CHAPTER 5

DIET AND NUTRITION

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Meeting the nutritional needs of penguins is essential if they are to survive and reproduce in captivity. Developing appropriate dietary guidelines involves using information 1) from feeding ecology data, 2) from published nutrient requirement data 3) on food availability to zoos and 4) on food preference. It is also essential to store and process food items correctly and provision the birds on appropriate schedules.

FEEDING ECOLOGY.

Composition of the diet.

Knowledge of food habits and feeding ecology of penguins in the wild is relatively recent, and is still limited. Although some data are available on all species, quantitative characterization of the diet is available for very few. Information on species of prey used, seasonal or annual variation, and sex or age differences is also very limited. Only for Little blue penguins (*Eudyptula minor*)and African penguins (*Spheniscus demersus*) are there data for non-breeding as well as breeding seasons.

The data on wild diets presented in Table 8 are taken primarily from summaries by Croxall (1987), with some additional information from Williams et al. (1992), Lishman (1985), and Croxall and Lishman (1987). As can be seen from the summary table, most species of penguins that are held in captivity consume a variety of food types in the wild. In general, high latitude species tend to use krill as well as fish; some species also take squid. The exception to this general pattern is the Chinstrap; for this species only krill and Amphipods are recorded.

Macaronis and Adelies also tend to rely heavily on krill, but this may vary by location; fish prey are also recorded for these two species. Penguins that live at lower latitudes, Little blue and the Spheniscus species, tend to rely much more heavily on fish than do the high latitude species. The prey fish used are often small-bodied surface-schooling forms.

Table 8. Prey items used by free-living penguins

Penguin Species	Krill	Squid	Fish (variety of spp.)	Sardine	Round Herring	Pilchard	Anchovy	Lanternfish / Myctophids	Maasbanker	Mullet	Icefish / Nototheniids
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							

Krill: Euphausiid crustaceans primarily in the genera *Euphausia, Thysanoessa,* and *Nyctiphanes*
Squid: Cephalopods in the genera *Loligo, Heteroteuthis, Argonauta, Nototodarus, Sepioteuthis, Teuthowenia, Psychroteuthis, Alluroteuthis, Kondakovia, Gonatus, Todarodes, Moroteuthis,* and *Lologunculus.*
Sardine: *Ramnogaster arcuata*
Round Herring: *Etrumeus teres*
Pilchard: *Sardinops ocellata, S. neopilchardus*
Anchovy: *Engraulis capensis, E. australis, E. ringens*
Massbanker: *Trachurus trachurus*
Mullet: *Mugil* spp.

Intraspecfic variation.

Of the few species that have been studied at more than one site or during more than one season, there are suggestions of variation in diet within a species. Many of the differences in diet may relate to differences in prey availability between sites. Seasonal differences in quantities of specific prey items are recorded for Little blue (Montague, 1982) and African penguins (Rand, 1960; Wilson, 1985). However, these patterns are not completely understood; in a few species populations from different sites take remarkably similar diets, and in African penguins there seem to be seasonal variations that are not entirely related to prey availability.

Broadly similar patterns in diet seem to remain from year to year with little annual variafion, particularly in the higher latitude species. However, in species such as Humboldt penguins, prey species (fish in particular) may shift with major oceanographic events such as El Nino. Historical changes in diet composition may occur related to changes in prey abundance, as has been documented for African penguins (Rand, 1960; Wilson, 1985). Competition with local fisheries operations may also affect the proportions of prey items in penguin diets.

The implication of known intraspecific variation in diet for captive management of penguins is that diets must be constituted to balance nutrients over time, not to mimic single reports of wild food items. Simple records of prey items taken do not necessarily reflect preferences nor evolutionary patterns.

FOOD PREFERENCE.

In captivity, it is generally accepted that there is individual variation in food preferences among penguins. Both the number and types of food species offered to the captive animal are artificially limited so that the animal will never have the selection that would be available under free-ranging conditions. Nonetheless, the animal may have an equivalent degree of variety in the captive diet, comparable to that actually consumed in the wild. Data from the wild suggest that the food items most consumed may not be those most preferred, but may be most available (Hays, 1984; 1986). Some differences in food choice may be based on physiological condition.

Selection of individual items in the diet may allow an animal to be selective within food categories. Animals probably do not select food items based on overall nutrient content; therefore animal preference is not necessarily an indicator of nutrient content. Food preference, or actually the refusal of food may be an indicator of quality, however. If fish is being refused, it should be checked for quality.

FISH HANDLING AND PREPARATION.

Since reliable availability of fish is critical to the success of captive programs, most fish purchases are made in bulk. This necessitates that the items are frozen and stored until use. Given the perishable nature of fish and seafood, food handling procedures are critical. Consult the draft code of practice for frozen fish (Organization for Economic Cooperation and Development and the International Institute of Refrigeration, 1969) for proper storage procedures.

To offer a variety of fish at any one time, it is often difficult to avoid storing the item for than a year. Many of the fish species used as food items are caught only seasonally; it is important to ask the supplier when a particular batch of fish was caught. Otherwise purchasing fish several times throughout the year does not ensure that a fresh catch has been obtained.

There are two possible approaches to offering a mix of food species throughout the year:

a) Offer items on a seasonal basis according to their catch, so that individual items are stored for less time. This way, for example, every three months a new type of fish may be offered. The advantage of this method is that relatively fresh fish will be fed. The disadvantage of this method is that possibly only one type of fish will be fed at a time, and if it is a less preferred fish or the catch is bad, there may be no back-up on hand. Also, shifting birds from one fish to another may take time and may occur at a critical time, e.g. during pre-molt or during breeding.

b) The second approach is to seasonally obtain the catch but store the items for up to a year and spread out usage evenly throughout the year. The advantage is that there will always be fish available and several types of items can be fed simultaneously.. The disadvantage is that frozen fish lose nutrients over time. It has been suggested that maximum storage time for fish be less than six months.

Fish that are purchased should be packaged in plastic-lined boxes. Fish may be block frozen or individually quick frozen (IQF). However, the packages should be of optimal size for proper thawing to occur; institutions using smaller quantities of fish may consider IQF or cuffing the blocks into appropriate sections so that only the proper quantity for use is thawed.

Proper fish storage is in a freezer less than -18^{o}C (0^{o}F) or a refrigerator between 7 – 10^{o}C (36 – 38^{o}F). The relative humidity should be 85 to 90%. When storing fish for prolonged periods (up to one year) it is preferable to maintain the freezer space at –2^{o}C (-10^{o}F) or lower. Refrigeration is used for short term thawing only. Stored fish shipments should always be rotated, on a "first in; first out" basis.

The thawing process must be carefully controlled; there is great potential for nutrient loss and microbial build-up if fish is thawed incorrectly. Possibilities for thawing fish include (Illinois Dept. Publ. Health, 1988; Manual of Naval Preventive Medicine, 1965):

a) (preferred) in refrigerated (2 – 3^{o}C or 36 – 38^{o}F) units so that the temperature of the fish itself does not exceed 7^{o}C (45^{o}F). This process may take up to 48 hours.

b) under potable running water at a temperature of 1 9^{o}C (70^{o}F) or below, with sufficient water velocity to agitate and float off loose particles into the overflow. If thawing under runriing water, the fish should be removed as soon as thawing begins and the fish starts to become pliable. The primary disadvantage of this method is that nutrients, vitamins, and minerals are leached from fish.

c) in a microwave oven set to defrost; this should be used only when the food will be immediately used for consumption.

Freezing tends to break down tissues, making the food much more susceptible to bacterial invasion after thawing. Therefore, the preferred method is to thaw the fish in a refrigerated space. Additionally, frozen fish, once thawed, should not be refrozen. Fish should not be thawed by exposure to excessive heat or immersion in water. The use of a fan to speed thawing causes loss of fluid through dehydration and should be avoided. Fish should never be thawed at room temperature.

During the thawing period, fish should be kept in a wrapping or container, to prevent desiccation, provide insulation, and allow the fish to thaw evenly. Only the portion of fish that will be used in a day should be removed from the freezer for thawing. If a large block of fish is thawed, it iS advisable to remove the outer, thawed fish as the block defrosts. This will help insure thawing of (the inner fish without keeping the outer fish thawed for a prolonged period.

The primary methods to minimize nutrient loss in fish are to avoid holding the fish under conditions which lead to fat breakdown and nutrient loss. It is also important to avoid leaching of the nutrients out of the tissues by holding the fish at appropriate temperatures and avo iding conditions where contamination can occur. Thawed products should be kept refrigerated until preparation for actual feeding. Fish should be processed for feeding out as close as possible to the feeding time; fish should be maintained at room temperature for as short a time as possible.

PROVISIONING FOOD.

The recommended method of feeding is to hand feed to individual animals, especially the supplemented (pilled or injected with supplements) fish. This will ensure each bird obtains adequate nutrients and allows the institution to monitor consumption. Pilled fish should not be fed in the water.

Other methods of feeding must ensure that fish remain cool, clean (no feces or other debris) and are consumed within a short time frame. In exhibits that are held below 4^{o} (40^{o}F), fish could be kept out in trays for several hours as long as birds are not defecating nor walking in the tray. However, care should be taken to avoid leaving fish in standing water.

If the animals are fed outside 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 build-up, nutrient loss or contact by disease-spreading pests.

The feeding schedule for adults used by most institutions is to feed twice per day, early and late. Some institutions increase the number of feedings during pre-molt and breeding. Birds should be fed ad libitum. An increase in intake should be expected pre-molt and a decrease during molt.

The quantity of food consumed per day can be estimated based on body size. An average, active adult penguin's food consumption on an as-fed basis is approximately 2-3% of body for the larger species such as the kings and emperors, and 10-14% for smaller species, such as

Humboldts and Rockhoppers. The specific quantities consumed, however, depend on the activity level and physiological state of the individual.

The size of food items should be appropriate for easy manipulation and swallowing**.** Use whole fish or every portion of the fish.

NUTRIENT REQUIREMENTS AND POSSIBLE TOXCITIES.

The discussion and background information on nutrient requirements and nutrient content of food items are presented on a dry matter basis. Note, however, that the recommendations are given on a fresh weight basis to avoid additional calculations when putting together the actual diet.

Published nutrient requirement data.

Despite consumption differences among species, it is likely that penguins have similar qualitative nutrient requirements for tissue metabolism. Although few studies have been conducted to establish nutrient requirements, the National Research Council has attempted to describe the nutrient requirements of domestic birds and mammals. Using the NRC guidelines along with data on components of wild penguin diets and nutrient content of food items available in zoos, it is possible to formulate appropriate diets for captive penguins (National Research Council, 1978-1985).

Nutrient content

If consumed in its entirety, the diet should contain the nutrients listed in Table 9 on a dry matter basis. These should be considered target nutrient levels until more specific nutrient levels are defined (range taken from fish content, bird and carnivorous mammal NRC requirements) (National Research Council, 1978-1985; National Research Council, 1987).

Table 9. Recommended nutrients for adult penguins, expressed in quantity per unit of diet (dry weight) (based on calculated analysis).

NUTRIENT	QUANTITY/day (range) *
Energy (kcal/g)	4-5 **
Crude protein (%)	20-25
Fat (%)	***
Fiber (%)	-
Linoleic acid (^{0}A)	1.11
Vitamin A (IU/g)	1.67 +
Vitamin D (lUig)	0.222-0.5
Vitamin E (lUIg)	0.4 ++
Thiamine (mg/kg)	100-120++
Riboflavin (mg/kg)	24.44
Niacin (mg/kg)	12.2-61.22
Vitamin B6 (mg/kg)	2.9-3.3
Folacin (mg/kg)	0.28-0.3
Vitamin B12 (mg/kg)	0.003
Pantothenic acid (mg/kg)	11.1
Choline (mg/kg)	1000-240
Biotin (mg/kg)	0.111
Vitamin C (mg/kg)	-
Vitamin K (mg/kg)	-
Calcium (%)	0.778-2.5 +++
Phosphorous (%)	0.33-0.44
Magnesium (%)	0.056
Potassium (%)	0.333
Sodium (%)	0.167
Iron (mg/kg)	66.7-80
Zinc (mg/kg)	38.9-50
Copper (mg/kg)	6.67
Manganese (mg/kg)	33.3-44.4
Colbalt (mg/kg)	-
Selenium (mg/kg)	0.111-0.156
Iodine (mg/kg)	0.389
Amino acids	~+
Arginine (%)	1.6
Tryptophan (%)	0.256
Lysine (%)	1.33
Methionine (%)	0.556
Cystine (%)	0.478
Phenylalanine (%)	0.8
Tyrosine (%)	0.689
Histidine (%)	0.389
Isoleucine (%)	0.889
Leucine (%)	1.5
Threonine (%)	0.889
Valine (%)	0.911
Taurine (%)	0.04 (for cats)

* Recommendations are based on requirements for domestic poultry as well as those for carnivorous mammals, except as noted below. Usually the higher of the ranges are shown.

** Energy requirement is based on that found in commonly fed fish and values for krill. It appears that if lipid content is maintained between those figures found for krill and commonly consumed fish: 6 and 15% (fresh weight), it should supply sufficient kcals (as long as enough fish are consumed). Kcals should run between t5 kcal/g (1.0-1.7 kcal/g fresh weight). Animals should be fed ad libitum.

*** Requirements for fat for many animals is between 3.5% dry matter basis. The fat content of fish may range from 1540%. Thus an appropriate range for fat in a penguin's diet may be from 2~30% The requirement for fat corresponds to a requirement for energy as well as specific essential fatty acids.

+ See discussion on special considerations for more vitamin information.

- No NRC requirement stated for this nutrient. This does not mean there is no requirement, just that studies have not been performed.

++ For fish eating animals this level of Vitamin E and Thiamine supplementation is recommended due to poly-unsaturated fats and thiaminases respectively in the fish.

+++ The higher value is for laying geese.

* + Amino acid requirements are based on domestic poultry and are higher than those for carnivorous mammals.

Water. Penguins acquire their water requirement through both their foods as well as free water. Because of their nasal salt glands, penguins can consume salt water. However, they can also easily consume fresh water to meet their needs. If the birds are held in only fresh water, salt can be added to the diet to ensure development of the nasal glands. See discussion of sodium for further details.

Energy. It is thought that birds eat to meet their energy needs and it is not recommended to limit energy intake of penguins unless the animals are unnaturally overweight. Several types of food items should be offered such as several species of fish and/or krill and/or squid in order to provide enough metabolizable energy to meet the animals' needs.

Penguins should consume higher quantities of less energy dense foods than of energy-rich foods. Nonetheless, limited fill capacity should not be a problem, given the energy content of most fish. The literature shows penguins carrying up to 20-30% of their body mass in their stomachs as they bring food to their chicks (Croxall and Lishman 1937). Thus, penguins appear to have a great capacity for filling their stomachs.

Energy intake is known to be associated with molt Captive penguins increase body fat and thus body mass prior to molt. There are several cues the animals use to begin molting. These may include environmental temperature, light cycle, food resource availability or possibly even food nutrient content, and hormones. It appears that if fed an adequate diet, most captive penguins will cycle their own intakes and molt normally--presumably if the other cues are present.

Vitamins and minerals. Vitamin A dietary requirements for most adequately-studied avian species are between 1.5 and 4.0 IU/g of diet on a dry weight basis. Based on limited data, the requirement for non-human primates and cats is 10 IU/g of dry diet, National Research Council, 1978-1985). However, it is possible that fish-eating birds may have a higher tolerance for vitamin A because comparatively high levels occur in their natural diet.

Vitamin D_3 dietary requirements for most adequately studied species are between 0.2 and 1.2 IU/g of diet on a dry weight basis. (National Research Council, 1978-1985).

Based on the destruction of vitamin E, which takes place over time in stored marine food products, it is felt that the vitamin E supplementation for marine animals may be 0.1 IU/g of the diet on a wet weight basis or approximately 0.4 IU/g of the diet on a dry weight basis (Engelhardt and Geraci, 1978).

Based on the presence of thiaminase in fish, it is felt that supplementation for a marine animal for thiamine may be 25 - 30 mg/kg diet on a wet weight basis or approximately 100 - 120 mg/kg diet on a dry weight basis (Geraci, 1986).

Whole fish fed to penguins contain adequate levels of calcium. Thus supplementation should not be required under normal conditions. This includes breeding/laying unless there are multiple clutches laid and it is felt that the female may be at risk of calcium deficiency. It has been reported by some institutions that problems have occurred which were felt to be due to a calcium deficiency. Some institutions thus supplement with additional calcium with no apparent ill effect.

However, care should be taken to determine the actual calcium level in the diet (by analyzing the fish) and examining the Ca:P ratio as well as the vitamin D levels, since these nutrients can interact and interfere with the metabolism of each other and, subsequently, deficiency symptoms.

Sodium is an essential nutrient for all animals however; it is thought by some that the requirement for sodium is a special consideration for the development of nasal glands of marine birds held in fresh water conditions. If the penguins are held in salt-water conditions, they probably receive enough salt to utilize their nasal glands. Some institutions, with fresh and saltwater environments, supplement penguin diets with salt, approximately 250 mg of NaCl/bird/day, without apparent harm. This topic continues to be debated.

Vitamin toxicities.

Please review Health Section for additional discussions of vitamin toxicities.

Fat soluble vitamins (A,D,E,& K) are stored in the body and thus it is possible to feed these vitamins to toxic levels (Machlim, 1984). It is felt that vitamin E is not extremely toxic although recent reports have shown that there may be problems with over-supplementation of vitamin B at 1,000 to 2,000 mg/kg (of dry diet (Nichols et al., 1989). Vitamin K has also been shown to be non-toxic in its natural form (phylloquinone) and the toxic level of menadione (the most available commercial form) is at least 1,000 times the dietary requirement. (Machlin, 1984.) Vitamins A and D may have toxic effects when fed in excess, however.

With vitamin A, chronic toxicity typically results from intakes 100 to 1,000 times nutritional requirements for a prolonged period (National Research Council, 1987). The symptoms associated with chronic vitamin A toxicity include: alopecia, anorexia and weight loss, general weakness and fatigue, bone changes, hepatocellular damage, excess mucous, inhibition of normal keratinization, thickened skin, and dermatitis.

Vitamin D_3 is 10 to 20 times more toxic than D_2 in many animals (National Research Council, 1987). Vitamin D_3 is the vitamin form available in animal products and many vitamin supplements. Most domestic animal species appear to be able to tolerate 10 times the level of vitamin D_3 they require for prolonged periods of time; Catfish and rainbow trout can tolerate as much as 20 and 500 times their requirements, respectively. Symptoms associated with chronic vitamin D toxicity include abnormal calcification of soft tissues especially kidneys, aorta and lungs.

FORMULATION OF APPROPRIATE DIETS.

When formulating diets for captive penguins, flexibility is needed to account for animal preferences, weight, exercise, physical condition, environment, and behavioral considerations as well as food availability. Thus guidelines for nutrient content rather than recommending specific food items in set quantities is appropriate. The guidelines allow flexibility in diet formulation while assuring that a nutritious diet is consumed.

Nutrient content of the food item also may affect selection of which foods to offer. Ideally, the

items chosen and supplements fed should complement each other in order to offer the animal a diet, which meets the nutrient requirements of that animal.

In order to avoid ultimate dependence on one particular food item, it is prudent to offer a variety of items to the animal. If the animal becomes [t1]imprinted" on a specific food item and if that supply for some reason becomes unobtainable, it may be very difficult to coax the animal to change. In addition, offering a variety of food items will help assure a complimentary nutrient profile in the diet.

Limited information is available on the nutrient content of whole fish fed to penguins (Gailey-Phipps, et al., 1982). It must be noted when examining the nutrient data for these items that nutrient content can vary radically among species, among individual lots within a species, among individual fish within a lot, as well as during storage. Thus, published values may/may not reflect the nutrients actually fed to penguins at any one specific time.

Types of fish selected can be chosen for specific nutrient content, availability and price, and for animal preference. It also is wise to consider quality a major factor. The facility holding penguins must make certain their food is of the highest quality. Human quality items should be insisted upon and the holding conditions must be monitored. Any item, which, upon receipt, appears to have undergone degradation or shows evidence of thawing, should not be accepted.

Nutrient composition of fish.

Table 10 shows a compilation of data available for a number of food species commonly offered to captive marine animals: capelin (*Mallatus villosus*); mackerel (*Scomberomorus sp.*); herring (*Clupea harengus*) and Columbia River smelt (*Thaleichthys pacificus*). Values were obtained from Bernard & Ullrey, 1989, and Sidwell, 1981. The vitamin data and the data on trout are unpublished data from Brookfield Zoo.

Table 10. Nutrient content of selected whole fish. All values are presented as averages in percent of the item on a dry matter basis (except energy which is presented as Kcal/g) dry matter basis.

Nutrient	Capelin	Herring	Columbia R. Smelt	Anchovy	Trout	Requirement
Dry matter (% of fresh weight)	18.77	27.72	22.69	29.7	23.7	-
Energy (kcal/g)	5.55	6.33	7.01	3.69*	6.48	4-5
Protein (%)	59.77	45.34	43.92	55.9	55.57	20-25
Fat (%)	14.83	34.00	42.88	16.16	34.52	20-30
Calcium (%)	1.69	1.66	1.09	?	2.10	0.6-2.0
Phosphorus (%)	0.37**	0.39	0.31	?	1.5	0.3-0.4
Vitamin A (IU/gm)	44	56	277	15	58	1.67
Vitamin E (IU/gm)	0.024	0.034	16	-	0.32	0.4

* Estimated from fat and protein.

** Compared to Brookfield's unpublished data, this value appears low. The unpublished data are closer to 1.2%.

Selecting fish as dietary items.

It can be seen that to formulate a diet which meets the probable nutrient requirements, a good mix of fish should be offered. It is important to be aware of the possible seasonal nutrient variations between different species offered, as well as to take into consideration the size of fish. Penguins generally accept only whole fish, therefore larger fish are often difficult to feed to many of the smaller penguin species. Of the fish presented, any will meet the protein requirement. However, in order to provide enough fat and energy, a combination of low fat fish with high fat fish is optimal. The ratios can be changed depending on availability and bird intake. To decrease the vitamin A in the diet and thus the possibility of toxicity, Columbia River smelt should not be offered as the only source of food.

Vitamin E and thiamine as well as any water soluble nutrients such as trace minerals may leach out of the fish while thawing, therefore in order to ensure provision of adequate nutrients, it is advisable to supplement the fish diet with these supplements. Please refer to the section on nutrient supplementation.

It is possible to achieve the nutrient levels outlined above by offering a diet consisting of a variety of food items. Fish that are commonly used by institutions housing penguins are listed below with the ranges of typical percentages in the diet as indicated in the 1993 PTS. Most commonly cited fish are marked by *.

Shrimp:	0
Krill:	0 to occasional
Squid:	0 to very low percentage
Fish:	
*Herring (small):	0 to 30%
*Herring (large):	0 to 100%
Anchovy:	0
Trout:	0 to 50%
*Capelin:	25 to 80%
*Columbia River Smelt:	10 to 100%
Whitebait (smelt):	0 to very low %
Silversides:	40% (one report)
Mackerel:	0

Nutrient supplementation.

As mentioned earlier, storage can affect the nutrient content of fish. The greatest concern with respect to this, is the loss of Thiamine and vitamin E (Geraci, 1980). Some species of fish contain the enzyme, thiaminase, which destroys thiamine during storage. Species thought to have recognizable quantities of thiaminase are mackerel, herring, smelt and clams. Marine products also contain high levels of poly- and mono-unsaturated fatty acids. Because vitamin E performs as an antioxidant, the breakdown of these oils during storage causes vitamin E destruction.

Considering the value of penguins and our mission of captive propagation, most institutions

supplement the diets of their penguins with vitamins and minerals. It is felt by many that, if there is a variety of high quality fish fed and if those items are stored and thawed properly, there may be no need for additional supplementation, other than vitamin E and thiamine. However, most institutions supplement with a variety of additional multi-vitamins and minerals. This is presumably to provide for any possible losses due to thawing or to ensure these nutrients are always present on a daily basis regardless of fish offered.

The supplements can be provided in pill form, hidden inside the fish and hand fed to each animal. Most institution employ this method. At least one institution injects the fish with vitamin supplement slurry. Please refer to the comments regarding parent rearing of chicks for notes on considerations during chick rearing.

There are many dietary supplements on the commercial market. Several products have been marketed specifically for marine animals. Because a general supplement like that shown in Appendix II provides a large number of nutrients in comparison to other supplements and it appears that the levels of nutrients provided in a general supplement are moderate, this type of basic supplement (along with additional vitamin E and thiamine and possibly salt), should adequately meet the nutrient requirements of penguins.

A sample combination of a total of 500 grams of a Columbia River Smelt, rainbow trout and herring mix with the supplements suggested in Table 11 will provide the nutrients as listed in Table 10.

Table 11. Sample daily diet on a dry weight basis for a 4.5 kg penguin consuming a mix (500 grams total wet weight) of herring, Columbia River smelt, and rainbow trout, with added supplements (1/4 Multivitamin every day; 1/4 salt tab; 1/4 thiamine tab; 1/2 vitamin E). This are minimal values since some nutrients were not analyzed in the fish and thus are calculated as Zero. The actual consumed levels will be higher because many of the nutrients entered as zero are contained in fish.

FISH WITH SUPPLEMENTS

NUTRIENT	Quantity consumed per day
Moisture (wet weight %)	77
Energy (kcal/g)	6.7
Protein (%)	61
Fat (%)	30
Vit. A (IU/g)	96
Vit. D_3 (IU/g)	0.8
Vit. E (IU/g)	0.535
Thiamine (mg/kg)	218
Riboflavin (mg/kg)	3.6
Niacin (mg/kg)	43
Pantothenic acid (mg/kg)	21
Vit. B6 (mg/kg)	4
Iron (mg/kg)	176

Folic acid (mg/kg)	0.861
Copper (mg/kg)	16
Manganese (mg/kg)	13
Vit. B_{12} (mcg/kg)	13
Biotin (mg/kg)	0.022
Calcium (%)	1.6
Phosphorus (%)	1.5
Cobalt (mg/kg)	-
Iodine (mg/kg)	0.47
Sodium (%)	0.63
Magnesium (%)	0.15
Zinc (mg/kg)	107
Potassium (%)	1.2
Chromium (mg/kg)	0.04
Selenium (mg/kg)	0.02
Molybdenum (mg/kg)	-
Vitamin K (mg/kg)	0.01

Additional thoughts on supplementation.

Vitamin A: Since fish contains considerable quantities of vitamin A, many supplements, which contain additional vitamin A, may put the animal at risk of toxicity (Dierenfeld et al., 1991; Walkee et al., in press). The best option would be to use a vitamin supplement, which contains no vitamin A. This option is not available in multivitamins at this time.

Vitamin D_3: Since D_3 levels in fish, although quite variable, can be considerable; the supplementation problem is also one of possible excess quantities in the diet. Again, the option may be to decrease supplements containing vitamin D_3, and again, this option may not be available in multivitamins at this time.

Vitamin E: Here the concern is for adequate levels in the diet to account for destruction in frozen fish. Most multivitamins contain lower than recommended level of 0.4 IU/g (dry mater basis) of vitamin B. Therefore, additional supplementation of Vitamin B is suggested.

Thiamine: Thiamine is provided in adequate quantities in some multivitamin supplements.

SPECIAL CONSIDERATIONS.

Marine fish versus fresh water fish.

Historically, most penguins have typically been fed marine fish. Given current problems with commercial fish availability, it is becoming more common to offer fresh water fish as food to penguins. This trend may continue as commercial hatcheries increase in number while the yield from marine fishing declines. It appears prudent to always feed a variety of fish to penguins and it may be necessary to include one or more species of marine fish in the diets at some level.

There may be some differences in general between fresh water fish and marine food items but additional studies should be performed. The reported differences include the following:

Protein: It should be noted that protein content can be overestimated in marine fish due to analysis methodology (Kjeldahl) and the contribution of non-protein nitrogen present in the cells for osmoregulation, especially in fish such as herring. Also marine invertebrates contain more free amino acids than the vertebrates, which may increase the availability of these nutrients. However the overall amino acid composition of fish and invertebrates is generally similar to other animal protein.

Cystine and methionine. Cystine and methionine, the sulfur amino acids that are important for feather production, may be the limiting amino acid in marine fish. Crustaceans may be lacking in cystine; however it is usually plentiful in fresh water fish.

Fat (lipid). Fish lipid is highly unsaturated. It has been reported that freshwater fish in general contain twice as many C1O and C18 fatty acids but less than half the quantity of C20 and one-seventh the quantity of C22 fatty acids than marine fish. Krill is high in unsaturated fatty acids and squid has 2-4 times the content of hexanoic and pentanoic fatty acids.

There are data appearing which discuss the topic of omega fatty acids and possible special requirements for these fatty acids for fish eating animals. This subject is continuing to be investigated and specific requirements for penguins have not been determined at this time. However, a short discussion is still in order.

It is true that it is crucial to provide the essential fatty acids in the diet. Omega 3 fatty acids may be important in the diets of penguins. Krill and herring have substantial quantities of eicosapentaenoic acid (BPA) while krill, herring, rainbow trout and squid possess substantial quantities of dihomo-g-linolenic acid (DHA). No values were available for Columbia River smelt nor whitebait. The contribution of the omega 6 fatty acids also differ. Possibly these may be a factor since some of these can be converted in the body to other fatty acids.

This protein (amino acid) and lipid (fatty acid) information serves to stress the importance of offering more than one type of food item to penguins at any one time. It also should be emphasized that as more information is generated on the nutrient content of food items consumed both by the free-ranging and captive penguins, actual requirement estimations should be refined.

Reported problems: Anchovies.

Demoic acid has been found in anchovies. Demoic acid is a toxic by-product of algae, which was found in anchovies in 1991. At that time, anchovies were recalled by the Food and Drug Administration and were discontinued in some institutions. Additionally, it has been reported that anchovies, because of their size and fleshiness, have soft bellies upon thawing and if not fed very quickly after thawing may cause problems, particularly histamine responses. These cases have not been documented and remain anecdotal at this time.

PARENT REARING OF CHICKS.

The most important aspect of nutrition and parent rearing of chicks is to offer enough fish to the parents to adequately feed the chicks and themselves. Thus the quantity of fish offered to parents rearing chicks should be increased. It appears that during chick rearing, parents should be fed ad libitum.

Although the actual levels of fat and energy in the diets of free-ranging penguins are unknown, it appears that they consume an array of fish species containing varying levels of nutrients. In particular however it was noted that large quantities of anchovy were consumed by some free-ranging penguins. Following is a comparison of the fat content (%) of some fish (from previous table):

Anchovy	Capelin	Mackerel	Herring	CR-Smelt
16.16	14.83	39.46	34.00	42.88

Anchovy, a common food item for some penguins in the wild, is not a particularly energy-rich fish. Additionally, Adelie penguins have been found to feed exclusively on krill when nesting Nagy & Obst, 1992). Krill contain 26 to 65% fat on a dry matter basis. This suggests that it may not only be the nutrient content of the fish fed, but possibly more importantly, the quantity of fish fed that leads to successful breeding and rearing of penguins.

Until more is known, it appears wise to feed a variety of whole fish to penguins in quantities adequate to supply energy and protein needs. If problems arise, the method of feeding and supplementing each animal should be reviewed. It does not appear necessary to supply additional fat in the diet. Remember too, that if fat or oil is added to the diet, thereby increasing the energy content of the diet, other nutrients will be diluted.

There is a concern that if parents feeding chicks are fed their supplements at one time, they may regurgitate that feeding and thus all the supplements to the chicks, resulting in a potential toxicity problem for the chicks. To remedy this concern, some institutions spread out the supplementation schedule offering supplements in many fish, several times per day; others eliminate supplements altogether; and some make no changes.

HAND-REARING.

(Please refer to the husbandry section for hand-rearing schedules and protocols.)

Nutrient recommendations.
The nutrient requirements of growing penguin chicks are not known. However, based on the successes of Sea World hand-rearing diets and on data from which the recommended levels for adult penguin nutrients were drawn, it is possible to recommend nutrient levels and diets for hand-rearing penguins.

Following (Table 12) is a comparison of nutrients recommended for adult penguins, nutrients present in an adult diet, and nutrients present in the current Sea World Hand-rearing Formulas. See discussion of the formulas, which follow. It is probable that either of the Sea World formulas will meet the nutrient requirements of a growing penguin chick.

Table 12. Nutrients on a dry weight basis.

	Recommended for adults *	Adults diet	Hand Rearing SW Milkshake **	Hand Rearing Alt-Shake +
Moisture (wet weight %)		77	82	82
Energy (kcal/g)	4-5	6.7	5.66	5.78
Crude protein (%)	20-25	61	49	50
Fat(%)	20-30	30	41	42
Fiber (%)	-	-	-	-
Linoleic acid (%)	1.11	-	1	1
Vitamin A (IU/g)	1.67	96	78	49
Vitamin D_3 (IU/g)	0.222-0.5	0.8	1	2.8
Vitamin E (IU/g)	0.4	0.535	1.58	0.47
Thiamine (mg/kg)	100-120	218	882	167
Riboflavin (mg/kg)	2-4.44	3.6	62	18
Niacin (mg/kg)	12.2-61.22	43	43	167
Vitamin B_6 (mg/kg)	2.9-3.3	4	58	15
Folacin (mg/kg)	0.28-0.8	0.861	2.2	2.8
Vitamin B_{12} (mg/kg)	0.003	0.013	0.2	0.3
Pantothenic acid (mg/kg)	11.1	21	62	13
Choline (mg/kg)	1000-240	-	118	119
Biotin (mg/kg)	0.111	0.022	1.07	0.441
Vitamin C (mg/kg)	-	-	12	383
Vitamin K (mg/kg)		0.01	1.1	0.01
Calcium (%)	0.778-2.5	1.6	1.0	1.5
Phosphorous (%)	0.33-0.44	1.5	1.18	1.2
Magnesium (%)	0.056	0.15	0.089	0.11
Potassium (%)	0.333	1.2	1.2	1.2
Sodium (%)	0.167	0.63	0.7	0.7
Iron (mg/kg)	66.7-80	176	67.5	180
Zinc (mg/kg)	38.9-50	96	8.2	70
Copper (mg/kg)	6.67	16	39.5	52
Manganese (mg/kg)	33.3-44.4	13	0.8	6.9
Selenium (mg/kg)	0.111-0.156	0.02	-	-
Iodine (mg/kg)	0.389	0.47	0.49	1.43
Amino acids				
Arginine (%)	1.6		1.55	1.58
Tryptophan (%)	0.256		0.886	0.305
Lysine (%)	1.33		2.47	2.51
Methionine (%)	0.556		0.766	0.78
Cystine (%)	0.478		0.322	0.32
Phenylalanine (%)	0.8		1.225	1.25
Tyrosine (%)	0.689		0.299	0.9
Histidine (%)	0.389		0.684	0.7
Isoleucine (%)	0.889		1.64	1.67
Leucine (%)	1.5		2.47	2.52
Threonine (%)	0.889		1.33	1.35
Valine (%)	0.911		1.61	1.64
Taurine (%)	0.04		-	-

* Refer to previous tables for additional details.

** Nutrients calculated from past and present Sea World formulas. Since the inclusion of predigested protein supplement in the past formula was only 0.06% of the total diet, neither of these formulas is significantly different in nutrients.

Hand-rearing formula.

Following is the past hand-rearing diet used by Sea World of San Diego. This diet has remained the same in major ingredients since 1987. Vitamin supplementation has changed somewhat throughout the years. In addition to this past formula, Sea World of San Diego supplemented its hand-reared penguins with additional calcium, vitamin B, Thiamine, and infant vitamins (for a vitamin D3 source). The current formula utilized by Sea World of Florida and now by Sea World in San Diego is a similar diet. However, whole herring (less heads, tails, fins and skin) and calcium gluconate in place of calcium carbonate is used. Both report successful hand rearing. Successful hand rearing has been reported with both the past and current hand-rearing formulas. Success utilizing a Sea World type diet has been reported (Miller and Searles, 1991). Others have used a squid, sprat and prawn based diet successfully (Stevenson and Gibbons, 1993).

SEA WORLD HAND-REARING FORMULA, PAST

440 grams herring fillet
440 grams krill
473 grams (ml) half and half
473 grams water
3 ea, 7 grain Brewer's yeast tablets
500 mg Thiamine
"6 lb" Mazuri Sea Bird Vitamins
4000 mg calcium carbonate
2000 1U vitamin B
1 ea Lactinex tablet
1.5 cc predigested liquid protein

SEA WORLD HAND-REARING FORMULA, CURRENT
440 grams herring fillet
440 grams krill
473 grams (ml) half and half
473 grams water
8 e, 7 grain Brewer's yeast
300 mg Thiamine
"6 lb" Mazuri Sea Bird Vitamins
4000 mg calcium carbonate
2000 IU vitamin E

As successes continue to be documented and reported, it is probable that additional reliable hand-rearing formula will become available, or that these may be modified.

SUMMARY.

Food habit information for free-living penguins is limited but shows some patterns. High-latitude species tend to use krill as well as fish, whereas lower latitude penguins rely more heavily on

fish, particularly small surface-dwelling forms. There is known variation in diets within penguin species as well as between species; it is important that captive diets balance nutrients over time, and not mimic single reports of wild diets.

Captive programs depend on reliable availability of fish, generally frozen and stored until use. It is critical to store and handle the fish properly. Generally, a variety of fish species is desirable; because each fish is caught seasonally, it is important to inquire when the fish was caught and frozen. It is preferable to keep frozen fish at –20°C (-10°F) or less, and to thaw only the needed daily quantity in a refrigerator at 2 to 3°C (36 to 38°F), never letting the fish itself exceed 7°C (45°F).

It is recommended that individual penguins be hand-fed, particularly the supplemented fish; supplemented fish should not be allowed to sit in water. In large colonies pan-fee4ing the non-supplemented fish is acceptable if the fish remains cooler than 7°C (45°F) and is not contaminated with pests, feces or other debris. The specific quantity of fish consumed per individual penguin is based on body size and physiological state, particularly related to breeding or molting.

Captive diets can be formulated appropriately based on probable nutrient requirements and nutrient content of fish and supplements. Probable requirements for adult penguins are provided; although supplementation of most vitamins and minerals may not be necessary, most institutions provide additional multi-vitamins and minerals to ensure adequate nutrients. Particular attention should be paid to adequate supplementation of vitamin E and thiamin. The selection of fish species should be made to meet probable requirements for protein, fat, and energy. Generally any fish will meet the protein requirement; a combination of low-fat and high-fat fish is optimal for meeting the penguins' needs for fat and energy. Both marine and fresh-water fish can be used in captive diets; known differences between them are discussed.

The most important aspect of nutrition related to parent-feeding chicks is to offer enough high quality fish to the parents to adequately feed the chicks and themselves. It appears wise to feed a variety of whole fish at this time to meet protein and energy needs of the adults plus growing young. A variety of supplementation regimes are reported by institutions with successful parent rearing. Some institutions have successfully used supplemental feeding of young in the nest.