A DIFFERENT ANGLE ON GEOMETRICAL ANALYSIS OF DIETS: DEVELOPING A TOOL FOR USING GEOMETRY TO COMMUNICATE NUTRITION TO LAYPEOPLE

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Abstract

Geometric analysis provides an intuitive and powerful tool to examine the diet and feeding behavior of animals. Because of its visual nature, it may also be a powerful tool to assist in communications with laypeople, such as clients or zoo staff members, who are often intimidated by a more numerical analysis. A new tool, a ternary graph using color for a fourth axis, allows the visualization of diets on a simple graph. By comparing a proposed diet to defined regions for that species, a layperson can quickly see whether or not a proposed diet fits within a target range. By making "live" adjustments to the diet together, the nutritionist and client can converge on a diet that is balanced nutritionally but also encompasses the training, enrichment and social needs of the animal.

Introduction

Geometric analysis, a technique developed by Raubenheimer and Simpson (1997, 1999) provides an intuitive and powerful tool to see how diets converge on nutritional targets, to identify nutritional priorities of animals, and examine how different diet ingredients contribute to the overall diet and feeding behavior of animals. One use of geometric analysis that has not been as thoroughly explored is using nutritional geometry to communicate with laypeople, such as clients or zoo staff members. Over 60% of the British population is considered "innumerate" or has a strong negative emotional reaction to numbers (Coben et al. 2003), and the US lags behind England in many mathematical surveys. In my experience, showing some clients a traditional diet analysis (i.e., results from a nutrition lab or a diet composition calculated on a spreadsheet) can be very intimidating. Human nutritionists have spent a great deal of effort developing ways to increase nutritional literacy in human populations. They've developed widely used tools such as standard serving sizes, Food Pyramids, uniform nutritional labeling, the MyPlate tools, diabetic exchange tables, point systems, and others. What these tools share is their focus on visual depictions and simple metrics that laypeople can understand. The goal of this paper is to present one possible way that something similar might be accomplished in a zoo setting.

The goal of a nutritional consultation in a zoo or similar setting is typically to find a diet that meets the animal's estimated nutrient requirements while simultaneously meeting training, enrichment and social goals for the animals. A positive, collaborative approach involves working side-by-side with the zookeeper or manager to find a workable compromise between the foods they would like to feed and those that meet the nutrient requirements of an animal. Unfortunately, this often involves balancing diets in front of them and exposing them to complex tables of numbers. While some staff are receptive to this and interested to learn more, many others have more negative reactions, and this can hinder the collaborative diet design process.

With a small amount of orientation, I've found that using a modified geometric framework graph provides a non-threatening, visual way to develop diets cooperatively with non-nutritionists.

The original tool developed by Simpson and Raubenheimer (1995; 1999) depicted two nutrients (a third nutrient could be evaluated on a diagonal axis with training; Fig 1). While this provided a valuable new tool to the field of nutritional ecology, these graphs are not always easily interpreted by laypeople. Human nutritionists have begun using ternary graphs (triangle plots), with the three axes being the proportion of calories from protein, fat, and carbohydrates, to communicate individual food or diet composition (Fig 2). Different popular human diet plans aim for different regions of this triangle (Fig 2b; http://nutritiondata.self.com).

In the realm of animal nutrition, Hewson-Hughes used ternary plots very effectively in his work identifying the nutritional targets of domestic cats. These graphs provide a visually compelling story of cats' dietary selection goals when consuming dry food (pink triangle) and canned food (blue triangle) diets (Fig 3; Hewson-Hughes et al. 2011).

Although these plots work well for carnivores, these ternary plots have a flaw that becomes apparent when using them for non-human, non-carnivore diets – they group all carbohydrates together. A diet containing mostly sugar will appear in the same area as one containing mostly fiber, despite the fact that these have very different physiological implications. A constant challenge in zoo diets for many animals is keeping the non-structural carbohydrate (NSC) proportion (primarily sugars and starch) low, while maintaining adequately high levels of structural carbohydrates (SC, cellulose, hemicellulose, etc.). To visually display this would require a fourth axis (protein, fat, NSC, SC), which would render a ternary graph challenging to read.

The goal of this project was to develop a simple, visually effective way to communicate macronutrient composition of a diet, including separating structural and non-structural carbohydrates. In addition, this tool should allow "live" comparisons of a proposed diet with a recommended target range.

Methods

Fourth axis

A ternary plot using protein, fat, and carbohydrate has shown itself in both human and animal nutrition to be an effective communication tool. To address the need for a fourth dimension (separating carbohydrates into SC and NSC), I used *color* as a fourth axis, with a scale that ranges from green (at least 80% of the carbohydrate calories are from non-structural carbohydrates) through yellow (at least 40%) to red (less than 20% of the carbohydrate calories are from non-structural carbohydrates).

Caloric content

ME: The caloric content of the whole diet was calculated using published metabolizable energy (ME) values of the individual ingredients. When different ME values were available for different taxa (i.e., foregut fermenters, hindgut fermenters, primates, birds, etc.), the value deemed most relevant for the particular species was used. If only one ME value was available, it was used regardless of animal taxa. Because ME data were missing entirely for some diet ingredients, diets for which less than 95% of the dry matter had published ME values were excluded. 6 diets out of 146 were excluded, leaving 140 diets in the analysis.

Protein and Fat ME: The caloric contribution of each macronutrient in the diet was estimated using Atwater's values of 9 kcal/g of fat and 4 kcal/g of protein.

Total Carbohydrate, By Difference: The total amount of carbohydrates was estimated using the USDA method of "carbohydrates, by difference (TC)": 100- (protein + fat + ash + water).

SC ME: To determine the calories from NSC vs. SC, several estimations had to be made. To estimate SC, the maximum value of NDF, ADF, CF and TDF was used. Obviously these four analyses are not directly comparable to one another. The calories from SC were estimated as 1.9 kcal/g * SC.

NSC ME: Very few ingredients had starch or sugar values available. Therefore, NSC was also determined by difference as: TC – SC. NSC was estimated to contain 4 kcal/g.

NSC:SC: The proportion of NSC was determined as NSC (kcal)/Total Carbohydrate (kcal).

Target ranges

To determine the target ranges for different groups of animals, a sample of 80 unique diets were selected (a single diet shared by many animals was just used once) that had been in use for at least a year with minimal changes and no known metabolic issues. Although it is not known whether these diets are "ideal", they appear to be working well. Like all zoo diets, they have been adjusted over time to meet the various needs of our animals and are currently our best estimate as to an optimal diet at this time.

Each diet was graphed on a ternary plot by diet type. Species were divided into the following diet type groups based on nutritional ecology and taxonomy: carnivores (consumers of whole vertebrate prey including mammals, birds, and reptiles), insectivores (many xenarthrans, bushbabies, smaller amphibians and reptiles), browsers (black rhinos, giraffe, gorillas, sloths, etc.), grazers (zebras, white rhinos, cattle, and hippos), frugivores, omnivores (mostly small mammals and rodents), and avian generalists (mostly small granivorous birds).

For "live" interactions with keepers, an Excel spreadsheet is used with a ternary plot generated by code by Fernando Cinquegrani (http://www.prodomosua.eu/ppage02.html). For the fourth axis, color was used to describe the proportion of SC to NSC. Red was used for diets containing more than 80% of the carbohydrate calories from NSC, orange for diets between 60 and 79.9%, yellow for diets between 40 and 59.9%, lime green for diets between 20 and 39.9%, and dark green for diets that were extremely low in carbohydrates, such as carnivore diets.

Within each manually classified group, the NSC/SC proportion was averaged (Table 1) and the entire group was assigned to a single color band based on the average.

Results

The regions graphed can be viewed in an interactive demo at:
https://zoonut.shinyapps.io/Triangle3/

Discussion & Conclusion

The development of the colored regions has been very helpful both for analyzing diets and working with the keepers. When analyzing diets, oddities where a diet falls outside of the expected range can be quickly noted and examined. For example, flamingos were classified as carnivores, but fall quite far outside the other carnivorous bird diets. Potentially, we might reconsider the composition of our flamingo diets, or reclassify flamingos as omnivores or avian generalists rather than as carnivores.

When I meet with keepers, we can simply work with the familiar diet ingredient amounts and the ternary graph. I begin by adding in all of the keepers' requests for training and enrichment items, and we then adjust the diet together until their diet (as depicted on the graph) is the correct color and within the target range. This can be done without staff ever encountering a single number. In my experience, if we generate a diet that (a) contains feeds typical for that species (b) that falls within the target region and (c) is the correct color, then balancing micronutrients requires very few additional adjustments. The impact of adding some high-sugar training or enrichment items becomes quickly apparent, and educational conversations about how to meet training goals while not unbalancing a diet can take place more easily.

In short, this tool offers a visually appealing technique that appeals to many nutrition clients and makes balancing diets collaboratively easier. It has the potential to allow us to evaluate diets against a new scale. Although this tool is based off one institution's current zoo diets, this technique could be expanded to include wild diets or diets from multiple institutions.

Literature Cited

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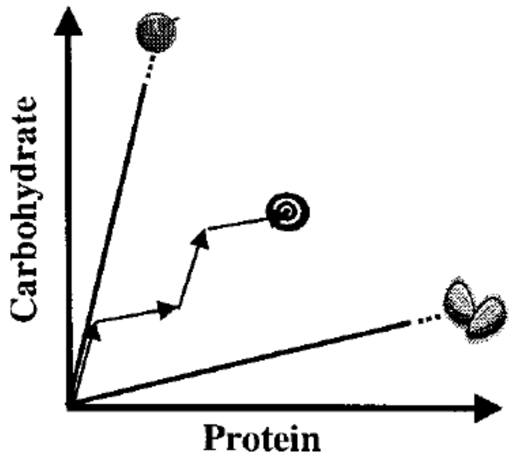

Figure 1. An example of geometric analysis where an insect might select from among two foods, neither of which is ideal, in order to reach a nutritional target (Raubenheimer and Simpson 1999).

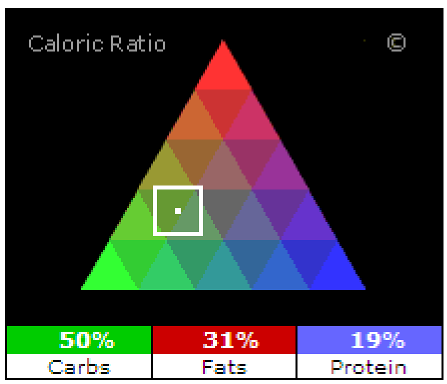

Figure 2a. The use of a ternary diagram in human nutrition.

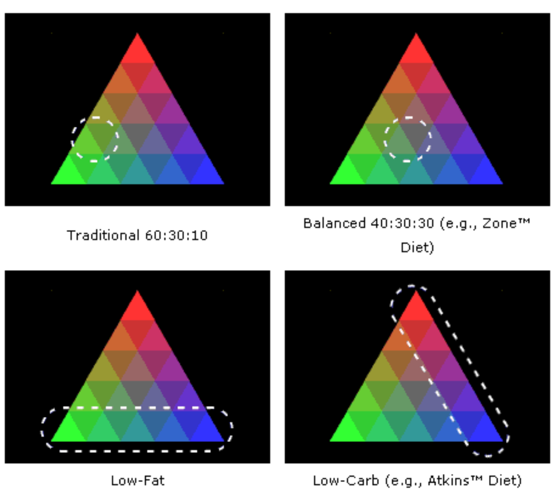

Figure 2b. Human diet plans as graphed on a ternary graph.
(http://nutritiondata.self.com/help/analysis-help#cp-pyramid)

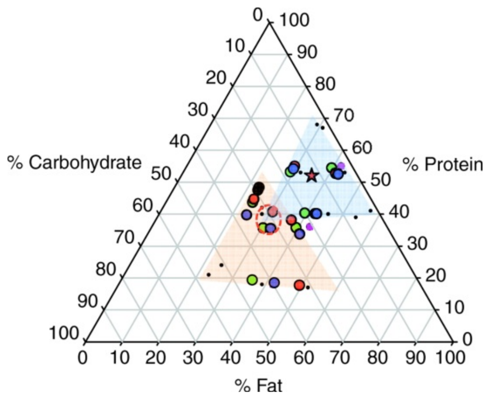

Figure 3. Dietary selection for particular nutrient targets by domestic cats. When cats were offered 3 dry diets at the apices of the red triangle, they selected a target within the red circle. When they were offered diets at the apices of the blue triangle, they selected a mixture within the red star (Hewson-Hughes et al. 2011).

Table 1. Ratio of non-structural carbohydrate (NSC) to structural carbohydrate (SC)

DietType	Color	Average	SD
Carnivore	Dark green	18%	19%
Grazer	Light green	21%	9%
Browser	Yellow	59%	9%
Omnivore	Orange	67%	18%
Insectivore	Orange	75%	9%
Frugivore	Red	80%	12%
Avian	Red	94%	6%