Analysis of nutritional quality and food digestibility in male Javan rhinoceros (*Rhinoceros sondaicus*) in Ujung Kulon National Park

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Abstract
The Javan rhinoceros *(Rhinoceros sondaicus)* is the rarest species of rhino. The last remaining wild population is found only in Ujung Kulon National Park (UKNP), Banten, Indonesia, where the conservation of its habitat is a crucial management priority. The Javan rhino is typically arbivorous, feeding on leaves, shoots and saplings. Three healthy male rhinoceros were observed as samples to study their home ranges, the nutritional quality and digestibility of food plants, and nutrient intake. Following the trails of Javan rhinoceros allowed in-depth observation of their feeding habits in their natural habitat. Comparing the acid insoluble ash (AIA) content of faeces and in the dry weight of food provided reliable estimates of digestibility, and this method has potential for wider application in situations where total collection of faecal matter is not feasible. There was a strong positive correlation between the size of home range and diversity of food intake, and between the size of home range with the numbers of wallow holes used. The quantity and quality of food intake were variable among rhinoceroses and over time. Overall energy consumption was related to the size of the animal, while the digestibility of plants consumed appeared to be influenced by individual age and habitat conditions. Analysis of patterns of consumption showed that rhinos generally selected the food that was most readily available. 'Preferred' food plants (e.g. *Leea sambucina, Zanthoxylum rhetsa,* and *Diospyros macrophylla*) were not among those identified in the UKNP as being most highly nutritious (e.g. *Moringa citrifolia, Callicarpa longifolia, Chisocheton microcarphus*). This discrepancy could suggest that the studied rhinoceros live in a nutritionally suboptimal habitat. Moreover, even if overall nutrition is adequate, marked fluctuations in nutrient intake over the mean that rhinos may face shortages of specific nutrients, especially fat, at certain times of the year. This is turn may affect the size of home ranges and limit the population density that can be supported by the habitat. Thus measures to improve habitat quality by planting nutritious food plants could make a significant contribution towards safeguarding the future of the last remaining wild population of Javan rhinoceros.

Résumé
Le rhinocéros de Java *(Rhinoceros sondaicus)* est l'espèce la plus rare des rhinocéros. La seule population sauvage se trouve uniquement au parc National d'Ujung Kulon (PNUK) à Banten, en Indonésie, où la conservation de son habitat est une priorité essentielle de la gestion. Le rhinocéros de Java est généralement arbivore. Il se nourrit de feuilles, de pousses et de jeunes arbres. On a observé trois rhinocéros mâles en bonne santé en tant qu'échantillons pour étudier leur habitat vital, la qualité nutritionnelle et la digestibilité des plantes alimentaires, et l'apport en matière nutritive. Le suivi des sentiers des rhinocéros de Java a permis l'observation en profondeur de leurs habitudes alimentaires dans leur habitat naturel. La comparaison de la teneur en cendres insolubles dans l'acide des matières fécales et du poids net de la nourriture a fourni des estimations fiables de digestibilité, et cette méthode a le potentiel d'une application plus large dans les situations où la collecte totale de matières fécales n'est pas possible.

Il y avait une forte corrélation positive entre la taille de l'habitat vital et la diversité de la quantité d'aliments et entre la taille de l'habitat vital et le nombre de trous de bourbe utilisés. La quantité et la qualité de l'apport alimentaire étaient variables parmi les rhinocéros et au fil du temps. La consommation globale de l'énergie est liée à la taille de l'animal, tandis que la digestibilité des plantes consommées semblait être influencée par l'âge de l'individu et les conditions de l'habitat. L'analyse des modes de consommation a montré que les rhinocéros choisissaient généralement la nourriture qui était la plus facilement disponible. Les plantes alimentaires « préférées » (par exemple *Leea sambucina, Zanthoxylum rhetsa* et *Diospyros macrophylla*) ne figuraient pas parmi celles identifiées dans le PNUK comme ayant la plus haute valeur nutritive (par exemple Moringa Morinda, Callicarpa longifolia, Chisocheton microcarphus). Cela pourrait suggérer que les rhinocéros étudiés vivaient dans un habitat sous-optimal sur le plan nutritionnel. En outre, même si la nutrition générale était adéquate, les fluctuations marquées dans l'apport en matière nutritive pourraient montrer que les rhinocéros feraient face à la pénurie de matières nutritives spécifiques, en particulier la graisse, à certains moments de l'année. Cela pourrait affecter la taille des habitats vitaux et limiter la densité de la population pouvant vivre dans cet habitat. Ainsi des mesures visant à améliorer la qualité de l'habitat par la plantation de plantes alimentaires nutritives pourraient contribuer de façon significative à la sauvegarde de l'avenir de la dernière population sauvage restante du rhinocéros de Java.

Introduction

The Javan rhinoceros *(Rhinoceros sondaicus*) is one of the rarest mammals alive, with a population of approximately 50 animals. It is classified by the IUCN as 'critically endangered'. The species is now found only in a core area of 30,000 ha in Ujung Kulon National Park (UKNP) in Banten Province, West Java, Indonesia. Following the recent extinction of the species in Vietnam, this population provides the only hope of the species' survival. The population in UKNP is still breeding regularly. However, a single population represents a considerable risk from a conservation perspective. The species is vulnerable to natural catastrophes (volcanic eruption, tsunami), disease, poaching and climate change, any of which could potentially cause extinction by devastating the entire population in a short period of time. Historically the population in UKNP reached an extreme low with only 25 animals in 1962. By 2010, the population had increased to an estimated 47 animals (Hariyadi et al. 2011). The Javan rhinoceros is solitary and free-ranging, and dependent on food availability in its restricted habitat. Therefore, the nutritional quality of its food needs to be carefully monitored and, where necessary, managed.

Like other species of rhinoceros, the Javan rhino is an exclusive herbivore. Typically Javan rhinos are arbivorous, feeding on leaves, shoots and saplings. As there have been very few Javan rhinos held in captivity, and none in the last century, there are few records of dietary patterns, food consumption, digestibility of different food plants, and nutritional intake. However, studies carried out by Bogor Agriculture University identified approximately 200 plant species consumed by the Javan rhinoceros (Putro 1997). Dietary studies on Sumatran rhinoceros *(Dicerorhinus sumatrensis)* in semi-wild settings (Mundiany et al. 2005) and greater one-horned rhinoceros (Rhinoceros unicornis) in captivity (Clauss et al. 2005; Dierenfeld et al. 2006) provide reference data for comparative analysis.

Previous research by the NGO Yayasan Mitra Rhino (YMR) (2004) indicated that the habitat in UKNP is changing slowly but constantly due to ecological processes such as the spread of invasive of palm species *(Arenga obtusifolia)* and climate change. These two factors contribute to the reduction in the quantity and diversity of plants (Huxman and Scott 2007). In particular, the hyperabundance and allelopathic nature of *A. obtusifolia* is threatening the availability of typical food plants in the rhinos' diet (Putro 1997; YMR 2004). These changes in habitat and vegetation affect the quantity and quality of food available to Javan rhinos in UKNP, potentially leading to deficient nutrient intake and other associated health issues.

Nutrient deficiencies may result in reduced uptake of glucose and a consequent reduction of lactate dehydrogenase and AMP kinase enzyme activities (Allen and White 1998; Suzuki et al. 2003) and disruption of key metabolic pathways. Nutrition-related diseases also includes iron overload and iron storage disease, which can cause mortality and morbidity (Candra et al. 2012).

The object of this research was to study the diet and nutrient uptake of wild Javan rhinos in UKNP, in order to contribute to habitat management, and identify potential risks to the population arising from restricted food availability and inadequate food quality.

Methods

Selection of rhinos for monitoring

Research in the UKNP was conducted on three male rhinoceros (coded as 12, 13, and 18 by WWF based on visual identification using video camera trapping). The rhinos were followed intensively for six days each month over a period of observation from October 2009 to April 2010. This research targeted male rhinos, for three reasons. Firstly, because males show home range patterns that are relatively consistent over time. Secondly, males also display feeding profiles that are consistent over time, while females can be affected by pregnancy and rearing of young (White et al. 2007). Finally, it was also easier to find male rhinos as they are more numerous than females with a male: female ratio of approximately 3:2 (Hariyadi et al. 2011). The rhinos selected in this study had relatively flat home range habitats that allowed the collection of faeces for Acid Insoluble Ash (AIA) measurements to estimate digestibility.

Home ranges

The three individual adult male rhinoceroses selected as samples were recorded through the video trap activities of WWF Indonesia during April 2008–June 2009. Each individual had a different distribution area on the UKNP peninsula. Based on the rhinoceros density described by Sriyanto et al. (1995), Rhino 12 was representative of an area with high population density on the southern side of the peninsula; Rhinos 18 and 13 were representative, respectively, of medium and low population density areas in the west and north of the peninsula The three areas were defined by vegetation structure with plant densities ranging from 7,000 to 16,000 individuals/ha for undergrowth plants, 5,200–8,400 individuals/ha for seedlings, 650–1,200 individuals/ha for saplings, 80–180 individuals/ha for poles and 70–50 individuals/ha for trees. Vegetation characteristics of rhinoceros home ranges are shown in Table 1, based on the vegetation analysis conducted by Rahmat et al. (2007), who recorded a total of 231 plant species of which 184 (80%) were the usual food plants of the Javan rhinoceros.

Tracking

Rhinoceros were tracked by following each rhinoceros directly along previously identified trails. To avoid stress to the rhinoceros caused by presence of humans, observers followed the movement of rhinoceros at a distance of approximately 2–4 km (24–30 hours) behind. This distance placed the viewer at a relatively safe distance, so that human presence could not be detected by the rhinos through the senses of smell, hearing, or vision. Teams followed predetermined transects in the estimated home ranges of the three rhinos and the location of the occurrence of the first visual contact with each rhinoceros and verification of the identity of the individual animal was defined as the starting point. Data recording commenced from this starting point, which continued by following tracks for seven months from October 2009 to April 2010, for a minimum of six intensive days every month or until the rhinoceros could not be located or no longer tracked. When contact was maintained, the end point of observation was defined as the location where the rhinos arrived back at the starting point (after about 10–20 days), so the overall path of the rhinoceros formed a closed circle.

Track findings and coordinate information on each rhinoceros' trajectory were obtained using GPS (Garmin 76CSX) and were then recorded as a digital map to illustrate the rhinos' movements within their respective home ranges. Home ranges and movements shown by these three rhinos were compared to the food intakes (recorded during field observation) and nutrient composition (described through proximate analysis) to obtain the correlation among the four parameters described below (palatability, food quality, food intake and digestibility).

Table 1. The dominant vegetation and plant species in the Javan rhinoceros home ranges (source: Rahmat et al. 2007)

Rhino	Population density in home range	Dominant vegetation in home range				
		Undergrowth	Seedling	Sapling	Pole	Tree
12	High	*Donax canaeformis*	*Leea sambucina*	*Arenga obtusifolia*	*A. obtusifolia*	*Hibiscus tiliaceus*
13	Low	*D. melanochaetis*	*L. sambucina*	*Euginia polyantha*	*Ardisia humilis*	*Bedfordia arborescens*
18	Medium	*D. melanochaetis*	*E. polyantha*	*Ardisia humilis*	*Cerbera manghas*	*Vitex pubescens*

Food intake

The information about the composition of the food preferences of each rhino was recorded using the method explained in Birkett and Stevens-Wood (2005). Three observer groups (five persons per group) identified the plant species consumed by observing the frayed cut characteristic of rhinoceros browse marks. In addition, food plants could be identified by the presence of shorter branches on one portion of the plant. Observers noted that fresh browse and bite marks (made no longer than 30 hours previously) were marked by damp frayed branch ends with little or no discoloration of the woody tissue. Evidence of feeding prior to the observation period, i.e. more the 30 hours previously, was disregarded.

The amounts of each plant consumed by the rhinoceros were estimated by cutting equivalent amounts of twigs or branches from the same plant from the tip to the point where the bite marks occurred. The cut branches were weighed (±10 g) to obtain the fresh weight consumed per plant and for each feeding site. Dry weight was estimated by sun-drying the branches and then weighing them again. The quality and quantity of nutrient intake based on dry weight of food plants were done using the reference model (Sumatran rhinoceros) that shows average dry weight intake to be 2.9% of body weight (Dierenfeld et al. 2006).

Palatability

Palatability was determined by identifying feed plants with the largest quantity consumed based on the estimation of fresh weight intake as described above. The five food plant species consumed in the highest amounts by each individual rhinoceros were categorized as plants with high palatability.

Food quality

Food plant samples that had been identified and dried were sent to the Livestock Research Agency Laboratory (BALITNAK; located at Ciawi, Bogor, Indonesia). The dried samples were subjected to further a drying process by heating them in an oven at 105°C until reaching constant weight to obtain final dry weight. Gravimetric methods were used to determine water content from these samples. The total water content in a food plant species was defined as the total difference between fresh and dry weights recorded in the field combined with the additional water content obtained from laboratory analysis. The dried food plants were further analysed using proximate analysis to measure the contents of protein, fat, energy, crude fibres, calcium, phosphorus, and acid insoluble ash (AIA). The methods used were based on work method instruction (*Instruksi Kerja Metode,* IKM) codes as set out in the laboratory's national accreditation (no. LP-347-IDN) for conducting analyses, as shown in Table 2.

Nutrient intake was calculated based on the intake of dry matter (DM) multiplied by the amount of nutrients (protein and fat) from proximate analysis. The intake of these nutrients was presented in units of grams per day for each individual, while energy intake was presented in units of kilocalories (kcal) per day for each rhinoceros where 1 kcal is equal to 4,184 kJ.

Digestibility

The measurement of digestibility was carried out using methods introduced by Van Keulen and Young (1977) who calculated the absorption coefficient (also known as percent digestibility) using the differences between AIA content in food and in faeces. This approach is highly suitable for studies of species such as the Javan rhinoceros that can only be studied in their natural habitat, where the calculation of digestibility coefficient using conventional total faecal collections is almost impossible.

The digestibility calculation using AIA as a parameter relies on the availability of fresh faecal samples. The procedure for obtaining fresh samples as outlined in Fernando et al. (2006) consisted of six

Table 2. Methods used by the Livestock Research Agency Laboratory (BALITNAK, Ciawi, Bogor, Indonesia), for the proximate analysis of Javan rhino food plants. IKM: work method instruction (Instruksi Kerja Metode)

Element analyzed	IKM number	Method
Water	01	Gravimetric
Protein	02	Kjehldahl destruction – auto analysis
Fat	03	Gravimetric and extraction with Soxhlet
Energy	04	Bomb calorimeter
Crude fibers	05	Extraction of acid and base
Ash	06	Gravimetric
Calcium	09	Atomic absorption spectrophotometric (AAS)
Phosphorus	10	Spectrophotometry
Acid insoluble ash (AIA)		Gravimetric

steps. First a fresh rhino footprint was located, not older than three days. The fresh footprint was recognized by the integrity of the footprint, damp soil condition, and the absence of leaves and fungi. Attention was paid to the location to ensure that the faecal sample selection excluded those faeces immersed in water or those found within wallow holes. The faecal samples *(boli)* needed to be intact and in good condition with no signs of immersion in river or rain water.

Rhino faeces were found in dung piles consisting of four to five boli and the freshness of the faeces was determined from the colour, dampness, and the presence of insects surrounding the dung pile. Fresh faeces (not more than one hour after excretion) were greenish brown in colour with surface dampness due to mucus, and the presence of many flies. Two boli were taken from each dung pile for sampling, to obtain the weight of fresh faeces. Faecal samples were also sun dried to obtain the dried weight prior to shipment to laboratory for proximate analysis. Prior to proximate analysis the sun-dried faecal samples were dried at 105°C to obtain constant weight. A similar procedure was done on food samples where fresh food, sun-dried food, and final dry weight were measured to ensure that the sample reached constant weight prior to proximate analysis.

As described by Van Keulen and Young (1977), the formula used in calculating AIA percentage was:

$$\% \text{ AIA} = \text{weight of acid insoluble ash} / \text{total sample weight} \times 100$$

Based on the calculation of AIA percentage in food and faeces, the digestibility of dry food was calculated using the following formula:

$$\% \text{ digestibility} = (\text{AIA Faeces} - \text{AIA}_{\text{Consumed food}})/\text{AIA}_{\text{Faeces}} \times 100$$

This calculation was corrected using a (–10%) coefficient as is common in digestibility analysis using AIA methods (Mainka et al. 1989; Sims et al. 2007). The correction factor was used to take into account a likely over-estimation of dry weights due to the persistence of water content in the samples (Sims et al. 2007).

Data analysis

The data were analysed and presented using descriptive statistics: correlation analysis using Pearson’s model to determine the correlation between home range size with food diversity, water in food intake with season; and regression analysis to further identify correlations between water in food intake and seasonal rainfall.

RESULTS

Characteristics of home range

Trajectories for each rhinoceros in this study were obtained by tracing the trail of each rhino. Each individual rhinoceros travelled different distances and home range differed in terms of size, and availability of food, water, and wallow holes. There was a strong positive correlations between the size of home range (in hectare) and diversity of food intake (numbers of vegetation types consumed) ($R=0.9971$), and between the size of home range and the number of wallow holes used ($R=0.9998$) (Table 3). The home range data sets show that Rhinoceros 12 had a relatively small home range of 169 ha compared to Rhinos 13 and 18 with home ranges of 974 ha and 631 ha respectively. A summary of the home range sizes and roaming distances of rhinoceros observed in this study is presented in Table 3, while Table 4 shows home range areas compared to food diversity and numbers of wallows.

Palatability

In addition to the variations of home ranges, each rhinoceros exhibited differences and distinct preferences in diet consumption as shown in Table 5. Based on the average fresh food intake, *Leea*

Table 3. Range size (ha) and the total distance travelled (km) over 6 days of observation by each rhinoceros observed during the period of this research.

Rhino No	Range size (ha)	Distance travelled (km)
12	169	26.40
13	974	45.93
18	631	44.70

Table 4. Comparison of home range size (ha), food diversity (no. of plants), and number of wallow holes.

Rhinoceros	Home range size (ha)	Food diversity (no. of plants)	Numbers of wallow holes
12	169	45	15
13	974	84	33
18	631	70	25

Table 5. Food plants with high palatability based on percentage of fresh food intake per day by each rhinoceros during the study period. Local names for the above plant species are listed in Table 6.

Rhinoceros	High palatability food plants
12	*Leea sambucina, Dracontomelon puberulum, Amomum megalocheilos, Spondias pinnata*
13	*Zanthoxylum rhetsa, Lantana camara*
18	*Diospyros macrophylla, Ficus hispida*

sambucina and *Ficus hispida* were the most consumed food plants contributing 58% of the average monthly fresh food profile of the three rhinoceros combined.

Comparison of food plants with identified as being highly palatable (Table 5) with data on food plant abundance extrapolated from Rahmat et al. (2007) showed that 'preferred' plants were also generally among those most abundant in the respective home range.

Quality and quantity of nutrient intake

Proximate analysis and food quality (calculated based on estimated dry weight intake) identified water, nutrient (protein and fat), and energy contents of the consumed food plants as presented in Table 6.

Comparison of the results of proximate analysis preferred plants with data on plants identified as being highly nutritious (see Table 7 below) showed that 'preferred' food plants have relatively low fat content (1.49–4.45%) and average to high energy (3,521–4,151 kcal/kg DM) compared to highly nutritious species.

Identification of food plants with high quality nutrients

Food plants with high nutrient quality were identified from those collected based on the water, protein, fat and energy content revealed by proximate analysis, as shown in Table 7. Water is considered as a crucial component in food plants to help the hydration of the rhinoceros when roaming in their home range.

It is notable that the preferred food plants listed in Table 5 and analysed in Table 6 are not the same as the high quality food plants shown in Table 7. Of the preferred food plants *Zanthoxylum rhetsa* is the one with the best protein profile (Table 6). However, its protein content (equal to the protein content of *Alstonia angustiloba*; Table 7) is only moderate when compared to highly nutrient-rich plant groups. The fat content of the high palatability plants is generally very low compared the nutritious plant groups. All the nutritious food plants are available throughout UKNP, but the distribution is clustered (Rahmat et al. 2007) and thus variations of consumption among the three rhinoceros are likely due to the different availability of these plants in the their home ranges.

Additionally, proximate analysis of the dried food plant samples identified *Spondias pinnata* as the food plant species with most calcium (4.70 g/100 g) and *Hibiscus sp* as the food plant species with most phosphorous (0.3 g/100 g).

Table 8 shows the calculation of water and dry food intake for individual rhinoceroses. The data from this table shows that there were marked fluctuations in the daily intake of water, nutrients, and energy, suggesting that the availability of these components was not always constant throughout the year.

Table 6. Fresh food intake and nutrient profile (based on calculated dry weights) of high palatability food plants.

Food plant Scientific name	Local name	Consumer Rhino	Average fresh food intake (g/day)	Water (%)	Protein (%)	Fat (%)	Energy (kcal/kg)
Leea sambucina	Sulangkar	12	1,232.86	8.93	5.60	3.07	3,607
Dracontomelon puberulum	Dahu	12	66.09	10.51	9.84	1.49	3,906
Amomum megalocheilos	Tepus	12	845.50	9.58	10.24	1.63	4,151
Spondias pinnata	Kedondong	12	257.73	9.42	9.16	2.62	3,005
Zanthoxylum rhetsa	Kitanah	13	164.31	16.33	17.11	1.94	3,667
Diospyros macrophylla	Kicalung	13	70.71	9.85	10.96	1.96	4,098
Ficus hispida	Bisoro	18	1,217.55	13.11	11.84	1.97	2,721
Lantana camara	Cente	18	344.85	8.37	7.67	4.11	4,004

Note: Water content is measured after food plant sample is dried to constant weight. Fresh food plants normally contain 60-80% more water than the numbers in this table.

Table 7. List of food plants with high water, energy, and nutrient (protein and fat) contents.

Scientific name	Local Names	Water (g/100g)	Protein (g/100g)	Fat (g/100g)	Energy (kcal/kg)
Moringa citrifolia	Cangkudu	7.38	23.39	6.30	4,460
Callicarpa longifolia	Areuy katumpang	8.76	23.61	6.69	4,110
Chisocheton microcarphus	Kilangir	8.65	20.64	6.00	4,656
Alstonia angustiloba	Lame peucang	8.26	17.11	8.61	4,358
Callicarpa longifolia	Areuy katumpang	8.76	23.61	6.69	4,110
Macaranga spp	Mara	13.38	10.78	6.78	3,901
Derris thyorsifolia	Areuy kawao	7.12	15.22	2.83	4,718
Pterospermum javanicum	Bayur	6.94	12.36	2.06	4,678
Percampyulus glances	Geureung	8.56	16.37	2.49	4,702
Paederia scandens	Areuy kipuak	55.17	4.97	0.95	1,951
Alstonia scholaris	Lame koneng	61.08	3.83	2.18	2,090
Costus speciosus	Pacing	45.86	5.30	0.57	2,247

Note: Water content is measured after food plant sample is dried to constant weight. Fresh food plants normally contain 60-80% more water than the numbers in this table.

Table 8. Daily nutrient intake of Javan rhinoceros, based on monitoring data for 3 individuals from October 2009 to April 2010.Table 8. Daily nutrient intake of Javan rhinoceros, based on monitoring data for 3 individuals from October 2009 to April 2010.

Months	Average Daily intake			
	Water (g/ind./day)	Protein (g/ind./day)	Fat (g/ind./day)	Energy (Kcal/ind./day)
Rhinoceros 12				
October	12,210.67	2,329.76	722.11	106,425.43
November	10,261.18	3,284.15	691.30	110,558.90
December	7,355.67	3,078.29	805.71	110,390.86
January	7,245.54	3,867.34	837.45	108,189.17
February	9,910.54	3,645.52	714.04	115,648.82
March	6,217.66	3,390.10	814.22	116,187.79
April	11,719.08	3,262.34	833.03	97,126.64
Rhinoceros 13				
October	8,717.90	3,368.18	862.80	107,764.21
November	5,701.30	3,525.92	1,024.76	110,277.33
December	25,845.94	3,189.64	843.35	104,138.53
January	39,583.31	2,801.85	772.96	108,282.19
February	23,177.69	3,031.93	792.43	102,863.56
March	7,833.53	3,051.91	740.54	103,822.78
April	11,441.88	3,606.06	1,018.07	107,074.28
Rhinoceros 18				
October	7,703.83	2,187.60	483.97	74,442.95
November	41,941.89	2,216.91	540.81	73,271.44
December	18,220.86	2,224.86	508.90	11,096.92
January	14,771.97	2,308.80	519.12	65,560.39
February	13,673.87	2,297.90	527.48	65,876.67
March	8,475.32	2,019.82	494.39	68,890.20
April	2,978.38	2,016.33	622.94	76,055.70

The calculation of total water, nutrient and energy intake for each rhinoceros observed in this study is shiwn in Table 9. Descriptive analysis of the average daily dry food intake shows differences between Rhinoceros 18 with the other two rhinoceros (12 and 13). This is attributed to the small body size (body weight) of Rhinoceros 18 compared to the other two, since dry food intake is known to correlate positively with body weight (Dierenfeld et al. 2006).

Table 9. Average daily intake of water, protein, fat, and energy by three Javan rhinoceroses.

Rhinoceros (code)	Water (g/ind./day)	Protein (g/ind./day)	Fat (g/ind./day)	Energy (kcal/ind./day)
12	9,274.34	3,265.36	773.98	109,218.23
13	17,471.65	3,225.07	864.99	106,317.56
18	15,395.16	2,181.75	528.23	62,170.61

Table 10. Dry food digestibility of the three rhinoceroses based on the proportion of acid insoluble ash (AIA) in food and faeces, and showing corrected values calculated by applying a (–10%) correction factor based on Mainka et al. (1989).

Rhinoceros code	AIA in food	AIA in faeces	% digestibility	% digestibility (corrected)
12	18.68	216.92	91%	81.9%
13	201.11	881.48	77%	69.3%
18	216.19	1,007.22	79%	71.1%

In the study, water intake from fresh forage plants was highly variable among months and among individuals, with no clear pattern emerging from data for the three rhinos. This is highlighted by the fact that the highest monthly water consumption (Rhino 18; almost 42,000 g/ind./day) and the lowest consumption (Rhino 13; less than 6,000 g/ind./day) were both recorded in the same month (November). Protein intake was relatively stable throughout the year. Fat and energy intake were more variable, again with no clear patterns observable (the very low value for energy intake by Rhino 18 in December represents an anomaly for which we can offer no explanation). Overall, the results suggest that Javan rhinos in UKNP may be affected by depleted water, nutrient and energy content in their diet due to the limited availability of food resources at certain times of the year.

Weight and age of studied rhinos

The weights of the rhinoceros in this study were estimated based on the regression table developed for the greater one-horned rhinoceros developed by Purchase (2007). The approximate ages of the rhinoceroses were already known from camera trap data. Thus the ages and weights of the three animals could be specified as follows:

- Rhinoceros 12 (old adult, ca. 65–70 months): 1,000 kg
- Rhinoceros 13 (adult, ca. 50 months): 1,000 kg
- Rhinoceros 18 (weaned young adult, ca. 25 months): 700 kg

Digestibility

The calculation of dry food digestibility done using the method described in Van Keulen and Young (1977) shows that the digestibility lay in the range of 77–91%, with average digestibility at 83% (Table 10). Corrected digestibility, using the (–10%) correction factor as explained above, ranged from 69.3% to 81.9%. Food consumed by Rhino 12 showed the highest level of digestibility (Table 10).

The corrected food plant digestibility for Javan rhinoceros calculated using AIA in this study (69.3–81.9%) is comparable to results for Sumatran rhinoceros calculated by the total collection method (57.49–80.45%) as described in Mundiany et al. (2005) and DM digestibility (82%) calculated by Dierenfeld et al. (2006).

Discussion

Method

Following the trails of rhinoceros trails and their movements proved to be a useful method for in-depth observation of the Javan rhinoceros, which has potential as a standard procedure for monitoring the feeding habits of the rhinoceros and ascertaining the nutritional values of the food available in the natural habitat. Such procedures could also be used for more monitoring other health-related variables, for example too ascertain stress levels by analysis the presence of hormone metabolites in faeces.

The similarity of digestibility results from AIA with those obtained using the conventional total collection method (Dierenfeld et al. 2006) suggests that the AIA method provides a reliable estimate of dry food digestibility, that is particularly useful in situations where total collection of faecal matter is not feasible.

Ranges

The three rhinos monitored had very different range sizes. The range of Rhino 13 was more than five time large than that of Rhino 12, with the range of Rhino 18 being intermediate in size. There are three possible factors that could influence the differences in the Javan rhinoceros' home ranges: the age of the rhinos, the presence of other male rhinos in the vicinity (territoriality) and the availability of water and food resources.

With regard to age, Rhino 12 is known to be the oldest of the three rhinos, and older rhinos are known to prefer smaller territories, so this could be a contributory factor.

With regard to territoriality, Dinerstein (2003) records that male rhinoceros in India and Nepal *(Rhinoceros unicornis)* tend to have non-overlapping home ranges with other males, while the female rhinoceros home ranges show overlaps with the home ranges of male rhinoceros. Behaviour records from video camera monitoring (Hariyadi et al. 2010) show that rhinoceros never shows negative interaction (aggression) towards one another except during mating seasons where males compete to mate. In fact, the records show an occurrence of positive interaction between two adult male rhinoceros in a wallow holes. Nevertheless it is likely that, in densely populated areas where other males are present, a male rhinoceros will reduce its home range to avoid overlapping territories provided there is an adequate supply of resources. The sizes of home ranges in this study were negatively proportional to population density: Rhino 12, in the densely populated area, had the smallest home range (169 ha), while Rhino 18, in the most sparsely populated area, had the largest home range (974 ha). This suggests that rhinos' preference for non-overlapping territories was a factor influencing home range size.

With regard to resource availability, Dinerstein (2003) notes that the home range of the rhinoceros tends to expand during the dry season and diminish during the rainy season due to the greater availability of forage and water resources during the latter. Thus in an area that is rich of resources needed to sustain the life of rhinoceros (food, water, wallow, and salt availability) large home ranges may not be necessary, and more rhinoceros can inhabit such areas. By contrast, in resource-poor areas, rhinoceros may need to increase the size of the home range in order to ensure access to sufficient amounts of food, water, minerals, and salt. In other words, the larger home ranges of Rhinos 13 and 18 could be the result of the need to cover a larger area in the search for food and water.

Evidence in this respect from our study is inconclusive. The observations indicated a strong correlation among home range size, the diversity of food plants, and the numbers of wallow holes. The greater density of wallow holes in the range of Rhino 12 (ca. 8 per 100 ha) compared to those of Rhinos 13 and 18 (ca. 3 per 100 ha) could indicate better quality habitat, for example with respect to salt and water availability. On the other hand, while data on the diversity of food plants is more difficult to interpret, the results do not provide evidence for differences in the quality of vegetation (as food for rhinos) among the three home ranges.

Overall the evidence suggests that the immediate causes of the smaller home range of Rhino 12 are the age of the individual and the population density of rhinos in this area. However, high population density in the area could itself be a result of a more favourable habitat.

Food quality

One rhinoceros (Rhinoceros 18) showed relatively low daily nutrition intake compared to the other two rhinos. However, this was likely linked to the reduced body weight of this individual (Table 9).

Food consumed by Rhino 12 showed the highest level of digestibility (Table 10). Rhinoceros 12 is an old male rhinoceros with the smallest home range size, suggesting that age and, possibly, habitat conditions (food diversity and availability) may account for the greater digestibility of food consumed by Rhino 12 compared to the other two animals. It is known that habitat condition, age, physiology and genetics of the individual rhinoceros can all cause variation in digestibility levels.

Food plants assessed as being of high palatability for each rhino were in fact those most readily available in the respective location. This suggests that availability, rather the palatability, is the main factor governing selection of food plants. This in turn suggests that food availability is the most likely determinant of the food quality. In other words, the typology of the habitat shapes the food quality of the rhinoceros: rhinos select the food that is most readily available

These findings call into question of method of using data on amounts of plants consumed to measure palatability. In the remainder of this discussion we will therefore reference to food 'preferences' rather than palatability.

Proximate analyses show the diversity of the types of food based on preference and nutrient contents. It is notable that the 'preferred' food plants (e.g. *Leea sambucina, Zanthoxylum rhetsa,* and *Diospyros macrophylla;* Tables 5 and 6) were not among those identified as being most highly nutritious (e.g. *Moringa citrifolia, Callicarpa longifolia, Chisocheton microcarphus;* Table 7)

The low fat content of the preferred food plants is particularly noteworthy. Dietary fat provides essential fatty acids and/or fat-soluble vitamins, crucial components in synthesis of various hormones including steroid hormone that plays irreplaceable role in reproductive cycles in both males and females (Koolman and Röhm 2001). Dietary fat intake therefore needs to be taken into account when planning measures to promote increased reproduction of the Javan rhinoceros.

The analysis highlights that nutritious plants contribute to rhinoceros diet in different ways. For example, *Derris thyorsifolia,* the species that contributes most in terms of energy, has a notably low fat content compared to several other species (Table 7). Similarly, high levels of minerals such as calcium and phosphorus, that play a vital role in metabolic processes, were detected in food plants that do not appear in the list of highly nutritious plants based on fat, protein and energy content. These observations highlight the importance for rhinoceros health of maintaining a diverse and balanced diet.

Management interventions

This discrepancy between preferred food and the most nutritious plants could suggest that the three rhinoceros live in a nutritionally 'poor' habitat, at least with respect to an optimal habitat containing a larger proportion of highly nutritious food plants. Marked fluctuations in water and nutrient intake over the monitoring period (Table 8) further suggest that, even if overall nutrition is adequate, rhinos may face shortages of water and specific nutrients, especially fat, at certain times of the year. This is turn may affect the size of home ranges and limit the population density that can be supported by the habitat.

Thus conservation objectives could be furthered by measures to improve habitat quality by planting a range of high value food plants such as: *Harrisonia perforata, Spatholobus ferrugieus,* and D*racontomelon puberulum* (high protein); *Alstonia angustiloba* and *Macaranga spp.* (high fat); or *Deris eliptica, Bambusa spinosa, Pterospermum javanicum, Chisocheton microcarphus,* and *Spatholobus ferrugieus* (high energy).

Conclusions

The study reveals differences in the compositions of the diet of the three rhinoceros which are most likely related to food plant availability in their respective home ranges. The size of the three home territories ranged from 169 ha and 974 ha and this variation is also likely to be related, directly or indirectly, to food availability. While the study shows that overall food intake was adequate, the diet of the three rhinos was suboptimal compared what is potentially available in UKNP. There were indications of fluctuations in intakes of water, nutrients and energy that could lead to temporary shortages of food, water and/or specific nutrients, such as fat. Thus measures to improve habitat quality by planting nutritious food plants could make a significant contribution towards safeguarding the future of the last remaining wild population of Javan rhinoceros.

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