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Nutrient, fatty acid, amino acid and mineral analysis of natural prey of the Hawaiian monk seal, *Monachus schauinslandi*

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Abstract

Proximate nutrients, gross energy content, mineral, amino acid and fatty acid composition were determined for teleost, cephalopod and crustacean prey of the Hawaiian monk seal. Crude protein was highest in the octopus, *Octopus cyanea* (80.0%), crude fat was highest in the Muraenid teleost, *Gymnothorax eurostus* (14.1%), whereas crude ash was highest in the lobster, *Panulirus marginatus* (11.6%). Gross energies ranged from 4.0 ± 0.01 kcal g^{-1} in the Labrid teleost *Bodianus bilulunatus* to 6.0 ± 0.12 kcal g^{-1} in the moray eel, *Gymnothorax undulatus*. Essential amino acids occurred in lower concentrations as a percentage of the total amino acids (35.8 ± 2.6%) than non-essential amino acids (64.2 ± 2.6%), but the ratio of individual amino acids to total amino acid concentrations were similar to those required by some monogastric terrestrial species and fingerling salmon. The fatty acid concentrations varied widely among species (range = 1.2–16.5 mg 100 mg^{-1}); however, the teleosts had higher total fatty acids than the non-teleosts. This study indicates that, from a nutritional standpoint, some prey may be more beneficial to the Hawaiian monk seal; however, these prey are not necessarily the most abundant or available to some populations of the monk seal.

Keywords: Proximate analysis; Prey composition; Energy; Protein; Fatty acid; Amino acid; Minerals; Hawaiian monk seal

1. Introduction

The population of Hawaiian monk seals, *Monachus schauinslandi*, has been declining by ≈ 5–6% year^{-1} [16], and one cause of this decline is the starvation of juvenile seals at the main breeding atoll of French Frigate Shoals (FFS) [4]. Because starvation may be related, in part, to the nutritive value of prey, a detailed nutrient analysis of these prey and a determination of the extent they are assimilated is important to understanding this decrease in the FFS subpopulation.

The Northwestern Hawaiian Islands extend for ≈ 1000 km and include six atolls and related coral reefs, which provide habitat for Hawaiian monk seal prey. At least 30 families of teleosts, eight species of octopi and 21 species of squid have been identified in the diet of the Hawaiian monk seal [5] in proportions of 78.6% (teleosts), 15.7% (cephalopods) and 5.7% (crustaceans). Given the great diversity of prey, it is important to know the variation in the nutrient, amino acid and fatty acid compositions among these prey.

Previously, the rate of passage of digesta [6] along with the assimilation efficiency of four prey of the Hawaiian monk seal were determined [7]. Each prey was assimilated differently and different species are known to have different energetic and nutritional qualities [13,14]. Fecal nitrogen loss decreased in proportion to increases in apparent digestible nitrogen intake, whereas the digestive efficiency and metabolizable energy of the diets examined were positively correlated with the amount of gross energy ingested [7]. These studies demonstrate considerable differences in the occurrences, digestion and nutrient composition of some prey, therefore, it is important to determine the nutrient

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profiles of as many natural prey of the Hawaiian monk seal as possible. This will help determine if some prey are more nutritionally beneficial than others and which prey might be needed for growth and maintenance of healthy seals for future use in the management of these seals.

2. Materials and methods

All of the following prey families and/or species were found in the diet of the Hawaiian monk seal [5]. To assess the nutrient composition of the various prey species, teleost families in the Labridae (*Anampses cuvier*, *Bodianus bilunulatus*, *Gomphosus varius*, *Oxycheilinus unifasciatus*, *Thalassoma ballieui*), Scaridae (*Chlorurus perspicillatus*), Holocentridae (*Myripristis amaena*, *Neoniphon sammara*), Balistidae (*Melichthys vidua*, *Sufflamen fraenatus*), Muraenidae (*Gymnothorax eurostus*, *G. rueppelliae*, *G. undulatus*), Congridae (*Conger cinereus*), and Kuhliidae (*Kuhlia sandvicensis*), in addition to cephalopods (Octopoda (*Octopus cyanea*) and Teuthoidea squid (*Loligo* sp.)), and Decapoda crustaceans (lobster, *Panulirus marginatus*) were used for this study. Approximately 500g wet weight of each species were collected. For all teleost species and the Teuthoidea, a minimum of five individuals was used for the analysis, except for the Scaridae where only one large individual was used. For the Octopoda, three individuals were used. For the crustacean, eight individuals were used; however only the tail flesh with no exoskeleton was analyzed, because monk seals have been observed in the wild breaking the tail section off before ingesting it [9] and also the chitinous exoskeleton is found in fecal and regurgitate samples, therefore it is believed that they do not digest it. The samples were analyzed for dry matter, ash, crude protein and crude fat using standard methods of the Association of Official Analytical Chemists [1], and for macro- and micromineral composition. All analyses were done by Agricultural Diagnostic Services Center at the University of Hawaii, Honolulu, HI. Because the authors did not anticipate that carbohydrate (CHO) would be a major component of the prey items, CHO content was estimated by difference where:

$$\begin{aligned}&\text{CHO (\%)}\\&= 100\%\ \text{dry matter} - (\%\ \text{crude protein} + \%\ \text{crude fat}\\&\quad + \%\ \text{ash}) \qquad (1)\end{aligned}$$

Gross energy of prey was determined using a Parr Adiabatic Bomb Calorimeter. For small samples that were used up completely in the analysis of protein, fat, ash, fatty acids and amino acids, gross energy was calculated rather than measured. This calculation was based on Pond et al. [15] where:

$$\begin{aligned}&\text{GE (kcal \% dry matter}^{-1})\\&= (\%\ \text{crude protein} \times 5.65) + (\%\ \text{crude fat} \times 9.4)\\&\quad + (\%\ \text{CHO} \times 4.15) \qquad (2)\end{aligned}$$

Fatty acid (FA) and amino acid (AA) profiles of the prey species were determined using duplicate subsamples following the procedures described in Tamaru et al. [19]. It has been shown that amino acid requirements can be determined from milk proteins [18]; therefore, amino acid data for this study were categorized as essential (EAA) or non-essential (NEAA) based on Davis et al. [2] who studied the amino acid composition of pinniped milk. EAA% and NEAA% were calculated by dividing EAA and/or NEAA by the Total AA, which were all expressed as mg 100 g^{-1} dry tissue weight. Because of the cost and difficulty in analyzing tryptophan, the level of this amino acid was not determined. Nomenclature for FA was based on McDonald et al. [10]. Comparisons were made using analysis of variance and Student's t-test for parametric data and Mann–Whitney test for nonparametric data [17]; the level of significance was $P \leq 0.05$ for all analyses.

3. Results

Calculated gross energies from composition data did not differ from those analyzed by bomb calorimetry for the same species ($t = 1.29$, $P = 0.21$). Therefore, in all cases except where a lack of sample prohibited it, the authors used the measured, not calculated, gross energy data. The gross energies ranged from 4.2 ± 0.05 (*Gomphosus varius*) to 6.0 ± 0.12 (*Gymnothorax undulatus*), and varied significantly among species ($F = 72.70$, $P = 0.000$) and teleost family ($F = 5.14$, $P = 0.003$), but not phyla (Table 1). Dry matter was higher in teleosts ($30.7 \pm 4.7\%$) than cephalopods ($17.0 \pm 0.1\%$; Mann–Whitney, $P = 0.030$), as was ash ($6.2 \pm 2.2\%$ and $1.3 \pm 0.3\%$, respectively; Mann–Whitney, $P = 0.031$). Crude protein, crude fat and CHO did not differ between teleosts and cephalopods. Crustaceans could not be statistically compared to the other phyla due to low sample size, but had the lowest crude protein and highest ash and CHO content of all the prey analyzed.

Among the macrominerals (Table 2), teleosts had higher levels of calcium (Mann–Whitney, $P = 0.031$) and phosphorus (Mann–Whitney, $P = 0.009$) than cephalopods, but lower levels of sodium (Mann–Whitney, $P = 0.009$), whereas potassium and magnesium levels did not differ between the two phyla. Although the lobster could not be compared statistically because of low sample size, it had the lowest level of phosphorus and the highest levels of calcium, potassium, magnesium and sodium of all species examined. Among the microminerals (Table 2), only the copper levels differed between teleosts and cephalopods, with levels higher in cephalopods (Mann–Whitney, $P=0.009$). Differences in the other microminerals were not seen because of the great variation in levels (e.g. boron: non-detectable to 23.0 ppm; iron: 40.0–315.0 ppm; copper: 6.0–181.0 ppm; and zinc: 36.0–343.0 ppm).

The EAA profiles were similar among prey species (Table 3), except for lysine, which was highest in the octopus, *Octopus cyanea* (7.2 mg 100 mg^{-1}). Total EAA was lowest for *Neoniphon sammara* (16.3 mg 100 mg^{-1}) and highest for *Bodianus bilunulatus* (25.0 mg 100 mg^{-1}). Total amino acid content was lowest for the Holocentridae and Kuhliidae, and was highest for the lobster (Fig. 1). Total concentrations of EAA did not differ between teleost and non-teleost prey.

The NEAA profiles of each prey were fairly similar to each other with a few exceptions (Table 4). Arginine had a broad range among the prey species, with a low of 2.5 mg 100 mg^{-1} (*Kuhlia sanvicensis*) and a high of 9.7 mg 100 mg^{-1} (*Panulirus marginatus*). Serine and tyrosine were low among all prey species examined. Total NEAA was lowest for *Kuhlia sanvicensis* (29.6 mg 100 mg^{-1}) and highest for *Bodianus bilunulatus* (47.7 mg 100 mg^{-1}). Total concentrations of NEAA did not differ between teleost and non-teleost prey (Fig. 1). Overall, the NEAA were more abundant in the prey than the EAA (Mann–Whitney, $P=0.001$), although this varied with prey type.

Comparing the proportions of amino acids assumed essential to the Hawaiian monk seal based on studies concerning milk proteins of pinnipeds [2] with known proportions needed for growth and maintenance in other species (Fig. 2), it is apparent that most of the EAAs are present in the prey phyla at similar levels required by the other species, with a few exceptions. The different phyla of monk seal prey and all phyla combined but weighted to reflect natural percentages of prey found in the diet of the monk seal [5] are providing similar amounts of histidine and valine as required by the salmon, pig and rat, and more isoleucine than is needed by salmon, but not by the pig or rat. In addition, leucine, lysine and threonine are all present in

Table 1
Proximate composition and gross energy (expressed on dry matter basis) of prey types of the Hawaiian monk seal[a]

Prey	Gross energy (kcal g^{-1})	Dry matter (%)	Crude protein (%)	Crude fat (%)	Ash (%)	Carbohydrate (%)
TELEOSTS						
Labridae						
Anampses cuvier	5.2 ± 0.06	33.2	60.9	6.5	6.7	25.8
Bodianus bilunulatus	4.0 ± 0.01	28.2	67.5	0.4	6.5	25.6
Gomphosus varius	4.2 ± 0.05	33.1	62.3	3.3	6.7	27.8
Oxycheilinus unifasciatus	4.5 ± 0.04	31.8	67.5	1.4	5.9	25.3
Thalassoma ballieui	4.6 ± 0.11	37.6	58.4	4.2	7.9	29.6
Scaridae						
Chlorurus perspicillatus	4.9[b]	23.9	60.9	0.5	4.5	34.0
Holocentridae						
Myripristis amaena	4.8 ± 0.24	35.7	57.0	5.0	9.7	28.3
Neoniphon sammara	5.1 ± 0.04	40.5	51.4	8.7	6.1	33.8
Balistidae						
Melichthys vidua	4.8[b]	25.5	65.6	1.0	7.8	25.5
Sufflamen fraenatus	4.8[b]	29.5	53.9	3.1	6.6	36.4
Muraenidae						
Gymnothorax eurostus	5.6[b]	34.6	57.8	14.1	3.2	25.1
G. rueppelliae	5.1 ± 0.10	28.3	76.3	1.1	4.5	18.2
G. undulatus	6.0 ± 0.12	32.0	62.0	10.9	2.7	24.4
Congridae						
Conger cinereus	4.9 ± 0.01	25.7	78.1	2.1	3.9	15.9
Kuhliidae						
Kuhlia sandvicensis	5.4 ± 0.01	30.7	68.1	6.7	10.3	14.9
CEPHALOPODS						
Octopoda						
Octopus cyanea	5.0 ± 0.08	16.9	80.0	0.4	1.5	18.1
Teuthodea						
Loligo sp.	4.8 ± 0.06	17.1	75.0	1.1	1.1	22.8
CRUSTACEANS						
Decapoda						
Panulirus marginatus	4.8 ± 0.07	29.6	46.44	0.6	11.6	41.35

[a] Values are given as the mean $\pm$ 1 SD.
[b] Calculated gross energy.

Table 2
Macro- and micro-mineral analysis (expressed on dry matter basis) of prey types of the Hawaiian monk seal

Prey	Calcium (%)	Phosphorus (%)	Potassium (%)	Magnesium (%)	Sodium (%)	Boron (ppm)	Mang (ppm)	Iron (ppm)	Copper (ppm)	Zinc (ppm)
TELEOSTS										
Labridae										
Anampses cuvier	5.9	2.9	1.1	0.2	0.5	5.0	12.0	55.0	10.0	49.0
Bodianus bilunulatus	8.5	4.0	1.2	0.2	0.6	6.0	4.0	61.0	10.0	92.0
Gomphosus varius	6.5	3.1	0.9	0.2	0.5	6.0	4.0	112.0	7.0	65.0
Oxycheilinus unifasciatus	6.5	3.2	1.1	0.2	0.6	5.0	9.0	40.0	6.0	64.0
Thalassoma ballieui	9.2	4.4	1.0	0.3	0.5	6.0	4.0	51.0	6.0	83.0
Scaridae										
Chlorurus perspicillatus	8.0	3.4	1.1	0.3	0.6	14.0	16.0	136.0	10.0	48.0
Holocentridae										
Myripristis amaena	11.7	5.4	0.8	0.2	0.5	0.0	1.0	44.0	7.0	104.0
Neoniphon sammara	8.4	4.0	0.5	0.2	0.5	4.0	2.0	106.0	7.0	47.0
Balistidae										
Melichthys vidua	9.9	4.0	0.8	0.4	0.6	12.0	10.0	315.0	12.0	131.0
Sufflamen fraenatus	11.8	5.1	0.5	0.2	0.5	8.0	15.0	106.0	7.0	343.0
Muraenidae										
Gymnothorax eurostus	2.5	1.4	0.5	0.1	0.4	3.0	9.0	72.0	6.0	39.0
G. rueppelliae	5.1	2.7	0.9	0.1	0.6	4.0	9.0	46.0	8.0	69.0
G. undulatus	1.7	1.2	0.8	0.1	0.4	5.0	5.0	91.0	6.0	36.0
Congridae										
Conger cinereus	2.1	1.4	1.4	0.1	0.5	3.0	8.0	51.0	10.0	73.0
Kuhliidae										
Kuhlia sandvicensis	7.9	3.7	0.9	0.2	0.5	0.0	3.0	100.0	6.0	107.0
CEPHALOPODS										
Octopoda										
Octopus cyanea	0.9	0.9	1.1	0.3	1.1	12.0	4.0	142.0	38.0	51.0
Teuthodea										
Loligo sp.	0.1	1.1	1.1	0.2	1.2	4.0	3.0	53.0	181.0	102.0
CRUSTACEANS										
Decapoda										
Panulirus marginatus	13.5	0.8	1.3	1.3	1.6	23.0	4.0	106.0	94.0	82.0

Table 3
Essential amino acids (EAA, expressed as mg 100 mg^{-1} dry weight) of some Hawaiian monk seal prey[a]

Prey	His	Ile	Leu	Lys	Met	Phe	Thr	Val	Total EAA	EAA%[b]
TELEOSTS										
Labridae										
Anampses cuvier	1.2	1.8	4.7	5.1	0.8	2.3	3.3	2.4	21.5	35.1
Bodianus bilunulatus	1.3	2.4	5.1	5.6	1.8	2.4	3.9	2.6	25.0	34.5
Gomphosus varius	1.3	1.8	4.9	5.5	1.2	2.8	3.4	2.5	23.3	37.5
Oxycheilinus unifasciatus	1.2	2.4	4.9	5.7	1.2	2.9	2.8	3.1	24.3	39.6
Thalassoma ballieui	1.2	1.8	4.3	4.6	0.6	2.2	3.3	2.3	20.2	32.1
Holocentridae										
Myripristis amaena	1.1	1.5	3.2	4.5	1.4	1.7	2.4	2.1	17.9	35.9
Neoniphon sammara	1.1	1.3	3.1	3.5	0.6	2.4	2.5	1.8	16.3	33.0
Muraenidae										
Gymnothorax undulatus	1.2	1.4	3.6	4.5	0.5	1.9	2.7	2.1	18.0	31.6
Congridae										
Conger cinereus	1.5	2.0	5.7	6.1	0.9	1.8	3.9	2.4	24.3	36.5
Kuhliidae										
Kuhlia sandvicensis	1.6	1.7	3.5	5.1	1.1	2.3	2.7	1.8	19.8	40.1
CEPHALOPODS										
Octopoda										
Octopus cyanea	1.5	1.9	4.2	7.2	0.4	1.9	3.0	2.3	22.4	38.1
Teuthodea										
Loligo sp.	1.4	1.8	4.3	4.6	0.2	1.0	3.0	2.1	18.4	36.6
CRUSTACEANS										
Decapoda										
Panulirus marginatus	1.6	1.9	5.4	6.3	1.1	2.9	3.2	2.2	24.6	35.4

[a] Amino Acids: Histidine (His); Isoleucine (Ile); Leucine (Leu); Lysine (Lys); Methionine (Met); Phenylalanine (Phe); Threonine (Thr); Valine (Val).

[b] EAA% = EAA/Total AA × 100.

higher percentages than is required by the other organisms, while methylalanine and phenylalanine within the different phyla and the weighted combined prey are present in lower percentages than is required for the salmon, pig and rat.

The FA profiles were similar among prey species for all but palmitate (16:0), which had a wide range of 0.3% (*Bodianus bilunulatus*) to 5.7% (*Neoniphon sammara*; Table 5). Saturated FAs (14:0, 16:0, and 18:0) constituted the same amount of the total FAs as unsaturated FAs. The total amount of FAs of all prey species (Fig. 3) ranged from 1.2% (*Bodianus bilunulatus*) to 16.5% (*Gymnothorax undulatus*) and also differed between teleost and non-teleost prey (Mann–Whitney, $P = 0.002$).

Palmitate, which can be synthesized and is needed for synthesizing other fatty acids, accounted for $26.6 \pm 5.9\%$ of the total fatty acids (Fig. 4) and was higher in teleost than non-teleost prey (Mann–Whitney, $P = 0.014$). Arachidonic acid, an essential FA needed for growth, accounted for only $9.3 \pm 8.0\%$ of the total FAs and did not differ between teleosts and non-teleosts. Docosahexaenoate (DHA), a FA involved with vision and brain function in mammals, comprised $13.9 \pm 9.3\%$ of the total FAs and also did not differ between teleosts and non-teleosts.

4. Discussion

Based on the analysis of some prey of the Hawaiian monk seal, the findings support the theory that nutrient, amino acid and fatty acid compositions are different among prey. In general, monk seals are eating prey high in protein; however, they may be lacking some essential amino acids, in particular isoleucine and phenylalanine, required in other terrestrial species. Alterations in amino acid sequence directed by DNA caused by the lack of any particular amino acid can cause poor growth, abnormal function and disease. Phenylalanine is one of the biosynthetic precursors of some neurotransmitters, and hence, meals low in this amino acid can directly influence brain function [3]. Therefore, it is important to determine the degree to which the lack of these amino acids in the diet could affect the Hawaiian monk seal.

Species within the Holocentridae and Kuhliidae contained the least amount of total amino acids, whereas the lobster contained the most, indicating that crustaceans may be more beneficial nutritionally in this aspect than some teleosts to the Hawaiian monk seal. The fact that monk seals are eating a mixture of teleosts, cephalopods and crustaceans [5], however, may help overcome this problem of some prey providing higher levels of total amino acids provided that all prey are equally available. For example, although lobster had the highest concentration of amino acids among the prey tested, it has not been seen in high occurrence in the diet of monk seals [5], whereas moray eels (Muraenidae) are among the top five prey in the diet and one species (*G. undulatus*) contains the greatest concentration of fatty acids of all of the prey tested.

Crude protein was found to be higher in cephalopods than in teleosts; however, this may have been overestimated, because the total amino acids did not differ between teleosts and non-teleosts. Crude protein analysis may be a less accurate estimate of protein content because non-protein nitrogens such as free amino groups and nucleotides are included with this method. Amino acid analysis probably reflects the true protein content of the prey examined and crude protein should be used with caution in estimating protein levels of monk seal prey.

The Hawaiian monk seal is foraging on prey that are all generally high in protein, and therefore, the distinguishing factor in the nutritional benefits of these prey stems from the amount of fats and fatty acids, and hence, gross energy, they contain. A wide range of both crude fat and total fatty acid content was seen among the prey examined, with teleosts containing more fats than cephalopods or crustaceans. This is particularly important when one looks at which prey the monk seals are eating. For example, seals at FFS, are eating fewer eels than seals at other islands [5] possibly due to lack of availability of this prey. Yet one species of eel examined contained the greatest percentage of total fatty acids. Because it is the juvenile seals at FFS that are starving, this lack of high fat prey in the diet of monk seals there may be a factor. Other teleost prey were also found to be high in fat, but because prey determination through scat analysis was accurate to the family and not species level [5], the authors can not determine the extent to which the monk seals are obtaining these prey that are high in fat. Furthermore, high variability in crude fat and gross energy were seen among species of teleosts within families such as the Labridae, Holocentridae and Muraenidae.

Differences in gross energy were found among teleost families, and in general, prey with higher gross energy content should be energetically more beneficial to monk seals; however, energy content alone does not take into account the energy expended during foraging. For example, Labrids are often found in great numbers on the reefs, are smaller in size and may be easier to catch, whereas Muraenid eels live in holes, are solitary

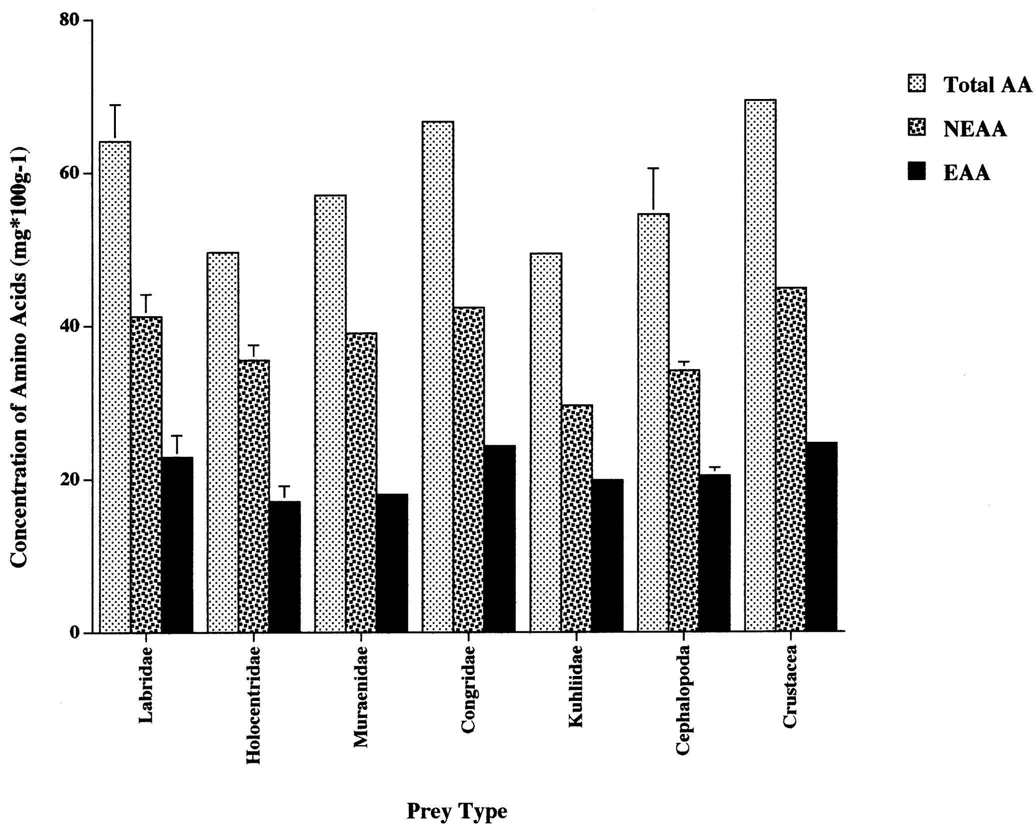

Fig. 1. Total amino acids (total AA), essential amino acids (EAA) and non-essential amino acids (NEAA) of some Hawaiian seal prey types. Error bars represent the mean $\pm$ 1 SD.

Table 4
Non essential amino acids (NEAA, expressed as mg 100 mg^{-1} dry weight) of some Hawaiian monk seal prey[a]

Prey	Ala	Arg	Asp	Glu	Gly	Ser	Tyr	Total NEAA	NEAA%[b]
TELEOSTS									
Labridae									
Anampses cuvier	5.2	5.0	7.3	11.1	6.6	2.6	1.9	39.8	64.9
Bodianus bilunulatus	6.8	5.1	8.2	13.3	8.8	3.4	2.1	47.7	65.6
Gomphosus varius	5.0	4.7	7.0	10.6	6.8	2.6	2.4	39.0	62.6
Oxycheilinus unifasciatus	6.5	4.2	6.3	8.6	7.0	2.3	2.3	37.1	60.4
Thalassoma ballieui	5.8	4.8	7.9	11.3	8.5	2.8	1.8	42.8	67.9
Holocentridae									
Myripristis amaena	4.5	3.9	5.5	8.6	5.8	2.1	1.7	32.0	64.1
Neoniphon sammara	4.9	3.9	5.0	8.3	7.1	1.9	2.0	33.1	67.0
Muraenidae									
Gymnothorax undulatus	5.6	4.9	6.3	9.8	8.5	2.3	1.7	39.0	68.4
Congridae									
Conger cinereus	5.7	5.2	7.8	12.3	7.0	2.9	1.6	42.4	63.5
Kuhliidae									
Kuhlia sandvicensis	3.9	2.5	7.0	8.5	3.6	2.2	2.0	29.6	59.9
CEPHALOPODS									
Octopoda									
Octopus cyanea	3.7	5.2	6.4	10.4	4.7	2.9	3.0	36.3	61.9
Teuthodea									
Loligo sp.	3.6	4.6	7.5	8.9	3.7	2.5	1.2	31.9	63.4
CRUSTACEANS									
Decapoda									
Panulirus marginatus	4.3	9.7	7.3	12.5	5.6	2.9	2.5	44.8	64.6

[a] Amino Acids: Alanine (Ala); Arginine (Arg); Aspartic acid (Asp); Glutamic acid (Glu); Glycine (Gly); Serine (Ser); Tyrosine (Tyr).
[b] NEAA% = NEAA/Total AA × 100.

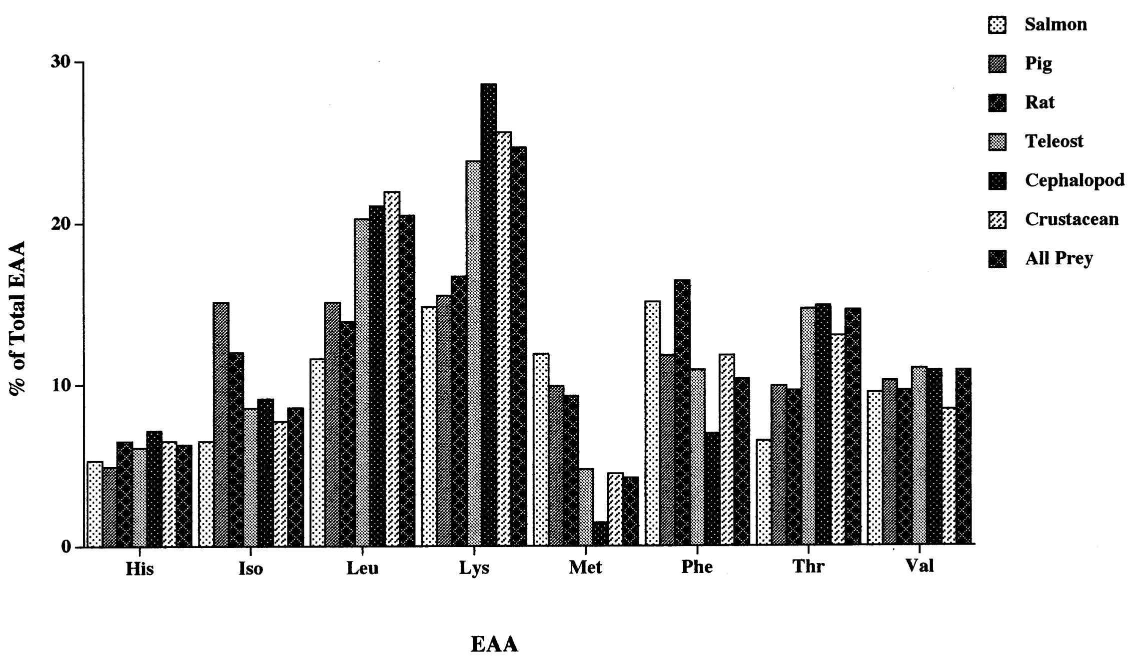

Fig. 2. Essential amino acids (%) for teleosts, cephalopods, crustaceans and all prey combined (weighted to reflect the frequency of occurance in the diet of the Hawaiian monk seal [5]) compared to the required essential amino acids for the fingerling salmon, young pig and rat (taken from Mertz, 1975 [11]). Histidine (His), Isoleucine (Leu), Leucine (Leu), Lysine (Lys), Methionine (Met), Phenylalanine (Phe), Threonine (Thr) and Valine (Val).

Table 5
Fatty acid concentration (expressed as mg 100 mg^{-1} dry weight) in tissue of Hawaiian monk seal test prey[a]

Prey	14:0	16:0	16:1*n*7	18:0	18:1*n*9	18:2*n*6	18:3*n*3	18:4*n*3	20:1*n*9	20:4*n*6	20:5*n*3	22:1*n*11	22:6*n*3
TELEOSTS													
Labridae													
Anampses cuvier	1.5	4.0	0.8	1.2	1.7	0.2	0.1	0.2	0.2	1.1	2.0	0.1	0.8
Bodianus bilunulatus	0.0	0.3	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.1
Gomphosus varius	0.3	0.9	0.1	0.3	0.3	0.1	0.0	0.0	0.0	0.3	0.2	0.0	0.5
Oxycheilinus unifasciatus	0.3	1.1	0.3	0.6	0.6	0.1	0.5	0.0	0.0	0.4	0.3	0.0	0.6
Thalassoma ballieui	0.7	1.4	0.3	0.7	0.6	0.1	0.1	0.0	0.1	0.5	0.3	0.5	0.5
Holocentridae													
Myripristis amaena	0.3	1.1	0.2	0.5	0.5	0.1	0.0	0.0	0.1	0.1	0.2	0.0	0.8
Neoniphon sammara	1.7	5.7	1.3	1.7	2.6	0.3	0.1	0.0	0.3	0.7	0.9	0.1	0.9
Muraenidae													
Gymnothorax undulatus	1.2	5.3	1.6	1.6	3.2	0.9	0.1	0.1	0.3	0.4	0.5	0.0	1.3
Congridae													
Conger cinereus	0.6	3.3	0.6	1.0	1.4	0.2	0.1	0.1	0.1	0.6	0.6	0.0	0.9
Kuhliidae													
Kuhlia sandvicensis	0.7	3.8	1.0	1.2	2.4	0.3	0.2	0.2	0.4	0.4	1.2	0.4	2.5
CEPHALOPODS													
Octopoda													
Octopus cyanea	0.3	0.4	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.5	0.2	0.0	0.5
Teuthodea													
Loligo sp.	0.2	1.1	0.0	0.3	0.1	0.1	0.0	0.0	0.2	0.1	1.0	0.0	2.1
CRUSTACEANS													
Decapoda													
Panulirus marginatus	0.0	0.3	0.1	0.2	0.2	0.1	0.0	0.0	0.0	0.5	0.2	0.0	0.1

[a] Fatty acids: 14:0 (Myristate); 16:0 (Palmitate); 16:1*n*7 (Palmitoleate); 18:0 (Stearate); 18:1*n*9 (Oleate); 18:2*n*6 (Linoleate); 18:3*n*3 Linolenate); 18:4*n*3 (Octadecatetraenoate); 20:1*n*9 (Eicosenoate); 20:4*n*6 (Arachidonate); 20:5*n*3 (Eicosapentaenoate); 22:1*n*11 (Erucate) 22:6*n*3 (Docosahexaenoate).

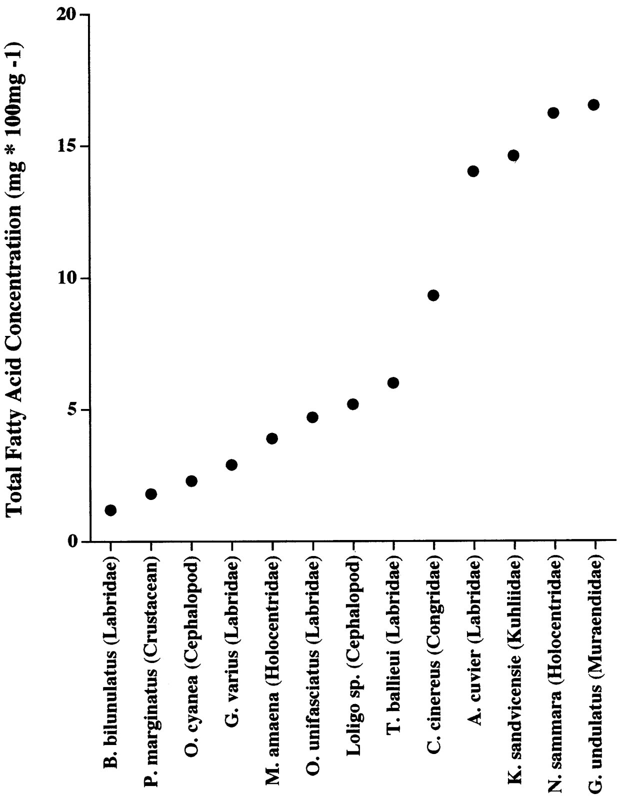

Fig. 3. Variations in total fatty acid concentration (mg 100 mg^{-1}) of Hawaiian monk seal prey.

dwellers, and have tough leathery skin. This may help explain why the rank of teleosts from highest to lowest based on their gross energies (Muraenidae > Holocentridae > Scaridae > Balistidae > Labridae) is not the same as the rank of teleosts found in the diet (Labridae > Holocentridae > Balistidae > Scaridae > Muraenidae [5]).

Prey species of the Hawaiian monk seal were not examined for seasonal differences; however, spawning, and hence, reproductive state, typically occurs throughout the year in the tropics [8,12,20]. The prey examined in this study were not checked for all reproductive states, but did include both males and females. In addition, although multiple subsamples were not collected for each prey species, in all cases except for the Scaridae, several individuals were pooled before analysis. The presence and abundance of eggs in the prey, and hence, sex and reproductive status would affect the crude fat and gross energy of the prey. Because the different prey species may have been of different sexes or in different reproductive states when collected, this may help explain some of the variability of fat content observed. In addition, because only the tail flesh was used to represent the lobster in this study, no reproductive structures were present, which may account for the relatively low crude fat found for the lobster. It is important to note that palmitate, arachadonate and DHA were all high in the prey examined, indicating that the Hawaiian monk seal is obtaining prey that are nutritionally rich in these nutrients. This could be very beneficial to their health and, ultimately, their survival.

The CHO content of marine carnivores like fish and squid are usually not measured because they are often considered negligible in animal tissues. In the present study, however, the gross energy levels, which include CHOs, that were measured by bomb calorimetry were not significantly different from the calculated gross energies, where the CHO values were obtained by difference. This indicates that the high percentage of CHO found in the prey is accurate. High CHO in marine carnivores is probably due to the high proportion of muscle mass, and is important for energy utilization and heat retention. Therefore, the role and percentage

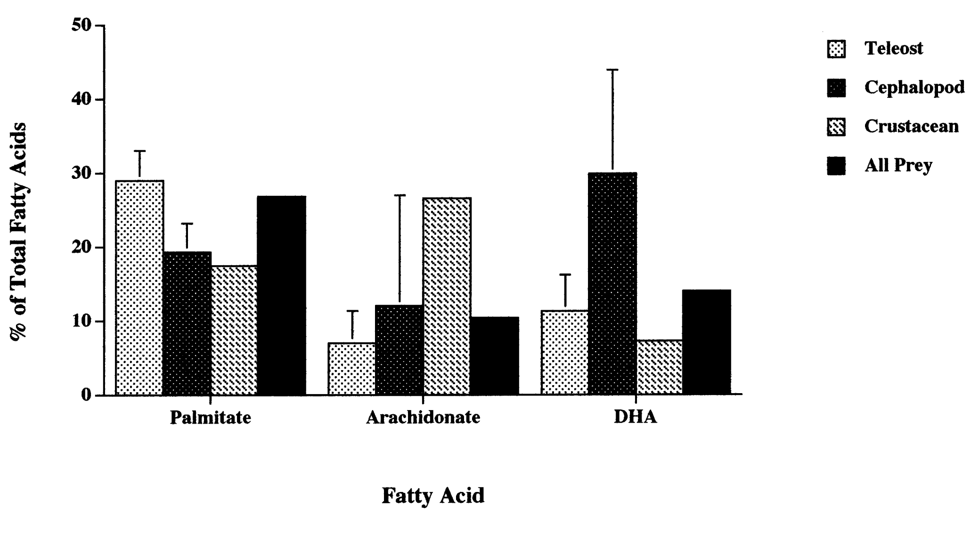

Fig. 4. Palmitate, Arachadonate and Docosahexaenoate (DHA) as a % of total fatty acids for teleosts, cephalopods, crustaceans and all prey combined but weighted to reflect their natural occurrences in the diet of the Hawaiian monk seal (from [5]).

of carbohydrates found in many marine animals may need to be re-examined.

The concentrations of minerals in the prey species varied considerably, but in general, the lobster, *Panulirus marginatus*, contained the highest levels of the macrominerals important in metabolic energy transfer and the formation of nucleic acids (phosphorus), bone formation and blood clotting (calcium), neuromuscular control (magnesium) and osmotic pressure and pH maintenance (sodium). Because lobsters are high in the above minerals, one would expect their occurrence in the diet to be correspondingly high; however, lobsters have only been found to occur in the diet of the Hawaiian monk seal at $\approx 0.2\%$ [6]. Most of the microminerals were found in highest concentrations among the more highly consumed teleost prey, including those important as enzyme substrate activators (manganese and zinc) and as metalloenyzmes (iron and copper).

This study has provided further insight into the feeding ecology of the Hawaiian monk seal by examining the nutrient composition of several of its prey and has not shown a lack of any particular nutrient in the diet. Although some of these prey appear to be more nutritious than others, these prey may not be available to the seals, and hence, a diet that encompasses a greater percentage of these prey types and/or a diet that encompasses several different prey types would be most beneficial to the seals. Further studies are focusing on determining digestibilities of the amino acids and fatty acids of some of the natural prey types. Future studies should examine seasonal differences in specific prey and encompass a greater variety of prey types.

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