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Title: **A global survey of banteng *(Bos javanicus)* housing and husbandry**

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Running head: **banteng husbandry survey**

ABSTRACT

Banteng *(Bos javanicus)* are an example of a species of conservation concern without current "best practice" guidance, as they have been the focus of little applied husbandry research. Despite their elevated conservation status, and established, increasing global captive population, zoos do not yet have information on optimal husbandry. To help address this problem, a husbandry survey was distributed to all global holders of banteng. Questions focused on herd demographic structure, exhibit features (including mixed-species exhibition), dietary provision, and behavioral management. Completed surveys from 16 zoos enabled analysis of contemporary practice between institutions. Results indicate differences in enclosure size between zoos, and that herd size is unlikely to predict enclosure size. Herd sizes are smaller than wild examples, and enclosure space (per animal) is significantly smaller than a potential wild range. Banteng are frequently maintained successfully in mixed species exhibits alongside a wide range of other taxa. Nutrient analysis focused on fiber and protein, and although provision of these nutrients appears comparable between zoos, more work is needed on browse and forage intake to determine overall diet suitability. Behavior management shows variation between zoos, with numerous collections providing browse but only a minority undertaking training, and not all providing enrichment. The overall diversity in findings between zoos suggest future research areas that should focus on key aspects of behavioral ecology, such as wild foraging behavior, food plant selection and day/night activity patterns, which may help underpin husbandry guidelines and excellent animal welfare.

Keywords: Banteng, *Bos javanicus*, survey, evidence-based husbandry, zoo animal welfare.

INTRODUCTION

Developments to the husbandry of captive animals have progressed considerably over the time that wild species have been maintained in captivity [Hosey et al., 2009]. However, in spite of notable advances, gaps still exist in our knowledge of zoo animal management that could detract from maintenance of thriving populations and positive welfare states [Melfi et al., 2005]. Research into wild ecology, behavior and natural history is the best way to fill such gaps [Kleiman, 1985; Melfi, 2005; Melfi, 2009]. Species that receive less attention in the research field of "evidence-based husbandry" are those that could be managed incorrectly. A potential disparity between the number of animals of a particular species held in zoos and the frequency of research interest on these species is noted by several authors [Anderson et al., 2008; Melfi, 2009]. The focus of this paper, an ungulate species, is part of one such mammalian group that can receive less research attention when compared to other zoo mammals [Rose and Robert, 2013].

One approach that characterizes the attempt to enhance zoo animal welfare via achievement of optimal husbandry standards is the development of species-specific guidelines for zoo animals [Mellen, 1994; Rose and Roffe, 2013]. Such guidelines aim to identify the most appropriate and most suitable management approaches for particular taxa [Fletchall et al., 1995; Galama et al., 2002]; they generally contain standardized information on ecology as well as a description of how biological and behavioral needs of a species can be best met in captivity [Barber et al., 2010]. Husbandry guidelines are increasingly being developed to a species-specific level but again, there are gaps in the availability of these guidelines as well as in the amount of empirical evidence that they contain. A new move towards "Best Practice Guidelines" [EAZA, 2015] aims to showcase the most important aspects of husbandry that have been shown to promote highest welfare standards for a particular species. Important natural history information, and details on wild behavioral ecology, evolutionary adaptations and life history strategy should be collected on species that are housed in zoos and used to formulate such best practice guidance.

Banteng biology

The banteng (*Bos javanicus*) is a wild bovid from South-East Asia, currently classified as "Endangered" by the IUCN Red List [Timmins *et al.* 2008]. Recent population estimates range between 5000 and 8000 individuals, distributed between small and isolated populations [Groves et al., 2011]. Considering this level of threat, it is perhaps not surprising that banteng are maintained in captivity. Breeding is coordinated by an EEP (European Endangered Species Programme) in European Associations of Zoos and Aquaria (EAZA), and within AZA (Association of Zoos and Aquariums) banteng are a candidate species for a potential future SSP (Species Survival Plan). Research into the wild demographics of banteng populations reveal that an average herd typically comprises of between eight and 12 animals with a core consisting of adult females and their dependent offspring [Gardener et al., 2014; Groves et al., 2011]. A single mature male will typically form loose associations with a herd, but outside of this arrangement can be solitary or join a bachelor group [Gardener et al., 2014]. Average longevity is suggested around 20 years, with the oldest known captive banteng reaching 27 years [Groves et al., 2011].

Information on wild ecology and habitat selection is limited. Literature does suggest that banteng are generalists but that they may potentially favor areas of dense forest incorporating open patches of grassland [Gardener et al., 2014; Groves et al., 2011]. Sumardja and Kartawinata [1977] indicate a grazing preference for several genera of grasses, with other research highlighting opportunistic foraging on bamboo and palm, as well as on the saplings of several tree species [Groves et al., 2011]. Such information supports the characterization of banteng as an intermediate feeder [Hofmann, 1973; Hofmann and Stewart, 1972]. A useful review of foraging ecology and food plant selection is provided by Timmins et al. [2008], which may be helpful to those attempting to formulate naturalistic captive diets.

Attempts to fully meet the challenges of conserving banteng and maintaining them appropriately in captivity may be hindered by the lack of available best-practice guidelines. With a substantial global population of 291 animals across 31 Zoological Information Management System (ZIMS) registered zoos (as of February 2016) there could be substantial variation in what is considered to be the most appropriate husbandry standard for this species. The most relevant document currently available takes

the form of a set of guidelines produced by the AZA Bison, Buffalo and Cattle advisory group [Joseph 2004]. This document focusses solely upon existing trends in wild cattle management from the AZA region and does not include a significant amount of banteng-specific detail; this lack of specificity and reference only to institutions in a particular area has the potential to limit usefulness to maintaining banteng on a global scale. Within the AZA Wild Cattle and Camelid TAG, banteng have been identified as a priority species and a "Call to Action" has been put out to encourage new holders to become involved with this species, and to support more work into informed husbandry and management practice [B. Huffman, personal communication]. As such, it would appear to be the perfect time to bring together what information is currently known about banteng housing and husbandry, to determine any common trends that may be working well.

Aims and Objectives

The combined factors of the banteng's threat category, and its economic and ecological importance within its range states [Nguyen 2009; Solti *et al.* 2000; Talib *et al.* 2003], and a push to increase support for banteng exhibition within zoos, emphasize why this species should be considered a species worthy of relevant research in zoological institutions. This paper aims to collate information on current practices for the maintenance of banteng in captive institutions globally, and to add knowledge to an area of zoo husbandry lacking in evidence-based information. As such, it is not intended to act as a comparison between current practices and any "best practice" publications available for similar species, but simply to compare current husbandry practices between zoos. This paper also hopes to highlight key similarities and differences in husbandry practice, in the hope that this will act as a basis to direct the application of future empirical investigations into specific aspects of husbandry, which will in turn provide information necessary to develop specific guidelines for banteng.

METHODS

Institutions holding banteng were sourced from ZIMS, and specific contacts were provided by relevant EAZA and AZA TAG representatives. Data were collected via a questionnaire sent to all global holders of banteng in August 2014. To encourage zoos to fill in the survey, an application to the British and Irish Association of Zoos and Aquariums (BIAZA) Research Committee for project support was made, and granted. Information was requested on i) the number of animals held, ii) type and size of housing (indoor and outdoor) and exhibit features, iii) other species housed in the enclosure if any, iv) feeding practices and content of diet provided, v) use of enrichment, and any abnormal or stereotypic behavior patterns observed in the animals kept.

Collections Involved

In total 25 institutions across four continents were contacted, comprising all holders at the time of study. Completed surveys were received from 16 institutions (giving a 64% return), providing a total study population of 86 animals. The zoos that responded were Wildlife Reserve Singapore: Night Safari, Taronga Western Plains Zoo, West Midlands Safari Park, Chester Zoo, Royal Zoological Society of Scotland: Edinburgh Zoo, Zoo Berlin, Safaripark Beekse Bergen, Cerza Zoo, Parc de Lunaret, Safari de Peaugre, Royal Burgers' Zoo, Rotterdam Zoo, Zoo Miami, San Diego Zoo Safari Park, Saint Louis Zoo and The Wilds. Table 1 provides detail on the overall study population whilst providing anonymity to each of the above institutions.

Table 1: Study population of banteng at each institution; with information relating to the total population, number of calves and the age range of animals maintained at the time of the survey.

Zoo I.D.	**Total population (male. female.unknown)**	**Number of calves (<12 months)**	**Age range of animals kept (years)**
Z1	1.5	1	<1 - 15
Z2	3.3	1	<1 – 10
Z3	2.1	1	< 1 – 10
Z4	2.5	2	< 1 - 15
Z5	1.2.3	1	<1 – 20
Z6	1.2	0	6 – 15
Z7	1.1	0	1 – 10
Z8	1.4	2	< 1 – 10
Z9	2.2	0	1 – 15
Z10	1.6	0	1 - 15
Z11	4.4	1	<1 – 20
Z12	3.5	0	1 - 20

Z13	1.5	1	<1 - > 20
Z14	1.3	0	1 - > 20
Z15	1.4	1	<1 – 20
Z16	2.4	1	< 1- 15

173

174 **Data Analysis**

175 All data were tested for normality before statistical analyses (using Minitab version 17) were
176 undertaken. Overall difference in each zoo's enclosure area was determined using a one-factor Chi-
177 squared test, as was any difference between the number of single-species verses mixed-species
178 enclosures. Any difference in the size of single-species versus mixed-species exhibits (MSE) was
179 analyzed using a one-way ANOVA. For comparing between the amount of outdoor and indoor space
180 provided, and each zoo's total population, a simple linear regression was used. To determine any
181 relationship between population size and space per animal (indoor and outdoor) a one-way ANOVA
182 with an interval plot was used. All diets fed were nutritionally analyzed using Zootrition® version
183 2.6. Dietary content of crude protein and acid detergent fiber (ADF), as well as provision of browse
184 and provision of enrichment (as differences between zoos) were evaluated using a one-factor Chi-
185 squared test.

186 **RESULTS**

187 Results have been split into demographic data, enclosure size and type data, diet and behavioral
188 management data. Overall, results show there to be specific differences between the average size of a
189 wild herd and the sizes of herds managed by these zoos (Figure 1), as well as between the home range
190 size of wild banteng and accessible space within these zoos (Figure 5). There is a trend for zoos with
191 larger herds to provide the animals with more outdoor space, but this is a very weak relationship
192 (Figure 3). We also found that banteng are currently maintained with a wide range of different species
193 in MSE (Table 2), and that diets fed show no significant variation in key nutrients between collections
194 (Figure 6).

195 **Demographics**

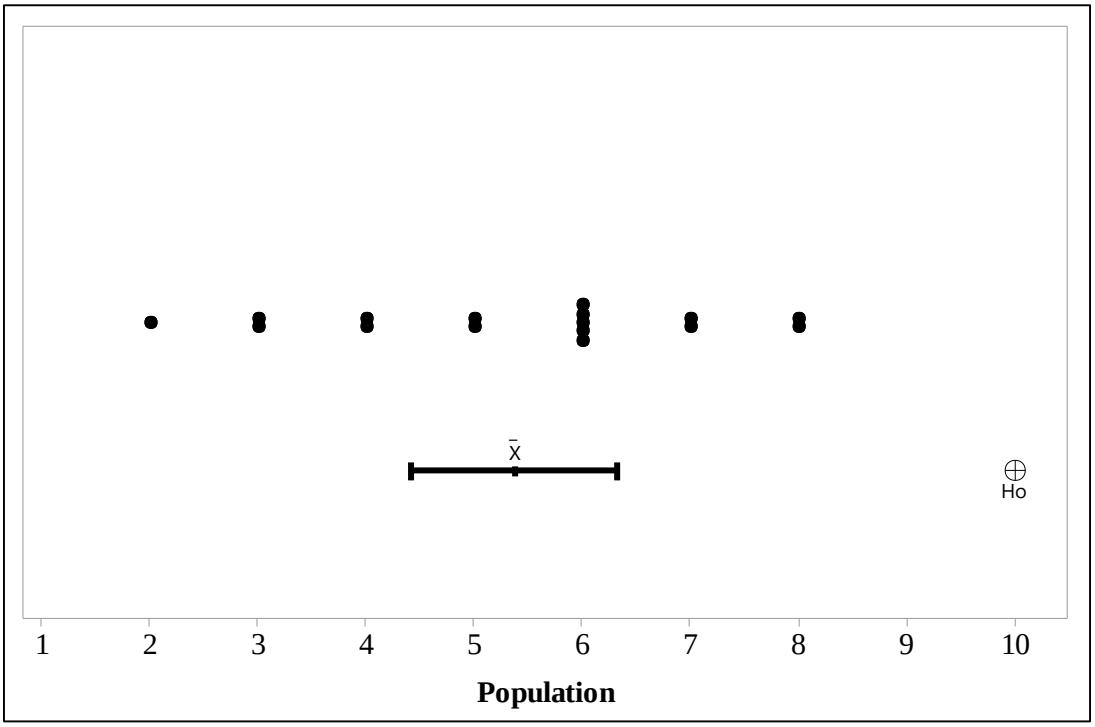

Figure 1: comparison of zoo population size against an average wild herd size (H0). Mean of captive population given as X with 95% confidence intervals. Using data from Groves et al. [2011] and Gardener et al. [2014], and taking a median wild herd size of ten shows that zoos are holding herds smaller than may otherwise occur naturally.

There is a strong significant difference between captive and wild group size (t= -10.37; df= 7; P<0.001), as shown by Figure 1. Whilst adult bulls can be solitary outside of the breeding season and young bulls may be found in pairs or trios, the basic social system for banteng is a female-centered herd lead by older cows. When reviewing data from Gardener et al. [2014] there may be a much higher deviation from wild herd structure present as free-living herds of 30 animals may be regularly recorded.

Enclosure

Figure 2 shows there to be differences between each zoo when comparing space provided in outdoor and indoor enclosures. Outdoor space: χ^2= 115069; df= 15; P<0.001. Indoor space χ^2= 366.66; df = 11; P<0.001. However, there is no significant difference between each zoo's total population size and the amount of space provided per animal (outside, F= 0.61; df= 6; P= 0.717; indoor, F= 0.24; df= 6;

P= 0.950). A weak association between herd size and total outdoor space provided is noted (Figure 3) and this relationship may tend towards significance with the inclusion of more institutions. It is possible that zoos may be building capacity for increased growth in herd size in the future and this may also explain the lack of significance between herd size and indoor space provision (Figure 4). All but two collections were intentionally trying to breed their banteng.

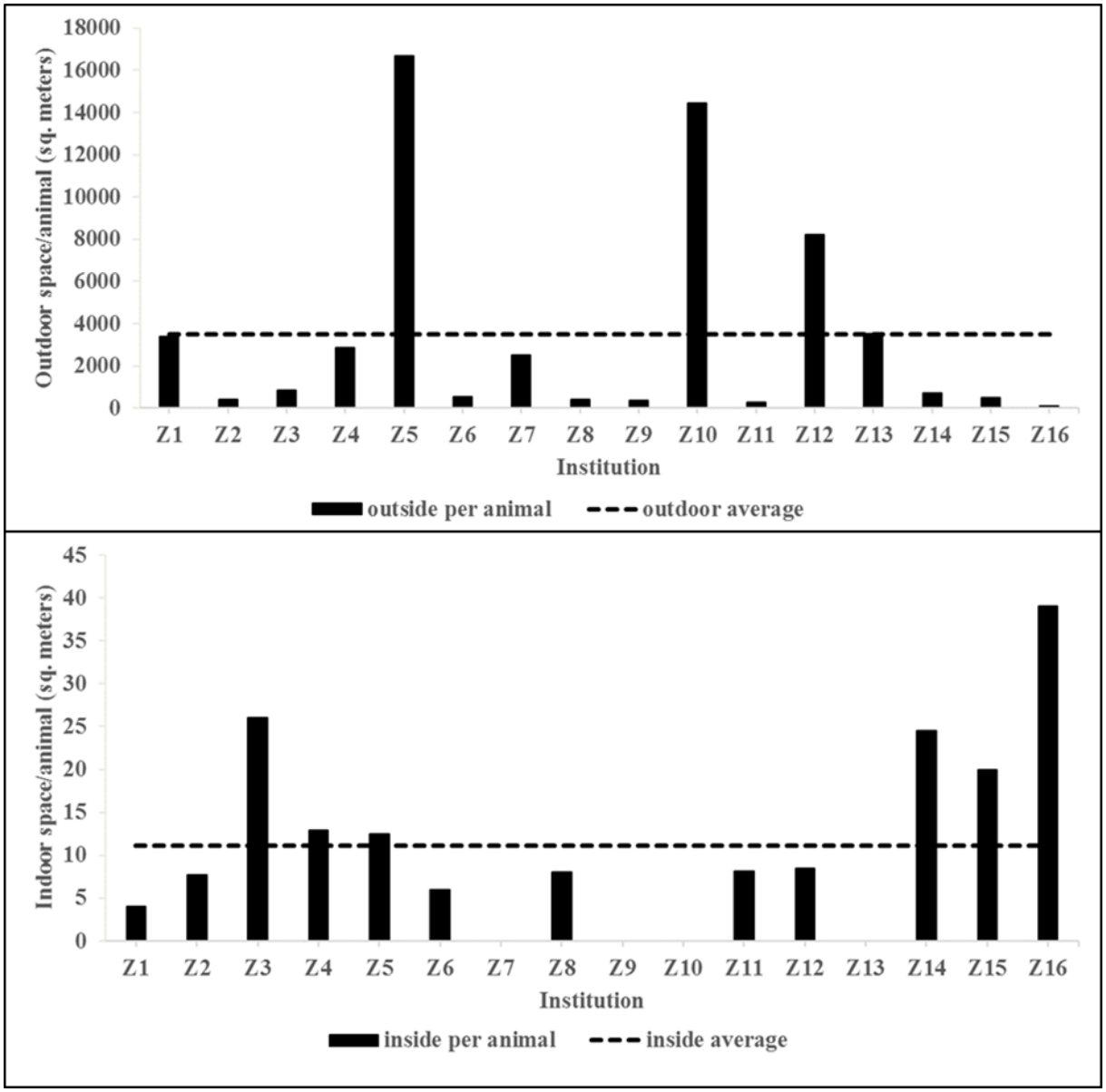

Figure 2: space per individual animal provided by each zoo against the overall average from all responses. Top: outdoor space, below: indoor space. Dashed line shows the mean across collections. As some collections did not have indoor housing for their animals this was not included in the calculation.

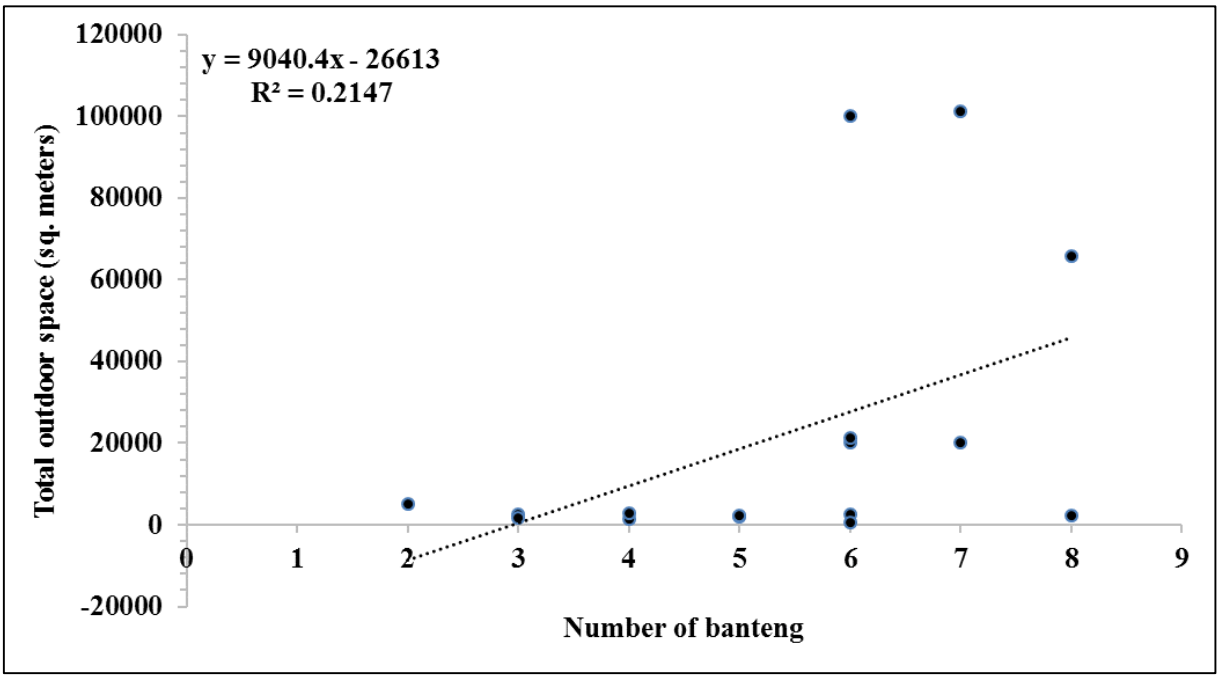

Figure 3: linear regression showing a weak relationship between larger herd size and outdoor space provided, which may tend towards significance with a larger sample size (P=0.071).

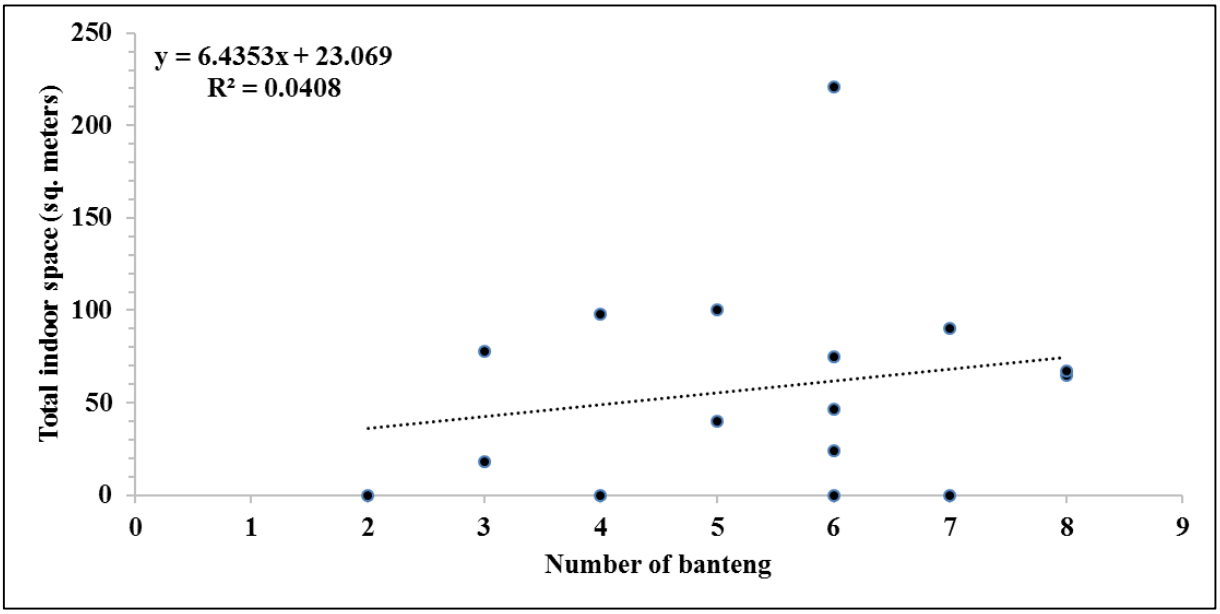

Figure 4: linear regression showing no relationship between herd size and indoor space at each zoo (P = 0.715).

When comparing space provision in the zoo to population density in the wild, there is an evident discrepancy between wild home range size and zoo enclosure sizes (Figure 5). Data on wild banteng population density are hard to find. Values in published literature range from 0.3 animals/per km^2 in Huai Kha Khaeng Wildlife Sanctuary in Thailand [Prayurasiddhi, 1997], to one animal/km^2 in Ujung Kulon National Park in Java [Hoogerwerf, 1970] and four animals/km^2 for the non-native population of northern Australia [Bradshaw et al., 2007].

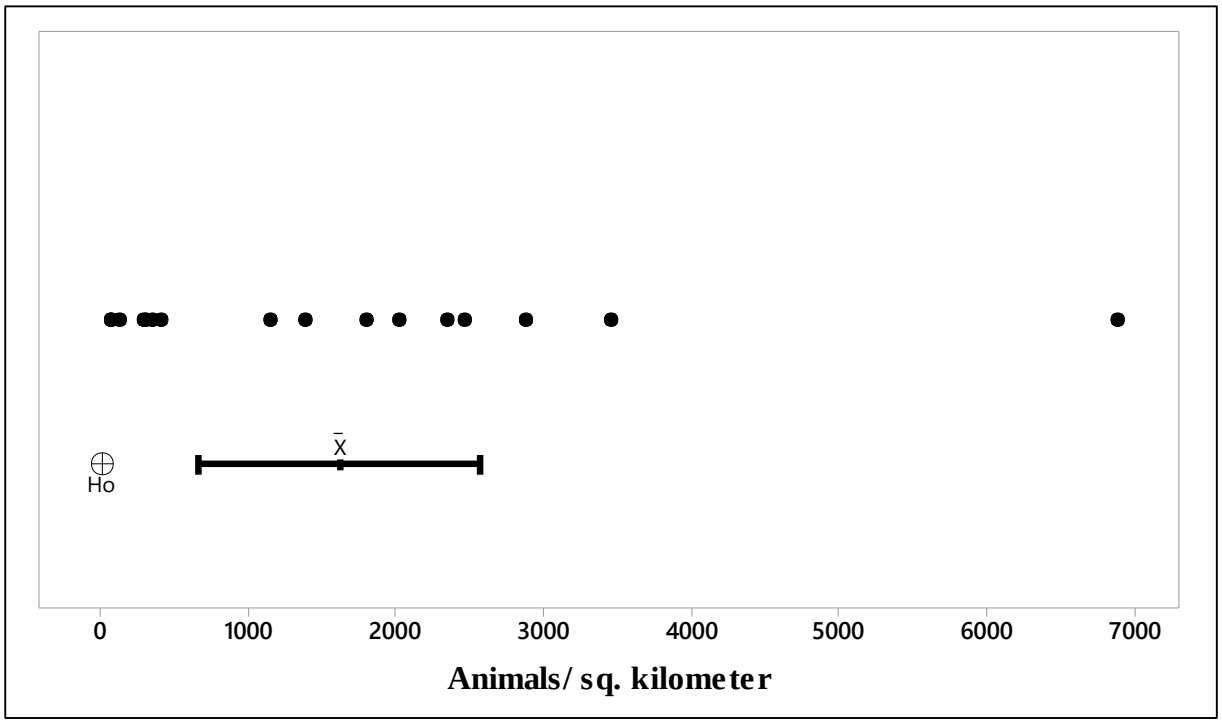

Figure 5: Plot showing the stocking density of captive herds when compared to wild populations. Hypothesized mean taken from literature given as H0 and calculated mean of sample population (with 95% confidence internals) indicated.

Taking the highest free-roaming stocking density of four banteng/km^2 from Bradshaw et al. [2007], and comparing to calculated animals/km^2 densities from these zoo survey data, there is a highly significant difference in captive stocking density when compared to wild home ranges ($t= 3.61$; $df= 15$; $P= 0.003$). Zoos with smaller enclosure areas (total of indoor and outdoor space) have a higher number of banteng per available square kilometer. Observations of a previously-captive herd released into the wild showed that animals used an area of around 8km^2 [Prayurasiddhi, 1997].

When assessing MSEs, there is no significant relationship between the size of each zoo's exhibit and whether it contains multiple species (F= 2.67; df=1; P= 0.125). However, as can be seen in Table 2, a number of different MSE combinations were noted across the completed surveys. This popular method of display is another pertinent area for future research.

Table 2: List of the range of species used in multi-taxa exhibits, showing the number of zoos that house each species with banteng.

Ungulates	
Domestic water buffalo *(Bubalus bubalis)*	1
Blackbuck *(Antilope cervicapra)*	5
Chinese goral *(Nemorhaedus griseus)*	1
Fringe-eared oryx *(Oryx beisa callotis)*	1
Nilgai *(Boselaphus tragocamelus)*	2
Scimitar horned oryx *(Oryx dammah)*	1
Sichuan (Tibetan) takin *(Budorcas taxicolor tibetana)*	1
Speke's gazelle *(Gazella spekei)*	1
Transcaspian urial *(Ovis orientalis arkal)*	1
Bactrian camel *(Camelus bactrianus)*	1
Axis deer *(Axis axis)*	1
Bactrian deer *(Cervus elaphus bactrianus)*	1
Barasingha *(Rucervus duvaucelii)*	1
Burmese brow-antlered deer *(Panolia eldii thamin)*	4
Fallow deer *(Dama dama)*	1
Indian hog deer *(Axis porcinus)*	3
Pere David's deer *(Elaphurus davidianus)*	3
Reeve's muntjac *(Muntiacus reevesi)*	3
Sika deer *(Cervus nippon)*	5
Grevy's zebra *(Equus grevyi)*	1
Persian onager *(Equus hemionus onager)*	1
Przewalski's horse *(Equus ferus przewalskii)*	1
Greater one-horned rhinoceros *(Rhinoceros unicornis)*	1
Primates	
Siamang *(Symphalangus syndactylus)*	1
Pig-tailed macaque *(Macaca sp.)*	1
Aves	
Sarus crane *(Grus antigone)*	2
Ostrich *(Struthio camelus)*	1

Diet

Review of diet provision across institutions (with browse excluded from analyses) shows no significant difference between offered values of protein ($\chi 2$= 154.5; df= 15; P=1.000) and ADF ($\chi 2$= 454.6; df= 15; P=0.887). As can be seen in Figure 6 zoos seem to be offering similar levels of fiber and protein to their banteng, however as this is for forage, produce and pelleted feeds only, values may change when browse, grazing and natural foraging is included too.

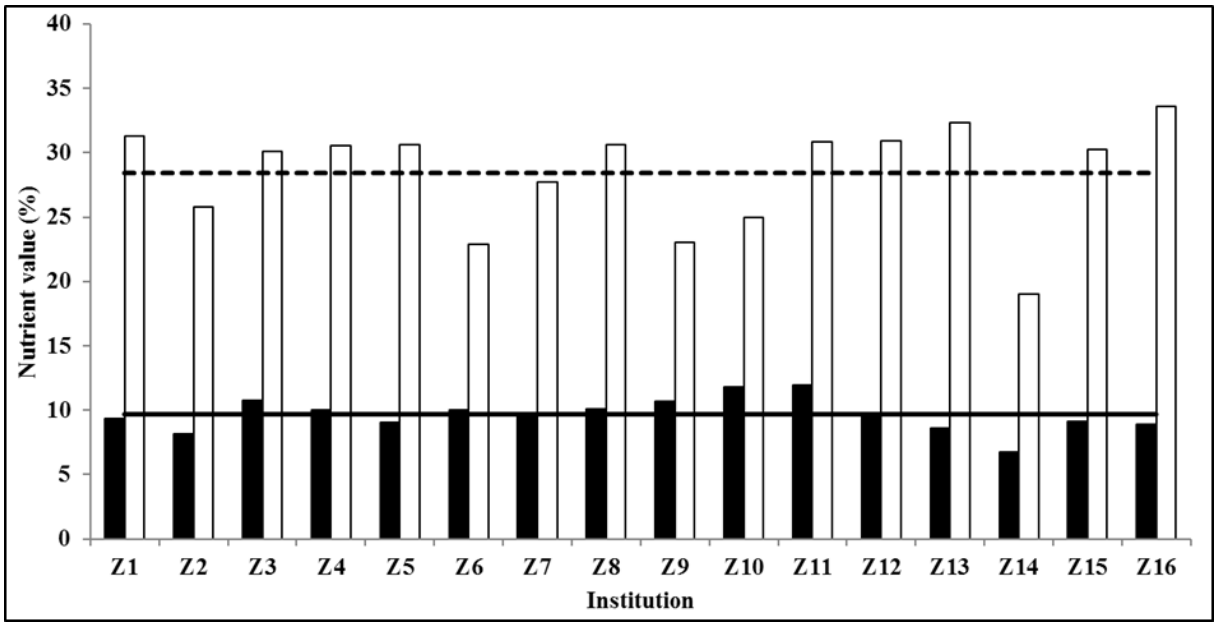

Figure 6: values for crude protein and ADF for all 16 zoos surveyed. Black bar = crude protein values; white bar = ADF values; solid black line = crude protein average; dashed black line = ADF average.

Behavioral management

The majority of zoos provided browse as part of regular husbandry routines (Figure 7), only 25% performed any positive reinforcement training (PRT) with their animals and ~1/3 zoos provided enrichment (that was not in the form of browse). Only two collections noted historic occurrence of stereotypic behaviors in their animals in the form of self-mutilation on exhibit barriers and excessive licking of calves.

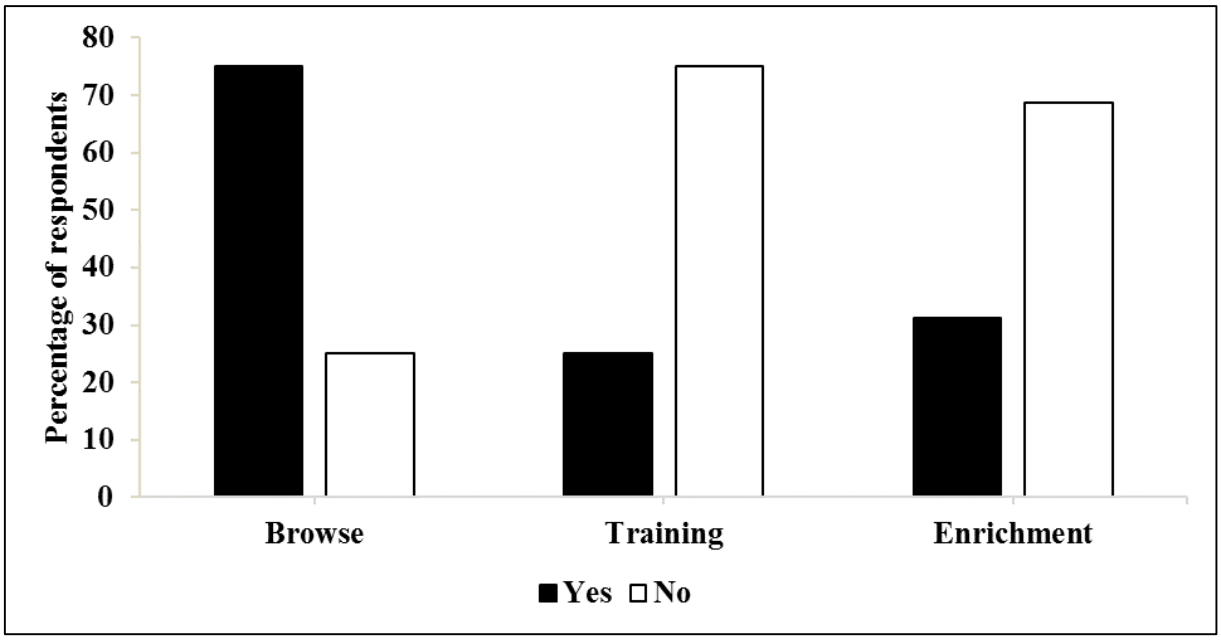

Figure 7: behavioral management of banteng. Black bar = yes; white bars = no.

Enrichment provided was detailed as: scatter feeds, use of ice blocks, moving log feeders, spices and scents rubbed around the exhibit, and food provided in waterways. Some zoos also considered other animals around the banteng to be enriching (e.g. live fish that were also resident in the waterways in the banteng's enclosure). Table 3 contains a breakdown of enrichment provision by zoo, alongside other factors of management. The diversity of behavioral management approaches can be clearly observed.

Table 3: A summary of total population, overall enclosure size (both indoor and outdoor), exhibition type (MSE or not), frequency of enrichment provision and occurrence of training.

Zoo I.D.	**Total number of animals**	**Indoor enclosure size (m^2)**	**Outdoor enclosure size (m^2)**	**MSE?**	**Enrichment Schedule**	**PRT**
Z1	6	24	20234	Yes	Weekly	No
Z2	6	46.19	2520.5	No	None	No
Z3	3	78	2560	No	Weekly	Yes
Z4	7	90	20020	Yes	None	No
Z5	6	75	100075	Yes	None	No
Z6	3	18	1658	Yes	None	No

Z7	2	N/A	5000	Yes	None	No
Z8	5	40	1995	Yes	None	No
Z9	4	N/A	1389	No	Daily	Yes
Z10	7	N/A	101171	Yes	None	Yes
Z11	8	65	2255	Yes	Weekly	Yes
Z12	8	67.35	65796.55	Yes	None	No
Z13	6	N/A	21153	Yes	None	No
Z14	4	98	2794	No	Weekly	No
Z15	5	100	2389	Yes	None	No
Z16	6	221	651	No	None	No

DISCUSSION

These results show that there are areas of good husbandry that are clearly beneficial to positive welfare for captive banteng. Relevant management practices include the maintenance of herd gender ratios that reflect occurrence in natural systems, as well as the regular provision of browse in a high proportion of the institutions sampled.

There is a disparity between the size of a wild banteng's home range and the overall space available to those housed in the zoo (Figure 5). Data from Bradshaw et al. [2007] were chosen for this comparison as their results were thought to be most comparable to space provided in a captive setting; whilst these banteng were not in a native range state, they would still be experiencing a naturalistic activity pattern with freedom to travel and move widely, therefore making a relevant benchmark for an investigation into wild versus zoo housed space use. Whilst it may not always be feasible to provide all captive species with the same quantity of space as lived in by free-roaming individuals, it is important to consider the impact of any potential space restriction on natural behavior patterns. More research is needed into banteng behavioral ecology to determine if there is a strong motivational need to travel over long distances, or whether banteng are content in smaller areas if all required resources are provided. It is well known that in some species with roaming tendencies welfare can be compromised by restrictive captive space [Clubb and Mason, 2003; Mason, 2010]; such information is not documented for many ungulate species and this could pose a useful research area for the future.

Demographic information

Results show that the single mature male to multiple mature female social system that typifies the species in the wild [Gardener et al., 2014; Groves et al., 2011] is mirrored in the institutions surveyed, although captive herd size is shown to be significantly smaller than wild herd size. It is acknowledged that the size of social groupings needs to be considered when managing captive animals for optimum welfare [Swaisgood & Schulte, 2010; Price and Stoinski, 2007], however animals maintained in captivity face different environmental pressures to wild conspecifics and therefore plasticity with regards to group size is deemed appropriate [Estevez et al., 2007].

At the time of data collection, no zoos provided information on bachelor herds being maintained, however since the survey was undertaken, information on management of an all-male herd at one US facility has been forthcoming. Currently, the Saint Louis Zoo manages young male banteng in a single-sex social group, to then distribute animals to other institutions as and when needed [M. Fischer, personal communication]. As evidence exists for the presence of bachelor herds *in-situ* [Gardener *et al.* 2014], such a management option is clearly biologically feasible (and natural to banteng social structure) should needs arise within the captive population. The change in status of banteng in North America, where the species is no longer in an SSP [B. Huffman, personal communication], raises an interesting question of whether these animals are being kept solely for display or for future captive breeding potential. It may be that program managers for banteng do not currently have a need to encourage numerous zoos to create bachelor herds to meet their program goals, i.e. limited numbers of surplus male individuals or limited need to hold non-breeding males outside of another group. As wild bachelor groups are regularly seen and given that this is one aspect of banteng sociality that zoos have not fully explored, investing time to determine optimum formation and management of bachelor groups could increase productivity and/or breeding rates to better reach sustainability should this be required in the future. As only two of the zoos contacted said they were not intentionally breeding (at that time), it is likely that banteng numbers in captivity will continue to increase and such single-sex management methods will become more common.

Enclosure space, features and occupants

There are significant differences between the sizes of each zoo's enclosure (Figure 2), as would be expected based on the locale of each collection and whether it is rural or urban. However, it does not appear that herd size or whether banteng are housed in a single species or MSE can predict how much space will be provided for them (Figures 3 and 4). As previously suggested this could potentially be explained by the fact that zoos may be incorporating plans for future expansion in the number of animals held in a herd, or even linked to the range of zoological institutions included in the responses. It is widely acknowledged that the environments provided to wild animals in captivity vary between safari parks and traditional zoos [Hosey et al., 2009]; with both types of institution represented in this survey it is possible that this factor has influenced the results. The lack of relationship between total herd size and enclosure size highlights the potential need for a minimum space requirement for captive banteng. Such a concern is legitimate due to the need for zoo animals to have suitable amounts of space to promote good overall physical and psychological health [Clubb and Mason, 2007; Mason et al., 2013], and to allow for the expression of important natural behaviors [Nicol, 2007]. With minimum space requirements per animal often provided in existing husbandry manuals, further investigation into whether or not space provision is a welfare concern for captive banteng needs to be carried out to inform future best practice guidelines should they be produced.

The majority of these banteng holders maintain their animals in MSEs (Table 3). This fact, plus the wide range in other taxa included in these MSEs (Table 2), suggests that it is possible to mix banteng successfully and hence add to their visitor interest and educational value. MSE are noted as having increased conservation value in zoos as they are believed to further engage visitors by improving aesthetics (increased activity levels when animals are on show) and, when the appropriate species are selected, providing an accurate representation of natural systems [Dalton and Buchanan-Smith, 2005; Hosey et al., 2009; Veasey and Hammer, 2010]. In some cases, the multi-species interactions provided by a MSE can be enriching for the animals themselves [Coe and Klein, 1986; Forthman, 1998; Hosey et al., 2009; Leonardi et al., 2010]. Using wild ecological information on interspecies encounters, such as niche separation [Heymann and Buchanan-Smith, 2000], can enable stable and positive MSE to be created. Even though many of the species detailed in Table 2 would not naturally

encounter one-another in the wild (including blackbuck, as the most frequently mixed species) the educational, value-adding and enriching effects of MSE justify their use for banteng.

Diet and feeding practice

A lack of any significant difference in values for crude protein and ADF in each zoo's diet (Figure 6) shows that, at least in terms of nutrients provided, nutritional husbandry of banteng can be considered relatively consistent between collections. However, such consistency of provision cannot be deemed an indication of overall dietary efficacy and may instead merely refer back to the idea presented in work by Melfi [2009], commenting on a tendency to focus only on avoiding poor welfare rather than on optimizing the care provided. Initially, this study aimed to compare values from zoo diets with recommended nutrient values for the species. As no such recommendations for banteng, or even for closely related taxa, were forthcoming, and only recommendations for domestic cattle in production systems were found, such analyses were not possible. These lack of comparative data and also of any investigations into potential consequences associated with poor diet further reinforces the need for wild cattle dietary research to provide zoos with the tools needed to evaluate what they feed and how it is fed to captive wild bovids.

The provision of browse to banteng by 79% of the responding institutions is encouraging as it reflects the species' flexibility in wild foraging style and that free-living banteng will seasonally utilize browse when needed [Gardener et al., 2014; Groves et al., 2011]. Such a finding also reflects the move away from browse being seen as an "optional extra" for ruminant ungulates, and one that is an important requirement for maintaining sound digestive health and natural behavioral repertoires. Pure grazers are not found in tropical rainforests [Bodmer, 1990] and such evidence supports the need for diet review in banteng. As a tropical forest bovid this species may require a much more diverse diet with more seasonal variation. Zoos should be commended for providing browse to their banteng, and we would suggest that all collections add browse to the daily diet of their animals whenever possible.

Behavioral management

379 With only a small number of institutions reporting that they undertook PRT and provided (non-
380 browse) environmental enrichment for their banteng, the behavioral management of this species is
381 another pressing area for further investigation. Despite the fact that only two institutions reported ever
382 having seen any abnormal behavior in their captive banteng, the welfare benefits of enrichment
383 provision [Carlstead and Shepherdson, 1994; Carlstead and Shepherdson, 2000; Newberry, 1995;
384 Robinson, 1998], and PRT schemes [Desmond and Laule, 1994; Laule, 2003; Laule et al., 2003] are
385 well-known in a growing number of zoo taxa. Such aspects of husbandry should be developed in
386 order to further achieve optimal management of banteng. One factor that may limit use of PRT and
387 environmental enrichment is the size of enclosures and the size of herds maintained. Being a
388 component of a social group is in itself enrichment, one can argue that banteng in larger herds are
389 automatically being provided with social enrichment. Likewise, larger enclosures can provide more
390 opportunities for social and spatial complexity (e.g. via a range of topography, substrates, and
391 opportunities for separation and aggregation) and hence such aspects of management are also
392 enriching to the banteng's environment. As choice and control are fundamental to positive welfare
393 states [Broom, 1991], those banteng in larger, socially-complex environments are potentially the
394 animals whose behavioral needs are most fulfilled. Therefore, zoos that provide the maximum outdoor
395 space feasible, with the largest manageable herd size, are providing an enriched experience for their
396 animals, as demonstrated in the low rates of abnormal behaviors noted from this survey.

397 Of the four collections that undertake PRT, three have outdoor enclosure sizes smaller than the mean
398 for this study population. And of the five collections that give (non-browse) environmental
399 enrichment, all have an outdoor enclosure smaller than mean. As such, it may be that zoos with
400 smaller exhibits provide more occupational enrichment for their banteng to account for reduced
401 outdoor space. Smaller enclosure sizes may also facilitate working with banteng in PRT and hence
402 explain why those zoos with larger exhibits are less likely to use this husbandry method. Interestingly,
403 there is no trend between a zoo's herd size and PRT or enrichment use.

404 We know that ungulates can respond well to the provision of enrichment [Rose and Roffe, 2013] and
405 the creation of an enriched environment [Rose and Robert, 2013] so there should be no barrier to

406 designing and implementing biologically-relevant enrichment programs for banteng. Gathering
407 evidence on wild activity budgets, promoting natural feeding and rumination periods [Baxter &
408 Powman, 2001] and using species-specific environmental enrichment may help enhance the display of
409 banteng to zoo visitors as well as ensure that all banteng held in zoos can achieve positive welfare
410 states and an excellent quality of life in captivity.

411

412 **CONCLUSIONS**

413 1. This husbandry survey shows that whilst captive banteng herd sizes are significantly smaller
414 than wild herd sizes, animals are maintained in biologically-appropriate sex ratios.
415 2. The size of enclosures provided to zoo-housed banteng are significantly smaller than potential
416 wild home range size, and total herd size does not predict the size of the enclosure provided in
417 captivity. Similarly, when banteng are exhibited with a variety of other species, such a MSE
418 approach does not predict a larger enclosure size.
419 3. When excluding browse and natural grazing/foraging, diets currently provided across these
420 institutions do not show significant variation in levels of crude protein or ADF.
421 4. If banteng are considered intermediate feeders, increasing the type and variety of browse and
422 forage, as well as factoring in seasonal changes to feeding style, could be beneficial to health
423 and welfare.
424 5. A minority of institutions carry out (non-browse) environmental enrichment and PRT; this
425 may be a factor of enclosure size. Nonetheless stereotypical behaviors are rare in this captive
426 population of banteng.
427 6. Captive banteng would further benefit from focused research into wild activity patterns,
428 optimal enclosure size based on their behavioral needs, and species-specific nutrient
429 requirements and diet presentation.

430

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