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Effects of Diet on Nutritional Content of Whole Vertebrate Prey

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Proximate composition (moisture, lipid, protein, ash), vitamin A and vitamin E content, and six minerals (Cu, Fe, Zn, Mg, Mn, Ca) were measured in quail, rats, mice, and guinea pigs raised on at least two different diets per species. Feed composition varied substantially but erratically in lipid, vitamin A, vitamin E, and mineral content. All unsupplemented feeds had less vitamin E than NRC recommendations and most feeds contained less Mn than recommended. Most feeds deviated from the manufacturer's guaranteed analysis. There were significant effects of diet on body mass, moisture, lipid, ash, vitamin A, vitamin E, Ca, and Cu content for quail. There was a significant effect of diet on vitamin A content of mice; there were no other effects of diet on mammalian species. There was no correlation between diet composition and body composition for any species. Rats and mice differed significantly in vitamin A, Fe, and Cu content when raised on the same diet. We suggest that (1) it is difficult to assume or assess composition or adequacy of commercial diets without laboratory analysis, (2) supplementation of diets with whole foods can potentially reduce diet quality, (3) nutrient differences in quail are related to differences in growth, and such age-related differences may be more important in determining nutrient content than diet, (4) there were significant species differences in responsiveness to changes in diet, and (5) whole domesticated prey are a potentially inadequate source of vitamin E for raptors and of Mn and Cu for all carnivores.

Key words: vitamins, minerals, body composition, feed composition, growth

INTRODUCTION

Nutrition is documented to affect health [Gershwin et at., 1985], growth, reproduction [NRC, 1978, 1984] and longevity [Good and Gajjar, 1986] in a variety of animals. The nutritional status of raptors and other carnivores, which are frequently fed domesticated whole prey, is dependent not only on the type of prey [Bird and Ho, 1976; Dierenfeld et at., 1995; Clum et al., 1995], but also on the quality of the diet

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those prey were fed [Dierenfeld et at., 1989]. Many breeders purchase the prey that they feed out, and thus have no control over the diet of these prey. Even breeders that raise their own prey species typically use commercial feeds for logistic and financial reasons.
The diets that are commercially and locally available for domesticated species have been designed to produce healthy prey species as a final product, i.e., they are often created with either maximal growth or maximal reproduction as a goal. They have not been designed to support maximal health and reproduction of a secondary consumer such as a raptor, which frequently must derive all of its nutritional requirements from a single source. Thus, it is difficult to predict how commercially available diets may affect the nutritional content of prey species and, subsequently, the nutritional status of raptors.

Nutritional status of prey depends not only on the occurrence of nutrients in the food but also on the ability of prey to extract these nutrients. Because different species are subject to different selection pressures (natural or artificial), the ability to assimilate nutrients can vary substantially between species [Ruppert, 1980; Speakman, 1987; Ferraris et at., 1989; Barton and Houston, 1993], and thus different species fed similar diets may have a different nutritional content. By the same token, any given species will not process all nutrients in the same manner [e.g., Dierenfeld et at., 1995], and thus it is difficult to assess the nutritional quality of a prey item by examining only one or two nutrients.

We measured proximate composition (moisture, lipid, protein, ash), vitamin A and vitamin E content, and copper (Cu), iron (Fe), zinc (Zn), magnesium (Mg), manganese (Mn), and calcium (Ca) of four domesticated species raised on at least two different diets per species. The objectives of this work were to assess (1) the variability of nutrient composition in some commonly used, commercially available diets, (2) the impact of this variability on body composition of prey commonly fed to raptors, and (3) the relative responsiveness of different species to changes in diet.

METHODS

Experimental Design

We set up feeding trials for four species of domesticated animals; *Coturnix* quail and mixed breed rats, mice, and guinea pigs. Both males and females were used for quail, but only males were used for the other three species. After hatching, quail (n=*50,* each diet) were placed in the middle deck of a five-deck Petersime brood unit and raised to 6 weeks of age. Quail were fed (ad libitum) either Gamebird Starter, Turkey Starter, or Turkey Starter supplemented with 220 lU/kg of vitamin E (Purina Mills, St. Louis, MO). Water was provided ad libitum. Three pregnant female mammals of each species were housed in standard laboratory mammal cages (one female per cage) until litters were weaned. Mice were fed (ad libitum) Rodent Chow (#5001), Mouse Chow (#5015), Formulab Chow (#5008) (Purina), or Formulab Chow supplemented with a mixed grain. Rats were fed (ad libitum) Rodent Chow, Rat Chow (#5012), Formulab Chow, or Formulab Chow supplemented with a mixed grain. Guinea pigs were fed (ad libitum) Guinea Pig Chow (#5025) (Purina) or a locally manufactured guinea pig feed All animals were provided with water ad libitum. After weaning, three individuals from each diet treatment of each species were randomly selected (one from each litter) and placed together in new cages. Mice were raised to 12 weeks, rats to 11 weeks, and guinea pigs to 10 weeks of age.

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Laboratory Analyses

At the end of the trials each animal was killed and weighed to the nearest 0.1 g. Feathers were removed from birds and three individuals of each sex from each treatment group and species were ground separately. Four replicate samples were immediately taken from each individual: two for vitamin analysis and two for moisture, lipid, ash, and mineral analysis. The remainder of the ground sample was frozen and two replicate samples taken at a later time for protein analysis. One 500 g sample was also taken from each type of feed and stored at -10ºC for up to 3 months prior to analysis.

Moisture content was determined by drying samples to a constant weight in a vacuum oven at 60ºC. Lipid content of dried samples was determined indirectly using Soxhlet extraction [Ellis, 1984]. Fat-free dry samples were ashed in a muffle furnace at 550ºC for 3 days [Ellis, 1984] to determine ash content. Protein content of thawed wet tissues was assayed by the Biuret method [Horwitz, 1975]; samples were corrected for any moisture loss during freezing by redrying a second set of samples. Tissue extraction and analysis of retinol and alpha- and gamma-tocopherol were modifications of the general methods of Taylor et al. [1976], as described in Douglas et al. [1994], using high-performance liquid chromatography. Extraction of feed was performed according to the method described by Combs and Combs [1985]. Vitamin A activity was calculated as 0.3 g all-trans retinol = 1 IU [Olson, 1984]. Vitamin E was calculated by summing alpha- and gamma-tocopherols, where 1 mg alpha-tocopherol = 1.1 IU and 1 mg gamma-tocopherol = 0.1 IU [Machim, 1984]. Ashed samples were prepared for mineral analysis according to the method of Parker [1963]. Ca, Cu, Fe, Zn, Mg, and Mn levels were measured on a Perkin-Elmer atomic absorbance spectrometer.

Statistical Analyses

Diet differences within species were analyzed using a one-way ANOVA. Relations between feed content and body content were examined using regression analysis. Sex differences and differences between any two species or diets were analyzed using a Student's t test or the Mann-Whitney *U* statistic. Comparison of multiple dependent variables was corrected by a sequential Bonferroni method [Rice, 1989]. Significance was assigned at the level of (corrected) $P < 0.05$. Analyses were run using SYSTAT [Wilkinson, 1990].

RESULTS

Feed composition varied substantially but unpredictably in lipid, vitamin A, vitamin E, and mineral content (Tables 1, 2, 3). All unsupplemented feeds had less vitamin E than National Research Council recommendations [NRC, 1978, 1984]. Quail, mouse, and rat feeds (with the exception of Rodent Chow) had less Mn than recommended. Unsupplemented quail feeds also had less vitamin A, and rat feeds had less lipid than suggested. Fat levels of feeds were consistently lower and ash content of feeds (except Guinea Pig Chow) was consistently higher than the guaranteed analysis provided by the manufacturer. Protein levels, given the variability of

TABLE 1. Nutrient composition of quail diets*

	Supplemented Turkey Starter	Unsupplemented Turkey Starter	Gamebird Starter	NRC (quail)
Moisture (%)	10.3	9.3	8.0	N/A
Lipid (%)	2.3	1.1	2.1	—
	(>3.0)	(>3.0)	(2.5)	
Protein (%)	20.0	20.4	25.5	24
	(>26.0)	(>26.0)	(30.0)	
Ash (%)	8.1	7.0	7.0	N/A
Vitamin A (lU/kg)	**7,667**	**3,500**	**2,600**	5,000[a]
Vitamin E (lU/kg)	**68.2**	**11.8**	**8.7**	12[a]
	(220)			
Calcium (mg/kg)	18,519	17,079	12,450	800
Copper (mg/kg)	16.2	18.7	16.5	6
Magnesium (mg/kg)	1,643.5	1,285.1	1,525.0	300
Iron (mg/kg)	198.6	161.9	221.5	100
Manganese (mg/kg)	**65.1**	**76.4**	**9.0**	90[a]
Zinc (mg/kg)	23.8	127.3	128.0	25

*All data except moisture content presented on a dry matter basis. Numbers in parentheses are manufacturer's guaranteed analysis.
Numbers in bold indicate at least a 25% difference in nutrient content among feeds.
~aIndicates at least one feed below NRC recommended levels for this nutrient [NRC, 1984].

replicate samples from whole prey (see below), cannot be said to differ from manufacturer's guaranteed analysis. For diets where a guaranteed analysis of vitamins and minerals was available, levels of vitamin A, vitamin E, Mg, Cu, and Mn were lower than expected (except mineral levels of Rodent Chow), and levels of Ca, Fe, and Zn were higher than expected.

Female quail were significantly heavier than male quail in all treatment groups ($P_{gamebird}$ = 0.0008; P_{turkey} = 0.0001; $P_{suppturkey}$ = 0.0173). There was a significant effect of diet on body mass of quail for both males (P= 0.003) and females (P = 0.00001), and the degree of sexual size dimorphism was almost three times higher in the groups fed Turkey Starter (20%) and supplemented Turkey starter (19%) than in the group fed Gamebird Starter (7%). In addition, one-third of the females fed on Turkey Starter (supplemented or unsupplemented) were producing eggs at 6 weeks of age, while none of the females fed on the Gamebird Starter were reproductively active. There was no effect of diet on adult weight for mammals (P_{rat} = 0.928, P_{mice} =0.326; $P_{guineapig}$ = 0.588). There were no significant sex differences in proximate composition, vitamin content, or mineral content following correction for multiple comparisons (Table 4). Protein samples were highly variable within sexes and within treatments, probably as a result of sampling bias in the relatively small (<0.5 g) subsamples. As a consequence, the sum of proximate analyses in many cases exceeded 100%.

There were significant effects of diet on nutrient composition of quail for moisture, ash, vitamin A, vitamin E, Ca, and Cu; there were marginally significant differences (adjusted P < 0.10) for Mg and Fe (Table 5). There was no effect of diet on nutrient composition of rats (Table 6) or guinea pigs (Table 7) following corrections for multiple comparisons; mice differed only in vitamin A content (Table 8).

There was no correlation between diet composition and prey composition of quail for vitamins (P_A = 0.473; P_E = 0.189), minerals (P_{Ca} = 0.422; P_{Cu} = 0.791),

TABLE 2. Nutrient composition of rodent diets*

	Rodent Chow	Mouse Chow	Rat Chow	Formulab Chow	NRC (mice)	NRC (rats)
Moisture (%)	8.3	8.6	10.8	8.9	N/A	N/A
Lipid (%)	**2.5**	**5.6**	**2.1**	**2.0**	5	5[a]
	(>4.5)	(>11.0)	(>4.0)	(>6.5)		
Protein (%)	15.0	15.3	15.2	15.2	18	12
	(>23.4)	(>l7.5)	(>22.5)	(>23.5)		
Ash (%)	**11.2**	**6.1**	**7.3**	**7.6**	N/A	N/A
	(<6.9)	(<5.5)	(<6.0)	(<6.8)		
Vitamin A (lU/kg)	**9,100**	**12,300**	**6,767**	**6,133**	500	4,000
	(22,000)	(30,000)	(12,000)	(15,000)		
Vitamin E (lU/kg)	**13.4**	**9.2**	**12.6**	**14.8**	20a	30a
	(49.0)	(35.2)	(32.0)	(55.0)		
Calcium (mg/kg)	**20,531**	**12,188**	**14,827**	**13,762**	400	500
	(9,500)	(8,000)	(10,100)	(10,000)		
Copper (mg/kg)	**24.4**	**15.0**	**13.4**	**13.4**	4.5	5.0
	(18.0)	(19.4)	(20.4)	(16.0)		
Magnesium (mg/kg)	**2,218.8**	**838.8**	**1,136.6**	**1,068.0**	50	40
	(2,100)	(1,600)	(2,000)	(2,000)		
Iron (mg/kg)	**317.5**	**135.4**	**237.4**	**239.6**	25	35
	(198.0)	(145.0)	(188.6)	(200.0)		
Manganese (mg/kg)	**91.3**	**38.0**	**32.4**	**16.3**	45a	50a
	(64.3)	(119.3)	(69.0)	(70.7)		
Zinc (mg/kg)	**194.4**	**123.4**	**105.0**	**99.8**	30	12
	(70.0)	(102.2)	(71.0)	(73.3)		

*All data except moisture content presented on a dry matter basis. Numbers in parentheses are manufacturer's guaranteed analysis [PMI Feeds, Inc., 1995]. Numbers in bold indicate at least a 25% difference in nutrient content among feeds. aIndicates at least one feed below NRC recommended levels for this nutrient [NRC, 1978].

or proximate composition (P_{1lipid} = 0.825; P moist = 0.048).Quail fed Game-bird Starter weighed less (P_{males} = 0.013, $P_{females}$ < 0.001) and were significantly lower in lipid *(P* < 0.001) and vitamin E *(P* = 0.003), and higher in moisture *(P* = 0.001), vitamin A *(P* = 0.025), Ca *(P* = 0.050), and Cu *(P* = 0.019) than birds fed on Turkey Starters. Birds fed unsupplemented Turkey Starter were significantly lower in lipid *(P* < 0.001) and vitamin E *(P* = 0.048), and higher in moisture *(P* = 0.019), Ca *(P* = 0.003), and Cu *(P* = 0.0 17) than birds fed supplemented Turkey Starter (see Table 5). There was no correlation between feed composition and body composition for vitamin A in mice *(P*= 0.869).

When rats and mice were raised on identical diets, mice had significantly higher levels of vitamin A (P_{rodent} = 0.0073, $P_{fomulab}$ = 0.0068), Fe (P_{rodent} = 0.0043, $P_{formu1ab}$ = 0.0001) and Cu ($P_{fomulab}$ = 0.0006) than rats (see Tables 6 and 8).

DISCUSSION
Diet Composition

Our analysis of diet composition is taken from single samples, rather than an average of replicate measures, and therefore must be interpreted with caution. However, several potentially important results warrant discussion. First, we found the nutrient content of commercially available feeds to vary in an unpredictable manner,

TABLE 3. Nutrient composition of guinea pig diets and grain*

	Commercial Guinea Pig Chow	Local guinea pig feed	Grain	NRC (guinea pigs)
Moisture (%)	9.4	8.3	9.8	N/A
Lipid (%)	**2.4** (>4.0)	**1.1** (>2.5)	3.6	1.0
Protein (%)	16.1 (>18.5)	16.5 (>14.0)	15.0	18.0
Ash (%)	8.4 (<8.5)	10.4	4.0	N/A
Vitamin A (lU/kg)	**29,733** (30,000)	**2,633**	167[a]	23,333[a]
Vitamin E (lU/kg)	**15.9** (50.0)	**8.9**	11.6[a]	50[a]
Calcium (mg/kg)	15,124 (11,000)	14,815	4,923	900
Copper (mg/kg)	**14.1** (17.7)	**10.8**	7.1	6.0
Magnesium (mg/kg)	1,757.4 (3,500)	1,419.8	843.6	200.0
Iron (mg/kg)	**290.4** (298)	**1,517.3**	89.3	50.0
Manganese (mg/kg)	**54.7** (76.1)	**80.9**	8.4[a]	40.0
Zinc (mg/kg)	90.4 (69.5)	91.1	73.5	20.0

*All data except moisture content presented on a dry matter basis. Numbers in parentheses are manufacturer's guaranteed analysis IPMI Feeds, Inc., 1995]. Numbers in bold indicate at least a 25% difference in nutrient content among feeds.
[a]Indicates at least one feed below NRC recommended levels for this nutrient [NRC, 1978].

but to generally fall below recommended levels for vitamin A, vitamin E, Mn, and lipid [NRC, 1978, 1984]. These results indicate that without a complete guaranteed analysis, it may be difficult to assess or assume composition or adequacy of commercial feeds. Many feeds come only with a guaranteed analysis for proximate composition because feed composition changes both regionally and from lot to lot depending upon market prices of ingredients. Feeds that come with a complete analysis are often more expensive because they are manufactured in smaller quantities, or because holding composition constant may require the use of more expensive ingredients.

Our results also suggest that even guaranteed analysis of feeds may not always be a reliable indicator of diet quality. Some of the discrepancies between guaranteed and observed nutrient values may be related to storage problems, since some nutrients are labile [Combs,1992]. However, the 50% decrease in vitamin A and 70% decrease in vitamin E that we observed after 3 months of storage at -10°C (assuming feeds originally contained manufacturer's guaranteed levels) is much greater than the expected 24% decrease in vitamin A and 0% decrease in vitamin E at 22°C over 6 months provided by the manufacturer [PMI Feeds, Inc., 1995]. Different methods of vitamin assay could also explain these discrepancies. It should be noted, however, that our observation of lower levels of fat-soluble vitamins is consistent with our observation of lower lipid levels. Our study found lipids to be consistently lower than the

TABLE 4. Nutrient composition of whole male and female quail fed three diets[¥]

	Supplemented Turkey Starter			Unsupplemented Turkey Starter			Gamebird Starter		
	Male	Female	*P**	Male	Female	*P**	Male	Female	*P**
Moisture (%)	61.1 ±1.8	61.5 ±4.0	0.513	65.1 ±3.1	65.7 ±1.8	0.827	71.5 ±1.4	67.8 ±3.9	0.050
Protein (%)	69.9 ±15.6	73.4 ±22.7	0.749	64.9 ±14.6	71.5 ±6.8	0.670	79.5 ±10.2	72.8 ±12.1	0.423
Lipid (%)	51.6 ± 2.1	46.7 ±7.5	0.513	33.2 ±6.3	26.3 ±3.2	0.275	13.6 ±1.5	20.2 ±3.2	0.050
Ash (%)	7.1 ±1.0	6.8 ±1.2	0.827	9.6 ±1.3	12.0 ±1.7	0.127	12.0 ±1.2	12.1 ± 1.3	0.827
Vitamin A (IU/kg)	34,322 ±5,003	39,444 ±3,762	0.275	32,988 ±10,950	66,444 ±30,525	0.127	155,222 ±38,966	93,344 ±75,621	0.275
Vitamin E (IU/kg)	85.4 ±4.8	115.3 ±42.6	0.513	41.6 ±13.3	79.3 ±31.2	0.050	44.3 ±10.3	34.9 ±6.0	0.275
Calcium (mg/kg)	24,364 ±4,162	23,304 ±4,841	0.827	32,685 ±4,178	43,615 ±6,561	0.127	44,120 ±8,984	37,886 ±10,229	0.513
Copper (mg/kg)	2.0 ±0.1	1.8 ±0.2	0.275	2.7 ±0.6	3.0 ±0.7	0.827	3.5 ±0.4	2.9 ±0.7	0.275
Magnesium (mg/kg)	412.5 ±77.5	388.3 ±11.0	0.513	578.6 ±255.2	752.7 ±209.3	0.513	604.3 ±44.2	557.6 ±75.1	0.513
Iron (mg/kg)	51.4 ±2.5	63.4 ±7.9	0.050	85.1 ±27.9	112.4 ±33.9	0.275	87.2 ±5.2	50.1 ±4.5	0.050
Manganese (mg/kg)	3.9 ±0.6	5.1 ±0.9	0.127	6.6 ±2.1	8.4 ±4.3	0.513	7.1 ±0.9	7.5 ±2.7	0.827
Zinc (mg/kg)	38.3 ±7.4	44.5 ±7.0	0.513	55.0 ±9.1	54.3 ±26.7	0.827	72.3 ±3.4	53.7 ±14.7	0.050

[¥]All data except moisture content presented on a dry matter basis. Values are means ± one standard deviation.
*Unadjusted *P* values. No comparisons significant following correction for multiple comparisons.

manufacturer's guaranteed analysis, using the same assay (ether extract). These results suggest that what is added to the feed during manufacturing is not necessarily what is ultimately available for consumption. This is more likely to be a problem with feeds that are manufactured or purchased in large quantities.

It is also notable that the most expensive feeds are not necessarily the highest in nutrient content. Gamebird Starter, which is more expensive than the unsupplemented Turkey Starter, has more protein, but less (and less than recommended) vitamin A, vitamin E, and Mn. Mouse Chow, which is relatively expensive, has higher (and higher than recommended) vitamin A than the other mammal feeds, but less (inadequate) vitamin E and less (but adequate) Fe.

Mixed grains were added to the diet of rats and mice because we hypothesized that supplementation with a whole, natural, food might improve nutrition. With the exception of moderate (but inadequate) amounts of vitamin E and moderate (adequate) amounts of Zn, grain had a relatively low nutrient content. If rats and mice preferentially consume grain, and they appear to do so, supplementation with grain could actually reduce overall diet quality. Preferential consumption of relatively poor-quality whole foods has been documented anecdotally for a number of species in zoos.

TABLE 5. Nutrient composition of whole quail fed three diets*

	Supplemented Turkey Starter	Unsupplemented Turkey Starter	Gamebird Starter	P
Moisture (%)	61.2 ± 2.8	65.4 ± 2.3	69.6 ± 3.3	0.00050[a]
Lipid (%)	49.2 ± *5.6*	29.7 ± 5.9	16.9 ± 4.2	0.00001[a]
Protein (%)	71.7 ± 17.5	67.6 ± 11.4	75.2 ± 10.2	0.663
Ash (%)	7.0 ± 1.0	10.8 ± 1.9	12.0 ± 1.1	0.00001[a]
Vitamin A (lU/kg)	36,883 ± 4,853	49,717 ± 27,504	124,283 ± 63 578	0.00372[a]
Vitamin E (lU/kg)	100.3 ± 31.7	60.4 ± 29.8	39.6 ± 9.1	0.00313[a]
Calcium (mg/kg)	23 835 ± 4,103	38,151± 7,748	41,003 ± 9,263	0.00229[a]
Copper (mg/kg)	1.9 ± 0.2	2.8 ± 0.7	3.2 ± 0.6	0.00213[a]
Magnesium (mg/kg)	400.4 ± 51.3	665.6 ± 229.5	580.9 ± 60.8	0.01526
Iron (mg/kg)	57.4 ± 8.	4 98.7 ± 31.6	68.6 ± 20.7	0.01624
Manganese (mg/kg)	4.5 ± 0.9	7.5 ± 3.2	7.3 ± 1.8	0.05806
Zinc (mg/kg)	41.4 ± 7.3	54.7 ± 17.8	63.0 ± 13.9	0.04673

*A1l data except moisture content are presented on a dry matter basis. Values are mean ± one standard deviation.
[a]Indicates significant differences between treatments following correction for multiple comparisons.

TABLE 6. Nutrient composition of whole rats red four diets[¥]

	Rodent Chow	Rat Chow	Formulab Chow	Formulab Chow w/grain	*P**
Moisture (%)	66.2 ±1.0	62.7 ±2.6	64.3 ±2.4	65.3 ±1.6	0.054
Lipid (%)	34.9 ±3.5	48.0 ±8.5	34.9 ±5.2	34.4 ±9.1	0.041
Protein (%)	78.6 ±3.5	59.4 ±17.9	63.4 ±14.3	62.4 ±23.5	0.751
Ash (%)	8.5 ±2.0	6.1 ±0.9	7.5 ±2.1	6.9 ±1.5	0.411
Vitamin A (lU/kg)	49,256 ±26,906	34,922 ±21,456	68,244 ±23,220	154,756 ±234,464	0.626
Vitamin E (lU/kg)	73.0 ±41.4	130.4 ±13.4	210.5 ±68.7	147.4 ±45.7	0.041
Calcium (mg/kg)	31,270 ±6 980	27,330 ±9,790	22,856 ±4,636	24,597 ±4,357	0.495
Copper (mg/kg)	1.8 ±0.4	1.6 ±0.1	1.3 ±0.4	1.8 ±0.5	0.433
Magnesium (mg/kg)	401.7 ±104.7	298.1 ±64.1	247.3 ±134.9	364.9 ±92.9	0.310
Iron (mg/kg)	57.9 ±6.7	36.1 ±13.7	43.0 ±3.9	50.4 ±12.3	0.122
Manganese (mg/kg)	3.1 ±0.3	1.2 ±0.6	2.9 ±0.9	1.9 ±1.2	0.310
Zinc (mg/kg)	38.6 ±15.2	18.2 ±2.1	35.0 ±10.0	29.5 ±4.8	0.120

[¥]All data except moisture content are presented on a dry matter basis. Values are means ± one standard deviation.
*Unadjusted *P* values. No comparisons significant following correction for multiple comparisons.

In this study, we found diet composition to have very little relation to body composition

TABLE 7. Nutrient composition of whole mice fed four diets*

Mouse Formulab Formulab Chow Rodent Chow Chow Chow w/grain *P*					
Moisture (%)	69.0	67.7	66.9	65.2	0.098
	±2.0	±1.4	±2.6	±3.7	
Lipid	16.9	24.0	23.7	28.0	0.121
(%)	±6.1	±5.4	±8.8	±10.6	
Protein	66.8	72.8	64.4	49.3	0.738
(%)	±15.4	±34.0	±20.8	±15.3	
Ash	12.5	10.0	9.2	9.8	0.335
(%)	±0.8	±1.1	±l.6	±3.8	
Vitamin A	1,759,122	917,644	657,344	448,067	0.003a
(lU/kg)	±315,279	±394,086	±196 887	±196,854	
Vitamin E	88.0	60.8	74.4	68.4	0.361
(lU/kg)	±26.4	±11.2	±18.2	±11.8	
Calcium	45,277	34,494	32,076	35,435	0.422
(mg/kg)	±3,020	±5682	±6,185	±17,511	
Copper	3.9	3.9	3.9	5.1	0.483
(mg/kg)	±0.8	±0.8	±0.2	±1.9	
Magnesium	622.9	438.6	431.9	474.8	0.140
(mg/kg)	±49.8	±20.6	±54.2	±183.1	
Iron	124.4	104.0	76.4	100.7	0.042
(mg/kg)	±18.6	±4.0	±0.4	±26.4	
Manganese	6.2	5.3	5.3	4.5	0.678
(mg/kg)	±1.7	±1.8	±1.7	±1.6	
Zinc	59.4	53.5	44.0	58.2	0.224
(mg/kg)	±6.7	±8.7	±5.7	±13.1	

*All data except moisture content presented on a dry matter basis. Values are means ± one standard deviation.
[a]Indicates significant difference between treatments following correction for multiple comparisons.

in all four species. There were, however, significant differences in most nutrients between treatment groups in quail, where the only treatment difference was diet. This may be because different diets resulted in different body size at 6 weeks of age (the age of sampling). Although birds on different diets began at the same weight and ultimately achieve the same weight (Clum et al., unpublished observations), overall birds fed supplemented Turkey Starter grew fastest and birds on Gamebird Starter grew slowest. Growth rate is typically defined as the slope of the line at the inflection point of the growth curve [Ricklefs, 1968]. However, these birds were not sampled at the inflection point (the point of maximum growth) but at a point when the birds fed Turkey Starter were becoming reproductively mature (as evidenced by egg production in a portion of the population) and the birds fed Gamebird Starter were not yet mature. At the time of sampling, therefore, birds on Gamebird Starter probably maintained a higher growth rate than birds fed Turkey Starter. Preliminary data from another portion of this study have shown that both male and female quail have much higher nutrient content at 2 weeks of age than at 6 weeks of age (Clum et al., unpublished observations). Although there were no sex differences in nutrient content at 2 weeks (Clum et al., unpublished observations) or at 6 weeks (this study), at 16 weeks of age nutrient content of females that were mobilizing resources for reproduction had almost doubled, whereas nutrient content of males remained unchanged (Clum et al., unpublished observations). These results suggest that nutrient content may be linked to nutrient demand. Since growth is the predominant factor affecting

Effects of Diet on Nutritional Content of Whole Vertebrate Prey. N.J. Clum, M.P. Fitzpatrick and E.S. Dierenfeld. *Zoo Biology*.

TABLE 8. Nutrient composition of whole guinea pigs fed two diets[¥]

	Commercial Guinea Pig Chow	Local guinea pig chow	P^*
Moisture (%)	69.3 ± 1.8	68.2 ± 0.9	0.513
Lipid (%)	45.4 ± 11.0	46.8 ± 2.0	0.050
Protein (%)	58.9 ± 14.9	43.8 ± 5.5	0.127
Ash (%)	8.9 ± 0.6	9.5 ± 1.3	0.448
Vitamin A (lU/kg)	19,989 ± 3,000	13,022 ± 2,647	0.050
Vitamin E (lU/kg)	29.8 ± 0.9 18.	5 ± 3.2	0.050
Calcium (mg/kg)	29 459 ± 4 428	30 926 ± 4,924	0.827
Copper (mg/kg)	6.1 ± 4.2	5.1 ± 1.4	0.827
Magnesium (mg/kg)	637.3 ± 39.6	672.8 ± 147.6	0.827
Iron (mg/kg)	51.9 ± 6.8	60.9 ± 0.9	0.050
Manganese (mg/kg)	6.6 ± 0.5	6.5 ± 0.8	0.827
Zinc (mg/kg)	64.4 ± 23.7	28.4 ± 12.9	0.050

[¥]AlI data except moisture content presented on a dry matter basis. Values are means ± one standard deviation.
*Unadjusted *P* values. No comparisons significant following correction for multiple comparisons.

metabolism prior to maturation, we might expect nutrient content to be proportional to growth rate. This suggestion is supported by data on proximate composition that show birds on Gamebird Starter to have the highest moisture and lowest lipid content, and birds on supplemented Turkey Starter to have lowest moisture and highest lipid content. Higher moisture content is an indication of tissue immaturity in birds and is associated with faster growth [Ricklefs, 1979], while lipid content is an indication of food consumption exceeding nutrient demand, and increases as growth decreases [O'Connor, 1977]. The limited data available on age-related changes in nutrient content indicate that differences in body composition associated with age/size can be substantial (variation of 200 - 400%; (Clum et al., unpublished observations) [Douglas et al., 1994; Dierenfeld et al., 1995], and could obscure diet differences unless the magnitude of diet differences is quite large. Vitamin E, which showed the greatest variation between diets in this study (over 500%), was the one nutrient that was highest in birds fed supplemented Turkey Starter and lowest in birds fed Gamebird Starter. These results suggest that feeds designed for maximum growth may produce the maximal nutrient content in whole prey, *but only jf the animals are harvested during the period of maximal growth.*

Mammals showed very little difference between treatment groups compared with quail. This could be related to the fact that, unlike quail, whose nutrient content appears to be related to growth, the mammals in this study were fully mature and there were no differences in body size (or growth) between treatments at the time of sampling. It is also possible that there may simply be species differences in response to diet changes. Such differences were evident from the difference in nutrient content between mice and rats when raised on the exact same diet. Mice were generally higher in vitamin A and mineral content and lower in vitamin E than rats. Species differences in nutrient content have been noted in other studies [Bird and Ho, 1976; Douglas et al., 1994; Clum et al., 1995; Dierenfeld et al., 1995] although comparisons are not usually controlled for diet. The absence of treatment effect in mammals may also be related to the magnitude of nutrient differences in the diet; vitamin content, for example, was relatively consistent across mammal feeds. Mineral content was more variable (typically 200 - 250%), but even higher levels may be required in the diet to produce a detectable difference in body composition. The form (synthetic vs. natural) of nutrients in the diet may also influence the level of response to changes in diet composition. Synthetic vitamin E, for example, is known to have a lower biological activity than the natural form [Ochoa et al., 1992], but the synthesized form is much less expensive and therefore more frequently used as a supplement. This is not necessarily a

problem if biological activity is taken into consideration when formulating diets. Reduced bioavailability may be more problematic for minerals because, unlike synthetic vitamins, which have the same chemical structure as natural forms, supplemented minerals are in a completely different form (generally oxides and sulfates) than minerals occurring in whole foods (which are often chelated to amino acids) [Manspeaker et al., 1987]. Reduced bioavailability of synthetic vitamins and minerals may require higher dietary levels to effect changes in body composition.

All prey analyzed in this study would meet known requirements of domestic mammalian carnivores for vitamin A, Ca, Mg, and Fe (vitamin A, 2,440 - 10,000 IIJ/kg; Ca, 0.4 - 1.2%; Mg, 0.04 - 0.1%; Fe, 60 - 100 mg/kg) [NRC, 1985, 1986; Robbins, 1983]. Although all but one treatment (guinea pigs fed locally manufactured feed) met recommended levels of vitamin E for mammalian carnivores (20—80 lU/kg) [NRC, 1982, 1985, 1986], it has been suggested that raptors may require up to 10 times more vitamin E to protect against deficiencies [Dierenfeld et al., 1989; Calle et al., 1989]. In contrast to data reported by Dierenfeld et al. [1995], who found Cu and Zn to be present in adequate amounts, we found Cu to fall below recommended levels (5.0—7.3 mg/kg) [NRC, 1985, 1986] in all quail treatments, all rat treatments, and all but one mouse treatment. Bird and Ho [1976] also found relatively low levels of Cu in rats and chickens (4.5 mg/kg), but not in mice (8.0 mg/kg). Zn fell below recommended levels for mammalian carnivores (30—50 mg/kg) [NRC, 1985, 1986] in one rat treatment and one guinea pig treatment. Mn levels were consistently lower than recommended levels in adult rats (5—10 mg/kg) [NRC, 1985, 1986], but were adequate, if low, in quail, mice, and guinea pigs. Mn levels have previously been found to be inadequate only in juvenile rodents [Dierenfeld et al., 1995].

CONCLUSIONS

1. It is difficult to assume or assess composition or adequacy of commercial diets without laboratory analysis.
2. Supplementation of diets with whole foods may potentially reduce overall diet quality.
3. Nutrient differences in quail were related to differences in growth, and such age-related differences may be more important in determining nutrient content than diet.
4. There were significant species differences in responsiveness to changes in diet.
5. Whole domesticated prey are a potentially inadequate source of vitamin E for raptors and of Mn and Cu for all carnivores.

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