Providing more protected space for tigers *Panthera tigris*: a landscape conservation approach in the Western Ghats, southern India

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Abstract Conservation of large carnivores is challenging as they face various threats, including habitat loss and fragmentation. One of the current challenges to tiger *Panthera tigris* conservation in India is the conversion of habitat to uses that are incompatible with conservation of the species. Bringing more tiger habitat within a protected area system and in the process creating a network of connected protected areas will deliver dual benefits of wildlife conservation and protection of watersheds. Focusing on the southern Indian state of Karnataka, which holds one of the largest contiguous tiger populations, we attempted to address this challenge using a conservation planning technique that considers ecological, social and political factors. This approach yielded several conservation successes, including an expansion of the protected area network by 2,385 km², connection of 23 protected areas, and the creation of three complexes of protected areas, increasing the protected area network in Karnataka from 3.8 to 5.2% of the state's land area. This represents the largest expansion of protected areas in India since the 1970s. Such productive partnerships between government officials and conservationists highlight the importance of complementary roles in conservation planning and implementation.

Keywords Conservation planning, conservation practice, habitat fragmentation, India, landscape connectivity, large carnivore conservation, protected areas, tiger

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Introduction

Poaching of tigers *Panthera tigris* and their prey, and loss and fragmentation of habitats are the critical threats to the survival of this large carnivore, which survives in only 7% of its historical range (Dinerstein et al., 2007; Wikramanayake et al., 2010). These causes have resulted in local or demographic extinction of tigers in several areas across the species' range (Tilson et al., 2004; Gubbi, 2006; Datta et al., 2008; Lynam, 2010; Wright, 2010). Similarly, lack of connectivity between protected areas or tiger populations reduces genetic exchange and thus adversely affects demographic viability (Linkie et al., 2006; Mondol et al., 2013; Sharma et al., 2013).

India holds the highest number of wild tigers (c. 2,500) and is vital for the continuing survival of the species (Seidensticker et al., 2010a). However, a rapidly increasing human population, an expanding economy, and a consequent increase in infrastructural projects are leading to further fragmentation of tiger habitats. Meeting the competing demands of development and the preservation of wildlife habitats is the biggest challenge faced by governments, managers and conservationists in a developing country such as India, where significant changes in land use are occurring (DeFries et al., 2010; Mondal & Nagendra, 2011; Gubbi et al., 2014).

Protected areas are a mainstay of tiger conservation but often lack connectivity, which is key to ensuring both genetically and demographically viable populations. Protected areas also have additional layers of protection against diversion of forestland for non-forestry activities (e.g. mining, highways, dams). Enhancing the protected area network would therefore provide protected space for more breeding tigresses and also ensure that landscape corridors are preserved, facilitating multi-directional connections for this far-ranging species (Chapron et al., 2008; Rathore et al., 2012; Mondol et al., 2013; Sharma et al., 2013). Tigers have high dispersal capabilities, moving within and between habitat patches if suitable connectivity exists (Seidensticker et al., 2010b; Wikramanayake et al., 2011; Joshi et al., 2013). However, in the absence of suitable connectivity for natural colonization/recolonization from other source sites expensive reintroduction activities must be undertaken in areas where tigers face local extinction, as in

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Sariska and Panna Tiger Reserves in India and planned reintroductions in China (Karanth, 2003; Morell, 2007; Mondal & Nagendra, 2011).

One of the solutions for ensuring viable tiger populations is to recover populations in a few core areas and link them through tiger-compatible landscapes (Goodrich et al., 2013). Hence, maintaining forest connectivity between tiger populations and adding new areas into which existing populations can expand is important for long-term persistence (Wikramanayake et al., 2004; Walston et al., 2010; Jhala et al., 2011).

Conservation planning studies are typically based on ecological factors but lack input from key stakeholders, including policy-makers, and therefore they fail to influence direct action (Knight et al., 2006, 2008). Successful conservation outcomes depend not only on biological knowledge but on the understanding of the political and economic climate, the skills and commitment to ensure effective implementation, and land-use planning (McNeely, 1987; Bennett, 2003; Johnsingh et al., 2010). Above all, political support is critical to achieve significant conservation goals.

Here we describe the conservation planning approach taken by government officials and conservation organizations to increase the connectivity between 23 protected areas in the Western Ghats landscape within the southern Indian state of Karnataka. We present the final designated land-use plans, as well as the lessons learned, to aid replication in other forest landscapes under threat from conversion.

Study area

The Western Ghats, a biodiversity hotspot, is a mix of protected areas and multiple-use forests in a human-dominated landscape that spans six Indian states. Within Karnataka it occupies $>$ 42,000 km^2, with 22 protected areas that harbour tiger, elephant *Elephas maximus*, lion-tailed macaque *Macaca silenus* and other threatened species (IUCN, 2013) that are wide-ranging or endemic. Karnataka holds one of the largest contiguous wild tiger populations (c. 400 tigers). However, most protected areas in the state (mean area c. 225 km^2) are scattered and unconnected. They were designated during the mid 1970s, and in 2011 occupied 3.8% of the state's land area (191,791 km^2). Although some are being protected effectively under the Wildlife Protection Act 1972, they are becoming increasingly isolated under pressure from industrial and other economic development activities. Some have a perimeter-to-area ratio that does not favour conservation (Menon & Bawa, 1997).

Methods

In conservation planning for the protected area network, carried out during November 2011–July 2014, we used a combination of geographical information system (GIS) and social interaction approaches to achieve connectivity and expansion of protected areas. We embedded social and political factors into the planning process to develop an optimality criterion.

Forests in India that are protected by law but are open for multiple uses are categorized as reserved forests, state forests or minor forests. Forests within these categories can be designated as protected areas under the Wildlife Protection Act 1972 but the designation of other categories of forests as protected areas involves several legal processes. Hence, reserved, state and minor forests were the primary targets for designation as protected areas (Table 1). Additionally there would be no discrepancy in land title and tenure because reserved, state and minor forests are owned by the forest department.

We considered reserved, state and minor forests adjoining or between protected areas, to maintain connectivity. There are no published data on preferred habitats used by dispersing tigers but as tigers are habitat generalists we assumed they would disperse through most forested habitats that have sufficient cover at ground level. Areas with large human settlements are not suitable for dispersal of tigers (Smith et al., 1998) and therefore were not considered.

All forestland in the state has been digitized by the Karnataka State Remote Sensing Applications Centre, and these data were used in the planning process. Using GIS analysis we initially selected reserved, state and minor forests that were relatively unfragmented, based on our knowledge of the area and ground-referencing to categorize ambiguous areas. We identified integrity and connectivity as important criteria that could be used to identify reserved, state and minor forests that were suitable both ecologically and politically for designation as protected areas.

The expansion and connectivity of the protected area network were considered at three spatial scales: small areas that form critical corridors between protected areas and provide temporary refuge to tigers and their prey; larger reserved, state or minor forests connecting existing protected areas; and large tracts of reserved, state or minor forests that would support self-sustaining populations of tigers if enhanced protection could be provided, in addition to connecting two or more protected areas.

Using GIS analysis we ranked the suitability of each reserved, state or minor forest by considering the percentage of forest cover (integrity) and the contiguity of the forest to other forests or protected areas, to identify the forests with the highest connectivity importance (connectivity irreplaceability).

Forests with higher percentages of forest cover were assigned higher scores, denoting higher integrity. Connectivity irreplaceability helped to identify the most suitable forests for maintaining habitat contiguity between protected areas. We scored each reserved, state and minor

TABLE 1 A comparison of the status of reserved forests and protected areas in India in the context of various issues, indicating the legal and conservation gains that can be achieved by designating reserved forests as protected areas.

Issue	Reserved forests	Protected areas
Diversion of forestland for development activities such as highway construction, mining, & other industries	Forestland can be diverted under the Forest Conservation Act 1980. No approval is required from wildlife authorities except for certain categories of industry if they lie near the protected area boundary.	Forestland diversion requires approval from the State Board for Wildlife (chaired by the Chief Minister of the state), the National Board for Wildlife (chaired by the Prime Minister) & the Supreme Court, in addition to the procedures under the Forest Conservation Act 1980, the Environment Protection Act 1986 & The Scheduled Tribes & Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006. Field inspection reports by subject experts on the State & National Board for Wildlife are required. Mitigation measures may be suggested when required.
Management focus	10-year management plans focus on forestry operations, commercial exploitation & multiple uses.	10-year management plans focus on wildlife protection, habitat improvement for wildlife, supporting tourism activities & conservation outreach.
Legal protection	Two federal laws (Forest Conservation Act 1980; The Scheduled Tribes & Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006) & other regional/state laws support conservation. Land in the immediate vicinity of reserved forests is unprotected.	Four federal laws (Wildlife Protection Act 1972; Forest Conservation Act 1980; Environment Protection Act 1980; The Scheduled Tribes & Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006) & other regional laws provide substantial support for protection. Land uses in areas in the immediate vicinity of the protected area can be regulated to make them compatible with wildlife protection & reduce external threats (e.g. mining, farming of exotic faunal species) under the Environment Protection Act 1986.
Human–wildlife conflict	Little or no importance	Budget is allocated to build/strengthen physical barriers to prevent movement of conflict-prone species into croplands & human settlements.
Budget	There is a focus on tree planting & other similar schemes but no emphasis on protection against fire, poaching & other pressures.	Emphasis is on habitat improvement, fire damage control, anti-poaching initiatives, intelligence gathering, & related matters.

forest for irreplaceability, based on its importance as a connectivity corridor.

We assigned each reserved, state and minor forest separate scores of 0–10 for integrity and connectivity irreplaceability, as indicators of their ecological importance. Forests with 100% cover were given a score of 10, as were forests that were the only link to an adjoining forest or protected area. The scores for integrity and connectivity decreased with decreasing forest cover and with an increasing number of areas of connectivity, respectively. Each reserved, state and minor forest was then given an additive score from both parameters to prioritize for inclusion in the protected area expansion process.

Political and social dynamics played a critical role in the expansion of the protected areas. We (conservationists, government officials and a sport celebrity) facilitated the process of designating and notifying protected areas through discussions with and education of elected representatives and key political leaders. In a representative democracy such as India it is important to convince elected representatives, who are accountable to the electorate.

Results

From our spatial analysis we identified 4,767.4 km² of reserved, state and minor forests lying outside the protected area network. Of these we initially selected 2,596.9 km² for designation as protected area, based on their suitability scores for integrity and connectivity irreplaceability, and on government approval (Supplementary Table S1). Of the existing network of protected areas in the Western Ghats in the state of Karnataka, six were already connected in three

TABLE 2 Protected area complexes in Karnataka and neighbouring states (Fig. 1) that provide contiguous habitats, with area before and after the programme to expand connectivity and expansion of protected areas. The numbers in parenthesis correspond with those in Fig. 1.

Complex	Protected areas	Area before (km^2)	Area after (km^2)
Bhimgad–Anshi	Bhimgad Wildlife Sanctuary (1) Madei Wildlife Sanctuary[1](2) Bhagvan Mahaveer Wildlife Sanctuary[1](3) Mollem National Park[1](4) Netravali Wildlife Sanctuary[1](5) Cotigao Wildlife Sanctuary[1](6) Hornbill Conservation Reserve (7) Dandeli Wildlife Sanctuary (8) Anshi National Park (9)	2,046.7	2,294.7
Sharavathi–Kudremukha	Sharavathi Wildlife Sanctuary (12) Mookambika Wildlife Sanctuary (13) Someshwara Wildlife Sanctuary (14) Kudremukha National Park (15)	1,367.2	1,716.42
Shettihalli–Bhadra	Shettihalli Wildlife Sanctuary (16) Bhadra Tiger Reserve[2] (17)	895.76	1,240.92
Bannerghatta–Nagarahole	Nagarahole Tiger Reserve (21) Bandipura Tiger Reserve (22) Waynad Wildlife Sanctuary[3] (23) Mudumalai Tiger Reserve[4] (24) Sathyamangalam Tiger Reserve[4] (25) Biligirirangaswamy Temple Tiger Reserve (26) Malai Mahadeshwara Wildlife Sanctuary (27) Cauvery Wildlife Sanctuary (28) North Cauvery Wildlife Sanctuary[4] (29) Bannerghatta National Park (30)	5,251.87	7,038.19
Total		9,561.53	12,290.23

[1]Protected area in the neighbouring state of Goa
[2]Recently approved by the government
[3]Protected area in the neighbouring state of Kerala
[4]Protected area in the neighbouring state of Tamil Nadu

complexes. Our planning produced three contiguous protected area complexes (a fourth complex, Shettihalli–Bhadra, is approved by the government and the notification process is ongoing), such that 23 of the protected areas are now connected (Table 2). The protected area network of Karnataka increased from 3.8 to 5.2% of the state's land area (Fig 1, Table 3) and the perimeter-to-area ratio decreased.

The median forest cover of the reserved, state and minor forests was 26.4 km^2 (range 4.1–432.1 km^2) and the mean percentage forest cover was 89.5% (range 41.3–100%). The mean forest cover score was 9.3 (range 5–10) and the mean connectivity irreplaceability score was 7.25 (range 5–10).

Over 33 months we held 13 meetings (formal and informal) with the Chief Minister, Forest Minister and elected representatives of the local constituencies. We were able to convince them of the importance of expanding the protected area network for tigers to reduce human–wildlife conflict, and because of the importance of these forests as watersheds. We also emphasized that the rights of local people would be protected by the 2006 Forest Rights Act (TSTOTFD, 2006), which recognizes the rights of traditional forest dwellers. Although most political leaders were positive, some were sceptical initially and then became supportive, with others remaining sceptical and unwilling to act. The scepticism can be attributed to prior experience of the strict scrutiny and multiple stages of inspection of development activities in protected areas, under the Wildlife Protection Act 1972. Political leaders who were supportive had a positive approach to nature conservation in general.

Thirty-seven reserved, state and minor forests (mean area = 39.3 km^2, range 4.2–111.0 km^2) in 10 forest administrative divisions, and one area (6.3 km^2) that was under the ownership of the revenue department (non-reserved forest) were added to existing protected areas, and three reserved forests (75, 388.5 and 442.7 km^2) were declared a new protected area (906.2 km^2). The total increase in protected area was 2,385.6 km^2, resulting in three distinct, contiguous landscapes of protected area (Bhimgad–Anshi, 1,546.7 km^2; Sharavathi–Kudremukha, 1,716.4 km^2; Bannerghatta–Nagarahole, 4,456.2 km^2). If protected areas

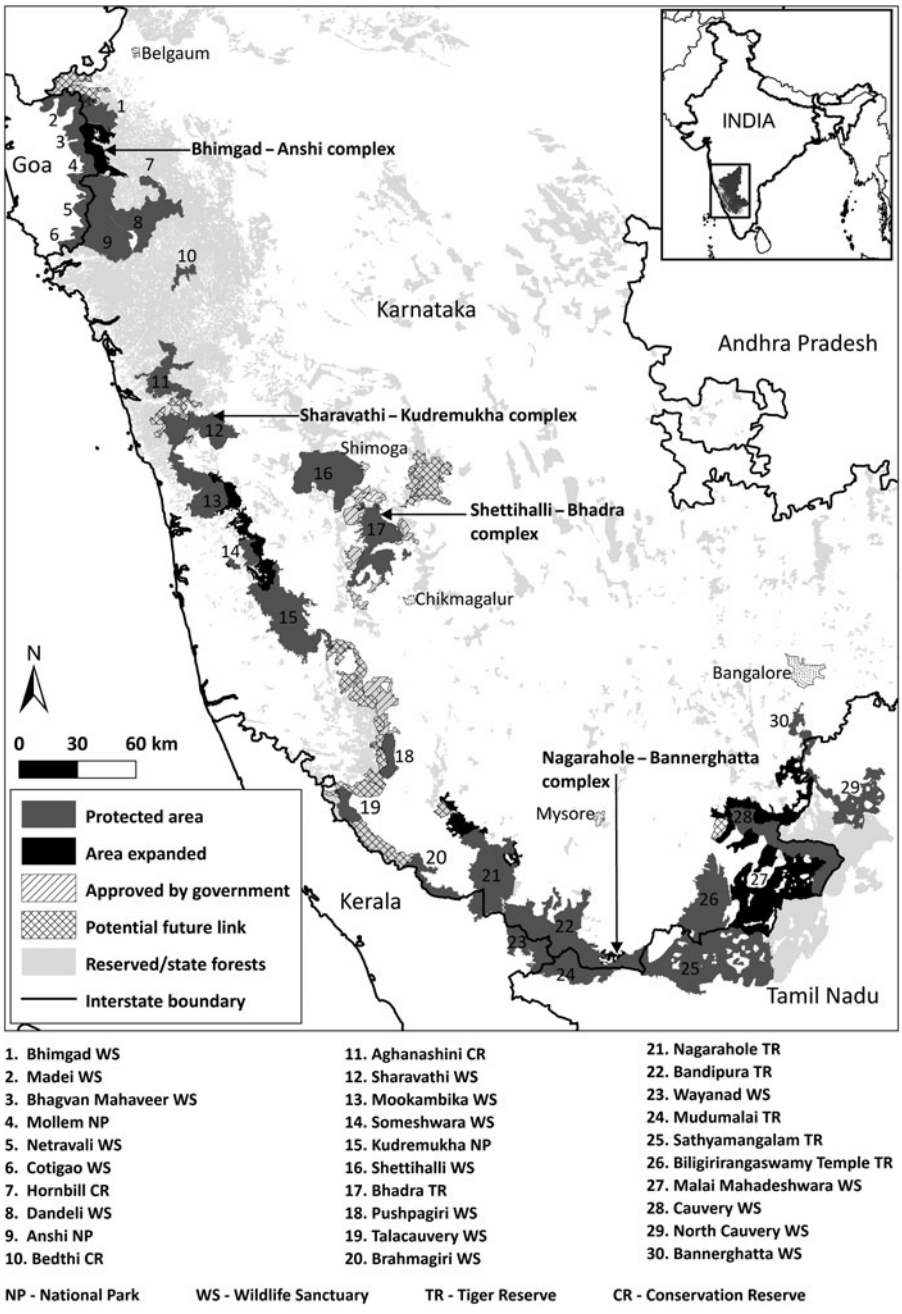

FIG. 1 Network of protected areas, and protected area complexes (Table 2), in the Western Ghats, southern India.

in the neighbouring state of Goa are included, the protected area network in the Bhimgad–Anshi landscape covers 2,242.2 km², and if the protected areas in the neighbouring states of Tamil Nadu and Kerala are included, the contiguous network of protected areas in the Bannerghatta-Nagarahole landscape covers 7,038.2 km². In addition, the government has approved the addition of 348.4 km² to Bhadra Wildlife Sanctuary, increasing its area from 500.2 to 848.6 km², and 213 km² to Pushpagiri Wildlife Sanctuary, increasing its area from 102.6 to 315.6 km² (Fig. 1). This will increase the protected area network in Karnataka from 5.2 to 5.5% of the state's land area. Although we identified a total area of 4,767.4 km² we were unable to notify 1,819.1 km² because of lack of approval and consensus from elected representatives.

Discussion

Most conservation planning involves academic exercises. Knight et al. (2008) found that < 6% of conservation planning studies influenced conservation action. However, by focusing on a global flagship species in one of the world's most populous countries, where translating planning recommendations into conservation action is particularly difficult, we have managed to interlink 23 protected areas. In the first large-scale expansion of protected areas in India

TABLE 3 Characteristics of expanded protected areas, with habitat type, area before and after expansion, and perimeter-to-area ratio before and after expansion.

Protected area	Predominant habitat type(s)	Area before expansion (km^2)	Area after expansion (km^2)	Perimeter-to-area ratio before expansion	Perimeter-to-area ratio after expansion
Dandeli	Dry deciduous	638.35	886.41	0.35	0.28
Mookambika	Tropical evergreen	247	370.37	1.6	1.46
Someshwara	Tropical evergreen	88.4	314.25	0.93	0.59
Bhadra[1]	Dry & moist deciduous, semi-evergreen	500.2	848.6	0.63	0.68
Pushpagiri[1]	Evergreen & semi-evergreen	102.59	315.91	0.63	1.07
Nagarahole	Dry & moist deciduous	643.39	843.96	0.35	0.4
Bandipura	Dry deciduous	872.24	878.56	0.41	0.52
M M Hills[2]	Dry & moist deciduous		906.18		0.43
Cauvery	Dry deciduous & woodland savannah	510.52	1,027.53	0.43	0.38
Bannerghatta	Dry deciduous	104.27	260.51	1.31	1.06

[1]Approved by the government
[2]Newly designated; hence blank cells for area before expansion and perimeter-to-area ratio

since the 1970s we have made substantial progress in protecting the habitat of tigers and other species. We also successfully reduced the perimeter-to-area ratio of most protected areas. However in two cases (Nagarahole and Bandipur) the ratio increased marginally; this was inevitable as the only available critical forest patches for connectivity were linear.

We engaged in a process of negotiation and dialogue with decision makers regarding areas that were ecologically critical but for which there was political opposition to designation as protected areas. A pragmatic approach had to be taken, by initially excluding areas for which elected representatives were unwilling to support designation (e.g. areas around Bhadra Wildlife Sanctuary and Kudremukh National Park). However, these areas continue to be a priority for tiger conservation, and support for expansion of protected areas must be fostered through continued dialogue with elected representatives, as proved successful in the subsequent decision to expand Bhadra Wildlife Sanctuary.

The current challenge for tiger conservation in India is to halt the conversion of habitats outside protected areas to uses that are incompatible with tiger conservation. We have demonstrated that a collaboration between government agencies, civil society and individuals can build political momentum at the necessary scale to support such conservation. We believe there is an additional c. 1,800 km^2 of reserved, state and minor forests (Supplementary Table S1) in Karnataka with evidence of tiger presence (Jhala et al., 2011) that could be added to the protected area network as priority regions for investment in tiger conservation by the state and civil society.

Priority-setting approaches on the basis of optimality criteria, using exhaustive biological inventories, have been proposed as the ideal way to identify land for designation as protected area (Peres, 2002). However, optimality criteria do not take into account connectivity, level of protection of conservation units, land ownership or political willingness, all of which are critical factors for conserving wildlife habitats. We have shown that through consensus of key stakeholders it is possible to implement solutions, even though they are less-than-optimal from an academic perspective, for tiger conservation in the Western Ghats.

The areas now designated as protected areas not only support wildlife but are vital watersheds and include the complex hydrological regimes of 16 rivers. These include the Cauvery, Nethravathi, Paalar, Bhadra, Varahi, Gundia, Kumaradhara, Seetha and Kaali rivers, the protection of which was an important negotiating point during discussions with the elected representatives of the local constituencies. Despite the growing human population and the need for land for various development activities, we are hopeful that Karnataka state will make further progress in conserving and enhancing protection for the tiger.

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Biographical sketches

Sanjay Gubbi has broad interests in the ecology and conservation of large felids, and in their interactions with humans. He has worked to bring about important changes for tiger conservation in the Western Ghats. Kaushik Mukherjee is interested in wildlife conservation policy implementation. M.H. Swaminath is interested in wildlife, forest conservation, and climate change policies. H.C. Poornesha works on conservation of wildlife habitats in the Western Ghats through geographical information systems analysis and conservation planning.