Heat sensors in Bardiya National Park

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Heat stress and ongoing research in Bardiya N.P.

The PhD candidate Mr. Shyam Thapa has been collecting information on grass quality, the distribution of the vegetation, and landscape of fear to understand the distribution and numerical abundance of deer (mainly chital) as prey for tiger in Bardiya NP. The ultimate aim of this work, apart from the contribution to conservation science, is to provide information to manage the Park and its wildlife. The work focuses on tall grass and its inability to provide fodder sufficiently, and the distribution of the deer over the different vegetation types to better understand the utility to allow deer to feed. An important additional consideration is that the activity of the deer, and their distribution over the park appears to be strongly governed by the temperatures they experience. Coupled to the increasing concerns of the effects of heat waves on wildlife, expected to further increase in frequency, intensity and duration due to climate change, a need to link information on temperature and heat stress to the existing research agenda has been identified. Knowledge of this will increase the capacity for management by the DNPWC and for advice by NTNC.

Heat stress for tigers and black globes

A severe threat for the long-term survival of Nepal's rare large mammals is the increase of air temperatures due to climate change in the period when the monsoon builds up and air humidity is highest. Indeed, a relative air humidity (RH) of only 80% but a temperature (T) above 34 ^{o}C is already extremely dangerous to human life (Fig. 1). The so-called discomfort index (DI) is calculated as DI = T -0 0.55 * (1 – 0.01 RH) * (T – 14.5) in which T is in ^{o}C and RH in %. The average temperature of the Indian sub-continent has risen already 0.7 ^{o}C since 1900, and is projected to increase another 4.4 ^{o}C till 2100; even more worrying is that the frequency of heat was is projected to increase 3- to 4-fold while average heat wave duration is expected to double (Krishnan, R., et al. [2020]. Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India).

Climate change models predict a rather fast increase in temperature for northern India and the Terai of Nepal. During recent years, every monsoon there is an increase in fatalities due to heat stroke, and particularly neonates pass away in increasing numbers in hospitals. Little is known of fatalities amongst wild mammals or birds. Reports from India till now focus on drowning during flooding events and reduced milk production as effect of heat (Sirohi & Michaelowa 2004 https://www.researchgate.net/publication/226241280_Sufferer_and_cause_Indian_livestock_and_climate_change) but thousands of cattle perished during heat waves in Australia and the USA (Lees et al. 2019: Animals 2019, 9, 322; doi:10.3390/ani9060322). Also or cattle, a heat stress index is available (see Jeelani et al. 2019: https://doi.org/10.1016/j.jtherbio.2019.03.017) which shows major effects if that index is higher than 80 with formula HS = $(1.8*T^{o}C+32)-((0.55-0.0055*RH)*(1.8*T^{o}C-26.8))$. Because their physiology is different from that of people, the stress index is different.

- Caution
- Extreme Caution
- Danger
- Extreme Danger

	temperature (°C)																
Relative Humidity (%)	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
40	27	28	29	30	31	32	34	35	37	39	41	43	46	48	51	54	57
45	27	28	29	30	32	33	35	37	39	41	43	46	49	51	54	57	
50	27	28	30	31	33	34	36	38	41	43	46	49	52	55	58		
55	28	29	30	32	34	36	38	40	43	46	48	52	55	59			
60	28	29	31	33	35	37	40	42	45	48	51	55	59				
65	28	30	32	34	36	39	41	44	48	51	55	59					
70	29	31	33	35	38	40	43	47	50	54	58						
75	29	31	34	36	39	42	46	49	53	58							
80	30	32	35	38	41	44	48	52	57								
85	30	33	36	39	43	47	51	55									
90	31	34	37	41	45	49	54										
95	31	35	38	42	47	51	57										
100	32	36	40	44	49	54											

Heat stress Index (ºC)	Category	Dangers
27–32	Caution	Fatigue possible with prolonged exposure and/or physical activity
32–41	Extreme caution	Sunstroke, heat cramps and heat exhaustion possible with prolonged exposure and/or physical activity
41–54	Danger	Sun stroke, heat cramps or heat exhaustions likely, and heatstroke possible with prolonged exposure and/or physical activity
Above 54	Extreme danger	Heat/sunstroke highly likely with continued exposure

Figure 1. Human heat index table and broadly corresponding health impacts (National Weather Services, 2014. Beat the Heat Weather Ready Nation Campaign. National Oceanic and Atmospheric Administration. This may serve as an indication how mammals like tigers, rhino and primates could be affected (see text).

Humans can better cope than many mammals with heat because of their copious sweating ability, their bare skin, and their many behavioural adaptations including the building of fans or air conditioning. These options are not available to wild mammals. They can try to achieve evaporative cooling in shaded, windy areas or by immersing in waterbodies that have temperatures lower than about 34 degrees C. Ruminants (such as deer) can cope relatively well with high temperatures because of specialized arteries cooling the brain, which horses, rhinos, tigers and humans do not have. In ruminants, arterial blood is cooled in the nasal cavity through evaporative cooling from where the arterial blood flows to the brain. This cooling in the nasal cavity is not possible at high relative humidity of the air. Deer are also known to cool by licking their coat: whence evaporative cooling is possible (by standing on exposed places to pick up wind) if the relative air humidity is low. Tigers do not have a well-developed arterial cooling system for their brain, so high temperatures can become more easily fatal for them then for deer. They can achieve evaporative cooling by wetting their fur if the relative humidity is low. And, like rhinos, they can achieve cooling by immersing in water under the condition that this water is some degrees cooler than their body temperature. However, during a prolonged heat wave, small standing water bodies become too warm if the relative humidity is high or if irradiation is high (see for formulas: Losordo & Piedrahita 1991 *Ecological modelling 54*, 189-226) and they have to find flowing water. Yet even from zoo studies, little is known yet about the thermal requirements of tigers (see Stryker, J. A. (2016). Thermoregulatory behaviour assessment and thermal imaging of large felids. PhD. Thesis University of Guelph) but prolonged temperatures above 37 ^{o}C in the shade with high relative humidity can be thought to be as dangerous to people as to tigers, but also to other mammals which all have a normal body temperature around 37 ^{o}C.

Because wild mammals in the present Anthropocene are confined to smallish protected areas, out of which they are not welcome due to crop damage or depredation on livestock and humans, there is an urgent need to investigate (a) the current heat load landscape, (b) the heat load landscape of areas close to the Terai reserves. Even though there is much discussion about ‘climate change’, of only a few mammals it has been shown that heat stress may limit their numbers and distribution; a rare study which shows this, is work on the elk (Lenarz, M. S., Nelson, M. E., Schrage, M. W., & Edwards, A. J. (2009). Temperature mediated moose survival in northeastern Minnesota. The Journal of Wildlife Management 73, 503-510). Yet given the rapidity of climate warming in northern India and the Terai, and the dangerous situations already occurring to people, it stands to reason to assume that tigers will be badly affected in the coming decades.

There are at present two important measuring systems in place all over Nepal, namely the series of weather stations that are maintained by Nepali authorities, and the temperature sensing satellites, e.g., of the European Union. Complex formulas that derive the air temperature from these satellite data are available but ground-truthing from Nepal is nearly absent (see J. Hooker, G. Duveiller & A. Cescatti [2018] A global dataset of air temperature derived from satellite remote sensing and weather stations. Scientific Data volume 5, Article number: 180246). Moreover, the satellites do not measure relative humidity. For temperature, there is an additional source of information, often overlooked, and that can be found in many cameras. Many cameras that are used as camera traps also have a thermometer, and that information is logged. However, the relation between camera temperature, air temperature and the temperature that animals and humans sense is not very clear.

The temperature that people and animals sense (‘feel’, ‘experience’) is measured inside so-called ‘black globes’. These are hollow copper spheres, painted black, to measure radiant temperature. The blackness is meant to make the globe work as a perfect black body (see, e.g., https://en.wikipedia.org/wiki/Black_body) that is in thermal balance with its surroundings. The ones we have used have a diameter of seven cm. Also animals, including naked humans, radiate and absorb energy as if they are black bodies regardless of skin colour.

Proposition – the aim

Because previous work in Bardiya National Park, we believe that this Reserve is ideally suited for calibrating equipment that is already in place (see below, under 3) but because of it abutting the Siwaliks, this Reserve has the physical propensity to be extended into the hills to mitigate for climate change. Finally, because the Warden has expressed his wish to investigate the lay-out and design of water holes over the Park, an understanding of the heat landscape and thermal stress is important.

Here we propose through the deployment of a number of black globes and some hygrometers in Bardiya N.P. and its surroundings to achieve the following:

1. Calibrate the European satellite data that measure the temperature in Nepal at a scale of 1 km x 1 km with ground data (see: https://sentinel.esa.int/web/sentinel/user-guides/sentinel-3-slstr/resolutions/spatial/1km). Please be ware that the long wave bands of the thermal bands necessitate a large-scale pixel size.

2. Calibrate the black globes with the official weather stations that Government maintains at (i) Karnali Chisapani, (ii) Rajapur, (iii) Babai Bridge, and (iv) Guleriya. There are no functioning weather stations in Bardiya NP (pers. comm. Shyam Thapa, November 2020).

3. Calibrate the thermosensors inside camera types that are deployed for camera trapping in Bardiya NP. In Bardiya, through the support of the Himalayan Tiger Foundation, three types of cameras for camera trapping are deployed, to wit: Reconyx HC500, Reconyx HF2 Hyperfire and Browning. Both Reconyx types have temperature sensors while the Brownings do not. In Bardiya NP, there are 20 cameras of the Reconyx HC500type and 22 of the Reconyx HF2 Hyperfire type.

4. Determine the heat stress index for different habitats of the Park at different times of the year as has been determined for people as for cattle (and to be used for tigers and deer).

The purpose:

1. To be able to extrapolate from the European satellite system's heat images the real air temperatures across the whole of Bardiya and beyond into the Siwaliks.

2. To be able to use all Reconyx cameras that are deployed in Bardiya NP or elsewhere as reliable heat sensors.

3. To better be able to map habitat suitability (and especially heat stress) for tigers and deer over the year for the whole of Bardiya and adjacent terrain.

4. To enable NTNC to pro-actively investigate the neighbouring Siwaliks (through remote sensing) that may become the “thermal refuge” for tiger and deer in future if the climate warms up further, and further to enable NTNC to advice the management of the existing Park considering the optimal allocation and design of pools and waterholes for creating “thermal refuges” within the Park.

5. To compare activity patterns of deer and tigers, such as detected by the vertical camera trap network, with the heat landscape, the heat phenology over the day and thermal stress indices as determined by the black globes and the hygrometers.

Implications for management and design of Bardiya National Park

There are two important implications of the outcome. The first is the long-term design of the boundaries of this National Park (and others in the Terai). The predicted climate change for India are just as relevant for that country as for the Terai of Nepal. Heat waves are projected to increase infrequency (3- to 4-fold) and the average one will last twice as long as the at present ones, and the average temperature will increase another 5.5 ^{o}C. The results of these measurements will allow the relevant authorities to investigate whether it is expedient to increase the parks’ boundaries into the hills. Since the decrease in temperature (the lapse rate) is 0.6 ^{o}C per 100 meter altitude gained, an increase in temperature due to climate change can be compensated with an increase in altitude of 900 m. Indeed, due the proximity of the Himalayas and its foothills, Nepal is one of the very few countries that can do adaptive management and as such can take a leading role in climate mitigation and nature conservation.

The second implication of this proposed investigation, is the increased understanding of the role of water holes for large mammals. These are not only for water provisioning to quench thirst, but also to enable tigers and rhinos to cool down during a heat wave. In the cattle industry, this is already getting attention (see, e.g., https://www.mla.com.au/contentassets/4517a8f3dd64489da503f1b0ee3b0a3b/flot.322_final_report.pdf) .

The number of black globes and hygrometers needed:

1. To adequately calibrate the 20 cameras of the Reconyx HC500type and 22 of the Reconyx HF2 Hyperfire type cameras, per camera type five are sufficient (so totally fourteen black globes). These should be stratified for habitat type (closed forest, gallery forest, etc.; see point 4 below).

2. To calibrate the black globes against professionally maintained weather stations (four government maintained stations), four black globes are sufficient.

3. To determine the average temperature in a 1 x 1 km pixel as measured by the European Sentinel satellite system, five black globes per pixel are reasonably needed, while five pixels are statistically satisfactory. This would lead to twenty-five black globes being needed, but this array can to a major extent overlap with the ten needed for # 1but not for #2 (they are too far removed from the others).

4. To adequately measure relative humidity, necessary for calculating the heat index as given in Figure 1, it would be highly desirable to have a number of hygrometers in different habitat types, namely, (i) near the Karnali in open riverine land, (ii) in the middle of a grassy plain (phanta), (iii) in the shade of a large tree on a phanta , (iv) in a forest edge, (v) in a riverine forest, (vi) in a Sal forest with much undergrowth, and (vii) in a Sal forest without undergrowth. Small hygrometer with internalized data loggers are available. Because relative humidity is critically dependent on the local temperature, each of these hygrometers should be accompanied by a black globe. Per habitat type this should be repeated ("*in duplo*") to account for variability.

The total number of black globes needed is thus 10 (for #1), 4 (for #2), 5 (for #3; i.e. 5 for the five midpoints of a square kilometre, and 2 x 7 (for #4) totalling 36. These will be of two types, namely, the simple black globes with sensors and loggers (22 pc.) and black globes with relative humidity sensors and loggers (14 pc.).

The simple black globes with sensors (iButton-type DS1925L) can store 125,440 time-stamped values, allowing for a high measurement frequency.

The black globes with relative humidity and temperature sensors (HOBO U23-001A) can store 21,000 time-stamped values allowing for a lower measurement frequency.

Costs:

- The price of a simple black globe, inclusive of data logger, is € 90/-; 22 black globes thus cost € 1980/-
- Import tax is 15% thus the tax for these 22 black globes is € 297/=
- Integrated black globes with hygrometers and loggers are € 170 per piece and14 are foreseen, thus € 2380/-
- Import tax is 15% thus the tax for the hygrometers is € 357/-
- Transport costs can be paid by WUR under mailing contract, thus € 0,00

Total costs: € 5014/=

Note #1: for the import of camera's into Nepal, a tax rate of 15% was charged by customs in Nepal. There is no export tax from the Netherlands. We assume that this rate will be applied again.

Note #2: The Himalayan Tiger Foundation presently supports wage costs of technicians, so the work to deploy these black globes and sensors is not thought to be a heavy burden on DNPWC and NTNC.

Deployment in Bardiya NP one year; afterwards to Nar Valley.

For an adequate measurement series, one full year is sufficient. After that, all black globes and hygrometers should be removed from Bardiya NP and be deployed in and around Nar Valley for the Snowleopard project of Ashok Subedi.

All data should be shared with Wageningen University. Publications must include staff of NTNC as co-author.