INVESTIGATIONS INTO THE NUTRITIONAL COMPOSITION OF MOON JELLYFISH, AURELIA AURITA

Marnie Rackmil, BA, 1,2,3* Amy Messbauer, BS, 2 Michael Morgano BS, 2 David Denardo, BS, 2 Ellen S. Dierenfeld, PhD 4

1 Columbia University, Center for Environmental Research and Conservation, Columbia University, New York, NY; 2 New York Aquarium, Brooklyn, NY; 3 Current affiliation: Columbia University, Division of Preventive Medicine and Nutrition; 4 Current affiliation: St. Louis Zoo, St Louis, MO

Abstract

Proximate nutrients, fat-soluble vitamins A and E, and mineral composition of the moon jellyfish, Aurelia aurita, were measured in wild specimens from Jamaica Bay, NY, and in captive cultured specimens from the New York Aquarium (reported as mean ± SE). Crude protein content of free-ranging jellyfish was approximately twice that seen in captive animals (9.20% ± 0.40% dry matter (DM) versus 4.95% ± 0.20%); conversely, fat content of cultured jellyfish was about twice that of wild animals (5.16% ± 1.00% and 2.05% ± 0.37% DM, respectively). The cultured A. aurita in this study had higher fat levels than any other reported to date in the literature for this species. Wild A. aurita contained significantly less vitamin E than did cultured counterparts (9.8 ± 4.8 IU/kg vs. 51.4 ± 16.5 IU/kg DM), likely a function of captive dietary enrichment. Mineral composition also varied widely between wild and captive jellyfish. Wild A. aurita contained 1420 ± 160 mg/kg phosphorus (P), 55.3 ± 3.1 mg/kg iron (Fe), and 17.9 ± 0.1 mg/kg zinc (Zn), whereas captive cultured A. aurita contained 2870 ± 80 mg/kg P, 119 ± 2 mg/kg Fe, and 72.8 ± 2.5 mg/kg Zn. Physical differences between wild and captive specimens were also found. In order to assist in understanding possible links to differences in body composition, proximate nutrients and mineral concentrations in the captive diet were also analyzed and are reported. Information obtained from this study may assist in development of more effective dietary husbandry guidelines for captive jellyfish. Additionally, nutrient/mineral composition of jellyfish and other coelenterates may be a useful indicator of water quality and habitat suitability, as well as useful in applied feeding management of sea turtles, for which jellyfish are a primary food source.

Introduction

Since the first applications of zoo nutrition, the field has focused extensively on mammal, avian, and piscine species. Less work, however, has been done on the nutritional needs of invertebrate species held in zoos and aquaria. It is therefore crucial that the nutritional needs of invertebrates be investigated.

Aurelia aurita, the moon jellyfish, is one such organism that is commonly housed in aquaria, and for which nutritional data remain sparse. Several marine biologists, including Lucas, 19 Anninskiy, 2 and Larson 16 have studied the proximate composition of A. aurita. Fukuda and Naganuma 9 investigated fatty acid composition and Lane et al., 18 Shick 22 and others studied amino acid concentrations. Spangenberg 26 and Lucas 18 have observed A. aurita growth under
controlled conditions. However, while *Aurelia sp.* is one of the most commonly studied scyphozoans, as seen in Arai, in comparison with mammals, information regarding the nutritional needs and composition of *Aurelia sp.* is still somewhat lacking.

Dawson and Jacobs report that *A. aurita* is the scyphozoan most commonly housed in aquaria. The frequency with which *Aurelia sp.* is held in captivity is likely due to a number of factors, including a large range and the fact that they are a cold water, nonzooxanthellated species. *A. aurita* has been found to inhabit coastal waters from 50°N to 50°S, with various sub- or sibling species likely throughout the region. The species or subspecies of *A. aurita* described by Dawson and Jacobs as occurring in the Northeast Atlantic, including the species studied in this investigation, has also been found by Schroth et al. off the coast of Norway, Iceland, England, and Germany, as well as in the Black Sea. Sibling species can be found throughout various other waters.

As a scyphozoan, *Aurelia sp.* exhibits a biphasic life cycle containing both polyp and medusae stages. While the polyp stage is clearly important in culturing the species, it will not be discussed in this paper. This paper discusses only the medusae, a bell-shaped form containing epidermis, gastrodermis, and relatively thick mesoglea. Immediately prior to the medusa stage, *A. aurita* may be considered to be in the ephyra stage, which is an intermediate between the two forms (or possibly simply a small medusa). In various cnidarians the mesoglea has been found to contain a protein matrix that serves a major role in muscle contraction.

Based upon analyses of gut contents, *A. aurita* medusae have been determined to be opportunistic zooplankton feeders. Various studies suggest that feeding occurs primarily on copepods, with fish larvae, barnacle larvae, and a variety of microorganisms as other food sources. Prey selection appears to be related to medusa size, with umbrella diameter positively correlated to the number of prey and number of types of prey found in the gut. The diet of any organism provides energy as well as some of the molecules used in order to survive, and the proximate composition of an organism is thus closely related to its diet. In this respect, *Aurelia sp.* appears to be no different from any other animal. Fukuda and Naganuma report that the fatty acid composition of *A. aurita* clearly reflects its diet.

Past investigations have examined the chemical and nutritional composition of *A. aurita*, yet these relationships need to be further investigated. The goal of this project was to examine and compare the nutrient composition of wild and captive New York Aquarium (NYA)-cultured *Aurelia aurita*. Many aquaria follow the same general procedure in terms of feeding and housing their jellyfish specimens, and thus the outcome of this study may be applicable to more than one institution. In the future, these data can be used to suggest test diets that may lead to better health of aquaria reared *Aurelia sp.* as well as increased cost-effectiveness for aquaria. This project thus also examines the nutrient composition of the diet fed to aquarium-reared jellyfish.

The data obtained in this investigation are likely to be useful in other arenas as well. As jellyfish can only obtain nutrients from the water in which they live, the minerals and mineral levels found in *A. aurita* may be indicative of the overall water quality in their locales. Furthermore, since *A. aurita* and other jellyfish are often eaten by sea turtles, the nutritional data obtained in this study may provide insight into sea turtle nutrition.
Methods

Sample collection. Wild A. aurita medusae between 5 and 12 cm in umbrella diameter were collected from a boat in Gerritson Creek, New York. Gerritson Creek, as part of Jamaica Bay located off of Brooklyn, NY, receives water from the Atlantic Ocean as well as effluent from the John F. Kennedy Airport and the Metropolitan Water Authority. Gerritson Creek also contains considerable marine debris.

Medusae were visually identified and captured in a one-day trip in June 2003. Collection occurred on an incoming tide from surface water with a salinity of 16.5 ppt and a temperature of 19°C. Medusae between 8 and 12 cm in umbrella diameter were collected (n = 40, mean diameter (± SD) = 8 ± 2 cm) via netting of surface water. After capture, jellyfish were placed in a bucket of sea water until all were collected. The medusae were then measured for umbrella diameter and placed into individual plastic bags in an ice chest. Upon return to the lab, medusae were rinsed off in sea water (from the intake pipeline discussed below) to remove excess salt, blotted dry on a plastic tray to remove excess water, and weighed. Samples were then replaced in plastic bags and put in a subzero freezer for approximately one day. Frozen wild Aurelia sp. were then combined into three groups, hereafter known as samples, pooled weights were 216, 380, and 254 g, respectively.

Captive A. aurita medusae between 5 and 10 cm in umbrella diameter (n = 43, mean (± SD) = 6.5 ± 1 cm) were obtained from the NYA’s jellyfish cultures. This culture originated from a strand that was wild-caught offshore of Brooklyn, NY, during 2002, and was propagated at the Aquarium. Medusae were obtained from a closed kreisel system with a relatively constant salinity of 32 ppt and a relatively constant temperature of 16°C. Water changes of approximately 10% of tank water occurred weekly, with input water from an intake pipeline approximately 4.5 m deep and 60 m offshore from Coney Island, NY.

Jellyfish were removed from the kreisel via net and were placed in a bucket of water taken from the kreisel. Individuals were then rinsed in this water and blotted against a plastic tray to remove excess water. Umbrella diameter was then measured and the jellyfish were weighed. Individual jellyfish were placed into individual plastic bags and placed in a subzero freezer for approximately one day. Captive jellyfish were then combined into two sample groups (hereafter known as samples) with pooled weights of 330 and 230 g, respectively.

Diets and Diet Sample Preparation. Diets were prepared according to the manner in which NYA-cultured jellyfish are fed. This diet includes Super Selco®- (Artemia Systems, Inc., Baasrode, Belgium) enriched Artemia salina fed to Aurelia sp. once or twice daily, Cyclop-eeze (Argent Labs, Redmond WA, USA) fed to growing Aurelia sp. once daily, and a mixture of various foods (including clam (unknown spp.) and capelin (Mallotus villosus)) fed twice weekly.

Brine shrimp, A. salina, were enriched with Super Selco®, a nutritional supplement, according to NYA procedure. Decapsulation was completed by Aquarium staff members: 425 grams of Salt Creek Select Brine Shrimp Eggs (Salt Creek, Inc., Salt Lake City, UT, USA) were mixed with 32g of NaOH and then placed in a solution containing 1000 mL Cl₂ and 500 mL distilled H₂O. The brine shrimp were then rinsed in tap water until the chlorine smell dissipated. One and one
quarter cups, approximately 265g, of decapsulated cysts were placed in 50 liters of sea water from the intake pipeline in a cylindrical polyvinylchloride (PVC) tank to hatch. The tank temperature was heated to 26.6°C and an oxygen line was placed in the tank to allow aeration. After 24 hours, casings and unhatched cysts were drained from the bottom of the tank and hatched A. salina were washed in salt water from the intake pipeline. A. salina were then enriched with Super Selco® according to Aquarium procedure and Woods30 (0.6g Super Selco®/liter). Thirty-one grams of Super Selco® were emulsified in a Waring blender for three minutes and placed in 50 L sea water from the intake pipeline in the cylindrical PVC tank. After 24 hours, A. salina were removed and drained into a net. Excess water was squeezed out, and the 254 g sample was frozen in a subzero freezer for 24 hours.

One hundred fifty-seven grams of Cyclop-eeze® were obtained from a 400 gram frozen case. This sample was placed in a subzero freezer for 24 hours.

The mix of capelin, clam, and mysis (Mysis relicita) was prepared according to Aquarium procedure. Three female capelin with roe, weighing 15.7, 14.2, and 16.2 g were obtained from a commercially prepared lot of North Atlantic capelin from Great Atlantic Seafood Co, Inc., (Portland, ME, USA). One clam from the New York area of the Atlantic Ocean, weighing 27.7 g, was obtained from a frozen pallet of clam from Doxsee Sea Clam Co, Inc. (Point Lookout, NY, USA). Twenty-eight grams of frozen M. reticulata were obtained from a 1.134 kg block from Piscine Energetics (Enderbery, BC, Canada).

The capelin, clam, and mysis were placed in a blender and homogenized. This sample is hereafter known as the “capelin mix.” The weights of capelin, clam, and mysis used in this study are meant to be representative of what is used at the Aquarium, as there are day-to-day variations.

**Nutritional Analysis.** Frozen samples were partially thawed and ground using a food processor in the Bronx Zoo Nutrition Laboratory, Bronx, NY. Vitamins A and E extraction and analysis of wet tissues followed previously cited methods for meat samples.7 Remaining samples (wild A. aurita, captive A. aurita, Super Selco® enriched A. salina, Cyclop-eeze®, and capelin mix) were freeze-dried for three days; sample weight before and after freeze-drying was recorded to determine water content. All methods of proximate analysis (crude protein, crude fat, ash) were the same for the various samples, according to standardized laboratory procedures for meat samples.1 Macro- and trace minerals were assayed via inductively coupled plasma-mass spectrometry or atomic absorption (Se only) at the Laboratory for Large Animal Pathology and Toxicology (University of Pennsylvania, Kennett Square, PA).

**Statistical Analysis.** A least squares regression of diameter vs. mass of individual wild and captive A. aurita was performed using SPSS 11.5 for Windows. B0, b1, R-squared, and standard error values were found for both data sets. ANOVA F-tests were performed to determine statistical significance between populations. SPSS 11.5 for Windows was also used to examine differences in crude protein, fat, ash, vitamin A and vitamin E activity of wild vs. captive Aurelia sp. samples. Mann-Whitney U tests for 2 unrelated independent samples were performed for each parameter. Mann-Whitney U statistics, Wilcoxon W statistics, and p-values were obtained, with a level of significance set at P=0.05.
Results

_Umbrella Diameter and Mass_. A linear relationship (Figure 1) was found between umbrella diameter and wet weight in both wild and Aquarium-reared _Aurelia sp_. Wild _Aurelia sp_. caught off of Jamaica Bay (n=40) yielded a relationship of Mass (g) = 4.71 x Umbrella Diameter (cm) - 21.17, with a standard error of 3.97 for b0 and 0.47 for b1, and R-squared = 0.79. An ANOVA F-test resulted in an F statistic of 99.71 and a p-value ≤ 0.000. Captive _Aurelia sp_. yielded a relationship of Mass (g) = 4.56 x Umbrella Diameter (cm) - 17.33, with a standard error of 2.39 for b0 and 0.35 for b1, and R-squared = 0.72. There were no statistical differences between sample groups for umbrella diameter or wet weight.

_Proximate Nutrient Composition of _A. aurita_._ Nutritional / chemical composition as percent of dry matter (DM) is seen in Table 1. Samples contained 97-98% water.

Crude protein content was found to be significantly higher in wild _A. aurita_ samples than in captive _A. aurita_ samples with a p-value of 0.002 (Mann-Whitney U statistic = 0.00, Wilcoxon W statistic = 15.00). Fat content was found to be significantly higher in captive samples than in wild samples, with a p-value of 0.009 (Mann-Whitney U statistic = 2.00, Wilcoxon W statistic = 23.00). Percent ash was found to be greater in wild samples than in captive samples, with a p-value of 0.05 (Mann-Whitney U statistic = 0.000, Wilcoxon W statistic = 6.00). Vitamin E activity was significantly higher in captive samples than in wild values, with a p-value of 0.004 (Mann-Whitney U statistic = 17.00, Wilcoxon W statistic = 62.00). Differences in vitamin A activity were not statistically significant (p-value= 0.240; Mann-Whitney U statistic = 28.00, Wilcoxon W statistic = 64.00).

Using the Atwater method to determine energy content, [Energy Content (Kcal/g) = 4 X % carbohydrate content + 9 X % fat content + 4 X % protein content (USDA)], wild _A. aurita_ samples contained 0.55 to 1.3 kcal/g DM and captive _A. aurita_ samples contained 0.66 to 1.65 kcal/g DM (the higher number, in each case, determined by calculating total carbohydrates as (100 - ash - protein - fat) in case other constituents not measured might have been present). This translates to approximately 0.01 to 0.03 or 0.04 kcal/g of wet tissue in samples.

_Proximate Nutrient Composition of Aquarium Provided Diet_. Nutritional differences are evident in the various foods provided at NYA and are seen in Table 2.

_Mineral Composition of _A. aurita_ and NYA Provided Diet_. _A. aurita_ were analyzed for sodium (Na), magnesium (Mg), phosphorous (P), potassium (K), calcium (Ca), manganese (Mn), iron (Fe), cobalt (Co), arsenic (As), copper (Cu), zinc (Zn), molybdenum (Mo), cadmium (Cd), selenium (Se), and lead (Pb). Striking differences were found in Zn levels, with wild _A. aurita_ containing 72.8 ± 2.5 mg/kg Zn, and captive _A. aurita_ containing 17.9 ± 0.1 mg/kg (DM basis). Phosphorus levels were also quite different; 2870 ± 80 mg/kg in wild and 1420 ± 160 mg/kg in captive cultured _A. aurita_. Magnesium levels were 3.95 ± 0.09 mg/kg in wild and 0.54 ± 0.01 mg/kg in captive _A. aurita_. Levels of the other studied minerals were comparable between wild and captive-bred groups. These data are shown in Table 3, as is the mineral composition of the aquarium prepared diet.
Discussion

Composition. This study was able to determine the proximate composition of wild, Jamaica Bay, NY, *A. aurita*, as well as of captive, NY Aquarium-cultured *A. aurita* originating from a Brooklyn, NY strain. The investigation showed that the proximate compositions differed, with the wild *A. aurita* possessing approximately half the fat and twice the protein of captive reared counterparts.

It is useful to compare the data in this study to the data obtained from prior studies (Table 1). Ash has been reported as 79% DM by Larson^{16} and as 20-54% DM in other studies,^{4} with larger medusae containing less ash.^{17} Protein has been reported as 1.9 percent overall DM,^{5} as 2-8 percent DM in umbrella tissue,^{17} and as 4-23% DM in gonadal tissue.^{17} Carbohydrate has been reported as 0.3-2% DM in Lucas^{17} and as 2.8% DM in Schneider.^{5} Lipid has been reported as 0.9-2.9% of DM in whole animals,^{5} and as 2.6-6% of DM in the gonads.^{17} Although they did not appear physically obese, captive-reared jellyfish in this study may have been chemically obese by comparison with wild medusae and literature data, but there are few physiologic measures to make a definitive determination.

In addition to the quantitative differences, a number of physical attributes did appear to differ between the wild and captive *A. aurita* examined in this study. Upon handling by the investigators, live Aquarium-reared jellyfish produced more mucus and stung more often than did their live, wild counterparts. After placement in a subzero freezer for 24 hours, tissues from Aquarium-reared *A. aurita* crumbled when handled, while tissues from wild caught *A. aurita* did not. Finally, Aquarium-reared *A. aurita* appeared to exhibit gonads when their umbrella diameters reached approximately 3 cm, while the wild Jamaica Bay *A. aurita* did not exhibit gonads until they were approximately 6 cm in umbrella diameter. It is possible the captive animals reached sexual maturity at an earlier age than wild jellyfish.

From the data presented here, there appear to be significant differences in the proximate compositions of wild and Aquarium-cultured *A. aurita*. However, this study does not prove that the Aquarium-reared *A. aurita* are unhealthy, nor can it alone be used to assume that diet changes should be made in order to replicate the proximate composition of the wild *A. aurita*. In order to make these assertions, chemical composition and diet must be correlated with observed reproductive and overall success [rather than size or sexual maturity which has been studied by Lucas];^{17} controlled feeding trials on diets of different composition should be conducted.

Such nutritional studies on *A. aurita* medusae must be applied to aquaria husbandry practices. Aquarium husbandists are often feeding what they believe to be the best diet based upon trial-and-error practices rather than on scientific data. Qualities that may make the animal look better for public presentation may not necessarily be optimal for the animals. When taken together, these factors are suggestive of imperfect constitution and possible nutritional imbalance. All other husbandry factors, such as water quality, density of medusae, kreisel size, and various other factors must, of course, be recognized as well.

Many factors directly observed in this investigation may also suggest nutritional issues in the captive jellyfish. During this investigation, the crumbling of *A. aurita* tissue was readily
apparent in captive samples and not present in wild caught samples. This is perhaps indicative of structural integrity flaws within the captive *A. aurita*. As the proteinaceous mesoglea acts as a major factor providing structural support, the apparent low protein levels in the captive samples may underlie this problem. While reported values of crude protein content do go as low as 2.1% of DM in *Aurelia* spp. (Table 4), they may not be applicable to this size or strain of medusae.

The gonadal development by small sized captive medusae (3 cm) was similarly visually apparent in captive *A. aurita* but not in wild *A. aurita*. This may also be the result of either over- or undernutrition in the captive stock. Wild specimens did not appear to develop gonads until they had reached a much larger size, with the smallest gonad-exhibiting wild caught medusa 6 cm in umbrella diameter, and most gonad-exhibiting medusae at least 8 cm in umbrella diameter.

It has been shown that medusae in food-limited areas produce gonads at an earlier size than do medusae at larger sizes. Prior studies have shown food-limited *A. aurita* to produce gonads at 4.5 cm and 5 cm with well-fed medusae producing gonads at over 9 cm in umbrella diameter. Thus, Aquarium-reared *A. aurita* may be “food-limited” or may be receiving a diet deficient or imbalanced in one or more critical nutrients.

Spangenberg has reported that subsequent to gonadal development and sexual maturation, *A. aurita* regressed and disintegrated. This may also be the cause of the hypothesized structural integrity problem. Most obviously, however, it suggests that early gonadal development, such as in the Aquarium *A. aurita*, is “unhealthy” and results in high mortality. Additionally, early gonadal development in starved *A. aurita* has been shown to result in fewer offspring. Taking into account the small size of the Aquarium-reared *A. aurita*, it is possible that the presence of gonadal tissues led to, or is a result of the comparatively high fat content. The chemical composition of *A. aurita* is significantly related to the different tissue types present in the medusa, including gonadal tissues; Lucas reports gonadal tissue as far fattier (with a fat content of 2.6-6.0% of DM) than other tissue (with a fat content less than 3.4% of DM).

It is thus apparent that the captive, New York Aquarium-reared *A. aurita* (Brooklyn strain) had proximate nutritional compositions that differed from those of wild, Jamaica Bay (Brooklyn) *A. aurita*. The captive *A. aurita* may thus be overfed some nutrients and underfed others. In order to determine if this is the case, future research involving growth trials and further compositional analysis must be completed, as will be discussed.

**Future Research.** One avenue of future research is to provide differing diets in *ex situ* growth trials, after which proximate composition can be determined. As this study examined the proximate composition of the diet fed to Aquarium-cultured *A. aurita*, fat and protein sources can be identified. Super Selco® enriched *Artemia* had a higher fat content than did any of the other foods studied. Cyclo-eze® had a higher protein content than did any of the other food studied. Note that the water content value of enriched *Artemia* was not obtained due to laboratory error (but rather was estimated from other studies conducted at the same institution). Cyclo-eze® was not found to have any vitamin A activity; however, preparation for HPLC may have been incorrect and thus led to an inaccurate value. The capelin mix contained a high standard error for all values, especially percent ash. This may be due to poor homogenization of the sample, although the sample did visibly appear to be homogenized.
Using the nutritional composition data obtained in this investigation, various trials can be performed. One recommended trial is to use nonenriched *Artemia* nauplii rather than Super Selco®-enriched nauplii as the mainstay of the captive diet. Prior studies have shown that *A. aurita* are attracted to *Artemia* and growth trials in ephryae *A. aurita* (*A. aurita* in the stage prior to medusa) have found *Artemia* to be an efficacious diet that led to higher growth rates than did diets of particulate clam meat. Furthermore, the majority of studies involving *ex situ* *A. aurita* used unenriched *Artemia* as the primary diet.

While studies have shown that various types of fish grow more successfully when fed Super Selco® enriched rather than unenriched nauplii, e.g., Woods, this has not been studied in *A. aurita*. In fact, there are no published data regarding feeding Super Selco® enrichment to scyphozoans. As *A. aurita* are not fish, but rather invertebrates, it is possible that the fatty acids provided by Super Selco™ are unnecessary in *A. aurita*. Previous investigations show that unenriched *Artemia* nauplii contain 13% fat rather than the 24% found in the enriched nauplii in this study. Using this diet would thus likely reduce the overall fat content of the *A. aurita*.

Anecdotal reports by other aquariums have stated that *A. aurita* fed nonenriched *Artemia* nauplii diets do not “look good.” However, as discussed earlier, external appearance does not necessarily equate with optimal health. If test trials show that it is in fact the case that the fatty acids provided by Super Selco® are necessary for the *A. aurita*, further trials could alternate feeding enriched vs. nonenriched nauplii to determine the optimized frequency with which enriched nauplii should be fed.

Additional growth trials might alter the Aquarium diet in other ways, such as increasing the amount of Cyclop-eez® and decreasing the amount of *Artemia*. This would presumably increase the protein content and possibly result in better tissue integrity. With any diet, however, it is important to note that husbandry practices may have to change as well. Providing a more proteinaceous diet might require lowering water temperatures, as protein metabolism produces more heat than does fat metabolism. Using other foods such as the capelin mix might require increased tank cleaning and water changes as a result of oil in the diet.

Furthermore, as the captive cultured *A. aurita* originated from the same strain as did the wild, Jamaica Bay *A. aurita*, it may be useful to obtain more data as to the proximate composition of the wild *A. aurita*. For the reasons discussed earlier, including seasonal and water chemistry changes, the proximate composition of *A. aurita* should be determined in samples from water closer to the Aquarium intake pipeline, and over various seasons. This will provide a stronger basis of comparison for captive *A. aurita* samples.

Additional Avenues of Investigation. In order to apply this investigation to future research, it is important to note a number of factors that may have affected the results. These factors include: sample size, water chemistry, and other possible analytical inaccuracies.

As *A. aurita* samples contained 97-98% water, it was impossible to use individual jellyfish (mean = 15 g) for multiple laboratory tests which required 0.5 g each. Additionally, due to time and budget constraints of New York Aquarium / Wildlife Conservation Society staff members,
this study was only able to examine 40 wild *A. aurita* and 43 captive *A. aurita*. Thus, large numbers of jellyfish were homogenized to create a small number of freeze-dried pools, which were sampled for laboratory analysis. Therefore, sample size was fairly low for chemical composition tests.

Results may also have been affected by the fact that water chemistries from Jamaica Bay and the Aquarium kreisel were not analyzed. As *A. aurita* are believed to be osmoconformers, water chemistry may have had an effect on chemical composition. Shick\textsuperscript{22} reports dissolved amino acid uptake as relative to temperature, environmental conditions, and feeding. It is thus difficult if not impossible to separate “nutrition” from water chemistry. Therefore, one cannot assume that differences in composition are exclusively due to diet rather than environment. This is especially the case when one considers that laboratory analysis did not differentiate whether or not the proteins, fats, and other compounds present in *A. aurita* were of dietary origin and simply a factor of gut contents rather than utilization and incorporation by the organism. Thus begs the question of “What’s in the water?”

Concerning water chemistry, it is useful to consider that sampling *A. aurita* during a different season may have resulted in differing chemical compositions. Fatty acid composition has been shown to differ in samples of *A. aurita* collected in April/June compared with August/September. This is likely a result of temperature change in the marine ecosystem leading to increased diatom prey in April/June and increased detritus in August/September.\textsuperscript{9} Similarly, seasonal variation in diet has been observed through gut content analysis.\textsuperscript{14} It is thus to be expected that overall nutritional composition will change between seasons as well (this will also affect intake water at the NYA).

Examining this data, it is also important to take into account the laboratory processes and calculations. In order to obtain crude protein values for this study, nitrogen content was multiplied by 6.25, as discussed in Robbins.\textsuperscript{21} However, this constant has not been precisely determined for jellyfish.

Finally, examining the wild-caught Jamaica Bay *A. aurita*, it is important to note that there are no data to prove that these free-ranging jellyfish are healthy. Assuming that because they live in the wild, they are healthy, is naïve at best. As *A. aurita* were taken from low salinity surface waters, and as a number of water sources flow into Jamaica Bay with possibly contaminated water, sampled *A. aurita* may or may not have had ideal chemical compositions.

These critiques, however, can be somewhat rectified by comparing data from this study to data from other investigations (Table 1). These data do show that captive reared *A. aurita* samples in this study contain a higher fat content than has been reported in any other population.

**Conclusion**

Proximate compositions between Aquarium-reared *A. aurita* and wild, Jamaica Bay *A. aurita* differ in various ways including fat, protein and mineral content. While this is likely the effect of diet, further research is needed to determine other factors as well as whether or not these
differences are significant. Understanding the nutritional composition of *A. aurita* can lead to valuable insights into the marine ecosystem as well as for the aquaculture community.

The direct implications of this study are of considerable use to the aquarium community. The study provides background data that can be used to formulate more nutritious diets for Aquarium-reared *A. aurita*. Such diets can lead to better health, longevity, and appearance in captive specimens. Additionally, a more cost-effective diet can be formulated. As *Artemia* cysts and enrichment preparations such as Super Selco® are expensive, other diets and sources of nutrition may be quite useful.

This study also has broad indirect applications. *A. aurita* are a major food source for loggerhead sea turtles and other animals, and understanding the nutritional composition of *A. aurita* can likely lead to a better understanding of their predators’ needs. This is especially important as the proximate composition of *A. aurita* significantly differs from the composition of more traditionally studied organisms such as fish. Furthermore, understanding the feeding patterns of *A. aurita* may result in a better understanding of where they will become invasive, while their composition may be an indicator or water quality.

**Acknowledgments**

We would like to thank Jasmine Thomas and the Wildlife Nutrition Department of WCS for laboratory assistance and analytical support. We would like to thank Don Melnick and Andrew Baker for editorial assistance and advice during earlier drafts of this paper. We would like to thank CERC for financial support, and the New York Aquarium for use of their facilities.

**LITERATURE CITED**


**Figure 1**: Comparison of umbrella diameter to mass
Table 1. Nutritional composition of *Aurelia sp.* Values are mean ± standard error; all values on a dry matter basis, except water content.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Wild <em>A. aurita</em>, This study</th>
<th>Captive <em>A. aurita</em>, This study</th>
<th>Wild, whole <em>A. aurita</em>¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (%)</td>
<td>97-98</td>
<td>97-98</td>
<td>ND</td>
</tr>
<tr>
<td>Crude Protein (%)</td>
<td>9.20±0.4</td>
<td>4.95±0.2</td>
<td>2.1-28.6</td>
</tr>
<tr>
<td></td>
<td>n=4</td>
<td>n=6</td>
<td></td>
</tr>
<tr>
<td>Crude Fat (%)</td>
<td>2.05±0.37</td>
<td>5.16±1.00</td>
<td>0.2-3.4</td>
</tr>
<tr>
<td></td>
<td>n=6</td>
<td>n=4</td>
<td></td>
</tr>
<tr>
<td>Carbohydrate (%)</td>
<td>None Detected</td>
<td>None Detected</td>
<td>0.4-2.9</td>
</tr>
<tr>
<td></td>
<td>n=9</td>
<td>n=6</td>
<td></td>
</tr>
<tr>
<td>Ash (%)</td>
<td>69.88±0.70</td>
<td>64.87±0.12</td>
<td>20-79</td>
</tr>
<tr>
<td></td>
<td>n=3</td>
<td>n=3</td>
<td></td>
</tr>
<tr>
<td>Vitamin A Activity (IU/g DM)</td>
<td>0.045±0.019</td>
<td>0.070±0.40</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>n=9</td>
<td>n=8</td>
<td></td>
</tr>
<tr>
<td>Vitamin E Activity (IU/kg DM)</td>
<td>9.8±4.8</td>
<td>57.4±16.5</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td>n=8</td>
<td>n=8</td>
<td></td>
</tr>
</tbody>
</table>

¹Reported values are from Arai,⁴ and Schneider²⁴ as reported in Bailey.⁵
ND = not determined
Table 2. Nutritional composition of New York Aquarium diet ingredients fed to captive jellyfish. Values include mean ± standard error.

<table>
<thead>
<tr>
<th>Foodstuff</th>
<th>Enriched Artemia</th>
<th>Cyclopeze®</th>
<th>Capelin mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrient</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Content (%)</td>
<td>ND(^1)</td>
<td>83.48</td>
<td>80.77</td>
</tr>
<tr>
<td>Crude Protein (% of DM(^2))</td>
<td>43.54 ± 1.35</td>
<td>63.36 ± 2.04</td>
<td>42.60 ± 1.98</td>
</tr>
<tr>
<td>Crude Fat (% of DM)</td>
<td>23.95 ± 0.37</td>
<td>23.06 ± 1.60</td>
<td>20.00 ± 1.34</td>
</tr>
<tr>
<td>Ash (% of DM)</td>
<td>11.80 ± 0.52</td>
<td>15.36 ± 0.38</td>
<td>19.42±13.72*</td>
</tr>
<tr>
<td>Vitamin A Activity (IU/g DM)</td>
<td>3.5 ± 0.54</td>
<td>None</td>
<td>37.10 ± 7.09</td>
</tr>
<tr>
<td>Vitamin E Activity (IU/kg DM)</td>
<td>68.64 ± 3.34</td>
<td>101.03 ± 2.21</td>
<td>160.94 ± 28.72</td>
</tr>
</tbody>
</table>

\(^1\)ND = not determined  
\(^2\)DM = dry matter  
* These values may include analytical error.
Table 3. Mineral content of wild-caught and captive-reared *Aurelia* sp., and ingredients in captive diets. Values are mean ± standard error; all values on a dry matter basis, in mg/kg (ppm).

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Wild <em>Aurelia</em> sp. (n=3)</th>
<th>Captive <em>Aurelia</em> sp. (n=2)</th>
<th>Enriched Artemia</th>
<th>Cyclopeeze</th>
<th>Feed Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>244000 ± 4400</td>
<td>265000 ± 13000</td>
<td>15700</td>
<td>35200</td>
<td>16800</td>
</tr>
<tr>
<td>Magnesium</td>
<td>27900 ± 210</td>
<td>28300 ± 1200</td>
<td>2580</td>
<td>9220</td>
<td>1740</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>2870 ± 80</td>
<td>1420 ± 160</td>
<td>11000</td>
<td>6630</td>
<td>10800</td>
</tr>
<tr>
<td>Potassium</td>
<td>11700 ± 500</td>
<td>13050 ± 1050</td>
<td>13400</td>
<td>8500</td>
<td>14500</td>
</tr>
<tr>
<td>Calcium</td>
<td>8380 ± 160</td>
<td>9030 ± 290</td>
<td>785</td>
<td>3890</td>
<td>9330</td>
</tr>
<tr>
<td>Manganese</td>
<td>3.95 ± 0.09</td>
<td>0.54 ± 0.01</td>
<td>9.69</td>
<td>15.1</td>
<td>14.3</td>
</tr>
<tr>
<td>Iron</td>
<td>119 ± 2</td>
<td>55.3 ± 3.1</td>
<td>86.7</td>
<td>417</td>
<td>309</td>
</tr>
<tr>
<td>Cobalt</td>
<td>0.07 ± 0.01</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>0.73</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Arsenic</td>
<td>1.77 ± 0.01</td>
<td>1.05 ± 0.04</td>
<td>25.1</td>
<td>6.42</td>
<td>4.66</td>
</tr>
<tr>
<td>Copper</td>
<td>6.08 ± 0.52</td>
<td>4.25 ± 0.57</td>
<td>5.41</td>
<td>11.2</td>
<td>11.5</td>
</tr>
<tr>
<td>Zinc</td>
<td>72.8 ± 2.5</td>
<td>17.9 ± 0.1</td>
<td>111</td>
<td>83.3</td>
<td>86.2</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.453 ± 0.010</td>
<td>0.370 ± 0.034</td>
<td>0.223</td>
<td>0.417</td>
<td>2.61</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.14 ± 0.1</td>
<td>0.07 ± 0.03</td>
<td>&lt;0.03</td>
<td>0.16</td>
<td>0.39</td>
</tr>
<tr>
<td>Selenium</td>
<td>0.37 ± 0.09</td>
<td>0.30 ± 0.01</td>
<td>1.56</td>
<td>2.28</td>
<td>1.99</td>
</tr>
<tr>
<td>Lead</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>80.4</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
</tr>
</tbody>
</table>