some management practices that enhance habitats for tigers or their prey, such as the  
375 burning of grasslands, may harm other species, such as the critically endangered pygmy hog  
376 (*Porcula salvania*) (Narayan and Deka, 2002).

377

### 378 *3.3 Government compensation*

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

391

392           Whether or not protected areas have people living inside them, all protected areas have  
393 people living nearby. In some locations, people living on a reserve's edge have come to tolerate  
394 the presence of a reserve as essentially someone else's property (Badola, 1999; Wilshusen et al.,  
395 2002). This tolerance is severely tested when animals stray out of protected areas and encounter  
396 humans and settlements on the edge. Tigers, leopards, elephants, and bears often inflict  
397 considerable costs on nearby inhabitants, including human casualties, property damage, and  
398 depredation of livestock or crops, all of which generally affects economically stressed  
399 communities (Karanth et al., 2013). Inevitably, this leads to increased animosity as well as the  
400 retaliatory killing of animals (Dickman et al., 2011; Harihar et al., 2014). Increasingly,  
401 compensation schemes are addressing this issue (Karanth et al., 2018b). In some cases, Non-  
402 Governmental Organizations (NGOs) offer a suite of benefits to offset livestock losses.  
403 Examples include community-run insurance schemes and livestock protection measures against  
404 snow leopard and wolf depredation (Mishra et al., 2003). While certainly helping, these are  
405 limited in scale and funding. Now NGO initiatives are more focused on facilitating government  
406 pay-outs. For example, Project Wild Seve (wildseve.org) works around Bandipur and  
407 Nagarhole Tiger Reserves in the southern state of Karnataka. Between 2015-2018, they helped  
408 expedite \$230,000 of government compensation for 5339 families (K K Karanth, *unpublished*  
409 *data*).

410

### 411 *3.4 Local community investment*

412 The rapid increase in the number of Community Reserves and Conservation Reserves has  
413 potential for communities to benefit economically while conserving nature (Shahabuddin and  
414 Thadani, 2018). To illustrate this potential, we again draw on an example from northeast India.

415 Eaglenest Wildlife Sanctuary (103 km<sup>2</sup>), lies in the western part of Arunachal Pradesh. It is an  
416 important Sanctuary, ranging from the plains up to 3,000m and containing a huge diversity of  
417 species (Price, 2012, Figs. 1, 2a).

418

419         The Eaglenest Biodiversity Project started in 2003 in partnership with the local Bugun  
420 tribe (Mohan and Athreya, 2011). The project has met with some success. Most notably, local  
421 people currently manage ecotourism. For 8 months of the year, ecotourism employs about 25  
422 people and supports several businesses. While large mammals appear to be more abundant inside  
423 the Sanctuary than outside it (Velho et al., 2016), there have been no studies of change in  
424 extraction activities by local people. However, in 2016, the Buguns of Singchung village set  
425 aside 16 km<sup>2</sup> of village forest adjacent to Eaglenest as a Community Reserve, thereby restricting  
426 its exploitation. The success of the Eaglenest project so far depends on an interplay of factors  
427 including few external pressures, linking local socio-economic benefits to the integrity of the  
428 wilderness through ecotourism, influential individuals who brought together stakeholders, and a  
429 comprehensive biodiversity inventory. Furthermore, a Supreme Court litigation that helped  
430 relocate a proposed road outside its boundaries, helped in conveying to the local community a  
431 sense of the global importance of its biodiversity.

432

### 433 *3.5 Local champions*

434 Exceptional individuals — “conservation champions” — have been known to be vital to the  
435 success of Tiger Reserves despite various odds against them (Post and Pandav, 2013). These are  
436 individuals dedicated to the locality and integrated into the community. The relatively young  
437 Pakke Tiger Reserve (Fig. 2a, 862 km<sup>2</sup>) in western Arunachal Pradesh has performed much

438 better than Namdapha, which we considered in an earlier section. One reason for this is the  
439 presence of dedicated forest officers, resulting in greater participation of local communities, in  
440 conjunction with strong leadership and law enforcement. Importantly, from 1999 onwards, a  
441 local officer from the Nyishi community engaged the community living on the south-eastern  
442 boundary. After 2006, new leadership provided by another Nyishi officer strengthened law  
443 enforcement and developed initiatives to build local institutions to support conservation (A.  
444 Datta, pers. obs.). Tigers, herbivores, and primates all appear to have increased in numbers (Jhala  
445 et al., 2015; Selvan et al., 2014). Besides local personalities, Pakke has probably been more  
446 successful than Namdapha because it is more accessible than Namdapha and the community that  
447 surrounds Pakke is a dominant tribe in the state with political power. The community around  
448 Namdapha remains a largely marginalized, little-known tribe.

449

### 450 *3.6 Ecotourism*

451 A promising way to gain local support for a park is through increased income. Most obviously,  
452 nature-based tourism can provide economic benefits (Karanth et al., 2012). More than 3 million  
453 visits to National Parks were recorded in 2015, more than a threefold increase since 2005  
454 (Karanth et al., 2017).

455

456 We consider economic benefits to local people from the presence of protected areas. Data  
457 are generally scarce, but a recent government-commissioned assessment of six Tiger Reserves  
458 generated some figures of park-derived local income (Verma et al., 2015). Local workers  
459 employed by the Forest Department at the Sundarbans receive \$500,000 annually. For Periyar,  
460 patrolling by locals with accompanying tourists garnered \$250,000 per year. In some protected

461 areas, part of the gate fees goes to communities living on the park edge for development  
462 schemes—estimated at \$50,000 for Sundarbans. For Corbett, employment of (daily wage)  
463 workers and guides generated approximately \$1.3 million in wages annually. These amounts are  
464 relatively small when considering the size of surrounding populations. Furthermore, around  
465 Corbett, the purchasing of land by external hoteliers has led to local disillusionment and  
466 conflicts, partly stemming from the fact that little of the revenue stays locally (Rastogi et al.,  
467 2015).

468

469         However, estimates of economic benefits from parks ignore many other indirect sources  
470 of revenue, including from tourists who stay locally. In 2006-2007, at Kaziranga, tourists were  
471 estimated to have spent \$5 million, of which about \$1.6 million went to local enterprises  
472 (Hussain et al., 2012). The extent to which this income stayed in the surrounding community is  
473 not known. Karanth and DeFries (2011) studied hotels and homestays near 10 Tiger Reserves.  
474 From their data, assuming an occupancy rate of 50%, we estimated an average monthly inflow of  
475 \$9,000–\$48,000 in room fees (depending on the park), with just 2%–6% of this going to salaries  
476 for local employees. Again, this ignores many other benefits flowing to communities, but the  
477 information available suggests relatively limited local benefits. Overall, these findings imply  
478 considerable opportunities for improvement in local income generated by protected areas. For  
479 example, studies based on travel costs invariably find that entrance fees could be raised as a  
480 means to increase revenue (Guha and Ghosh, 2009; Badola et al., 2010). Any measures taken to  
481 improve local profits require appropriate reforms to ensure equitability in the distribution of  
482 benefits, and greater local involvement in ecosystem management and protection activities  
483 (Rastogi et al., 2010).

484

485 *3.7 Local benefits from expansion of the edge*

486 Global reviews show that degradation of habitat adjacent to reserves has considerable impact on  
487 reserve health (Laurance et al., 2012). Thus, an additional strategy for increasing the success of  
488 protected areas could be to improve edge habitat. This should be possible to do with local  
489 economic benefits. Restoration efforts can be through both single-owner private land (e.g. tea  
490 estates, Mudappa et al., 2014) or community-based efforts in reserved forest (e.g. for hornbills  
491 [Rane and Datta, 2015]). Small but valuable interventions include encouraging surrounding  
492 coffee plantations to be organic, shade, and wildlife friendly, with associated consumer  
493 certification (Anand et al., 2008; Bose et al., 2016; Chang et al., 2018). More extreme  
494 interventions transform lands to private reserves, which are particularly effective when adjacent  
495 to protected areas (Karanth and Karanth, 2012). At present, India has only a few private reserves  
496 (e.g. Jabarkhet Nature Reserve in Uttarakhand and Sai Wildlife Sanctuary in Karnataka). The  
497 idea of private reserves remains controversial because benefits to local communities require co-  
498 operation among many small landholders (Karanth and Karanth, 2012), with the alternative again  
499 being land annexures by powerful interests (Rai, 2012). Nevertheless, when applied fairly, after  
500 careful social impact assessment and in participation with local communities to ensure equitable  
501 returns, private reserves have potential.

502

503 Finally, public lands next to protected areas could be better developed for conservation  
504 and associated ecotourism. For example, we obtained records from the Uttarakhand Forest  
505 Department, which show that visits to Corbett National Park increased from 62,600 in the year  
506 2000 up to 280,000 tourists in 2015, but remained capped at about the number in 2016 and



507 2017. Associated with both the increase and the limit, more tourists started to visit adjoining  
508 Ramnagar Reserved Forest (Supplemental Figure 3). Approximately 60 km<sup>2</sup> of the Reserved  
509 Forest were designated as Pawalgarh Conservation Reserve in 2012, where tourism is regulated  
510 and comes with entry fees helped further to promote regulated eco-tourism. The number of  
511 tourists visiting Pawalgarh now rivals that visiting Corbett (Supplemental Figure 3).

512

#### 513 **4. Conclusions**

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

523

524 Protected areas vary considerably in their conservation outcomes (Oldekop et al., 2016).  
525 In India, factors affecting success vary with the degree to which the region is developed. For  
526 example, well-developed institutional infrastructure in Corbett makes management of tourists  
527 and economic opportunities for local people the critical issues (Rastogi et al., 2010). In contrast,  
528 the remoteness of parks in Arunachal Pradesh in north-east India results in major threats from  
529 deforestation and hunting (Aiyadurai et al., 2010; Datta et al., 2008a; Pandit et al., 2007; Velho

530 et al., 2012). Within Arunachal Pradesh, effectiveness of protection also varies greatly. This is  
531 due largely to the lack of strong institutional mechanisms in the Government (mainly the Forest  
532 Department), unlike in most other parts of the country. Hence, local factors become even more  
533 important in determining success. These differences are likely to apply to other developing  
534 countries as well, where the most pristine areas may experience the highest variance in  
535 conservation successes.

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

548

549         A major message from our assessment is the lack of data, and prompts one to ask what  
550 should be the important priorities for research. We identified three particular needs. First, more  
551 study of the landscape matrix in which protected areas are embedded would be exceptionally  
552 valuable, especially as many protected areas are relatively small and connectivity is a major

553 issue. For example, in Uttar Pradesh some Tiger Reserves actually have a lower density of tigers  
554 than does the surrounding Reserved Forest (Chanchani et al., 2016). We need a greater  
555 understanding of what factors drive this, how other species are doing in Reserved Forests, and  
556 how biodiversity prospects could be improved without detriment to human uses of the forest.  
557 Second, very little long-term monitoring of populations in protected areas is happening in India.  
558 Apart from tigers, this is not co-ordinated centrally, unlike the missions of many societies in the  
559 US and Europe (e.g. the British Trust for Ornithology in the UK). Third, a much better  
560 understanding of cash benefits of protected areas, particularly from tourism, is required (Karanth  
561 et al., 2017). We suspect that they are larger than currently appreciated.

562

563           With respect to practical efforts, especially for NGOs involved in conservation, our  
564 review emphasizes the importance of individuals and organizations investing energy intensively  
565 at single sites rather than in a more diffuse manner, and interactively with local populations. For  
566 policy makers, we have two recommendations. First, management of surrounding Reserved  
567 Forests to include scientific monitoring and management in collaboration with local communities  
568 would be an effective way forward; legal backing is already in place given the Supreme Court  
569 order that up to 10km from a protected area can be considered an eco-sensitive zone. Through  
570 these measures, India can endeavour to get Reserved Forests designated as IUCN Category VI  
571 protected areas, which will lend support to the country's claim of having already exceeded the  
572 Aichi target (17%) in terms of area under protection (Pande and Arora, 2014). Second, we echo  
573 the arguments of Bindra (2017) that it is critical to focus on the protected areas we have, with  
574 development and denotifications allowed only under exceptional circumstances. The 5% of land  
575 currently designated as protected is essential to the conservation of India's biodiversity, not only

576 through targeted efforts for threatened species, but to maintain populations of less-threatened  
577 species.

578

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912 **Figure legends**

913 **Figure 1** *Upper left* Heat maps of threatened bird and mammal species (IUCN categories of  
914 Vulnerable, Endangered and Critically Endangered combined). Birds from BirdLife International  
915 and Handbook of the Birds of the World (2017) *Bird species distribution maps of the world*.  
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917 *Species. Version3, May 2017*. <http://www.iucnredlist.org>. Both downloaded on April 10th, 2018.  
918 *Lower left* National Parks (red) and Sanctuaries (blue) >10 km<sup>2</sup> (from the Wildlife Institute of  
919 India's database) overlaid on human population densities (gridded Population of the World,  
920 Version 4: Population Count, Revision 10. <https://doi.org/10.7927/H4PG1PPM>. Accessed 14  
921 April 2018.) The main shades separate densities below (lighter) and above (darker) India's  
922 average (330 people/km<sup>2</sup>). *Right* The number of bird species whose ranges intersect National  
923 Parks (large points) and Sanctuaries (small points) against park area. Red symbols are protected  
924 areas to the north and east of Bangladesh. Letters (above the point) refer to 4 protected areas  
925 mentioned in the text: H- Hollongapur, E- Eaglenest, P-Pakke, N- Namdapha (see Fig. 3).

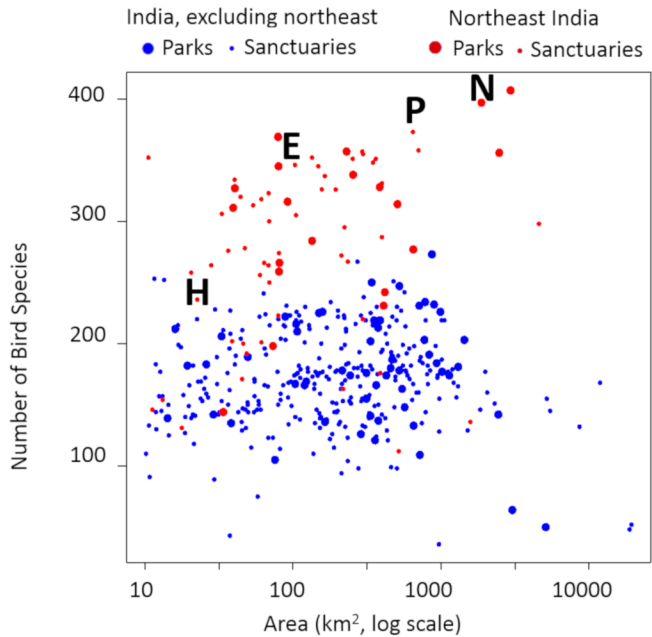
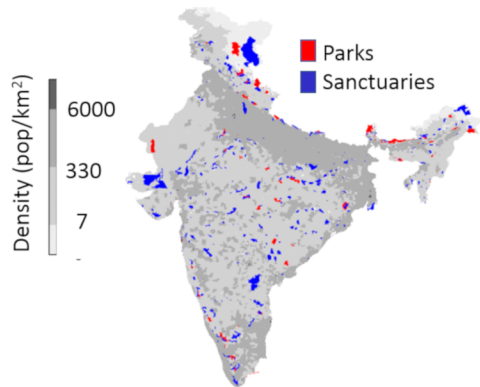
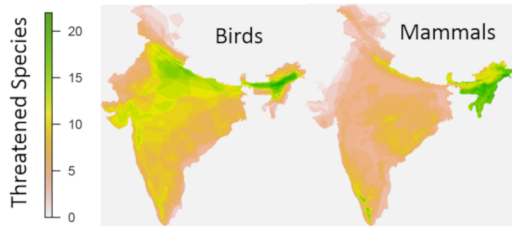
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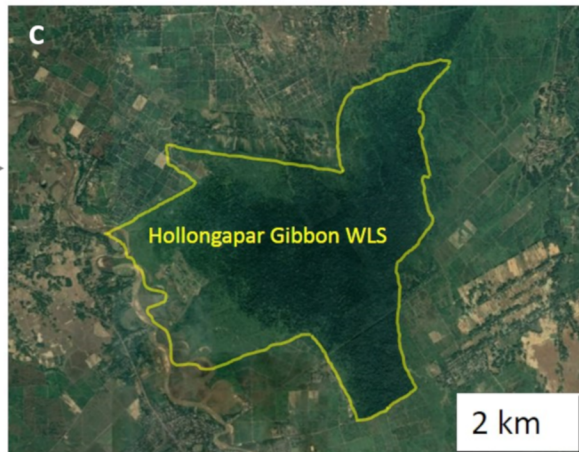
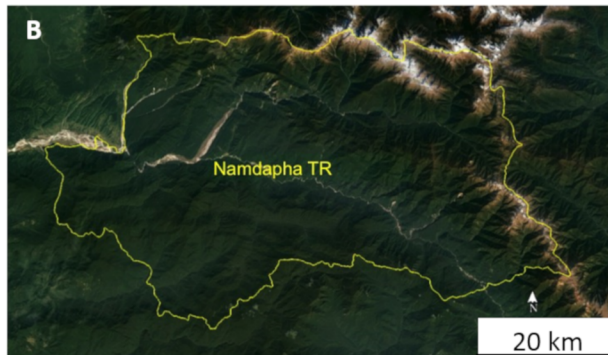
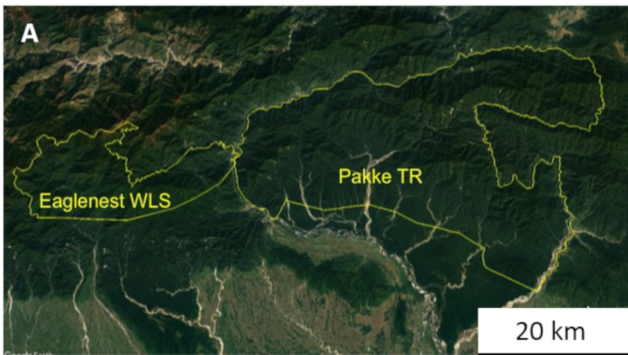
927 **Figure 2** Four protected areas in northeast India (overlain on Google earth images). (A) Pakke  
928 Wildlife Sanctuary and adjoining Eaglenest Wildlife Sanctuary extend from the plains to 3000m  
929 in Arunachal Pradesh. Local communities deforested the plains area of Assam ~15 years ago. (B)  
930 Namdapha National Park (100m - 4500m in elevation) is embedded in a larger forested matrix,  
931 but has suffered extensive hunting pressures. (C) The small Hollongapar Gibbon Sanctuary (~21  
932 km<sup>2</sup>) is flanked to the west by degraded land ripe for reclamation, separating it from a river, and  
933 on the other 3 sides by tea estate. Seven species of primates may occur in the Sanctuary  
934 including the Endangered Western Hoolock Gibbon, although one, the Assam macaque (*Macaca*

935 *assamensis*) has not been seen for several years (D. Chetry and U. Borthakur, *personal*  
936 *observations*).

937

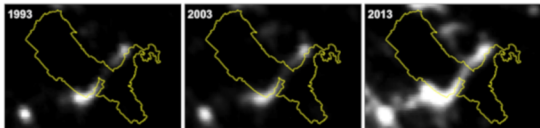
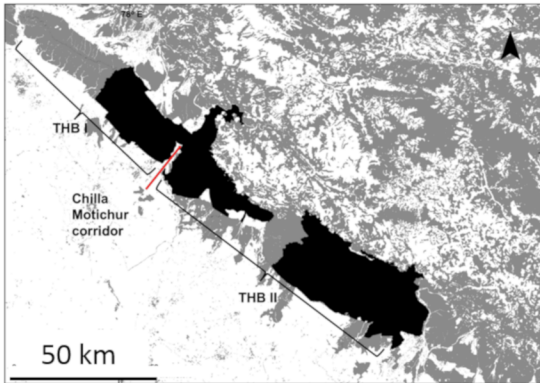
938 **Figure 3** Two case studies illustrating functional connectivity across tiger landscapes. (A) The  
939 western Terai Arc Landscape showing Tiger Habitat Blocks I and II in black, with the Chilla-  
940 Motichur corridor providing tenuous connectivity between the two. Deterioration of connectivity  
941 due to development within the corridor is indexed by nightlight data (1993, 2003, 2013). The  
942 tiger population is currently just two females in Block I despite an estimated carrying capacity of  
943 80 (redrawn from Harihar et al., 2018). (B) Landscape resistance surface inferred for tiger  
944 movement in Central India based on genetic data is best explained by traffic intensity and human  
945 settlements (orange). Protected areas are indicated in green and positions of genetically typed  
946 tiger individuals are marked as purple dots (redrawn from Thatte et al., 2018).







A



B

