Rattanawat Chaiyarat*, Suriya Saengpong, Wanchai Tunwattana and Panisa Dunriddach

Habitat and food utilization by banteng (*Bos javanicus* d'Alton, 1823) accidentally introduced into the Khao Khieo-Khao Chomphu Wildlife Sanctuary, Thailand

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Abstract: This research evaluates habitat and forage use by a reintroduced population of endangered banteng (*Bos javanicus* d'Alton, 1823) in Khao Khieo-Khao Chomphu Wildlife Sanctuary, Thailand based on fieldwork conducted between November 2007 and September 2009. Thirteen banteng bred in Khao Kheow Open Zoo were accidentally introduced into the Khao Khieo-Khao Chomphu Wildlife Sanctuary in 1988. Forage species were identified by fecal analysis. The results from field study of showed that the population structure ratio among adults, juveniles and calves was 1:0.5:0.3, respectively. A multiple logistic regression habitat suitability model classified banteng as associated with mixed deciduous forest and agricultural areas (cassava and coconut), at low elevation, distant from human settlements. The kernel density estimate of area use for agriculture was 0.32 km^2, and for mixed deciduous forest the estimate was 10.75 km^2 and 6.2 km^2 in the dry and wet seasons, respectively. When the wet and dry seasons are combined, the total area use for agriculture was 0.35 km^2 and for mixed deciduous forest, it was 11.40 km^2. Twenty-three forage species were identified using a combination of fecal analysis and direct observation. Fecal specimens contained high levels of moisture and protein. Major risks to the feral banteng population are low genetic diversity, habitat destruction and poaching. These findings are important for possible translocations elsewhere.

Keywords: banteng; forage species; habitat selection; reintroduction.

***Corresponding author: Rattanawat Chaiyarat,** Wildlife and Plant Research Center, Faculty of Environment and Resource Studies, Mahidol University, Phuttamonthon, Nakhon Pathom, 73170, Thailand, e-mail: rattanawat.cha@mahidol.ac.th
Suriya Saengpong and Panisa Dunriddach: Khao Kheow Open Zoo, Zoological Organization of Thailand, Sriracha, Chonburi, Thailand
Wanchai Tunwattana: Ubonratchathani Zoo, Zoological Organization of Thailand, Muang, Ubonratchathani, Thailand

Introduction

Introductions, in which animals are translocated to areas outside their historic range, can contribute to restoration programs (Conant 1988) when the population and habitat of the animal has decreased in its historic range. The role of captive breeding and introduction programs that aim to augment or re-establish wildlife populations has increased dramatically (Griffith et al. 1989, Ebenhard 1995, Robert et al. 2015). Propagation and reintroduction techniques require an understanding of the fundamental ecological requirements and life history of the species concerned (Sarrazin and Barbault 1996, Robert et al. 2015) and the identification of appropriate areas for species introduction or restoration (Dobson et al. 1997, Shugart et al. 2001). Some examples of successful reintroductions of mammals are ibex (*Capra ibex ibex* Linnaeus, 1758) in Italy (Stüwe and Nievergelt 1991), reindeer (*Rangifer tarandus* Linnaeus, 1758) in Finland (Kojola et al. 1991), bison (*Bison bison* Linnaeus, 1758) in Canada (Charles and White 2001), Asiatic one horned rhinoceros (*Rhinoceros unicornis* Linnaeus, 1758) in India (Sinha et al. 2001), white rhinoceros (*Ceratotherium simum* Burchell, 1817) in Botswana (Tjibae 2002), elk (*Cervus canadensis* Erxleben, 1777) in the United States (Schneider et al. 2006) and gaur (*Bos gaurus gaurus* Smith, 1827) in India (Sankar et al. 2013). Reintroductions are more successful with adults than with young animals (Adcock et al. 1998).

Banteng (*Bos javanicus* d'Alton, 1823) (Family Bovidae) are short-haired bovid cattle with rufous-chestnut coats with a dark dorsal stripe in females and young. In mature males, the coat is blue-black or dark chestnut in color. Both sexes have white "stockings" on their lower legs, a white rump, a white muzzle and white spots above the eyes in some subspecies viz *Bos javanicus javanicus* with dark brown-back pelage color, *Bos javanicus birmanicus* with a brown pelage and heavy-set facial features, and *Bos javanicus lowi* with very dark pelage coloration and stout compact body size (Gardner 2014, Matsubayashi et al. 2014, Ishige et al. 2016).The horns of females are short and tightly curved, pointing inward at the tips. Their build is trim and distinctly recalls that of domestic cattle (*Bos taurus indicus* Linnaeus, 1758). Bulls may attain a weight of 600 kg to 800 kg, while females range from 590 kg to 670 kg (Lekagul and McNeely 1977). Their average lifespan in the wild is 11 years, although it is common for captive banteng to live into their late teens and they may reach 20–25 years (Lekagul and McNeely 1977, Gardner et al. 2016). They are distributed in Cambodia, Indonesia (Bali, Jawa, Kalimantan), Laos People's Democratic Republic, Myanmar, Vietnam and Thailand (Gardner et al. 2016). The global wild banteng population is estimated at approximately 8000 individuals (Gardner et al. 2016). The wild banteng population in eastern Cambodia was estimated at between 2700 and 5690 individuals (Phan and Gray 2010, Gray et al. 2012), and only *circa* 470 in Thailand (Srikosamatara 1993, Srikosamatara and Suteethorn 1995) although the latter population has increased since then in its primary stronghold in Thailand's Western Forest Complex (Trisurat et al. 2010). Banteng in Thailand avoid evergreen rainforest and usually reside in more open dry deciduous forests (Phan and Gray 2010), but in the more humid areas of Java and Borneo, they occupy primary forest and secondary forest formations that have resulted from logging and fires, and enter tracts of sub-humid forest on occasions (Wharton 1968) as well as beaches and freshwater swamps. The predominant habitat type in Sabah is tropical lowland dipterocarp forest (Gardner et al. 2014).

Banteng is listed as globally endangered by the IUCN Red List of Threatened Species (Gardner et al. 2016), but is not listed in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Gardner et al. 2016). In Thailand, banteng is fully protected under the Reserved and Protected Animals Act, B.C.2535 (Lekagul and McNeely 1977), but remains threatened by habitat loss and degradation (Srikosamatara 1993, Prayurasiddhi 1997), commercial hunting for the wildlife trade (Srikosamatara and Suteethorn 1995) and diseases transmitted by domestic cattle (*Bos taurus* and *Bos indicus*) in the few protected areas where they still occur (Chaiyarat and Srikosamatara 2009). Active interbreeding in captivity to develop the livestock industry and accidental hybridization in the wild between banteng and domesticated cattle may reduce the purity of the genetic status of both the wild and captive populations (Purwantara et al. 2012).

Thirteen banteng in enclosures of the Khao Kheow Open Zoo, Chonburi, Thailand escaped into the adjacent forest areas of Khao Khieo-Khao Chomphu Wildlife Sanctuary in 1987 (Prakobphon 1988) before any reintroduction program had started. To our knowledge no study was ever mounted to investigate how the banteng have since adapted to their new environment, although their use of forest areas was noted anecdotally by a keeper from the Open Zoo. The present study aimed to investigate the recovery potential of these escaped banteng as a sample model for future reintroduction programs to promote the conservation of this endangered bovid.

Materials and methods

Study area

The study was carried out with permission from the Department of National Parks, Wildlife and Plant Conservation, Thailand in Khao Khieo-Khao Chompu Wildlife Sanctuary (13°14′45″N 101°4′15″E, area: 144.7 km^2) and the adjacent Khao Kheow Open Zoo (total area: 8 km^2), administered by the Zoological Parks Organization of Thailand, in Muang and Sriracha Districts, Chonburi Province (Figure 1). Roughly half (71.6 km^2; 49.5%) of the total area lies at elevations ranging from 220 m to 550 m. The average annual temperature was 29.1°C with an average rainfall of 1299 mm/year, most of which fell during the wet season between June and September (Royal Forest Department 2002). The habitat composition comprises mixed deciduous forest (37.5%), dry evergreen forest (51.6%), agricultural area (cassava and coconut; 6.3%), grassland (2.1%), secondary forest (2.2%) and water sources (0.3%) (Figure 1). The dominant trees were *Pterocarpus macrocarpus*, *Xylia xylocarpa*, *Canarium subulatum*, *Anogeissus acuminata*, *Garuga pinnata* and *Schleichera oleosa* (Royal Forest Department 2002).

Methodology

Thirteen banteng (two males and 11 females) were successfully bred in the zoo from one pair obtained from the Western Forest Complex of Thailand in Khao Kheow Open Zoo. They were kept in a 320 ha enclosure and fed beef cattle food, grasses and sweet potato and allowed to graze on natural vegetation in their enclosure. Artificial salt-licks were provided as supplemental nutrition (Prakobphon 1988). In 1987, all of these banteng escaped from the enclosure into the adjacent forest. Our observations were made between November 2007 and September 2009, some 20 years after this introduction to Khao Khieo-Khao Chompu Wildlife Sanctuary.

A non-invasive method was employed to analyze the population structure of the banteng. New tracks of banteng were searched twice a week every 2 weeks between

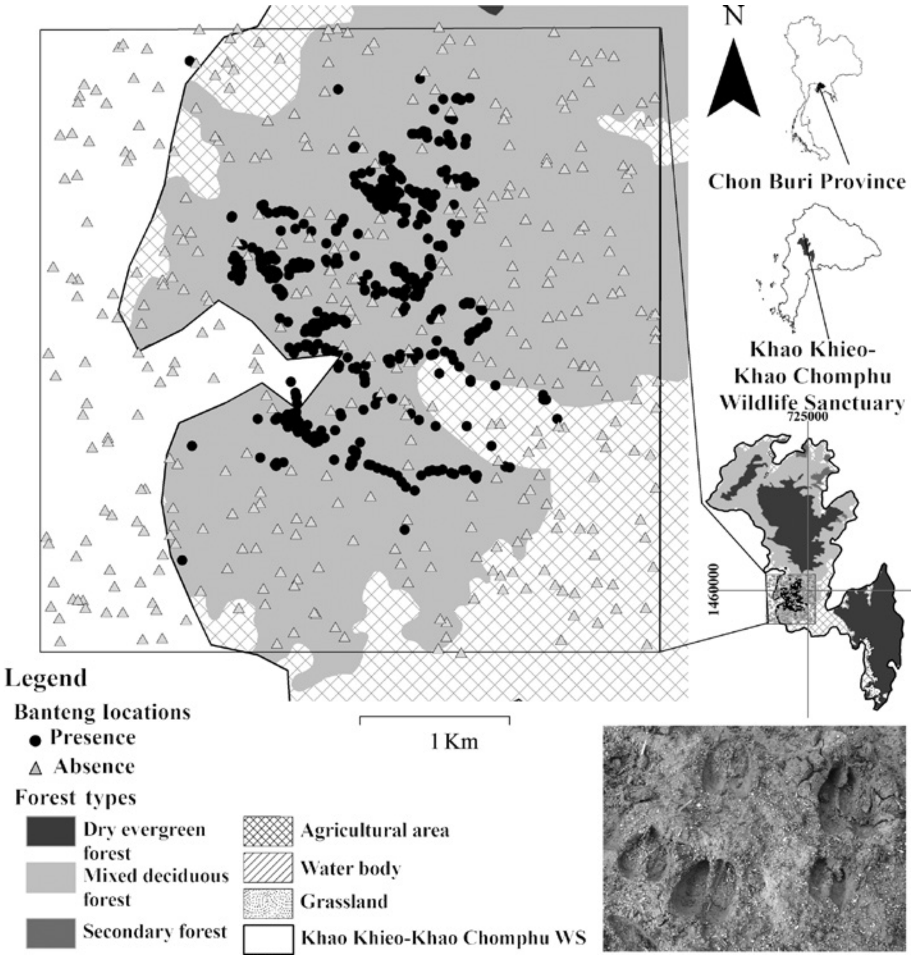

Figure 1: Location of a presence and absence of accidentally introduced banteng from 1210 random points and the forest types of Khao Khieo-Khao Chompu Wildlife Sanctuary, Thailand.

November 2007 and October 2008. We estimated the herd size and age of each individual and population structure by measuring complete hoof prints (Jewell and Alibhai 2013). The maximum length and breadth of each hoof print were measured internally on the depressed earth or mud so as to reduce measurement errors. The ratio between fore- and hind-hooves of new tracks was compared with the tracks of banteng of a known age class still in captivity at the Khao Kheow Open Zoo (Table 1). Three age classes were recognized: calves (<12 months), juveniles (>1–2.5 years) and adults (>2.5 years) (Lekagul and McNeely 1977, Prayurasiddhi 1997). Each ratio was counted as an individual to reduce over counting the same individual multiple times. In combination with an examination of photographs this enabled the minimum number of banteng of each age class to be estimated. Domestic cattle and gaur were absent from areas used by banteng so there was no possibility of confusion over the identity of hoof prints.

Habitat utilization was calculated using a combination of field observations between November 2007 and October 2008 and geographic information system (GIS) habitat modeling was analyzed in 2009. Multiple logistic regression models were fitted to study the habitat attributes associated with the presence and absence (Fielding and Haworth 1995) of banteng.

A total of 1210 randomly allocated points were selected in the area known to be used by banteng (17.2 km) using digital map (slope, average sea level, water source, human settlement, aspect and forest type layers) of Khao Khieo-Khao Chompu Wildlife Sanctuary (Royal Forest Department 2002). The position of the directly observed animals and their signs (fresh complete hoof prints, resting sites, dung and feeding sites) were recorded with a global positioning system (GPS) and their locations were imported into a digital map. Habitat composition was analyzed from land use layers (human settlement and forest type) of the Khao Khieo-Khao Chompu Wildlife Sanctuary digital map (Royal Forest Department 2002). After successive processes to determine important characteristics of feature attributes and eliminate unwanted details and

Table 1: Ratio between fore- and hind-hooves of banteng of a known age class in captivity, unknown age class of accidentally introduced banteng and population structure from tracks (n = 55) in Khao Khieo-Khao Chompu Wildlife Sanctuary (KKKC), Thailand.

Age class (year)	Hoof print size (cm)							Estimated of accidentally introduced banteng in KKKC (cm)	
	Fore-hoof			Hind-hoof			Distance between fore and hind-hoof	Number	Population structure
	Width	Length	Ratio	Width	Length	Ratio			
Calf (<1)									
Known age (cm)[a]	8	9	<0.9	7.5	8	<0.8	45		
Unknown age (cm)[b]	7.9 ± 1.2	9.2 ± 1.1	0.9 ± 0.5	7.2 ± 1.1	8.9 ± 1.1	0.8 ± 0.0	46.7 ± 9.3	6	0.3
Juvenile (>1–2.5)									
Known age (cm)[a]	9	10	>0.90	8.5	9	>0.9	53		
Unknown age (cm)[b]	10.1 ± 0.7	11.2 ± 0.7	0.9 ± 0.2	9.2 ± 0.6	10.1 ± 0.7	0.9 ± 0.0	53.3 ± 11.1	9	0.5
Adult (>2.5–15)									
Known age (cm)[a]	11.2–11.5	12–12.5	>0.90	10	11.9	>0.9	58–60		
Unknown age (cm)[b]	10.9 ± 0.9	11.8 ± 0.9	0.9 ± 0.2	9.7 ± 0.8	10.7 ± 0.8	0.9 ± 0.0	61.2 ± 10.3	19	1
Total								34	
Kruskal-Wallis (χ^2)[c]	17.93	16.37	27.50	16.91	15.27	21.52	9.29		
p-Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		

[a]Known age class of captive banteng in Khao Kheow Open Zoo.
[b]Unknown age class of accidentally introduced banteng of Khao Khieo-Khao Chompu Wildlife Sanctuary.
[c]Kruskal-Wallis test for unknown age class of accidentally introduced banteng of Khao Khieo-Khao Chompu Wildlife Sanctuary.

classification of data into classes, land use maps were resampled to a 30 m pixel resolution [30 m UTM pixel, ArcGIS 9.3 (ESRI 2007)] for slope (%), elevation (average sea level; m), distance from water source (m), distance from human settlement (km), aspect and forest type [mixed deciduous forest, dry evergreen forest, agricultural area (cassava and coconut), grassland, secondary forest]. Data on topography were obtained from a digital elevation model generated by the Royal Forest Department (2002) from 1:50,000 topographic maps. The digital elevation model was used to generate slope and then resampled to a 30 m pixel resolution (Table 2). These parameters were used to estimate the distance between parameters in each pixel and each banteng observation point. The habitat parameters were imported into the R program (R Core Team 2016) for multiple logistic regression analysis and model fit statistics. The optimum values for these parameters were decided when the classification error rate was minimized. The best model was selected using Akaike's information criterion (AICs) (Akaike 1973) adjusted for small sample sizes (Burnham and Anderson 2004). The used-versus-unused design and standard logistic regression validation techniques were used, including confusion matrices, Kappa statistic and receiver operating characteristic (ROC) curves (Boyce et al. 2002). Backward model selection began with all candidate variables included; each variable was then removed, one at a time; and the model fit was assessed (Burnham and Anderson 2004).

The kernel density estimate (KDE) boundaries on the innermost 95% of the 817 presence data points were used to estimate the area use (Seaman et al. 1999) of the banteng. The model derived from this equation was used to create an area use map in ArcGIS 9.3.

Observations on diet were made along animal trails in order to identify grazed areas between November 2007 and October 2008 and analyzed in 2009. The species of plants grazed, plant characteristics (grasses, shrubs, trees, etc.), parts consumed and utilization period (time of observation) were noted. Field identification of species was made according to Radanachaless and Maxwell (1994). Species that could not be identified in the field were brought to the Royal Forest Department's Herbarium for subsequent identification. Scientific names of the forage species followed Smitinand (1980).

Fecal analysis was undertaken to confirm the banteng forage species consumed and to determine their relative frequency in the diet. Fecal analysis also helped to complete the plant species list as it was not always possible to identify from field observations all the forage species eaten by the banteng. Fecal analysis followed the methodology suggested by Anthony and Smith (1974). Samples were obtained only from the middle of fresh feces to ensure no contamination by plant or soil material, and 100 g per sample was analyzed. The samples (<1 month after collection) were washed by straining the material through running water. Samples were bottled and boiled for 30 min after which 5

Table 2: Environmental factors for multiple logistic regression models predicting habitat suitability of accidental introduction of banteng from 1210 random points in the study area of Khao Khieo-Khao Chompu Wildlife Sanctuary, Thailand.

Environmental factor	Frequency (%)	
	Presence	Absence
Slope (%)		
0–10	52.1	76.1
10–20	35.5	12.5
20–30	2.6	5.2
31–40	9.7	3.8
41–50	–	1.9
51–60	–	0.3
61–70	–	0.3
>71	–	–
Elevation (m)		
60–100	8.1	25.8
101–200	78.0	59.2
201–300	11.9	8.7
301–400	2.0	6.3
>401	–	–
Distance from water (m)		
0–100	31.6	22.6
101–200	27.1	18.2
201–300	24.7	20.1
301–400	13.4	15.8
401–500	3.1	8.2
501–600	0.1	3.5
601–700	–	4.6
701–800	–	4.1
801–900	–	1.9
901–1000	–	1.1
Distance from human settlement (km)		
0.1	0.1	12.2
1.1–2	12.0	20.7
2.1–3	72.5	50.0
3.1–4	15.1	16.9
4.1–5	0.4	0.3
>5	–	–
Aspect		
North	12.6	18.8
East	–	0.3
South	37.3	12.8
West	17.1	10.9
No aspect	33.0	48.9
Forest type		
Mixed deciduous forest	97.3	61.1
Dry evergreen forest	–	–
Grassland	–	–
Secondary forest	–	–
Agricultural area	2.7	38.9

cc of nitric acid was added before boiling for further 15 min. This process aided the separation of tissue fibers exposing epidermal cells. After cooling, 5 cc of formalin was added to each sample to preserve the specimens.

Fecal epidermal cell slides were prepared by taking one piece of plant tissue from each bottled sample, spreading it on the slide, adding a drop of xyline and covering the sample with a cover-slip. Ten slides from each dung sample were prepared this way to represent the variety of species present in any one sample.

A reference epidermal cell plant species slide collection (trees, herbs and grasses) was prepared for plants collected in the field. These were compared with epidermal cells from the fecal slides under a microscope. Documents prepared by Prayurasiddhi (1999) also aided the identification. Additional notes were made on whether the species was a monocotyledon or dicotyledon. The presence of seeds was also noted.

The frequency of individual forage species consumed (RF) was calculated as follows:

$$RF = (\text{Total number of times species observed in dung samples / Total number of dung samples}) \times 100 \quad (1)$$

Ten samples of the most commonly consumed dietary items based on RF were collected from banteng feeding areas. The new shoots were collected and sent to Khao Kheow Open Zoo Animal Nutrition Laboratory for plant nutrient value analysis. Information was sought on the moisture content, crude protein, ash, crude fiber, fat, potassium and calcium. Analysis of carbohydrates was not possible.

Results

Population structure

Since their escape, the banteng have increased from 13 individuals to at least 34. Fifty-five fresh complete hoof prints could be classified into appropriate age categories. Most hoof prints were identified as adults. The population structure ratio among adults (19), juveniles (9) and calves (6) was 1:0.5:0.3, respectively (Table 1).

Habitat utilization

A total of 1210 randomly observed points comprised 817 points with signs of banteng and 393 points with no signs of banteng (neither gaur nor domestic cattle were present in the study area). The model coefficient in both step 1 (ΔAICs = 17.591) and step 2 (ΔAICs = 24.781) of multiple

Table 3: Multiple logistic regression models predicting habitat suitability of accidental introduction of banteng from 1210 random points in Khao Khieo-Khao Chompu Wildlife Sanctuary, Thailand.

Model set	ΔAICs	Nagelkerke R^2	Parameter	Coefficient	SE	Wald statistic	p-Value
Step 1[a]	17.591	0.373	Slope	0.028	0.01	8.268	0.004
			Elevation	−0.008	0.002	25.537	<0.0001
			Forest type	−2.903	0.27	115.268	<0.0001
			Aspect	0.086	0.071	1.466	0.226
			Human	0	0	15.055	<0.0001
			Water	−0.003	0.001	30.458	<0.0001
			Constant	4.612	0.567	66.269	<0.0001
Step 2	24.781	0.372	Slope	0.021	0.008	7.623	0.006
			Elevation	−0.007	0.001	26.197	<0.0001
			Forest type	−2.86	0.267	114.936	<0.0001
			Human	0.001	0	15.991	<0.0001
			Water	−0.003	0.001	32.953	<0.0001
			Constant	4.773	0.552	74.668	<0.0001

The models reported here were the best models for each model set as indicated by Akaike's information criterion (AICs) values and selected from all possible models using the predictor parameters of distance from slope, elevation, forest type, aspect, human and water source.
[a]Variable(s) entered on step 1: slope, elevation, forest type, aspect, human, water source.

logistic regression showed that suitable habitats of banteng were lower elevation ($\beta=-0.008\pm0.002$, $p\leq0.0001$), specific to mixed deciduous (795 points) and agricultural areas (22 points) ($\beta=-2.903\pm0.27$, $p\leq0.0001$), near water sources ($\beta=-0.003\pm0.001$, $p\leq0.0001$), but far from human settlements ($\beta\leq0.000\pm<0.000$, $p\leq0.0001$). The aspect was not significantly different ($\beta=0.086\pm0.071$, $p=0.226$) (Tables 2 and 3). The model fit statistics (ROS plot) gave an area under the curve (AUC) score of 0.78 in all models (Table 4 and Figure 2).

The 817 detection points comprising 496 points from the dry season and 321 points from the wet season were used to calculate the dry season and wet season area use, respectively. Kernel density estimates for area use were 11 km^2 (agriculture area = 0.25 km^2, mixed deciduous forest = 10.75 km^2) in the dry season and 6.2 km^2 mixed deciduous forest in the wet season. When combined between wet and dry seasons, the total area use was 11.75 km^2 (agriculture area = 0.35 km^2, mixed deciduous forest = 11.40 km^2) (Figure 3). The agricultural area was illegally used as a cassava and coconut plantation.

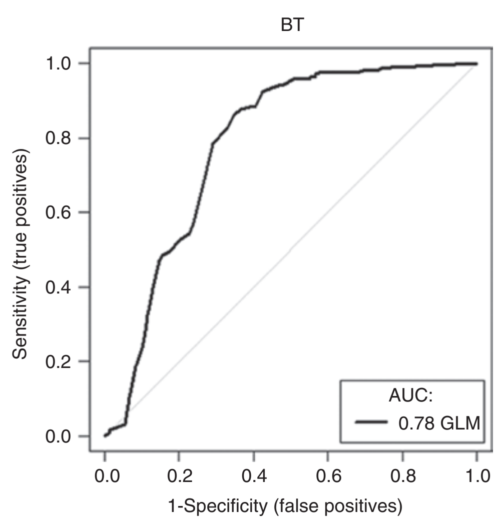

Figure 2: Receiver operating characteristic (ROC) curve plot with evenly spaced thresholds marked along the ROC curves and area under the curve (AUC) for banteng habitat suitable model.

Table 4: Overall prevalence (from all 1210 points), area under the curve (AUC) from the receiver operating characteristic (ROC) plot and range of kappa values for banteng habitat suitability model.

Model	Threshold	PCC	Sensitivity	Specificity	Kappa	AUC
1	0.00	0.70	1.00	0.00	0.00	0.78
2	0.10	0.76	0.99	0.23	0.29	0.78
3	0.20	0.78	0.99	0.32	0.38	0.78
4	0.30	0.80	0.98	0.38	0.44	0.78
5	0.40	0.80	0.97	0.41	0.45	0.78
6	0.50	0.81	0.97	0.45	0.48	0.78
7	0.60	0.82	0.94	0.54	0.52	0.78
8	0.70	0.80	0.87	0.62	0.51	0.78
9	0.80	0.65	0.59	0.78	0.31	0.78
10	0.90	0.40	0.16	0.95	−0.07	0.78
11	1.00	0.30	0.00	1.00	0.00	0.78

Diet

Banteng are browsers rather than grazers. Seven species of grasses (30.4%), including *Melientha repens*, *Leptochloa*

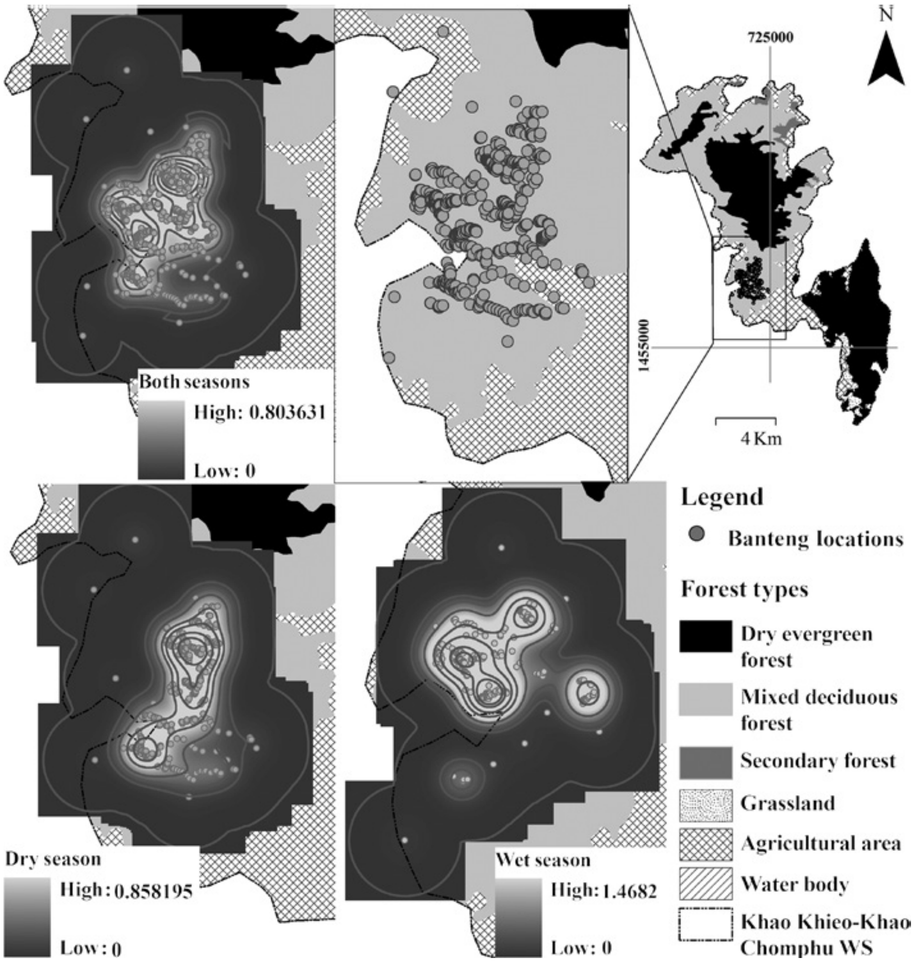

Figure 3: Kernel density estimates for area use were 11 km^2 in the dry season and 6.2 km^2 in the wet season with a total area use of 11.75 km^2 in Khao Khieo-Khao Chompu Wildlife Sanctuary, Thailand.

chinensis and *Imperata cylindrica*, six species of trees (26.1%) including *Ficus racemosa* and *Spondias bipinnata*, five species of herbs (21.7%) including *Celosia argentea*, *Sphaerantus africanus* and *Commelina benghalensis*, three species of shrubs, *Aeschynomene americana*, *Manihot esculenta* and *Clerodendrum paniculatum* (13%) and two species of climbers, *Dioscorea hipida* and an unknown species (8.7%), were fed upon in the mixed deciduous forest and agricultural area. Species identification was not always possible. Banteng diets varied between seasons with fewer forage species being consumed during the dry season (nine species) and 20 species during the wet season (Table 5).

Fecal analysis

One hundred and ninety-seven fresh banteng fecal specimens (134 in the wet season and 63 in the dry season) were obtained from mixed deciduous forest and agricultural areas. Among 23 diet species observed by direct observation seven species of grasses, five species of herbs and three species of tree seedlings were also identified from fecal sampling. During the wet season 11 species of plants were found in fecal matter, whereas in the dry season only five species were found. Five unknown species were most often eaten during the wet season (RF = 79.7%), while *Imperata cylindrica* was eaten in the dry season (RF = 55.2%) more frequently than in the wet season (RF = 17.9%). Five unknown species contributed significantly to diet in both seasons (RF = 79.4% in the wet and 17.9% in the dry season) (Table 5).

Food quality assessment

The 23 forage species noted during direct observation which were sampled contained high levels of moisture

Table 5: Forage species, characteristics, parts utilized and relative frequency in diet from field observations and in dung of accidentally introduced banteng in Khao Khieo-Khao Chompu Wildlife Sanctuary, Thailand.

Family	Scientific name	Plant	Utilization	Relative frequency of eaten (%)		Relative frequency in dung (%)	
		Characteristics[a]	Part[b]	Dry	Wet	Dry	Wet
Gramineae	*Melinis repens* (Willd.) Ziska	G	YL	–	7.3	–	–
Gramineae	*Axonopus compressus* (Sw.) Beauv.	G	YL	–	4.9	0.8	–
Gramineae	*Panicum repens* L.	G	YL	–	4.9	–	–
Gramineae	*Leptochloa chinensis* (L.) Nees	G	YL	–	4.9	0.8	–
Gramineae	*Pennisetum pedicellatum* Trin.	ExG	YL	26.1	14.6	10.4	–
Gramineae	*Imperata cylindrica* (L.) P.Beauv.	ExG	YL	26.1	9.8	55.2	17.9
Gramineae	*Brachiaria mutica* (Forssk.) Stapf	ExG	YL	8.7	7.3	–	–
Compositae	*Sphaeranthus africanus* L.	H	YL	–	4.9	0.8	1.6
Compositae	*Chromolaena odoratum* (L.) R.M.King *et* H.Rob.	ExH	YL	–	2.4	3	–
Commelinaceae	*Commelina bengalensis* L.	H	YL	–	2.4	–	–
Amaranthaceae	*Celosia argentea* L.	H	YL	4.4	–	0.8	1.6
Dioscoreaceae	*Dioscorea hispida* Dennst. var. *hispida*	CH	YL	4.4	4.9	–	–
Musaceae	*Musa acuminata* Colla	H	YL	4.4	7.3	1.5	0.7
Labiatae	*Clerodendrum paniculatum* L. var. *diversifolium* C.B.Clarke	S	YL	–	2.4	–	–
Papilionoideae	*Aeschynomene americana* L.	ExS	YL	–	2.4	–	–
Euphorbiaceae	*Manihot esculenta* Crantz	ExS	YL	13	4.9	5.2	1.6
Anacardiaceae	*Spondias bipinnata* Airy Shaw *et* Forman	T	F	8.7	–	–	–
Moraceae	*Ficus racemosa* L.	T	YL	4.4	–	3.7	3.5
	Unknown species 1	T	F	–	2.4	–	–
	Unknown species 2	C	YL	–	2.4	–	–
	Unknown species 3	T	YL	–	2.4	–	–
	Unknown species 4	T	YL	–	2.4	–	–
	Unknown species 5	T	YL	–	4.9	17.9	79.4

[a]Plant characteristics: G, grass; ExG, exotic grass; H, herb; CH, climber herb; ExH, exotic herb; S, shrub; ExS, exotic shrub; T, tree; C, climber.
[b]Utilization parts: YL, young leaves; F, flowers.

and protein. This was especially true for *Celosia argentea* (protein 19.1%), *Manihot esculenta* (protein 18.5%) and *Aeschynomene americana* (protein 18.3%), while grass species ranged between 7% and 13% protein. Lipid, phosphorus and calcium were low in all dietary items assayed (Table 6).

Discussion

During their prior period of captivity, the banteng were intensively checked for diseases, underwent general medical checkups and received minimal human contact (Prakobphon 1988) as recommended for megaherbivores by IUCN/SSC Reintroduction Specialist Group (Soorae 2010). This was ultimately advantageous for them when they were accidentally introduced into the wild, as they were healthy and able to adapt to their new environment.

The increase in the population (from 13 individuals to 34 individuals) was not high compared to Indonesian banteng introduced in Lam Pao Wildlife Conservation Development and Promotion Station, Kalasin province, Thailand, which increased from one male and three females in 1975 to 70 individuals after 30 years (Saijuntha et al. 2013). The ratio of adults to calves (1:0.3 in this study) was low compared with the population structure of wild banteng (1:1.5–2) in Huai Kha Khaeng Wildlife Sanctuary (Prayurasiddhi 1997). The ratio indicates a very low reproductive rate in the Khao Khieo population, lower even than that found in Baluran National Park, Indonesia (cow:subadult; 1:0.67) (Pudyatmoko et al. 2007).

The habitat suitability model in both step 1 and 2 showed the same trend, the accidentally reintroduced banteng selected lower elevations, mixed deciduous and agricultural areas, near water sources, but far from human settlements. The AUC from the ROC plot was equal (AUC = 0.78) in all models, step two model at sensitivity of 0.99 was optimum (Asaoka et al. 2016). A similar habitat preference was found in wild populations of banteng in Thailand (as in Huai Kha Khaeng Wildlife Sanctuary where they mostly inhabited mixed deciduous forest;

Table 6: Food quality of banteng from all dietary habits observed in the field at Khao Khieo-Khao Chompu Wildlife Sanctuary, Thailand (n = 10).

Scientific name	Food quality (%)						
	Moisture	Crude protein	Ash	Crude fiber	Lipid	Phosphorus	Calcium
Melinis repens (Willd.) Ziska	81.6 ± 0.2^{h}	10.2 ± 0.3^{hi}	12.6 ± 0.2^{l}	17.9 ± 0.7^{i}	0.7 ± 0.4^{bcd}	0.5 ± 0.6^{hij}	0.2 ± 0.3^{a}
Axonopus compressus (Sw.) Beauv.	80.6 ± 0.1^{f}	9.5 ± 1.5^{gh}	13.1 ± 0.5^{m}	20.1 ± 0.4^{kl}	1.3 ± 0.3^{fg}	0.4 ± 0.5^{lfgh}	$0.6 \pm 0.^{def}$
Panicum repens L.	82.6 ± 0.8^{j}	13.0 ± 0.8^{j}	7.9 ± 0.3^{h}	18.1 ± 0.3^{i}	0.8 ± 0.0^{bcd}	0.6 ± 0.5^{k}	0.5 ± 0.5^{d}
Leptochloa chinensis (L.) Nees	79.7 ± 0.2^{d}	8.9 ± 0.8^{f}	6.9 ± 0.2^{g}	17.5 ± 0.4^{i}	0.8 ± 0.2^{bcde}	0.4 ± 0.1^{efghi}	0.2 ± 0.2^{b}
Pennisetum pedicellatum Trin.	83.2 ± 0.2^{k}	6.3 ± 0.4^{e}	5.9 ± 0.2^{e}	19.6 ± 0.2^{ijk}	0.7 ± 0.5^{abcd}	0.5 ± 0.0^{hijk}	3.0 ± 0.5^{p}
Imperata cylindrica (L.) P.Beauv.	82.3 ± 0.3^{j}	7.0 ± 0.2^{e}	4.6 ± 0.3^{c}	18.1 ± 0.1^{i}	0.7 ± 0.5^{abcd}	0.3 ± 0.5^{efg}	2.5 ± 0.4^{q}
Brachiaria mutica (Forssk.) Stapf	68.1 ± 0.1^{a}	8.4 ± 0.3^{hi}	4.6 ± 0.1^{de}	15.3 ± 0.1^{ij}	1.6 ± 0.4^{i}	0.1 ± 0.0^{abc}	0.6 ± 0.2^{fg}
Sphaeranthus africanus L.	80.0 ± 0.3^{e}	14.6 ± 1.0^{k}	16.8 ± 0.1^{h}	15.9 ± 4.3^{h}	0.5 ± 0.5^{abc}	0.2 ± 0.2^{de}	1.9 ± 0.5^{o}
Chromolaena odoratum (L.) R.M.King *et* H.Rob.	80.2 ± 1.0^{e}	14.9 ± 0.7^{k}	7.1 ± 0.1^{g}	18.7 ± 0.2^{ij}	0.4 ± 0.1^{ab}	0.3 ± 0.1^{efg}	1.0 ± 0.5^{j}
Commelina bengalensis L.	81.0 ± 0.5^{g}	5.2 ± 0.2^{d}	13.4 ± 0.1^{m}	5.4 ± 0.8^{bc}	0.7 ± 0.5^{abcd}	0.5 ± 0.6^{igk}	1.7 ± 0.4^{n}
Celosia argentea L.	80.1 ± 0.5^{e}	19.1 ± 0.3^{n}	11.0 ± 0.5^{k}	19.0 ± 0.4^{jk}	0.7 ± 0.3^{bcd}	0.4 ± 0.6^{fghi}	1.1 ± 0.6^{l}
Dioscorea hispida Dennst. var. *hispida*	81.2 ± 0.1^{g}	0.8 ± 0.4^{e}	6.6 ± 0.1^{f}	6.77 ± 1.8^{de}	2.6 ± 0.2^{i}	0.3 ± 0.6^{ef}	1.6 ± 0.8^{n}
Musa acuminata Colla	83.5 ± 0.0^{l}	1.5 ± 0.0^{a}	1.3 ± 0.1^{a}	3.2 ± 0.4^{a}	0.3 ± 0.0^{a}	0.1 ± 0.1^{a}	0.1 ± 0.0^{a}
Clerodendrum paniculatum L. var. *diversifolium* C.B.Clarke	79.5 ± 0.6^{c}	10.3 ± 0.8^{i}	7.4 ± 0.1^{h}	7.4 ± 0.6^{ef}	2.6 ± 0.7^{i}	0.5 ± 0.5^{jk}	0.6 ± 0.5^{de}
Aeschynomene americana L.	83.1 ± 0.3^{k}	18.4 ± 0.3^{m}	5.4 ± 0.4^{d}	19.0 ± 0.8^{ij}	1.0 ± 0.2^{cdef}	0.4 ± 0.1^{ghi}	1.1 ± 0.2^{k}
Manihot esculenta Crantz	70.8 ± 0.1^{b}	18.5 ± 0.6^{o}	5.8 ± 1.7^{de}	18.3 ± 0.6^{l}	1.0 ± 0.1^{defg}	0.4 ± 0.0^{ijk}	0.6 ± 0.4^{ef}
Spondias bipinnata Airy Shaw *et* Forman	89.2 ± 0.0^{n}	3.2 ± 0.3^{b}	4.6 ± 0.3^{b}	15.0 ± 0.2^{h}	4.3 ± 0.1^{k}	0.1 ± 0.5^{ab}	0.5 ± 0.5^{c}
Ficus racemosa L.	86.1 ± 0.2^{m}	13.9 ± 0.2^{j}	20.6 ± 0.8^{o}	26.5 ± 0.2^{m}	1.9 ± 0.2^{hi}	0.4 ± 0.8^{efghi}	7.3 ± 0.4^{r}
Unknown species 1	70.6 ± 0.5^{cd}	3.8 ± 0.7^{c}	5.6 ± 0.3^{e}	4.4 ± 0.3^{b}	2.7 ± 0.7^{j}	0.2 ± 0.0^{bc}	0.8 ± 0.5^{h}
Unknown species 2	79.5 ± 0.5^{c}	10.3 ± 0.4^{i}	8.8 ± 0.2^{j}	10.3 ± 0.3^{g}	1.4 ± 0.2^{gh}	0.2 ± 0.5^{cd}	0.8 ± 0.5^{i}
Unknown species 3	80.4 ± 0.2^{f}	10.4 ± 0.0^{i}	8.3 ± 0.3^{i}	8.3 ± 0.3^{f}	1.2 ± 0.1^{efg}	0.2 ± 0.1^{bc}	0.7 ± 0.8^{gh}
Unknown species 4	80.1 ± 0.5^{e}	15.6 ± 0.9^{l}	5.7 ± 0.1^{e}	5.7 ± 0.0^{cd}	2.5 ± 0.2^{j}	0.3 ± 0.0^{de}	0.6 ± 0.5^{de}
Unknown species 5	81.9 ± 0.4^{i}	9.1 ± 0.6^{fg}	7.3 ± 0.6^{g}	7.3 ± 0.4^{ef}	1.5 ± 0.9^{gh}	0.1 ± 0.5^{ab}	1.4 ± 0.6^{m}
In-utero[a]	26.4	31.2	24.2	9.3	25.2	1.1	2.7

[a]Nutrient composition of nutrition *in-utero* (Yusuf et al. 2015). Means followed by a common letter in the same column for each food quality are not significantly different from each other using an LED test ($p > 0.05$).

Prayurasiddhi 1997). Although more than 50% of the Khao Khieo-Khao Chomphu Wildlife Sanctuary was closed canopy dry evergreen forest, this habitat was avoided (Wharton 1968). Mixed deciduous forest was limited and fragmented in and around Khao Khieo-Khao Chomphu Wildlife Sanctuary, contributing only 46.3 km^2 (32% of the total area) and including some agricultural areas, making the habitat overall less suitable. Low food quality may be the reason why the habitat areas used by banteng were larger in the dry season than the wet season, as found in translocated roe deer in a Mediterranean habitat (Carvalho et al. 2008).

Fecal analysis confirmed that banteng adapted well to the dietary environment of Khao Khieo-Khao Chomphu Wildlife Sanctuary, where the diet was broadly similar to that found by Prayurasiddhi (1997) for Huai Kha Kaeng Wildlife Sanctuary (leaves, grasses, herbs, bamboos and tree bark). Some dietary items, especially grass species, may be limited in the dry season (Chaiyarat 2002), when banteng change to browse more on dicotyledons. A similar switch to dicotyledonous herbs (during periods of water stress) was shown by introduced banteng in Australia (Bowman et al. 2010).

Almost all forage species eaten by banteng in Khao Khieo-Khao Chomphu Wildlife Sanctuary contain higher levels of moisture and fiber than food given to domestic banteng in Indonesia (Yusuf et al. 2015), but protein was lower and most forage species (other than *Imperata cylindrica* – available year-round) were only available during certain periods of the year. The mineral content in consumed species was relatively higher than in wild water buffalo dietary items (Chaiyarat 2002) or pasture grasses (Peiris and Perera 1996), but lower than domestic banteng feed in Indonesia (Yusuf et al. 2015). Of the forage species consumed at Khao Khieo-Khao Chomphu Wildlife Sanctuary only *Pennisetum pedicellatum* Trin. contained higher Ca than domestic banteng feed (Yusuf et al. 2015). The low forage quality at Khao Khieo-Khao Chomphu may have contributed to the low reproductive and population increase rates, and habitat improvements such as prescribed burning may be required to ensure the long term sustainability of the banteng population there.

Low genetic diversity is likely a major conservation concern for the banteng population at Khao Khieo-Khao Chomphu as all individuals came from a highly inbred group (of 13 individuals, all of which were themselves descendants of a single pair) (Prakobphon 1988). A similar problem of inbreeding was found in introduced banteng in both the northern Australian population (Bradshaw et al. 2007) and Lam Pao Wildlife Conservation Development and Promotion Station population (Saijuntha et al. 2013). Although inbreeding may contribute to low fecundity, this might not necessarily be true for all inbred mammal populations, for example Bornean elephants (Alfred et al. 2011), but it is better to have high genetic diversity in the population. Improving grazing quality in the agricultural areas inside the wildlife sanctuary and enlarging the wildlife sanctuary into surrounding cropland might help increase the population. However, patrolling the area in order to reduce poaching for horns and meat is also important. Five banteng carcasses were found poached during field observations in 2008. The poaching of females would both affect population size and also depress recruitment. The location of the population, on the border between Khao Khieo-Khao Chomphu Wildlife Sanctuary and adjacent agricultural areas, might further promote human and banteng conflict and poaching and increase the potential risk of disease transmission from domestic livestock. Lack of knowledge and application is an indirect threat to long term conservation of the banteng population as in the case of the Borneon elephant (Alfred et al. 2011). The marginal viability of the present banteng population is probably incompatible with the idea that banteng from elsewhere might be introduced into Khao Khieo-Khao Chomphu Wildlife Sanctuary. Management of the current genetic resource is a very important issue to build up a comprehensive database on the population trend. Improving public awareness by conducting outreach programs and strict law enforcement by patrolling, combined with habitat management along the habitat site might reduce human and banteng conflict in the area. Finally, this research might be used to improve knowledge of banteng behavior, habitat selection and food quality, which has relevance for future planned translocations.

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