

Chapter 5

Nutrition

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Executive Summary

Flamingos have highly specialized feeding mechanisms, primarily the bill, which can sieve small food particles from water. However, they appear highly adaptable to the availability of different types of food in the environment. The diet of a single individual of some species could vary from almost totally herbivorous (*Spirulina sp.* cultures) to essentially carnivorous (*Artemia salina*). Most flamingos consume a diversity of foods. A wide range of feeding behaviors has been described for flamingos, used to obtain food from parts of the environment as different as the surface of mud flats and the bottom of bodies of water.

A variety of commercially available, grain-based diets containing 20 to 40% protein, developed using the nutrient requirements of poultry and duck species, have proven successful for maintenance, growth, and reproduction of flamingos in captivity and should be provided as the staple diet. There is no evidence that different flamingo species have different nutrient requirements; most important is providing a particle size (for food as well as grit) optimized for the filtration mechanisms of any particular species (1-4 mm for the larger species; < 1 mm for the smaller species). Reflecting the size range of the flamingos (1.8 kg *Phoeniconaias minor* to 3.5 kg for *Phoenicopterus ruber*, energy estimates range from 160 to 200 kcal (660 to 830 kjoule) daily per individual to between 230 and 290 kcal (960 to 1200 kjoule), respectively, depending also on activity level. Energy needs would be supplied by 2-4% of body mass in dry food containing 3 to 3.5 kcal/g daily. If diets are presented as slurry (up to 75% water) this may represent 10% of body mass.

Little formal investigation has addressed the issue of management/enrichment foods for flamingos. The majority of captive flocks are maintained in outside ponds during much of the year, and birds can usually be seen feeding on naturally occurring foods. The importance of appropriate exhibit pools is essential for flamingo enrichment. In the absence of naturally occurring organisms, possible enrichment items could include a range of small whole prey such as krill, copepods, and aquatic insect larvae to duckweed (*Lemna sp.*), chopped greens, and algae species. At the Bronx Zoo, bird staff working with a group of young American flamingos determined that frozen krill could function as a food reward for operant conditioning.

Introduction (CDS)

Flamingos are best known for their vivid coloration and for the shape of their bills, both characteristics strongly related to feeding and nutrition. While we don't know, ultimately, why flamingos are pink instead of green or black or blue, we do know that their pink coloration depends on the ingestion of carotenoid pigments, which are chemically altered before deposition in the feathers. The shape of the beak is one of a complex of modifications that specialize various species for straining small food items from water – although the bill tip can still be used to 'grasp and throw' larger morsels (Zweers et al., 1995). The ability to filter small particles, coupled with the

ability to tolerate water of high salinity, allows flamingos to exploit some food sources that are unavailable to other species.

The captive nutrition of specialized feeders like the hoatzin or koala is constrained by physiological and anatomical specializations that restrict the types of food the animals can process. While flamingos have specialized mechanisms for feeding, that specialization affects the size of items ingested, not the type. The diet of wild flamingos can actually be quite varied. Basic guidelines for the nutrition of ducks and poultry appear to adequately predict the nutritional requirements of flamingos, and a variety of commercial products are available to fulfill these requirements.

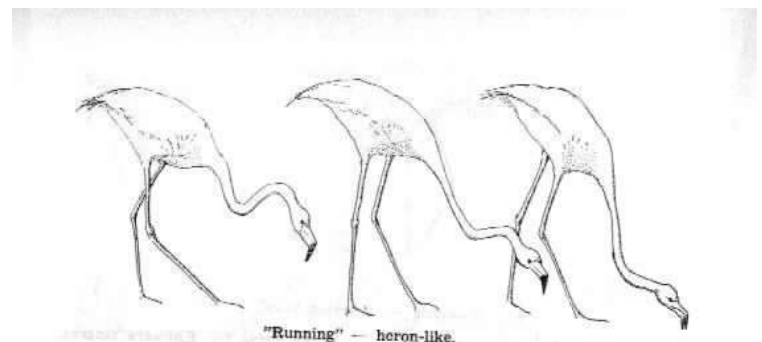
Feeding Behavior (CDS)

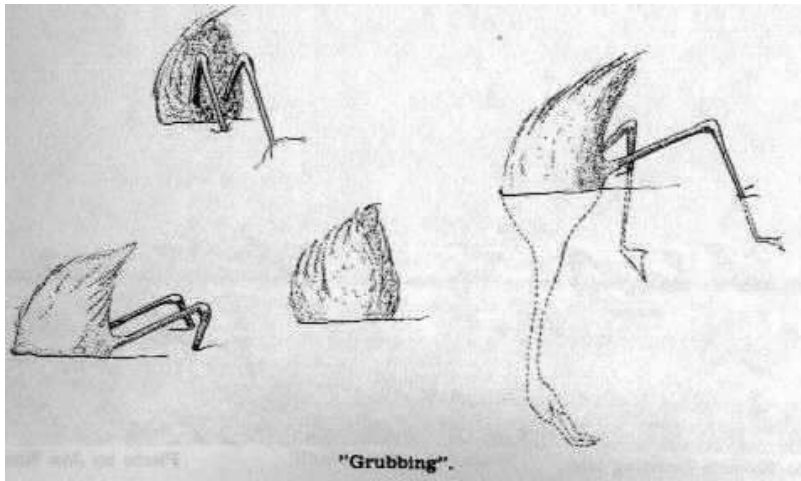
Flamingos have a repertoire of feeding behaviors, which allow them to feed on land, on water surfaces, on mud flats, at the water's edge, in the water column, or from benthic mud or sand (Allen, 1956; Jenkin, 1957). Rooth (1965, 1976) illustrated seven different feeding behaviors for the Caribbean flamingo. These behaviors generally target different types of organisms, found in different parts of the aquatic environment. Arengo and Baldassare (1999) report that in low-salinity ponds in Mexico, 99% of potential food was found in substrate samples. In high salinity ponds, only 13% of potential food items were found in the substrate, with 87% occurring in the water column. Arengo and Baldassarre (1998) also note that pond substrates changed, with increasing salinity, from mud and sand to algal mats to precipitates, which form a hard crust at very high salinity. Britton and Johnson (1987) noted hard, gypsum precipitates in high saline lakes in France and indicated that these crusts might preclude feeding from the lake bottoms.

As feeding behaviors have not been reported in equal detail for all species, it is not known to what extent the repertoire of feeding behaviors is shared. It is probable that all *Phoenicopterus* species exhibit the range of feeding behaviors illustrated below, corresponding to the variety of foods used by these birds. The lesser, James', and Andean flamingos are less well studied and are more specialized feeders (Jenkin, 1957, Vareschi, 1978; Caziani and Derlindati, 2000). It is not known whether these species use all the methods of feeding described for *Phoenicopterus*, especially 'stomping' and 'grab and throw'. The following descriptions are based on Allen, (1956), Jenkin (1957) and Rooth (1965,1976).

(Illustrations from Rooth, 1976, used with permission from Dr. A. O. Debrot, Subdirector, Carmabi Foundation, STINPA, Netherlands Antilles)

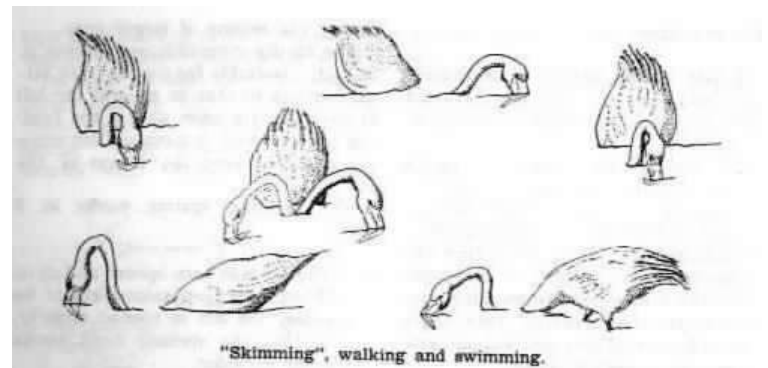
Grab and Throw: the bill tip is used to pick up large food items -- small fish, mollusks, gastropods -- in very shallow water, on the water's surface, pond bottom or on shore. This occurs while stationary, walking or running. Rooth calls this 'running' and other authors 'pecking'.



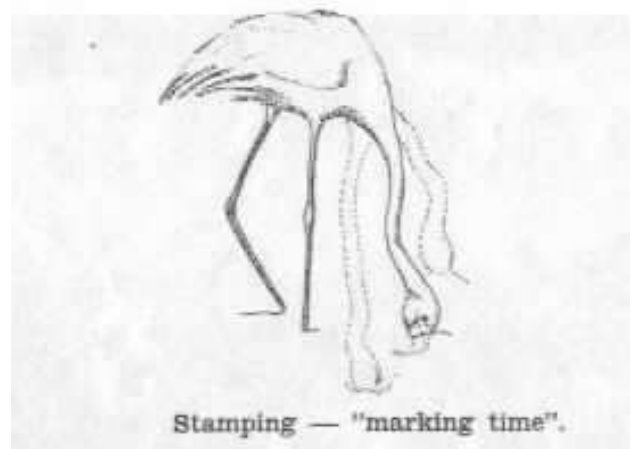


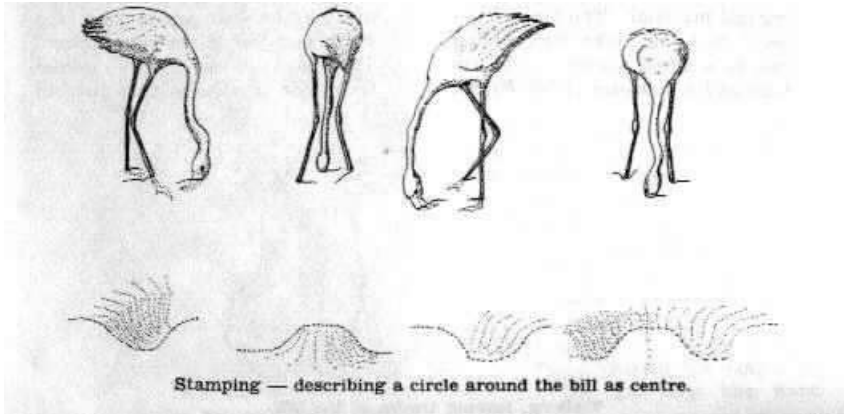
Grubbing: birds are floating in water, with the beak in substrate -- birds can reach the bottom at a depth equal to the length of their neck, which in *P. ruber*, is about 30 cm deeper than the length of their legs.

Skimming: the point of the bill skims through the upper layer of water as the bird walks or swims.



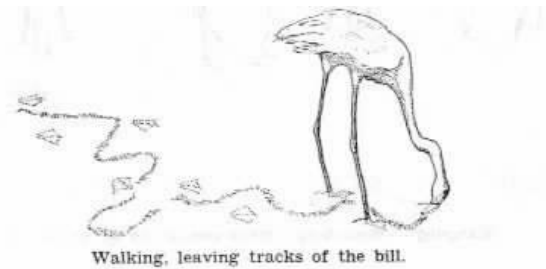
Stamping 1: marking time -- the heel joint is continually extended and retracted, alternating both legs; the head, inverted, is moved back and forth a short distance above the bottom. This can occur while the bird is stationary or moving slowly backwards. Food items from the substrate are filtered or pecked.





Stamping 2: circling around the bill -- the inverted bill is held at a center point, near the substrate, while the bird's feet stamp in a circle around it. A circle takes about a minute, and the bird's head is lifted and lowered several times. The action of the feet deposits a small mound at the center of the circle, containing mollusks, gastropods, and other invertebrates on a bed of sand. Lighter organic debris collects in the groove around the mound but is apparently not consumed.

Trailing: inverted bill is dragged lightly along the surface of mud or water, leaving a meandering track 1-2 cm deep. 'Organic ooze', algae, diatoms are ingested in this way. Tests showed organic content of mud near tracks to be 5-95% (Allen, 1956; Rooth, 1965, 1976). Rooth calls this behavior 'walking'.



Walking, while filtering in water column (no illustration)

Feeding -- Bill Structure and Mechanics (CDS)

Jenkin (1957) produced a monograph on flamingo feeding that is still the best single reference on the subject. She synthesized sources on flamingo diets going back to the 18th century. The specialization and proposed function of the structures comprising the flamingo bill are also described in detail. Jenkin's information has been widely used and cited by other authors. Mascitti and Kravetz (2002) provide additional detail on the bills of the three South American flamingo species.

In a 'typical' bird, when the beak is open, the gape has a 'V' shape, the width of the gape increasing with distance from the head. The characteristic 'bent' shape of the flamingo bill serves to keep the edges of the upper and lower mandible more or less parallel when the beak is opened, and especially when the beak is not fully opened. This facilitates the use of the lamellae on the bill surfaces as a filtration system or sieve by keeping the space between the mandibles constant. Where in most bird species the lower mandible moves against the upper, in flamingos the upper mandible moves to produce the gape. When filtering, the neck is curved down so that the upper mandible is in the water. This allows the birds to feed with their heads closer to their bodies than would be possible if feeding took place with the lower mandible in the water. This is especially important for feeding behaviors that involve stirring up food with the feet.

The flamingos can be divided into two groups based on the shape up the upper jaw. Birds in the genus *Phoenicopterus* have 'shallow-keeled' bills, while the other three species have 'deep-keeled' bills (Jenkin, 1957, Mascitti and Kravetz, 2002). In 'deep keeled' species, the upper bill is very narrow and fits into the lower so that it is not visible in profile (Jenkin, 1957). In all flamingo species, the upper and lower mandibles support a complex and diverse array of lamellae, which vary within and among species in their size, shape, spacing, placement and flexibility (see Figures 1 and 2). These lamellae function as sieves during feeding and, in some cases, also as devices that exclude large items. Mesh size can be adjusted by 'tuning the gape' (Zweers et al., 1995). Filtering can take place with the bill closed, as well as open.

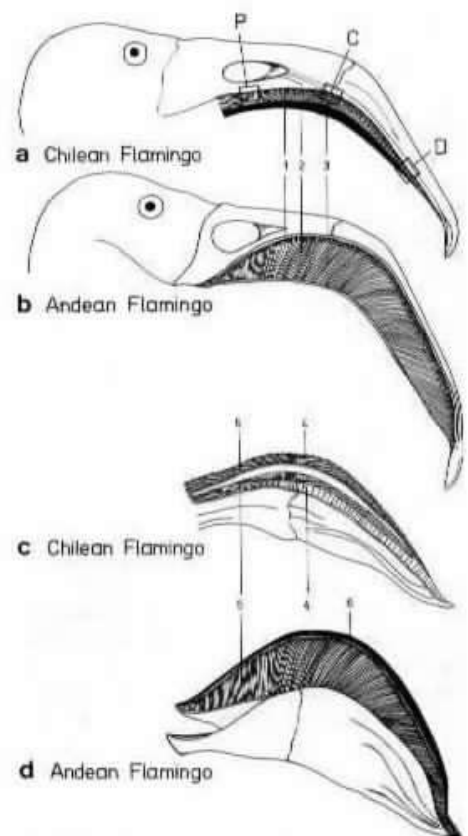


FIGURE 2. Lateral view of the jaws of two flamingo species. Upper jaw of (a) the shallow-keeled bill of Chilean Flamingo and (b) the deep-keeled bill of Andean Flamingo. Lower jaw of (c) the shallow-keeled bill of Chilean Flamingo and (d) the deep-keeled bill of Andean Flamingo. The upper jaw of Chilean Flamingo is wider than that of Andean Flamingo, and the free edge of the keel has a broad central portion uncovered by lamellae. In Andean Flamingo, the free edge of the keel is almost completely covered by lamellae. The lower jaw of Andean Flamingo has a large lamellated area in the inner sides of the bill, (1) marginal lamellae, (2) keel covered by inner submarginal rows, (3) free edge of the keel, (4) serrated ridgelike outer submarginal rows, (5) hillocklike inner submarginal rows, (6) Expanded inflexed borders of the lower jaw. Letters indicate regions of the bill: (P) proximal, (C) curvature, (D) distal.

Figure 1. Mascitti and Kravitz, 2002, p. 76, with express permission of the copyright holder, the Cooper Ornithological Society.

The flamingo tongue is substantial in all species, filling the mouth when the beak is closed. Withdrawal of the tongue produces a vacuum, drawing liquid into the mouth. The tongue then moves forward, forcing the liquid through the sieves formed by the bill (Zweers et al., 1995). Size and shape of the tongue vary, but in all species the tongue carries an array of spines, presumed to move food particles from the bill back into the throat (Jenkin, 1957). Taste buds are not found in the beak or tongue (Jenkin, 1957), but a group of taste buds has been described in mucosa of the ventral esophagus, which is behind the tongue (Bath, 1906). According to Jenkin (1957), two other types of sense organs are present in both jaw and tongue, especially near the bill tip and the edges of the mandibles. These organs, Herbst corpuscles and Grandry bodies, are found in the tongue and bill of waterfowl (Zweers et al., 1995) and may function primarily as pressure sensors.

The process of feeding is an extremely dynamic and complicated coordination of different bill surfaces, tongue, throat and head (Jenkin, 1957; Allen, 1956; Rooth, 1965). Zweers et al. (1995) has developed a detailed description, building on the earlier work, from video recordings of feeding by a trained, captive flamingo (*P. ruber*). The tongue is used to bring water into the mouth, then to force it out through the sieve formed by the lamellae on the bill. Jenkin (1957) reports that fresh stomach contents are nearly dry and concludes that little water is swallowed during the feeding process. Differences in bill structures among the flamingo species make it likely that details of the feeding process differ as well. A given species may also use different methods to filter different types of food (Jenkin, 1957).

Zweers et al. (1995) confirmed the observation (Mascitti, 1998) that filtering by flamingos does not depend only on the size of particles. An individual greater flamingo (other birds were present in the facility) was offered monotypic suspensions of measured amounts of seeds of different sizes, ranging from millet and poppy seed to pea-sized pieces of bread. These corresponded to maximum measured diameters of 0.25 -12.0 mm. The optimal size for filtering was 2-4mm, based on the number of seeds filtered in 60 seconds. While most of the seeds tested were accepted, the smallest seeds were too small to filter, and the bird eventually refused to feed on them. The largest seeds (peas and marrowfats) eventually discouraged the bird from feeding, as they were too large to filter. Interestingly, while the bird picked up pea-sized pieces of bread, it did not peck at the larger seeds. The video showed that the smallest seeds were filtered with the bill closed.

Offered mixtures of different seeds within the optimal size range, the bird was able to select grass seed (preferred) from barley, milos, or mung beans. In a test of discrimination among seeds of larger sizes, milos were ingested but not mung beans. Several mechanisms come into play here,

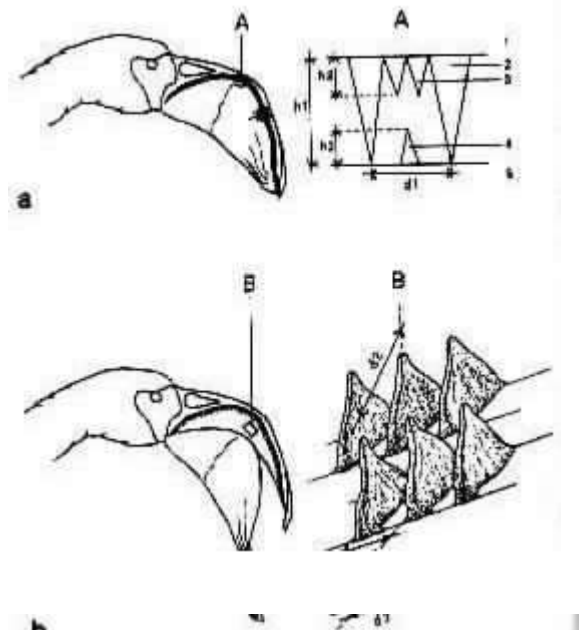


FIGURE 1. Measurements of the lamellae. (a) Generalized scheme of the closed bill and sieve showing the marginal lamellae of the upper jaw and the outer and inner submarginal lamellae of both jaws. In the sieve diagram (A), numbers represent (1) upper jaw, (2) marginal lamellae, (3) outer submarginal lamellae of the upper jaw, (4) outer submarginal lamellae of the lower jaw, (5) lower jaw. (b) Generalized picture of the open bill showing the inner submarginal rows, magnified in (B). Letters indicate measurements used in the analysis (see text). The positions of the scanning electron micrographs in Figures 3, 4 and 5 are indicated by the rectangle with arrow.

Figure 2. From Mascitti and Kravitz, 2002, p. 74, with express permission of the copyright holder, the Cooper Ornithological Society.

including manipulation of the gape to create filters of different sizes, for both inflow and outflow, and using the tongue to direct water outflow to different places along the bill, corresponding to different filter sizes. Sympatric flamingo species, *P. ruber roseus/Phoeniconaias minor* in Africa and *P. chilensis/Phoenicoparrus andinus* and *jamesi* in South America, have different optimal particle sizes and, therefore, may not compete directly for food (however, see Caziani and Derlindati, 2000). Table 4 (copied below) shows different sizes of particles found in the gizzards of the South American flamingo species.

TABLE 4. Gizzard contents of three South American flamingo species, classified by type of item and size. Items are percentages, presented as mean \pm SD. Diatom percentages were calculated from the total number recorded in lake water samples at Laguna de Pozuelos (availability) or found in gizzards; seed and grit percentages were calculated only from gizzard contents. Chilean Flamingo ($n = 1$) and Andean Flamingo ($n = 3$) specimens were collected in May; James' Flamingo ($n = 3$) specimens were collected in December (Mascitti 1998).

	Availability in lake	Chilean Flamingo	Andean Flamingo	James' Flamingo	
		Gizzard	Gizzard	Availability in lake	Gizzard
Diatom size (μm)					
0–20	39.7 \pm 9.6	0	11.6 \pm 3.0	72.0 \pm 15.0	27.2 \pm 11.7
21–40	39.2 \pm 8.8	0	0.5 \pm 0.2	20.3 \pm 10.4	51.9 \pm 9.0
41–60	16.8 \pm 7.8	0	2.1 \pm 0.3	5.0 \pm 4.4	14.8 \pm 3.5
61–80	2.1 \pm 1.9	0	33.0 \pm 8.0	1.8 \pm 1.8	2.2 \pm 1.4
81–100	2.0 \pm 1.0	0	51.2 \pm 10.1	0.6 \pm 0.8	0.6 \pm 0.7
101–120	0.2 \pm 0.2	0	1.6 \pm 0.2	0.2 \pm 0.2	2.4 \pm 2.5
>120	0.1 \pm 0.2	0	0.0 \pm 0.0	0.0 \pm 0.1	0.9 \pm 1.0
Seed size (μm)					
700 \times 1200		98.0	0.0 \pm 0.0		0.0 \pm 0.0
Grit size (μm)					
<60		1.0	2.0 \pm 1.3		0.5 \pm 0.3
60–90		0.5	1.3 \pm 0.6		4.9 \pm 5.6
91–150		0.5	1.2 \pm 0.3		30.7 \pm 8.1
151–250		1.0	1.7 \pm 0.8		47.8 \pm 31.2
251–500		5.0	3.2 \pm 2.4		16.2 \pm 20.9
501–1000		92.0	90.7 \pm 4.5		0.0 \pm 0.0

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Comparative Digestive Anatomy (ESD)

Length of intestinal tract (gizzard to caeca) ranged from 1.7 to 2.9m in *Phoenicopterus sp.*, and 2.3 to 4.4 m in the smaller species (*Phoeniconaias minor* and *Phoenicoparrus sp.*) ($n=29$; Kear and Duplaix-Hall, 1975). In the same birds, caeca length ranged from 2.9 to 4.6% of total intestinal length (*Phoenicopterus sp.*) but only 0.9 to 1.3% of total intestinal length in the latter group. These differences suggest that fermentation processes (to break down complex carbohydrates such as those of chitinous exoskeletons?) may play a larger role in digestive physiology of the more omnivorous species compared with enhanced digestive surface area of the more herbivorous species.

The Food of Wild Flamingos

Information on the food of wild flamingos derives from analyses of crop, gizzard and stomach contents (for example Allen, 1956; Jenkin, 1957; Mascitti and Kravetz, 2002; Tourenq et al., 2001), from sampling environments where flamingos feed (for example, Arengo and Baldassare, 1995, 1998, 1999, 2002; Mascitti, 1998; Soto, 1988; Casler and Este, 2000; Caziani and Derlindati, 2000) and comparing areas where flamingos feed to areas where they have been excluded (Hurlbert and Chang, 1983). Because flamingos can use different feeding methods and can filter selectively, and

because some food items (algae, slime) are processed faster than others (seeds, mollusks), in most cases, the relative proportions of items consumed are not known. Flamingos of the same species, in nearby bodies of water, can be consuming very different diets (Jenkin, 1957; Hurlbert, 1982; Hurlbert et al., 1986; Vareschi, 1978; Arengo and Baldassari, 1999; Baldassare and Arengo, 2000). Feeding by large flamingo flocks has significant impact on the relative abundance of available food items in a given body of water (Tuite, 2000; Hurlbert et al., 1986). However, because in some areas flamingos feed on 'monocultures', we know that diets for individuals of some species can vary from 100% herbivorous (*Spirulina*) to 100% carnivorous (*Artemia*).

Foods reported for species of flamingos

Phoenicopterus ruber ruber

Polychaetes, mollusks, copepods, amphipods, chironomids, crustaceans, seeds of widgeongrass (*Ruppia maritima*), tubercles of muskgrass (*Chara fibrosa*) gastropods, organic 'ooze'/mud, annelids, insect larvae, invertebrate taxa: Mytilidae, Solecurtidae, Cephalaspidae, Chironomidae, Nematoda, Lymnaeidae, Oligochaeta, Veneridae, Malacostraca, Cerithidae, Batilaria, brine shrimp (*Artemia sp.*), brine flies (*Ephydra sp.*), shrimp, fish; grit **References:** Allen, 1956; Jenkin, 1957; Espino-Barros and Baldassare, 1989; Schmitz et al, 1990; Bildstein et al., 1991; Schmitz and Baldassarre, 1992; Arengo and Baldassare, 1998, 1999, 2002; Este and Casler, 2000; Casler and Este, 2000.

Phoenicopterus ruber roseus

Aquatic invertebrates, organic mud, mollusks, crustaceans, seeds of *Carex*, *Cyperus*, *Ruppia*, *Scirpus* and *Medicago sp.*, insect larvae, annelid worms, vegetable matter, ants (!), corixid beetles; grit **References:** Allen, 1956; Jenkin, 1957; Johnson 1997; Tourenq et al., 2001.

Phoenicopterus chilensis

Calanoid copepods (5 species of *Boeckella*, *Parabroteas sarsi*), daphnia, brine shrimp, chironomid larvae, amphipods, corixids, cladocerans, ostrocods, snails, annelids, crustacea, mollusks, aquatic plants; grit **References:** Allen, 1956; Jenkin, 1957; Hurlbert, 1982; Hurlbert et al, 1986; Soto, 1988.

Phoeniconaias minor

Spirulina platensis and other sp., rotifers -- *Brachionus dimidiatus*, *B. plicatilis*, *Hexartha jenkiniae*, *Anabaenopsis arnoldii*; *A. elenkinii* (algae), diatoms (*Bacillariophyceae*, *Navicula*), nauplii and first copepodites, cyanophytes, corixid beetles, seeds of sedge, blue-green algae (*Myxophyceae*); grit **References:** Allen, 1956; Jenkin, 1957; Vareschi, 1978; Tuite, 2000

Phoenicoparrus andinus

Surirella sp. and other diatoms >80 microns, algae; protozoa, nematodes, organic mud; immature sand crabs; insect and crustacean larvae, grit **References:** Jenkin, 1957; Hurlbert, 1982; Hurlbert and Chang, 1983; Caziani and Derlindati, 2000.

Phoenicoparrus jamesi

Organic mud, algae, diatom frustules (25 species), vegetable residues (scant), preferring to forage in shallow (2 cm) water, consuming diatoms <60 microns; grit. **References:** Jenkin, 1957; Hurlbert, 1982; Mascitti, 1998

Phoenicoparrus andinus

Surirella sp. and other diatoms >80 microns, algae; protozoa, nematodes, organic mud; immature sand crabs; insect and crustacean larvae, grit **References:** Jenkin, 1957; Hurlbert, 1982; Hurlbert and Chang, 1983; Caziani and Derlindati, 2000.

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Organic mud, algae, diatom frustules (25 species), vegetable residues (scant), preferring to forage in shallow (2 cm) water, consuming diatoms <60 microns; grit **References:** Jenkin, 1957; Hurlbert, 1982; Mascitti, 1998

Composition of Native Foods (ESD)

No published reports of the specific chemical composition of native foods eaten by flamingos were found. A generic summary of nutrient composition of types of foods that may be consumed by free-ranging flamingos is found in Table 1. These data were extracted from the literature and do not

Nutrient	Dried <i>Spirulina</i> sp. ^a	<i>Artemia</i> <i>salin</i> ^a	Copepods ^b	Diatoms ^b Mixed spp.	Shrimp- <i>Penaeidae</i> & <i>Panalidae</i> ^a
Water, %	4.68	89.09		76.00	75.86
Protein, %	60.29	57.20	50.00	17.14	84.13
Crude Fat, %	8.10	12.85	35.00		7.17
Vitamins					
Vitamin A, IU/g	5.98	454.50		14.07	7.46
Vitamin E, IU/kg	52.45	1.41		7.17	33.97
Vitamin B ₁ , Thiamin, mg/kg	24.97				1.16
Vitamin B ₂ , Riboflavin, mg/kg	38.5				1.41
Vitamin B ₃ , Niacin, mg/kg	134.49				105.72
Vitamin B ₆ , Pyridoxine, mg/kg	3.82				4.31
Vitamin B ₁₂ , Cobalamin, IU/kg	0.00				2.11
Folacin, mg/kg	0.99				0.12
Pantothenic Acid, mg/kg	36.51				11.43
Vitamin C, mg/kg	105.96	31.10			82.85
Minerals, %					
Calcium	0.13	0.07	0.30		0.22
Potassium	1.43	1.37	0.43		0.77
Magnesium	0.20	0.20	0.43		0.15
Sodium	1.10	2.32	1.27		0.16
Phosphorus	0.12	1.23	0.70		0.85
Ca:P Ratio	1.08	0.06			0.26
Concentration, mg/kg					
Copper	63.99	8.98	10.00		10.94
Iron	298.99	103.37	53.00		99.83
Manganese	19.93	19.68	4.00		2.07
Selenium	0.08				1.57
Zinc	20.98	125.98	90.00		45.98

Table 1. Nutritional content of some foods utilized by flamingos in the wild. Samples were commercially obtained and do not necessarily reflect wild dietary ingredients. All data (except water) is presented on a dry matter basis. Data extracted from ^aZootrition software (Wildlife Conservation Society, 1999) and ^bWCS Wildlife Nutrition Laboratory, unpublished.

represent actual dietary samples; nonetheless, some general statements can be inferred from this information. On a dry basis, these types of foodstuffs contain a variable protein content (invertebrates ranging from 16 to about 66% on a dry basis; widgeongrass seeds, 6 to 17%), and moderate to high fat and carbohydrate concentrations (7% to >30%; 5 to >50%, respectively), as well as quite high concentrations of vitamin E, vitamin C (both antioxidant vitamins), and B vitamins. With natural foods providing good sources of vitamin C, it is conceivable that the flamingo has a dietary requirement for this nutrient, but the ascorbic acid synthetic ability of the flamingo has not been established. Vitamin A concentration, on the other hand, is relatively low in natural foodstuffs, while carotenoid pigments may be quite high; presumably the flamingo meets its vitamin A requirements through enzymatic conversion of dietary carotenes. Mineral concentrations vary; sodium and chloride concentrations reported are, in general, high whereas calcium (Ca) content is quite low. Only in algal species (and diatoms) are Ca:P ratios >1.

Carotenoids and Feather Pigmentation (DLM)

While we still do not understand the ecological significance of the pink color of flamingos, clearly, color-feeding is a significant aspect of flamingo feeding husbandry. Proper coloration from dietary carotenoids is important, not only aesthetically from an exhibition perspective, but may be a component of behavioral recognition, reproductive success, and impact other physiological and health processes. Between 500 and 600 carotenoid pigments have been identified in vertebrates, some specifically responsible for coloration of feathers, skin, eyes, scales, beaks, and egg yolks. Pigmentation of feathers and exposed tarsal and facial skin of flamingos is derived from yellow, orange and red molecular components found in the natural diet (Fox and Lint 1975). Only plants synthesize carotenoid pigments; however, many animals (including insects, mollusks, crustaceans and fish) concentrate and further metabolize them to provide a rich dietary food source for birds.

The deposition of pigment into specific tissues is dependent upon three primary factors:

1. The quantity of the appropriate carotenoid in the diet.
2. The bird's capacity to digest and absorb specific carotenoids and metabolize them to the correct chemical form (factors that improve fat digestion can improve carotenoid incorporation).
3. The capacities of specific tissues to take up carotenoids and insert them into the structure of growing tissue.

Dietary carotenoids may be used directly to pigment tissues or metabolized to other carotenoids prior to incorporation; as a consequence, tissue carotenoids may differ from those consumed. It is not known if the feather follicles can further metabolize carotenoids in order to change feather color, or if color discrimination only occurs at the level of carotenoid uptake from the blood. Each carotenoid appears to have its own individual pattern of absorption, plasma transport and metabolism, and there are considerable species differences in the types of carotenoids that are preferentially absorbed and metabolized (Stradi, 1998).

Pigmentation in the Flamingo

The pigments mainly responsible for the plumage color of flamingos are the red carotenoids canthaxanthin, phoenicoxanthin and astaxanthin (Comben, 1976), and metabolism has been studied in detail (Fox, 1975; Fox and Lint, 1975). Flamingos effectively absorb and utilize β -carotene as a precursor for skin and feather pigments (e.g. astaxanthin), but they do not readily

utilize many dietary xanthophylls, including astaxanthin. Instead, astaxanthin is converted from canthaxanthin and deposited in feathers (Klasing, 1998). They demonstrate a selective metabolic preference for ingested carotenes over xanthophyllic fractions, and oxidize carotenes in a stepwise manner (first to ketones, such as echinenone and then to the chief derivatives, canthaxanthin from β -carotene and phoenicopterone from β -carotene) (Fox and Lint, 1975). The hydroxylation of canthaxanthin to phoenicopterone and astaxanthin occurs at the site of epidermal and feather growth (Fox, 1975). Trials with β -carotene, lycopene, and zeaxanthin failed to produce any detectable metabolic results (Fox, 1975).

Captive birds can live, reproduce, and appear healthy when consuming a diet devoid of carotenoids as long as vitamin A is provided. However, due to the highly developed social behavior of many species of free-living birds, carotenoids may be required for breeding success. There is some debate as to whether poorly colored birds are less likely to breed. Only sexually mature adult flamingos are fully colored, and it is possible that individuals 'recognize' potential breeding partners by the depth of their red coloration. According to early anecdotal literature and speculation (Kear, 1974), more consistent breeding results were achieved when zoos recognized the importance of the bright color in flamingos and added carotenoids to the diet. However, no significant correlation between coloration and reproductive fitness has been demonstrated experimentally in captive flamingos, information is clearly equivocal, and other factors apart from coloration appear more important in breeding success (AZA & EAZA Ciconiiformes Advisory Groups, CICAG, pers. comm.) On the other hand, captive flamingo diets are much less variable than wild diets, so variation in coloration may be less than in the wild.

Pigmentation Loss in the Flamingo

Although pigments are deposited in the liver, blood, fatty tissue, exposed tarsal and facial skin, feathers and yolk (Fox and Lint, 1975), if deprived of their natural food and carotenoid supplementation, flamingos become pale in color. Birds lose blood carotenoids on a carotene-deficient diet considerably faster than they restore canthaxanthin to the blood on a carotene supplement. This may be because the anabolic accumulation of canthaxanthin requires expenditure of chemical energy for oxidation of the hydrocarbon carotene (Fox and Lint, 1975).

The red leg color of the James' flamingo tends to fade in captivity, and the violet chest of the Andean flamingo may also be lost (Kear and Palmes, 1980). Apart from diet, environmental conditions may also impact the ability of flamingos to express normal coloration. "Stress" can modify hormones such as thyroxine and corticosterone to negatively impact xanthophyll metabolism; direct effects of stress on flamingo pigmentation have not been examined.

Canthaxanthin, the primary feather pigment, is a rather unstable compound and warrants a continuous dietary supply as long as the birds are molting. At other times of the year, limited body stores in adipose and liver tissues can be utilized to maintain color. Canthaxanthin pigment is generally considered to be nontoxic, with an LD50 determined at about 25 mg/kg (in experiments conducted with laboratory model species). However, high levels of dietary carotenoids fed to flamingos have resulted in dull plumage, with the skin of the head developing a purplish tinge (Comben, 1976). Excesses in other species have resulted in mineral deposition in the retina. In addition, high levels of carotenoids can compete with fat-soluble vitamins (A, D, E, and K) for absorption, transport and deposition pathways within the body, and excessive levels can indirectly lead to deficiencies of these vitamins (Comben, 1976).

Pigmentation of Crop Milk

Once flamingos have laid and hatched their eggs, both adults feed the young by crop secretion for up to three months in the wild and up to one year, or even into the next breeding season, in captivity. This secretion (for nutrient composition see Handrearing Section) is formed by glands that lie close together in the upper digestive tract (Studer-Thiersch, 1975). Crop milk secretions fed to chicks are bright red in color for the first few weeks of the chick's life and gradually fade. While the red color was once accredited to blood in the secretion, it has been clarified that the coloration results from canthaxanthin carotenoids at a concentration of 0.4 mg/100mL (van Bockstaele, 1974; Fox, 1975). Adults tend to lose plumage color during feeding of chicks. It has been surmised that they are meeting specialized needs of the chick for vitamin derivatives (Kear, 1974) through pigment mobilization. Despite carotenoids being made available to the developing chick in the egg yolk and crop milk, chicks fail to assimilate any pigments into tissues (Fox, 1975).

Health Issues Linked to Captive Diets (ESD, DLM)

Leg problems (see Health and Medicine, Chapter 6) and obesity in captive flocks may be associated with diets high in energy content that result in too rapid growth, but nutritional diseases/ imbalances have rarely been reported in flamingos. An imbalance of Ca and P due to high Ca relative to P more likely underlies this observation -- levels of Ca above 1% have been shown to result in bone deformations in poultry. Early diets designed for captive flamingos, comprising dried shrimp and cereal grains, resulted in mineral imbalances and vitamin deficiencies (Wackernagel, 1975) – in particular, vitamin A due to oxidative deterioration. The appearance of rachitic bones together with a hyperplastic parathyroid gland can result from vitamin A antagonism known to exist with vitamin D (Mertz et al., 1985). Chilean flamingos have exhibited a condition superficially similar to rickets, involving bending of the tibio-tarsus and thickening of the head of the bone (refer to Health and Medicine, Chapter 6 for further details). The condition has not been found in young under about four weeks old, but birds at all later stages of plumage have been affected (Humphreys, 1975), suggesting that yolk storage reserves and/or crop secretions may be better balanced with regard to fat-soluble vitamins compared to diets consumed by older birds. Vitamin A toxicosis has not been reported in flamingos; nonetheless, interactions among the fat-soluble vitamins (A, D, and E) probably warrant further investigation in/of this group. Vitamin E deficiency has been reported but not experimentally induced in captive flamingos (Fowler, 1986; Dierenfeld and Traber, 1992). Circulating concentrations of vitamins A and E in flamingos may be useful in evaluating health status (see below). High levels of vitamin E measured in wild foods (Table 1), along with elevated concentrations of polyunsaturated fatty acids (which oxidize readily) in both wild and captive diets suggest a possible increased dietary requirement for this nutrient in its role as an antioxidant. Hemosiderosis (iron accumulation in extraneous tissues) in flamingos has been reported anecdotally as a health issue (although not a primary pathology) and may be linked to excess dietary iron and/or antioxidant status in association with vitamins C and vitamin E; this condition is currently under investigation (Marques, pers. comm.)

Feeding Requirements of Captive Flamingos (ESD)

Placement of Feeders and Diet Form

Historically, it was recommended that flamingos be fed in bowls, troughs, or pools away from main water bodies to minimize fouling of exhibit water (Testa and Johnson, 1992; Kear, 1974). However, behaviorally as well as physiologically, feed or feeder placement directly in or on the water can provide an optimal feeding environment and this is recommended when possible. Bildstein et al. (1991) demonstrated that the food intake of juvenile Chilean flamingos was at most 82% that of adults due to aggressive displacement, hence, appropriately spaced and adequate numbers of feeding stations should be available to minimize aggression between birds. Feeding stations should have access from all sides to permit less dominant birds an easy escape if they are displaced.

Nutritionally complete diets ground to a fine particle size (fed either dry or mixed with water to provide a slurry), small-dimension (1-5 mm) dry crumbled diets, and larger (1 cm diameter) extruded floating diets have all been successfully fed to captive flamingos. This reflects their adaptability to different sizes and shapes of dietary ingredients. Feeding stations should be available for free-choice feeding throughout the day. The significance of filtration of nutrients directly from exhibit ponds should not be overlooked in the feeding of flamingos, although its contribution has not been quantified in captive birds.

Grit has been reported in digestive tract contents of all species. Unless it is available as part of the exhibit substrate, grit should be provided separately in the size range of 500 to 1000 μ m for the larger flamingo species, and 90-250 μ m for the smaller species.

Nutritional Requirements of the Flamingo

Water - Flamingos can survive by drinking ocean-strength seawater through efficient filtration mechanisms and secretion of hyperosmotic solutions of sodium chloride (Bildstein et al., 1995). Many free-ranging flamingos occasionally travel long distances to drink and bathe at freshwater sites; captive flamingos, however, showed no preference for feeding in fresh, saline, or hypersaline solutions during one short-term study (Bildstein et al., 1995). Fresh, potable water should be constantly available to flamingos in captivity.

Energy - Despite the variety of feeding habits among species, there are no data to surmise that nutritional requirements of flamingos differ substantially from those established for domestic ducks or geese, and biliary bile acid composition suggests that flamingos are more closely related to Anseriformes compared to other Ciconiiformes (Hagey et al., 1990). Seeds of grasses and tubers have been found in crops and stomachs of free-feeding flamingos, hence, plant-based diets (see also Table 1) appear entirely suitable for these species, and few nutritional problems have been reported for this group. Energetics calculations based on dry commercial feeds containing between 3 and 3.5 kcal/g (12.5 to 14.6 kjoule/g) suggest that a 3 kg *Phoenicopterus ruber* requires between 230 and 290 kcal per day (960 to 1200 kjoules per day) depending on activity level (Aschoff and Pohl, 1970). This level would be supplied by consumption of 65 to 100 g of dry food per individual (2-3% of body mass). If diets are presented as a slurry (up to 75% water), this may represent 260 to 400 g of food offered daily, or up to 10% of body mass. Similar calculations for a 1.8 kg *Phoeniconaias minor* result in energetics requirements of 160 to 200 kcal (660 to 830 kjoule), which

would also be met by feeding a slightly higher percentage of body mass at 2.5 to 3.5%, or 45 to 65g of dry food (180 to 250g of slurry). Kear (1974) fed 364g (slurry) per bird to a flock of 275 in a mixed exhibit; other zoos feed between 200 – 300 g per bird daily (wet slurry).

Protein - Based on poultry nutrient requirements, Wackernagel (1975) recommended that diets for captive flamingos contain not less than 13% protein. The inclusion of a large proportion of animal ingredients and algae in the diet of free-ranging flamingos, however, might suggest a higher protein intake in nature (see Table 1 for nutrient composition of some native foods). Diets, however, are invariably diluted with plant materials, mud, and other filtrates to provide a lower overall protein content, and commercially available diets or mixes used in zoos containing between 20 and 45% protein (see Table A1) have been shown to support reproduction. Respondents from an earlier captive diet survey (Roberts and Hesch, 1992) reported that a majority of US zoos (83%) incorporated green produce, shrimpmeal and trout or even cat extrusions to commercial diets fed the lesser flamingo in an effort to meet presumed higher protein (or other nutrient) requirements of this species, but current data do not support this assumption. Species differences in protein requirements, variation due to physiological stage, and/or the importance of seasonality in dietary protein content or availability have not been examined in flamingos.

Vitamins and Carotenoids - Native foods eaten by flamingos appear to contain less vitamin A, and more vitamin E, than typical diets formulated for domestic poultry. Additionally, if high carotenoid supplementation is required for proper coloration, this may decrease absorption of vitamin E from the diet, thus increasing dietary vitamin E requirement. In general, domestic avian vitamin E requirements appear to underestimate dietary needs of this nutrient for flamingos in captivity. The ratio of A:D:E may be more important than any one fat-soluble constituent, with dietary concentrations of 20,000 IU vitamin A, 2000 IU vitamin D3, and 200 IU vitamin E per kg dry matter suggested as reasonable for captive flamingos. Due to potential toxicity problems with canthaxanthin reported in other species at levels >25 mg/kg, future inclusion of this pigment in animal diets may be limited or discontinued in Europe (EAZA Flamingo Husbandry Manual, 2002). Other pigments and/or mixed carotenoid products may prove effective in feeding and coloration of flamingos. Pigmentation is required in the diet for coloration only during feather formation; however, its inclusion year-round has not been shown to be detrimental to health (when levels are not excessive).

Minerals - Requirements do not appear to differ from those of domestic poultry species. Adult flamingos are unlikely to require more than about 1% calcium (dry basis). Accordingly, the dietary P content should be approximately 0.5%. The wild environment of the flamingo is highly saline, resulting in expectations of a captive diet high in salt. However, the flamingo excretes salt via supra-orbital glands and does not require a high salt intake in captivity; they also ingest very little water with their food. High concentrations of salt can lead to excessive consumption of water and attendant problems with ventilation control (NRC, 1994). Diets recommended for the domestic fowl, containing 0.5 % NaCl, have proven to be adequate (Wackernagel, 1975).

Composition of Captive Diets (ESD)

The chemical composition of a number of diets fed to flamingos in North American zoos is summarized in Appendix Table 1A, along with suggested recommendations for nutrient ranges. Diets included in the table represent commercially available products fed as sole items, as well as mixed practical rations utilized by two zoological institutions with proven reproductive success. Chemical analyses of commercial diets do not indicate any significant differences between breeding

and maintenance diets, and zoos generally do not vary diets seasonally. Faced with a lack of published data from controlled, comparative studies, it is not possible to say whether these diets based on poultry requirements are adequate to support optimal reproduction or growth (NRC 1985; 1994). Based on available data, all formulated diets reported herein appear to be capable of maintaining captive flamingos, and at least minimally meet requirements for growth and reproduction. Hand-rearing information is presented in a separate chapter; no provision for geriatric animals has been identified.

Recommendations for standardized flamingo nutrient ranges are based on these practical diets in combination with information from native foods and domestic poultry requirements. Currently, vitamin A is being offered to captive flamingos in significantly higher concentration than those recommended by the NRC (1994) for laying poultry, with at least one commercial diet exceeding maximum tolerance levels suggested for poultry. While vitamin A toxicosis has not been reported in flamingos, imbalances of fat-soluble vitamins can result in antagonisms and overt deficiencies of other nutrients. With pigmentation of flamingos dependent on uptake of other fat-soluble constituents, further nutrient interactions must also be considered. Given that the presentation of flamingo diets is often in a liquid form, allowances have been made for potential oxidative deterioration of specific nutrients.

The majority of North American zoos use canthaxanthin as a pigment added to the diet: Roxanthin Red (10% dry canthaxanthin beadlets manufactured by Roche) or Carophyll Red (10% pure canthaxanthin) have been added in the range of 25mg/kg food (Wildlife Conservation Society) to 1g/kg food at Slimbridge (Griswold, 1975). Approximately 10 g of canthaxanthin has historically been fed on a daily basis to 275 birds at Slimbridge (Kear, 1974). Comben (1976) believes that delivery of the carotenoid through a 'soup' mixture is wasteful and that a pelleted mixture is more economical. Some zoos now use mixed carotenoid products, with some commercial feeds incorporating mixed carotenoids at manufacture. A suggested dose of pigmentation in flamingo diets, which has resulted in feather coloration equivalent to free-ranging birds when scored using a standardized color index (Wildlife Conservation Society, in preparation) is 23 mg canthaxanthin per kg dietary dry matter; 50 mg/kg mixed carotenoids (Betatene 7.5%) also provides suitable coloration.

Physiological Assessment of Nutritional Status (ESD)

It may be valuable to develop a standardized feather color scoring system for use in flamingo management to establish quantitative links between dietary constituents and bird appearance, as well as to compare geographic differences among flocks both in situ and ex situ. These data can then be correlated with reproductive and health parameters. Prototypes of such a system exist; conversion to an Internet-based system has been proposed, with funding, implementation, and dissemination pending (Dierenfeld and Sheppard, unpublished data). Color will be scored against fine-grade international color standards used in the graphics industry.

Fat-Soluble Vitamins A and E

Table 2 summarizes values of vitamin A (measured as retinol) and vitamin E (measured as tocopherol) in the blood of provisioned free-ranging Caribbean flamingos and captive Caribbean, Chilean and lesser flamingos. While vitamin E levels are not significantly different among flamingo species, the vitamin A levels in the free-ranging Caribbean flamingos are significantly lower than

any of the species maintained in captivity. The detection of the retinyl palmitate ester (A-palmitate, Table 2) often indicates the presence of a synthetic source of vitamin A from the diet or can be an indication of high dietary levels of vitamin A. Retinyl esters were not measured in the zoo-held flamingos but were seen in the provisioned free-ranging birds with access to a commercial diet. Presumably these semi free-ranging flamingos were meeting vitamin A needs through conversion of dietary carotenoid pigments; the presence of the retinyl esters, then, may have been an indication of dietary excess.

There were no significant differences in circulating concentrations of vitamin E among flamingo species measured. Overall, the flamingo values reported here are more similar to ranges seen in carnivorous birds (10-40 µg/mL) rather than herbivorous/ granivorous species (2-10 µg/ml; (Dierenfeld and Traber, 1992). The Lesser Flamingo, which feeds predominantly on algae, tended towards the values for herbivorous species. Gamma-tocopherol, the predominant form found in seeds, although measured in all plasma samples, was only detected in blood samples from the provisioned free-ranging flamingos.

Species	Retinol (µg/ml)	A-palmitate (µg/ml)	a-Tocopherol (µg/ml)	g-Tocopherol (µg/ml)
Semi Free-ranging Caribbean (n=53)	0.046 ± 0.22 (.00312-1.443)	0.014 ± 0.072 (0.0005 - 0.4630)	19.04 ± 10.08 (4.3-38.9)	2.15 ^a ± 0.91 (1.0-4.0)
Caribbean (n=15)	0.44 ^b ± 0.33 (0.12 - 0.77)	NA	15.41 ± 6.49 (0.26 - 25)	ND
Chilean (n=55)	1.23 ^c ± 0.56 (0.16 - 2.29)	NA	21.20 ± 8.9 (0.54 - 34.28)	ND
Lesser (n=6)	0.73 ± 0.16 (0.45 - 0.92)	NA	13.20 ± 2.11 (9.95 - 15.39)	ND

Table 2. Plasma or serum retinol, A-palmitate (retinyl palmitate), a-tocopherol and g-tocopherol levels (mean ± SD and range) measured in provisioned free-ranging Caribbean (*Phoenicopterus ruber ruber*) flamingos and captive Caribbean (2 facilities), Chilean (*P. chilensis*; 2 facilities) and lesser (*Phoeniconaias minor*) flamingos (Wildlife Conservation Society Nutrition Laboratory and Norkus, unpublished data). NA = not analyzed, ND = not detected.

Carotenoids

In flamingos, total blood carotenoid have been measured comprising 96% canthaxanthin at a total concentration of 2.64 mg/100 mg blood, with only 4% being β-carotene (Fox and Lint, 1975). A more recent assessment of circulating carotenoid concentrations in provisioned semi free-ranging Caribbean flamingos (Table 3) demonstrated a considerably different distribution, with almost 80% of total carotenoids (0.02/0.03) remaining as β-carotene. This might suggest that this compound was not needed for vitamin A synthesis in the provisioned birds.

	Lutein	Cryptoxanthin	β-Carotene	Total Carotenoids
Mean ug/mL ± SD	1.20 ± 0.72	0.61 ± 0.46	0.024 ± 0.037	0.0304 ± 0.021
Range ug/mL	0.20 - 2.89	0.04 - 2.26	0.001 - 0.207	0.004 - 0.092

Table 3. Carotenoid values from provisioned free-ranging Caribbean flamingos (n=41). Values for total carotenoids are based on a β-carotene standard (Norkus, unpublished data 1999).

Conclusion

In summary, there is very little published data pertaining to the nutrition of captive or wild flamingos, probably because nutritional problems are rare in flamingos. Aside from issues of feather pigmentation loss, there are few published references documenting nutritional deficiencies or toxicities in flamingos maintained in captivity. Diets currently being employed by zoological institutions vary substantially, and recommendations have been made for a uniform flamingo diet in Table A1, CicAG (Ciconiiformes Advisory Group) Diet. These recommendations are based on a combination of published requirements for the laying hen, inferential evidence from natural foods, and practical husbandry experience with flamingos and other avians. Given that the presentation of flamingo diets is often in a liquid form, allowances have been made for potential deterioration of specific nutrients.

In addition, there are several areas of flamingo nutrition suggested for further detailed research:

- Assessment of nutritional composition of wild diets
- Extent of conversion of carotenoids to vitamin A
- Interactions of fat-soluble vitamins and carotenoid supplementation
- Interactions among vitamin D, calcium and phosphorus
- Assessment of calcium status in adults and chicks throughout the breeding season
- Intake and digestion by different species, and responses to various commercial products
- Effects of temperature on intake and protein nutrition
- Vitamin E requirements
- Significance of vitamin E/Se in the prevention of capture myopathy
- Effect of fatty acid complex on oxidation and antioxidant nutrition
- Vitamin C metabolism.

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Products Mentioned in the Text:

Betatene 7.5%, Cognis Corporation, Nutrition & Health, 5325 South Ninth Avenue, LaGrange, IL 60525

Carophyll and Roxanthin Red, Hoffmann-LaRoche, Inc., 45 Waterview Boulevard, Parsippany, NJ 07054

Flamingo Complete, Mazuri, P.O. Box 66812, St. Louis, MO 63166-6812

Flamingo Fancier, Zeigler Bros, Inc., 400 Gardners Station Rd., P.O. Box 95, Gardners, PA 17324

Flamingo Fare, Reliable Protein Products, Inc., 70-105 Frank Sinatra Drive, Rancho Mirage, CA 92270

Flamingo AP, HMS Zoo Diets, Inc., Bluffton, IN 46714

Nutrient	Mazuri	HMS	Reliable	Zeigler	Diet	Diet	Wackernagel	Breeding/ Laying	CICAG Diet
	Flamingo Complete	Flamingo AP	Protein Flamingo Fare	Flamingo Fancier	Zoo A	Zoo B	1975	Poultry (chicken, duck, geese) NRC, 1984, 1994	2002
Energy, ME (kcal/kg)	3410.00	2497.00		2860.00				2900 to 3200	3000.00
Water, %	10.00	10.00	45.00	15.00		10.00		10.00	
Protein, %	22.22	32.50	45.45	22.00	32.83	20.30	20.00	14 to 17	20 to 40*
Crude Fat, %	6.11	5.40	14.55	5.00	7.98	4.93	3.00	-	1% linoleic
Vitamins									
Vitamin A, IU/g	36.11	26.70	-	-	17.55	14.56	20.00	4.44	20.00
Vitamin D ₃ IU/g	6.67	7.19	-	-	2.97	3.59	2.00	0.2 to 1.0	2.00
Vitamin E, IU/kg	81.11	133.33	-	-	26.32	240.90	75.00	5.5 to 11.1	200.00
Vitamin K, mg/kg	1.11	-	-	-	-	-	4.00	0.55	1.00
Vitamin B ₁ , Thiamin, mg/kg	18.89	1.26	-	-	1.55	4.71	6.00	0.89	5-10
Vitamin B ₂ , Riboflavin, mg/kg	13.33	15.28	-	-	5.30	15.20	8.00	2.4 to 3.8	10-20
Vitamin B ₃ , Niacin, mg/kg	113.33	-	-	-	36.15	64.90	-	11 to 20	25-35
Vitamin B ₆ , Pyridoxine, mg/kg	15.56	-	-	-	2.31	5.98	7.00	3 to 5	10-20
Vitamin B ₁₂ , Cobalamin, mg/kg	0.04	11.00	-	-	0.01	2.16	60.00	0 to 0.004	0.004
Folacin, mg/kg	2.00	2.55	-	-	0.79	1.23	2.00	0.28 to 0.35	1.5-3
Pantothenic Acid, mg/kg	25.56	52.11	-	-	10.00	31.10	35.00	2.44	10-20
Vitamin C, mg/kg	-	-	-	-	38.94	-	75.00	-	-
Calcium, %	1.72	2.80	-	-	2.59	0.89	4.00	2.5 to 3.8	1 to 3
Chloride, %	0.29	-	-	-	0.98	-	-	0.15	0.20
Magnesium, %	0.22	0.22	-	-	0.20	0.83	-	0.06	0.10
Phosphorus, %	1.03	1.28	-	-	1.05	0.33	1.20	0.33 to 0.43	0.5-1
Potassium, %	0.68	1.15	-	-	1.04	0.87	-	0.17	0.20
Sodium, %	0.17	0.50	-	-	0.86	0.19	-	0.15	0.20
Sulphur, %	0.27	-	-	-	0.15	0.75	-	-	-
Ca:P Ratio	1.67	2.19	-	-	2.47	2.70	3.33	7.5 to 8.8	2-5
Cobalt mg/kg	0.22	-	-	-	2.31	1.25	0.15	-	0.20
Copper, mg/kg	14.44	21.76	-	-	11.84	50.83	4.00	7 to 9	15.00
Iodine, mg/kg	1.67	2.13	-	-	2.49	1.25	0.70	0.33	0.5-1.0
Iron, mg/kg	355.56	330.00	-	-	107.11	181.00	75.00	50 to 70	50-100
Manganese, mg/kg	104.44	225.00	-	-	59.25	75.00	75.00	25 to 60	50-75
Selenium, mg/kg	0.34	0.44	-	-	2.25	0.72	-	0.1 to 0.2	0.2-0.3
Zinc, mg/kg	105.56	273.25	-	-	58.41	221.00	70.00	50 to 75	50-100

Table A1. Summary of nutrients (dry matter basis, except water) contained in diets utilized for flamingos maintained in captivity in North American zoological facilities. Data represent four major commercial formulations utilized, and 2 "in-house" mixtures.

*Maximum values are outlined for vitamins A, D, and E in the CICAG recommendations while all other values are minimum requirements or ranges. Wackernagel (1975) provides recommended values for the flamingo based on nutritional requirements of the laying hen.