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Short Communication

Feeding Soluble Carbohydrates to Wild Florida Manatees (*Trichechus manatus latirostris*): A Prescription for Refeeding Syndrome

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The Florida manatee *(Trichechus manatus latirostris)* is a subspecies of the West Indian manatee found in the coastal and associated waters of Florida. The Florida manatee is a true aquatic herbivore and known to forage on over 60 species of plants with an intake of approximately 10% body on an as fed basis [1]. All members of the Sirenia are hindgut fermenters with long retention times for ingesta that contributes to the overall weight cellulose digestibility of these species. For both manatees and dugongs *(Dugong dugon)* this digestibility approaches 90% [1]. Manatees require a high quantity of a low-energy vegetation to meet their dietary requirements [2].

In wildlife rehabilitation centers and in zoological collections, commercially grown salad greens such as romaine lettuce (*Lactuca sativa L. var. longifoliaare*) are the common staple and sometimes supplemented with root vegetables. Romaine lettuce has lower acid detergent fiber (ADF) and neutral detergent fiber (NDF) and high levels of non-fiber carbohydrate (NFC), which include soluble carbohydrates (starch and sugars), in comparison to wild forages for manatees [3]. In a critical care situation such as rehabilitation, such a digestible and high energy food is essential for the initial recovery of injured manatees. In other hindgut fermenting mammals, such as horses, a shift from high fiber intake to one with a high intake of NFC can lead to serious gastrointestinal disturbance including clostridial overgrowth [4] in the short term. Type 2 diabetes and or metabolic syndrome are possible over a longer period [5]. Recent evaluation of fructosamine in wild and captive manatees has demonstrated a reference value for fructosamine to be similar to domestic cattle and horses [6]. In this same work, a population of long-term captive manatees has been shown to have marked elevations in fructosamine as well as pathologies that can be directly attributed to long standing type 2 diabetes. The author has also documented a per-acute death due to pulmonary embolism in an obese captive-reared Florida manatee in rehabilitation and a dystocia in a female manatee that had been hospitalized during the last several months of its pregnancy. The term fetus was stillborn after hours of labor and was 25% larger than the reported ranges for manatee calves. Both instances are consistent with complications of obesity due to persistent feeding a high intake of an energy dense, highly digestible feed beyond what is required for the recovery from the initial insult leading to hospitalization.

An unusual mortality event was documented in Brevard County, Florida in 2013 due to a die off of the native seagrasses. Clostridial overgrowth was suspected in this UME [7]. Macroalgae and seagrass samples provided by the authors of this report during this investigation do demonstrate approximately a doubling of the soluble NFC fraction and halving of the fiber fractions (ADF and NDF) in the macroalgae known to be consumed compared to the seagrass sample analyzed (Table 1). This data was not included in this publication but is readily available upon request and is being processed as a separate publication.

Plant	ADF %DM	NDF % DM	Total fiber fraction %DM	NFC %DM
Syringodium spp. (seagrass)	21.9	49.2	71.1	26.9
Haladule spp. (seagrass)	28.0	52.5	80.5	22.9
Solenaria spp. (macroalgae)	6.8	37.6	44.4	39.2
Chondria spp. (macroalgae)	7.0	26.0	33.0	51.1
Gracilaria spp. (macroalgae)	7.2	26.3	33.5	51.0
Unidentified brown drift algae	14.4	28.4	42.8	43.1

Table 1: *Carbohydrate fractions on a dry matter basis (DM) of seagrasses and macroalgae consumed by Florida manatees during the 2013 unusual mortality event. ADF: Acid Detergent Fiber; NDF: Neutral Detergent Fiber; NFC: Non-Fiber Carbohydrate.*

A mortality event in Lake Ossa, Cameroon was reported in the African manatee (*Trichechus senegalensis*) due to a die off of Antelope grass (*Echinochloa pyramidalis*) with the manatees then consuming a significant amount of an emergent *Salvia spp* of water moss [8]. The investigation into this mortality event was not as comprehensive as the ones conducted on UME's involving Florida manatees for logistical reasons and the natural history varies somewhat between the two species, but consumption of a plant species with a lower cell wall content (water moss) would be expected to have a similar digestive effect the West African manatee as the macroalgae has shown in the Florida manatee during the 2013 UME. This could at least in part explain some of the mortality observed in Cameroon.

The recent decrease in seagrass, a mainstay of manatee forages on the Atlantic coast of Florida, in the Indian River Lagoon (IRL) has led to the starvation deaths of hundreds of manatees in this habitat. An attempt to mitigate this loss was initiated once the total manatee death toll for the entire state of Florida reached 1000 individuals. This effort consisted of supplementing the wild manatees predominately with romaine lettuce. While the acceptance was initially poor, this manatee population was reported to start eating significantly on January 20th. The manatee mortality report provided by the Florida Fish and Freshwater Conservation Commission (FWC) on March 11 (https://myfwc.com/research/manatee/rescue-mortality-response/statistics/) was utilized to summarized mortalities closely associated with this recent event in the IRL and shown in table 2. This manatee mortality database was evaluated to compare mortalities in Brevard County, Florida. Brevard County has had the highest mortality associated with the current UME associated with the IRL. Assuming that most of the starving, emaciated manatees were counted in the category "Verified; non necropsied" this group for Brevard County was tallied for calendar year 2021 and from Jan 20, 2022, until March 11, 2022. This end date was the latest available to the public at the time of this review. For all of calendar year 2021, the daily death rate was 0.71 manatee deaths per day for the category defined above. In the period when the manatees were eating the supplemented romaine and greens in early 2022, the daily mortality rate increased to 5.14 manatee deaths per day in Brevard County.

	2021	2022
"Verified; Not Necropsied"	261	252
Days	365	49
Daily Mortality Rate	0.715068	5.142857

Table 2: *Manatee mortality in Brevard County Florida associated with the unusual mortality event (UME) related to seagrass die off. Data for 2021 includes the entire calendar year while 2022 mortalities are only from Jan 20, 2022, until March 11, 2022.*

In malnourished or starving animals, an acute shift from mobilizing fat stores and protein as a source of energy to a diet of soluble carbohydrates can lead to refeeding syndrome [9]. While this apparent dramatic increase in manatee mortality during the supplemental feeding period is yet unexplained, one possible reason could be refeeding syndrome. Once starving animals or people start to take oral or

parenteral nutrition, an increased insulin secretion occurs. This in turn increases cellular uptake of phosphorus and can lead to hypophosphatemia. Hypophosphatemia is the hallmark of refeeding syndrome but is often unrecognized in animals. Clinical cases of newly admitted manatees to one manatee rehabilitation center have been found to develop lethargy with 24 - 48 hours of feeding romaine lettuce and other greens. Low serum phosphorus has been discovered associated with this lethargy and corrected. In rehabilitation centers, weak animals can be placed in shallow pools, or the adjustable floors can be lifted and allow weak animal to breath until stabilized. Wild manatees could potentially beach themselves, but generalized weakness from hypophosphatemia could also directly contribute to drowning.

While recent epidemiology of manatee rehabilitation has included all admissions from the time of entry [10], historically manatees dying within 72 hours of admission were excluded from consideration when reporting to management staff and various agencies. As a result, higher survival rates of 85% were reported compared to approximately 70% by the end of the published study [10]. One possible explanation for this difference in reporting could be that some of these manatees had refeeding syndrome which went unrecognized, and therefore ended up being excluded from the data.

While supplemental feeding can be a useful tool in wildlife management, suitable forages for herbivores should be considered to match the digestive and metabolic capacities of the targeted species. Existing knowledge of the pathology of feeding high levels of soluble carbohydrates in domestic hindgut fermentation animals, combined with existing knowledge of nutritional analysis between wild forages for manatees and romaine, shared clinical experience with manatees fed romaine, and even investigations into the pathologies associated with short and long-term feeding of NFC suggest that feeding such an item on a landscape scale carries considerable risk. The lessons of the UME in Brevard of 2013 demonstrated that wild manatees with a high intake of naturally occurring forages with low fiber and high NFC could, and did, cause serious health issues leading to mortality. This lesson appears to have been downplayed to the detriment of possibly hundreds of manatees in the early part of 2022. A high fiber and low NFC forage, with low soluble carbohydrates, should be explored as a viable option if supplementation on an ecological scale should ever need to occur again. Such forages have been successfully used in both rehabilitated and long-term captive manatees (Figure 1) and have even helped stabilized manatees with documented type 2 diabetes.

Figure 1: *Long term captive Florida manatee (Trichechus manatus latirostris) consuming timothy grass (Phleum pratense) hay.*

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