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Evaluating a survey landscape for tiger abundance in the confluence of the Western and Eastern Ghats

S. S. Lingaraja[1], Swayam Chowdhary[1], Rashmi Bhat[2] and Sanjay Gubbi[2,3,*]

[1]BRT Tiger Reserve, Karnataka Forest Department, Government of Karnataka, Chamarajanagara 571 127, India
[2]Nature Conservation Foundation, Mysuru 570 002, India
[3]State Board for Wildlife, Government of Karnataka, India

Due to the current depleting trends in tiger population, range countries have committed to double tiger numbers by the year 2022. However, some areas, including source sites, across the range countries lack scientifically estimated tiger numbers both at the larger landscape and at the protected area level. Here we report a population of tigers, from Biligiri Rangaswamy Temple Tiger Reserve (BRTTR), using camera trap based capture-mark recapture in a spatially explicit likelihood and Bayesian analyses that yielded an estimate of ~55 tigers with a density of about 6.8 tigers/100 km^2. BRTTR nestled in a larger tiger landscape, perhaps contributes dispersing individuals to the adjoining forests, calling for integrated monitoring and management efforts for the entire landscape. This data set could help in designing long-term, landscape level plans and outcomes.

Keywords: Biligiri Rangaswamy Temple Tiger Reserve, camera trapping, capture–recapture method, tiger.

CURRENTLY, tigers (*Panthera tigris*) survive in a mere 7% of their former range with less than 3,500 individuals estimated to be living in the wild[1,2]. Within the 13 range countries, India is a key site for long-term survival of tigers in the wild[3]. However, Cambodia recently announced the local extinction of its tiger species, thus depicting depleting populations. Project Tiger, initiated in 1972, was perhaps the pioneering collaborative programme between government and non-government organizations towards the protection of tigers. Since then, in India and the world over, substantial financial investments and resources have been spent on conservation of the species during the past five and half decades.

Sizeable funding has also been invested on research and monitoring activities[4,5]. In recent years the Indian federal government has taken initiatives to estimate tiger numbers on a nation-wide scale[6–8], which in itself is a laudable effort. In a country that is large and complex in so many different ways, attempting to collate data on such a spatial scale is exemplary.

Walston *et al.*[9] argue source sites as key areas for long-term conservation of the species. However, lack of

*For correspondence. (e-mail: sanjaygubbi@gmail.com)

scientific data even in identified source sites highlights the necessity to carry out benchmark estimates for many of the established protected areas. Karanth *et al.*[10] remark 'these sources are currently identified based on anecdotal evidence', highlighting the importance of developing site-level data for areas that lack population information. This helps in identifying source sites with high levels of certainty on tiger numbers, helping manage tiger populations in a true meta-population framework. Though attempts have been made to map occupancy of tigers at wider scales[10–12], there is a need to estimate density, and absolute abundance at individual protected area scale, where reasonable logistical opportunities and resources exist. This could ultimately help in achieving global tiger recovery targets through improved coverage of scientifically assessed data. The range countries have committed to double existing tiger numbers by the year 2022 (ref. 13). Hence, estimating for tiger densities in areas where there is gap of data is extremely important from a global tiger recovery perspective. We also demonstrate that such peer-reviewed data would provide an important ecological evaluation to demonstrate the desired effect on tigers, a key measure of the resource investments made by governments and civil societies. This study assumes importance in the background of these global objectives.

The objectives of the study were to: (a) establish baseline estimates of tiger densities in an area where previously no scientific estimation of tiger numbers has been published; and (b) support conservation efforts by monitoring tiger population in the reserve.

Karnataka state within India is a key tiger range with five tiger reserves designated jointly by the state and federal governments. Of these, Biligiri Rangaswamy Temple Tiger Reserve (BRTTR) (574.8 sq. km, BRT) was declared as a tiger reserve in 2011. These forests were initially declared as a protected area in 1974 with an area of 324.4 sq. km, and additional areas were added in 1987. Currently an area of 359.1 sq. km is notified as core, and 215.7 sq. km as the buffer of the tiger reserve as per legal provisions. Only a part of the tiger reserve is identified as a regional priority Tiger Conservation Landscape (TCL–67), and is recognized as a survey landscape[1]. This is defined as 'large areas of structural land cover under low human influence where tiger status is unknown'. To our knowledge, BRT does not have any peer-reviewed, published data on tigers[14].

BRT is part of a larger landscape consisting of other protected areas including Malai Mahadeshwara (MM) Hills and Cauvery Wildlife Sanctuary, and Bannerghatta National Park in Karnataka, and Satyamangalam Tiger Reserve and North Cauvery Wildlife Sanctuary in Tamil Nadu state (Figure 1).

Most parts of BRT are rugged and hilly, with altitudes of 620–1,950 msl, with an annual temperature range of 18–38°C, and receiving an average rainfall of 650 mm (range 600–3,000 mm) in the low-lying plateaus, and 1,990 mm in the upper reaches of the hills. Due to this variation in altitude and rainfall, BRT hosts a diversity of habitats within its boundaries including evergreen and semi-evergreen forests, dry and moist deciduous forests, and scrub growth. Climax vegetation called *Sholas* (montane wet temperate forests) are found in higher elevations of the tiger reserve.

Important prey species for large carnivores, that include tiger, leopard (*Panthera pardus fusca*), and dhole (*Cuon alpinus*), in BRT comprises gaur (*Bos gaurus*), sambar (*Rusa unicolor*), chital (*Axis axis*), wild pig (Sus scrofa), barking deer (*Muntiacus muntjak*), four-horned antelope (*Tetracerus quadricornis*) and others. BRT also supports good densities of Asian elephants (*Elephas maximus*), and is estimated to host 1.7 elephants/km^2 (ref. 15), emphasizing its importance for elephant conservation.

BRT is home to the Soliga forest dwelling communities who live in 63 hamlets in and around the tiger reserve. About 2,900 families (~12,250 people) live within the limits of the tiger reserve.

Camera trapping was carried out using the protocol suggested by the National Tiger Conservation Authority[16] to ensure standardization of methodology across the country. Camera traps were deployed in a total of 157 locations during March and May 2015 resulting in 66 sampling occasions in two blocks for logistical ease. This ensured that the assumption of a closed population was met, where there is no loss (emigration) or gain (immigration) in large carnivore populations within the study site.

ScoutGuard passive infrared motion detection digital camera traps were set at an optimal height of ~60 cm to ensure that flanks of the tigers were photographed. Each camera trap was set to operate for 24 h duration. The images downloaded from the cameras were sorted based on the wildlife species captured. Individual tigers were first identified using the Wild-ID, a pattern recognition software[17], to match tiger stripes and cross-checked manually, after which every individual tiger was given a temporary identification number as prescribed under the National Tiger Conservation Authority (NTCA) protocol. After this, capture history and trap deployment matrices were developed as suggested by the Spatially Explicit Capture–Recapture (SECR) and SPACECAP operational manuals[18,19]. Habitat masks were constructed by placing a buffer of 2 km around the rectangle that connected the outermost camera trap points. All potential tiger habitat within this area was digitized using Google Earth imagery (Google Inc. Ver 7.1.5.1557).

The camera trap data was analysed using the SECR package that is based on SECR methodology. This statistical package (SECR on R platform) is superior to earlier methods that relied on traditional capture–recapture methods, as SECR uses information on capture histories in combination with the spatial locations of captures in a

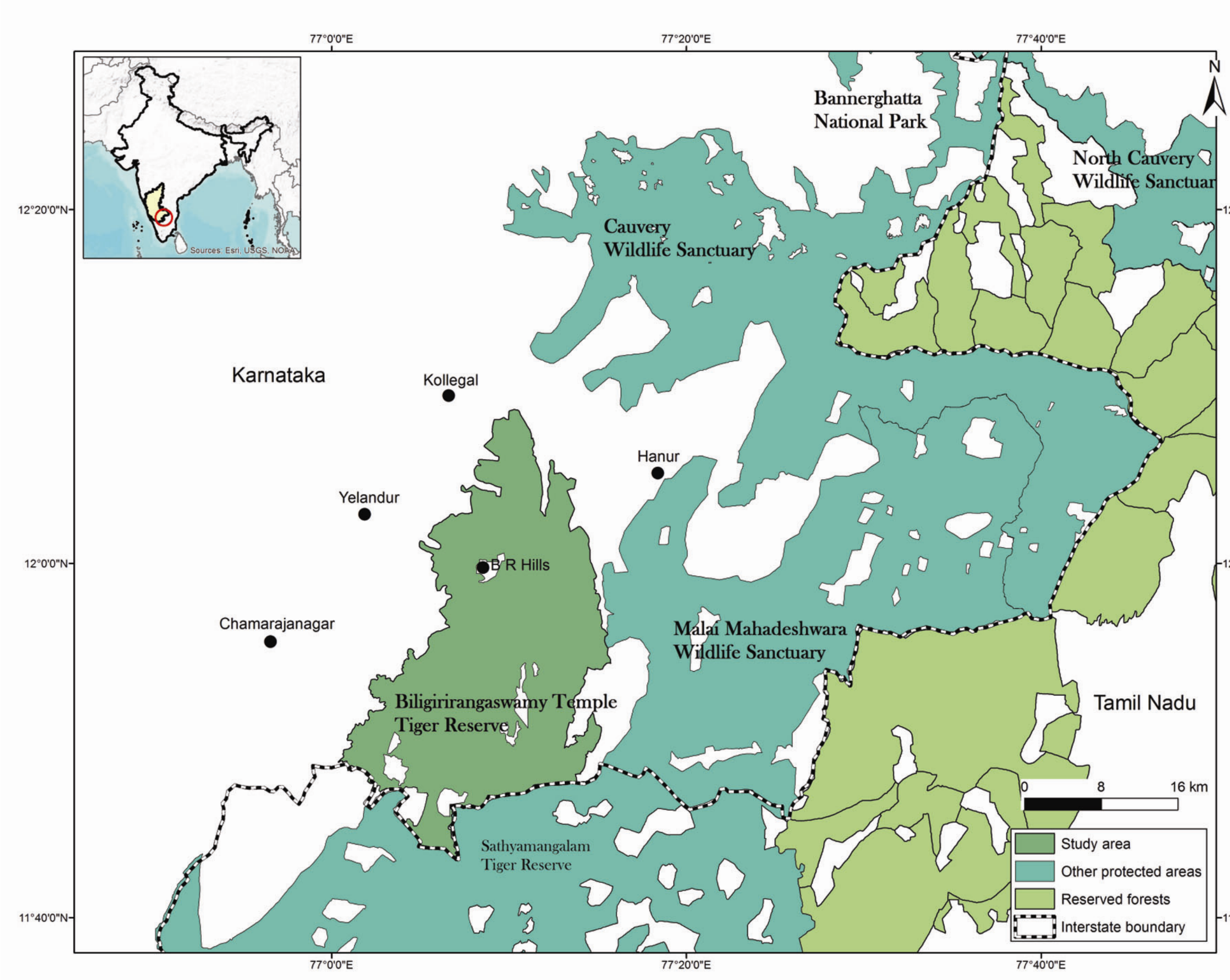

Figure 1. Landscape of Biligiri Rangaswamy Temple Tiger Reserve and the adjoining protected areas and multiple use forests.

likelihood framework[18]. SECR methods also overcome edge effects that are problematic in conventional capture–recapture methods[18]. Such modelling is also not affected by small sample size[20]. We used a half-detection function with the parameter g_0 (magnitude of detection function) constant across animals, occasions and traps.

For comparison, we also carried out the analysis using SPACECAP – another software package that uses the SECR methodology in a Bayesian framework[19]. All required matrices and buffer were created as per the SPACECAP software requirement. The data was run with a spatially explicit, non-behavioural response and half-normal detection function with a 2 km buffer.

Camera traps were placed at 157 locations resulting in a trapping effort of 4655 days. The mean distance between camera trap locations was 1.3 km (0.6–3.57 km). During the 66-day sampling period, a total of 535 tiger photographic 'captures' were obtained from the camera trapping efforts.

A total of 48 adult individual tigers were unambiguously identified and were considered for analysis. Further, two sub-adults and eight cubs that were individually identified were excluded from the analysis, as young animals are known to have different capture probability compared to the adults[21]. Of the 48 individual adult tigers that were unambiguously identified, 17 were males, 24 were females and 7 individuals were of unknown gender.

Data from SECR analysis suggests that tiger density in BRT was 6.86 tigers/100 km^2 and approximately 55 individuals might live within the study area (Table 1). SPACECAP package yielded a density of 6.81 tigers/100 sq. km, and an abundance of ~55 tigers (49–59, Table 2).

Our data depicts BRT as an important source site for this landscape, considering the fact that the adjoining Satyamangalam Tiger Reserve (2.98 tigers/100 km^2), and MM Hills Wildlife Sanctuary (0.66 tiger/100 km^2) have much lower density of tigers[8,22]. Hence, the greater BRT landscape does benefit significantly from the protection of this tiger reserve. Till date, BRT has the highest estimated tiger numbers in the greater BRT landscape[8,22], perhaps acting as a source site for MM hills, Cauvery,

Table 1. Results of the SECR analysis using SECR software package for tigers in Biligiri Rangaswamy Temple Tiger Reserve during 2015

	Link	Estimate	SE estimate	lcl	ucl
D	log	6.86	0.997	5.17	9.11
g_0	logit	9.64E-03	8.69E-04	8.08E-03	1.15E-02
σ	log	2.68E+03	1.04E+02	2.48E+03	2.89E+03

D, Tiger density/100 km^2, g_0, Magnitude of detection function; σ, Spatial scale of detection function.

Table 2. Summary statistics from SECR analysis using SPACECAP software package for tigers in Biligiri Rangaswamy Temple Tiger Reserve during 2015

	Posterior mean	Posterior SD	95% Lower HPD level	95% Upper HPD level
σ	2674.248	98.745	2479.711	2861.656
λ_0	0.024	0.002	0.020	0.029
Ψ	0.138	0.018	0.101	0.175
N_{super}	54.485	2.666	49	59
D	6.81	0.33	6.13	7.38

σ, Scale parameter of detection function; λ_0, Expected encounter rate of an individual tiger whose home range is exactly at the trap location; Ψ, The ratio of the number of tigers actually present within the state space; N_{super}, Population size of individuals, D, Density of tigers/100 km^2.

and the adjoining reserved forests. The documentation of tigers that are common between BRT and MM hills is an indicator of this claim, and also emphasizes the existence of a structural and functional corridor between these two protected areas (Gubbi *et al.* in prep).

This data set could help in managing a secure, genetically viable tiger population and help in designing long-term, landscape level plans and outcomes. This assumes greater importance especially when tiger habitats are lost even within TCLs[23]. Similarly, a coordinated camera trapping effort in the entire greater BRT landscape during the same time period would provide a better, more robust estimate. In addition, it helps a coordinated management effort where decisions against poaching, diversion of forest land, and addressing other critical threats can be undertaken based on the data available at a landscape level.

This exercise also depicts effective collaborative work between government agencies, and civil societies that could be very useful in influencing public policy. Similarly, it also highlights the commitment of the government to view suitably designed and implemented research as a priority activity which is otherwise seen as non-priority by protected area staff[4].

The recent incidences of human–tiger conflict in the tiger reserve (one human injury and two human deaths were reported during 2014–15) are also perhaps an indicator of the area reaching ecological carrying capacities. Hence, interventions for large cat conflict mitigation need to be setup immediately. Better conflict mitigation should be analogous to wild prey improvement to reduce conflict. This issue is becoming a great challenge in areas that have high tiger densities.

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Land-use/land-cover change dynamics and groundwater quality in and around shrimp farming area in coastal watershed, Cuddalore district, Tamil Nadu, India

P. Nila Rekha*, R. Gangadharan, P. Ravichandran, Shirley Dharshini, Wilmart Clarke, S. M. Pillai, A. Panigrahi and A. G. Ponniah

Central Institute of Brackishwater Aquaculture, 75, Santhome High Road, R. A. Puram, Chennai 600 028, India

The present study was envisaged mainly to ascertain the influence of aquaculture on salinization of coastal groundwater resources in the Cuddalore district of Tamil Nadu located between 11°30′N–11°20′N and 79°38′E–79°48′E. Watershed-based multidisciplinary approach combining GIS and Remote Sensing, and hydro-geochemistry has been applied. The land-use study revealed that though aquaculture was initiated after 1991, the groundwater quality in some locations showed elevated total dissolved solids and electrical conductivity content during that time itself, supporting the fact that aquaculture has been initiated in *in situ* saline area. Land-use change dynamics showed no defined relationship between area of culture and the groundwater quality, indicating that there was no salinity build-up due to shrimp farming. Besides major chemical compositions, the hydro-geochemical analysis using Chadha's plot suggests that reverse ion exchange is dominant in the study area due to the natural geological condition and it controls the groundwater quality rather than sea water incursion to a large extent. Thus these analyses clearly bring out the fact that shrimp farming is not the main reason for the source of salinity in the study area.

Keywords: GIS and remote sensing, hydrogeology, groundwater, salinization, watershed, shrimp farming.

THE world aquaculture production continued to grow, reaching 97.2 million tonnes (live weight) during 2013 with an estimated value of US$ 157 billion[1] and is perceived as one of the avenues to meet the growing demand for seafood. In addition, aquaculture has great potential for alleviation of poverty and generation of wealth for the people living in coastal areas, especially in developing countries. At the same time, aquaculture development is challenging because it might bring out significant environmental issues which could impair coastal resources. Environmentalists elsewhere have pointed out the boom and bust cycle, disease problem, and socioeconomic impacts of shrimp farming[2,3]. The impacts of shrimp farming reported are economic benefits, utilization of marginal lands and water for economic benefits, the conversion of important coastal ecosystems like lakes, salt pans, mangroves and agricultural lands to aquaculture farms[4–6], salinization of drinking water resources adjacent to shrimp farms[7], nutrient loading of coastal water bodies and estuaries[8,9], multi-user conflicts and escape of aquaculture stocks, viz. biological pollution of wild population. Briggs and Smith[10] estimated the nitrogen and phosphorus from intensively developed shrimp ponds in Thailand as it was reported that these inputs were not converted to shrimp biomass as expected, rather there was a possibility that they were released into the surrounding environment[11,12]. It may be mentioned here that in many studies the range and severity of shrimp farming impacts have been either exaggerated or misrepresented, mainly owing to the high profitability/visibility of the aquaculture sector, failure to distinguish between actual and hypothetical hazards[13] and projection of piece meal studies which were location-specific.

Brackishwater aquaculture basically utilizes saline water either from sea or estuary or creek. The groundwater salinization in and around shrimp farming area is

*For correspondence. (e-mail: rekha@ciba.res)