Abstract

Despite the colossal efforts invested towards their conservation, the status of many threatened carnivores in key conservation landscapes remains unknown. The dhole *Cuon alpinus* is an endangered social carnivore whose geographic range has reduced by c. 80% in the last century. Northeast India is of conservation significance since it forms a critical link between south Asian and Southeast Asian dhole populations. In this study, we first compiled presence records of dholes across northeast India from multiple sources. Second, we conducted systematic camera-trap surveys in one part of the same region– Dampa Tiger Reserve, Mizoram. We examined the influence of ecological and management factors on fine-scale site-use by dholes. Our results from Dampa showed a positive association between sambar *Rusa unicolor* encounters, distance to forest boundary and presence of forest department personnel on dhole site-use, underscoring the importance of prey and protection efforts (in terms of patrolling by forest guards). Our findings also highlight the need for targeted, multi-scale assessments of dhole ecology across other sites in northeast India.

Keywords: *camera traps; distribution; dhole; endangered; management; northeast India*

The dhole *Cuon alpinus* is an endangered social carnivore found in forested landscapes of south and Southeast Asia. Historically widespread across Asia, global dhole range has reduced by c. 80% (Wolf & Ripple, 2017). Their current distribution extends across most of south and Southeast Asia and parts of China, with occurrence largely restricted to protected reserves (Kamler et al., 2015).). The protected forest landscapes south of River Ganges in India are a global stronghold for the species (Acharya, 2007; Srivathsa et al., 2014; Punjabi et al., 2017), with India supporting the largest dhole population in the world (Kamler et al., 2015). However, the species has undergone local extirpation across parts of its former range due to decline in prey, loss of habitat, and possible disease prevalence (Karanth et al., 2010; Srivathsa et al., 2014). Information on dholes from northeast India in particular is severely limited and relatively recent (Gopi et al., 2010; Bashir et al., 2014; Lyngdoh et al., 2014), in spite of the fact that this

landscape shares a forest continuum with Myanmar and Southeast Asia, making it an important region for the species in terms of its global range.

Current knowledge of dholes from northeast India is restricted to landscapes north of River Brahmaputra (Ginsberg & Macdonald, 1990). This is primarily due to the paucity of baseline ecological data from the region, given its highly undulating terrain, limited access, wet climatic conditions, and prevalent socio-political insurgencies. In this study, we first provide a compilation of dhole presence records across northeast India (based on data extracted from multiple sources). Using information obtained from systematic camera trap surveys, we then determine factors influencing fine-scale site-use by dholes within Dampa Tiger Reserve, Mizoram. We discuss the implications of our results for dhole conservation in northeast India, where the focus of wildlife managers is currently directed towards population recoveries and local recolonisation of tigers *Panthera tigris*. We provide general recommendations on potential management interventions that could facilitate conservation of dholes in a hitherto neglected landscape.

This study was conducted in Dampa Tiger Reserve in Mizoram State of northeast India, within the Indo-Myanmar Biodiversity Hotspot (Mittermeier et al., 2004; Figure 1). The reserve is contiguous with the Chittagong Hill Tract region of Bangladesh to the west. The core area of the reserve covers 500 km^2, and the multi-use buffer covers an area of 488 km^2. The Lushai Hills traverse through the reserve resulting in a highly undulating topography with elevation ranging between 250–1,100 m. Annual average rainfall of the reserve ranges from 2,000 to 2,500 mm. Dampa supports a high diversity of carnivores, amongst which dhole is the most frequently photo-captured predator on camera traps. Other carnivores include four species of felids, and two species of ursids (Singh & Macdonald, 2017). Herbivores such as elephant *Elephas maximus*, gaur *Bos gaurus*, sambar *Rusa unicolor*, red serow *Capricornis rubidus*, muntjac *Muntiacus muntjak*, and wild pig *Sus scrofa*, have also been recorded in this study.

We compiled dhole presence from nine northeastern States of India (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura and West Bengal). We searched for records (2010 onwards) in newspaper reports, published scientific papers, grey

literature (including species checklists), and reports by forest department personnel/local informants or naturalists/scientists working in the region. For each presence record, we collected associated information such as the type of evidence (direct/indirect), date of sighting, administrative status of location (protected/non-protected area), resource person and source literature. We attributed reliability scores for each record (1-5; with 1 being most reliable, and 5 least reliable; Supplementary Table S1).

From December 2014 to March 2015, 79 pairs of Cuddeback Ambush IR (Model 1187; Cuddeback Digital, USA) camera traps were deployed within an area of 80 km^2 in the north-eastern part of Dampa's core area. At each trap station, two cameras were placed facing each other, at c. 30 cm height above ground, on either side of forest trails or on riverbeds (Singh & Macdonald, 2017). Inter-trap distance maintained in the study area was 1.02 km (±0.33 SD), with traps remaining active for an average of 64 days, range = 3 to 91 (Singh & Macdonald, 2017). While the set-up was designed to obtain photo-captures of complementary flanks of wild felids, it also generated photo-captures of other carnivores. Since, dholes generally use forest trails and riverbeds for movement, marking territories and hunting; our sampling design was therefore feasible for obtaining information on their spatial distribution.

We examined site-use patterns using an occupancy approach that accounted for imperfect detection (MacKenzie et al., 2002). We treated each trap-station as a site, and each trap day (24 hour period) as an independent temporal replicate. During exploratory analyses we calculated Moran's I values to check for spatial dependence of detections. Spatial dependence dropped beyond 2.3 km, with <10% of distance-pairs falling within the first distance class (Supplementary Fig. S1). We considered this to be negligible with respect to the total number of trap stations and detections, and treated each trap-station as an independent site. The detection matrix therefore contained 0s and 1s (non-detections and detections) for 74 sites (cameras/data from 5 additional sites could not be retrieved), with varying number of temporal replicates (range = 3 to 91 days).

We used photo-capture frequencies of key prey species (sambar n = 236, muntjac n = 145, wild pig n = 92; predicted influence- positive), distance to reserve boundary (predicted

influence- positive), photo-capture frequencies of forest department personnel (predicted influence- positive) and photo-capture frequencies of other humans (predicted influence-negative) as factors likely to influence site-use by dholes. We used trap effort (number of days a trap station was active) in each site as a covariate for detection probability, predicting that higher effort would translate to higher detectability. We tested singular and additive effects of the covariates where each represented an ecologically plausible hypothesis. Covariates were checked for cross-correlations and z-transformed prior to analyses. Models were ranked using Akaike Information Criterion corrected for small sample sizes (AICc; Burnham & Anderson 2002). Parameter estimation and model comparisons were carried out in program PRESENCE v11.9 (Hines, 2006).

We obtained presence records from 80 unique locations since 1990. Of these, we considered 41 records based on date of reporting (2010 onwards) and reliability scores (1–3). In case of multiple records for the same site, we considered the most recent record, with the highest reliability score. Most records were from Arunachal Pradesh (n = 14) and Assam (n = 8). Mizoram and Nagaland had five records each, followed by West Bengal (4), Meghalaya (3), and Sikkim (2). There were no recent records of dhole presence from Manipur and Tripura. A total of 5,033 camera trap-days in Dampa generated 500 photo-encounters of dholes, collapsed into 92 detections (one per 24 hour duration) across 33 sites. Using the top-ranked occupancy model (Table 1), we estimated average site-use probability at psi = 0.50 (SE 0.03; Figure 2) and trap-level detectability at p = 0.87 (SE 0.02). Top three models received somewhat similar support based on AICc scores; we interpret the covariate effects on probability of site-use from these models. Sambar encounters, forest department personnel encounters and distance to reserve boundary had positive effects on probability of site-use by dholes (Table 2; Figure 3). The slope coefficient associated with ‘effort’ as a covariate for detectability was positive (mean = 0.23; SE 0.2).

Dholes are found across several parts of northeast India, including areas outside protected reserves. Previous global assessments indicated that the species faced near or complete local extirpation in the region south of River Brahmaputra (Ginsberg & Macdonald, 1990). In this study, we explicated such gaps in knowledge with updated spatial information. Corroborating

current knowledge from other landscapes, we showed a positive relationship between dhole site-use and sambar presence (Acharya, 2007; Andheria et al., 2007; Punjabi et al., 2017). Across their extant distribution, dholes exhibit a range overlap with competing large predators such as tigers and leopards *Panthera pardus*. Wildlife managers in this region and elsewhere subscribe to unsubstantiated notions that dhole presence impedes colonisation by tigers, and consequently treat dholes as 'problem' species. Contrary to this, it has been shown that multi-carnivore complexes with tigers, leopards and dholes can exist provided the reserves support adequate densities of medium- to large-sized prey species (Karanth et al., 2017).

Dampa is an important refuge for dholes in northeast India. It supports large tracts of inviolate protected spaces, and habitat connectivity with forested landscapes of the Chittagong Hill Tract region to the west, Mamit Forest Division to the north, and Thorangtlang Wildlife Sanctuary to the south. Our camera trap data indicate presence of a large herbivore guild in Dampa, with at least five prey species of medium and large ungulate herbivores. Such factors can together allow for long-term persistence of dholes in the reserve. Our findings re-emphasize the importance of protected areas, which can serve as population source sites and sustain dhole populations across the region. In areas with low prey densities, carnivores may show significant dependence on livestock (Khorozyan et al., 2015), and are consequently stigmatised. There exists a strong negative relationship between livestock owners and dholes in Arunachal Pradesh (Mishra et al., 2004; Lyngdoh et al., 2014) and other locations in the region. Given that dholes also occur outside reserves in this region, they are vulnerable to retribution killing, thereby threatening their long-term persistence. Negative interactions between people and dholes necessitate intervention mechanisms aimed at reducing poaching pressure to allow recovery of prey, especially species such as sambar which are impacted by low recovery rates following prolonged instances of poaching (Steinmetz et al., 2009). Our findings need to be augmented with a more systematic and rigorous ecological survey across locations identified in this study, specifically in States such as Mizoram and Nagaland, so as to facilitate a pan-northeast India strategy for dhole conservation.

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Author contributions

PS, AS and DWM conceived the ideas; PS collected the data; PS and AS analysed the data; PS led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

Conflicts of Interest

None

Ethical standards

Data on presence records were elicited from published literature, media reports, and a network of researchers and naturalists who agreed to share information. All necessary research permits were obtained from the State Forest Department of Mizoram to conduct camera trap surveys.

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Supplementary material

Table S1. Reliability scores assigned to each record of dhole presence, corresponding source, evidence and resource person/literature evidence.

Figure S1. Correlogram with Moran's I values showing spatial dependence of data generated at 74 camera trap stations in Dampa Tiger Reserve, Mizoram.

309 **Table 1.** Model comparisons to estimate probability of site-use by dholes, and associated ecological/management factors in Dampa
310 Tiger Reserve, Mizoram (2014–2015). The table shows 11 top-ranked models (based on AICc scores) tested against the intercept-only
311 model [psi(.), p(.)]. Acronyms: sbr- sambar encounter frequency; fdp- encounters of forest department personnel; bdy- distance to
312 reserve boundary; eff- trap effort; hum- human activity; pig- wild pig encounter frequency; mjk- muntjac encounter frequency

Model	AICc	ΔAICc	AICc weight	Model Likelihood	Parameters	Deviance
psi(sbr+fdp+bdy),p(eff)	862.47	0	0.4041	1	6	850.47
psi(sbr+fdp),p(eff)	863.24	0.77	0.275	0.6805	5	853.24
psi(sbr+fdp+bdy+hum),p(eff)	863.98	1.51	0.1899	0.47	7	849.98
psi(sbr),p(eff)	867.29	4.82	0.0363	0.0898	4	859.29
psi(sbr+bdy),p(eff)	867.74	5.27	0.029	0.0717	5	857.74
psi(sbr+pig),p(eff)	868.28	5.81	0.0221	0.0547	5	858.28
psi(sbr+hum),p(eff)	868.32	5.85	0.0217	0.0537	5	858.32
psi(sbr+pig+mjk),p(eff)	870.24	7.77	0.0083	0.0205	6	858.24
psi(fdp+bdy),p(eff)	870.74	8.27	0.0065	0.016	5	860.74
psi(bdy),p(eff)	873.22	10.75	0.0019	0.0046	4	865.22
psi(fdp),p(eff)	873.55	11.08	0.0016	0.0039	4	865.55
psi(.),p(.)	874.19	11.72	0.0012	0.0029	2	870.19

313

Table 2. Slope coefficient estimates (standard errors in parentheses) for ecological and management covariates influencing site-use by dholes in Dampa Tiger Reserve, Mizoram (2014–2015). Table includes coefficient estimates from the top three models whose AICc scores were less than 2. Acronyms: sbr- sambar encounter frequency; fdp- encounters of forest department personnel; bdy- distance to reserve boundary; hum- human activity

Model	sbr	fdp	bdy	hum
psi(sbr+fdp+bdy),p(eff)	1.35 (0.59)	0.86 (0.45)	0.54 (0.34)	-
psi(sbr+fdp),p(eff)	1.36 (0.55)	0.76 (0.42)	-	-
psi(sbr+fdp+bdy+hum),p(eff)	1.29 (0.58)	1.12 (0.72)	0.51 (0.34)	-0.54 (0.84)

330 **Figure captions**

331

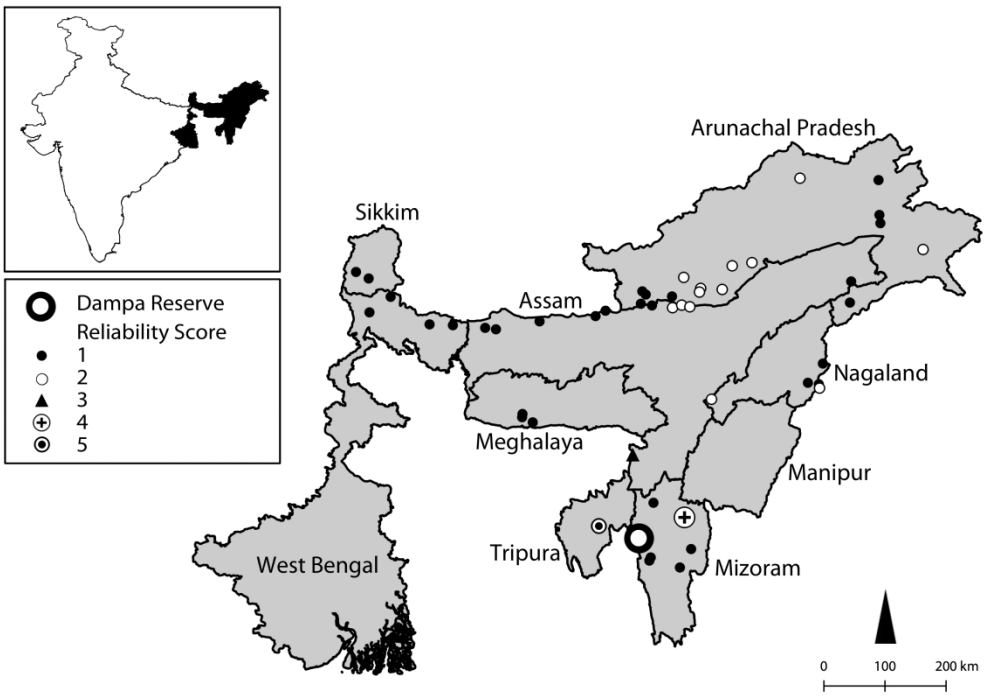
332 **Figure 1.** Study region showing the States of northeast India, location of Dampa Tiger Reserve in Mizoram and point locations from
333 where dhole presence was recorded (with corresponding reliability scores). Inset: Location of the study region in India.

334

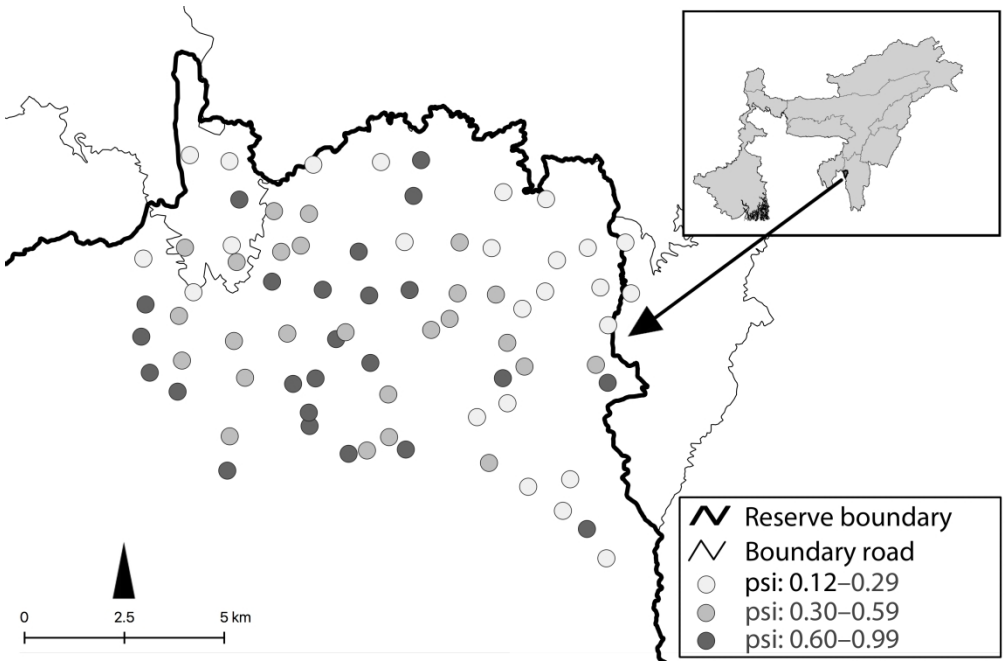
335 **Figure 2.** Estimates of probabilities of site-use by dholes in Dampa Tiger Reserve (2014–2015), based on systematic camera trapping
336 surveys and occupancy modelling.

337

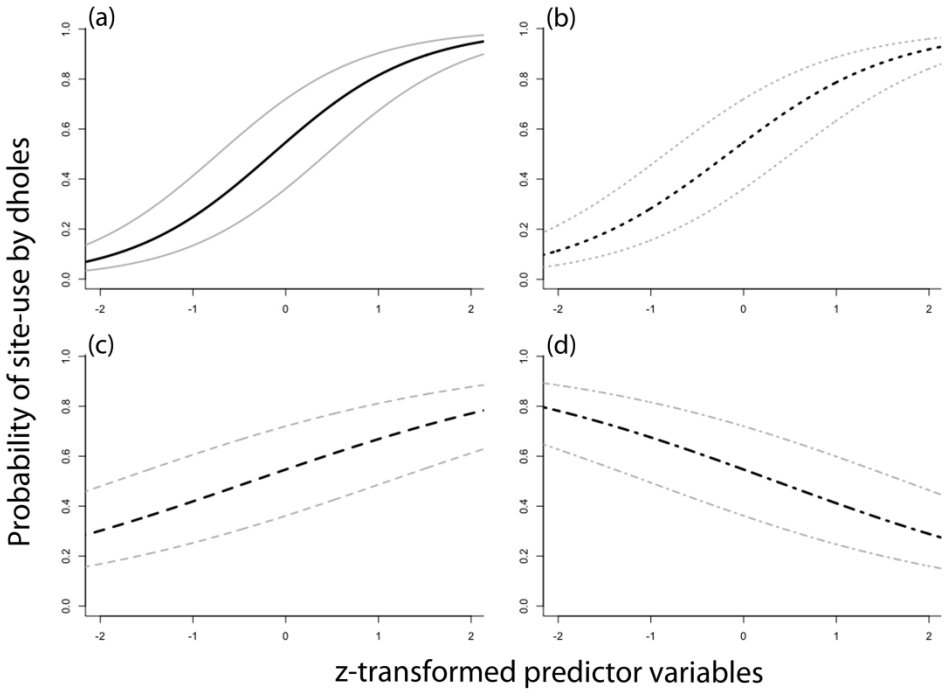
338 **Figure 3.** Relationship between individual predictor variables (a) sambar encounter frequency, (b) forest department encounter
339 frequency, (c) distance to reserve boundary and (d) human activity, and estimated site-use probabilities for dholes in Dampa Tiger
340 Reserve (2014–2015). The grey lines represent 95% confidence intervals.



Study region showing the States of northeast India, location of Dampa Tiger Reserve in Mizoram and point locations from where dhole presence was recorded (with corresponding reliability scores). Inset: Location of the study region in India.



Estimates of probabilities of site-use by dholes in Dampa Tiger Reserve (2014–2015), based on systematic camera trapping surveys and occupancy modelling



Relationship between individual predictor variables (a) sambar encounter frequency, (b) forest department encounter frequency, (c) distance to reserve boundary and (d) human activity, and estimated site-use probabilities for dholes in Dampa Tiger Reserve (2014–2015). The grey lines represent 95% confidence intervals.

Supplementary Table

Sl. No.	State	Location	Year	Reliability Score 1	2	3	4	5	References
1	Arunachal Pradesh	Itanagar WLS (incl. neighbouring villages)	2010-2011		✓				Gopi et al. 2010; Lyngdoh et al. 2014
2	Arunachal Pradesh	Eaglenest WLS	2013	✓					Velho et al. 2015
3	Arunachal Pradesh	Pakke landscape (incl. Seijosa/Pakke Kesang/Seppa & neighbouring villages)	2010, 2010-2011	✓	✓				Gopi et al. 2010; Lyngdoh et al. 2014; Selvan et al. 2014
4	Arunachal Pradesh	Talle Valley WLS (incl. neighbouring villages)	2010-2011		✓				Gopi et al. 2010; Lyngdoh et al. 2014
5	Arunachal Pradesh	Segalli FD, Papumpare district	2010-2011, 2017		✓				Gopi et al. 2010; Lyngdoh et al. 2014; Bunty Tao RFO (social media)
6	Arunachal Pradesh	Namorah, West Kameng district	2010		✓				Gopi et al. 2010; Lyngdoh et al. 2014
7	Arunachal Pradesh	Kamlang WLS	~2017		✓				Deepankar Barman
8	Arunachal Pradesh	Anini, Dibang Valley	2012	✓					Shashank Dalvi
9	Arunachal Pradesh	Migging, Upper Siang	2018		✓				Shashank Dalvi
10	Arunachal Pradesh	Mayodia Pass, Mishmi Hills	2011	✓					Dhritiman Mukherjee
11	Arunachal Pradesh	Mehao WLS	~2015, 2018	✓	✓				Anoko Mega
12	Arunachal Pradesh	Yazali, Lower Subansiri district	2017		✓				Bunty Tao, RFO (social media)
13	Arunachal Pradesh	Singchung-Bugun VCR	2013	✓					Velho et al. 2015
14	Arunachal Pradesh	Between Luthong and Khonsa, Tirap district	2018	✓					Khunwang Tangjang
15	Assam	Nameri TR	2013-2018		✓				Deepankar Barman
16	Assam	Patharia Hills RF, Karimganj	2015-2016			✓			Talukdar & Choudhury (2017)
17	Assam	Jeypore-Dihing, Dibrugarh district	2009-10	✓					Kashmira Kakati
18	Assam	Bornadi WLS, Udalgiri & Baksa districts	2013-18	✓					Deepankar Barman
19	Assam	Ripu-Chirang, Kokrajhar & Chirang districts	2013-18	✓					Deepankar Barman
20	Assam	Doimara, Sonitpur district	2006, 2007, 2009, 2018	✓					Shashank Dalvi
21	Assam	Panbari, Bansbari-Bhuyanpara Ranges,	2010-11,	✓					Borah et al. 2012; Borah et al. 2013; Lahkar et al. 2018; Borah et al. 2014; Chakraborty

		Manas TR, Kokrajhar & Barpeta districts	2012, 2016-17				et al. 2015
22	Assam	Khalingduar RF, Udalguri	March 2013	✓			Photographed by Jayanata K. Das
23	Meghalaya	Siju WLS	2013-14		✓		Kashmira Kakati
24	Meghalaya	Balphakram NP	2013-14		✓		Kashmira Kakati
25	Meghalaya	Near Rewak RF Beat Office	2013	✓			Kashmira Kakati
26	Mizoram	Dampa TR	2014-18	✓			Singh & Macdonald (2017); Priya Singh
27	Mizoram	Thorangtlang WLS (incl. Tleu, Lunglei district)	May 2018	✓			Photograph received by Priya Singh
28	Mizoram	River Tlawng, near Hortoki, Kolasib district	2013-18	✓			Pu Lalhruaitluanga
29	Mizoram	Phullen, Aizawl district	2013-18			✓	Pu Lalhruaitluanga
30	Mizoram	Khawnglung WLS	2018-19	✓			Lianrema, Forest Guard
31	Mizoram	Chalrang, Champhai district	2018	✓			Local hunter conveyed to A. Halliday
32	Nagaland	Fakim WLS	2015	✓			Satem Longchar
33	Nagaland	Saramati peak	2011		✓		Shashank Dalvi
34	Nagaland	Near Pungro, Kiphire district	2011	✓			Harkirat Sangha
35	Nagaland	Choklangan, Tuensang district	2015	✓			Satem Longchar
36	Nagaland	Intanki NP	2013, 2018		✓		Longchar, 2013; Satem Longchar
37	Sikkim	Khangchendzonga BR	2008-10	✓			Bashir et al., 2013; Sathyakumar et al. (undated)
38	Sikkim	Maenam WLS	2016	✓			Anon. (2016-17)
39	Tripura	Gumti WLS	2018			✓	Anon. (2018)
40	West Bengal	Jaldapara WLS (Kodalbasti area)	2014	✓			New report on 18th April, 2014, in 'India's Endangered'.
41	West Bengal	Mahananda WLS	2018	✓			News report on 7th March, 2018, in 'The Statesman'.
42	West Bengal	Neora Valley NP	2018	✓			News report on 13th Jan, 2018, in 'The Telegraph'.
43	West Bengal	Buxa TR	2012-2014, 2014, 2016, 2017	✓			Shome (2019); News report on 29th Nov, 2017, in 'The Times of India'; News report on 27th Aug, 2016, in 'The Telegraph'; News report on 29th Nov, 2017, in 'The Telegraph'; Dey & Chowdhury (2014)

FD- Forest Division; NP- National Park; RF- Reserved Forest; TR- Tiger Reserve; VCR- Village Community Reserve; WLS- Wildlife Sanctuary

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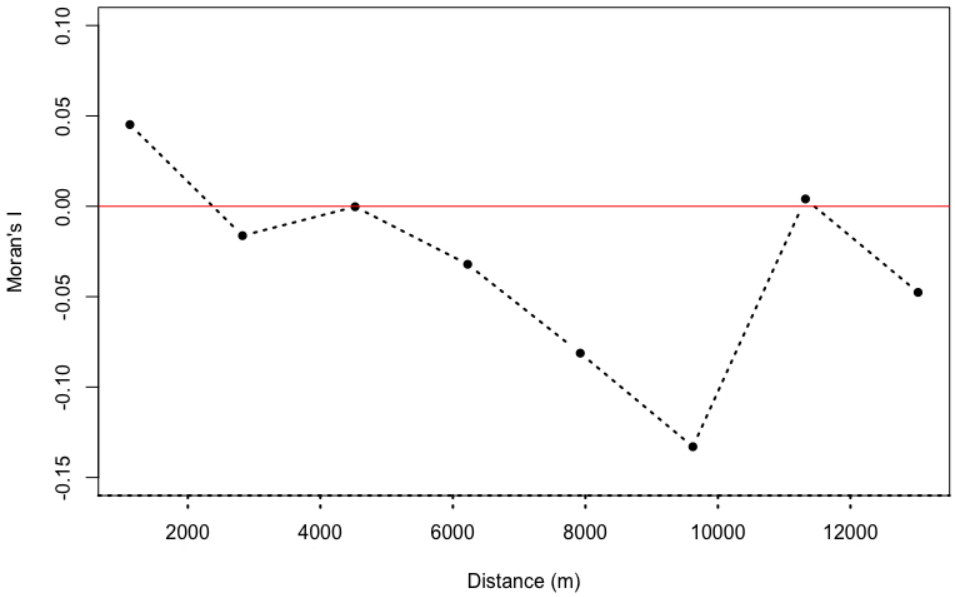

Supplementary Fig. 1

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