Assessment of Ecological Carrying Capacity of Royal Bengal Tiger in Chitwan- Parsa Complex, Nepal

Department of National Parks and Wildlife Conservation
Babarmahal, Kathmandu, Nepal
2020 July

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AIC	Akaike information criterion
BCC	Biodiversity Conservation Centre
CI	Confidence Interval
CNP	Chitwan National Park
DNPWC	Department of National Parks and Wildlife Conservation
DFSC	Department of Forests and Soil Conservation
ECC	Ecological Carrying Capacity
GPS	Global Positioning System
Ha	hectare
IUCN	International Union for Conservation of Nature
MOFE	Ministry of Forests and Environment
NP	National Park
NTNC	National Trust for Nature Conservation
PHVA	Population and Habitat Viability Assessment
PNP	Parsa National Park
TAL	Terai Arc Landscape
VTR	Valmiki Tiger Reserve
WWF	World Wide Fund for Nature
ZSL	Zoological Society of London

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Ministry of Forest and Environment
Department of National Parks & Wildlife Conservation

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Summary

Nepal has been carrying out successful tiger conservation since 1970s. Over the years, once dwindling, tiger population in lowlands have recovered. Nationwide tiger surveys have shown and steady increase in tiger population in the country. Nepal is on course to be one of the first tiger range countries to fulfil its commitment and achieve the target of doubling tiger numbers by 2022 set during the Global Tiger Summit in 2010. However, significant challenges remain ahead, particularly ensuring sufficient secured interconnected habitats for the species to be conserved over the long term, along with minimal human-tiger conflict. This study was conducted, on a special request by the Government of Nepal, to establish a method for estimating tiger ecological carrying capacity (ECC) of a site and provide a baseline ECC estimate of tigers in the Chitwan-Parsa Complex, a priority tiger conservation landscape. The approach and estimate would then help Government of Nepal to develop appropriate management interventions to conserve optimum number of tigers over the long term.

Densities of tigers, the largest felid, are mediated mainly by available biomass (or abundance) of medium-to-large ungulates. As part of this study, a systematic line-transect distance sampling survey provided density estimates for all ungulate species in the plains and Chure hills of the Chitwan-Parsa Complex. This was the first complete ungulate survey of both habitats in the Complex. Tiger ECC models based on prey biomass and prey densities provided similar estimates. Currently, Chitwan-Parsa Complex can support a significant population of approximately 175 tigers with Chitwan able to support 136 tigers and Parsa 39 tigers. Currently, Chitwan NP has an estimated 93 tigers and Parsa NP 18 tigers.

The study, however, emphasis the development of a specific tiger ECC model for the Terai-Arc Landscape incorporating improved ecological data particularly on average tiger meat intake and kill rate. The study also recommends the development of a dedicated tiger conservation management plan for the Chitwan-Parsa Complex, through a Population and Habitat Viability Assessment (PHVA) workshop, to guide protected area managers and policy makers in conserving optimum number of tigers within the Complex in the long term.

Introduction

Nepal has been always on the forefront of tiger (*Panthera tigris)* conservation. In 1900s, the Royal Bengal tiger (*Panthera tigris tigris)* population in lowland Nepal started to dwindle mainly by the excessive hunting prior to 1950s primarily by then royalties and afterwards by the increased migration of people into the plains as a result of malaria eradication in lowland plains. The later resulted in the loss of more than 200,000 ha of Terai forest in span of about 30 years between 1950 and 1980 and since has been one of the prominent threat to the tigers. With the similar pattern of deforestation, reduction and fragmentation of tiger's habitat across the world led towards global attention for tiger conservation at the 1969 IUCN meeting in New Delhi, India. The meeting called for a major tiger conservation effort, globally (Smith et al. 2010).

Chitwan National Park (CNP) was established in 1973 and over next 14 years Nepal established four more protected areas in lowland Nepal with the goal of increasing tiger habitats. Nepal's stride for tiger conservation extended beyond the establishment of protected areas for which Nepal Government collaborated with the Smithsonian Institution which initiated the Smithsonian Tiger Ecology Project in Chitwan National Park in 1973. This was the joint project of Nepal's Government, the Smithsonian, and later the National Trust for Nature Conservation, then King Mahendra Trust for Nature Conservation (NTNC) and the WWF which was implemented under the leadership of Department of National Parks and Wildlife Conservation (DNPWC).

This collaborative synergy nurtured a strong commitment to conservation research and setup a foundation of tiger conservation not only in Nepal but also the other tiger bearing countries through creating a knowledge hub that included 14 PhDs, more than 40 MS degrees and over 100 scientific publications. These scientific studies guided the tiger conservation continuously with additional research conducted periodically to update the knowledge on the new problems and the paradigms. The strong commitment from the Government was well executed by the DNPWC, DFSC and support from conservation partners led to the recovery of once dwindling tiger population not only in Chitwan but all over the tiger bearing protected areas in lowland Nepal. Since then, Nepal has been on the forefront of tiger conservation and has well adapted its tiger conservation with the emerging issues through a strategic shift in the tiger conservation approach. Since 1970s, tiger conservation or moreover wildlife conservation approach has been shifted from strict protection to participatory conservation and further into the landscape level conservation in contrary to the protection of tigers in isolated habitat. During each paradigm shift in the conservation, new issues and challenges has been emerged and those have been addressed through a proper scientific research and the findings well reflected into the conservation efforts through an adaptive management.

At the Global Tiger Summit in 2010, heads of tiger range countries committed to doubling wild tiger numbers across its range. Nepal committed to increasing its wild tiger population to 250 adult individuals (Global Tiger Initiative Secretariat 2011). This target was based on the baseline of 121

Photo 1: A female tigress with her cubs photographed in Chitwan National Park during National Tiger and Prey base Survey, 2018.

(95% CI 100 - 191) adult tigers established during the first landscape-level tiger population estimation carried out during 2008 - 2009 (Karki et al. 2009). The 2018 landscape-level tiger population survey carried out by the DNPWC and partners put the estimate of tigers in the country at 235 (95% CI 220-274) adult tigers (DNPWC and DFSC. 2018). It was evident from the survey result that the country was on right track to achieve the target of doubling the tiger number.

However, some conservationists have questioned further growth in the population given limited habitat and prey density (Karki et al. 2015, Aryal et al. 2016). Post 2018 survey, Chitwan NP also reported some incidents of tiger mortality that was identified as the consequence of male fighting probably due to limiting resources. Additionally, scientists and conservationist warned that doubling the tiger numbers could lead to increase conflict with humans and may compromise the coexistence policy that has been a core of tiger conservation in the country. Others emphasise growth with improved connectivity and management of existing habitats (Thapa et al 2016). This led to a national debate among the tiger scientist and conservationist about the size of tiger population that can be supported with the available prey base and the habitat in the country. DNPWC led this discussion over a long period involving the tiger scientists and conservationists in the country to find out a way forward. Meanwhile, the national tiger and prey base survey 2018 reported decrease in tiger population in Chitwan compared to previous estimate when the adjoining parks in both Nepal (Parsa National Park

(PNP)) and in India (Valmiki Tiger Reserve(VTR)) showed a remarkable increase in tiger population. This further fuelled the discussion directed towards need to assess the size of tiger population that can be supported in Chitwan and adjoining areas based on the available prey base.

In this context, there is now an urgent need to estimate the ecological carrying capacity (ECC) of tigers so that the species can be conserved optimally, with minimal human-tiger conflict, across its habitat in the country. This is required to address both the ecological needs of the species as well as to appropriately address the human dimension in tiger conservation. Both of these aspects need to be understood well in order to continue the successful tiger conservation in Nepal. Realising this need to understand the ECC of tigers, DNPWC formed a high level ECC study Technical Committee chaired by the Deputy Director General of DNPWC. The committee comprised of members of technical committees at DNPWC, representative from Ministry of Forests and Environment (MoFE), and experts from partner organisations. Under the leadership of the DNPWC, the study was conducted with involvement of foreign and Nepali scientists.

The ECC is most closely defined as "the maximum number of animals of a given (tiger) population supportable by the resources (in this study, ungulate prey of tiger) of a specified area" (Caughley 1976, McCullough 1992). It implies that for a given level of resources in an area, a population should experience density-dependent changes in population characteristics and growth rate. However, as resource availability varies (either increase or decrease), the ECC is expected to change and is hence not a fixed value (Caughley 1976, McCullough 1992, Amin et al. 2006). Nevertheless, as a population approaches its ECC, density-dependent effects on species life-history parameters are expected to be manifested. Amongst large mammals, this includes delayed ages at first calving, delayed time to next conception after giving birth (longer inter-calving intervals), lowered infant, calf and sub-adult survival, lowered survival of old animals and overall slow or declining population growth rates (Amin et al. 2006). In case of tiger populations approaching or exceeding ECC, human-tiger conflict can also significantly increase particularly in human-dominated landscapes.

Most current carnivore ECC models are based on prey abundance or biomass as generally carnivores appear to be limited by food resources, especially with felids being obligate meat-eaters. Tigers, the largest felid, prey almost exclusively on large ungulates, are socially dominant over other sympatric carnivores and thus their densities in protected habitats are mediated mainly by prey abundance rather than interspecific social dominance and competitive exclusion.

Study objective

The overall aim of the tiger ECC study was to inform protected area managers and policymakers on appropriate management interventions to conserve optimum number of tigers, within the Terai landscape, over the long term. This study is focused in the Chitwan-Parsa Complex, a Priority Tiger Conservation Landscape of Nepal in order to estimate the ECC of Royal Bengal Tiger.

Materials and methods

The Chitwan-Parsa Complex

The Terai Arc Landscape (TAL), a trans-boundary tiger conservation landscape, encompasses about 25,800 km^2 of potential tiger habitat spanning the Terai flood plains and Bhabar tracts of northern India and southern Nepal (Johnsingh et al. 2004, Wikramanayake et al. 2004, Seidensticker et al. 2010). The eastern section of this landscape covering 8,000 km^2 (from Bagmati river in the east to Narayani river in the west; Figure 1) is a Priority Tiger Conservation Landscape. Supporting around 140 adult tigers (Jhala et al. 2015, DNPWC & DFSC 2018), this trans-boundary section of the landscape is administered under two protected areas in Nepal (CNP & PNP), one tiger reserve in India (VTR) and several multiple-use forest divisions of Nepal and India. Extending along the Himalayan foothills, this region consists of floodplains, Dun valleys, Bhabar tract, and Shiwalik and Chure hills that range from 100 m to 900 m with a low water table and streams disappearing into permeable sediments. The vegetation primarily comprises Sal (*Shorea robusta*) dominated forests and some miscellaneous associations (Maurya & Borah 2013). It is only along the East Rapti, Narayani (in Nepal) and Gandak rivers (in India) that the typical Terai floodplain habitats consisting of wet grasslands occur within this section.

In the eastern TAL, the Chitwan-Parsa-Valmiki Complex covers 2,330 km^2. Tiger densities (adults/100 km^2) are highest in Chitwan National Park (3.28 [SE: 0.19] with 93 adult tigers) followed by Valmiki Tiger Reserve (1.49 [SE: 0.32] with 23 adult tigers) and Parsa National Park (0.92 [SE: 0.15] with 18 adult tigers) (Jhala et al. 2015, DNPWC & DFSC 2018).

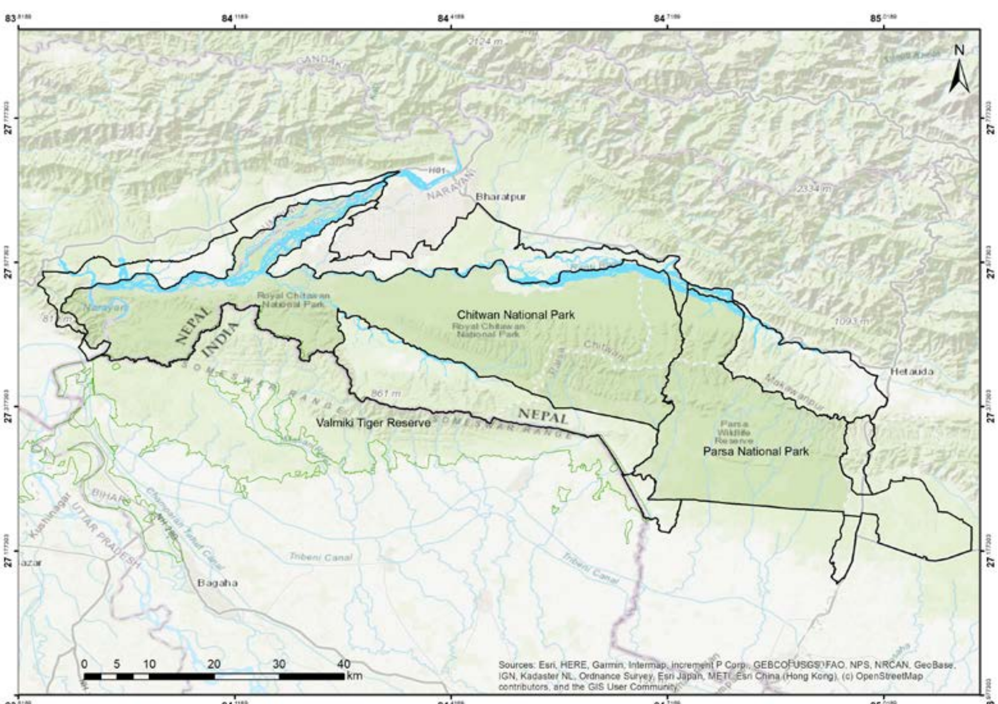

Figure 1:. The Eastern Terai Arc Landscape.

Tiger prey species density estimation

In the national status assessments of tigers, prey surveys were only conducted in the plains of Chitwan-Parsa, due to terrain and logistic reasons (DNPWC & DFSC 2018). In order to obtain tiger ECC estimates for the individual protected areas and the landscape, up-to-date prey density estimates across all tiger habitats were obtained as per the approval from DNPWC following the recommendation in the preliminary Tiger ECC report submitted in 2018 (DNPWC 2018, unpublished report).

A two-day orientation training on line transect survey was carried out prior the survey for the field personnel. They were trained on the use of compass, range finder, Global Position System (GPS), and data recording through both theoretical and practical session.

Photo 2: Field personnel learning to use range finder, compass and data recording.

Tiger prey surveys were carried out between 29 April 2019 and 25 May 2019 across all habitats in Chitwan-Parsa. Surveys consisted of 605.1 km line transects systematically positioned in the plains and Chure hills (Figure 2). The surveys involved six teams further subdivided to ten teams (Annex I) on elephant back in the floodplain (grasslands, riverine and sal forests) and on foot in the Chure foothills.

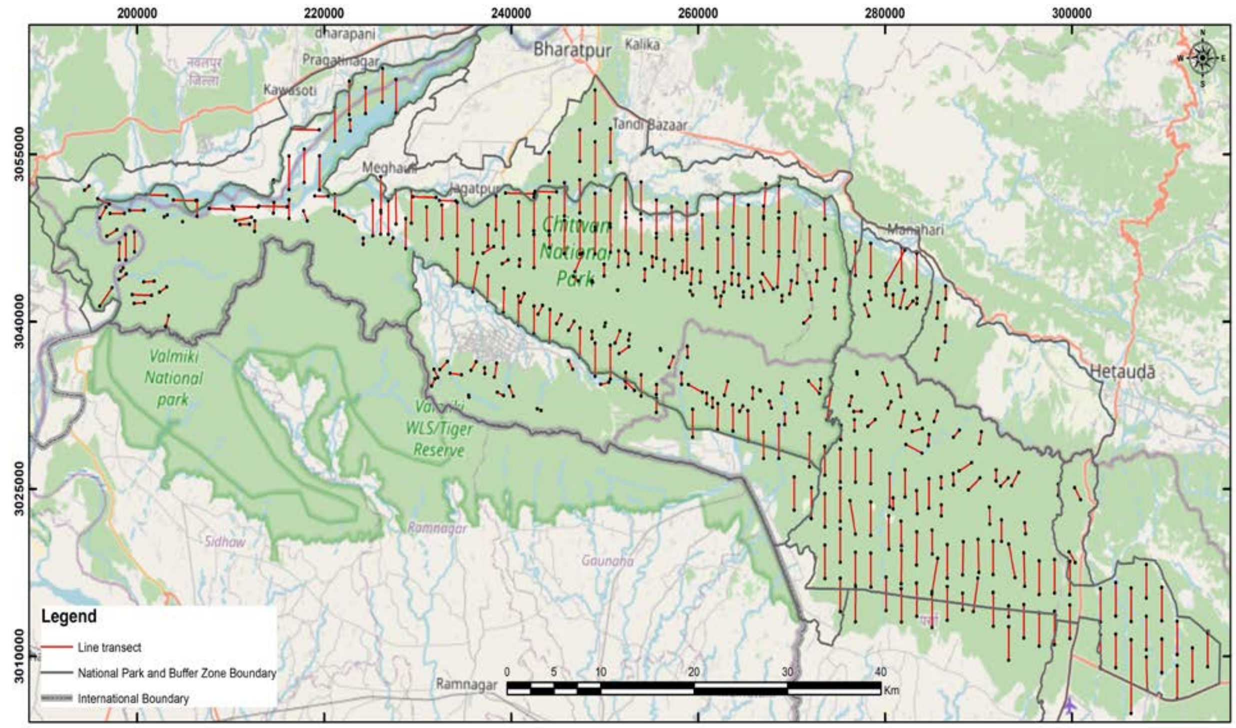

Figure 2: Spatial coverage of line transects in the Chitwan-Parsa Complex, Nepal (2019).

Each team had two observers, one looking to the left of the transect and the other right of the transect, and an elephant handler who looked for animals in the front along the transect. One of the observers recorded the animal sightings in a standard data form (Annex II). Tiger prey ungulate species surveyed included four deer species spotted deer (*Axis axis*), sambar (*Rusa unicolor*), hog deer (*Axis porcinus*), barking deer (*Muntiacus vaginalis*), blue bull (*Boselaphus tragocamelus*), wild boar (*Sus scrofa*) and gaur (*Bos gaurus*).

Photo 3: Field personnel on elephant back during prey base survey in Chitwan National Park.

Transect surveys were conducted between 0630 hours and 0930 hours in the morning and in the afternoon between 1530 and 1830 hours when all the animals are assumed to be active. For each animal observation, the species, radial distance to the animal or centre of the group, animal bearing, transect bearing, group size, total number of adults, total number of young, GPS location, and date and time were recorded. Range finder and compass were used to measure radial distance, and animal and transect bearings.

The data were compiled in Excel (Microsoft Office Professional Plus 2010) and analysed with DISTANCE 7.2 software package (Thomas et al. 2010). First, separate conventional distance sampling analyses was carried out for each species in Chitwan and Parsa NPs. Models of the detection function with the half-normal, hazard rate and uniform key functions with cosine, simple polynomial and

Hermite polynomial adjustment terms were considered. Adjustment terms were constrained, where necessary, to ensure the detection function was monotonically decreasing. Model selection among candidate models was performed by comparing AIC (Akaike information criterion) values. Model fit to the data was checked using Chi-square test. Second, analysis for the combined species dataset was carried for each of the protected areas using the multiple covariate distance sampling engine in Distance software. It was assumed species to influence the scale of the detection function but not its shape. Both global and separate species detection function estimation were also selected in the analysis.

Tiger ecological carrying capacity estimation

For the purpose of this study, model based on prey biomass similar to Carbone & Gittleman (2002) and model based on prey density developed by Karanth and colleagues (2004) were used. Both of these methods are based on the amount of food resource available to tigers at a given site in a given time.

1. Tiger ECC model based on prey biomass

An average adult tiger requires an intake of 5 - 6 kg of meat per day to meet its energy needs (Tamang 1979, Barbiers et al. 1982, Sunquist 1981). Over a year about 2000 kg of meat would be consumed by an adult tiger. Therefore, 20,000 kg of prey would sustainably support an adult tiger over a year assuming a 15 percent recruitment rate with other co-predators exploiting five percent of the prey. The ECC for tigers can then be estimated by calculating prey biomass from prey densities estimated at sites and using the following equation.

$K = (PB / 20000)$

where K = tiger ECC (per 100 km^2), PB = prey biomass (per 100 km^2).

This also corresponds to the scaling relationship between predator and prey density across the order Carnivora, where 10,000 kg of prey supports about 90 kg of a given carnivore species and using an average tiger body mass of 181 kg (Carbone & Gittleman 2002).

2. Tiger ECC model based on prey densities

Karanth and colleagues (2004) developed a mechanistic model to scale tiger densities to prey densities rather prey biomass. At sites with prey remaining at carrying capacity under natural conditions, it is expected that surplus animals are removed by predators. Based on field studies, Karanth and colleagues (2004) assume this rate at approximately 15% and further hypothesize that tigers (apex predators) crop approximately 10% and other sympatric predators such as leopards and dholes exploit the remaining 5%. As body mass of individual ungulates (20 kg – 1,000 kg) and the proportion of the kill consumed by tigers are both highly variable factors, prey availability represented in terms of ungulate densities rather than biomass is used in this model. Therefore, by assuming 10% cropping by tigers and applying an average kill rate of 50 ungulates per adult tiger per year (observed in field studies), ECC can be estimated using the following equation:

$K = (0.1 / 50) * PD$

where K = tiger density (per 100 km^2), PD = prey density (per 100 km^2).

The model was developed and tested using estimated tiger and prey densities from 11 ecologically diverse sites across India (Karanth et al. 2004)

Results

Tiger prey species density estimates

In total, 207 line transects covering 372.4 km and 113 line transects covering 232.7 km were conducted in Chitwan NP and Parsa NP respectively. In Chitwan NP, 106 transects (270.5 km) were surveyed in the plains and 101 transects (101.8 km) were surveyed in the Chure hills. In Parsa NP, 63 transects (160.9 km) were surveyed in the plains and 50 transects (71.9 km) were surveyed in the Chure hills. There were insufficient detections of blue bull and gaur for density analysis (Table 1).

Table 1: Number of group observations and individual counts of tiger prey ungulate species recorded in the line transect surveys in Chitwan National Park and Parsa National Park.

Species	Total number of observations			Total number of animals counted		
	Chure hills	Plains	Total	Chure hills	Plains	Total
Chitwan						
Barking deer	7	43	50	7	55	62
Blue bull	0	0	0	0	0	0
Gaur	4	6	10	25	58	83
Hog deer	3	67	70	4	173	177
Sambar	35	62	97	74	108	182
Spotted deer	18	153	171	262	1354	1616
Wild boar	7	20	27	14	30	44
Parsa						
Barking deer	3	33	36	3	35	38
Blue bull	0	5	5	0	18	18
Gaur	0	1	1	0	1	1
Hog deer	0	0	0	0	0	0
Sambar	7	64	71	11	126	137
Spotted deer	6	45	51	27	285	312
Wild boar	4	40	44	14	78	92

Exploratory analyses revealed a few (<5) data recording errors and these observations were excluded from the analyses.

Spotted deer were the most abundant prey ungulate species in Chitwan and Parsa NPs. Wild boar was the only species at a higher density in Parsa NP than in Chitwan NP. All other prey ungulate species were less abundant in Parsa NP. Hog deer were not recorded in Parsa NP (Figure 3).

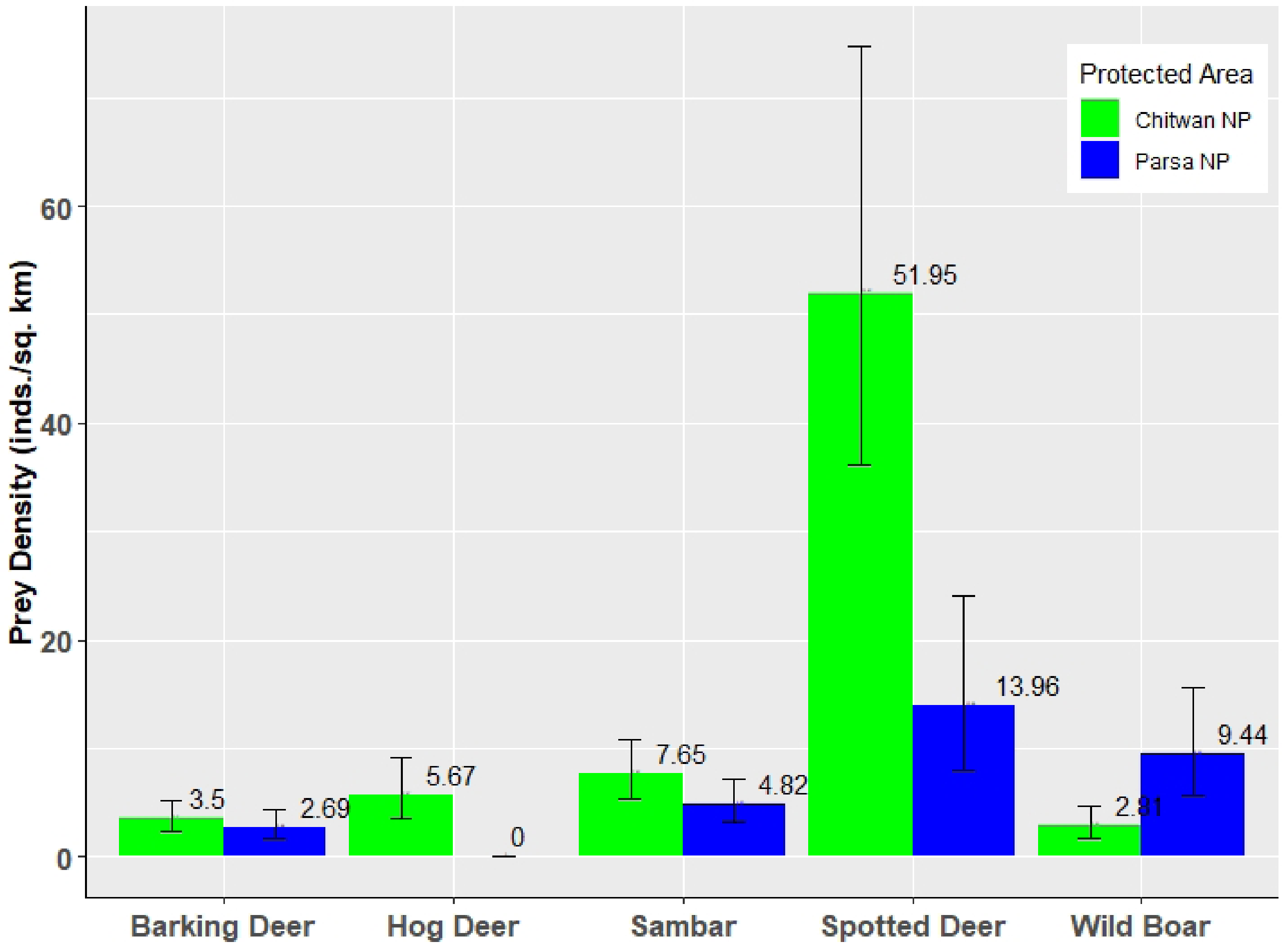

Figure 3: Individual density of prey species in Chitwan and Parsa National Parks with 95% Confidence Interval.

The details of the selected model to estimate the individual prey density, detection probability (95% CI), effective strip width (m), and the estimated average group size (95% CI) is presented in Annex III.

Tiger ecological carrying capacity estimates

Using the prey density estimates, tiger ECC under the two models for each protected area and for the entire forest complex were estimated. The following average body weights were used: barking deer (21 kg), sambar (134 kg), spotted deer (47 kg), hog deer (43 kg) and wild boar (32 kg) to estimate prey biomass from prey density (Baral & Shah 2008). The total prey density and prey biomass for Chitwan, Parsa and Chitwan Parsa Complex is presented in the following Figure 4 and Figure 5

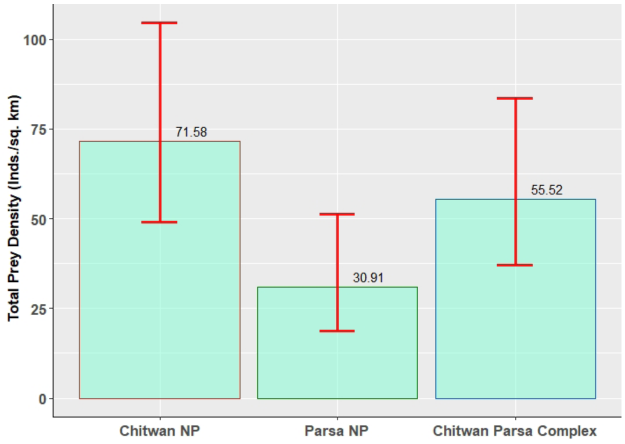

Figure 4: Showing the total prey density in Chitwan, Parsa and Chitwan- Parsa Complex.

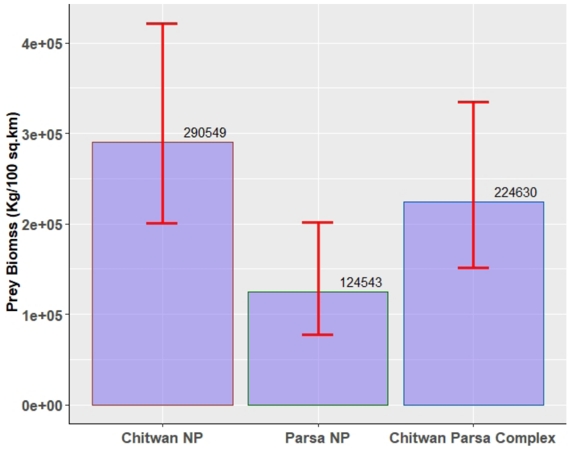

Figure 5: Showing the total prey biomass in Chitwan, Parsa and Chitwan- Parsa Complex.

Both the prey biomass and prey density methods produced very similar tiger ECC estimates (Figure 6). The tiger ECC estimate based on the prey biomass was found to be 138 individuals for Chitwan and 39 individuals for Parsa. Likewise, the tiger ECC estimate based on the tiger density was found to be 136 individuals for Chitwan and 39 for Parsa.

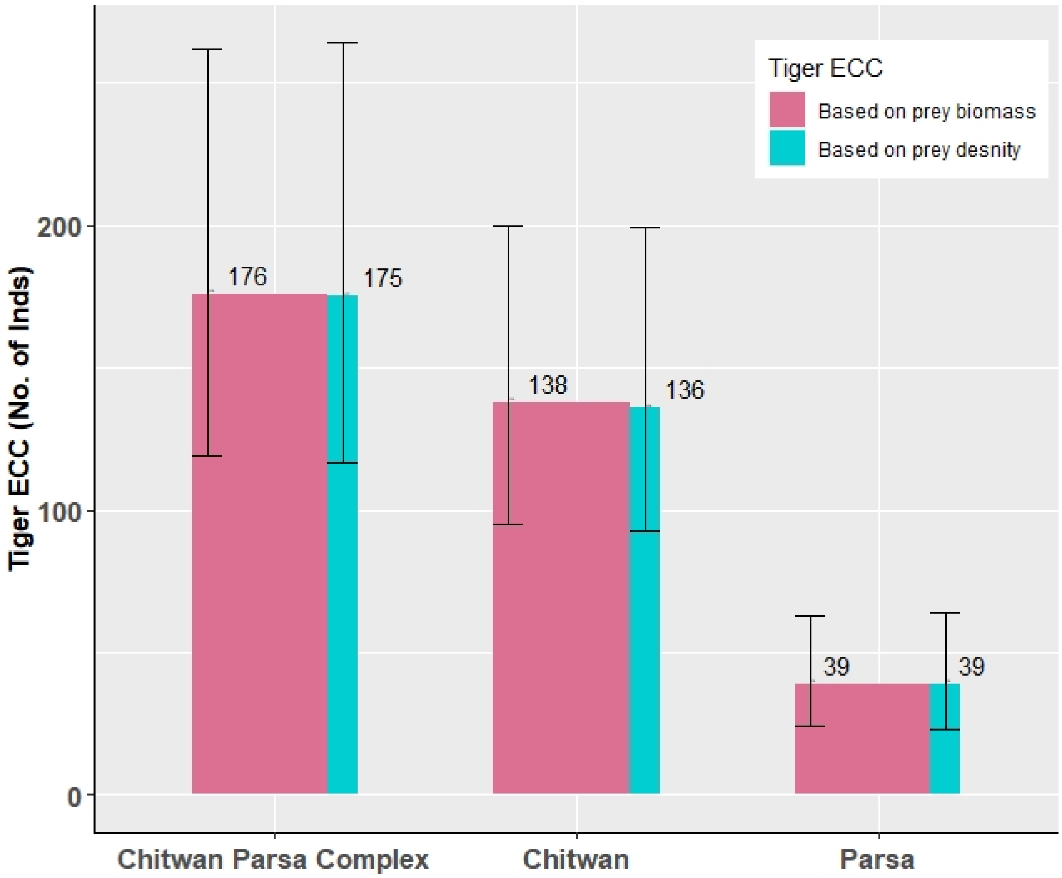

Figure 6: Estimate of tiger ECC with 95 % CI for Chitwan- Parsa Complex, Chitwan NP and Parsa NP based on prey biomass and prey density.

Chitwan NP and Parsa NP also have a population of 368 and 105 gaur respectively based on a total count in 2016 (DNPWC 2016). However, tiger scat-based studies have shown gaur to contribute a very small percentage of a tiger's diet (Kapfer et al. 2011, Lamichhane et al. 2019). With gaur (average body weight: 800 kg) included in the model, the tiger ECC estimates are 152 (95% CI 109 - 214) and 43 (95% CI 28 - 67) for Chitwan NP and Parsa NP respectively.

Photo 4: A herd of spotted dear observed in Chitwan National Park during prey base survey 2019.

Discussion

The tiger energetic requirement models produced very similar tiger ECC estimates and highlight that current prey densities in the Chitwan-Parsa Complex can support a significant population of about175 tigers. Suitable undisturbed habitats in the buffer zones and corridors could support additional tigers. However, amongst the two protected areas, Chitwan core area is expected to support over 136 adult tigers and Parsa core area to support over 39 adult tigers.

The results showed a huge difference in the number of tigers that can be supported by the Chitwan compared to Parsa despite Parsa covering as much as nearly two third the size of Chitwan. This difference can be attributed to the huge difference in the overall prey density in these two NPs. Though the densities of species other than spotted deer are more or less similar, there is the significant difference in the spotted dear densities between these NPs. (51.95 individuals/km^2 in Chitwan and 13.96 individuals/km^2 in Parsa) Figure 7.

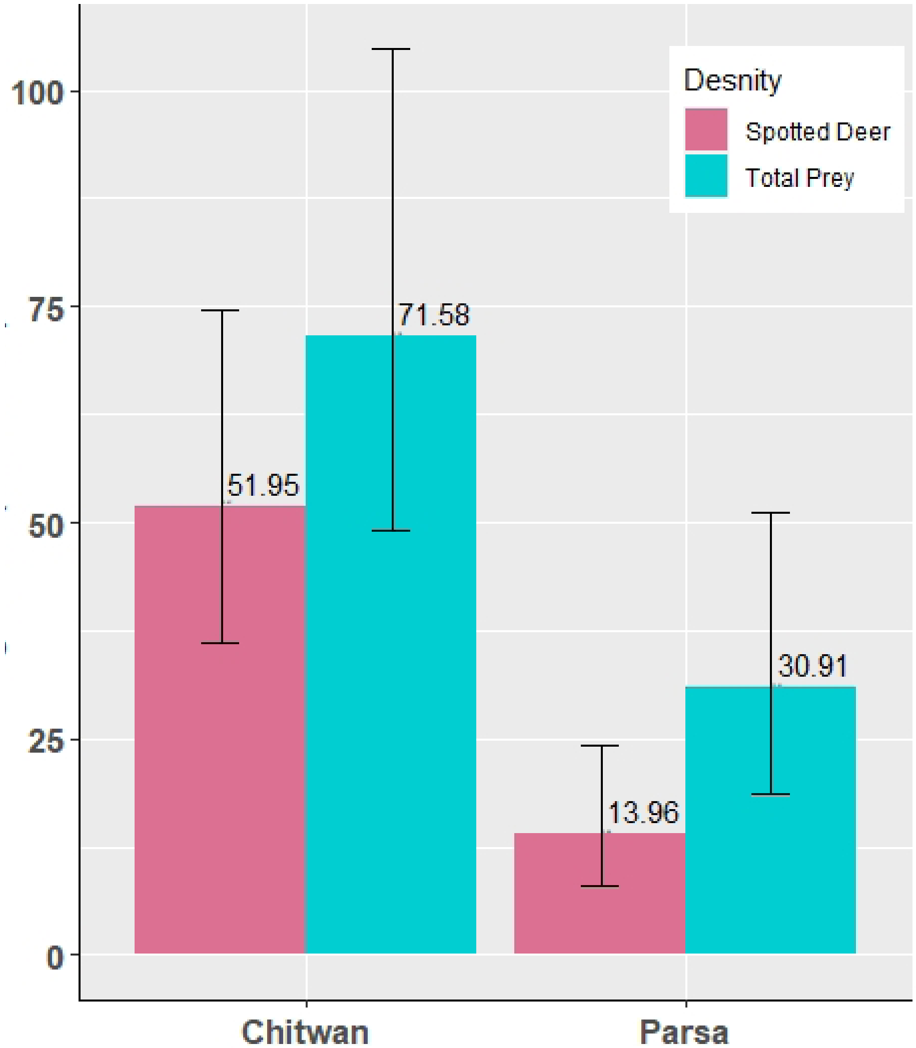

Figure 7: Showing the spotted deer density in Chitwan and Parsa compared to the total prey density in Chitwan Parsa.

This underlying difference in the prey densities in Chitwan and Parsa is mainly due to the difference in quantity and quality of suitable habitat (grasslands and wetlands) for prey species primarily spotted deer. The study also found that the current tiger densities in Chitwan and Parsa (DNPWC and DFSC 2018) are much lower than the potential densities that could be realised with the current densities of prey base (Table 2).

Table 2: Estimated tiger densities for Chitwan and Parsa National Parks and potential tiger density (ECC) based on prey availability.

National Park	Tiger Density Individuals/100km2 (DNPWC&DFSC 2018)	(ECC)Potential Tiger Density Individuals/100km2 (This Study)
Chitwan National Park	3.81	14.5
Parsa National Park	1.49	6.22

Photo 5: A Sambar deer observed in Chitwan National Park during prey base Survey, 2019.

In both NPs, small and medium sized prey constitute the highest proportion (90 % in Chitwan and 85 % in Parsa) among all available prey. The sambar deer, a large sized prey, (along all individual prey included to estimate the total density of prey base), constitute small proportion of prey base (10 % in Chitwan and 15 % in Parsa). This means that tigers are required to hunt more often to meet their energy requirement which in turn consumes more energy that would probably have effect on the fecundity, offspring to adult ratio as well as the survival of the individuals (Gittleman & Thompson 1988). This might have been the reason for the relatively lower tiger densities compared to the potential tiger densities based on the study of current ECC of tigers in Chitwan Parsa Complex, which estimates tiger ECC based on the availability of food i.e. prey biomass only.

The carrying capacity of the tiger is primarily dependent upon the availability of the prey species (energetics). The prey availability (abundance/density) is dependent upon the availability of the productive patches of habitats mainly the grasslands as most of the prey base in Chitwan- Parsa Complex are grassland dependent. This provides an opportunity to park management to increase the current carrying capacity of the tigers up to a threshold level. Availability of space, interspecific and intraspecific relationship within the ecosystem together with availability of food resources could determine the threshold level of ECC.

In terms of grassland habitat, Chitwan has a total of 8,955.2 ha which is 9.6 % of total core area. Additional 1541.9 hectare (ha) of grassland habitat occurs in the buffer zone area (CNP 2016). However, Parsa has about 530 ha of grassland habitat which is only 0.85 % of total core area (PNP 2018) (Table 3).

Table 3: Status of grassland and water sources in Chitwan and Parsa National Parks.

Habitats	Unit	Chitwan NP	Source	Parsa NP	Source
Grasslands	Area	8955.2 ha – in core 1541.9 ha – in buffer zone	CNP 2016	530 ha	PNP 2018
Grasslands patches	No	425	CNP 2016	<15	
Wetlands (Permanent)	No	83	CNP 2015	<15	
Major Perennial Rivers	No	5 (Reu, Rapti, Narayani, Dhungre, Budi Rapti)		1 (Rapti)	

Likewise, Chitwan is also relatively moist with comparatively more number of waterholes and natural water bodies in comparison to Parsa (Table 3). The perennial water sources including Narayani and Rapti rivers along the boundary of Chitwan NP, Reu river dissecting the core area and oxbow lakes formed by these rivers act as year round source of water in Chitwan. Whereas, Parsa has very few perennial sources of water that tends wildlife to depend upon the artificial waterholes most of which dries out during the hot season. In addition, flooding during the monsoon season in the rivers in Chitwan helps create a suitable grassland for ungulates which is largely lacking Parsa. The lack of sufficient water and productive grassland habitat could have been the major stress for prey population in Parsa that might have regulated the populations at a low density.

Recommendations

Habitat management

In Chitwan, many of the grassland patches are covered with tall and dense grasses along with woody vegetation and invasive species which is not preferred by grassland dependent species such as spotted deer. Management of grasslands by increasing the mosaics of suitable patches considering the requirement of various grassland species will help tiger population as well as supports the overall biodiversity. Around 45% of the grassland patches in Chitwan have an area less than 5 ha with few large grasslands clumped together (CNP 2016). Increasing the area of smaller grassland patches through management intervention would help increase the suitability of those smaller patches to many grassland dependent prey species. Increasing the area of grasslands can help support more tigers and will also increase the carrying capacity of the tigers in Chitwan. In Chitwan, tigers are already using many forest and grasslands patches within buffer zone while there is still opportunity to increase the suitable habitat outside Chitwan National Park in Buffer Zone and forests outside protected area along the corridors and additional forest in Churia hills in the northern side connected with Chitwan National Park through Barandabhar corridor forest.

In Parsa, there might be limited opportunity to increase the area of grasslands due to the predominant drier soil condition and less water sources. Increasing the productivity of the existing grasslands through regular management interventions would help to increase the number of prey supporting more tigers whereas it is equally important to identify the places with good soil moisture condition to create new grasslands. It may be required in some parts to manage the grasslands along with artificially regulating the soil moisture condition. Increasing the number of waterholes with year round supply of water would also help prey and tigers along with wildlife which is already been practiced inside the park. This could help further increase the tiger population within ECC of tigers in the park.

Effective grassland management makes it possible to reintroduce and build up populations of large prey and can also increase the reproduction rate of deer species. Management should aim to maintain areas of intact grassland that are not cut or burnt, on a rotational basis (Peet 1997; Peet et al. 1999). Burning by management should also be carried out during the early part of the dry season to minimize loss of breeding animals (Peet et al. 1999). Saplings of various trees and bushes should be removed periodically from grasslands to prevent succession to shrubland and eventually forest. Community-managed grasslands could also be setup, such as the one initiated in Chitwan National Park buffer zone in Nawalparasi District working along similar lines to that of community forestry, to fulfil the needs of local village people for cattle fodder and thatch grasses (Dhan Bahadur Chaudhary pers. comm. 2019).

Urgent action is also needed to control the spread of invasive alien plant species particularly the fire adapted *Mikania micrantha* in Chitwan NP. It has invaded 45% of the major floodplain habitats at various levels (Murphy et al. 2013). Failure to control this invasive species is likely to significantly reduce the herbivore carrying capacity of the park.

Improvements in ECC estimation

For the longer term, it would be useful to develop a specific tiger ECC model for the Terai-Arc Landscape. This should incorporate improved data on tiger prey recruitment and ecology, co-predator densities, and tiger behaviour ecology and home ranges. Site- or region-specific data on average tiger meat intake and kill rate would improve tiger ECC estimates. For example, assuming an average meat intake of 7 kg day^{-1} tiger^{-1} (average adult tiger meat intake: 4.4 – 5.6 kg day^{-1}; adult male tiger meat intake: 6.7 – 8.3 kg day^{-1}; female tiger at peak lactation meat intake: up to 10 kg day^{-1}) would result in ECC estimates: 108 (95% CI 75 - 157) tigers for Chitwan NP; 31 (95% CI 19 - 49) tigers for Parsa NP; and 139 (95% CI 94 - 207) tigers for Chitwan-Parsa Complex. Similarly, an average kill rate of 61 ungulates per adult tiger per year (kill every 6 days based on smaller prey availability) would result in ECC estimates: 112 (95% CI 77 - 163) tigers for Chitwan NP; 32 (95% CI 19 - 53) tigers for Parsa NP; 144 (95% CI 96 - 216) tigers for Chitwan-Parsa Complex.

Similar to Hayward et al. (2007) functional relationship of lion density to preferred prey biomass and biomass of prey within the preferred weight range, a functional relationship could be developed for tigers. To develop this relationship, reliable data on tiger density (close to ECC) and prey density from multiple sites across the range will need to be compiled. Reliable estimates of species body weights will also be required to convert prey density estimates to prey biomass. The predictive ability of the developed model can be compared with existing ECC models.

A TAL tiger ECC model would be a significant advancement to conservation science and management of tigers across the range. However, developing such a model is reliant on generating robust tiger and prey density estimates, and collaboration with tiger scientists and institutions across the range.

A tiger conservation management plan for the Chitwan-Parsa Complex

It would be important to develop a tiger conservation management plan for the Chitwan-Parsa Complex with an overall objective of conserving optimum number of tigers within the Complex over the long term. The plan can be formulated in a multi-stakeholder Population (and Habitat) Viability Assessment (PHVA) workshop. Using reliable prey density and tiger ECC information generated through this study and utilizing available information on the life history parameters of tigers and prey, a population viability analysis (PVA) model can be developed. Carter et al. (2015) developed a spatially explicit individual-based model for Chitwan. By updating the prey density information for these models and extending the area of inference, a PVA model for the Complex would be very useful as a management tool. This tool can then be used during the planning workshop to simulate probable effects of management actions on the tiger and their prey populations and help make informed decisions to ensure that the optimum number of tigers are conserved in the landscape over the long term. For instance, understanding how grassland management affects prey reproduction rate and therefore tigers (Peet 1997) or assessing how management actions aimed at other species affect tigers (e.g. Murphy et al. 2013) or habitat management that makes it possible to introduce / build up populations of large ungulates such as gaur and blue bull.

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Annex I

Survey Plan

SN	Camp/Area	Team member			Transects			
		Observer	Elephant staff	Total Team Member	No of transects lowland	Transects /Lowland	No. of transects Chure	Transects /Chure
1	Extension area	Anil Parsai/Pramod Regmi & Asok Kumar Ram, Raj Bansi Dhami, Manoj, cook	2 elephant with 6 Staff	11	27	264, 265, 266, 269, 270, 273, 274, 278, 277, 281, 282, 185, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301,	12	C153, C154, C155, C156,C157,C158,C159,C160,C161 ,C162,C163,C164
2	Gadhuwa	Binod Darai & Om praksah haudhary, Hasta Bahadur Shahi, 1 cook, Diver	2 elephant with 6 staff	13	41	148, 149, 158, 159, 165, 171, 172, 182, 183, 189, 190, 192, 193, 194, 195, 207, 206, 205, 204, 208, 209, 210, 215, 216, 217, 227, 228, 229, 230, 231, 241, 242, 243, 244, 245, 250, 251, 258, 259, 262, 263,	51	C53, C63, C66, C68, C71, C72,C73,C80,C81,C85,C87,C89,C90,C93,C96,C98,C99,C100,C101,C105,C106,C107,C108,C112,C113,C114,C119,C123,C122,C120,C127, C126,C121,C130,C131,C132,C137 ,C139,C140,C141,C143,C144,C145,C146,C147,C148,C149,C150,C151,C152
3	Kasara	Dr. Aashish Gurung, Prakash Upreti, Gopal Ghimire/John Lhumy Nuppa & Dip Prasad Chaudhary,Ram Krishna Nepal (Kasara), Cook	2 elephant with 6 staff	12	43	134, 126, 127, 125, 120, 111, 104, 98, 91, 84, 80, 77, 75, 71, 69, 70, 72, 74, 78, 81, 82, 85, 86, 90, 89, 67, 65, 63, 64, 59, 60, 55, 56, 52, 53, 47, 45, 41, 38	30	C23,C24,C25,C26,C27,C28,C29,C30,C35,C36,C37,C38,C39,C40,C41, C43,C176,C47,C48,C50,C52,C55,C59,C62,C178,C66,C63,C68,C177,C64
4	Nawalparasi	Saneer Lamichane, Bishnu Lama & Tika Ram Tharu, Surendra Chaudhary, Ankalesh Chaudary, Cook	2 elephant with 6 staff	11	21	17, 20, 25, 28, 29 32, 34, 35, 36, 37, 39, 42, 43, 46, 49, 50, 54, 58, 62,	24	C1,C2,C3,C4,C5,C6,C7,C8,C10,C11,C12,C13,C14,C15,C16,C17,C18, C19,C20,C21,C22,C165,C166,C167
5	Sauraha	Rishi Ranabhat, Binod Shrestha & Tirtha Lama,Balram Ram, cook	2 elephant with 6 staff	11	25	88, 93, 94, 95, 102, 101, 100, 106, 107, 108, 109, 113, 114, 115, 116, 117, 122, 121, 129, 130, 1007	15	C42,C44,C45,C46,C49,C51,C53,C54,C174,C56,C175,C57,C60,C61,C65
6	Pyaridhap	Ram Kunwar, Ramesh Darai & Harkaman Lama,Laxmi Bahadur Raut, Cook	2 elephant with 6 staff	12	24	249, 236, 222, 221, 214, 200, 199, 185, 184, 178, 176, 177, 168, 169, 170, 155, 154, 152, 153, 145, 144, 140, 138, 139	37	C58, C67,C68, C180, C69, C70, C74, C75, C76, C77,C79, C84,C82,C88,C86,C83,C95,C91,C94,C92,C97,C102,C103,C104,C110, C109,C179,C117,C115,C111,C124 ,C118,C129,C134,C133,C135,C128
Sum total				70	181		169	

Annex II

Data recording sheet

बाघको आहारा प्रजातिको सर्वेक्षण, २०७६ **Prey base Survey, 2019**	डाटाशीट: लाइन ट्रान्जेक्ट सर्वेक्षण **Datasheet: Line Transect Survey**

मितिः _____________ सर्भे स्थानः ___________ बासस्थानको किसिम ___________ समूह न/Group No: _________ प्रेक्षक/Observer: _________________

ट्रानजेक्ट न/Transect no: _______ ट्रानजेक्ट बेरिंग/Transect bearing: ___________ सर्भे विधि : पैदल हिँडेर ( ) / हात्तीमा चढेर ( ) मौसम_____________

सुरु जी.पी.एस/Start GPS: E ____________________ N ___________________ सुरुको समय/Start time: _________________

अन्तिम जी.पी.एस/End GPS: E ____________________ N ___________________ सकिएको समय/End time: ________________

क्र. न. S.N	प्रजाति Species	जम्मा संख्या Total no	विवरण (Animal details)			जनावर देखिएको (Animal sighting)		देखिएको समय Time observed	बासस्थान को किसिम Habitat type	जनावर देखिएको स्थानको जी.पी.एस GPS	
			भाले Male	पोथी Female	बच्चा Young	दिशा (बेरिंग) bearing	दुरी distance				
										E:	Wpt.
										N:	
										E:	Wpt.
										N:	
										E:	Wpt.
										N:	
										E:	Wpt.
										N:	
										E:	Wpt.
										N:	
										E:	Wpt.
										N:	
										E:	Wpt.
										N:	
										E:	Wpt.
										N:	

बासस्थान किसिम: सा: साल जंगल, मि: मिश्रित जंगल, न: नदितटीए बन, ला.घा: लामो घासेमैदान, छो.घा: छोटो घासेमैदान, सी: सिमसार

Habitat type: SF - Sal forest, MF - Mixed Forest, RF - Riparian Forest, TG - Tall Grassland, SG – Short Grassland, W-Wetland, S – Streambed

Annex III

Tiger prey ungulate species density estimates with 95% confidence intervals (in brackets), 2019 in Chitwan National Park and Parsa National Park.

Species	Model	Density estimate (95% CI) (individuals / km²)	Detection probability (95% CI)	Effective strip width (m)	Estimated average group size (95% CI)*
Chitwan					
Barking deer	Half normal with no adjustments	3.50 (2.33 – 5.25)	0.22 (0.18 – 0.27)	22.03 (17.73 – 27.38)	1.17 (1.06 – 1.30)
Hog deer	Half normal with no adjustments	5.67 (3.51 – 9.16)	0.25 (0.21 – 0.30)	34.96 (29.27 – 41.75)	2.18 (1.82 – 2.61)
Spotted deer	Hazard rate with no adjustments	51.95 (36.14 – 74.68)	0.18 (0.15 – 0.21)	35.42 (29.98 – 41.85)	8.19 (6.55 – 10.21)
Sambar	Hazard rate with no adjustments	7.65 (5.37 – 10.89)	0.15 (0.11 – 0.19)	29.16 (22.74 – 37.40)	1.75 (1.56 – 1.98)
Wild boar	Half normal with no adjustments	2.81 (1.67 – 4.73)	0.29 (0.21 – 0.40)	20.47 (14.99 – 27.96)	1.72 (1.34 – 2.21)
Parsa					
Barking deer	Half normal with no adjustments	2.69 (1.67 – 4.33)	0.26 (0.20 – 0.34)	31.17 (24.04 – 40.42)	1.08 (1.02 – 1.14)
Spotted deer	Half normal with no adjustments	13.96 (8.07 – 24.13)	0.39 (0.32 – 0.49)	39.25 (31.72 – 48.58)	4.98 (3.60 – 6.88)
Sambar	Half normal with 2 cosine adjustments	4.82 (3.24 – 7.17)	0.27 (0.22 – 0.32)	47.85 (40.31 – 56.81)	1.53 (1.32 – 1.76)
Wild boar	Hazard rate with no adjustments	9.44 (5.72 – 15.56)	0.23 (0.17 – 0.31)	22.85 (17.01 – 30.71)	2.27 (1.82 – 2.84)

*size bias corrected

Annex IV

Chitwan-Parsa Complex tiger ecological carrying capacity estimates with 95% confidence intervals (in brackets), 2019.

Protected area	Tiger ECC model based on prey densities		Tiger ECC model based on prey biomass	
	Prey density (individuals per km^2)	Tiger ECC(95% CI)	Prey biomass (kg/100 km^2)	Tiger ECC (95% CI)
Chitwan NP (952 km^2)	71.58 (49.02 - 104.71)	136 (93 - 199)	290,549 (200,360 - 421,850)	138 (95 - 200)
Parsa NP (627 km^2)	30.91 (18.70 - 51.19)	39 (23 - 64)	124,543 (77,367 - 201,280)	39 (24 - 63)
Chitwan-Parsa Complex (1579 km^2)	55.52 (37.05 - 83.58)	175 (117 - 264)	224,630 (151,520 - 334,270)	176 (119 - 262)

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