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Research Article

Intake, Utilization, and Composition of Browses Consumed by the Sumatran Rhinoceros (*Dicerorhinus sumatrensis harissoni*) in Captivity in Sabah, Malaysia

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The significant threats to the fewer than 30 wild *Dicerorhinus sumatrensis harrissoni*, the Bornean sub-species of the Sumatran rhinoceros, are obvious and include poaching, habitat loss, and environmental changes. Subtle effects on population survival, however, include nutritional or other diseases, which affect morbidity and reproductive success. To address these issues and focus on animals within their natural range, this feeding trial and analysis characterizes the diet fed to the only three captive *D. s. harissoni* in the world housed at the Sumatran Rhino Breeding Center (SRBC) in Sabah, Malaysia. The study provides an indication of the variance in nutrient composition in local browse, and a comparison with other captive feeding studies. Mean dry matter intake (DMI), comprising ~90% native browse species, equaled 3.55% (range = 2.8–4.1%) of body mass, with a dry matter digestibility averaging 82%. The mean crude protein content of native browses ($n = 8$ spp.) averaged 11.2% (DM basis; range = 5–23%, depending on plant part), with available protein measured at 7.8%. Leaves contained significantly ($P < 0.001$) more crude protein, and less ($P < 0.001$) fiber (neutral detergent fiber, acid detergent fiber, and lignin) than twig fractions analyzed, but animals consumed both fractions rather non-selectively.

†In loving memory of Annelisa Kilbourn.

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Of minerals quantified, Na and P were potentially limiting in native browses compared to equid nutrient requirements, and Se may have been marginal. Ca, K, and Fe levels in particular were high in most native browses. Specifically, iron ranged from 45–1,400 mg/kg (mean = 230 mg/kg DM), with only three preferred species containing this nutrient at $<$100 mg/kg. Excess dietary iron has been linked with health issues in browsing rhinos. Additionally, high levels of other minerals (for example Mn, with a mean of 382 mg/kg DM in this study), can precipitate deficiencies in crucial elements such as calcium. In view of the structural and chemical variations of the different parts of the same plants, dietary guidelines should be developed and incorporated into the basic husbandry of these animals that include increasing the number and combinations of species of browse offered daily to adjust for variance in protein, fiber, other nutritional components and food preference, to increasing the quantity of food offered per day based on desired weight gain and reproductive status. This, combined with information on the free-ranging rhinoceros diet composition, and additional intake and digestibility trials (with concurrent serum analysis to evaluate nutritional status) should greatly assist in providing optimal diets for this highly endangered species. Zoo Biol 25:417–431, 2006.

Keywords: herbivore nutrition; native vegetation; minerals; perissodactyl; protein

INTRODUCTION

Although the historic range of this species covered large areas of Asia and South-East Asia [Van Strien, 1974], current population estimates for the endangered Sumatran rhinoceros (*Dicerorhinus sumatrensis*) number fewer than 300 animals, limited to the Malay Peninsula and the islands of Sumatra. The number of the Bornean sub-species (*D. s. harrissoni*) is believed to be $<$30 individuals. Survival in captivity has also been very disappointing over 17 years, with mortality rates over 60% and few births from wild-caught animals. Understanding the species' ecology and biology in the wild, protecting respective habitats, as well as concerted efforts to improve husbandry and breeding success for this species in captivity is imperative [Zainal-Zahari et al., 1989, 1990]. Determining how feed availability affects the demographics of the wild populations and the health of captive animals requires investigation and can help to evaluate the effects of changing habitat on carrying capacity and population growth.

Similar to other browsing rhinos in North American facilities, the health of the Sumatran rhinoceros in captivity seems strongly linked to dietary husbandry [Dierenfeld, 1995]. Stool consistency problems, gastric torsion, and metabolic imbalances have been reported, possibly due to captive diets [Papas et al., 1991; Dierenfeld, 1995; Smith et al., 1995; Dierenfeld et al., 1995; Paglia and Dennis, 1999]. Excesses or deficiencies in several feed components, including iron, calcium, phosphorus, selenium, vitamin E, and protein have been linked to diseases in browsing rhinos [Miller et al., 1986; Hardy and Adams, 1989; Papas et al., 1991; Smith et al., 1995; Clauss et al., 2002; Grant et al., 2002; Dierenfeld et al., 2005]. Captive recommendations to offer browses such that nutrient intake more closely duplicates natural forage composition [Dierenfeld et al., 1994, 2000, 2005; Dierenfeld, 1995; Clauss et al., 2002] have been suggested, but appropriate quantities or combinations, as well as seasonal and local nutritional variability of these browses can be significant. This study was conducted to evaluate the chemical composition and utilization of diets fed to captive Sumatran rhinos in Sabah, Malaysia, in an effort to better define diet suitability for improved captive dietary management and nutrition of the species based on the resources available in country. These animals receive diets that are largely dependent on natural foods from their rain forest habitat. Although browse species and amounts are similar to those selected by free-ranging animals (Kilbourn, personal observation), species diversity is reduced, and selection is based on human choice.

MATERIALS AND METHODS

Animals

In 1997 and 1998, three (1.2) Sumatran rhinos were housed at the Sumatran Rhinoceros Breeding Center (SRBC) in Sabah, Malaysia, within the northern strip of the Sepilok Forest Reserve (N 05° 51.841′, E 117° 57.003′). These animals are under the care of the Sabah Wildlife Department (J.H.L.). The mature male, "Tanjung," with an estimated birth date in the wild of 1989, was captured in southeastern Sabah and brought into captivity in 1993. One of the two mature females, "Lunparai" was captured as an orphaned juvenile living under a stilt house in 1989. "Gelugob," the second female, was captured in 1994 and her date of birth was estimated to be 1990.

Feeding Trials

Two 4-day-period feeding trials were conducted in February–March 1998. Methodology attempted to duplicate that of Dierenfeld et al. [2000] to allow direct comparisons between this group and the group of captive Sumatran rhinos studied previously. Rhinos were individually housed and fed in adjacent outdoor "bomas" throughout the trials; no other significant husbandry changes were made, hence we felt 4-day trials were adequate to characterize the diets already being fed. Estimations of passage time were conducted by placing inert rubber markers in whole bananas or carrots several weeks before the feeding trails [Frape et al., 1982], and monitoring time of recovery in feces. On trial initiation and completion, body weights were taken. During the trials, total wet weight of food offered, leftovers, and total fecal mass were measured daily to the nearest 0.1 kg. Corrections were made for dehydration by duplicating environmental conditions with unfed portions of browse. Diets were placed in the shade, and fresh water was available at all times. Trace mineralized salt blocks were provided without restriction during the trial but were weighed at the start and end of the trial to estimate consumption.

Diets included locally-grown wild browse, which was offered four times daily. Four species of browse were offered in approximately the same ratios during the pre-trial (5-day) and sample collection (4-day) periods. The percent leaf to twig ratios were calculated each day for each species, and samples were placed in an incubator to dry. Browse species, local names, and amounts fed are presented in Table 1.

Produce consisted of locally-obtained whole unpeeled bananas (6.4 kg consumed per individual per day) and jackfruit (900 g/individual daily). During off-trial periods, additional species of browses eaten were collected for analysis

TABLE 1. Diets offered daily to Sumatran rhinoceros (*Dicerorhinus sumatrensis*) during feeding trials conducted at the Sumatran Rhino Breeding Center, Sepilok, Malaysia, February–March, 1998

Component	Amount (kg)
Trial 1 browse (offered 4 × daily)	
Nangka-nangka (*Ficus lepicarpa*)	15
Tangau (*Merremia gracilus*)	15
Ara benjamina (*Ficus benjamina*)	16
Nangka (*Artocarpus heterophyllus*)	18
Bananas (*Musa* spp.) with peel	6.4
Jackfruit (*Artocarpus* spp.) with peel	0.9
Trial 2 browse (offered 4 × daily)	
Tapak badak (*Macaranga pearsonii*)	15
Tapak gajah (*M. gigantea*)	15
Kacangan (*Centrosema pubescens*)	15
Kulimpapa (*Vitex pubescens*)	15
Bananas (*Musa* spp.) with peel	6.4
Jackfruit (*Artocarpus* spp.) with peel	0.9

Trace mineral salt block (KNZ brand) available ad lib. Composition: 38% Na, 0.2% Mg, 3,000 mg/kg Fe, 830 mg/kg Mn, 810 mg/kg Zn, 220 mg/kg Cu, 100 mg/kg I, 18 mg/kg Co.

(see Table 2 for additional species analyzed). The Herbarium Department at the Forest Research Center (FRC), a section of the Forestry Department of Sabah, confirmed the plant sample identifications.

Sample Collection

Representative samples (minimum 50 g) of browse species offered and recovered during the trials were dehydrated in the incubator at a consistent temperature (60°C) to determine dry matter content. Leaves and twigs were separated to determine leaf to twig (L:T) ratios, and samples were weighed daily until the weights were constant, then placed in plastic containers with desiccant until they were submitted for analysis to the Wildlife Nutrition Laboratory at the Wildlife Conservation Society.

Feces were collected during the morning cleaning of the rhino pens. After total collections and weighing, approximately 1.0 kg sub-samples of feces were obtained from each animal daily and dried in the incubator. A challenge with this species included their routine defecation in water. All three animals voided in this manner, so we felt that it was a consistent variable that could not be avoided. Samples were placed in burlap bags and allowed to drain for 5 min before total wet weight collection.

Chemical Assessment

All dried leaf, twig, and fecal samples were ground in a Wiley mill to pass through a 2-mm screen, and analyzed separately. Moisture, crude and bound protein, neutral (NDF) and acid detergent fiber (ADF), sulfuric acid lignin, total ash, and macro- and micromineral concentrations were determined on browses using methods described by Dierenfeld et al. [1995] for browses. Minerals assessed included Ca, P, Mg, K, Na, S, Cu, Fe, Mn, Mo, Se, and Zn using inductively coupled

TABLE 2. Chemical composition of other local browses fed to Sumatran rhinos (*Dicerorhinus sumatrensis*) at the Sumatran Rhino Breeding Center, Sepilok, Malaysia[a]

Local name (scientific name)	Buruni (*Artocarpus dadah*)		Putih Sebelah		Pulai (*Alstonia spatulata*)		Langsana (*Pterocarpus indicus*)		Mangga (*Mangifer indicus*)		Seri-kalang			Tapai-Tapai (*Macaranga triloba*)		
Nutrient	L	T	L	T	L	T	L	T	L	T	L	T	Fruit	L	T	Flowers
Leaf:twig ratio (%)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Crude protein (%)	14	5.9	28.3	13.3	18.6	6.1	27.2	15.4	9.4	3.7	13	5.4	16.5	15.8	6.3	11.3
AD-CP (%)	2.9	1.2	3.1	3.9	1.5	1.5	1.7	2.7	1.9	1.8	3.3	3.1	4.4	1.7	2	1.7
NDF (%)	42.3	71.4	40.4	57.2	26.3	76.1	54.4	59.5	38.9	63	47.3	81.4	38.7	31.4	62.2	32.4
ADF (%)	38.4	57.7	26.0	45.5	21.2	63.6	31.8	47.5	33.4	54.6	33.7	55.7	37.1	24.8	59.0	26.8
Acid lignin (%)	10.8	14.8	9.7	12.4	8.1	17.4	1.5	10.9	10.4	15.7	9.5	22.2	12.9	7.6	17.7	1.9
Ash (%)	8.8	4.64	18.48	13.82	7.69	5.49	6.85	8.03	12.21	7.91	19.16	11.4	16.93	5.97	4.07	7.17
Ca (%)	0.49	0.38	4.38		1.44		0.76	0.43	3.06	2.37	5.53	2.83		0.87	0.99	1.04
K (%)	1.67	1.53	1.8		2.41		2.64	3.16	0.92	1.2	2.05	1.94		1.51	0.85	1.95
Mg (%)	0.43	0.29	0.48		0.3		0.36	0.23	0.22	0.14	0.6	0.42		0.29	0.21	0.45
Na (%)	0.022	0.021	0.102		0.013		0.012	0.009	0.019	0.013	0.041	0.053		0.014	0.009	0.019
P (%)	0.17	0.13	0.32		0.21		0.26	0.22	0.10	0.09	0.19	0.12		0.14	0.1‘0	0.17
Cu (mg/kg)	5	6	5		3		15	14	2	5	6	7		7	5	8
Fe (mg/kg)	292	90	115		114		113	56	107	96	209	99		193	60	103
Mn (mg/kg)	374	243	123		49		665	330	232	85	162	84		326	327	479
Mo (mg/kg)	1.1	<1.0	1.1		<1.0		1.0	<1.0	<1.0	<1.0	1.4	<1.0		<1	<1	1
Se (mg/kg)	0.062	n/a	n/a	n/a	n/a	0.251	0.059	n/a	0.055	0.045	0.057	n/a	n/a	0.051	0.047	n/a
Zn (mg/kg)	27	36	31		19		26	26	15	24	27	19		24	25	28

AD-CP, acid detergent crude protein; ADF, acid detergent fiber; L, leaf; n/a, not analyzed; NDF, neutral detergent fiber; T, twig <2 cm diameter.
[a]Not used in feeding trials conducted February–March, 1998, but collected simultaneously; all nutrients except water expressed on a dry matter basis.

plasma-atomic emission spectroscopy [Stahr, 1991]. All nutrients in paired leaf versus twig fractions were compared by Student's *t*-test, with $P = 0.05$.

RESULTS

Body Weight, Diet Consumption, and Fecal Production

No problems were apparent during the trial, and animals maintained body condition and health. Body weight for these three animals ranged from 500 kg in the male to 570 kg in the larger female (Table 3), which are consistent with previous reports for this subspecies, weighing less than their mainland or Indonesian counterparts.

Dry matter intake (DMI) for Sumatran rhinos in this trial ranged from 10.8–17 kg, with a mean of 13.9 kg or 2.9% (range = 2.8–4.3) of body mass (Table 3). Rhinos ate $>50\%$ of browse offered, and showed no apparent selective consumption of leaves versus twig portions. Food consumption was minimal during the night and during the middle of the day, whereas dawn and dusk seemed the most significant feeding times. Tanjung, the male, tended to eat a greater proportion (both as % BW and total DMI) of food offered than either of the females, but amounts were not substantially different across animals.

Estimated transit time, based on the visualization of the rubber pellets in feces, ranged from 24 to <48 hr. Daily fecal output averaged 2.0–6.7% of body mass on a wet basis, or <1–1.2% on a dry matter basis (Table 3). Fecal output and diet consumption followed expected patterns and there were no indications of either constipation or diarrhea.

Diet Composition

The chemical composition of diets consumed in this study are presented in Table 4; detailed analysis of browses is found in Table 5. Fecal composition is found in Table 6, and digestibility estimates from the trials are found in Table 7.

TABLE 3. Average body weights, daily fecal production, and daily diet consumption (kg as-fed basis and as a % of body weights) of Sumatran rhinos (*Dicerorhinus sumatrensis*) during feeding trials at Sepilok, Malaysia, 1998

Animal ID and body weight (kg)	Gelugob (541 ± 1.41)		Lunparai (570.0 ± 5.66)		Tanjung (496.5 ± 7.78)	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Feces (kg)	14.4 ± 2.9	19.3 ± 6.6	22.9 ± 4.17	34.5 ± 9.5	10.8 ± 1.0	25.6 ± 8.7
Range	11.0–17.5	11.0–25.0	19.0–28.0	23.0–46.0	10.0–12.0	13.0–33.0
Fruit consumed (kg)[a]	7.3+0.1	7.3+0.1	7.3+0.1	7.3+0.1	7.3+0.1	7.3+0.1
Browse consumed (kg)[b]	44.3 ± 17.2	35.9 ± 1.03	36.9 ± 5.0	31.4 ± 4.5	46.1 ± 4.7	41.5 ± 1.22
Mineral salt block (kg)	n.d.	0.375	n.d.	0.250	n.d.	0.650
Dry matter intake (% of body mass)	3.82	3.26	3.10	2.76	4.29	4.06

n.d., not determined.
[a]Offered 6.4 kg bananas with skins, 0.9 kg jackfruit.
[b]Offered 60 kg of 4 spp. of native browses (~15 kg each type) were fed daily.

TABLE 4. Chemical composition of diets consumed by Sumatran rhinos (*Dicerorhinus sumatrensis*) during feeding trials at Sepilok, Malaysia, 1998[a]

Animal ID	Gelugob		Lunparai		Tanjung	
Nutrient	Trial 1[b]	Trial 2	Trial 1[b]	Trial 2	Trial 1[b]	Trial 2
Water (%)	59.5	59.1	59.8	59.6	59.3	58.2
Crude protein (%)	10.0	10.5	10.4	10.4	10.5	10.3
AD-CP (%)	2.7	3.4	2.9	3.4	2.9	3.4
NDF (%)	43.8	52.8	46.7	52.3	46.9	52.4
ADF (%)	38.3	46.6	41.5	46.2	41.5	46.2
Acid lignin (%)	16.7	21.0	17.0	20.8	17.1	20.8
Ash (%)	10.8	7.3	10.6	7.3	11.0	7.2
Ca (%)	1.74	0.81	1.53	0.81	1.65	0.82
K (%)	1.81	1.61	2.03	1.62	2.02	1.60
Mg (%)	0.19	0.31	0.21	0.31	0.21	0.31
Na (%)	0.02	0.83	0.02	0.63	0.02	1.23
P (%)	0.21	0.15	0.18	0.15	0.19	0.15
Cu (mg/kg)	10.2	12.5	10.0	11.4	10.4	14.8
Fe (mg/kg)	358.1	329.4	263.5	311.6	311.7	361.8
Mn (mg/kg)	154.7	729.1	167.5	717.8	171.9	740.6
Mo (mg/kg)	<1.0	0.46	<1.0	0.45	<1.0	0.46
Se (mg/kg)	0.08	0.1	0.07	0.10	0.07	0.1
Zn (mg/kg)	56.0	52.7	56.1	48.3	61.1	61.2

AD-CP, acid detergent crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber.
[a]All nutrients except water expressed on a dry matter basis.
[b]TM salt block intake not quantified.

Overall, water content averaged 57% and did not vary between leaves and twigs of the same species. The mean leaf to twig ratio was 50:50, with a range from 30–63% leaves. Leaves were higher in crude protein (CP; $P<0.001$) compared to twigs of the same species 14.6 ± 4.3 versus $7.8\pm3.3\%$ of dry matter (DM). Bound protein (nutritionally unavailable) comprised 2.8 ± 0.9 (twigs) to $4.0\pm1.1\%$ (leaves) of total dry matter in browses; hence effective available protein was about 10.6% in leaves compared to 5.0% of DM in twigs. All fiber fractions were significantly lower in leaves compared to twigs of the same species ($P<0.01$). Neutral detergent fiber (NDF) in leaves averaged $44.4\pm9.5\%$ of DM compared to $64.6\pm9.7\%$; acid detergent fiber (ADF) was $37.9\pm10.1\%$ in leaves versus $57.6\pm10.2\%$ in twigs, and lignin averaged $18.1\pm7.8\%$ in leaves compared to $21.2\pm7.8\%$ in twigs. Chemically, leaves contained less potentially digestible fiber (41% of NDF was lignified) compared to twig fractions (32% lignified). The hemicellulose (HC) content (NDF–ADF) did not differ between leaf and stem fractions, averaging 6.7 ± 4.4 % of DM.

Ash (mineral) content of native browses also differed significantly ($P<0.01$) between leaf and twig fractions of the same species, but not for all minerals. Only Mg and Fe contents were higher ($P<0.05$) in leaf compared to twig fractions (0.31 ± 0.01 vs. $0.23\pm0.13\%$ [Mg] and 505 ± 451 vs. 122 ± 93 mg/kg DM [Fe] respectively). Calcium (0.2–4.3%), K (0.9–3.9%), and Mg (0.1–0.5%) seemed in relative excess, especially compared to equid dietary requirements of 0.3–0.4%, 0.3–0.5%, and 0.1% (respectively) for these minerals [National Research Council, 1989]. Sodium

TABLE 5. Chemical composition of browses fed to Sumatran rhinos (*Dicerorhinus sumatrensis*) during feeding trials conducted at the Sumatran Rhino Breeding Center, Sepilok, Malaysia, February-March, 1998[a]

	Nangka-nangka (*Ficus lepicarpa*)		Tangau (*Merremia gracilus*)		Ara Benjamina (*Ficus benjamina*)		Nangka (*Artocarpus heterophyllus*)		Tapak Badak (*Macaranga pearsonii*)		Tapak Gajah (*Macaranga gigantea*)		Kacangan (*Centrosema pubescens*)		Kulimpapa (*Vites pubescens*)	
Nutrient	L	T	L	T	L	T	L	T	L	T	L	T	L	T	L	T
Leaf:twig ratio (%)	62.5	37.5	38.5	61.5	67.0	33.0	61.5	38.5	46.0	54.0	35.0	65.0	49.7	50.3	55.9	44.1
Water (%)	65.6	65.2	48.4	60.8	62.6	57.2	55.1	57.0	57.1	50.0	60.2	63.2	66.1	67.9	42.8	45.8
Crude protein (%)	11.5	5.8	19.0	12.5	9.2	5.1	14	7.4	14.7	9.6	12.3	4.6	22.6	12.4	13.4	5.3
AD-CP (%)	2.5	1.8	3.9	2.4	3.8	2.6	3.5	2.6	5.5	3.5	5.5	4.5	3.2	1.9	4.3	2.7
NDF (%)	35.4	43.4	36.4	65.7	37.5	70.6	34.4	63.9	49	68.9	56.4	74.3	56.7	59.5	49	70.3
ADF (%)	32.5	38.8	27.4	63.8	35.9	60.2	23.9	58	46.9	61.8	54.3	71.7	42.5	47.3	40	59.2
Acid lignin (%)	8.9	13.2	11.7	13.9	19.6	24.6	13.6	19.9	29	32	29.7	31.5	13.5	12.7	18.9	22.1
Ash (%)	16.61	7.65	8.9	8.89	11.79	4.93	15.2	12.27	11.49	7.46	7.56	6.48	10.1	8.38	7.26	6.1
Ca (%)	2.37	1.1	0.56	0.24	1.78	0.97	2.92	2.73	1.07	1.39	0.6	0.82	0.77	0.7	0.92	0.95
K (%)	2.92	1.91	2.75	3.88	1.41	1.09	1.31	1.47	1.23	1.2	1.59	1.76	2.75	3	1.15	1.52
Mg (%)	0.33	0.1	0.28	0.21	0.27	0.17	0.19	0.1	0.45	0.44	0.37	0.4	0.31	0.17	0.29	0.23
Na (%)	0.007	0.102	0.008	0.023	0.006	0.014	0.018	0.013	0.029	0.117	0.036	0.012	0.02	0.044	0.018	0.032
P (%)	0.12	0.17	0.19	0.22	0.09	0.09	0.22	0.44	0.14	0.17	0.11	0.09	0.24	0.21	0.17	0.17
Cu (mg/kg)	7	13	22	18	2	6	8	14	6	13	7	9	10	7	7	9
Fe (mg/kg)	337	328	143	46	45	58	1400	125	658	128	230	54	866	162	364	80
Mn (mg/kg)	532	87	305	130	75	137	129	93	1700	823	839	611	203	157	830	981
Mo (mg/kg)	1.1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.3	1.0	<1.0	<1.0	1.3	1.0	<1.0	<1.0
Se (mg/kg)	0.136	n/a	0.096	n/a	0.113	n/a	0.123	0.128	0.136	0.174	0.109	0.121	0.11	0.104	0.067	0.046
Zn (mg/kg)	242	174	24	30	11	18	36	47	22	33	20	21	31	48	57	72

AD-CP, acid detergent crude protein; ADF, acid detergent fiber; L, leaf; n/a, not analyzed; NDF, neutral detergent fiber; T, twig <2 cm diameter.
[a]All nutrients except water expressed on a dry matter basis.

TABLE 6. Chemical composition of feces produced by Sumatran rhinos (*Dicerorhinus sumatrensis*) during feeding trials at Sepilok, Malaysia, 1998[a]

Animal ID	Gelugob		Lunparai		Tanjung	
Nutrient	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Water (%)	84.0±2.65	84.8±2.22	83.3±4.04	85.5±1.10	81.0±3.46	83.5±4.43
Crude protein (%)	10.0±0.93	11.7±1.20	10.6±0.10	11.5±1.08	7.0±1.17	12.3±0.06
AD-CP (%)	4.57±1.52	4.18±0.72	4.20±0.75	3.20±0.85	2.83±0.38	3.43±0.81
NDF (%)	77.2±4.57	82.5±4.34	76.4±3.45	82.6±2.21	85.6±7.13	79.8±5.91
ADF (%)	72.7±5.60	74.1±4.07	71.5±5.63	76.0±5.08	76.3±2.50	75.5±3.13
Acid lignin (%)	36.4±0.62	37.4±1.72	34.5±4.15	37.3±1.05	31.2±2.34	36.9±2.21
Ash (%)	8.9±0.58	7.0±0.65	11.7±1.68	8.8±1.10	8.1±1.81	8.21±0.73
Ca (%)	1.40±0.05	1.10±0.26	1.42±0.06	0.88±0.08	1.02±0.11	1.16±0.16
K (%)	0.28±0.15	0.33±0.38	0.77±0.13	0.73±0.23	0.29±0.20	0.41±0.25
Mg (%)	0.09±0.01	0.11±0.01	0.09±0.01	0.12±0.01	0.07±0.01	0.13±0.01
Na (%)	0.04±0.02	0.10±0.07	0.08±0.02	0.27±0.10	0.06±0.04	0.12±0.07
P (%)	0.13±0.03	0.12±0.04	0.21± 0.01	0.16±0.03	0.10±0.03	0.15±0.03
Cu (mg/kg)	12.7±0.58	12.0±1.63	13.0±0.0	15.0±1.41	8.3±0.58	13.3±2.31
Fe (mg/kg)	548.7±59.0	532.0±39.5	629.0±103.3	608.0±109.6	428.7±104.7	623.8±40.5
Mn (mg/kg)	381.3±29.3	674.3±213.1	559.7±86.2	1029.75±163.0	336.0±101.8	918.8±184.6
Mo (mg/kg)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Se (mg/kg)	0.03±0.01	0.05±0.01	0.09±0.02	0.15±0.06	0.04±0.01	0.11±0.02
Zn (mg/kg)	85.0±4.58	73.8±6.95	115.7± 27.02	59.8±9.64	93.3±0.58	94.5±24.8

AD-CP, acid detergent crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber.
[a]All nutrients except water expressed on a dry matter basis.

TABLE 7. Digestion coefficients calculated for Sumatran rhinos (*Dicerorhinus sumatrensis*) during feeding trials at Sepilok, Malaysia, 1998[a]

Animal ID	Gelugob		Lunparai		Tanjung	
Nutrient	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Dry matter (%)	90.2	83.5	79.7	68.2	90.2	79.7
Crude protein (% apparent)	88.8	81.7	79.1	73.0	93.6	75.7
NDF (%)	80.3	74.3	66.4	61.5	82.5	69.0
HC (%)	90.8	77.7	80.6	73.6	83.5	85.9
ADF (%)	78.7	73.8	64.6	66.2	57.2	66.8
Cellulose (%)	81.2	76.4	67.7	62.8	82.3	69.1
Acid lignin (%)	75.6	70.7	58.3	56.2	82.5	63.9

ADF, acid detergent fiber; HC, hemicellulose; NDF, neutral detergent fiber.
[a]Expressed on an dry matter basis.

(0.01–0.1%) was marginal (compared to requirements of 0.15%) as was P (0.1–0.4% vs. recommendation of 0.2–0.3%). Zinc (11–242 mg/kg) values varied considerably compared to dietary requirements for domestic herbivores (40 mg/kg for equids). Copper (0.1–0.4 mg/kg) seemed in relative deficiency (equid recommendation 10 mg/kg) whereas Fe (45–1,400 mg/kg) and Mn (49–1,700 mg/kg), especially in the leaves, were in relative excess compared to ranges known to support livestock and wildlife (40–50 mg/kg). Selenium levels ranged from 0.05–0.25 mg/kg, ranges encompassing the 0.1 mg/kg requirements for horses [National Research Council, 1989]. Molybdenum detected in samples was on average <1 mg/kg. When native browses (Tables 2, 5) are compared to diets consumed (Table 4), the need for a supplemental trace mineral block should be evaluated.

Diets consumed in Trial 2 were less digestible than browses eaten in Trial 1, related to higher fiber fractions in Trial 2. The negative correlation between dry matter digestibility (DMD) and NDF in these studies is described by the regression equation: DMD = 150.2–1.39 (% NDF), with an $r = -0.648$. The DMD (80–90%) of native browses and fiber fractions (62–83% for NDF, and 57–79% for ADF), however, was relatively high in these trials.

DISCUSSION

The DMD of the local browse diets consumed by the Sumatran rhinos in Sabah (~85%) was considerably higher than measured in Cincinnati with animals fed non-native browses (52%) [Dierenfeld et al., 2000], Sumatran rhinos fed native browses at other Asian centers (Michael, unpublished data) and those reported for another browsing rhino species, the black rhinoceros (*Diceros bicornis*) in zoo studies [Foose, 1982], or fed native browses (28–50% DMD) [Atkinson et al., 1997]. The overall diet consumed by these rhinos was about 35% lignified (acid lignin as a proportion of NDF), which compares to the animals in North America (31%) [Dierenfeld et al., 2000] and the Sumatran rhinos (27%) in Indonesia [Dierenfeld et al., 1994]. Browses at SRBC had similar NDF and ADF content as North American browses consumed, but were more highly lignified thus in theory should have displayed a lower digestibility. It is possible the higher effective fiber in Sabah influenced passage characteristics to retain ingesta for better digestion or the microbial flora of the GI tract was better adapted to native browses. Conversely, and more realistically, the rough technique for fecal collection employed may have underestimated fecal output, resulting in higher apparent digestibilities. Nonetheless, browse is an essential component of diets for this species, and should be considered more than just "enrichment."

Although water intake was not specifically quantified in this study, rough calculations of water intake from browse consumption alone resulted in 35.1–52.3 mL intake per kg body weight (BW), similar to values measured for Indian rhinoceros (*Rhinoceros unicornis*) fed dry diets (30–49 mL/kg) reported by Clauss et al. [2005]. In this respect, equid water intake estimates derived for maintenance under moderate environmental temperatures, of approximately 30–50 mL water ingested/kg BW/day, seem to fit the rhinos species well.

Mean crude protein levels (approximately 10% DM) in diets measured in our study were within ranges reported from browses consumed by free-ranging black rhino (6–22% of DM) and similar to those fed to captive Sumatran rhino in America (9–10%). Although crude protein was within ranges recommended for adult equine maintenance and marginal for reproduction (10–13% of DM) [National Research Council, 1989], dietary protein levels may actually be deficient in $>30\%$ (5 of 15) of the local species analyzed when one subtracts chemically unavailable protein (AD-CP, found in the lignin fraction of browses) from crude protein as described by Dierenfeld et al. [2000]. The acceptable range for dietary protein in browsing rhinos, however, may be narrow; protein levels of 10–13% considered excessive [Jones, 1979] have also been associated with laminitis in rhinoceros. Clearly these animals can be maintained and reproduce on diets containing 7–10% available dietary protein. Protein quality has not been investigated in detail in Sumatran rhino browses, including the influence of secondary plant compounds; further research in this area may be warranted.

Of interest is the fact that a species of *Vitex* was offered on a regular basis. Some species of *Vitex* exhibit a phyto-progesterone effect on the consumer, and have been shown to reduce libido in males; tinctures are consumed by monks in some European monasteries. The active ingredient(s) interfere with progesterone or LH receptors in females; *Vitex* is used in human applications to regulate irregular menstrual cycles, but should be avoided by pregnant women. Although *V. pubescens*, as consumed by rhinos in this study, may not exhibit the same effects, the possible presence of such chemical compounds emphasizes the importance of maintaining diet diversity when feeding native browses.

Sumatran rhinos have been shown to readily digest high fiber diets; other dietary carbohydrates that may be of even more interest in the overall health and management of the browsing rhinos (and other browsing species) may be the soluble fibers, non-structural carbohydrates, and simple sugars. Clarification of the chemistry and roles of these components is a current focus of non-ruminant herbivore and browsing species nutritional science.

Regarding mineral nutrition of the rhinoceros in this study, iron levels seemed excessive in 80% of native browse species analyzed. Iron overload associated morbidity and mortality has been identified in multiple species including rhinoceros [Kock et al., 1992; Montali and Citino, 1993; Paglia and Dennis, 1999; Dierenfeld et al., 2005]. Not as frequently seen in free ranging animals, the high prevalence and severity of hemosiderosis (the intracellular deposition of iron, caused by a potential combination of excessive dietary iron, low tannins, and high ascorbic acid) is not an uncommon pathologic lesion in rhinoceros in captivity [Kock et al., 1989; Spelman, 1989; Smith et al., 1995; Paglia and Dennis, 1999]. However, the Sumatran rhinoceros in captivity face these risks and hemosiderosis lesions have been identified despite diets of natural browses at SRBC (A.K., personal observation). Iron overload can also place an increased demand on vitamin E reservoirs, as it does in black rhinoceros [Dierenfeld et al., 1988]. Vitamin E deficiency is known to cause disorders of the reproductive, muscular, circulatory, and nervous systems in multiple species including the rhinoceros [Papas et al., 1991]. Further nutritional analysis of foods consumed by these animals, in combination with plasma (or other tissue) analysis to evaluate vitamin E status will provide references for appropriate dietary management. Selenium, another mineral with antioxidant properties, should also be monitored in Sumatran rhinoceros with respect to antioxidant health, because native browses were found to be low in this element.

Manganese was very high in the browse offered (mean = 383 mg/kg), which can precipitate deficiencies in crucial elements, primarily divalent cations. The mean Ca, 1.5%, is similar to that summarized from 40 spp. examined in native food plants in Indonesia (1.2% of DM) [Van Strien, 1985; Lee et al., 1993; Dierenfeld et al., 1995] and seems above levels recommended for the equine [National Research Council, 1989]; bioavailability, however, has not been investigated. Phosphorus (P) seems to be limiting in native browses, particularly in relation to calcium content, as it was in the North American Sumatran rhino study [Dierenfeld et al., 1995]. The balance between Ca and P is critical; these direct and indirect imbalances can affect the animal's health. Hemolytic and dermatitis problems in captive black rhinoceros have been associated with low phosphorus levels [Kock and Garnier, 1993].

Sodium (Na) also seems limited in native browses, one reason it is suspected that the Sumatran rhino frequent salt licks in the wild [van Strein, 1985; Lee et al., 1993] and why in captivity available salt is essential. However, the need for additional minerals in the supplemental salt should be evaluated carefully with respect to overall dietary balance. Even the relatively low consumption rate of the mineral block recorded in this study (Trial 2, Table 3) contributed substantially to mineral calculations in the diet (Table 4). High excretion concentrations of most minerals in feces (Table 6) suggest possible mineral overages.

Given the composition of native food plants eaten, excessively digestible diets are not considered appropriate for browsing rhinoceros species in captivity. However, simply offering native browse of unknown nutritional value, with limited selectivity available, may prove just as nutritionally imbalanced. Nutritional differences in different browse and parts of browses were apparent from this study; browses offered were based on a combination of species that address the nutritional variance of the plants, as well as individual preferences of the animals. Additionally, a mixture of native browse species, varied routinely, may prove beneficial to overall health and digestibility. Even when fed local browse, the selection, the combinations, the availability of other elements and multiple unknown other factors play important roles in the appropriate balance. Special attention should be paid to proper dietary mineral balance, and physiologic assessment through the use of measures including circulating plasma nutrient concentrations or enzyme activities are warranted to further evaluate mineral status.

Because dietary iron intake may be one of the important factors in the pathogenesis of generalized hemosiderosis, diets assessments addressing the apparent excess iron fed should be initiated. It is possible that antagonistic nutrients (pro-oxidant minerals, vitamins, fats), supplied at levels exceeding animals' requirements, lead to a necessity for elevated antioxidant vitamin supplementation in captive animals [Dierenfeld, 1995]. Vitamin E levels in feed and serum should be determined to evaluate the need for or level(s) of supplementation for this nutrient, particularly in light of documentation of high iron diets consumed.

CONCLUSIONS

1. Sumatran rhinos ($n = 3$) at the SRBC maintained body mass and condition at a DM consumption level of 2.8–4.3% of body mass; for weight gain or reproductive activity, dietary ingredients or amounts may need to be modified.
2. Diets were high in fiber, and moderate in protein content. Overall, native browses seemed more digestible than non-native browses evaluated in other studies with Sumatran rhinos.
3. Multiple species of browse should be fed daily, in quantities allowing consumption of 30–50 kg (as-fed basis) daily. Browse is an important component of natural diets, and should be considered essential in the diet, not just "enrichment."
4. Although plain or iodized salt blocks should be provided ad lib, diets seemed relatively imbalanced with respect to mineral nutrition, and the use of a trace mineralized salt block should be re-evaluated (or adjusted to provide only minerals that are required to balance diets). Mineral status of animals should be determined using physiologic measures (circulating plasma or enzyme activity studies).
5. The variability of native browse composition should be investigated in more detail, including soluble carbohydrate fractions (important for non-ruminant herbivores), and seasonal changes should be documented. These data, combined with preference studies, would help determine optimal feeding regimens for captive rhinos at SRBC.

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