NAT. HIST. BULL. SIAM SOC. 52(2): 151–162, 2004

POPULATION OF WILD WATER BUFFALO *(BUBALUS BUBALIS)* IN HUAI KHA KHAENG WILDLIFE SANCTUARY, THAILAND

Rattanawat Chaiyarat[1], Virayuth Lauhachinda[2], Utis Kutintara[3], Naris Bhumpakphan[3], Theerapat Prayurasiddhi[4]

ABSTRACT

Research was conducted during December 1999 to April 2001, to determine the size and structure of the wild water buffalo *(Bubalus bubalis)* population in Huai Kha Khaeng Wildlife Sanctuary (HKK), Thailand, one of only four wild water buffalo populations remaining on earth. The population in HKK was approximately 25 to 60 animals, and included 8 bulls, 22 cows, 4 subadults, 4 juveniles and 2 calves. This population size is similar to the estimated 30 to 40 individuals documented nearly 15 years ago, and suggests that the population has not grown despite significant conservation efforts over the last 15 years. Conservation and management of the population is considered a high priority. From a conservation management perspective, there is little choice: part of the wild water buffalo population needs to be separated out from the group and transferred to a new area. It may not be wise to maintain the entire population in one area. This is especially true in light of the relatively high probability of the group being wiped out by disease.

Key words: Population, habitat utilization, wild water buffalo, Huai Kha Khaeng Wildlife Sanctuary, Thailand

INTRODUCTION

The wild water buffalo *(Bubalus bubalis)* is a critically endangered species. The total world population is believed to be below 200 individuals by some and below 4,000 individuals by others who have worked in Northeast India (HEDGES, in press). Accordingly, the species was listed by the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES, 1979) as "Seriously Threatened," and by the International Union for the Conservation of Nature (IUCN) as "Endangered" (IUCN, 2000).

Huai Kha Khaeng Wildlife Sanctuary (HKK), Uthai Thani Province, western Thailand, has been recently identified by the IUCN as one of four key areas for the protection of wild water buffalo (HEDGES, in press). Other areas include Bastar and Raipur districts of Madhya Pradesh and Manas Wildlife Sanctuary / Project Tiger Reserve (India), Kosi Tappu Wildlife Reserve (Nepal), and Royal Manas National Park (Bhutan). Elsewhere in South and Southeast Asia there are only feral buffalo (HEDGES, in press).

[1] Department of Biology, Faculty of Science, Mahidol University, Bangkok, 10400, Thailand
[2] Department of Zoology, Faculty of Science, Kasetsart University, Bangkok, 10900, Thailand
[3] Department of Forest Biology, Faculty of Forestry, Kasetsart University, Bangkok, 10900, Thailand
[4] Department of National Parks, Wildlife and Plant Conservation, Bangkok, 10903, Thailand
Received 18 November 2003; accepted 28 September 2004.

In Thailand wild water buffalo have been reported to exist in relatively small herds totaling less than 40 individuals (LEKAGUL & MCNEELY, 1977). A population was "discovered" in 1964 when Royal Forest Department (RFD) officials investigating reports of hunting in the remote HKK forest area came upon the carcass of a wild water buffalo, providing evidence that wild water buffalo still existed in Thailand (NAKASATHEIN & STEWART-COX, 1990). The find was viewed by officials as significant, and HKK was set up to protect the endangered population. In 1970 SEIDENSTICKER & MCNEELY (1975) surveyed the sanctuary on foot, walking first from Huai Ai Yoh forest guard station west to HKK River, then following the river south to the sanctuary boundary. They concluded that there were two separate populations of wild water buffalo in the sanctuary; one located in the riverine tall grass areas near the confluence of the Huai Ai Yoh and a second group downstream near what is today Krung Krai Guard Station. The following year, a small herd of 6 wild water buffalo, 5 adults and 1 calf, were sighted during a helicopter reconnaissance 8 km south of Khao Bandai on February 8, 1976 (PRAYURASIDDHI, 1977). In 1985, the survey suggested the population to be between 35 and 40 individuals in the 70-km^2 area (NAKSATHIT & CHANARD, 1985). UICHAROENSAK (1992), another RFD researcher, undertook a follow-up survey of the same area, utilizing the same methodology. Observations were also made on species being grazed and on salt-lick use in the area. UICHAROENSAK (1992) found that wild water buffalo utilized all the forest types within a 1-km margin of the HKK river. The distribution of wild water buffalo was particularly high between Sob Huai Hin stream and Krung Krai Forest Guard Station. The study concluded the population to be between 36 and 39 individuals. A more recent survey in March 2000 found evidence for a larger population. PRAYURASIDDHI & CHAIWATANA (2000), using a helicopter and flying over the survey area on two consecutive days, estimated the population of wild water buffalo in the sanctuary at 72. On the first day 5 sightings were made and a total of 6 males, 21 females, and 8 subadults was recorded. The largest herd contained 23 individuals. On the second day 7 sightings were made, involving 10 males, 24 females, and 3 subadults. The distance between the sightings was not provided.

The social organization of wild water buffalo in Thailand has not been studied. According to HEDGES (in press), Asian wild water buffalo generally exhibit the social characteristics of wild cattle, with the basic unit appearing to be the cow-plus-calf, and groups having predominantly cows with calves and sub-adults, although groups may also contain adult bulls on occasion. Solitary bulls are the norm. Groups of sub-adult and adult males also occur, but these all-male groups tend to be rather ephemeral and do not show the same degree of cohesion as the groups of cows with offspring. Large herd sizes of 75–100 animals also occurred but these were more common when the species was more numerous (DANIEL & GRUBH, 1966). It is likely that these large groups were only temporary assemblages of small herds (PRATER, 1965). Our study attempted to estimate the population size and structure, and identify the major factors limiting the population of wild water buffalo in Thailand. We suggest some conservation and management strategies to ensure the long-term survival of wild water buffalo in Thailand.

METHODS

The current study was carried out in HKK during December 1999 to April 2001. Focus was placed on lowland areas near HKK River where wild water buffalo are known to occur. The population (P) of wild water buffalo in HKK Wildlife Sanctuary was estimated by

$$P = PD \times HS$$

where PD was population density of wild water buffalo in the sample area and HS was habitat suitability of wild water buffalo. A software package called "Elephant" developed by DAWSON & DEKKER (1992) was employed to determine the population density of wild water buffalo in HKK. The dung density was estimated by setting up a series of line transects in the study area and then surveying these transects for dung, as follows:

Nineteen line transects were set up at 1 km intervals from the HKK River in the first year (December 1999), and dung surveys were undertaken. Each transect was set up to run 1 km in either direction of a river median point for a total transect distance of 38 km. The 2-km transect length, 1 km on each side of HKK River, was established on the basis of information coming from preliminary surveys conducted for the habitat modeling section of the study i.e. 4-km long habitat modeling transects revealed that wild water buffalo rarely venture further than 1 km from HKK River. Transect data from this first year were used as a preliminary test to determine the number of line transects needed to estimate dung density at a confidence interval (CL) of 95%. This showed that the total distance of line transect required was more than 113.5 km. Sixty line transects totalling 120 km were set up at 250-m intervals during the following dry season (2000). A point on the river was selected, in this case, Ban Talingsoong. A 7.5-km line was run north and south of the point. Intervals of 250 m were marked along the line. Finally, transect lines were extended perpendicularly from the baseline for a distance of 2 km in each direction (Fig. 1). A survey of the 60 line transects was conducted in the dry season between December 2000 to February 2001 to determine dung density (BARNES *ET AL.*, 1997). Perpendicular distances of dung-to-transect were entered into "Elephant," where a Fourier Series Estimator was used to calculate the dung density. Dung decay rate determination was based on methods established by WILES (1980). Over 50 fresh dung samples were identified in the field during the dry season. Newly identified samples were flagged and given identification numbers. The location of each dung sample was then recorded along with the date of " fresh" observation. All traces of the 50 samples disappeared (i.e., degraded) after 115 days. The dung decay rate was then calculated using the Elephant software. Elephant employs BARNES & JENSEN'S (1987) dung decay rate equation. The 50 dung samples were entered into the program at day zero. After that, the number of dung still remaining after every 5 days was entered until all the dung disappeared.

We assumed that domestic animals located near the sanctuary, eating similar types of vegetation and experiencing similar weather to wild water buffalo in HKK, would have similar defecation rates. Hence, we observed 9 domestic water buffalo located in Huai Tabsalao, near the boundary of HKK Wildlife Sanctuary to obtain defecation rates. The animals were separated and monitored over 10 days, March 13–22, 2000. At night, animals were penned and the number of night-time defecations was observed and recorded the

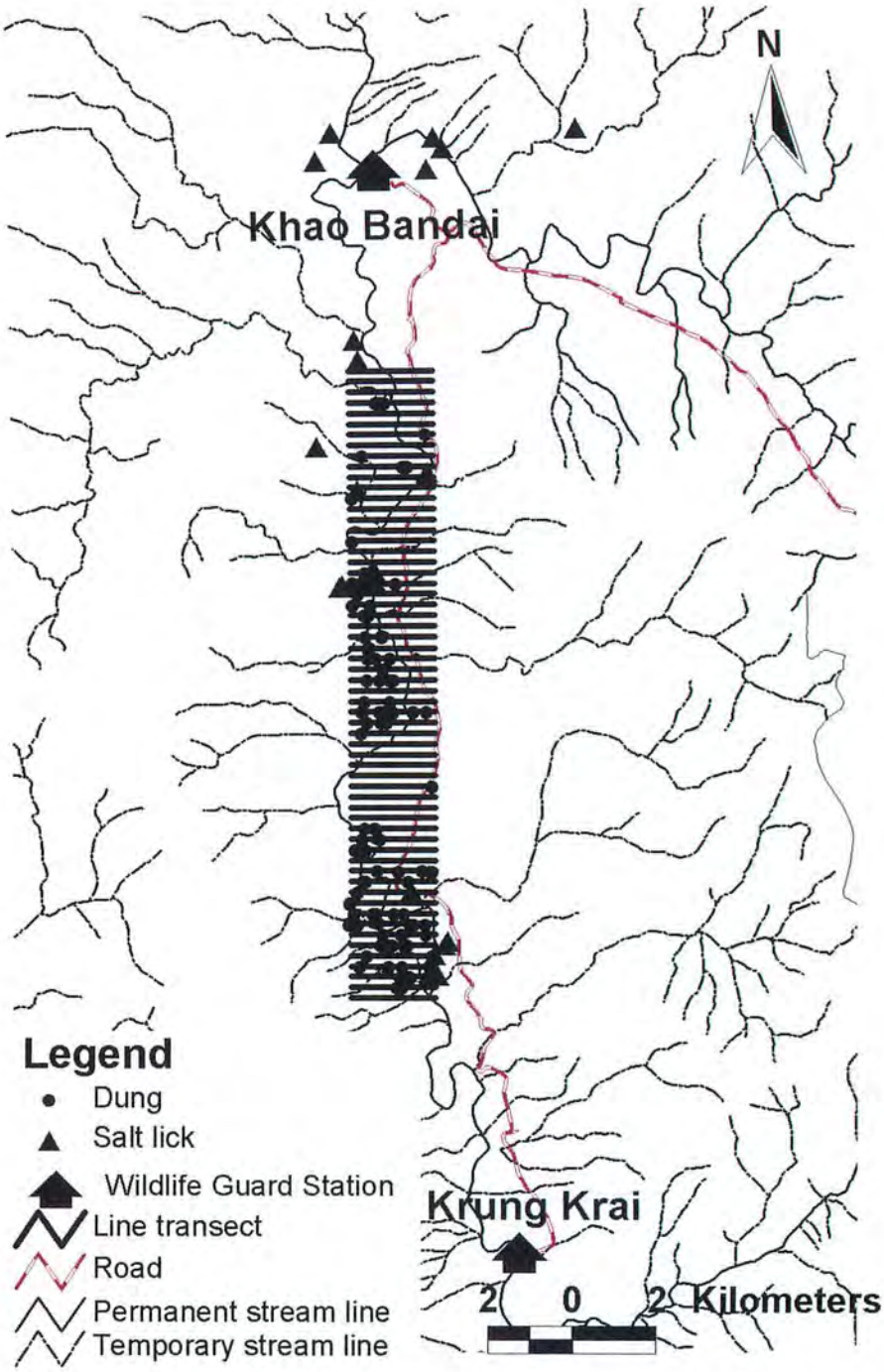

Figure 1. Distribution of dung along the transect lines totaling a distance 120 km.

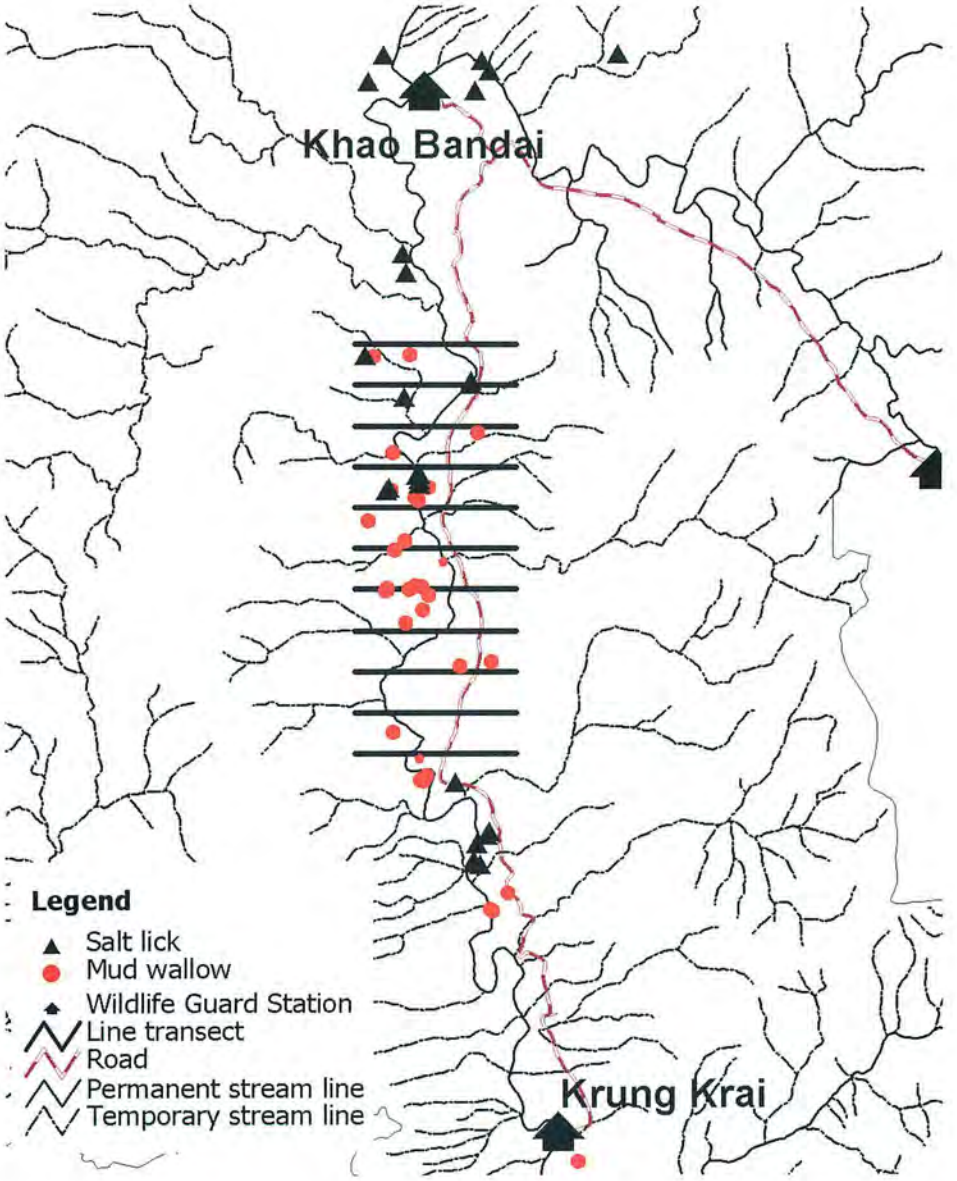

Figure 2. Eleven transect lines were set up using HKK River as a baseline, at one km intervals, totaled a distance of 44 km and included 440 segments.

following morning. The option of using a domestic population to determine the defecation rate is attractive since the dung-rate of individuals in the wild cannot be tracked.

Observations were made on wild water buffalo herd structure. Whenever a group of two or more wild water buffalo was observed in HKK, notes were made on the number of individuals in the group, as well as the age class and sex of each individual. The population structure ratio was based on both our and the sanctuary staff's observations between January 1998 and April 2000, though observations made by sanctuary officials rarely included a breakdown as to sex and age classes. Sightings of single individuals were not included in the 'herd' (2 or more individuals) structure computations. Age class establishment followed the recommendations of KENNETH & SANTIAPILLAI (1983). Size of animal, color and horn shape were used as age class defining features. Four age-class categories were noted: 1) calves of a small size, long brown hair, and no horns; 2) juveniles with straight horns; 3) subadults with upward curving horns; and 4) adults with wider spreading horns (over 2 years in age).

Opportunities to observe wild water buffalo in the sanctuary were rare despite extensive field work in the area. The habitat utilization was calculated by using a combination of field observation and habitat modeling, and GIS analysis. The multiple logistic regression models were fitted to topographic attributes of presence and absence in an area (HOSMER & LEMESHOW, 1989; MANLY *ET AL.*, 1993). The model was developed using elevation (m), slope (%), aspect (N, E, S and W), forest type, distance from salt licks, distance from wallow, distance from permanent water, distance from temporal water, distance from road and distance from human activity. Topographic information was derived from the Royal Forest Department GIS database (RFDGIS), digital elevation map at 100-m resolution (RFD 1997). Aspect and slope were calculated using slope and aspect functions in ArcInfo GRID (ESRI, 1999). Aspect was transformed into 4 continuous variables that described N, E, S and W exposures, with values from 315 to 360 and 0 to 45 = N, 45 to 135 = E, 135 to 225 = S and 225 to 315 = W. The forest types were derived from RFDGIS into riparian grassy habitat (RGH), mixed deciduous forest with bamboo (MDB), moist mixed deciduous forest (MMD), successional disturbed area (SDA), dry dipterocarp forest (DDF) and dry evergreen forest (DEF). The distance from permanent and temporary water sources, road and human activity were calculated using the command "Near" in ArcInfo (ESRI 1999) to determine the nearest distance from each factor. Eleven transect lines were set up (Fig. 2) using HKK River as a baseline, at 1-km intervals. One-hundred-meter segments were then marked off along each transect (cf. BHUMPAKPHAN, 1997). Transects and transect segments were each designated an identification number. Transect lines totaled a distance of 44 km and included 440 segments. Systematic surveys of the transect lines were conducted twice during a dry seasons (November 1999 though April 2000). The presence or absence of buffalo signs (dung or tracks) in each segment was observed and documented, as was the aspect, elevation, slope and forest type. The predictive model for wild water buffalo habitat utilization was created using the logistic regression equation where the probability of use of present site (pr[x]) is

$$\Pr[x] = \frac{\exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n)}{1 + \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n)}$$

where $x_1, \ldots, x_n$ are independent predictor variables and $\beta_0, \ldots, \beta_n$ are logistic coefficients (HOSMER & LEMESHOW,1989). In general, model precision is thought to be greater when models are developed from data that include a greater number of absent sites than present sites, perhaps because most study sites contain more unsuitable than suitable habitat (FIELDING & HAWORTH 1995). Stepwise backwards regression was used to eliminate those factors that were least significant (JOHNSON *ET AL.*, 2000). SPSS program was used to perform both the multiple logistic and stepwise backwards regressions. Classification error rates were used to evaluate fit of models. Outputs from the logistic regression models were compared with a cutoff value. Based on this comparison, each 100-by-100-m pixel of the study area was categorized into a dichotomous 0-1 variable that represented unsuitable and suitable habitat. The cutoff value was selected to maximize the difference between the proportion of correctly classified active sites and the proportion of incorrectly classified inactive sites.

RESULTS

The dung decay rate of wild water buffalo as calculated from observations in natural conditions was 0.01 per day (SD = 0.001, N = 50) (Fig. 3). In general, decay rates were faster near the beginning of observations, the first 50 days, than towards the end. Unexpected rains on 23 May 2000 removed the last 10 specimens before they had decayed fully. Dung decay rates can be influenced by several factors. Rainfall dramatically increases the rate of decay. Birds such as red jungle fowl *(Gallus gallus)* and green peafowl *(Pavo muticus)* commonly dig for insects in wild water buffalo dung thereby increasing the rate of decay. Furthermore, wild water buffalo themselves and other large mammal's trample on the dung. The fieldwork showed flies, dung beetles and fungi to be the major decomposers of dung during the period observed (December 1999 to May 2000). The average defecation rate as calculated from observations of domestic water buffalo was 7.26 dung/day (SD = 1.38, N = 84).

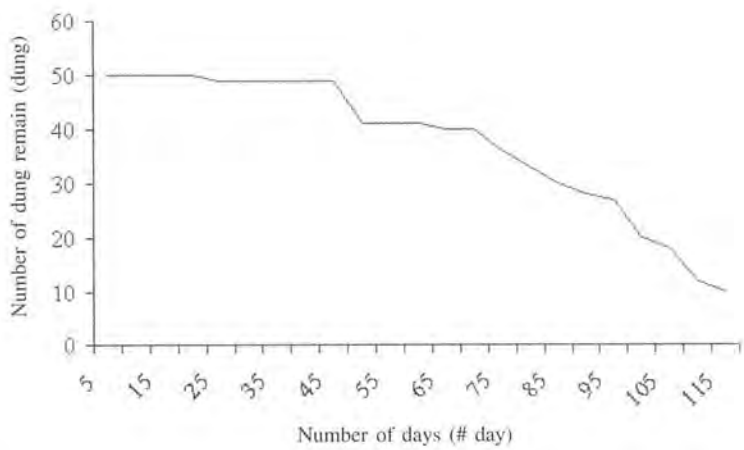

Figure 3. Wild water buffalo dung decay curve, starting with 50 dung piles

The population number from the second year of sampling, 0.27 animals/km^2 (0.16–0.38 animals/km^2), was considerably different from the number derived from the first year of sampling (0.15 animals/km^2.) Differences reflect the fact that the initial 19 line transect survey (38 km) was inadequate to produce a statistically significant result (CL = 95%, 34.57%CV). The number of dung piles from 60 line transects (120 km) was high, 161 dung piles/km^2. This rate produced an estimated density number of 0.27 animals/km^2 (CL = 95%, CV = 17.70%). The average herd size was estimated to be 5.67 individuals per herd (SD = 4.75, N = 21), with herd sizes ranging from 2 to 19 individuals. The most common herd size was small (2–5 animals). Large herds of over 10 animals were rarely found. The percent frequency of observations of different herd sizes were as follows: groups of 2–5 animals, 67%; 6–10 animals, 19%; 11–15 animals, 5%, and 16+ animals, 9%. The population structure ratio (which included individual sightings of adult bulls, adult cows, sub-adults, juveniles, and calves in the sanctuary) was 3.75 : 10.75 : 1.75 : 2.00 : 1.00 respectively (Table 1). This breaks down to an approximate population structure of 7 bulls, 21 cows, 4 sub-adults, 4 juveniles, 2 calves. It is noteworthy that a high percentage of sightings were of single adult bulls.

Wild water buffalo were found to be present in 156 transect segments and absent in 284 transect segments. Model coefficients differed among models, especially between the wet and dry season model (Table 2). Predicted habitat suitability increased with proximity to lower slope and elevation, nearer permanent streams, wallows, salt licks and riparian habitats in the southern part of HKK. The road and human activity influenced the habitat suitablility for wild water buffalo. The area suitable for wild water buffalo in the dry season was 150 km^2. The number of wild water buffalo in HKK Wildlife Sanctuary was estimated to be 25 to 60 animals. This estimate was based on the results of the dung decay rate, 0.01 dung per day, an average defecation rate of 7.26 dung/day, a population density of 0.16 to 0.38 animals/km^2), and an estimated habitat area (dry season; habitat suitability map) of 150 km^2.

DISCUSSION

Defecation rate.—It is important to note that there is likely to be some difference in defecation rates between domestic and wild animals because of the foods they consume. Furthermore, field observations during this research suggest that there may also be other factors influencing differences in defecation rates. For example wild water buffalo feed more in the morning and night, resting during the day, whereas domestic water buffalo, primarily feed during the day, since they are penned at night. KOSTER & HART (1988) suggest that animals should be observed in a natural setting, such as the forest, since the food items consumed in the natural habitat and zoo are quite different.

Population size.—The population of wild water buffalo in HKK was approximately 25 to 60 animals. Census of individuals was difficult for two reasons. First, it were very difficult to get close enough to individuals and herds to identify individuals. Second, it was also very difficult to visually differentiate among individuals (personal observations; HEDGES in press). Nevertheless with such a low population it should be possible to start collecting information on individuals such as close-up photographs showing distinguishing markings, coloration, horn size and shape, behavior, and DNA sample.

Table 1. Herd structure of wild water buffalo were found during January and April 2000.

No.	Date	Time	Adult bulls	Adult cows	Subadults	Juveniles	Calves	Total	Source[a]
1	Jan-98	-	5	6	4	4	-	19	3
2	20-Dec-99	15.10	1	3	1	-	-	5	1
3	15-Jan-00	14.40	-	1	-	-	-	1	1
4	15-Jan-00	16.00	-	1	1	-	-	2	1
5	5-Feb-00	16.00	1	-	-	-	-	1	1
6	5-Feb-00	17.20	1	-	-	-	-	1	1
7	6-Feb-00	-	-	1	-	-	1	2	2
8	19-Feb-00	14.17	-	2	-	-	-	2	1
9	20-Feb-00	13.40	1	3	-	2	-	6	1
10	20-Feb-00	16.45	-	2	-	1	1	4	1
11	20-Feb-00	17.55	-	3	1	-	-	4	1
12	20-Feb-00	18.25	1	-	-	-	-	1	1
13	21-Feb-00	14.20	-	-	-	-	-	7	2
14	21-Feb-00	16.30	-	4	-	-	-	4	2
15	1-Mar-00	-	-	-	-	-	-	12	2
16	3-Mar-00	9.00	-	2	-	1	-	3	1
17	3-Mar-00	14.40	1	-	-	-	-	1	1
18	9-Mar-00	12.15	-	3	-	-	-	3	1
19	11-Mar-00	16.00	-	-	-	-	-	6	2
20	15-Mar-00	17.15	1	3	-	-	-	4	1
21	16-Mar-00	9.00	1	-	-	-	-	1	1
22	16-Mar-00	18.20	1	-	-	-	-	1	1
23	17-Mar-00	17.35	1	4	-	-	2	7	1
24	18-Mar-00	16.00	-	2	-	-	-	2	1
25	7-Apr-00	-	-	-	-	-	-	17	2
26	8-Apr-00	15.40	-	-	-	-	-	1	2
27	10-Apr-00	-	-	3	-	-	-	3	2
28	19-Apr-00	18.30	-	-	-	-	-	5	2
29	19-Apr-00	-	-	-	-	-	-	2	2
	Total		15	43	7	8	4	127	
	%		11.81	33.86	5.51	6.30	3.15	100.00	
	Ratio		3.75	10.75	1.75	2.00	1.00		

[a]Source : 1 = Personal observation
2 = Reported by HKK wildlife sanctuary officers
3 = Reported by fire control officers (helicopter reconnaissance HKK)
Herd size calculations were based on sightings of two or more wild water buffalo together at one time eg., solitary individuals were discounted from this calculation.

Table 2. Multiple logistic regression coefficients for wild water buffalo habitat suitability models developed from 440 segment along 11 transect lines (44 km) along HKK river, Thailand.

	Model Dry season	
	Coefficient	SE
Constant	16.8611	13.4127
Slope	–0.0774	0.0167
Elevation	–0.0225	0.0068
N aspect	ns	
E aspect	ns	
S aspect	ns	
W aspect		
RGH	–8.6829	13.3236
MDB	ns	
MMD	ns	
SDA	ns	
DDF	ns	
DEF	ns	
Distance from permanent stream	ns	
Distance from temporal stream	–0.0009	0.0003
Distance from wallow	–0.0020	0.0004
Distance from salt licks	–0.0004	0.0002
Distance from road	+0.0011	0.0002
Distance from human activity	–0.0006	0.0001

Conservation implications.—A major conservation concern for the wild water buffalo population is that a single outbreak of disease such as rinderpest or foot-and-mouth disease could wipe out the entire population. During our research foot-and -mouth disease reached pandemic proportions globally. Wild water buffalo are the same species as domestic buffalo. There are domestic buffalo in the immediate vicinity of HKK. It would be very easy for diseases to pass from the domestic to the wild population. An example of one potential vector of transmission was the bull who until recently courted female domestics at the edge of the sanctuary.

There is also concern that while the group (or population) is healthy and there was no evidence of hunting, it does not appear to have grown in size during the past 15 years. The dung count survey shows a current population of 25 to 60. Other, track-based assessment carried out in the mid-80s and early 90s also showed populations of between 35 and 40 (cf. NAKSATHIT & CHANARD, 1985; UICHAROENSAK, 1992). The reason for this lack of growth seems to be limitation of suitable habitat in the area. Natural causes of mortality may also be limiting the population's ability to increase. High predation rates and the loss of calves may also be reasons for low population growth. Additionally, the population is heavily dependent on only one water source, the Huai Kha Khaeng River.

The conservation priority is to find a way to help the wild water buffalo population grow, as well as protect the group from the possibility of disease. Translocation of a small herd to another location separate from HKK is one means of achieving both priorities. However, translocation initiatives are controversial. The reason is the small size of the population, less than 100. Separating 4 or 5 individuals reduces the genetic diversity in the remaining wild population. The IUCN Action plan recommended against translocation in Nepal on the basis of a small population of 100 (HEDGES, in press). Thus, what seems to be the only choice (translocation) from a conservation management perspective needs to be reconsidered in the light of possible detrimental effects of small population size. The problems arising may be worse that the benefits. Rather, translocation seems more like a possible alternative to investigate, and one solution to the disease threat. For example, we should first evaluate the possibility of disease spreading into the wild population and improve veterinary care of the domestic herds, and eliminate or treat any feral population first.

ACKNOWLEDGMENTS

Our great appreciation and thanks are given to Miss Laura Johnson, University of Victoria, Canada, Dr. Rudy Rudran, Smithsonian Institution, USA, Mr. Theerapong Choomsangsri, Mr. Sompong Jantawayot and Forestry students of Kasetsart University for their technical support and friendship. We gratefully acknowledge Mr. Wirot Kempanya and Mr. Wanchanok Suvannakhorn for helping to facilitate this research. We offer warm thanks to Dr. Schwan Tunhikorn for his permission and encouragement to work with wild water buffalo in Huai Kha Khaeng Wildlife Sanctuary and my appreciation to Worldwide Fund for Nature (WWF-Thailand) for funding this research.

REFERENCES

BARNES, R. F. W., AND K. L. JENSEN. 1987. How to count elephants in forest. IUCN African Elephant and Rhino Specialist Group. *Technical Bulletin* 1: 1–6.

BARNES, R. F. W., K. BEARDSLEY, F. MICHELMORE, K. L. BARNES, M. P. T. ALERS, AND A. BLOM. 1997. Estimating forest elephant numbers with dung counts and a geographic information system. *J. Wildl. Mgt* 61(4): 1384–1393.

BHUMPAKPHAN, N. 1997. Ecology characteristics and habitat utilization of gaur (*Bos gaurus* H. Smith, 1827) in different climate sites. Dissertation, Kasetsart University, Bangkok.

CITES. 1979. Convention on international trade in endangered species of wild fauna and flora. Regulations and appendices published by the Federal Wildlife Permit Office, United States Fish and Wildlife Service, Washington, D.C., USA.

DANIEL, J. C., AND B. R. GRUBH. 1966. The Indian wild water buffalo, Bubalus bubalis (Linn.), in peninsular India: a preliminary survey. *J. Bombay Nat. Hist. Soc.* 63: 32–53.

DAWSON, S., AND A. J. F. M. DEKKER. 1992. Counting Asian elephants in forests. RAPA Publication, Food and Agriculture Organization of the United Nation (FAO), Bangkok, Thailand.

ESRI. 1999. ArcView GIS Version 3/ArcInfo Version 7. Redlands, California.

FIELDING, A. H. AND P. F. HAWORTH. 1995. Testing the generality of bird-habitat models. *Cons. Biol.* 9: 1466–1481.

HEDGES, S. (In press). Asian wild cattle and buffaloes. Status Report and Conservation Action Plan. IUCN/SSC Asian Wild Cattle Specialist Group, Gland, Switzerland.

HOSMER, D. W. AND S. LEMESSHOW. 1989. *Applied Logistic Regression.* John Wiley & Sons, New York.

IUCN. 2000. 2000 IUCN *Red List of Threatened Animals.* IUCN, Gland, Switzerland.

JOHNSON, B. K., J. W. KERN, M. J. WISDOM, S. L. FINDHOLT, AND J. G. KIE. 2000. Resource selection and spatial separation of mule deer and elk during spring. *J. Wildl. Mgt.* 64(3): 685–697.

KENNETH, R. A., AND C. SANTIAPILLAI. 1983. The ecology of free-living water buffalo *(Bubalus bubalis* L.*)* in Sri Lanka and with particular reference to Ruhuna National Park. *Tigerpaper* (FAO) 10(1): 20–26.

LEKAGUL, B., AND J. A. MCNEELY. 1977. *Mammals of Thailand.* Association for the Conservation of Wildlife. Bangkok, Thailand.

MANLY, B. F. J., L. L. MACDONALD, AND D. L. THOMAS. 1993. *Resource Selection by Animals. Statistical Design and Analysis for Field Studies.* Chapman and Hall, London.

NAKHASATHIEN, S., AND B. STEWART-COX. 1990. Nomination of the Thung Yai–Huai Kha Khaeng Wildlife Sanctuary to a UNESCO World Heritage Site. Wildlife Conservation Division, Royal Thai Forest Department, Bangkok, Thailand.

NAKSATHIT, N., AND T. CHANARD. 1985. Progress report in the ecology of wild water buffalo in Huai Kha Khaeng Wildlife Sanctuary, Uthai Thani Province and the surrounding area. RFD, Bangkok, Thailand. (in Thai)

PRATER, S. H. 1965. *The Book of Indian Animals.* Bombay Natural History Society, Bombay.

PRAYURASIDDHI, T. 1977. Progress report on wild water buffalo [*Bubalus bubalis* Linnaeus, 1758] in Huai Kha Khaeng Wildlife Sanctuary Uthai Thani Province, Thailand. Proceedings of the Wildlife in Thailand 8: 13–23. (in Thai)

PRAYURASIDDHI, T., AND S. CHAIWATANA. 2000. Aerial survey on population of wild water buffalo in the Huai Kha Khaeng Wildlife Sanctuary, Thailand. *J. Wildlife in Thailand* 8(1): 150–153 (in Thai).

Royal Forest Department (RFD). 1997. *Application of Remote Sensing and GIS for Monitering Forest Land Use Change in Huai Kha Khaeng Wildlife Sanctuary.* Royal Forest Department, Bangkok, Thailand (in Thai).

SEIDENSTICKER, J., AND J. MCNEELY. 1975. Observations on the use of natural licks by ungulates in the Huai Kha Khaeng Wildlife Sanctuary, Thailand. *Nat. Hist. Bull. Siam Soc.* 26: 5–34.

UICHAROENSAK, V. 1992. Ecology and current distribution of wild water buffalo [*Bubalus bubalis* Linnaeus, 1758] in Huai Kha Khaeng Wildlife Sanctuary, Uthai Thani Province. Special Problem, Kasetsart University, Bangkok, Thailand (in Thai).

WILES, G. J. 1980. Faces deterioration rate of four wild ungulates in Thailand. *Nat. Hist. Bull. Siam Soc.* 28: 121–134.