Comparative Diet Analysis Of Fish Species Commonly Consumed By Managed And Free-Ranging Bottlenose Dolphins (Tursiops Truncatus)

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Citation

K A Slifka, R S Wells, A J Ardente, S Crissey (deceased, November 23, 2002). *Comparative Diet Analysis Of Fish Species Commonly Consumed By Managed And Free-Ranging Bottlenose Dolphins (Tursiops Truncatus)* . The Internet Journal of Veterinary Medicine. 2013 Volume 10 Number 1.

Abstract

Managed bottlenose dolphins (Tursiops truncatus) cared for by the Chicago Zoological Society's Brookfield Zoo Seven Seas exhibit in Brookfield, Illinois, are fed primarily whole boney fish, a diet similar to that of free-ranging dolphins. However, the diets of the two dolphin populations differ in that managed dolphins are fed primarily frozen, stored, and thawed Canadian capelin (Mallotus villosus) and Atlantic herring (Clupea harengus) and free-ranging dolphins commonly consume a wide variety of live fish. Dolphins in Sarasota Bay, Florida, a coastal region where the Brookfield Zoo dolphins originated from, feed on numerous fish species, including pinfish (Lagodon rhomboides), pigfish (Orthopristis chrysoptera), toad fish (Opsanus beta) and striped mullet (Mugil cephalus), among many others. Considering that the nutrient composition of fish differs with species, marine location, season, and storage and handling methods, this is the first preliminary comparative analysis identifying nutrient variations in the fish commonly fed to one population of managed dolphins versus those consumed by a comparable population of free-ranging dolphins in one region of the world. The study results confirm differences particularly in dry matter content (range 19% capelin to 34% mullet), crude protein (range 53% pinfish to 69% capelin) , crude fat (range 11% pigfish to 22% herring), and individual minerals, across fish species. Future research is necessary to assess dolphin health in relation to diet nutrient composition by comparing clinical findings in either managed or free-ranging dolphins to the results of this diet analysis study.

INTRODUCTION

The diet fed to managed bottlenose dolphins (Tursiops truncatus) across facilities is similar to the diet consumed by free-ranging dolphins in that it is composed primarily of whole fish, but the diets differ in the species of fish consumed. Managed bottlenose dolphins cared for by the Chicago Zoological Society's Brookfield Zoo Seven Seas exhibit in Brookfield, Illinois, are fed primarily Atlantic herring (Clupea harengus) and Canadian capelin (Mallotus villosus) which are commercially caught in the northern Atlantic and Arctic waters bordering the coastlines of eastern Canada, Newfoundland, and the northwestern United States [1]. The Brookfield Zoo dolphins originate from the temperate and subtropical coastal and estuarine waters of the southeastern United States. The free-ranging dolphins in this region had historically been considered opportunistic feeders consuming a varied diet; however, more recent research involving dolphins in Sarasota Bay, FL, suggests that dolphins may preferentially select their prey, especially targeting soniferous fish [2,3]. In Sarasota Bay, a wide variety of fish, including pinfish (Lagodon rhomboides), pigfish (Orthopristis chrysoptera), toadfish (Opsanus beta), and striped mullet (Mugil cephalus), among many others, have been identified as common dolphin prey species [4]. The United States Department of Agriculture (USDA) reports the nutrient composition of primarily filleted fish prepared for human consumption, however nutrient data are limited for whole fish as consumed by dolphins. Additionally, nutrients have been demonstrated to vary both between fish species and within the same species depending upon location, sex, age, and season [5]. Thus, the goal of this study was to compare the nutrient composition of whole, bone-in fish fed to the Brookfield Zoo managed dolphins, herring and capelin, and readily available prey of a comparable population of free-ranging dolphins, including pinfish, pigfish, and mullet, to identify differences that may influence the health of managed bottlenose dolphins.

METHODS

To best represent the managed dolphin diet, a total of approximately 50 capelin (or 2 kg by weight) and 50 herring (or 2 kg by weight) were obtained as frozen stored samples from the Brookfield Zoo (Brookfield, IL) and Dolphin Connection (Hawk's Key, FL). Fish from each species were obtained from one lot and one vendor, with capelin caught in July off the Canadian and Newfoundland coasts and herring caught in the northwest Atlantic Ocean in January [1,6]. Ten live fish of each species, pinfish, pigfish, and striped mullet, were collected in June from Sarasota Bay, FL, representing the free-ranging dolphin diet. The fish were caught using a cast net by Mote Marine Laboratory, Sarasota, FL. The size of fish collected varied depending on the species: 77-140mm for pinfish, 69-168mm for pigfish and 164-285mm for mullet. All fish from each species were combined, bagged in Ziploc 1.75mm thick plastic storage bags, and stored frozen at -80□C. Analyses on pinfish, pigfish, and mullet were performed within 6 months of the catch date.

At the Brookfield Zoo Nutrition Laboratory (Brookfield, IL), each species was removed from frozen storage and pureed with liquid nitrogen in a 4L stainless steel laboratory blender (Waring Laboratory Science, Stamford, CT) to a fine powder. With one homogenized sample per fish species, samples were then dried at 60□C using a forced draft oven. Crude protein was determined using the Kjeldahl method, measuring nitrogen content then multiplied by 6.25 to quantify crude protein [7]. Crude fat was determined by Soxhlet ether extraction, and energy content by bomb calorimeter (Isoperibol Bomb Calorimeter, Parr Instrument Co., Moline, IL) [7]. Vitamin D, cholesterol and fatty acid analyses of fish were performed by Covance Laboratories (Madison, WI). Vitamin D was determined by high-pressure liquid chromatography (HPLC) using AOAC method 45.1.22, modified [7]. Total cholesterol was analyzed after saponification using gas chromatography according to AOAC method 994.10 [7]. Fatty acids were quantified by gas chromatography [8]. At the University of Illinois Laboratories of Veterinary Diagnostic Medicine (Urbana, IL), mineral analyses were performed using inductively coupled argon plasma (ICP) emission spectrophotometry (Iris AP ICP instrument, Thermo-Jarrell Ash, Inc.; Franklin, MA). Minerals included calcium, iron, magnesium, phosphorus, potassium, sodium, sulfur, and zinc. Analyses for vitamin A (retinol), vitamin E (□- and □-tocopherol), and carotenoids (lutein, zeaxanthin, □-cryptoxanthin, □-cryptoxanthin, and □-carotene) were conducted by HPLC at University of Illinois at Chicago, Department of Human Nutrition and Dietetics (Chicago, IL) according to the method described by Schreiner et al. [9].

RESULTS AND DISCUSSION

Results from the proximate analysis, vitamins, carotenoids, cholesterol, fatty acids, and mineral analyses performed on the managed diet capelin and herring and the free-ranging diet pinfish, pigfish, and mullet are reported in Table 1. This study provides the first published information comparing the nutritional composition of fish species commonly consumed by free-ranging and managed bottlenose dolphins. The proximate analyses revealed differences in the dry matter, crude protein (CP), and crude fat (CF) contents provided per unit measure, across fish species. A comparison of the fish fed to managed dolphins revealed that capelin had higher crude protein then herring, and herring had higher dry matter content and approximately twice the crude fat content of capelin. Of the three representative fish species consumed by free-ranging dolphins, pigfish was highest in crude protein and lowest in dry matter and fat content, while the dry matter, protein, and fat contents of the pinfish and mullet were very similar. Overall capelin and pigfish were similar in their proximate analysis profiles, whereas herring, pinfish, and mullet were more similar when comparing results across fish species from both diets. The results of this study suggest that a combination of capelin and herring fed to managed dolphins may provide balanced water, protein, and fat content, but whether a balance is achieved would depend upon the ratio of species fed. Ideally the managed diet would be balanced by emulating the nutrient profile of the free-ranging dolphin diet. To determine an overall free-ranging diet nutrient composition, future research should include analysis of additional fish species to better represent the variety of fish consumed and additional samples of all species analyzed, permitting statistical analysis of nutrient differences.

The dolphins' requirement for essential fatty acids has not been quantified, and data regarding fatty acid composition of the whole fish consumed by dolphins are limited. Cholesterol and fatty acid contents of fish reported in the literature involve filleted fish, so comparisons cannot be effectively made between the data gathered in this study and that which has been previously published (Lie 1994). Of the fish analyzed, capelin had the highest cholesterol content overall, which was twice that of the cholesterol levels in herring, pinfish, pigfish, and mullet. Among the total lipids analyzed, pinfish had the highest total saturated and polyunsaturated fat contents, but otherwise across species total lipids varied little. Capelin and herring had greater concentrations of individual fatty acids myristic (14:0), eicosanoic (20:1), linoleic (18:2), and docosahexaenoic

(22:6) acids and greater total omega-3 fatty acids, including eicosapentaenoic (20:5, EPA), docosapentaenoic (22:5, DPA), and docosahexaenoic (22:6, DHA), when compared with the free-ranging fish species. Cold water fish species are known to have high levels of omega-3 fatty acids, so the fatty acid composition of capelin and herring is expected when compared with the warm water fish species consumed by free-ranging dolphins [10,11]. The results of this study suggest that the managed dolphin diet would provide similar health benefits to dolphins, including anti-inflammatory effects and immune system regulation, as seen in other mammals consuming diets high in omega-3 fatty acids [12]. A comparative investigation of the white blood cell profiles, circulating immune system biomarkers, and circulating inflammatory cytokines of managed dolphins consuming a capelin and herring based diet and of free-ranging dolphins in Sarasota Bay, FL, should be performed to document if dolphins benefit from a diet high in omega-3 fatty acids.

Additionally, little is known about the vitamin profile of the dolphin diet or the vitamin requirements of dolphins. Of the vitamins analyzed in the fish fed to managed dolphins and those species consumed by free-ranging dolphins, the greatest difference identified was in vitamin D concentrations. Capelin had a lower concentration of vitamin D than all other fish species analyzed. Vitamin D is known to vary considerably among fish species, and it is not well understood if fish are able to synthesize vitamin D or if the vitamin is obtained solely from dietary absorption. Generally tissue vitamin D levels correlate with tissue fat concentration; therefore, with capelin's low fat content, it would be sensible that capelin would have a lower concentration of vitamin D than herring [13,14,15]. However, pigfish contradict this theory, with a similar fat content to capelin but vitamin D concentration that is 26 times greater than capelin. Again because little is known regarding vitamin D physiology in fish, there is much room for interpretation, and additional research should be directed at describing species variations particularly in light of the fishes' location, water environment, and natural diet. To determine if dietary vitamin D intake has clinical relevance, trends in vitamin D blood concentrations in free-ranging and managed dolphins should be monitored and compared with concentrations found in the respective diets and considered in light of animal health long-term, as immediate effects of dietary discrepancies may not be obvious [6].

Of the other vitamins analyzed, -tocopherol was not detected in the free-ranging fish species, but it was present in the capelin and herring consumed by managed dolphins. Gamma-tocopherol, one of the biologically active components making up vitamin E, is a potent antioxidant found primarily in plant matter and in foods high in linoleic acid [16,17,18]. The finding of -tocopherol in the capelin and herring may represent a difference in the fishes' natural diet in northern cold waters when compared to the temperate water free-ranging species. Additionally the carotenoids -carotene, lutein, and zeaxanthin were greater in concentration in the free-ranging fish species when compared with capelin and herring. Diet highly influences tocopherol and carotenoid levels so the discrepancy identified in the free-ranging fish species versus the fish fed to managed dolphins would be further explained by investigating the fishes' natural diets. Additionally, further research directed at monitoring dolphins for on-going disease processes and blood markers of immune system regulation may reveal if the tocopherols and carotenoids differences have clinical significance.

Mineral analysis revealed differences between the group of fish fed to managed dolphins when compared with fish consumed by free-ranging dolphins; however, within each diet group the fish species had similar mineral profiles. Calcium concentrations were higher in pinfish, pigfish, and mullet, and potassium, sodium, and zinc levels were all greater in capelin and herring. Concerning the micro-minerals, iron concentration was greater in the free-ranging fish species than managed species. This is an important finding because iron overload disease has been reported in managed dolphins, so with this preliminary information, it is less likely that the diet fed to managed dolphins is the primary underlying cause of the disease in managed populations[19]. Dietary mineral differences can have significant impacts on animal health, so expanding the analysis to include additional samples from each fish species would permit statistical analysis of results, identifying significance of discrepancies between fish species. Differences in the fishes' water environment, natural diets, body sizes and relative bone densities can impact mineral concentrations and warrant further investigation. Additionally, the processing methods of fish fed to managed dolphins, including frozen storage and thawing practices that tend to vary depending upon fish distributor and dolphin management facility, may influence fish tissue mineral concentrations and should be evaluated. Free-ranging and managed dolphins consuming these studied diets should have blood mineral profiles monitored over time to determine clinical relevance of diet mineral differences.

This preliminary study provides baseline information on the nutrient profile of fish fed to managed dolphins at the Brookfield Zoo and of fish commonly consumed by dolphins in Sarasota Bay, FL. The Brookfield Zoo dolphins originate from the coastal and estuarine waters of the southeastern United States, and as such, this population of animals is comparable to the Sarasota Bay dolphins. It is important to note that this diet comparison is not valid for all bottlenose dolphins because free-ranging T. truncatus occupies a wide range of temperate and subtropical waters worldwide and managed dolphins may be fed different fish species depending upon facility. While discrepancies in this diet analysis were seemingly minimal overall, specific nutrient differences including dry matter, crude protein, and mineral concentrations may have an impact on dolphin health. Future investigation should expand upon this diet analysis by increasing the sample size for each species analyzed to permit statistical analysis of results. Additional known free-ranging fish species could also be analyzed to develop a more holistic view of the varied free-ranging dolphin diet and to provide potential alternative fish as options to vary the diet of managed dolphins. However, providing variety is generally not the focus in feeding managed dolphins, and often the dolphins are fed based on the total weight of fish to be consumed daily. Therefore, the daily diet nutrient profile will differ depending on the proportions of fish species fed. The extent to which fish proportions impact the total daily nutrient composition for a given managed dolphin diet should be examined [3,20]. In addition, the nutrient composition of fish can alter secondary to season, natural diet of the fish, water environment or regional location, so investigating these factors will help describe natural variations expected in both the fish free-ranging and managed dolphin diets [21,22,23]. Once a more complete diet analysis is performed, the clinical relevance of identified nutrient differences should then be explored by monitoring animals' health over time on a specific known diet. In the management of any species, it is important to have a solid understanding of the animals' natural history and ecology, including the diet, to ensure that managed animals are provided with an environment that optimizes animal health.

Table 1a

Nutrient composition (DMB1) of fish species consumed by managed and free-ranging dolphins2

	Captive food items		Free-ranging food items		
Nutrient	Capelin	Herring	Pinfish	Pigfish	Mullet
Dry Matter, %	19.14	25.79	32.35	24.39	35.52
Crude Protein, %	69.93	62.79	53.92	62.82	56.61
Crude Fat, %	12.12	22.21	20.9	11.06	14.9
Vitamin D, IU/100g	99	1257	1600	2628	1286
Cholesterol, mg/100g	893	477	494	677	390
Retinol, µg/100g	742.8	285.2	360.3	1115.2	768.7
γ-Tocopherol, µg/100g	66.15	39.2	ND	ND	ND
α-Tocopherol, µg/100g	752.8	251	781.4	632.7	750.4
Lutein+Zeaxanthin, µg/100g	92.9	19.8	241.3	1266.5	200.5
α-Cryptoxanthin, µg/100g	ND	ND	ND	100.9	ND
β-Cryptoxanthin, µg/100g	43.3	ND	9.3	76.7	ND
β-Carotene, µg/100g	6.26	ND	33.37	107.8	53.11
Saturated fatty acids, g/100g					
Capric 10:0	0.05	0.04	0.03	0.04	0.03
Myristic 14:0	1.25	1.75	0.62	0.41	0.95
Pentadecanoic 15:0	<.05	0.08	0.37	0.16	0.92
Palmitic 16:0	1.88	2.76	3.74	2.13	2.61
Stearic 18:0	0.26	0.31	1.58	0.9	0.61
Monounsaturated fatty acids, g/100g					
Palmitoleic 16:1	1.78	1.13	1.3	0.62	1.66
Heptadecaenoic 17:1	0.05	0.04	0.31	0.21	0.21
Oleic 18:1	1.62	2.37	3.43	2.34	0.71
Eicosenoic 20:1	3.29	2.68	0.38	0.04	0.18

Table 1b

Nutrient composition (DMB1) of fish species consumed by managed and free-ranging dolphins2

Polyunsaturated fatty acids, g/100g					
Linoleic 18:2	0.26	0.31	0.15	0.08	0.15
Linolenic 18:3	<.05	0.16	0.12	0.04	0.15
Octadecatetraenoic 18:4	0.1	0.31	0.09	0.04	0.25
Arachidonic 20:4	0.05	0.08	0.56	0.45	0.38
Eicosapentaenoic 20:5	0.94	0.74	1.24	0.82	1.17
Docosapentaenoic 22:5	0.157	0.16	ND	ND	ND
Docosahexaenoic 22:6	1.2	1.21	0.9	0.62	0.46
Saturated fat, g/100g	3.24	4.3	6.49	3.65	5.07
Polyunsaturated fat, g/100g	2.45	2.91	3.77	2.38	3.01
Minerals, ppm					
Calcium	15879	15095	38996	48626	33991
Iron	53	76	101	90	135
Magnesium	887	1159	619	1034	815
Phosphorus	18873	15834	24206	33460	24416
Potassium	17408	13074	5738	9723	7726
Sodium	7412	12111	1571	4494	2108
Sulfur	11038	10133	8598	11505	8297
Zinc	78	78	51	53	62

[1] DMB = dry matter basis
[2] Nutrient concentrations reported represent a single analysis of each species.
ND = not detected

ACKNOWLEDGMENTS

We sincerely thank the Mote Marine Laboratory in Sarasota, FL, for their assistance in the procurement of fish for analysis. We also would like to thank the laboratories that performed the analyses and assisted with interpretation of results including: Drs. Phyllis Bowen and Maria Sapuntzakis at University of Illinois at Chicago, Dr. Gavin Meerdink and the staff of the Veterinary Diagnostic Medicine Laboratory at University of Illinois at Urbana.

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