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NUTRITION ADVISORY GROUP HANDBOOK

PENGUINS: NUTRITION AND DIETARY HUSBANDRY[a]

Authors

Sue Crissey, PhD
Daniel F. and Ada L. Rice
Conservation Biology & Research Center
Chicago Zoological Society, Brookfield Zoo
Brookfield, IL 60513

Kerri Slifka, MS
Daniel F. and Ada L. Rice
Conservation Biology & Research Center
Chicago Zoological Society, Brookfield Zoo
Brookfield, IL 60513

Patty McGill, PhD
Bird Department
Chicago Zoological Society, Brookfield Zoo
Brookfield, IL 60513

Reviewers

Duane E. Ullrey, PhD
Comparative Nutrition Group
Dept. of Animal Science
Michigan State University
East Lansing, MI 48824

Joni B. Bernard, PhD
Comparative Nutrition Group
Dept. of Zoology
Michigan State University
East Lansing, MI 48824

Provision of nutritional, behavioral, and environmental requirements is basic to the successful maintenance and reproduction of captive penguins. The following guidelines for nutrient intake and dietary husbandry were developed from studies of natural feeding ecology, published nutrient requirements of related species, information on potential penguin foods and their nutrient composition, and evidence of food preferences. Penguin foods are perishable and particularly susceptible to loss of thiamin and vitamin E. Therefore, suggestions for storage, handling, and supplementation are provided. Feeding methods are discussed, and calculated energy and nutrient concentrations in an example diet are presented.

[a]Adapted in part from the Nutrition Chapter of the AZA Penguin Taxonomic Advisory Group Husbandry Manual.

Feeding Ecology

Natural diets

Knowledge of the feeding ecology of free-ranging penguins is relatively recent and very limited.[3,5,10,11,21,24,34-36,38-41] Although qualitative information on feeding habits is available for most penguin species, information on consumed quantities of specific foods is exceedingly rare. Some food intake data are available for little blue (*Eudyptula minor*) and African (Cape, jackass) penguins (*Spheniscus demersus*) for both non-breeding and breeding seasons.[21,35] More recent ecological research has focused on the seasonality of fasting and the physiology of molt[6,7] and on feeding as it relates to incubation energetics.[28]

A summary of the food items consumed by free-ranging penguins is presented in Table 1. All species consume more than one type of food in the wild, generally fish, krill, and/or squid. High-latitude species tend to consume krill as well as fish, with some species also taking squid.[10] The exception to this generalization is the chinstrap penguin (*Pygoscelis antarctica*), which has been reported to consume only krill and amphipods.[10] Macaroni (*Eudyptes chrysolophus*) and Adelie (*Pygoscelis adeliae*) penguins rely heavily on krill, but fish consumption has been reported in some locations.[24] Penguins that live at lower latitudes, such as little blue penguins and the *Spheniscus* species, tend to rely much more heavily on fish than do the high-latitude species.[10] The prey fish used most often are small-bodied, surface-schooling forms.

Intraspecific variation

Among penguin species that have been studied at more than one site or during more than one season, there are suggestions of within species diet variations.[10,11] Much of the variation may relate to differences in prey availability,[10,11] but not all feeding patterns are clear. Both seasonal and site-based differences in quantities of specific prey items have been reported for little blue[27] and African penguins,[35] but African penguins sometimes exhibit seasonal variations in food selection that appear unrelated to prey supply.

Broadly similar patterns in diet composition persist from year to year with little annual variation, particularly in diets of high-latitude species. However, historical changes in diet composition have been reported for African penguins in relation to prey abundance.[35] For species such as Humboldt penguins (*Spheniscus humboldti*), supplies of prey fish may shift with major oceanographic events, such as El Niño.[19,20] For both of these penguin species and for others, the competition of human fisheries also may influence the prey species that are available.

One might anticipate that the larger average body size and bill dimensions of male penguins would result in consumption of somewhat larger prey than consumed by females. This sex-related difference has been documented in Gentoo penguins (*Pygoscelis papua*), but such differences have not been seen in Macaroni, chinstrap, and Adelie penguins.[40]

Nutrient Requirements and Related Concerns

The following information on nutrient requirements and nutrient content of food items is presented on a dry matter basis (DMB). Dry matter (DM) concentrations in whole fish and marine invertebrates range from about 14-37%.[2]

Published nutrient data

There are insufficient data from research with penguins to set nutrient requirements with certainty. Despite consumption of a variety of prey in the wild, it is likely that all penguin species have similar qualitative nutrient needs. It also is likely that the nutrient requirements of penguins are qualitatively similar to the nutrient requirements of most birds and mammals. The National Research Council (NRC) has published estimated nutrient requirements of domestic birds[31] and the carnivorous domestic cat.[29] Using these NRC estimates as guidelines, plus data on nutrient composition of free-ranging penguin foods and foods available in captivity, minimum nutrient concentrations in diets for captive penguins are proposed in Table 2. These levels should be considered tentative until more specific nutrient requirements for penguins are defined.

Water. Penguins obtain water from food as well as in liquid form.[23,33,37] Because of their nasal salt glands, penguins are able to consume salt water.[33] However, in captivity, fresh water is commonly provided to meet possible needs beyond the water from food. If penguins have access only to fresh water, extra salt has sometimes been added to the diet to ensure development and maintenance of nasal salt gland function.[12] Whether this is a necessary practice has not been established.

Energy. It is presumed that penguins eat to meet their energy needs and will consume a greater mass of less energy-dense foods than of energy-rich foods. Gut-fill limits should not be a problem, given the relatively high energy density of most fish and the penguin's considerable stomach capacity. Penguins have been reported to carry up to 20-30% of their body mass in their stomachs as they bring food to their chicks.[10] Free-ranging Adelie penguins brooding chicks were noted to have metabolizable energy (ME) needs 3.8 times their basal metabolic rate (studied by doubly labeled water). When foraging and off the nest, the ME required was 5.4 times higher than basal metabolic rate.[28]

Alterations in energy intake are associated with molt.[17] There are several cues that induce this process, including changes in ambient temperature, day length, food resource availability (and possibly food nutrient content), and associated hormonal changes.[17] It appears that if fed an adequate diet ad libitum and the environment accurately mimics seasonal light and temperature changes, most captive penguins will exhibit a normal annual cycle of food intake and will molt and reproduce normally.[26,41]

Energy requirements are considerable for growth of chicks. King penguin (*Aptenodytes patagonicus*) chicks were estimated, by mass and energy density of stomach contents, to consume an average of 3,646 kJ (871 kcal) of gross energy (GE) per chick per day during a 3-mo growth period.[5] The fish consumed contained 22-26 kJ (5.26-6.21 kcal) GE/g, DMB.

Vitamins and minerals. Dietary vitamin A requirements for studied avian species are between 1,700 and 5,600 IU/kg of diet on a DM basis.[31] Based on limited data, the vitamin A requirement for cats is 6,000 IU/kg of dietary DM.[29] It is possible that penguins, as fish-eating birds, have a high tolerance for vitamin A because comparatively high levels occur in their natural diet.[9] Whether this infers a high dietary vitamin A requirement has not been established. Studies with free-ranging macaroni penguins showed that vitamin A was mobilized from body stores during molt and reproduction.[16,17] Serum levels of vitamin A in captive Humboldt penguins[9] and plasma levels of vitamin A in captive Gentoo and rockhopper (*Eudyptes crestatus*) penguins[26] vary with diet fed and physiologic conditions, such as molt.

Vitamin D_3 requirements for most adequately studied bird species are between 220 and 1,000 IU/kg of diet on a DM basis.[31] Cats have a vitamin D_3 requirement of about 500 IU/kg of dietary DM.[29] Data on vitamin D_3 concentrations are available for very few penguin foods, but two species of smelt and one species of krill were found to have $\leq$633 IU/kg DM.[2] Atlantic mackerel, capelin, herring, and whitebait had vitamin D_3 concentrations that were much higher, ranging from 2,500 IU/kg DM in the latter to 16,800 IU/kg DM in the former.

Vitamin E is destroyed over time in stored marine foods.[2] It has been proposed that foods for marine animals should be supplemented with 100 IU of vitamin E/kg of diet on a wet basis or approximately 400 IU/kg DM.[15] Serum levels of vitamin E in captive Humboldt penguins[9] and plasma levels of vitamin E in captive Gentoo and rockhopper penguins[26] vary with diet and physiologic conditions, just as do serum and plasma vitamin A levels.

Thiaminases have been identified in mackerel, herring, smelt, and clams with activity sufficient to destroy much of the tissue thiamin during frozen storage.[2] It has been proposed that thiamin supplements should be added to marine animal diets, providing 25-30 mg/kg diet on a wet weight basis or approximately 100-120 mg/kg DM.[15]

Calcium concentrations in whole fish and krill (0.9-6.4% of DM)[2] seem adequate, even for breeding and laying penguins, and calcium supplements should not be required. Squid, however, are relatively low in calcium (0.1-0.2% of DM) and have an inverse calcium:phosphorus ratio. Some institutions have reported problems (without dietary details) in captive penguins that were ascribed to calcium deficiency during production of multiple clutches, and calcium supplements were used with no apparent ill effect.[12] However, consideration should be given to the concentrations of calcium, phosphorus, and vitamin D in dietary items (using analyses, if necessary), and to calcium:phosphorus ratio, since a disproportionate supply of one of these nutrients can adversely influence metabolism of the others.

Sodium is an essential nutrient for all animals. It is thought by some that the requirement for sodium is a special consideration for functional development of the nasal glands of marine birds with access only to fresh water.[12] Some institutions, with both fresh and saltwater environments, supplement penguin diets with salt at approximately 250 mg of NaCl/bird/day, without apparent harm.[12] The necessity for this practice has not been established, and it is noteworthy that the fish and invertebrates that have been analyzed, whether of marine or freshwater origin, contain sodium concentrations (0.2-5.5% of DM)[2] that are higher than the minimum need of any species for which a requirement has been established.

Based on analytical values for other nutrients in fish and marine invertebrates, it seems unlikely that other deficiencies would appear unless unwise food choices have been made or storage and handling of these foods has been below standards.[8]

Vitamin excesses. Fat-soluble vitamins A, D, and E accumulate in the body when intakes exceed need, and excessive amounts over extended periods will produce signs of toxicity.[25] It should be noted, however, that there are seasonal differences in the availability of these vitamins for some animal species in the wild, and the accumulation of body stores during comparatively short natural periods of plenty may be critical for health during periods of short supply.

Chronic vitamin A toxicity typically results from long-term intakes that are 100 to 1,000 times dietary requirements, although toxic signs have been reported from dietary levels as low as 10 times the requirement.[30] The most characteristic signs of chronic vitamin A toxicity include skeletal malformations associated with excessive bone remodeling, spontaneous fractures, and internal hemorrhage. Other signs include anorexia, slow growth, weight loss, impaired liver and kidney function, enteritis, conjunctivitis, suppression of keratinization, and thickened skin. Elevated serum levels of vitamin A have been observed in captive Humboldt penguins fed diets containing 59,800 IU of vitamin A/kg (DMB) for 12 months, but no toxicity signs were seen.[9]

Birds and many mammals appear to utilize vitamin D_3 more efficiently than vitamin D_2, and vitamin D_3 is about 10 to 20 times more toxic.[30] Vitamin D_3 is the primary form in animal tissues and in many vitamin supplements. Although most species appear to tolerate vitamin D_3 intakes up to 100 times the minimum requirement for less than 60 days, recommended maximum tolerable limits for long-term consumption by species that have been studied are about 4 to 10 times the requirement.[30] Signs associated with chronic vitamin D toxicity include anorexia, hypercalcemia, hypercalciuria, and calcification of soft tissues, especially kidneys, aorta, and lungs. There have been no reports of vitamin D toxicity in penguins.

Maximum tolerable levels of dietary vitamin E are quite high, but interference with blood clotting has been reported in pelicans with supplements of vitamin E adding 1,000 to 2,000 IU/kg of dietary DM.[32] Elevated serum levels of vitamin E have been observed in captive Humboldt penguins fed diets containing 58,600 IU of vitamin E/kg (DMB) for 12 months, but there were no signs of toxicity.[9]

Vitamin K has a relatively short metabolic half-life, and toxicity has not been demonstrated when large quantities of vitamin K were provided in a natural form such as phylloquinone. Furthermore, toxic dietary levels of menadione and its derivatives are at least 1,000 times the vitamin K requirement.[30]

Potential Penguin Foods and Their Nutrient Composition

Potential penguin foods

Several diets currently fed to penguins are presented in Table 5. Frozen fish and marine invertebrates are available from a number of commercial suppliers. Some are purveyors of human food but also sell to zoos and aquariums. Others serve the zoo and aquarium market exclusively. Regardless, the quality of products purchased for feeding to penguins should meet human food standards.[8] The supplier should use a Hazard Analysis Critical Control Point (HACCP) program to help ensure that fish and marine invertebrates have been handled appropriately.[8] Given the current status/depletion of wild fish stock,

suppliers should be encouraged to practice sustainable-use fishing. A list of potential foods is given in Table 3 with an indication of their size and usual locale and season of harvest.

Successful captive penguin husbandry depends upon a consistent source of high quality food that the penguins will eat. Because certain prey species are not available year-round, it may be necessary to purchase quantities sufficient for several months to ensure an uninterrupted supply. This necessitates that penguin foods be properly frozen and stored until used. Given the perishable nature of seafood, appropriate storage and handling procedures are crucial. These include freezing as soon as possible after catching and frozen storage that maintains an average product temperature of -18° to -30° C. Stock rotation should be practiced to ensure that foods are not stored for more than 4-6 months. Frozen foods should be thawed under refrigeration at temperatures of 2-3.5° C, as close in time as possible to feeding. See NAG Fact Sheet 005 "Feeding Captive Piscivorous Animals: Nutritional Aspects of Fish as Food"[2] and USDA publication "Handling Fish Fed to Fish-Eating Animals: A Manual of Standard Operating Procedures" [8] for additional details on freezing, storage, and thawing.

A fish substitute has been manufactured and is in the development and testing stage. The preliminary results proved promising in that body weight and condition were maintained for 10 months in feeding trials with three species of adult penguins.[18]

Nutrient composition

The nutrient composition of fish and marine invertebrates fed to captive piscivorous animals has been discussed by Bernard and Allen in NAG Handbook Fact Sheet 005.[2] Dry matter, crude protein, crude fat, gross energy, mineral, and fat-soluble vitamins A, D, and E concentrations in common fish and marine invertebrates are presented in that report. These values vary with species, age, gender, physiologic state, and season and locale of harvest.

Dry matter. Dry matter concentrations range from about 14-37% in penguin foods, so water intakes would be 2-6 times higher than dry matter intakes when these foods are consumed. If metabolic water from tissue oxidation of absorbed food or stored fat is added to the water in food, there may be little need for consumption of liquid water. However, definitive studies on water requirements of penguins in captivity have not been conducted.

Crude protein. Crude protein concentrations, on a DMB, range from about 33-77%. True protein concentrations in marine fish may be overestimated slightly by the analytical method for crude protein (N x 6.25) because of the contribution of non-protein nitrogen in osmoregulatory cells.[37] Amino acid requirements of penguins are unknown. Since penguins consume whole fish or marine invertebrates, a specific amino acid deficiency is unlikely. Marine invertebrates contain more free amino acids than do fish, but the overall amino acid composition of fish and invertebrates is generally similar to that of other animals.[23]

Crude fat. Crude fat concentrations, on a DMB, range from about 8-48% and tend to be inversely related to protein concentrations. Fish lipids are highly unsaturated. Generally freshwater fish contain twice as many C10 and C18 fatty acids but less than ½the quantity of C20 and 1/7th the

quantity of C22 fatty acids as do marine fish.[1] Salmonids, such as rainbow trout, are the exception to this generalization. They are as high in C18 and C20 ω-6 fatty acids and in C18 and C22 ω-3 fatty acids as are marine fish. Krill are high in unsaturated fatty acids, and squid have 2-4 times the concentration of hexaenoic and pentaenoic fatty acids as do krill.[1] Krill and herring have substantial quantities of eicosapentaenoic acid (EPA), and krill, herring, rainbow trout, and squid contain substantial quantities of docosahexaenoic acid (DHA). Omega fatty acid concentrations in foods, and special requirements for these fatty acids for humans and other animals, are being actively researched. Specific fatty acid requirements for penguins have not been determined, but ω-6 and ω-3 fatty acids may be as important in the diets of penguins as they appear to be for other animals.

Minerals. Ash concentrations range from 5-24%, on a DMB, are low in invertebrates, and are related to the proportion of bone in fish. Essential mineral concentrations in fish appear to be sufficient, although a few fish have relatively low concentrations of copper and manganese. Calcium concentrations in squid are likely to be inadequate, if used as a sole source of food. However, the mineral requirements of penguins have not been determined.

Fat-soluble vitamins. Concentrations of fat-soluble vitamins A, D, and E in freshly caught fish are probably adequate for penguins, and in some fish species, vitamin A and D levels are very high. However, as previously noted, vitamin E undergoes destruction during storage, and supplemental vitamin E should be provided. Vitamin K concentrations in whole fish have not been reported, but signs of deficiency in penguins are unlikely unless induced by feeding excesses of vitamins A or E.

Water-soluble vitamins. Water-soluble vitamin concentrations are not available for whole fish, although data have been published for the flesh of raw herring, mackerel, and squid.[22] Respective DM concentrations in the flesh of these three species were 36, 36, and 16%. The following water-soluble vitamin concentrations were found in flesh and are presented on a DMB in the same order as the species: thiamin – trace, 2.5, and 3.1 mg/kg; riboflavin – 5.0, 9.7, and 1.2 mg/kg; niacin – 114, 222, and 131 mg/kg; pantothenic acid – 28, 28, and not determined (ND) mg/kg; vitamin B_6 – 12.5, 19.4, and ND mg/kg; folacin – 139, ND, and 125 µg/kg; vitamin B_{12} – 167, 278, and 156 µg/kg; biotin – 278, 194, and ND µg/kg. Assuming that the viscera of fish and squid contain higher concentrations of these vitamins than does flesh (as has been found in mammals and birds), it is unlikely that supplements of water-soluble vitamins, except for thiamin, are required when whole fish and squid are fed.

Food Preferences

It is generally accepted that captive penguins have food preferences. The types and species of prey available for captive feeding are limited and may be quite different from the variety with which penguins evolved. Even data from free-ranging penguins suggest that the food items most consumed may not be those most preferred but may be foods that are most available.[20,21] Differences in food choice also may be influenced by physiologic circumstances, such as stage of the reproductive cycle.

Selection of particular food items may be an expression of food preference, but, lacking historical and long-term association with those foods, captive penguins appear not to make choices on the basis of nutritional wisdom. Food refusal, on the other hand, may be an indication of spoilage, and if

fish are refused, their quality should be checked. Ultimately, the responsibility for provisioning captive penguins with nutritionally adequate and healthful food is ours. To avoid dependence on a particular food item, it is prudent to offer a variety. If a penguin becomes "imprinted" on a specific food item and if that item becomes unavailable, it may be difficult to coax acceptance of an alternative. In addition, offering a variety of foods will help ensure that the diet provides a complementary and complete nutrient profile.

Feeding Methods

The recommended method of feeding is to hand-feed individual penguins, particularly when offering fish that have been injected with nutrient supplements or in which supplement tablets or capsules have been placed. This ensures that each bird will receive intended nutrients and allows the keeper to monitor food and energy consumption.

Methods of self-feeding are sometimes used, but keepers should ensure that food items remain cool and clean and are consumed within a short time after being thawed. In exhibits held at or below 4° C, fish may be offered in feeding trays for several hours as long as birds are not defecating nor walking in the trays. However, fish should not be left in standing water because of the potential for nutrient loss. Supplemented fish should not be fed in trays because of the potential for under- or over-dosing if individual penguins consume either no or several fish containing supplements. If penguins are fed outdoors in hot, humid, or sunny weather, it is important to feed only the amount that will be consumed immediately or while still iced to avoid microbial proliferation, nutrient loss, and contact by disease-spreading pests.

Adult penguins are commonly fed to appetite early in the morning and late in the afternoon, although the number of feedings may be increased during pre-molt and breeding. Appetite usually increases during the pre-molt period and decreases during molt. In a study with captive rockhopper penguins, all birds gained about 23-38% in body mass just prior to molting.[26] Among the penguin species that have been studied, most will fast during incubation and molting. In the wild, mean loss of body mass during molt is as much as 40% in macaroni penguins and 47% in king penguins.[6,16] During molt in captivity, losses can be as much as 50% of body mass. After these periods, penguins consume vast quantities of food and deposit considerable body fat and protein.[16]

There is no need to limit food intake below ad libitum levels unless the penguin is extremely overweight. The quantity of food one might expect captive penguins to consume per day can be estimated, based on their body mass. An average captive but active adult penguin's daily food consumption on an as-fed basis is approximately 2-3% of body mass for the larger species, such as kings and emperors (*Aptenodytes forsteri*), and 10-14% for smaller species, such as Humboldts and rockhoppers.[12] However, the specific quantities consumed depend on the activity level and physiologic state of the individual. In one study, free-ranging king penguins consumed (wet basis) an average of 1.84 kg daily.[5] Estimated daily consumption (wet basis) in another study with free-ranging king penguins was an average of 2.32 kg. Mean body mass of the king penguins was 11.8 kg, resulting in a calculated daily intake equivalent to as much as 20% of body mass.[34]

The size of food items offered should be appropriate for easy manipulation and swallowing. Purchasing specifications for fish and squid should include size designations so that they can be fed

whole. Whole food is accepted most readily, but if it must be cut because it is too large, all portions should be fed to ensure that the entire supply of nutrients contained in the whole food will be consumed. Lengths of fish consumed by free-ranging adult emperor penguins were 60 to 120 mm (~2.5-5 in), and lengths of squid consumed were 19 to 280 mm (<1-11 in). The largest squid consumed weighed 460 g.[36] Free-ranging adult king penguins consumed prey estimated to be 70 to 90 mm (2.8-3.5 in) long,[5] substantially smaller than the fish commonly fed in captivity.

Formulation of Appropriate Diets

When formulating diets for captive penguins, flexibility is needed to account for variations in food preferences, body mass, activity, physical condition, environment, and behavior, as well as food availability and nutrient content. Ideally, the items chosen (e.g., high-fat and low-fat fish) and supplements fed should complement each other so that nutrient and energy requirements are met.

It should be noted, when examining nutrient data for whole fish and marine invertebrates, that nutrient concentrations can vary among species, among individual lots within a species, among individual fish within a lot, as well as over a period of storage. Thus, published values may or may not reflect the nutrients actually fed to penguins at a specific time. Both the need to sample fish for nutrient analysis and appropriate sampling techniques have been discussed elsewhere.[2,37] To identify changes in animal condition due to diet, the nutrient content of the diet being fed must be quantified.

Types of fish selected can be chosen for specific nutrient content, availability, price, and animal preference. It also is wise to consider quality as a major factor. Quality sufficient for human food should be insisted upon, and holding and shipping conditions should be monitored. Any item which, upon receipt, appears to have undergone degradation or shows evidence of thawing should not be accepted and should never be fed.

Selecting dietary items

Of the fish usually used for captive animal feeding, any will meet the protein requirement. However, to provide appropriate amounts of fat and energy, supplies of both low-fat fish and high-fat fish are desirable. Ratios between them can be changed depending upon their availability and individual penguin condition and intake.

Marine fish versus fresh-water fish

Historically, most captive penguins have been fed marine fish. Given current problems with commercial fish availability, it is becoming more common to offer fresh-water fish, as well. This trend may continue as commercial fresh-water fish farms increase in number and the yield from marine fisheries declines. Although fresh-water fish may be used, it may be prudent to also feed one or more species of marine fish.

Nutrient supplementation

Many institutions supplement with a variety of multivitamins and minerals. This is presumably to provide for any possible losses due to storage, thawing, or to ensure that these nutrients are always present on a daily basis regardless of fish offered. Several products are marketed specifically for marine animals but differ in composition. If a variety of high quality fish are fed, and if they are stored and thawed properly, it is unlikely that supplements, other than of vitamin E and thiamin, will be needed.

Thiamin can be purchased in tablets and vitamin E in capsules. They can be hidden inside the mouth or gills of fish, and the supplemented fish hand-fed to individual penguins. Alternatively, solutions or suspensions of these vitamins can be injected into fish and the injected fish hand-fed. Supplements of 25-30 mg of thiamin and 100 IU of vitamin E should be provided for each kg of food (wet basis). Adjustments in the amounts of supplement provided should be made in proportion to the mass of food consumed. Calculated gross energy and nutrient concentrations in an example diet for a 4.5-kg penguin are shown in Table 4.

Parent Rearing of Chicks

The most important dietary adjustment, when chicks are being reared by their parents, is to offer enough fish to the parents so they may adequately feed themselves and their offspring. During chick rearing, parents should be fed ad libitum and frequently. Free-ranging emperor penguins fed their single chick the equivalent of about 7.5% of adult emperor penguin body mass in a 24-hr period.[36] Adelie penguins have been found to feed exclusively on krill when nesting. [28]

Until more is known, it appears wise to feed a variety of whole fish to nesting penguins, in quantities adequate to supply energy and protein needs. It does not appear necessary to supply additional fat in the diet.

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Table 1. Prey items consumed by free-living penguins. [3,5,10,11,21, 24, 34,35,38-41]

Penguin species	Krill[a]	Squid[b]	Sardines[c]	Round herring[d]	Pilchard[e]	Anchovies[f]	Lanternfish/ Myctophids	Maasbanker[g]	Mullet[h]	Icefish/ Notothenniids	Fish (various spp.)
Emperor	X	X								X	X
King		X								?	X
Adelie	X									X	X
Chinstrap	X										
Gentoo	X						X			X	X
Macaroni	X						X				X
Rockhopper	X	X					X			X	X
Little blue		X			X	X					X
Humboldt			?			X					X
African (pre-1960)	X	X			X	X		X	X		X
African (recent)	X	X		X		X		X			X
Magellanic	X		X								X

[a]Euphausiid crustaceans primarily in genera *Euphausia, Thysanoessa,* and *Nyctiphanes.*
[b]Cephalopods in genera *Loligo, Heteroteuthis, Argonauta, Nototodarus, Sepioteuthis, Teuthowenia, Psychroteuthis, Alluroteuthis, Kondakovia, Gonatus, Todarodes, Moroteuthis,* and *Loligunculus.*
[c]*Ramnogaster arcuata.*
[d]*Etrumeus teres.*
[e]*Sardinops ocellata, S. neopilchardus.*
[f]*Engraulis capensis, E. australis, E. ringens.*
[g]*Trachurus trachurus.*
[h]*Mugil* spp.

Table 2. Proposed minimum energy and nutrient concentrations (DMB) in adult penguin diets[a] based on requirements of domestic poultry,[31] cats,[29] and inferences from composition of wild foods.[2]

Nutrient	Minimum concentration
Gross energy, kcal/g	4.5
Crude protein, %	35
Fat, %	10
Calcium, %	0.8
Phosphorus, %	0.6
Magnesium, %	0.05
Potassium, %	0.5
Sodium, %	0.2
Iron, mg/kg	80
Copper, mg/kg	5
Manganese, mg/kg	5
Zinc, mg/kg	50
Selenium, mg/kg	0.2
Vitamin A, IU/kg	3,500
Vitamin D, IU/kg	500
Vitamin E, IU/kg	400[b]
Thiamin, mg/kg	100[c]

[a]Other nutrients, such as essential fatty acids, essential amino acids, vitamin K, and the other B-complex vitamins are probably required. Nevertheless, there is no evidence that inadequate concentrations are provided by fish and marine invertebrates. Whether vitamin C can be synthesized by penguin tissues has not been established. Freshly caught fish contain significant concentrations of this vitamin, and some destruction undoubtedly occurs during storage. However, signs of vitamin C deficiency in the penguin have not been described.

[b]Although this concentration of vitamin E may exceed the minimum requirement, about 400 IU/kg of DM provided by the supplement of 100 IU of vitamin E/kg of fresh fish is recommended to compensate for losses during peroxidation of unsaturated fatty acids.

[c]This concentration of thiamin undoubtedly exceeds the minimum requirement, but about 100-120 mg/kg of DM are provided by the supplement of 25-30 mg of thiamin/kg of fresh fish to compensate for destruction by thiaminases.

Table 3. Potential penguin foods, locale and usual months of harvest, and length and weight data.

Common name	Scientific name	Locale & months of harvest		Length/weight
Anchovies	*Engraulis mordax*			
Capelin	*Mallotus villosus*	Canadian coast	July-Aug	5-7 in; 10-15 fish/lb
Capelin	*Mallotus villosus*	Iceland coast	Jan-Mar	5-7 in; 10-15 fish/lb
Herring, Atlantic	*Clupea harengus*	US-Canada coast	Jan-Dec	9-12 in
Herring, Atlantic	*Clupea harengus*	US-Canada coast	Apr-May	< 9 in
Krill, superba	*Euphausia superba*	Antarctic	May-June	300-400/lb
Mackerel, Atlantic	*Scomberomorus scombrus*			
Mackerel, Pacific	*S. japonicus*	Calif. coast	Jan-Dec	½ lb /fish
Sardines, California	*Sardinops caerulea*	Calif. coast	Jan-Dec	4 fish/lb
Sardines, Spanish	*Sardinella aurita*			Mar-May, Aug-Oct
Smelt, fresh-water	*Osmerus mordax*	N. Lake Mich.		3-5 in; 23 fish/lb
Smelt, silver	*Hypomesus pretiosus*	Eureka, Calif.	June-Aug	5-9 in; 12-16 fish/lb
Silversides	*Menidia andens*	P.E. Island coast	Oct-Dec	2-3 in; 85-95 fish/lb
Squid, Ilex	*Ilex illecebrosus*	US East Coast	May-Sept	4-5 squid/lb
Squid, Loligo	*Loligo opalescens*	Calif. coast	Sept-Feb	5 in; 7-9 squid/lb
Trout, rainbow	*Salmo gairdneri*	Idaho, farmed		
Whitebait	*Allosmerus elongarus*	Eureka, Calif.	Apr-June	4-6 in

Table 4. Calculated dry matter, gross energy, and nutrient concentrations (DMB) in an example daily diet for a 4.5 kg penguin consuming a mix (500 g total wet weight) of herring, capelin, and rainbow trout, with recommended vitamin E and thiamin supplements.

Item	Calculated concentration
Dry matter in diet as presented, %	25
Gross energy, kcal/g	5.7
Crude protein, %	61
Fat, %	24
Calcium, %	1.6
Phosphorus, %	1.5
Magnesium, %	0.14
Potassium, %	1.4
Sodium, %	0.6
Iron, mg/kg	103
Copper, mg/kg	7
Manganese, mg/kg	5
Zinc, mg/kg	84
Selenium, mg/kg	1.1
Vitamin A, IU/kg	50,000
Vitamin D_3, IU/kg	4,000
Vitamin E, IU/kg	500[a]
Thiamin, mg/kg	100[b]

[a]Supplement provides 400 IU vitamin E/kg.
[b]Supplement provides 100 mg thiamin/kg.

Table 5. Penguin diets from selected zoos. Amounts are per bird, per day, as fed.

Penguins & zoo	Capelin	Herring	Lake smelt	Krill	Marine smelt	Surf smelt	Vitamin E (IU)	Thiamin (mg)	Multivitamin	NaCl (g)	Cod liver oil (tsp)
Humboldt											
Brookfield	341 g	170 g			170 g		100	25	0.4 g Windmill Daily Max. Form.		
King											
Detroit		1.5-2.5 lb					50	50		1	
Sea World Orlando		2-3 lb of mixed fish[a]					+[b]	250	1 Mazuri Vita-Zu Mammal Tablet[c]		
Rockhopper											
Detroit	0.25-0.5 lb					0.25-0.5 lb	33	25		0.5	
Sea World Orlando		1-1.5 lb of mixed fish[a]					+[b]	250	1 Mazuri Vita-Zu Large Bird Tablet[c]		
Chinstrap											
NYZS	275 g	70 g					76	19			
Sea World Orlando		1.5-2 lb of mixed fish[a]					+[b]	250	1 Mazuri Vita-Zu Large Bird Tablet[c]		
Macaroni											
Detroit	0.25-0.5 lb					0.25-0.5 lb	33	25		0.5	
Little Blue											
Detroit	0.125-0.25 lb					0.125-0.25 lb	33	12.5		0.25	1 tsp
Gentoo											
Sea World Orlando		2-2.5 lb of mixed fish[a]					+[b]		1 Mazuri Vita-Zu Large Bird Tablet[c]		
Magellanic											
Sea World Orlando		1.5-2 lb of mixed fish[a]					+[b]		1 Mazuri Vita-Zu Large Bird Tablet[c]		

[a] All species of penguins are fed a mix of capelin, large herring, lake smelt, and krill. Average total amount consumed is noted in the table.
[b] Vitamin E provided in the Mazuri Vita-Zu Large Bird and Mammal Tablets.
[c] Sea World Orlando also supplements with calcium gluconate at 650 mg (1 10-grain tablet) September-December for King penguins and 325 mg (1/2 10-grain tablet) September-November for Rockhopper, Chinstrap, Magellanic, and Gentoo penguins.

Appendix 1. Supplement Information

Brookfield Zoo

Windmill Daily Vitamin Maximum Formula: Windmill Health Products, West Caldwell, NJ 07006.
Vitamin E and thiamin: Sundown Vitamins, Boca Raton, FL 33487.

Detroit Zoo

Vitamin E and thiamin: ADH Health Products, Congers, NY.
Sodium chloride: Consolidated Midland Corp., Research Division, Brewster, NY.
Cod liver oil: Solgar Vitamin Co., Lynbrook, NY.

Sea Word Orlando

Thiamin and calcium gluconate: ADH Health Products, Congers, NY.
Mazuri Vita-Zu Large Bird Tablets and Mazuri Vita-Zu Mammal Tablets: PMI Nutrition International, Specialty Plant and Test Diet Facility, Richmond, IN.

Appendix Table 1. Nutrient composition per tablet of Windmill Daily Vitamin Maximum Formula.

Nutrient	Amount per tablet
Vitamin A, IU	5,000
Vitamin D, IU	400
Vitamin E, IU	30
Vitamin K, ì g	25
Vitamin C, mg	60
Thiamin, mg	1.5
Riboflavin, mg	1.7
Niacin, mg	20
Pyridoxine, mg	2
Pantothenic acid, mg	10
Folic acid, ì g	400
Vitamin B_{12}, ì g	6
Biotin, ì g	30
Calcium, mg	162
Phosphorus, mg	125
Magnesium, mg	100
Potassium, mg	80
Chloride, mg	72
Iron, mg	18
Copper, mg	2
Manganese, mg	3.5
Zinc, mg	15
Iodine, ì g	150
Selenium, ìg	20
Chromium, ì g	65
Molybdenum, ì g	160
Boron, ìg	150
Nickel, ìg	5
Silicon, mg	2
Tin, ì g	10
Vanadium, ìg	10

Appendix Table 2. Nutrient composition per tablet of Mazuri Vita-Zu Large Bird Tablet and Mammal Tablet

Nutrient	Large Bird Tablet	Mammal Tablet
Vitamin A, IU	8,250	16,500
Vitamin E, IU	125	250
Vitamin C, mg	125	250
Thiamin mononitrate, mg	100	200
Riboflavin, mg	7.5	15
Pyridoxine, mg	7.5	15
Pantothenic acid, mg	7.5	15
Folic acid, ì g	250	500
Biotin, ìg	125	250