Chapter 6. Nutrition

6.1 Nutritional Requirements

A formal nutrition program is required to meet the nutritional and behavioral needs of all species (AZA Accreditation Standard 2.6.2). Diets should be developed using the recommendations of nutritionists, the AZA Nutrition Scientific Advisory Group (NAG) feeding guidelines (http://nagonline.net/guidelines-aza-institutions/feeding-guidelines/), and veterinarians as well as AZA Taxon Advisory Groups (TAGs), and Species Survival Plan® (SSP) Programs. Diet formulation criteria should address the animal's nutritional needs, feeding ecology, as well as individual and natural histories to ensure that species-specific feeding patterns and behaviors are stimulated.

> **AZA Accreditation Standard**
>
> **(2.6.2)** The institution must follow a written nutrition program that meets the behavioral and nutritional needs of all species, individuals, and colonies/groups in the institution. Animal diets must be of a quality and quantity suitable for each animal's nutritional and psychological needs.

Gibbons are arboreal and forage for food in the upper forest canopy (Brockelman et al., 2014). Very rarely descending into the understory, the gibbon usually feeds in the main canopy or the emergents of their local environment (Ungar, 1995). Unlike other tropical mammals that are active soon after dawn and several hours before dusk, gibbons are most active during the hours of the morning, declining during the afternoon (Chivers, 1984). They follow foraging trails throughout the day, with daily range values of 1.3-1.7 km for the smaller rainforest gibbons and less than 850 m for the larger gibbons. Siamangs have smaller day ranges (1 km or less) and smaller home ranges (18–50 ha) than the smaller gibbons. Suwanvecho et al. (2017) report in their 6-year study that gibbons stopped at 9 to 12 locations daily to feed, making decisions on what to consume based on their knowledge of where preferred versus less preferred fruits are available in their habitat.

Gibbons are considered one of the major frugivores of Southeast Asia. Some research has shown gibbon species consume, on average, two-thirds fruits to one-third leaves, buds, flowers, and insects (Suwanvecho et al., 2017; Ruppell, 2013; Palombit, 1997; Orgeldinger, 1995). Several studies indicate all *Hylobates* spend 50-70% of their time foraging for fruits (Suwanvecho et. al, 2017; Palombit, 1997; Ungar, 1995; Raemaekers, 1979). Fig is the favorite fruit item consumed, with "ripe" pieces preferred (Suwanvecho et. al, 2017; Orgeldinger, 1995; Unger, 1995; Whitington & Treesucon, 1991). Leaves were the main dietary item for northern white-cheeked gibbons in Laos throughout the year (53-85% of monthly diet), but gibbons increased their fruit consumption whenever fruit was most abundant in the forest (Ruppell, 2013). Guan et al. (2017) noted that leaf consumption increased when fruits were less available.

Twitchell-Heyne and Pontzer (2016), in their literature review of 34 studies from the last five decades on wild gibbon feeding ecology, found significant differences among the genera. According to their review, *Nomascus* and *Hylobates* spent on average 49% and 61%, respectively, of their feeding time eating fruits (predominantly figs), followed by 26-44% leaves, 4-7% flowers, and 3-6% animal matter. Siamangs spent 53% of their feeding time eating fruits (predominantly figs), followed by 31% leaves, 9% flowers, and 7% animal matter. The genera had significant differences in their habitat, including amount of annual rainfall, latitude, altitude, territory, and forest size, which was reflected in differences in their diet composition. Of these genera, *Nomascus* spent the highest amount of time eating leaves, 44% of total feeding time, followed by the siamang at 31% (Twitchell-Heyne & Pontzer, 2016; Guan, et al., 2017). In habitats where smaller gibbons and siamangs co-occur in Sumatra and Malaysia, the larger siamangs rely more on young leaves than do the smaller lar gibbons, which eat more fruit (Palombit, 1997).

The considerable variability in available feeding ecology information for gibbons may be explained by annual and seasonal changes in their habitats. For example, trees usually do not have two heavy-fruiting years in a row. As the forest changes seasonally and annually, the "gibbons' menu" seems to be "reshuffled" every year (Suwanvecho et al., 2017). Therefore, gibbons are categorized as frugivorous but are adaptable to variable seasonal and annual availability. Some sources classify siamangs as more folivorous than gibbons based on select feeding ecology studies (Guan et al., 2017; Bartlett, 2011; NRC, 2003), but the totality of available feeding ecology data shows similar seasonal variability in their natural diet, and thus does not support classifying them differently from gibbons (Table 6.1). Both gibbons and siamangs demonstrate seasonal or regional patterns of higher folivory and frugivory.

Table 6.1. Natural diet composition reported for SSP-managed gibbon species (adapted from Chivers, 2000).

Species	Location	Source	Diet %: Fruit (fig)	Diet %: Leaves	Diet %: Other
N. leucogenys (White-cheeked)	Nam Kading Laos	Ruppell 2013	30.4 (3.5)	60.8	0.5 (flowers) 0.3 (insect)
		Bleisch & Chen 1991	21 (-)		72 (flowers) 7 (insect)
H. lar (White-handed)		Raemaekers 1977 1979,1980	50 (22)	29	20
	Ketambe	Palombit 1997	71 (45)	4	25 (insects)
	Kuala Lompat	Raemaekers 1977	50 (22)	29	7 (flowers) 13 (insects)
		Mackinnons 1980	64 (27)	31	1 (flowers) 5 (insects)
	Ketambe	Palombit 1992	71 (45)	4	2 (flowers) 23 (insects)
		Bartlett 2009	66 (19)	24	10
S. syndactylus (Siamang)		Chivers 1974, Palombit 1997	29-44 (19-31)	30-65	1-13
	Ulu Sempam	Chivers 1974	47 (41)	50	2 (flowers)
	Kuala Lompat	Chivers 1974	32 (24)	58	9 (flowers) 2 (insects)
		Raemaekers 1977	36 (22)	43	6 (flowers) 15 (insects)
		Mackinnons 1980	45 (31)	44	4 (flowers) 8 (insects)
	Ketambe	West 1981	59 (42)	24	4 (flowers) 2 (insects)
		Palombit 1992	61 (43)	17	1 (flowers) 21 (insects)

The gastrointestinal tract of the gibbon is very similar to other apes and hominids. They have a large simple gastric stomach, which is followed by a relatively long small intestine. However, as seasonal folivores, they differ in their slightly enlarged (yet shortened) colon, and thus are more closely related to the orangutans than other ape species in this regard (see Figures 6.1 and 6.2). In addition, as with many ape species, the colon is haustrated by the presence of three taeniae, which extend over most of its length (Stevens & Hume, 1995). This gastrointestinal anatomy facilitates digestion and absorption of nutrients (including short-chain fatty acids generated by colonic bacteria) from their naturally high-fiber diet.

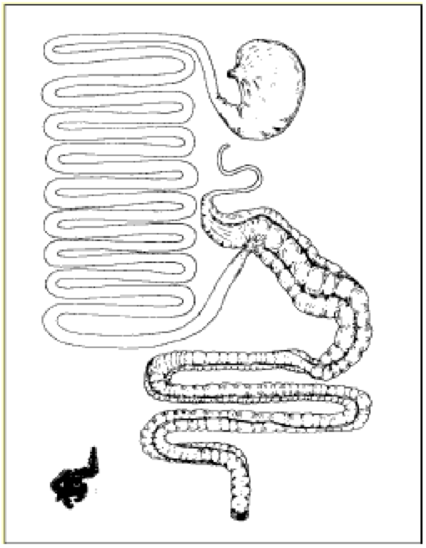

Figure 6.1. Illustration of orangutan (*Pongo pygmaeus*) gastrointestinal tract (Stevens & Hume, 1995) as reportedly similar to that of gibbons.

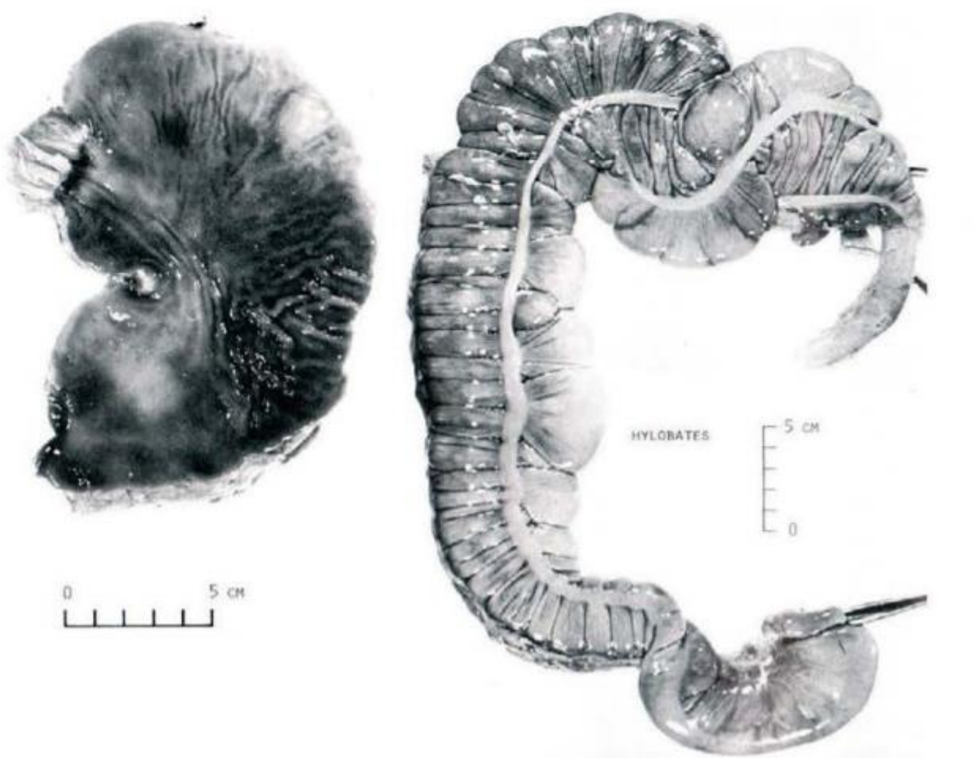

Figure 6.2. Images of a siamang stomach (left) and colon (right) (from Chivers & Hladik, 1980). The stomach (internal view) is opened around the lesser and greater curvature, with the esophagus opening at the upper left of the image and pyloric sphincter at the lower left of the image. The colon (external view) is shown with taenia coli, partly distended with and immersed in water; the ileum is clamped by forceps in the upper right of the image and the lower end of the descending colon is clamped in the lower right of the image.

Target nutrient ranges for gibbons are presented in Table 6.2. These ranges are a compilation of non-human primate and human nutrient targets, taken from the National Research Council's nutrient requirements of non-human primates (2003) and human dietary reference intakes (IOM, 2005, 2006, and 2011; NASEM, 2019), respectively. There are only five nutrients with an apparent increased upper target for reproduction (compared to maintenance) and those are noted in parenthesis behind maintenance targets.

Table 6.2. Target nutrient ranges for gibbon species for maintenance (values in parentheses are possible targets for reproduction) on a dry-matter basis.

Nutrient	Target[a]
Protein, %	11.2-22.0[b]
Fat, %	-
Neutral Detergent Fiber (NDF), %	10-30[c]
Acid Detergent Fiber (ADF), %	5-15[c]
Vitamin A, IU/kg	6,000-8,000 (10,000)
Vitamin D, IU/kg	1,200-2,500[d]
Vitamin E, mg/kg	50-100
Vitamin K, mg/kg	0.18-0.50
Thiamin, mg/kg	2.3-3.0
Riboflavin, mg/kg	2.4-4.0
Niacin, mg/kg	25-32 (36)
Pyridoxine, mg/kg	3.4-4.4
Folate (total), mg/kg	1.5-4.0 (5.61)
Biotin, mg/kg	0.06-0.20
Vitamin B_{12}, mg/kg	0.011-0.03
Pantothenic acid, mg/kg	10-12
Choline, mg/kg	750-1,100
Vitamin C, mg/kg	170-200[e] (240)
Calcium, %	0.55-0.80
Phosphorus, %	0.4-0.6[f]
Magnesium, %	0.08
Potassium, %	0.40-0.68
Sodium, %	0.2[g]
Iron, mg/kg	16-100[h]
Zinc, mg/kg	17-22
Copper, mg/kg	2-20
Manganese, mg/kg	5.0-20.0
Iodine, mg/kg	0.30-0.35 (0.58)
Selenium, mg/kg	0.11-0.3

[a]These targets are based on Primate NRC (2003) for primates in general and the human Dietary Reference Intakes (IOM, 2005, 2006, 2011; NASEM, 2019).
[b]Lactation and growing young – required concentrations are greatly affected by protein quality (amounts and proportions of essential amino acids), and this issue must be considered. Taurine appears to be essential for some primates through the first postnatal year.
[c]Although not nutrients, NDF and ADF when used at the concentrations shown for model species were positively related to gastrointestinal health.
[d]An individual's exposure to natural sunlight and or artificial UV radiation could be considered as a contributing source for the requirement.
[e]Ascorbyl-2-polyphosphate is a source of vitamin C that is biologically active and relatively stable during extrusion and storage.
[f]Much of the phytate phosphorus found in soybean meal and some cereals appears to be of limited bioavailability.
[g]The Primate NRC (2003) notes that diets containing 0.25-0.65% sodium (DMB) "appear to support maintenance of nonhuman primates but are likely to exceed minimum needs," and acknowledges an adverse effect on blood pressure in most primate species from excess dietary sodium. Thus, this target does not represent a true minimum requirement but will support maintenance needs without contributing to health concerns related to excess dietary sodium.
[h]The Primate NRC (2003) cautions that "because some primates appear to be susceptible to iron-storage disease, it might be desirable to limit dietary iron concentrations to near or slightly below this concentration (100 mg/kg)."

There are several factors that affect the nutritional requirements of gibbons.

Age: Nutrient requirements for growth are encompassed in the target ranges provided in Table 6.2. Growing animals in a group setting should be monitored to ensure that they appear to have access to the intended ratio of food items, especially to nutritionally complete feeds (NCF) (see Section 6.2). If group members appear to be out-competing younger animals for NCF, consider individually feeding NCF to ensure access to these nutrient-dense foods.

With increasing age beyond adult maintenance, animals naturally begin to lose muscle mass, which in turn leads to reduced energy expenditure from reduced metabolic rate and likely reduced activity as well (see Energy section below) (NRC, 2003). Older animals should be monitored for changes in activity and weight to guard against undesirable changes in body condition, although some degree of condition loss from age-related reduced muscle mass is unavoidable. Loss of muscle mass may be reduced or slowed through ensuring adequate dietary protein intake; recommended protein intake for geriatric humans is increased to at least 1.0-1.3 g/kg body weight to aid with attenuating loss of lean mass (Nowson & O'Connell, 2015).

Other changes that occur with older age include reduced physical function, development of chronic disease, and reduced dental function, all of which can impair nutritional status if not addressed. Diets for older animals will likely require individualized modifications to ensure maintenance of proper nutritional status.

Activity levels: Gibbons in managed care may be less active than their free-ranging counterparts for several reasons (e.g., restricted enclosure size and/or opportunity for natural movement like brachiation; seasonally restricted access to outdoor enclosures in colder climates; and reduced need for foraging behavior with typical diet presentation in captivity). Reduced activity translates to reduced energy expenditure and thus the amount of food required to meet energy needs, creating risk for excess weight gain and body condition if gibbons are fed in excess of their energy needs (see Energy section below). Daily activity should be encouraged through strategies such as modifying enclosure design (e.g., providing climbing structures), providing outside access whenever possible, modifying diet presentation (e.g., scattering across the enclosure and using feeding devices to facilitate and prolong natural feeding behaviors), and providing non-food interactive enrichment devices.

Reproductive status: Requirements for most nutrients do not appear to differ significantly for reproduction compared to those recommended for maintenance by the NRC for primates in general, except for vitamins A and C, niacin, folate, and iodine. Targets for reproduction are given in Table 6.2. Dietary protein intake at 1 g/kg BW is "associated with normal prenatal growth, normal birth weight, skeletal maturity and other outcomes," according to the NRC, and this level of protein intake should be provided by meeting the middle-to-upper end of the protein target in Table 6.2. Energy needs for reproduction (late gestation) may increase by 2.5-6.5% over maintenance (NRC, 2003).

Seasonal changes: Free-ranging gibbons demonstrate significant changes in diet composition seasonally based on availability of preferred items (Table 6.1; Ruppell, 2013; Guan et al., 2017). In captivity, food items can be provided more consistently throughout the year, so seasonal variation is not necessary, but may be implemented to vary the diet. No research is available on the effects of seasonally varying diets on the health of managed gibbon species. If gibbons have access to climate-controlled enclosures year-round, energy needs are likely to be relatively constant throughout the year due to reduced need for thermoregulation. For animals exposed to significant changes in temperature, the diet may need to be increased during colder weather to support increased thermoregulation and may be reduced in warmer months when activity levels may decline.

Energy: The energy requirements of gibbons are not known but can be estimated using available mammalian equations and measurements from other primate species; the Primate NRC (2003) contains a detailed discussion of energy requirements for primates. Basal metabolic rate (BMR), which is close enough to resting energy expenditure (REE) to use the two interchangeably, can be estimated for gibbons using the below equation from Kleiber (1975):

$BMR (kcal/d) = 70*(BW_{kg})^{0.75}$

Using this equation and representative body weights associated with healthy body condition for each species (see section 6.3), estimated BMR would be:

285-364 kcal/d for lar gibbons
301-394 kcal/d for white-cheeked gibbons
423-586 kcal/d for siamangs

Maintenance energy requirements (MER) are estimated by applying an activity factor to BMR based on the level of activity. Studies on managed baboons (fairly similar feeding ecology and body weight) suggest MER of 1.56xBMR, or $109*(BW_{kg})^{0.75}$ (Table 2-1 in NRC, 2003), which is very similar to minimal maintenance requirements (minimally active) for adult human males (1.5-1.55xBMR) (NRC, 2003). Another estimate of MER in adult omnivores with moderate activity, which may be appropriate for captivity, is 2xBMR or $140*(BW_{kg})^{0.75}$ (NRC, 2003). From a study comparing measured maintenance energy (ME) intake to estimated MER, average ME by managed apes and lemurs was equivalent to 1.4xBMR (calculated as $98*BW_{kg})^{0.75}$) (Table 2-1 in NRC, 2003). Using a range of 1.4-2xBMR, MER would be:

399-728 kcal/d for lar gibbons
422-788 kcal/d for white-cheeked gibbons
592-1172 kcal/d for siamangs

Although managed gibbons are likely to be less active than free-ranging gibbons, their activity level can be significant if the enclosure design allows for natural movement behavior, including brachiation. An estimate of the activity cost of brachiation was determined to be 1.5 times greater than that of walking for spider monkeys (NRC, 2003). Applying that factor to the above activity factor estimates would give a range of:

$MER=2.1\text{-}3xBMR$ or $147\text{-}210*(BW_{kg})^{0.75}$

as a plausible range of maintenance energy needs for more-active gibbons. Using this higher activity factor range, MER would be:

599-1092 kcal/d for lar gibbons
632-1182 kcal/d for white-cheeked gibbons
888-1758 kcal/d for siamangs

For comparison, analysis of diets fed to managed gibbons (see Appendices D-F) finds a range of:
330-992 kcal/d (mean 695 kcal/d) (n=8) offered per lar gibbon
379-1385 kcal/d (mean 784 kcal/d) (n=9) offered per white-cheeked gibbon
556-1551 kcal/d (mean 893 kcal/d) (n=13) offered per siamang

Based on weight ranges in Section 6.3 below, these average energy levels offered (not necessarily consumed) equate to:
77-107 kcal/kg body weight for lar gibbons
78-112 kcal/kg body weight for white-cheeked gibbons
53-81 kcal/kg body weight for siamangs

Compared to the MER estimates above, these representative managed diets appear to provide anywhere within the full range of activity factor estimates (1.4-3xBMR). This wide range is likely explained by a combination of factors, including diets offered in excess of consumption, diets supporting weights in excess of moderate body condition, and a wide range of energy expenditure by managed gibbons across institutions.

6.2 Diets

The formulation, preparation, and delivery of all diets must be of a quality and quantity suitable to meet the animal's nutritional and psychological needs (AZA Accreditation Standard 2.6.2). Food should be purchased from reliable, sustainable, and well-managed sources. The nutritional analysis of the food should be regularly tested and recorded.

Food Preparation:

Food preparation must be performed in accordance with all relevant federal, state, or local laws and/or regulations (AZA Accreditation Standard 2.6.1). Meat processed on site must be processed following all USDA standards. The appropriate hazard analysis and critical control points (HACCP) food safety protocols for diet ingredients, diet preparation, and diet administration should be established for gibbon species. Diet preparation staff should remain current on food recalls, updates, and regulations per USDA/FDA. Remove food within a maximum of 24 hours of being offered unless state or federal regulations specify otherwise and dispose of per USDA guidelines.

> **AZA Accreditation Standard**
>
> **(2.6.1)** Animal food preparation and storage must meet all applicable laws and/or regulations.

> **AZA Accreditation Standard**
>
> **(2.6.3)** If the institution uses browse plants as part of the diet or as enrichment items for its animals, the items must be identified and reviewed for safety prior to use.

Diet Composition:

Diets fed to managed gibbons of the three SSP-managed species were gathered from several different facilities (n=8-13 diets per species) in 2020 and analyzed. The diets represented in Appendix B cover the range of different diets that are offered to these species in U.S. institutions. The diets were divided into the following categories: fruit, leafy vegetable, starchy/root vegetable, non-root/non-leafy (other) vegetable, nutritionally complete feed (NCF), and other foods. The food items included in each category are listed in Appendix A.

Target ranges for inclusion of each food category, based on analysis of managed gibbon diets and nutritional considerations, are provided in Table 6.3. These ranges reflect the fact that there is no one 'ideal' diet composition for all gibbons in captivity, and that a wide range of combinations from the selected food categories can produce a nutritionally balanced diet (see Appendices D-F for analysis of representative diets fed). This provides flexibility for formulating diets to meet the needs of individual animals, which should be the foremost consideration when planning diets. Table 6.3 also provides potential quantities to feed from each food category based on application of target ranges to ranges of total food fed to each species across institutions surveyed for this care manual.

Table 6.3. Recommended diet composition targets for gibbons and potential amounts to feed an individual gibbon from each category by species.

Food Category	Target (% Diet) (as-fed)	Lar Gibbon (g/d)[a]	White-Cheeked Gibbon (g/d)[a]	Siamang (g/d)[a]
Fruit	0-20[b]	0-219	0-221	0-369
Leafy Vegetable	20-40	100-439	80-442	150-738
Starchy/Root Vegetables	0-20[b]	0-219	0-221	0-369
Other Vegetables	10-30	50-329	40-332	75-554
NCF	7-35	35-384	28-387	52-646
Other Food Items	<5	<25-55	<20-55	<37-92
Total	100	499-1097	398-1106	749-1846

[a] Values represent application of recommended target ranges to ranges of representative diets fed to each species in U.S. institutions (see below in text).
[b] Exceeding 20% may contribute to health concerns over time.

Food Categories:

Nutritionally Complete Feeds (NCF): These products are formulated to meet the needs of non-human primates and thus contain an appropriate and consistent array of nutrients (protein, fats, vitamins, and minerals). When NCF are included in the diet at an appropriate amount, additional vitamin and mineral supplementation is not necessary. Having a combination of these products in the diet provides different styles, flavors, and variety. However, NCF feeds are not formulated equally (e.g., extruded "biscuits" versus higher-moisture canned diets), so it is important to know the nutrient content of the products used in the diet and how their use affects the overall nutrient profile of the diet in conjunction with the other food items. A review of gibbon diets fed at AZA institutions finds NCF offered at a broad range of 4-49% of the diet across institutions, with a minimum of 7% NCF needed to meet all nutrient requirement targets. Thus, the suggested NCF target for gibbon diets is 7-35%, with the upper end based on the maximum amount of NCF in the majority of diets reviewed. NCF may be offered at a larger proportion of the diet if needed, but given the energy density of these feeds, diets with higher amounts may lead to excess weight gain if the energy content of the overall diet is not monitored.

There are anecdotal reports of digestive intolerance and other health problems ascribed to NCF for captive primates in general, but no published evidence supports caution against the appropriate use of these feeds in captive gibbon or other primate diets (Henry & Reppert, 2015). In the case of individual intolerance of all NCF, it is possible to formulate a nutritionally-complete diet without NCF but this will require micronutrient supplementation and oversight by a nutritionist or veterinarian with diet formulation experience.

Fruits: Primates known as frugivorous species in the wild are often provided high-fruit diets in captivity. Most cultivated fruits available from commercial sources are grown for human consumption, and thus are selectively bred and cultivated to appeal to human taste. These fruits are higher in sugars, lower in fiber, and are poorer sources of protein, vitamins, and minerals than their wild counterparts (Milton, 1999). For instance, commonly used cultivated fruits contain 14.4-84.5% (mostly >40%) sugar and 3.1-26.8% NDF on a dry-matter basis, whereas examples of wild fruits consumed by orangutans, gorillas and lemurs (gibbon-specific data not found) contain 12.8-62.4% (mostly <40%) sugar and 40.6-82.3% NDF on a dry-matter basis (Harrison, 2009; Popovich & Dierenfeld, 1997; Dierenfeld & McCann, 1999; USDA Food Data Central [https://fdc.nal.usda.gov/]; Schmidt et al., 2005). Because of these differences from wild fruits, some institutions have moved to "fruit-free" diets for many primate species, with reported benefits such as reduced food aggression in groups, reduced obesity, and reduced dental health problems (Plowman, 2013). Commercially available fruits are not essential for gibbons, so this approach may be worth trying for animals with weight management or other health challenges (e.g., diabetes) or group food aggression problems, but it may not be suitable for all institutions. Indeed, fruit can be included in a balanced diet for gibbons and can provide additional dietary variety/novelty, but should be minimized and utilized strategically (e.g. hand-fed, used as a high-value item for training) to encourage consumption of high-fiber and more nutrient-dense vegetables and nutritionally complete feeds, and to minimize adverse health impacts from excessive fruit. Furthermore, lower-sugar fruits (e.g. melon, papaya, strawberry) can be emphasized over higher-sugar fruits (e.g. banana, grapes) to further reduce the contribution of sugar to the diet from fruits.

Considering these factors and review of managed diets fed in AZA institutions, a reasonable target for managed gibbon diets is up to 20% fruit to allow for dietary variety and training needs while avoiding excess sugar and dilution of micronutrients in the overall diet. In the event more fruit is offered based on individual animal needs (e.g. older or underweight individuals with selective food acceptance), it should be noted that >40% fruit in the diet may result in dilution of micronutrients below target levels.

Presenting fruits as whole as possible will also improve their overall nutrient content by preserving the higher-fiber parts (e.g. peel/rind, core) of the fruit. Some institutions do not offer citrus or acidic fruits to gibbons due to observed or perceived intolerance of these fruits by their animals, or due to a long-standing reported intolerance of citrus (acidic) fruits by gibbons (Mootnick et al., 1987). However, that original source for this claim does not provide any specific evidence of intolerance or health problems from citrus fruits, but rather appears to rely on anecdotal or theoretical concerns based on gastrointestinal morphology and the absence of these fruits in their natural diet. Of the 63 institutional gibbon diets reviewed for this care manual, 22 (35%) specifically include citrus fruits in the diet at some frequency while seven (11%) intentionally exclude citrus; no patterns or trends were observed in the occurrence of gastrointestinal abnormalities or other reported nutrition-related health problems in gibbons between institutions offering versus excluding citrus fruits. Thus, citrus fruits do not necessarily need to be avoided for gibbons, but individual tolerance should be monitored if these fruits are offered within reason in the diet.

Vegetables: Leafy and other vegetables (including botanic fruits typically classified as vegetables) should comprise most of the diet by weight to best approach their natural feeding ecology with available food items, and to help provide dietary fiber and other nutrients. The emphasis should be on leafy vegetables given the seasonally high proportion of leaves in natural gibbon diets, followed by other vegetables.

Non-leafy vegetables can be divided nutritionally into starchy (botanical roots/tubers) and non-starchy (botanical fruits, stems, stalks, and flowers) vegetables, with the former typically being denser in energy, starch, and sugars than the latter (Henry et al., 2017). These vegetables can be included in the diet in myriad combinations while still producing a balanced diet (assuming adequate NCF), but it is advisable to aim for a lesser contribution from root/starchy vegetables to reduce the overall starch and sugar content of the diet. Providing more non-starchy/non-root vegetables (e.g. stems, stalks, flowers, botanical low-sugar fruits) than starchy/root vegetables also aligns with their natural feeding ecology, which does not include significant roots, tubers or bulbs.

Considering these factors and review of managed diets fed in AZA institutions, a reasonable target for managed gibbon diets is 20-40% leafy vegetables, 10-30% non-leafy/non-root vegetables, and 0-20% root vegetables. Depending on individual institution and individual gibbon needs, proportions of these items can vary from these ranges and still produce an overall balanced diet, depending on the quantity of NCF in the diet. If a selective animal will not consume leafy and/or non-leafy/non-root vegetables at the suggested proportions, dietary fiber needs can still be met by providing enough high-fiber NCF, as those feeds tend to be much higher in fiber than any cultivated produce on a dry-matter basis.

Of note, if a diet is both very high in fruit (>40%) and lower in NCF (6-10%), providing high-calcium leafy vegetables at 25% or more of the diet is important to help mitigate the detrimental nutritional impact of the combination of high fruit and low NCF.

Proteins and Other Foods: Several institutions offer various types of high-protein foods (e.g. hard-boiled egg, insects, nuts, seeds) in gibbon diets, usually infrequently (2-3x/week) and at <3% of the total diet, for reasons such as meeting perceived protein needs, for foraging, and/or to promote weight gain or maintenance. Feeding ecology studies indicate lar gibbons and siamangs spend up to 25% and 21%, respectively, of their feeding time foraging on invertebrates (insects), which are posited to meet protein needs when consuming high-fruit diets at times of the year (Palombit, 1997). Given the consumption of animal protein sources in wild diets, inclusion of appropriate protein foods at <7% as fed in modest amounts in managed diets is reasonable, but not necessary.

Other food items found in managed gibbon diets include various dried fruits, grain, or cereal products for training or enrichment, and other higher-calorie foods (oils, nut butters) for weight management goals. Unless needed for weight maintenance, these energy-dense ‘other’ items should be limited to <5% of the diet to prevent them from leading to undesirable weight gain and from diluting intended nutrient concentrations.

Dietary Supplements: The aforementioned review of managed gibbon diets for this care manual found at least 26 institutions offer some form of dietary supplement to gibbons. These supplements fell into two categories: multi-vitamin/mineral and probiotic/fiber. The most common supplement offered is some form of multivitamin or multivitamin/mineral supplement, followed by calcium, vitamin D, or a combination of the two. While rationale for vitamin/mineral supplements was not requested in the dietary survey, or provided in most cases, when a reason was provided the most common was veterinarian recommendation. Vitamin/mineral supplements are not necessary for managed gibbons fed a balanced diet as outlined above, but they may be warranted in individual cases based on imbalanced diet consumption, health conditions, therapeutic nutrition needs, environmental factors (e.g. inadequate UV light exposure in northern climates), and other circumstances.

Of the ten institutions that offer fiber (e.g. resistant starch, ground flaxseed, Metamucil) and/or probiotic supplements, most did not provide a rationale, but those that did indicated they are offered to treat loose stool; no comments were provided regarding the perceived efficacy of these supplements for this purpose. Currently there is no evidence of benefit of probiotics in gibbons, nor even for which strains at which doses would be most appropriate. Data also are lacking for efficacy of fiber supplements in treating chronic diarrhea or other GI abnormalities. Indeed, the American Gastroenterological Association advised against the use of probiotics for most GI disorders in humans citing lack of evidence of efficacy for most conditions, lack of evidence concerning potential harm, and associated costs of using these supplements (Preidis et al., 2020). Thus, no recommendation can be made for the use of these types of supplements, but they may be considered if desired since the risk of harm from their use appears negligible at this time.

If an institution elects to pursue a nutritional supplement for any reason, it is recommended that this process occur collaboratively between animal managers, veterinarians, and the nutritionist (where applicable) to determine the most appropriate supplement regimen for the individual, with consideration of product form, dose, route of administration, efficacy, safety, and cost.

Due to the variable individual needs of animals and institutions, it is not practical to recommend specific amounts to feed gibbons, but the total amounts of diets reportedly fed to the three SSP-managed species (499-1097 g/d [average 776 g/d] for lar gibbons, 398-1106 g/d [average 867 g/d] for white-cheeked gibbons, and 749-1846 g/d [average 1248 g/d] for siamangs), applied to the diet composition guidelines above, can be used as a starting point (see Table 6.3). After a balanced diet has been established, diet increases and decreases made for consumption, weight or body condition goals, behavior, and other reasons ideally should be made proportionately for all ingredients in order to maintain the intended nutrient composition of the overall diet. In cases where specific ingredients are adjusted, it is recommended to re-analyze the resulting diet to ensure it does not create nutrient imbalances or levels below the recommended targets. Diet changes made to promote weight loss or gain should aim for gradual loss or gain to avoid health and behavior problems arising from rapid weight changes. It is the professional opinion of the authors based on personal experience that, in general, diet changes of less than 3-5% are unlikely to produce significant weight changes, and diet changes greater than 15-20% at one time may be too drastic. Adjusting the diet significantly for weight or other goals should be collaboratively determined by animal care, veterinarian, and nutritionist (where applicable) input. Training gibbons for voluntary weighing is ideal to allow for use of regular weight data to guide the diet change process.

Diet Presentation: The diet should be fed throughout the day in small portions rather than one large daily feeding. Offering food in this pattern helps mimic gibbon feeding patterns in the wild, where they forage mostly during the day. Offering food items in several feedings also provides multiple interesting events throughout the day. Modifying when and how diet items are offered, especially with foods that require physical or mental effort, provides stimulation and facilitates natural feeding behaviors. For example, modifying the way the food is offered (e.g., whole, peeled, chopped into varying sizes, frozen, in a feeding device) may stimulate more investigation by the animal. Vegetables may be cooked on occasion as a means of varying diet presentation but should be offered raw most of the time for young and healthy gibbons in order to fully preserve the functional aspects of these higher-fiber foods. Furthermore, cooking starchy vegetables increases the quantity of readily available and fermentable simple carbohydrates in those foods, which may contribute to gastrointestinal and metabolic problems in sensitive individuals. As noted earlier, older animals with dental problems may require hard food items to be cooked in order to facilitate chewing of those foods, and this is an appropriate age-related modification to make.

Providing dietary variety by varying the foods offered within each category over the week, rather than offering the same many items daily, has many benefits. Food items offered less often may have more value than if offered daily, thus reducing loss of interest in certain items. In a group setting, this approach will prevent dominant animals from regularly selecting for only their preferred items at the expense of a balanced diet. Also important in a group feeding situation is the distribution of all food items over multiple feeding locations around the exhibit/enclosure to help ensure all individuals have the potential to receive a balanced diet (i.e., to prevent dominant animals from limiting access to food items by lower-ranking individuals). Fresh herbs may be offered as a leafy vegetable option to provide gibbons with novelty, but these should be offered in small servings due to their potency. Spices can also be added to food items, in small quantities, as another means of varying diet presentation.

Food-Based Enrichment: A routine enrichment program is important to the psychological welfare of managed primates, and is required by USDA regulation (Part 3, Subpart D, §3.81b) (APHIS, 2019). Novel food items can be used to provide dietary enrichment to gibbons. The review of managed gibbon diets for this care manual found many institutions regularly offer items such as nuts, seeds, grains, and dried fruits at small amounts for enrichment purposes. Such items easily lend themselves to scattering or use with puzzle feeders and other feeding devices to promote natural foraging behaviors. These energy-dense items can be appropriate for gibbons, but should be limited to small quantities (e.g. <2% of the overall diet) to prevent unintended increases in energy intake and dilution of the intended nutrient composition of the diet. It may be helpful to prepare a calendar for approved food enrichment, including appropriate quantities for each, if not a standard food item, to ensure enrichment foods are properly rotated and controlled. Varying the way in which the standard diet is offered, as discussed above, can also be as enriching as offering novel food items.

Browse: If browse plants are used within the animal's diet or for enrichment, all plants must be identified and assessed for safety prior to use (AZA Accreditation Standard 2.6.3). The responsibility for approval of plants and oversight of the program must be assigned to at least one qualified individual (AZA Accreditation Standard 2.6.3.1). The program should identify if the plants have been treated with any chemicals, near any point sources of pollution, and if the plants are safe for the species. The institution's animal care program must address the potential risks of animals being exposed to toxic plants growing around or near their exhibit space and exhibits should be checked regularly during the growing season (AZA Accreditation Standard 2.6.3.2).

> **AZA Accreditation Standard**
>
> **(2.6.3.1)** The institution must assign at least one qualified paid or unpaid staff member to oversee appropriate browse material for the animals (including aquatic animals).

Browse should be provided to gibbons as often as available to help replicate natural diets, especially leaves and flowers that seasonally comprise a significant portion of natural diets, and to facilitate natural feeding behaviors. A compilation from several institutions of approved browse species for gibbons is provided in Table 6.4 below. While this list is not exhaustive and these species appear to be safe for gibbons, animals consuming any new type of browse should be monitored (e.g. changes in behavior, stool quality and frequency) to identify potential individual intolerances of those species (e.g. risk of intestinal impaction from consumption of bark and stem [Janssen, 1994] and from species with long fibers, as has been reported from acacia in langur monkeys [Ensley et al., 1982] and fibrous plant part consumption by colobus [Irlbeck et al., 2001]). Browse consumption and acceptance should also be monitored to identify individual or group preferences to best utilize browse resources by minimizing waste.

> **AZA Accreditation Standard**
>
> **(2.6.3.2)** The institution's animal care program must address the potential risks of animals (including aquatic animals) being exposed to toxic plants growing in or near their exhibit space. Exhibits should be checked regularly during the growing season.

If fresh browse cannot be provided regularly based on availability, fresh commercially-grown leafy vegetables come the closest to replicating the nutritional content of leaves and thus can be incorporated into the diet at higher amounts to help fill the role of browse in natural diets. Using novel types of leafy vegetables, and/or in different presentations, can provide a different feeding experience from the leafy vegetables in the standard diet. Other institutions address the problem of seasonally limited sources of fresh browse by freezing and ensiling browse to feed during months when fresh browse is not available.

Table 6.4 Apparently safe browse species for gibbons.

Common Name	Scientific Name	Comments
Alder	*Alnus*	
Bamboo	*Bambuseae sp.*	
Banana	*Musa*	
Beech	*Fagus*	
Birch	*Betula papyrifera*	
Blackberry	*Rubus*	
Box elder	*Acer negundo*	
Corn stalks	*Zea*	
Cottonwood	*Populus deltoides*	
Crab Apple	*Malus*	
Dogwood	*Cornus*	
Ear-leaf Acacia	*Acacia auriculiformis*	
Elm	*Ulmus*	
Fig	*Ficus*	
Forsythia	*Forsythia*	
Giant reed grass	*Arundo*	
Grape	*Vitis*	
Hackberry	*Celtis occidentalis*	
Hibiscus	*Hibiscus*	

Hickory	*Carya*	
Honeysuckle	*Lonicera sp.*	fall berries are toxic
Hong Kong Orchid	*Bauhinia blakeana*	
Japanese Blueberry	*Elaeocarpus decipens*	
Lilac	*Syringa*	
Linden	*Tilia*.	
Mimosa	*Albizia julibrissin*	
Monkey Pod	*Albizia saman*	
Mulberry	*Morus alba*	
Pear	*Pyrus calleryana*	
Prickly pear cactus	*Opuntia*	remove thorns & hairs (glochids)
Raspberry	*Rubus*	
Redbud	*Cercis*	
River birch	*Betula*	
Sassafras	*Sassafras albidum*	
Silverberry	*Elaeagnus*	
Sugar maple	*Acer saccharum*	
Sumac	*Rhus*	including berries
Sunflower	*Helianthus*	
Sweet Gum	*Liquidamber styraciflua*	
Tulip Tree	*Liriodendron tulipifers*	
Viburnum	*Viburnum*	
Willow	*Salix sepulcralis*	

6.3 Nutritional Evaluations

Gastrointestinal disorders:

Chronic abnormal stool quality (i.e., loose stool, diarrhea) is commonly reported in managed gibbons according to the anecdotal experience of the SSP Nutrition co-advisors and surveys conducted by the SSP in the spring of 2020 for this care manual and by Munir & Nealen (2021).

In the latter survey (conducted online in 2017 with responses from 53 separate institutions from multiple countries), the authors sought to evaluate associations between reported captive gibbon diets and reported occurrence of chronic diarrhea (defined using Bristol stool score). They found that chronic diarrhea was commonly reported (26 of 53 respondents reported it in one or more of their gibbons), but occurrence was not associated with any particular species and was equally distributed among siamangs, lar gibbons, and white-cheeked gibbons in the sub-sample of institutions reporting this condition (31%, 29%, and 27%, respectively). They also found no apparent age structure or difference by sex in gibbons reported to have chronic diarrhea. Institutions reporting chronic diarrhea fed more non-citrus fruit (47.3%) than institutions without chronic diarrhea (35.3%) and offered food enrichment significantly more often (4.6 days per week) than institutions without chronic diarrhea (3.3 days per week); no association with chronic diarrhea was found for amount of citrus fruit, plant-based matter, and overall protein (broadly defined by assigned food categories rather than actual protein content of foods).

In the SSP survey limited to AZA-accredited institutions, chronic loose stool was defined as an individual with stools scoring a 4 or 5 on the provided fecal chart (Appendix G) an average of 4 times per week for 3 months or longer. Based on survey results, the prevalence of chronic loose stool among responding institutions ranges 31.4-33.3 percent across the three managed species with no significant difference in prevalence by sex (https://www.gibbonssp.org/medical/#StoolQuality); these findings are very similar to those reported by Munir & Nealen (2021). Also similar to the Munir & Nealen survey, this problem is typically reported as occurring in specific individuals (i.e., not in all animals that share common diet and housing), and most often without a known etiology; from the SSP survey, only 3-5% of cases have an accompanying medical diagnosis (mostly from infectious pathogens). Suspected non-infectious causes for chronic loose/abnormal stool include diet and stress.

In contrast to Munir & Nealen (2021), the SSP survey did not seek to evaluate dietary associations with chronic loose stool, but rather asked respondents to report on perceived dietary factors contributing to its occurrence and on dietary interventions employed to address this problem to identify commonalities in those factors. Among institutions reporting chronic loose stool or diarrhea in gibbons, the most common dietary modifications made to address this condition are pre- and probiotic supplements (e.g. Bene-Bac, brewer's yeast) and various sources of dietary fiber (e.g. konjac, psyllium, resistant starch, flaxseed meal, browse), as well as elimination of specific foods (citrus, tomato, enrichment foods) and adjustment of the diet itself (both increasing and decreasing fruits, increasing greens, decreasing or changing type of NCF, increasing browse). Of these dietary interventions, none is reported as consistently effective in resolving the issue, and dietary interventions were reported as helpful to some degree in only 25% of reported instances. Nonetheless, such dietary interventions may be tried if desired, in consultation with veterinary and nutritionist (where applicable) input, since individual animals may respond differently to dietary modifications. If the diet is modified to test the effect on stool quality, it is recommended to make changes one at a time, with sufficient time (e.g. at least two to four weeks) allowed between changes, to methodically assess the efficacy of individual and collective changes.

To aid in objectively identifying and monitoring stool quality, institutions should develop and consistently use a standardized stool scoring system (e.g. modified Bristol Stool Chart/Scale system) (example Appendix G). Such a system with daily monitoring is especially important when adding or changing interventions aimed at improving stool quality so that the efficacy of those interventions can be objectively assessed. For monitoring stool quality of a specific individual in a group setting, green food coloring can be given (1/4 tsp) in a food vector to that individual to aid in distinguishing its stool from that of others in the group; other colors may be effective as well, but may not produce the same color in stool as the dye itself.

Weight and Body Condition Assessment:

Standardized body condition indices need to be developed for gibbons. In the absence of such systems, gibbon body condition may be assessed by monitoring individual weights compared to reported ranges for managed animals assessed to be in healthy condition. While typical weight ranges may serve as a guide, each animal should still be assessed individually given differences in size and age among individuals.

A survey was conducted by the SSP for this care manual to gather information on typical weights and body conditions for the three managed species (spring 2020). Caregivers were asked to provide each gibbon's current weight and a subjective assessment of their body condition. Results from that survey are listed by species in Tables 6.5-6.7 below.

AZA institutions were also surveyed for available weights by age for each species to provide representative ranges of weights observed for different age categories. This information is summarized by species in Tables 6.8-6.10 below.

Table 6.5. Summary of reported weights and associated body condition category for adult managed lar gibbons (*Hylobates lar*) (collected from SSP survey of AZA institutions).

Body Condition Category	**Male**	**Female**
Underweight/ Under-conditioned	6.0 – 7.6 kg [n=3]	5.6 kg [n=1]
Good/Healthy/Moderate	6.6 - 9.9 kg (most 7 – 9 kg) [n=14]	6.4 – 10.2 kg (most 6.7 – 8.5 kg) [n=11]
Overweight/Over-conditioned	12.11 kg [n=1]	8.2 – 9.1 kg [n=1]

Table 6.6. Summary of reported weights and associated body condition category for adult managed white-cheeked gibbons (*Nomascus leucogenys)* (collected from SSP survey of AZA institutions).

Body Condition Category	**Male**	**Female**
Underweight/ Under-conditioned	7.3 – 8.2 kg [n=2]	6.2 – 7.5 kg [n=3]
Good/Healthy/Moderate	6.8 – 12.2 kg (most 7 – 10 kg) [n=15]	6.1 – 11.0 kg (most 7.3 – 10 kg) [n=23]
Overweight/Over-conditioned	10.4 kg [n=1]	8.2 – 11.6 kg [n=4]

Table 6.7. Summary of reported weights and associated body condition category for adult managed siamangs (*Symphalangus syndactylus)* (collected from SSP survey of AZA institutions).

Body Condition Category	**Male**	**Female**
Underweight/ Under-conditioned	11 – 12 kg [n=1]	9.2 – 12.2 kg [n=5]
Good/Healthy/Moderate	11.3 – 22.0 kg (most 14.5 – 17 kg) [n=19]	9.55 – 17.0 kg (most 11 – 14 kg) [n=19]
Overweight/Over-conditioned	16.0 – 17.4 kg [n=2]	13.25 – 14.0 kg [n=3]

Table 6.8. Body weights of managed lar gibbons (*Hylobates lar*) ranging in age from birth weight to 47 years of age (collected from SSP survey of AZA institutions).

Age Range, Years	Males		Females	
	Weights (kg)	No. of Animals	Weights (kg)	No. of Animals
Birth weight	-	-	-	-
< 1.0	1.27	1	-	-
1.0 – 2.5	1.5	1	1.4	1
2.5 – 3.5	-	-	-	-
3.5 – 4.5	4.5	1	5.0-5.71	2
4.5 – 5.5	-	-	-	-
5.5 – 7.5	7.0-7.13	2	-	-
7.5-10.5	7.26	1	6.4-7.22	2
10.5 - 12.5	-	-	-	-
12.5 - 20.0	6.58-9.85	4	8.48-10.2	2
20.0 - 25.0	-	-	6.7-8.3	2
>25.0	6.5-9.5	8	6.6-9.2	4

Table 6.9. Body weights of managed white-cheeked gibbons (*Nomascus leucogenys)* ranging in age from birth weight to 36 years of age (collected from SSP survey of AZA institutions).

Age Range, Years	Males		Females	
	Weights (kg)	No. of Animals	Weights (kg)	No. of Animals
Birth weight	0.6*	1	0.59	1
< 1.0	1.34-2.2	2	1.0-1.4	2
1.0 – 2.5	1.6-4.5	3	2.7-4.4	4
2.5 – 3.5	3.3-5.3	5	4.0-5.2	4
3.5 – 4.5	4.0-6.2	4	4.9-5.0	2
4.5 – 5.5	4.7-5.6	2	5.4-6.04	3
5.5 – 7.5	4.17-8.97	7	5.5-8.0	5
7.5-10.5	7.03	1	7.3-8.0	4
10.5 - 12.5	-	-	8.5	1
12.5 - 20.0	7.02-12.02	5	8.1-9.7	4
20.0 - 25.0	8.0-12.24	5	7.94-10.0	4
>25.0	7.3-9.8	4	8.12-10.66	8

*2 days old

Table 6.10. Body weights of managed siamangs (*Symphalangus syndactylus)* ranging in age from birth weight to 40 years of age (collected from SSP survey of AZA institutions).

Age Range, Years	Males		Females	
	Weights (kg)	No. of Animals	Weights (kg)	No. of Animals
Birth weight	0.59*	1	0.42	1
< 1.0	1.51	1	0.66	1
1.0 – 2.5	2.8-5.2	2	2.36-5.7	3
2.5 – 3.5	5.67-6.6	2	6.2-8.0	3
3.5 – 4.5	6.6-9.2	2	7.1-8.3	4
4.5 – 5.5	10.0-10.8	2	8.6-10.3	3
5.5 – 7.5	11.3	1	9.4-11.3	3
7.5-10.5	15.6	1	10.3-12.6	3
10.5 - 12.5	13.95-16.3	3	-	-
12.5 - 20.0	12.1-19.2	5	11.34-13.7	4
20.0 - 25.0	14.5-22	4	13.5	1
>25.0	13.61-16.82	6	9.55-17.02	11

*10 days old

Physical assessment (e.g., palpation) of animals, when possible, will also help inform body condition assessment and goal weight ranges; the abdomen is one area where excess fat is deposited (as in most primate species), but other areas to assess include chest, arm-pits (area observed to accumulate excess adipose tissue per experience of SSP advisors), thighs, and the pelvic/lower back area. Focal areas, such as the ribs, likely will still be easy to locate and palpate in moderately-conditioned gibbons given their arboreal nature, so caution should be used in underestimating body condition on that or any other single area. An assessment of the whole animal, including life-stage factors (growth, pregnancy, geriatric age), should be considered when determining body condition.

Serum Nutrient Data

Published serum nutrient references ranges for gibbons are not available apart from a limited sample of serum carotenoids in two siamangs (Slifka et al. 1999). Establishment of reference ranges for serum nutrient levels in these species is warranted to help guide assessment of nutritional status and corresponding nutrition interventions for managed gibbons.

References

[APHIS] Animal and Plant Health Inspection Service. (2019). Animal Welfare Act and Animal Welfare Regulations (APHIS Publication No. 41-35-076). U.S. Department of Agriculture. https://www.aphis.usda.gov/animal-welfare.

Barlett, T.Q. (2011). The Hylobatidae: Small apes of Asia. In C.J. Campbell, A. Fuentes, K.C. MacKinnon, S.K. Bearder, & R.M. Stumpf (Eds.), *Primates in Perspective* (2nd Ed) (pp. 300-312). Oxford University Press, New York, NY.

Brockelman, W. Y. et al. (2014). Evolution of small-group territoriality in gibbons. In J. Yamagiwa & L. Karczmarski (Eds.), *Primates and Cetaceans: Field Studies and Conservation of Complex Mammalian Societies* (pp. 213-230). Springer Japan KK, Tokyo, Japan.

Chivers, D. J. (1984). Feeding and ranging in gibbons: A summary. In H. Preushoft, D. J. Chivers, W. Y. Brockelman, & N. Cree (Eds.) *The Lesser Apes: Evolutionary and Behavioral Biology* (pp. 267-281). Edinburgh University Press, Edinburgh, United Kingdom.

Chivers, D. J. (2000). The swinging singing apes: Fighting for food and family in far-east forests. In *The Apes: Challenges for the 21st century, Conference Proceedings*. Brookfield Zoo, May 10-13, Brookfield, IL (pp. 1-28).

Chivers, D. J. & Hladik, C. M. (1980). Morphology of the gastrointestinal tract in primates: Comparisons with other mammals in relation to diet. *Journal of Morphology*, *166*, 337-386.

Dierenfeld, E.S. & McCann, C.M. (1999). Nutrient composition of selected plant species consumed by semi free-ranging lion-tailed macaques (*Macaca silenus*) and ring-tailed lemurs (*Lemur catta*) on St. Catherine's Island, Georgia, U.S.A. *Zoo Biology, 18*, 481-494.

Ensley, P.K., Rost, T.L., Anderson, M., Beinirschke, K., Brockman, D. & Ullrey, D. (1982). Intestinal obstruction and perforation caused by undigested acacia species leaves in langur monkeys. *Journal of the American Veterinary Medical Association*, *181(11),* 1351-1354.

Guan, Z., Ma, C., Fei, H., Huang, B., Ning, W., Ni, Q., Jiang, X., & Fan, P. (2017). Ecology and social system of northern gibbons living in cold seasonal forests. *Zoological Research*, *39*(4), 255-265. https://doi.org/10.24272/j.issn.2095-8137.2018.045

Harrison, M.E. (2009). Orangutan feeding behavior in Sabangau, Central Kalimantan. Doctoral Thesis, University of Cambridge. Cambridge, United Kingdom.

Henry, B.A. & Reppert, A. (2015). Nutritionally Complete Food-free Diets for Primates: Potential Benefits and Concerns. Proc. Eleventh Nutrition Advisory Group Conference. Portland, OR 27-30 September. (pp. 32-34).

Henry, B.A., Kendrick, E., Ortlepp, J., & Reppert, A. (2017). Produce Classification: Considerations for Improving Animal Diet Formulation. Workshop presented at the 12th Zoo and Wildlife Nutrition Foundation / AZA Nutrition Advisory Group Conference on Zoo and Wildlife Nutrition, Frisco, TX, 24-27 September.

[IOM] Institute of Medicine. (2005). Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids. Washington, DC: The National Academies Press.

[IOM] Institute of Medicine. (2006). Dietary Reference Intakes: The essential guide to nutrient requirements. Washington, DC: The National Academies Press.

[IOM] Institute of Medicine. (2011). Dietary Reference Intakes for Calcium and Vitamin D. Washington, DC: The National Academies Press.

Irlbeck, N.A., Knightly, F., Keeny, D., Moore, M.M., & Getzy, D.M. (2001). Ingestion of Viburnum x rhytidophylloides 'Alleghany' Potentially Lethal to White-mantled Balck Colobus (*Colobus guereza*). Proc. Of Nutrition Advisory Group 4th Conference on Zoo and Wildlife Nutrition, Disney's Animal Kingdom, 19-23 September.

Janssen, D.L. (1994). Morbidity and mortality of douc langurs (Pygathrix nemaeus) at the San Diego Zoo. In Annual Proceedings of the American Association of Zoo Veterinarians. St. Louis, MO.

Kleiber, M. (1975). *The fire of life: An introduction to animal energetics* (2nd ed.). R.E. Krieger Publishing Company.

Knott, C.D. (1998). Changes in orangutan caloric intake, energy balance, and ketones in response to fluctuating fruit availability. *International Journal of Primatology*, *19*(6), 1061–1079.

Milton, K. (1999). Nutritional characteristics of wild primate foods: Do the diets of our closest living relatives have lessons for us? *Nutrition, 15*(6), 488-498.

Mootnick, A.R., Haimoff, E.H., & Nyunt-Lwin, K. (1987). Conservation and captive management of Hoolock gibbons in the Socialist Republic of the Union of Burma. *AAZA 1987 Annual Proceedings*, 398-424.

Munir, G.M. & Nealen, P.M. (2021). A survey of captive hylobatid diets and their association with gastrointestinal disease. *Journal of Zoo and Aquarium Research, 9,* 73-80.

[NASEM] National Academies of Sciences, Engineering, and Medicine. (2019). Dietary Reference Intakes for Sodium and Potassium. Washington, DC: The National Academies Press.

[NRC] National Research Council. (2003). Nutrient Requirements of Nonhuman Primates. 2nd Ed. National Academy of Sciences, Washington, DC.

Nowson, C. & O'Connell, S. (2015). Protein requirements and recommendations for older people: a review. *Nutrients, 7*, 6874-6899.

Orgeldinger, M. (1995). *Feeding captive siamangs: A nutrition analysis and some proposals to enhance feeding in a more natural manner*. Animal Welfare Institute. https://awionline.org/content/feeding-captive-siamangs-nutrition-analysis-and-some-proposals-enhance-feeding-more-natural-

Palombit, R. A. (1997). Inter- and intraspecific variation in the diets of sympatric siamang (Hylobates syndactylus) and lar gibbons (Hylobates lar). *Folia Primatologica*, *68*, 321-337.

Plowman, A. (2013). Diet review and change for monkeys at Paignton Zoo Environmental Park. *Journal of Zoo and Aquarium Research, 1,* 73-77.

Popovich, D.G. & Dierenfeld, E.S. (1997). Gorilla nutrition. In J. Ogden and D. Wharton (Eds.), *Management of Gorillas in Captivity: Husbandry Manual, Gorilla Species Survival Plan.* American Association of Zoos and Aquariums.

Preidis, G.A., Weizman, A.V., Kashyap, P.C., Sadeghirad, B., & Morgan, R.L. (2000). AGA Technical Review on the Role of Probiotics in the Management of Gastrointestinal Disorders. *Gastroenterology*. doi: https://doi.org/10.1053/j.gastro.2020.05.060.

Raemaekers, J. (1979). Ecology of sympatric gibbons. *Folia Primatologica, 31*, 227-245. https://doi.org/10.1159/000155886

Ruppell, J.C. (2013). Ecology of white-cheeked crested gibbons in Laos. Doctoral Thesis, Portland State University. 1-135.

Schmidt D.A., Kerley, M.S., Porter, J.H., & Dempsey, J.L. (2005). Structural and nonstructural carbohydrate, fat, and protein composition of commercially available, whole produce. *Zoo Biology, 24*, 359–373.

Slifka, K.A., Bowen, P.E, Stacewicz-Sapuntzakis, M., & Crissey, S.D. (1999). A Survey of Serum and Dietary Carotenoids in Captive Wild Animals. *Journal of Nutrition, 129*(2), 380-390.

Stevens, C. E. and Hume, I. D. (1995). *Comparative Physiology of the Vertebrate Digestive System* (2nd ed.). Cambridge University Press.

Suwanvecho, U., Brockelman, W. Y., Nathalang, A., Santon, J., Matmoon, U., Somnuk, R., & Mahannop, N. (2017). High interannual variation in the diet of a tropical forest frugivore (*Hylobates lar*). *Biotropica, 0*(0), 1-11.

Twitchell-Heyne, A. K. & Pontzer, H. (2016). Geographic variation in gibbon diets. https://www.researchgate.net/publication/303971704

Ungar, P. S. (1995). Fruit preferences of four sympatric primate species at Ketambe, Northern Sumatra, Indonesia. *International Journal of Primatology*, *16*(2), 221-245.

Whitington, C. & Treesucon, U. (1991). Selection and treatment of food plants by white-handed gibbons (*Hylobates lar*) in Khao Yai National Park, Thailand. *Nat. Hist. Bull. Siam. Soc., 39*, 111-122.

Appendix A. Food categories and items in managed gibbon diets analyzed for Appendices B-F.

Fruit	**Starchy/ Root Veg**	**Other (non-root) Veg**	**Leafy Veg**	**Nutritionally Complete Food**	**Other**
apple	white potato	broccoli	bok choy	Mazuri Primate Leaf-Eater 5672/5M02	egg (hard-boiled)
banana	sweet potato/yam	cauliflower	collard greens	Mazuri Primate Browse 5MA4	almond
pear	carrot	celery	endive	Mazuri Primate LS Banana 5M1G	peanut
orange	corn	cucumber	escarole	Mazuri Primate LS Cinnamon 5M1S	mixed-nut
grapefruit	onion	eggplant	green leaf lettuce	Mazuri Primate Growth & Repro 5MA1	sunflower seed
grapes	beet	green bean	red leaf lettuce	Mazuri Primate Basix 5NAA	flax seed
kiwi	acorn squash	bell pepper (all colors)	cabbage	Mazuri Primate Maintenance 5MA2	resistant starch
cantaloupe	butternut squash	summer squash	kale	Purina Lab Diet Hi Pro Monkey 5045	Cheerios
mango	turnip	zucchini	mustard greens	Purina Lab Diet Monkey 5037/5038	oats
papaya	beans (canned or cooked)	tomato	romaine lettuce	ZuPreem Primate Diet (canned)	rice (cooked)
Plum	peas		spinach	ZuPreem Primate Diet (dry)	juice
Prune	lentils		watercress	Marion Leafeater	popcorn
strawberry			parsley	Mazuri Primate L/S Gel Diet 5B25 or other fortified gel-based diets	infant rice cereal
Blueberry					bird seed
blackberry					coconut oil
Raspberry					yogurt
fig (dried or fresh)					Metamucil Fiber Wafers
cranberries (dried or fresh)					chicken breast (cooked)
watermelon					
pineapple					
Raisins					

Appendix B. Representative diet compositions offered to SSP-managed gibbon species (as-fed basis).

Lar Gibbon							
Institution	**Diet Type**	**Fruit (%)**	**Leafy Vegetable (%)**	**Vegetable (%)**		**NCF (%)**	**Other (%)**
				Starch/ Root	**Non-Root**		
A	Group (1.1)	0	59	5	14	19	3
B	Individual	25	23	29	11	10	2
C	Group (1.2)	15	15	11	39	15	6
D	Group (1.1)	39	11	16	17	17	0
E	Group (1.1)	37	9	19	5	30	0
F	Individual (0.1)	22	32	15	23	9	0.6
G	Group (2.2.1)	38	5	17	35	2	4
H	Group (1.1)	40	9	37		12	2
Siamang							
Institution	**Diet Type**	**Fruit (%)**	**Leafy Vegetable (%)**	**Vegetable (%)**		**NCF (%)**	**Other (%)**
				Starch/ Root	**Non-Root**		
A	Group (1.1)	7	4	16	24	49	0
B	Group (1.1)	28	13	17	9	25	8
C	Individual (0.1)	17	14	16	3	49	0.2
D	Group (1.1)	0	13	29	33	25	0
E1	Individual (1.0)	6	9	16	10	57	2
E2	Individual (0.1)	8	7	22	11	52	1.1
F	Group (1.2)	17	47	18	6	13	0
G1	Individual (1.0)	19	7	19	26	29	0
G2	Individual (0.1)	18	7	19	28	28	0
H1	Individual (1.0)	42	8	15	9	25	0
H2	Individual (0.1)	42	9	15	9	25	0
I1	Individual (1.0)	10	15	16	20	37	2
I2	Individual (0.1)	12	15	15	19	35	4
White-Cheeked Gibbon							
Institution	**Diet Type**	**Fruit (%)**	**Leafy Vegetable (%)**	**Vegetable (%)**		**NCF (%)**	**Other (%)**
				Root/ Starch	**Non-Root**		
A	Group (1.1)	3	52	22	10	52	1.9
B	Individual (1.0)	16	48	10	2	48	0
C	Group (1.1)	24	25	15	21	25	0.8
D	Group (1.1)	29	25	13	14	25	0
E	Group (0.2)	24	10	9	19	10	1
F1	Individual	15	12	13	12	12	0
F2	Individual	16	16	18	15	16	0
G	Individual (1.0)	52	12	26		7	3
H	Individual	28	16	32	0	16	0

Appendix C. Nutrient analysis of representative diets of SSP-managed gibbon species.

Nutrient	Lar Gibbon	Siamang	WC Gibbon	Target Range[a]
Protein, %	13.5-22.7	14.3-20.3	14.5-20.4	11.2-22.0[b]
Fat, %	2.9-7.2	3.7-9.0	3.7-10.1	-
NDF, %	12.6-24.9	14.4-28.8	14.2-24.5	10-30[c]
ADF, %	7.4-16.0	8.6-18.5	6.1-16.7	5-15[c]
Vitamin A, IU/kg	85,131-248,265	102,862-445,223	69,038-385,359	6,000-8000
Vitamin D, IU/kg	945-2,741	1,020-3,992	1,069-5,696	1,200-2,500[d]
Vitamin E, mg/kg	79.8-199.7	102.0-253.4	86.1-219.2	50-100
Vitamin K, mg/kg	2.5-12.5	3.2-14.5	0.3-6.3	0.18-0.50
Thiamin, mg/kg	7.8-14.1	7.2-13.9	6.5-50.6	2.3-3.0
Riboflavin, mg/kg	6.4-11.7	7.6-13.7	6.2-14.2	2.4-4.0
Niacin, mg/kg	59.8-91.1	66.8-140.0	62.2-105.1	25-32
Pyridoxine, mg/kg	11.6-15.8	9.2-23.5	9.6-18.5	3.4-4.4
Folate (total), mg/kg	3.351-9.5194	5.224-12.589	3.776-10.460	1.5-4.0
Biotin, mg/kg	0.11-0.31	0.12-0.36	0.12-0.35	0.06-0.20
Vitamin B12, mg/kg	0.0094-0.0428	0.0148-0.0712	0.0125-0.0587	0.011-0.03
Pantothenic acid, mg/kg	29.6-56.1	36.0-98.9	6.8-70.4	10-12
Choline, mg/kg	1011-1848.5	927-1813	919-1396	750-1,100
Vitamin C, mg/kg	607-1566.7	725-2242	479-1594	170-200[e]
Calcium, %	0.42-1.05	0.67-1.15	0.44-1.07	0.55-0.8
Phosphorus, %	0.38-0.63	0.39-0.68	0.47-0.62	0.4-0.6[f]
Magnesium, %	0.14-0.22	0.14-0.23	0.14-0.21	0.08
Potassium, %	1.13-1.78	1.28-2.31	0.94-1.94	0.40-0.68
Sodium, %	0.13-0.36	0.16-0.35	0.15-0.35	0.2
Iron, mg/kg	93-393	131-311	104-344	16-100
Zinc, mg/kg	49.6-120.3	60.5-131.2	59.0-131.0	17-22
Copper, mg/kg	9.4-23.0	12.3-32.2	11.3-27.1	2-20
Manganese, mg/kg	36.0-101.4	45.0-100.3	31.0-97.4	5.0-20.0
Iodine, mg/kg	0.42-1.38	0.49-1.59	0.40-1.64	0.30-0.35
Selenium, mg/kg	0.1341-0.269	0.1268-0.4317	0.1108-0.3680	0.11-0.30

[a]These targets are based on Primate NRC (2003) and the human Dietary Reference Intakes (IOM, 2005, 2006, 2011; NASEM, 2019).

[b]Lactation and growing young – required concentrations are greatly affected by protein quality (amounts and proportions of essential amino acids), and this issue must be considered. Taurine appears to be essential for some primates through the first postnatal year.

[c]Although not nutrients, NDF and ADF when used at the concentrations shown for model species were positively related to gastrointestinal health.

[d]An individual's exposure to natural sunlight and or artificial UV radiation could be considered as a contributing source for the requirement.

[e]Ascorbyl-2-polyphosphate is a source of vitamin C that is biologically active and relatively stable during extrusion and storage.

[f]Much of the phytate phosphorus found in soybean meal and some cereals appears to be of limited bioavailability.

[g]The Primate NRC (2003) notes that diets containing 0.25-0.65% sodium (DMB) "appear to support maintenance of nonhuman primates but are likely to exceed minimum needs," and acknowledges an adverse effect on blood pressure in most primate species from excess dietary sodium. Thus, this target does not represent a true minimum requirement but will support maintenance needs without contributing to health concerns related to excess dietary sodium.

[h]The Primate NRC (2003) cautions that "because some primates appear to be susceptible to iron-storage disease, it might be desirable to limit dietary iron concentrations to near or slightly below this concentration (100 mg/kg)."

Appendix D. Nutrient composition of managed Lar Gibbon diets compared to target ranges on a dry-matter basis.

Nutrient	A (1.1)	B (each)	C (1.2)	D (1.1)	E (1.1)	F (0.1)	G (2.2.1)	H (1.1)	Target Range[a]
Protein, %	22.7	14.8	19.3	15.4	13.5	21.0	18.1	15.1	11.2-22.0[b]
Fat. %	5.7	7.2	5.1	4.3	2.9	5.7	4.3	4.9	-
NDF, %	23.3	13.9	20.4	11.6	17.0	24.9	19.3	12.6	10-30[c]
ADF, %	16.0	9.4	12.2	7.7	10.2	15.8	11.3	7.4	5-15[c]
Vitamin A, IU/kg	248265	176474	85131	154020	122555	175075	91221	99228	6,000-8000
Vitamin D, IU/kg	2300	1361	2741	1729	1206	2081	2347	945	1,200-2,500[d]
Vitamin E, mg/kg	171	3543	199.7	109.6	115.7	158.8	182.1	79.8	50-100
Vitamin K, mg/kg	12.5	3.5	3.0	2.7	3.2	4.9	2.5	2.6	0.18-0.50
Thiamin, mg/kg	9.9	11.2	9.6	14.1	7.8	8.8	9.4	11.1	2.3-3.0
Riboflavin, mg/kg	11.7	10.2	10.3	6.7	9.7	10.1	10.1	6.4	2.4-4.0
Niacin, mg/kg	79.0	88.5	83.2	65.1	91.1	84.0	85.1	59.8	25-32
Pyridoxine, mg/kg	13.6	15.8	12.1	11.6	15.7	12.1	12.3	10.3	3.4-4.4
Folate (total), mg/kg	9.5194	5.721	8.793	4.398	5.346	8.355	8.625	3.351	1.5-4.0
Biotin, mg/kg	0.27	0.16	0.31	0.19	0.11	0.24	0.28	0.14	0.06-0.20
Vitamin B12, mg/kg	0.0344	0.0247	0.0428	0.0107	0.0265	0.0350	0.0429	0.0094	0.011-0.03
Pantothenic acid, mg/kg	46.1	54.9	47.1	30.2	56.1	48.0	51.1	29.6	10-12
Choline, mg/kg	1848.5	1316	1297	1011	1186	1372	1224	1188	750-1,100
Vitamin C, mg/kg	1566.7	857	650	1145	1342	927	607	1319	170-200[e]
Calcium, %	1.05	0.47	1.01	0.53	0.49	0.90	0.94	0.42	0.55-0.8
Phosphorus, %	0.63	0.40	0.60	0.42	0.38	0.60	0.57	0.39	0.4-0.6[f]
Magnesium, %	0.22	0.14	0.17	0.15	0.16	0.22	0.17	0.15	0.08
Potassium, %	1.77	1.65	1.13	1.40	1.78	1.55	1.21	1.47	0.40-0.68
Sodium, %	0.36	0.18	0.27	0.28	0.13	0.23	0.24	0.21	0.2
Iron, mg/kg	288.6	102	286	168	93	393	317	153	16-100
Zinc, mg/kg	107.0	65.1	120.2	62.7	49.6	115.9	120.3	60.7	17-22
Copper, mg/kg	21.5	13.5	23.0	11.3	14.8	16.6	22.0	9.4	2-20
Manganese, mg/kg	78.4	37.1	82.3	37.3	39.8	101.4	91.3	36.0	5.0-20.0
Iodine, mg/kg	1.13	0.68	1.38	0.72	0.42	1.23	1.40	0.58	0.30-0.35
Selenium, mg/kg	0.2690	0.2410	0.2356	0.1904	0.1943	0.1341	0.1803	0.1641	0.11-0.30

[a]These targets are based on Primate NRC (2003) and the human Dietary Reference Intakes (IOM, 2005, 2006, 2011; NASEM, 2019).

[b]Lactation and growing young – required concentrations are greatly affected by protein quality (amounts and proportions of essential amino acids), and this issue must be considered. Taurine appears to be essential for some primates through the first postnatal year.

[c]Although not nutrients, NDF and ADF when used at the concentrations shown for model species were positively related to gastrointestinal health.

[d]An individual's exposure to natural sunlight and or artificial UV radiation could be considered as a contributing source for the requirement.

[e]Ascorbyl-2-polyphosphate is a source of vitamin C that is biologically active and relatively stable during extrusion and storage.

[f]Much of the phytate phosphorus found in soybean meal and some cereals appears to be of limited bioavailability.

[g]The Primate NRC (2003) notes that diets containing 0.25-0.65% sodium (DMB) "appear to support maintenance of nonhuman primates but are likely to exceed minimum needs," and acknowledges an adverse effect on blood pressure in most primate species from excess dietary sodium. Thus, this target does not represent a true minimum requirement but will support maintenance needs without contributing to health concerns related to excess dietary sodium.

[h]The Primate NRC (2003) cautions that "because some primates appear to be susceptible to iron-storage disease, it might be desirable to limit dietary iron concentrations to near or slightly below this concentration (100 mg/kg)."

Appendix E. Nutrient composition of managed White-Cheeked Gibbon diets compared to target ranges on a dry-matter basis.

Nutrient	A (1.1)	B (1.0)	C (1.1)	D (1.1)	E (0.2)	F1 (1.0)	F2 (0.1)	G (1.0)	H (each)	Target Range[a]
Protein, %	20.4	18.7	19.7	15.5	19.3	17.1	18.4	14.5	17.9	11.2-22.0[b]
Fat, %	9.2	3.8	3.7	4.9	5.1	6.2	5.5	10.1	3.8	-
NDF, %	22.1	24.5	15.5	18.7	16.3	14.7	21.5	14.2	20.8	10-30[c]
ADF, %	14.9	16.7	10.1	11.4	9.1	6.1	11.6	8.6	12.6	5-15[c]
Vitamin A, IU/kg	385,359	160,490	239,415	127,677	71,552	69,038	112,965	82,491	167,186	6,000-8000
Vitamin D, IU/kg	1859	2440	3033	2297	2686	5696	4687	1069	1855	1,200-2,500[d]
Vitamin E, mg/kg	162	173.5	86.1	161.9	219.2	153.4	128.9	116.1	137.3	50-100
Vitamin K, mg/kg	6.3	6.5	2.5	3.6	2.4	0.3	1.5	3.2	4.5	0.18-0.50
Thiamin, mg/kg	9.7	11.2	14.5	8.0	14.6	50.6	9.0	6.5	7.7	2.3-3.0
Riboflavin, mg/kg	12.3	14.2	7.4	8.7	11.6	9.0	9.3	6.2	8.9	2.4-4.0
Niacin, mg/kg	95.7	105.1	79.8	66.4	92.4	110.7	103.7	62.2	72.7	25-32
Pyridoxine, mg/kg	14.6	18.5	13.4	10.2	14.3	15.1	13.6	9.6	11.6	3.4-4.4
Folate (total), mg/kg	9.1977	10.460	5.821	6.301	10.362	7.204	8.182	3.776	6.450	1.5-4.0
Biotin, mg/kg	0.22	0.25	0.15	0.25	0.35	0.15	0.16	0.12	0.21	0.06-0.20
Vitamin B12, mg/kg	0.0319	0.0478	0.0201	0.0298	0.0479	0.0587	0.0565	0.0125	0.0312	0.011-0.03
Pantothenic acid, mg/kg	51.9	70.4	40.5	37.7	55.8	6.8	22.8	35.7	46.5	10-12
Choline, mg/kg	1281.2	1396	1371	1204	1379	1066	1299	919	1146	750-1,100
Vitamin C, mg/kg	1141.2	1422	754	479	686	655	775	1594	764	170-200[e]
Calcium, %	0.90	0.99	0.66	0.84	1.04	0.83	0.90	0.44	0.81	0.55-0.8
Phosphorus, %	0.57	0.57	0.48	0.51	0.62	0.58	0.62	0.47	0.53	0.4-0.6[f]
Magnesium, %	0.21	0.18	0.17	0.15	0.17	0.17	0.19	0.14	0.19	0.08
Potassium, %	1.94	1.68	1.53	1.25	1.17	0.94	1.14	1.40	1.31	0.40-0.68
Sodium, %	0.25	0.26	0.29	0.24	0.35	0.27	0.25	0.15	0.23	0.2
Iron, mg/kg	236.1	245	194	179	260	205	304	104	344	16-100
Zinc, mg/kg	90.5	106.6	84.4	87.2	131.0	100.1	114.2	59.0	102.3	17-22
Copper, mg/kg	18.1	24.1	11.3	18.7	27.1	19.3	19.4	13.0	15.3	2-20
Manganese, mg/kg	72.0	79.4	65.1	52.1	81.5	88.9	97.4	31.0	90.2	5.0-20.0
Iodine, mg/kg	0.89	1.15	0.93	0.95	1.64	1.17	1.28	0.40	1.11	0.30-0.35
Selenium, mg/kg	0.1873	0.2902	0.2151	219.1	283.4	368.0	264.3	241.0	110.8	0.11-0.30

[a]These targets are based on Primate NRC (2003) and the human Dietary Reference Intakes (IOM, 2015).

[b]Lactation and growing young –Required concentrations are greatly affected by protein quality (amounts and proportions of essential amino acids), and this issue must be considered. Taurine appears to be a dietary essential for some primates through the first postnatal year.

[c]Although not nutrients, NDF and ADF when used at the concentrations shown for model species were positively related to gastrointestinal health.

[d]An individual's exposure to natural sunlight and or artificial UV radiation could be considered as a contributing source for the requirement.

[e]Ascorbyl-2-polyphosphate is a source of vitamin C that is biologically active and relatively stable during extrusion and storage.

[f]Much of the phytate phosphorus found in soybean meal and some cereals appears to be of limited bioavailability.

[g]The Primate NRC notes that diets containing 0.25-0.65% sodium (DMB) "appear to support maintenance of nonhuman primates but are likely to exceed minimum needs," and acknowledges an adverse effect on blood pressure in most primate species from excess dietary sodium. Thus, this target does not represent a true minimum requirement but will support maintenance needs without contributing to health concerns related to excess dietary sodium.

[h]The Primate NRC (2003) cautions that "because some primates appear to be susceptible to iron-storage disease, it might be desirable to limit dietary iron concentrations to near or slightly below this concentration (100 mg/kg)."

Appendix F. Nutrient composition of managed Siamang diets compared to target ranges on a dry-matter basis.

Nutrient	A (1.1)	B (1.1)	C (0.1)	D (1.1)	E1 (1.0)	E2 (0.1)	F (1.2)	Target Range[a]
Protein, %	18.1	15.1	18.0	20.3	19.3	18.6	19.7	11.2-22.0[b]
Fat, %	3.7	5.6	3.7	5.4	9.0	5.3	4.7	-
NDF, %	18.1	14.4	17.9	23.2	20.7	19.9	28.8	10-30[c]
ADF, %	12.4	8.6	11.8	15.4	14.4	14.0	18.5	5-15[c]
Vitamin A, IU/kg	445,223	107,736	265,797	274,349	283,989	347,821	102,862	6,000-8000
Vitamin D, IU/kg	1,020	3,058	1,836	1,620	1,837	1,563	3,992	1,200-2,500[d]
Vitamin E, mg/kg	128.5	140.2	142.2	133.7	133.4	119.9	253.4	50-100
Vitamin K, mg/kg	14.5	3.9	5.8	5.5	10.2	8.7	3.2	0.18-0.50
Thiamin, mg/kg	7.8	7.4	9.2	8.1	10.8	10.3	13.9	2.3-3.0
Riboflavin, mg/kg	9.2	7.6	10.5	9.7	13.7	12.9	17.2	2.4-4.0
Niacin, mg/kg	70.8	66.8	85.2	76.6	99.3	94.1	140.0	25-32
Pyridoxine, mg/kg	14.1	9.2	14.9	12.9	17.9	17.0	23.5	3.4-4.4
Folacin, mg/kg	7.128	7.605	8.636	7.030	9.346	8.447	12.589	1.5-4.0
Biotin, mg/kg	0.12	0.19	0.19	0.20	0.21	0.18	0.36	0.06-0.20
Vitamin B12, mg/kg	0.0148	0.0210	0.0317	0.0271	0.0377	0.0321	0.0712	0.011-0.03
Pantothenic acid, mg/kg	36.0	40.5	46.3	48.8	60.0	55.3	98.9	10-12
Choline, mg/kg	1306	1294	1205	1461	1428	1264	1813	750-1,100
Vitamin C, mg/kg	2154	884	1053	1486	2242	2164	725	170-200[e]
Calcium, %	0.78	0.67	0.82	0.81	0.96	0.90	1.15	0.55-0.8
Phosphorus, %	0.47	0.46	0.52	0.57	0.55	0.52	0.68	0.4-0.6[f]
Magnesium, %	0.23	0.14	0.19	0.20	0.17	0.17	0.19	0.08
Potassium, %	2.31	1.28	1.81	1.71	1.86	1.90	1.41	0.40-0.68
Sodium, %	0.35	0.19	0.28	0.28	0.34	0.35	0.26	0.2
Iron, mg/kg	178	184	191	311	214	191	284	16-100
Zinc, mg/kg	64.0	63.3	82.6	94.7	89.4	80.2	131.2	17-22
Copper, mg/kg	14.8	14.3	18.0	14.5	19.9	18.1	32.2	2-20
Manganese, mg/kg	50.6	52.6	60.1	82.6	65.4	60.8	100.3	5.0-20.0
Iodine, mg/kg	0.49	0.56	0.87	0.94	0.92	0.79	1.59	0.30-0.35
Selenium, mg/kg	0.1268	0.1931	0.1909	0.1415	0.3028	0.2697	0.4317	0.11-0.30

[a]These targets are based on Primate NRC (2003) and the human Dietary Reference Intakes (IOM, 2005, 2006, 2011; NASEM, 2019).
[b]Lactation and growing young – required concentrations are greatly affected by protein quality (amounts and proportions of essential amino acids), and this issue must be considered. Taurine appears to be essential for some primates through the first postnatal year.
[c]Although not nutrients, NDF and ADF when used at the concentrations shown for model species were positively related to gastrointestinal health.
[d]An individual's exposure to natural sunlight and or artificial UV radiation could be considered as a contributing source for the requirement.
[e]Ascorbyl-2-polyphosphate is a source of vitamin C that is biologically active and relatively stable during extrusion and storage.
[f]Much of the phytate phosphorus found in soybean meal and some cereals appears to be of limited bioavailability.
[g]The Primate NRC (2003) notes that diets containing 0.25-0.65% sodium (DMB) "appear to support maintenance of nonhuman primates but are likely to exceed minimum needs," and acknowledges an adverse effect on blood pressure in most primate species from excess dietary sodium. Thus, this target does not represent a true minimum requirement but will support maintenance needs without contributing to health concerns related to excess dietary sodium.
[h]The Primate NRC (2003) cautions that "because some primates appear to be susceptible to iron-storage disease, it might be desirable to limit dietary iron concentrations to near or slightly below this concentration (100 mg/kg)."

Nutrient composition of managed Siamang diets continued compared to target ranges on a dry-matter basis (continued).

Nutrient	G1 (1.0)	G2 (0.1)	H1 (1.0)	H2 (0.1)	I1 (1.0)	I2 (0.1)	Target Range[a]
Protein, %	17.7	17.7	14.3	14.5	18.4	18.8	11.2-22.0[b]
Fat, %	5.0	5.0	3.8	3.9	5.3	5.8	-
NDF, %	21.5	21.7	16.3	17.0	25.4	24.5	10-30[c]
ADF, %	15.1	15.3	10.7	11.1	17.4	16.8	5-15[c]
Vitamin A, IU/kg	255,983	253808	211,377	200,004	265,860	249,045	6,000-8000
Vitamin D, IU/kg	1,725	1,705	1,207	1,375	2,250	2,262	1,200-2,500[d]
Vitamin E, mg/kg	132.5	131.5	102.0	113.8	164.0	159.3	50-100
Vitamin K, mg/kg	6.3	6.2	4.7	4.6	4.5	4.3	0.18-0.50
Thiamin, mg/kg	8.3	8.3	7.2	7.7	10.6	10.4	2.3-3.0
Riboflavin, mg/kg	12.1	12.1	10.5	11.2	11.1	11.2	2.4-4.0
Niacin, mg/kg	85.9	85.8	76.3	82.5	85.2	82.5	25-32
Pyridoxine, mg/kg	14.9	14.9	13.7	14.8	14.2	13.9	3.4-4.4
Folacin, mg/kg	6.594	6.556	5.224	5.622	9.812	9.581	1.5-4.0
Biotin, mg/kg	0.18	0.17	0.13	0.14	0.28	0.29	0.06-0.20
Vitamin B12, mg/kg	0.0248	0.0245	0.0232	0.0273	0.0416	0.0416	0.011-0.03
Pantothenic acid, mg/kg	46.9	46.6	44.0	49.5	53.0	52.6	10-12
Choline, mg/kg	1179	1184	927	984	1628	1788	750-1,100
Vitamin C, mg/kg	2113	2103	1499	1418	1119	1079	170-200[e]
Calcium, %	0.82	0.82	0.69	0.71	0.95	0.92	0.55-0.8
Phosphorus, %	0.48	0.48	0.39	0.40	0.61	0.60	0.4-0.6[f]
Magnesium, %	0.18	0.18	0.16	0.16	0.18	0.17	0.08
Potassium, %	1.97	1.97	1.68	1.67	1.57	1.52	0.40-0.68
Sodium, %	0.26	0.26	0.16	0.16	0.28	0.28	0.2
Iron, mg/kg	132	131	176	175	296	289	16-100
Zinc, mg/kg	61.3	60.9	60.5	635	115.1	113.1	17-22
Copper, mg/kg	14.6	14.5	12.3	13.6	22.2	21.9	2-20
Manganese, mg/kg	45.2	45.0	56.7	58.6	85.2	83.0	5.0-20.0
Iodine, mg/kg	0.53	0.52	0.59	0.63	1.34	1.32	0.30-0.35
Selenium, mg/kg	0.2185	0.2166	0.1289	0.1524	0.2307	0.2498	0.11-0.30

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Appendix G. Example fecal quality scoring chart.

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1. Constipated: Dry, pelleted feces, may be separate hard lumps

2. Normal: Soft, smoother surface but may contain lumps, mostly maintains its shape

3. Normal: Soft, lacking form but edges intact

4. Loose: Pudding consistency, wet, splattery.

5. Diarrhea: Watery, little to no solid pieces