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Analysis of the nutritional components of Linnaeus's two-toed sloth *Choloepus didactylus* diets in UK and Irish zoos

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Abstract

Two-toed sloths *Choloepus* spp. are poorly studied folivores and currently lack species-specific research on the nutritional composition of their diet in the wild. Some studies have been published on zoo diets; however, direct comparison between collections is not common in the literature. A nutritional assessment was performed on nine zoo diets of *Choloepus didactylus* from eight zoological collections across the United Kingdom and Ireland. Diets were compared against one another to test if there were significant differences in the nutrient content between collections. Analysis focused on average dietary provision per sloth for the following nutrients: crude protein (CP), crude fibre (CF), Neutral detergent fibre (NDF), Acid detergent fibre (ADF), calcium (Ca), phosphorous (P) and nitrogen-free extract (NFE), which is an estimate of the easily digestible carbohydrates. Zootrition™ was used to determine the nutritional content of each diet. Results showed there were variations in the quantity of food provided per sloth as well as differences in the nutritional composition of diets between collections. Browse is recommended for this species; however, only five out of nine diets (56%) included browse. Compared to recent recommendations, all diets exceeded the minimum protein content recommended; however, fibre contents were lower than recommended. This may be due to limited browse and leafy vegetable provision in some of the diets. Browse is recommended for this species because it improves digestive health, increases overall NDF levels in the diets and reduces the NFE content. Conclusions drawn from this study highlight the importance of further nutritional research and consideration of published guidelines to improve the health and welfare of *C. didactylus* in zoos.

Introduction

Choloepus didactylus, commonly known as Linnaeus's two-toed sloth, Linné's two-toed sloth or the southern two-toed sloth (Superina et al. 2019), is one of six extant sloth species native to South America and currently listed as Least Concern on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Chiarello et al. 2022). *C. didactylus* is a solitary and strictly arboreal species that inhabits tropical lowland and montane forest distributed across South America (Kelleher and Ferguson 2019). Two-toed sloths are commonly kept in zoological collections to promote conservation efforts for this species and their natural habitat (Kelleher and Ferguson 2019), with a Species 360 Zoological Information Management System search showing 330 individuals in EAZA collections as of June 2024.

Nutrition is an integral part of the captive management of animals, as it plays a role in the prevention of disease and the longevity, growth and reproduction of a species (Dierenfeld 1997). Nutrition is also a major factor of The Five Domains Model, where it is involved in contributing to an animal's overall welfare state (Mellor 2017). Diets fed in zoological collections often reflect the needs of anatomically similar domestic species; however, the natural diet of a species should be studied carefully, and collections should strive towards replicating this in nutritional and physical aspects (Fens and Clauss 2024). Superina (2011) states that sloths are poorly studied folivores and their diets in zoos are different from those in the wild. There is currently a lack of species-specific research for *C. didactylus* and no published studies have directly analysed their diet in the wild (Chiarello 2008). Though recommendations on the captive diet of this species are available, i.e. Association of

Zoos and Aquariums (AZA) guidelines for sloth nutrition by Bissell (2021), direct comparisons between institutions are uncommon in the literature on this species. Common disorders associated with sloths in captivity include malnutrition and digestive diseases, such as abdominal distension, diarrhoea, stasis, rectal prolapse and dysbiosis (Vendl et al. 2016; Aguilar and Superina 2015). Inadequate nutrition could be a contributing factor, with both the nutritional content and food presentation playing important roles (Aguilar and Superina 2015).

In order to improve the welfare of *C. didactylus* in captivity, understanding their dietary needs as well as commonly used feeding approaches is necessary. Therefore, this study investigated and compared the nutritional components of diets provided to captive *C. didactylus* in zoological collections in the United Kingdom (UK) and Ireland.

Methods

This study was approved by the University Centre Sparsholt Ethics and Research Committee on 26 November 2020, ethical approval number UCS 0320.

Survey

Choloepus didactylus is commonly kept in zoos in the UK and Ireland, with 22 institutions housing a total of 51 individuals at the time of data collection (Species360 2024). A survey was distributed via email to all institutions in the UK and Ireland that could be found on the Zoological Information Management System (ZIMS) housing *C. didactylus,* in order to obtain animal records and diet sheets for each individual. The survey asked for the number of individuals, ages, sexes and groupings, any pregnant/ lactating individuals, health issues, provision of medication/ supplementation and any recent diet changes.

Eight institutions agreed to participate, and a total of nine diet sheets were obtained, due to one collection housing two pairs of *C. didactylus* with differing diets. A total of 15 animals were housed across the eight collections. The age, sex and groupings of *C. didactylus* varied between participating collections. All individuals were adults, and none were pregnant or lactating. No alterations were made to the way in which the animals were housed or the diet they were fed throughout this study. The ingredients and amounts listed on the diet sheets may be subject to change due to seasonal availability of food items; the diet sheets used in the present study were collected in late summer/ early autumn. Where weights were not specified for certain items, e.g. 1 stick of celery, an average as fed weight for this item was used. The amounts are self-reported amounts to be offered per day by each institution; whether they represent actually ingested amounts is unknown.

Data analysis

The analysis of each diet focussed on the following nutrients: crude protein (CP), crude fibre (CF), Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF), fat via ether extract (EE), nitrogen-free extract (NFE), calcium (Ca) and phosphorous (P). Five of the nine diets listed 'ad libitum browse' on the diet sheets, and due to the lack of specification of weights, collections were contacted, and whilst two collections stated that on average of 500 g as fed browse was provided, not all of this would be consumed. Cliffe et al. (2015) identified that (three-toed) brown throated sloths *Bradypus variegatus*, fed on leaf-only diets, consumed on average 195 g as fed leaves daily, which equated to 73 g dry matter. The NAG sloth nutrition guidelines (Bissel 2021) recommend an intake of 50 g as fed of leaf material, without explaining the rationale for this amount. For this study, it was assumed the two-toed sloths were consuming 73 g dry matter browse in any of the diets where browse is provided in addition to any other diet items. Where multiple species of browse were listed on the diet sheet, they were assumed to be consumed in equal quantities for calculation purposes.

The diets were created in a Microsoft Excel spreadsheet for one week and the average nutritional content for one individual daily was calculated. Amount of browse provided was estimated as detailed above. For all other items, as the diet items varied throughout the week, the whole weeks diet was entered into Excel, then amounts were divided by seven to get a daily average, and if diet applied to more than one sloth it was also divided by number of animals in the exhibit. The survey asked for details on food items which were routinely left over; no collections commented that this occurred regularly. The dietary management software 'Zootrition™ 2.7' (Dierenfeld 2021) was used to determine the nutritional content of the nutrients in each diet. Data on the nutritional composition of the fruits and vegetables were in the University Centre Sparsholt's copy of Zootrition™, as many of the food items have been previously analysed in the laboratory on site and uploaded to Zootrition, where any values were missing from food items these were completed from published research (Public Health England 2021: Schmidt et al. 2005: Schwitzer et al. 2009). The nutritional content of the species of browse provided in these diets was also determined using Zootrition™; however, some species were lacking in values. These gaps were filled in using average data from ZooPlants.Net. These values, as well as total ash, were then used to determine the Nitrogen-free Extract (NFE) content, in % DM, using the following equation: 100 – (CP + CF + EE + Total Ash), where all figures were % DM (Cherian 2020). Cultivated vegetables were categorised into starchy, watery and leafy for comparisons in the figures (Table 1).

Bissel (2021) gives recommendations for CP, NDF, ADF as

Table 1. Fruits and vegetables offered to the two-toed sloths according to survey results, including the grouping of vegetables in three categories.

Fruit	Starchy vegetables	Watery vegetables	Leafy vegetables
Apple	Butternut squash	Broccoli	Chinese leaf
Apricot	Carrot	Cauliflower	Kale
Avocado	Celeriac	Celery	Leafy lettuce
Banana	Parsnip	Courgette	Pak choi
Dragon fruit	Potato	Green beans	Rocket
Fig	Swede	Pepper (yellow/red)	Savoy cabbage
Grape	Sweetcorn		Spinach
Melon	Sweet potato		Watercress
Pear			
Plum			

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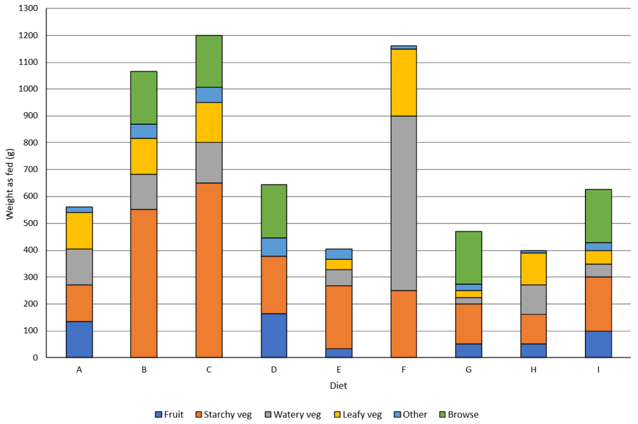

Figure 1. Comparison of the offered amounts of cultivated fruit, cultivated vegetables, browse and other food items in average daily diets at eight zoological institutions. Details on what the 'other' items in each diet were, can be found in the supplementary material. Note that these are amounts offered; whether these are actually ingested is not known.

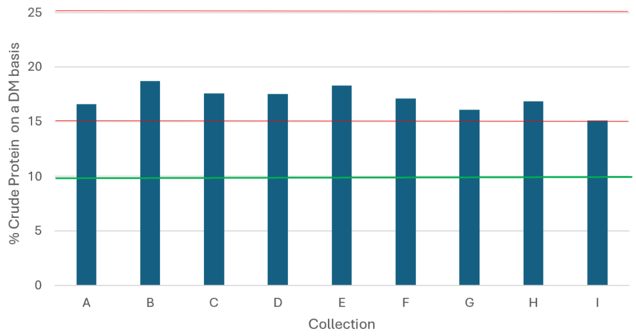

Figure 2. The percentage of crude protein on a dry matter basis in each diet. Red lines highlight the minimum and maximum concentration of protein recommended in the Bissel (2021) guidelines. These guidelines also state values as low as 10% are common and likely adequate, which is shown via the green line.

well as for Ca and P. The dietary levels of CP, ADF and NDF were statistically compared to these recommendations using a one sample t-test. The Ca:P ratios were calculated and found to be not normally distributed, and so were compared with the Bissel (2021) recommendations using a Wilcoxon Signed Ranked test. All inferential analysis was completed in Minitab 22.

Results

Sloths in the survey ranged from 6 to 25 years old, with a mean (SD) age of 13.4 ±6.9 years. Most collections (n=6) kept sloths in pairs (one male and one female in each pairing), with three collections housing a single sloth (two times a male, one female). Some of the sloths (Collections B, D, E, H, I) were kept in mixed species exhibits with species including callitrichids and birds. However, the diets outlined are those intended for just the sloths. Average weight of the sloths surveyed was 8.7 ±2.0 kg.

Figure 1 shows a comparison of amounts of fruit, vegetables, browse and other food items offered (on an as fed-basis). The reported amounts offered per animal had a large range, from 406 g as fed in E to 1200 g as fed in C. The majority of diets contained some cultivated fruit, and five of the nine diets had some browse included; for all of these, browse was provided for ad libitum consumption.

Diets had a narrow range of CP concentrations, ranging from Diet B with the highest content of CP (17.3 % in DM) and Diet I the lowest (15.3 %). All diets contained significantly more CP than the minimum level stated by Bissell ($T=5.71$, $p<0.001$, mean=17.1, SD=1.102), although most were at the lower end of the recommended range (15-25 % DM).

Figure 3 highlights the large variation in fibre levels across the diets. Bissell (2021) states that diets containing a minimum of 10–30% NDF (indicated by the red lines on the graph) and 5–15% ADF (indicated by the black lines) would be good targets for sloths.

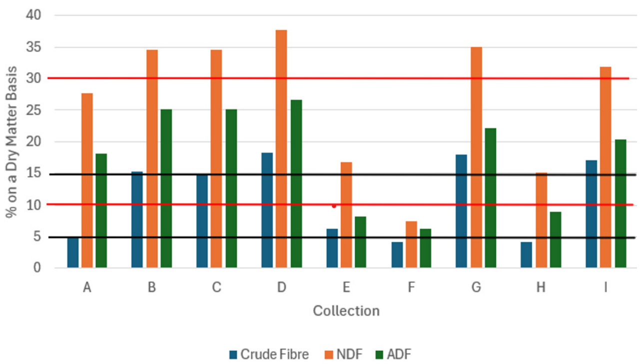

Figure 3. Percentages of Crude fibre, Neutral Detergent Fibre (NDF), and Acid Detergent Fibre (ADF) on a dry matter basis for each diet. Red lines indicate the recommended range of minimum NDF, and black lines the recommended range of minimum ADF concentrations in the diet from Bissel (2021).

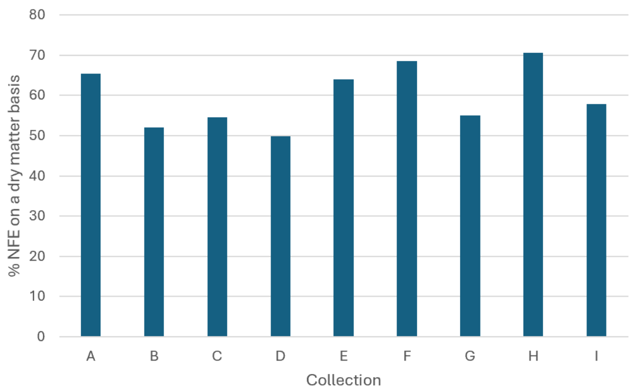

Figure 4. Percentage of Nitrogen-free Extract on a dry matter basis for each diet.

Table 2. Calcium: phosphorus ratios on a dry matter basis

A	B	C	D	E	F	G	H	I
2.85:1	3.4:1	3.3:1	5:1	6.9:1	1:1.03	6.93:1	1.8:1	5.4:1

Based on this, the diets, on average, significantly exceed the lower range of the minimum recommendation for NDF, i.e. 10 % DM (T=4.63, P=0.001), with all but one of the diets analysed (F) in or above the minimum recommendation range. This particular diet was composed of over 50% watery vegetables. All diets significantly exceeded the lower range of the minimum recommendation for ADF (T=4.81, P=0.001). There are no recommended values for crude fibre.

Nitrogen-free Extract levels ranged from 50 % to 71% of the dry matter content (Figure 4).

Only one diet did not meet the minimum recommended values for Ca, one was in the recommended range, and seven diets exceeded the maximum values from Bissell (2021) (Figure 5). By contrast, P concentrations were mostly below or at the low end of the range recommended by Bissell (2021) (Figure 5). Five of the diets did not meet the minimum requirements for phosphorous with diet F having less Ca than P. The Ca:P ratios of the diets were on average significantly greater than the recommended 1.4:1 ratio (W=43, P=0.009). No diets meet the requirements for a Ca:P ratio between 1 and 1.4:1.

Table 3 shows the diets in this study that include browse, along with the species utilised in each diet and when they are provided throughout the year. Table 4 shows the nutritional content of the browse species listed in the diets analysed.

Discussion

Diet composition and amounts

The total weights of the diets provided per individual sloth per day varied considerably between collections. The highest quantity of food offered (1200 g) was three times the amount provided in the lowest quantity diet, Diet H, with a total as fed weight of 400 g daily, as this collection did not provide browse. Cliffe et al. (2015) stated that strictly folivorous brown throated sloths *Bradypus variegatus* consume around 195 g as fed of leaves daily, much less than the amounts offered to *C. didactylus* in the collections reviewed for this study. However, brown-throated sloths are a smaller species, so it would not be unexpected for two-toed sloths to consume more food. Additionally, some sloths were housed in mixed-species exhibits, and while collections did not report excess food being left over each day, it is unknown how much was consumed by the other species in the exhibit. This study highlights the considerable variation in the amount of food fed to captive *C. didactylus.*

Diets consisted of a range of components including vegetables, fruit, browse, leaf-eater pellets, a commercial high fibre pellet designed for folivorous primate species, and boiled eggs. Four of the nine diets did not include any fruit, as in another reported diet that excluded fruit to reduce sugar content (Kelleher and Ferguson 2019). Cultivated fruit has been shown to contain higher levels of sugar and metabolisable energy, and lower levels of dietary fibre compared to wild fruit (Schwitzer et al. 2009). Many zoos have implemented fruit-free diets across a range of species, particularly primates (Hammerton et al. 2019), reducing the sugar content and increasing the fibre content, and as a result decreasing the prevalence of dental issues, obesity and digestive upset (Plowman 2013). Two individual sloths in this study had previously suffered from dental issues, resulting in teeth being extracted. Sloths lack

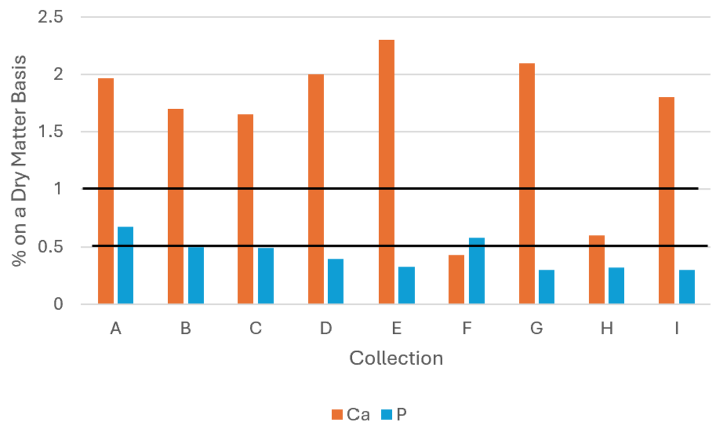

Figure 5. Percentage calcium and phosphorous content on a dry matter basis for each diet. Black lines show the minimum and maximum recommended concentration of both calcium phosphorous from Bissel (2021) guidelines.

Table 3. Species of browse provided to the relevant diets

Diet	Species of browse	Provision
B	Silver birch *Betula pendula* Hazel *Corylus avellana* Common lime *Tilia cordata* Sycamore maple *Acer pseudoplatanus* White poplar *Populus alba* White willow *Salix alba*	All year round
C	*B. pendula* *C. avellana* *T. cordata* *A. pseudoplatanus* *P. alba* *S. alba*	All year round
D	*S. alba* *T. cordata*	All year round
G	*S. alba*	When seasonally available
I	*S. alba*	When seasonally available

enamel on their teeth (Cliffe 2016; Montgomery 1978), so it can be assumed that this makes them more susceptible to the damage caused by a fruit-containing diet. Higher sugar diets in other hypsodont species, like equids, are associated with an increase in tooth demineralisation (Jackson and Kelty 2023). This poses the question whether a fruit-free diet should be more widely implemented.

It is worth noting that our analysis was based solely on the information provided by each collection on their diet sheets. Bond (2001) reviewed *C. didactylus* diets at Bristol Zoo and found that the diet actually offered often varied from that on the diet sheet. Also, the level of detail on the diet sheets varied, with some having specific weights in grams for each item and others just stating the number of items e.g. one carrot. This was also highlighted as an issue for dietary studies by Bond (2001) as they found the weight of a carrot varied from 54 g to 180 g. For the current study, it was not possible to travel to all of the collections to get more accurate weights of the food provided. It would be beneficial for future studies to obtain the specific weights of each item provided and also weights of any food not consumed, for an accurate account of what is consumed, rather than just what is being offered. This would also allow an accurate assessment of the nutrient composition of the actually consumed diets.

Collection I provided food three times a day, collections B, C, E and G twice per day and other collections fed once per day. Data were not collected on the methods of feeding; however, this should be considered in future studies. USDA (2024) recommends chopping food items into long thin pieces to aid sloths grasping them. *C. didactylus* are nocturnal (Cliffe et al. 2023); it would also be worthwhile considering this when deciding the time point in the day food is provided.

An area highlighted in this research includes variation in the quantity of food provided between collections. As well as this, the items that make up the diet vary, including the provision of browse, with only five out of nine diets providing browse. Bissel (2021) states that providing a regular rotation of browse is critical due to sloths not consuming one species of browse for an extended period. It is recommended that browse be rotated, with every three days to two weeks being typical; however, only two of the diets in this study provided three or more species of browse.

Table 4. Nutritional content of leaves and twigs of the browse species provided in diets on a dry matter basis (Zootrition and ZooPlants.net).

Nutrient	*B. pendula*	*C. avellana*	*T. cordata*	*A. pseudoplatanus*	*P. alba*	*S. alba*
CP (%)	14.2	14.5	10.7	18.4	16.8	19.5
CF (%)	27.8	16.3	19.1	20.6	22.1	
NDF (%)	37.3	29.3	30.7			19.8
ADF (%)	28.5	18.1	27.0			12.2

Diet nutrient contents

All of the diets offered met the minimum recommended crude protein values, and none of the diets exceeded the maximum values suggested by Bissell (2021). High levels of protein in sloth diets have been associated with kidney disorders, including urolithiasis (Rappaport and Hochman 1988). As a result, it is recommended that the amount of protein provided in captivity should not be excessive (Dünner Oliger and Pastor Nicolai 2017). The 'other' diet component, particularly the boiled eggs and leaf eater pellets, had higher protein levels than the other category ingredients. In the diets reviewed in this study, these items were provided in small amounts each week; however, if larger portions of these items were provided this may be a concern.

All diets that did not provide browse were lower in crude fibre, NDF and ADF; however, all diets still met the minimum recommendations for ADF and all but one met the minimum recommendations for NDF suggested by Bissell (2021). Dünner Oliger and Pastor Nicolai (2017) recommend that adult sloths of any species should be provided with 10-15% of their body weight in fresh browse daily; this amount exceeds reported food intake data for sloths, but might be based on a strategy to offer surplus to facilitate leaf selection by the animals. A review of Species360 data showed zoo-housed *C. didactylus* weigh on average 8.7 kg. This suggests that sloths should be provided at least 800 g as fed browse daily, which is a lot more than the amounts offered to sloths in this study. Whether the recommendation of 800 g fresh browse per day may be excessive cannot be decided to date.

The diets that contained browse were all higher in both NDF and ADF than the diets that did not contain browse, showing the benefits of including this in diets. The only diet that failed to meet the minimum recommended amount of NDF suggested by Bissell (2021) consisted of 50 % watery vegetables, 22 % leafy vegetables and no browse. As mentioned previously, cultivated fruit and vegetables are lower in fibre than wild fruit (Schwitzer 2009); however, leafy green vegetables generally have the highest fibre content among commercially available produce. Diets A and H also contained no browse but had proportionally higher levels of leafy green vegetables in the diet, allowing them to achieve more than the minimum recommended NDF levels. In sloths, diets with low levels of fibre can cause overgrown teeth, bloating and constipation, all resulting in further complications (Diniz and Oliveira 1999; Almeida et al. 2023).

Folivorous primate diets in natural habitats in South American species have fibre levels of 43-57% NDF and 33-41% ADF in DM (NRC 2003). The National Research Council (2003) suggested 30% NDF and 15% ADF in DM as fibre concentrations for folivorous primates under human care. This suggests that it may be adequate to aim for the top end of the current recommendations for sloths (Bissell, 2021; based on the NRC (2003) recommendations for primates) to achieve similar fibre levels as in their wild diets. Faecal scoring can be used to help assess if diets are meeting individual sloths' fibre requirements (Bissell 2021), so faecal consistency should be assessed regularly.

Diet H contained the highest NFE content (71.8%) and Diet D contained the lowest content (49.9%). A high NFE content indicates non-structural carbohydrates, including sugar and starch, with captive diets typically containing high NFE levels and much lower fibre levels than wild diets (Britt et al. 2015). Commercial fruits and vegetables are higher in NFE and lower in fibre than wild items, so the diets higher in fruit and vegetables are generally higher in NFE. Although there are no data on natural diets to compare to, Dünner Oliger and Pastor Nicolai (2017) acknowledge that the natural diet of both *Bradypus* and *Choloepus* spp. contain low levels of non-structural carbohydrates, and that a diet high in these nutrients could cause bloating, resulting in several health issues, including anorexia, atony, colic and dyspnoea in severe cases. The levels of fruit and starchy vegetables in the diet should be reviewed to reduce the NFE content, replacing these with higher fibre items like browse and leafy green vegetables.

Only one diet fell below the recommended concentration of calcium, and all the diets except this one exceeded the maximum values recommended by Bissell (2021). Several of the ingredients in the diets have higher calcium levels than the recommended maximum level of calcium, including the leaf eater pellets and much of the leafy green vegetables. The calcium to phosphorus ratios were mostly higher than the maximum recommended ratios, apart from Diet F where the phosphorus levels were higher than calcium. Most mammals have a recommended Ca:P ratio of between 1:1 and 2:1 and 1:1, so the 1:1-1.4 ratio range recommended by Bissel (2021) is not unexpected; however in other foregut fermenting species recommendations are closer to 2:1 (Böswald et al. 2021). Hypercalcemia and soft tissue mineralisation has been reported in zoo-housed sloths (Han and Garner 2016), especially in individuals given vitamin D, calcium and/or phosphorus supplementation, so the concentration of each of these nutrients in the diets should be reviewed. Diets containing 0.75-1% calcium and 0.5-0.75% phosphorus could allow for a balance of these nutrients whilst not providing an excess of either nutrient. However, this may be difficult when following the recommendation to provide browse. Wild sloths consume leaves from a range of trees in the wild, with Alvarez et al. (2004) highlighting 28 different species including fig trees (*Ficus* spp.). An analysis of the mineral content of fig leaves showed that they are high in calcium with a mean concentration of 4.3 % in DM, whereas phosphorus only averaged at 0.1 % in DM (Bougiouklis et al. 2020). Whilst fig leaves only represent a part of the wild diets, this may indicate that sloths are adapted to diets higher in calcium.

Vitamin D levels can also impact on calcium absorption, so further research should consider the balance of these three nutrients, as the present study does not indicate how much of the calcium provided is being absorbed. It was not possible to assess vitamin D levels in this study's diets due to limited data on Zootrition for vitamin D.

Since this study was conducted, at least two companies have produced commercial diet aimed at sloths that declare reduced vitamin D and calcium content compared to primate diets (Mazuri n.d., Granovit n.d.), showing industry interest in reducing these components in the sloth diets.

The results of this study highlight the inconsistencies that exist between zoological collections in the UK and Ireland regarding the nutrition of captive *C. didactylus.* Conclusions drawn from this study indicate that there are substantial differences in the diets that are provided to this species between collections. Unfortunately, these results could not be compared to wild data for *C. didactylus.* However, this study highlights the need for further research in this area. Comparisons to currently existing recommendations for sloths suggest that despite the variation between collections, most are meeting many but not all of the nutritional requirements. The levels of the amount of calcium, phosphorus and vitamin D would benefit from further consideration. Diets providing fruit were higher in NFE. Whilst no negative impacts on the health of the sloths in this study were reported, it would be worth reviewing if fruit should remain in these diets. Browse and leafy green vegetables appear to be essential in meeting the fibre requirements and reducing the amount of non-structural carbohydrates in the diet. Whether these items are problematic in terms of hypercalcaemia requires further investigation.

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