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Rock Hyrax: Diet Recommendations and Nutritional Pathology

Deborah McWilliams, MSc, RIL-TAG Nutrition Advisor

Yvonne Strode (ystrode@att.net), Rock Hyrax Species Manager

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Note: ***This diet and document is free of any charges with recognition of origin as the Rodent, Insectivore, Lagomorph Taxon Advisory Group (RIL-TAG) and Canada's Accredited Zoos and Aquariums Nutrition Advisory and Research Group. Specific questions may be directed to: Deb McWilliams,*** info@caza-narg.ca

Introduction

A review of 545 historic autopsy records (1912-2012) of TAG institutions holding rock hyrax was done to investigate the incidence of nutritional pathology in this species. As a retrospective study, the data is limited to using the autopsy terminology as stated. Therefore, those autopsy records included in the data can only viewed as having possible nutritive factors in the development of the pathology stated in each record.

Indicators of nutritional pathology were found in 57.6% of the autopsy records. Nutritional pathology was most often an incidental finding and not always stated as the cause of death. However, in those records with indicators of nutritional pathology, there were usually concurrent nutritional pathologies. In order of prevalence, the nutritional pathologies include diabetes, iron storage disease (hemosiderosis and/or hemochromatosis), inflammation of the gastrointestinal tract (GIT), GIT obstruction and, various nutritional pathologies (vitamin E deficiency, selenium deficiency, zinc deficiency and malnutrition).

To understand the pathogenesis of these nutritional pathologies in rock hyrax, it is essential to review the wild feeding ecology of the rock hyrax. After that review, a discussion of the nutritional pathology is given (in order of prevalence) with possible (and likely) diet-related and environmental factors in the pathogenesis as relates to the wild feeding ecology.

The final section of this document includes a recommended diet for captive rock hyrax. The diet recommendations will be made based on the wild feeding ecology of the rock hyrax and the nutrient requirement in form and function of the rock hyrax physiology that has evolved within its wild environment.

Wild Feeding Ecology of the Rock Hyrax

Rock hyrax are small herbivores with an average weight of 3.5 kg for adult animals (McNairn & Fairall, 1984). The average female weight is 3.6 kg and the male average weight is 4.0 kg (Olds & Shoshani, 1982). The rock hyrax as a species has evolved in warm, equatorial, humid sub-tropical environments with a thermal neutral zone (range) of 20º C-30º C (68º F-86º F)(Louw et al, 1973). The thermal neutral zone is the range of temperatures an organism is at equilibrium with the environment. "Equilibrium" means the animal uses very little energy to thermoregulate and it does not have to use energy to keep warm, nor use energy to cool itself.

Nutritional Niche. The rock hyrax is an herbivore – a browser - that will eat some grasses when preferred browse is not available (Paul-Murphy et al, 1982; Fourie, 1983). Grass intake is only about 15% of the yearly diet (Fourie, 1983). The preferred wild diet of the rock hyrax includes herbaceous plant species (flowers, shoots, fruit, buds, leaves), lichens (Olds & Shoshani, 1982; Fourie, 1983) and cactus pads (cladodes) (Hernández-Urbiola et al, 2011). The wild feeding pattern of the rock hyrax is to eat twice daily: morning and late afternoon (Leon, 1980). However, the rock hyrax will eat throughout day if the temperature is lower than its thermoneutral range.

Dentition. Rock hyrax have a dental pattern of permanent teeth of 34 (C I 1/2, 0/0, P 4/4 and M 3/3) (Olds & Shoshani, 1982). Rock hyrax eat by turning their head sideways and cutting with the premolars and molars (Fourie, 1983). The incisors are not used for eating, but they are used for biting (defense) or as tools (Franks et al, 1985). Only the two upper incisors are ever-growing (Olds & Shoshani, 1982).

Gastrointestinal Tract. The gastrointestinal tract (GIT) of the rock hyrax is both unique and fascinating. Rock hyrax are hindgut fermenters with two caeca connected by a large, proximal colon (connecting colon), and a distal colon (Eloff, 1983; Björnhag et al, 1994; Björnhag et al, 1995; Stevens & Hume, 1998).

The stomach is divided into glandular and non-glandular sections and food will remain in the stomach for up to four hours (Leon, 1980). The non-glandular section is slower moving and acts as a food reservoir and a site of fermentation before ingested food moves into the glandular portion of the stomach. The glandular section of the stomach has a higher motility where the fermented digesta is mixed. The stomach normally should have a high lactic acid level produced by GIT bacteria (Stevens & Hume, 1998). Despite the higher rate of motility in the glandular section of the stomach, the stomach of the rock hyrax would normally be processing variable levels of digesta at all times and normally should not be completely empty between feedings.

After leaving the glandular section of the stomach, ingesta travels through the small intestine (where water is absorbed) to the first cecum (left side of the abdomen). The first cecum (fermentation occurs here) is motile, but ingesta leaves the cecum slowly. After passing from the first cecum, the ingesta travels through the connecting colon (another location where water is absorbed as well as absorption of electrolytes and fatty acids) to the second cecum (colonic sac) located in the right side of the abdomen. The cecum/colonic sac has two appendages and this is where ingesta continues to be mixed (motile) and fermented before transport into and through the distal colon.

Passage of ingesta through the GIT is always forward-moving meaning ingesta is not re-cycled (retrograde) into any portion of the GIT track (Björnhag et al, 1994). As a result, this means that rock hyrax do not ruminate (chew cud) but they do grind their molars and this may appear as rumination (Leon, 1980). Rock hyrax are not copraphagic (cecotrophic) (Fourie, 1983)

Gastric transit time (GTT) in the rock hyrax GIT is reported as little as 16 hours (Clemens, 1977; Eloff, 1983). However, Paul-Murphy et al (1982) report that the GTT in hyrax on a high fibre diet can increase to as much as 106 hours (4.4 days) based on 95% of the marker to pass through the GIT. In general, a slower GTT results in higher digestive efficiency. Digestive efficiency is an important factor for high fibre diets and the GIT of rock hyrax is very efficient at digesting fibre. For an example, rock hyrax digest alfalfa pellets at a rate of 53.3% dry matter (DM) compared to 43.7% (DM) for rabbits and 60.8% (DM) for sheep (Paul-Murphy et al, 1982). Therefore, the diet of the rock hyrax should be high in fibres and the GTT should be slow, but ingesta should be constantly moving.

Volatile Fatty Acids. The complex GIT of the rock hyrax has evolved to digest a diet high in fibres and produce volatile fatty acids (VFAs). VFAs are also called short-chained fatty acids (SCFAs). SCFAs provide energy, microbial protein, aid in protein synthesis, support immune function and, produce B vitamins. SCFAs also produce ammonia that is needed to conserve nitrogen and water.

The three major sites of GIT fermentation to produce VFAs and lactic acid in the rock hyrax are the stomach and both ceca (Clemens, 1977). Lactic acid is produced in the stomach (Stevens & Hume, 1998) by bacteria. Lactic acid is important for digestive efficiency, stimulating peristalsis (motility), maintaining the gut pH (acid-alkaline balance), supporting immune function and produce B vitamins. Although the stomach environment has a high lactic acid level, the majority of the VFAs (SCFAs) that are produced in the stomach are acetic acid (87%-98%) (Stevens & Hume, 1998). Acetic acid (acetate) is important for the production of adenosine triphosphate (ATP) needed for many physiological processes such as gut fermentation, glucose metabolism and cellular metabolism. The ceca produce acetic, propionic and butyric acids (Leon, 1980). Among other roles, propionic acid (proprionate) is important in glucose metabolism. Butyric acid (butyrate) is an important energy source for cells of the GIT, it modulates inflammation of the gut mucosa and, it has a role in immune function. All these factors will become relevant when we discuss nutritional pathology later in this document.

SCFAs provide more than 70% of the energy needs of the rock hyrax and about 31-60% of metabolizable energy (ME) is produced in the ceca and colon (Stevens & Hume, 1998; Björnhag G et al, 1995). Eloff and Haven (1985) report that 69.9% of the BMR requirements for rock hyrax is provided by SCFAs. As a comparison, ruminant animals produce an average of 80% (Eloff and Haven, 1985) of their BMR requirements from SCFAs. Although the total VFA production is approximately equal between the ceca and colon (Eloff and Haven, 1985), there are differences in type of VFA produced. The molar percentage of SCFAs produced in the first and second ceca are acetic acid (72% and 67% respectively); propionic acid (14% and 21% respectively); and butyric acid (14% and 13% respectively). The production ratio of SCFAs (acetic, propionic and butyric acids) in the rock hyrax is typical of most animals with ceca (70:20:10 respectively)(Björnhag G et al, 1995).

Calcium metabolism. Rock hyrax have the ability to concentrate their urine to reduce water loss as part of an efficient physiology to successfully live in arid environments (Rübsamen et al, 1979). The concentrated urine of rock hyrax is a precipitate (insoluble solid) of calcium carbonate (whitish appearance after excretion) in a clear fluid that turns reddish-brown after urination. Concentrated urine is also seen in hamsters, rabbits and guinea pigs. The majority of excreted calcium is via urine, but some calcium is also excreted in feces (Leon & Belonje, 1979).

Dietary calcium intake does affect the amount of calcium excreted in the urine of rock hyrax, but it is also related to the amount of dietary fibre. For example, rock hyrax on high fibre diets had a gain of 7.8% calcium over what they consumed, but rock hyrax on low fibre diets lost 20.7% more calcium than they consumed (Leon & Belonje, 1979). Part of this calcium absorption mechanism - as explained by the researchers - is that high fibre diets move slower through the rock hyrax GIT allowing a greater percentage of calcium to be absorbed and used by the animal's physiology. Diets low in fibre move quickly through the rock hyrax GIT, calcium is not absorbed and it results in a net loss for the animal.

Metabolic Rate. The metabolic rate of an animal is an important consideration when formulating a captive diet. It is especially important for the rock hyrax because this species has a low metabolic rate (Fairall et al, 1983) and a metabolic rate much lower than the guinea pig, a species compared as similar to the rock hyrax (Fairall et al, 1983; Fourie, 1983).

A reflection of the low metabolic rate of rock hyrax is an average, normal core body temperature of only 35º C (Louw et al, 1973). Depending on the researcher, the metabolic rate of the rock hyrax is only 57% of the predicted value for eutherian (placental) mammals (Rübsamen et al, 1979); 40% below the expected eutherian metabolic rate (Rübsamen et al 1982); or, the adult metabolic rate is 21.6% below the expected rate for adults and 28.3% below the expected rate for juveniles (McNairn & Fairall, 1984). Despite the apparent lack of agreement at just how low the metabolic rate of the rock hyrax is compared to other eutherian species, researchers do agree that the metabolic rate of the rock hyrax is lower than expected when compared to other eutherian species.

Despite a low metabolic rate, wild rock hyrax do not store fat in the abdomen (Fourie, 1983), but they do store body fat around the kidneys and gonads (Fourie & Perrin, 1985). The literature does not appear to confirm or dispute evidence of subcutaneous fat in hyrax. However, species that have evolved in warm climates tend to have lower levels of subcutaneous fat and body fat tends to be localized in a specific body area (e.g., the humps of camels or around kidneys and gonads). Lower levels of subcutaneous fat allow for more efficient heat dissipation and localized body fat allows for insulation of important organs (kidneys and gonads in the rock hyrax). Localized body fat can be used as a source of stored energy.

Thermoregulation. Thermoregulation is included as a dietary factor in this document because of some unique physiology in the rock hyrax. As a species, rock hyrax have a limited thermal zone of only 20º C-30º C (68º F-86º F)(Louw et al, 1973). Rock hyrax use behavioural thermoregulation to maintain the thermal neutral zone by moving from cold to warm and hot to cool areas. For example, rock hyrax use their burrows to keep warm when it is cooler and to keep cool when it is warmer. The burrows of rock hyrax have temperature fluctuations of only 4º C (Rübsamen et al, 1982). Rock hyrax also bask. In addition, the fur of rock hyrax is designed to assist in behavioural thermoregulation. The rock hyrax has thicker fur on the dorsal surface (back) and thinner fur on ventral (stomach) surface. The thicker, dorsal fur allows for some protection from the environment and the thinner fur allows for heat dissipation and cooling if the animal lays flat on cool surfaces. The rock hyrax can also use pilo-erection to retain body heat (Fourie, 1983).

Some of the unique features of thermoregulation in the rock hyrax are their limited ability to cope with extremes in environmental temperature. For example, in lower ambient temperatures the metabolic rate of the rock hyrax decreases (McNairn & Fairall, 1979) and this has been described as torpor (Fairall et al, 1983). While torpor does include a reduction in metabolic rate, it also usually includes a significant drop in body temperature from which the animal recovers without harmful consequences. If the body temperature of a rock does drop in response to low ambient temperatures, there are harmful effects to the animal. Therefore, this species is not using torpor. The normal body temperatures of rock hyrax only fluctuate plus or minus (+/-) 2º C (3.6º F) and fluctuations greater or less than 2º C (3.6º F) result in cold or heat stress (Bartholomew and Rainy, 1971; Rübsamen et al, 1982; Omar & Magdy, 2009). When rock hyrax are allowed to behaviourally thermoregulate, they do not allow their body temperature to increase or decrease more than 2 º C (Rübsamen et al, 1982). Neonates and juveniles are most at risk for temperature extremes due to their smaller body size that creates a relatively larger surface area compared to internal area (McNairn &Fairall, 1984).

Cold stress. The physiological effects of ambient temperatures lower than the thermal neutral zone of

20º C (68º F) can result in cold stress (hypothermia) in the rock hyrax if they cannot use behavioural thermoregulation (move to a warmer location). The normal body temperature of the rock hyrax is 35º C (95º F) (Louw et al, 1973) and a decrease in body temperature of more than 2º C (3.6º F) will result in hypothermia (Bartholomew and Rainy, 1971). The pathophysiology of hypothermia is a concern in any species, but it is particularly of concern in the rock hyrax. It is a serious concern in the rock hyrax not only because of their lower metabolic rate, but because this species responds to lower ambient temperatures by furthering reducing their metabolic rate (McNairn & Fairall, 1979). In addition to pathology such as pancreatitis, acidosis and cellular death, hypothermia also affects the GIT (Mallet, 2002). The effects of hypothermia on the GIT include a loss of gut motility (peristalsis), bowel obstruction (ileus) and, damage to the gut mucosa especially in the stomach and duodenum. The gut mucosa is damaged because hypothermia causes an increase in gastric acid with a concomitant decrease in duodenal bicarbonate secretion. The increase in GIT acid and decrease in buffering causes inflammation and ulceration that kills cells and gut microbes.

A syndrome described as "Hyracoidea stress syndrome" can also result from ambient temperatures that are too cold (Omar & Magdy, 2009). This syndrome includes anorexia, pneumonia, loss of tonus (muscle tone), seizures, coma then death.

Heat Stress. Rock hyrax are equally at risk for heat stress (hyperthermia) and must be maintained in environments < 30º C (86º F). Even a slight increase in body temperature of more than 2º C (3.6º F) will result in hyperthermia (Bartholomew and Rainy, 1971). In general, as the ambient temperature increases, the body temperature of the hyrax will increase (Bartholomew and Rainy, 1971; Olds & Shoshani, 1982; Rübsamen et al, 1982; McNairn & Fairall, 1984). The rise in body temperature as a response to an increase in ambient temperature occurs despite physiological changes that would normally maintain homeostasis. For example, in response to an increase in environmental temperatures, the rock hyrax will increase respiration rate to as much as 200 per minute (normal is 35 to 40 per minute), sweat from foot pads, place full ventral (stomach) contact with the ground and extend legs forward and back (Bartholomew and Rainy, 1971). None of these mechanisms successfully reduce the animal's body temperature in response to high ambient temperatures.

Hydration

Wild rock hyrax have evolved in environments with limited groundwater. Therefore, their physiology has adapted by having a low metabolic rate and producing concentrated urine to limit water loss (Rübsamen et al, 1979).

In general, wild rock hyrax obtain water from the plants in their diet, but they drink when water is available and water must be provided in captivity. A minimum of 44 to 61 $ml/kg^{-0.82}$ of water should be provided for each rock hyrax daily (Louw et al, 1973; Rübsamen et al, 1979). Rock hyrax normally have high GIT levels of water similar to sheep and camels (Rübsamen et al, 1979) and this high GIT water level is essential to aid in the digestion of fibre and support gut microbes. For example, the total, average GIT contents (water plus ingesta) are approximately 27.7% to 37.1% of the body weight of an adult rock hyrax (Eloff & Hoven, 1985).

Nutritional Pathology

Table 1. Nutritional Pathology in Rock Hyrax 1912-2012 listed by Prevalence

Pathology	Incidence % of all Autospies	Incidence % of Autopsies with nutritional pathology	Nutritional Factor
Type II Diabetes	4.8	8.3	Excess simple carbohydrates (e.g., sugars) and/or excess carbohydrates
Diabetes related Dystocia	4.8	8.3	
Diabetes Prenatal and Neonatal Death****	18.9 **Total:** 28.5	32.8 **Total:** 49.4	
Iron storage disease (Hemosiderosis, Hemochromatosis)	15.8	27.4	High dietary iron levels or lack of iron inhibiting dietary levels (e.g., fibre, tannins, phytates) or excess dietary ascorbic acid
Acquired Immunodeficiency**	14.1	24.5	Dietary vitamin E deficiency, stress, dietary deficiency of omega fatty acids, dietary excess of omega 6 fatty acid, beta-carotene deficiency; disruption of GIT microbial population, dietary lack of micronutrients (vitamins, minerals), inappropriate dietary protein, fatty acid deficiency
GIT-"itis"*	10.6	18.5	Vitamin B deficiency, lack of dietary fiber, disruption of gut microbial population, high dietary level of carbohydrates (sugar, starch), lack of dietary fiber, refined carbohydrates
Cardiomyopathy	7.0	12.1	Imbalances of omega fatty acids, amino acids (L-carnitine, tryptophan), vitamins (B_1 (thiamine), choline, vitamin E) and minerals (calcium, copper, iron, magnesium, potassium, and selenium)
Intraspecies aggression	5.0	8.6	-
GIT Obstruction***	2.9	5.1	Rapid consumption of non-food materials (dirt, gravel, wood shavings); GIT pH extremes; microbial imbalance; fibre deficiency, loss of gut motility
Various++	2.9	5.1	All diet deficiencies
MBD+	2.6	4.5	Deficiencies of, dietary calcium and vitamin D_3, energy deficient diets, excessive calcium and/or vitamin D_3, high energy (fat rich) diets for growing animals, lack of dietary protein, skewed Ca:P ratio

***GIT"itis":** Gastrointestinal disease process potentially related to nutrition; includes colitis, enteritis, gastritis (did not use those records stating parasitic cause); occurred in adults and juveniles

**** Immune Dysfunction:** bacterial infections, skin disorders, viral infections, respiratory infections (e.g., pneumonias)

*****GIT Obstruction:** impaction, cecolith, enterolith, phytobezoars, etc

****** Diabetes Abortion, Stillbirth and/or Neonatal Death:** includes abortions, stillbirths, thickened placenta, placentitis, neonate anemia, neonate fatty liver, neonate myopathy, neonate hypoglycemia and neonate spleen dysfunction

+MBD: metabolic bone disease; includes osteomyelitis, osteomalacia, rickets, hypercalcemia, soft-tissue mineralization

++Various: Includes vitamin E deficiency, selenium deficiency, zinc deficiency and malnutrition

The average lifespan of wild hyrax is approximately 10 years (Fourie, 1983). However, the average lifespan of captive rock hyrax is only 3.2 years. That average would be much lower if neonatal deaths (< 1 month of age) were used in calculating the average. The apparent incidence of nutritional pathology appears to be a major factor in the short life spans of captive rock hyrax. Nutritional pathology is extensive in captive rock hyrax at a rate of at least 57.6% of the autopsy records. Nutritional pathology was most often an incidental finding (not a cause of death), but most animals appeared to develop more than one nutrition related pathology.

Table 1 (above) lists, in order of prevalence, the nutritional pathologies found in autopsy records of captive rock hyrax. These nutritional pathologies include diabetes, iron storage disease (hemosiderosis and/or hemochromatosis), inflammation of the GIT, GIT obstruction and, various nutritional pathologies (vitamin E deficiency, selenium deficiency, zinc deficiency and malnutrition).

Table 2 (below), illustrates the occurrence of nutritional pathology according to decade. While the data in Table 2 appears to suggest that captive rock hyrax have developed MORE pathology related to diet in the last two decades, I would argue that we should come to another conclusion based on the data in Table 2. The alternate conclusion is that zoological professionals in the last two to three decades have been more aware of nutritional pathology than previous decades. As a result, education and awareness of nutritional pathology has resulted in more frequent reporting and diagnosis of diet related pathology. The two best examples are iron storage disease (ISD) (hemosiderosis, hemochromatosis) and cardiomyopathy. The identification of these two pathologies related to nutritional factors has increased with many captive wildlife species in the past two decades because of research and education that has identified nutritional factors as causal factors. It is my opinion that these pathologies have not increased, but were under-reported in previous decades due to lack of awareness.

This section will discuss the nutrition-related pathology and the possible diet factors of each pathology. The last section in this document will provide a recommended diet for captive rock hyrax.

Table 2. Nutritional Pathology in Rock Hyrax 1912-2012 Historical Prevalence

Pathology	**1912-1980 % of all cases***	**1981-1990 % of all cases***	**1991-2000 % of all cases***	**2001-2012 % of all cases***
Type II Diabetes	11.53	3.85	30.77	53.85
Diabetes related Dystocia	15.38	15.38	38.46	30.77
Diabetes Prenatal and Neonatal Death	12.62 **Total: 12.9**	24.27 **Total: 19.4**	51.46 **Total: 45.8**	11.65 **Total: 21.9**
Iron storage disease (Hemosiderosis, Hemochromatosis)	2.33	4.65	34.88	58.14
Acquired Immunodeficiency	11.69	12.99	42.86	32.47
GIT-"itis"	5.17	12.07	43.10	39.66
Cardiomyopathy	2.63	0.00	23.68	68.42
Intraspecies aggression	11.11	40.74	22.22	25.92
GIT Obstruction	6.25	25.00	25.00	43.75
Various	6.25	25.00	43.75	25.00
MBD	50.00	7.14	7.14	35.71

*Nutritional pathology cases only

Type II Diabetes

The overall incidence of diabetes (Type II) in captive hyrax appears to be at least 28.5% of all autopsies and it is 49.4% of those autopsies identified with, at least, one nutritional pathology. In many cases, diabetes was not stated but it was often described. The findings in these autopsies are similar to Gamble et al (2004) who identified hyperglycemia and/or diabetes in rock hyrax 1 to 7 years of age housed in 7 of 10 zoological institutions. I divided the autopsies into diabetes, diabetes related dystocia and diabetes related abortion, stillbirth and neonatal death (< 1 month of age).

In general, diabetes is often found in captive wildlife species – especially herbivores – with diets high in fruits and vegetables relative to foods lower in starch and sugar and higher in fibre. Fruits and vegetables are inappropriate foods for captive herbivores because these provide low-fibre carbohydrates (starch, sugar) that are fermented quickly in the GIT. The fermentation of starch and sugars causes a change in gut pH, and this change in gut pH results in the death of symbiotic microorganisms essential to producing energy and nutrients for herbivore species. In addition, the quick fermentation of starch and sugar causes a rapid increase in blood glucose and a responsive increase in insulin ("insulin spike"). Chronic insulin spikes are the cause of insulin resistance (metabolic syndrome), a pre-condition for the development of Type II diabetes.

In addition, commercial herbivore pellets fed to captive rock hyrax can be a source of starch and sugar. For example, many of these foods have added sugars in the form of corn syrup solids, molasses, dextrose, glucose to make the feed palatable (tasty). Many commercial herbivore pellets are designed to meet the needs of domestic food animals and/or are formulated based on the requirements of domestic food animals, therefore may not be appropriate as feed for rock hyrax.

Pathology in herbivores like the rock hyrax related to diabetes includes poor body condition (are overweight or underweight), cardiomyopathy, neuropathies, immune dysfunction, kidney disease, pancreatitis, heart disease, sterility, impaired immune function and, retinopathy. Anemia is also a common finding in diabetic animals due to associated renal disease that limits the formation of red blood cells in bone marrow (McGill & Bell, 2006).

Diabetes related dystocia. The autopsy database reveals approximately 4.8% overall percentage of diabetes related dystocia. Dystocia related to diabetes is 8.3% of all cases with, at least, one nutritional pathology. Females with diabetes are most likely to have problem pregnancies including placentitis, spontaneous abortion, premature births, thickened placentas and, neglect their offspring.

Prenatal and Neonatal deaths. The data base of autopsies for rock hyrax reveal about an 18.9 overall percentage of diabetes related abortion, stillbirth or neonatal death. Abortion, stillbirth or neonatal death is 32.8% of all cases with at least one nutritional pathology.

If a diabetic female is able to have a full-term pregnancy, the neonates of diabetic mothers have significant diabetic-related pathologies. These diabetic-related pathologies include anemia, hypoxemia, hypoglycemia, fatty liver, hyperinsulinemia hypocalcemia, hypomagnesiumemia (Weintrob, Karp & Hod, 1996; Stenninger et al, 1998; Jawerbaum & White, 2010). Pancreatic islet fibrosis in neonate and juvenile rock hyrax is similar to that found in human infants born to diabetic mothers (Garner et al, 2004).

Offspring that survive > 1 month of age are immune-suppressed and live shortened lifespans due to opportunistic bacterial and viral infections (Weintrob, Karp & Hod, 1996; Jawerbaum & White, 2010). Those offspring that survive also have impaired glucose tolerance, diabetes and neuropsychological dysfunction (Weintrob, Karp & Hod, 1996; Stenninger E et al 1998).

Iron Storage Disease (ISD)

Iron storage disease (ISD) is also called hemosiderosis and hemochromatosis. Hemosiderosis is an abnormal deposition of iron (hemosiderin) in visceral organs (e.g., duodenum, kidneys, liver, lung, heart and spleen), lymph nodes and the GIT, but the hemosiderin deposit have not yet caused a disease process. Hemosiderosis becomes hemochromatosis when iron deposition in tissues causes a disease process because the organ or tissues can no longer function – the hemosiderin (iron) deposits have replaced healthy, functioning cells.

Some of the disease processes associated with ISD include cancer, diabetes, fibrosis of viscera, heart disease, immune system dysfunction, liver disease and, neuropathology. This is a disease that is often not found until post mortem (autopsy). The overall incidence of ISD in captive hyrax appears to be at least 15.8% of all autopsies and it is 27.4% of those autopsies identified with, at least, one nutritional pathology. It is important to note that ISD was reported in rock hyrax of all ages (fetal, juveniles and adults).

Current research has found the tendency to develop ISD is related both to a species physiological ability to bind iron (dietary iron sensitivity) and to captive diets. Research also has shown that once ISD develops, dietary measures can prevent further iron deposition, but it cannot eliminate the hemosiderin already deposited in tissues. Prevention is the important emphasis for this disease.

Research now indicates that many captive species are at risk for developing the disease. However, herbivorous species are especially at risk for ISD because captive diets are low in fibre, therefore the captive diets are also low in phytates and tannins. Phytates (phytic acid) and tannins are associated with dietary fibre and they bind (chelate) with excess dietary iron so it is not available for deposition in tissues. However, as with all nutrients, a balance is necessary because excessive dietary amounts of phytates and tannins can also bind to dietary calcium, magnesium, niacin, zinc and protein and make it unavailable for digestion.

Dietary sources of excess iron include most commercial herbivore pellets fed to captive rock hyrax because they are formulated for species with higher dietary iron requirements. Dietary ascorbic acid and ascorbic acid from supplements increases dietary iron absorption. Foods such as citrus, fruit and some vegetables are often not normally ingested by herbivore species in the wild and the dietary ascorbic acid contribute to ISD. The combination of excess dietary iron plus foods with ascorbic acid can be lethal.

Acquired Immunodeficiency

The overall incidence of markers for immune dysfunction for captive rock hyrax is at least 14.1% of all autopsies and it is 24.5% of those autopsies identified with, at least, one nutritional pathology. Immunodeficiency occurs when the ability of an organism's immune system is reduced or absent. Indicators of immune dysfunction include a high incidence of bacterial and viral infections, respiratory disorders (e.g., pneumonia) and skin diseases.

There are several potential sources as a cause of acquired immunodeficiency. However, for herbivorous species, a primary factor in acquired immunodeficiency is malnutrition related to an inappropriate diet that does not support GIT microbial populations. GIT microbial populations are essential to produce VFAs needed to support immune system function in herbivores.

***GIT"itis"**

GIT disease processes potentially related to nutrition are inflammatory and include colitis, enteritis and gastritis. In general, all of these disease processes include inflammation of tissues within the GIT. GIT inflammation, especially in herbivores, can result from a lack of appropriate gut flora and/or can kill the gut microbiological population. Inflammation of the GIT also destroys GIT tissue including microvilli needed to absorb nutrients and damaged tissue is replaced with non-functioning scar tissue. GIT inflammation was reported in juveniles and adults.

The pathobiology of GIT inflammation can be complex and can include several physical and psychological influences that are beyond the scope of this document. However, in my experience formulating diets for captive herbivorous species, diet usually is a major contributor to the development of GIT inflammation.

Cardiomyopathy

Cardiomyopathy is a disease of the myocardium (heart muscle) and symptoms include inflammation of the heart muscle, loss of heart muscle function and, arrhythmia. Nutritional factors in the development of cardiomyopathy for the rock hyrax include imbalances of omega fatty acids, amino acids (L-carnitine, tryptophan), vitamins (B_1 (thiamine), choline, vitamin E) and minerals (calcium, copper, iron, magnesium, potassium, and selenium). Omega fatty acids have an anti-inflammatory function, they lower blood pressure, have a role in maintaining normal heart rhythm and, omega fatty acids promotes artery dilation. Amino acids are needed for normal heart function including cellular energy metabolism, heart rate, lipid metabolism and, as a protective effect against cardiac necrosis. The functions of amino acids are interrelated meaning that a deficiency in one amino acid will affect the function of other amino acids. While we do not yet know the essential amino acids (those amino acids that must be obtained from food) of rock hyrax, rock hyrax are probably similar to most herbivores who must get their amino acids from both food sources and microbial protein.

Imbalances of several vitamins and minerals can be a factor in cardiomyopathy, but vitamin E particularly is important. Vitamin E has importance as an antioxidant with a role in immune function, inhibits platelet aggregation and promotes normal artery dilatation. In general, vitamin E reduces the effects of and/or protects against cardiomyopathy.

Intraspecies Aggression

Intraspecies aggression in captive animals is not necessarily a nutritional pathology although a lack of food resources could technically qualify if such a shortage caused aggression in animals housed together. However, I am not including intraspecies aggression in this document because of its relationship to nutrition.

Intraspecies aggression (bites and fractures from conspecifics) is the sixth most common problem I found in the autopsy database relative to the nutritional pathologies I have included in this document. The overall incidence of intraspecies aggression is 5.0% of all autopsies and it is 8.6% relative to those autopsies identified with, at least, one nutritional pathology. In general, the result of most aggression appeared to contribute significantly to the death of an animal.

Intraspecies aggression can result from numerous factors, including the tendency of animals to attack other animals that are in debilitated condition. For example, the questions we could ask is "Did the aggressive act occur because an animal was ill?" or "Did the aggressive act contribute to the deterioration of the animal"? However, most literature about aggression to conspecifics focuses on social structure and dynamics relative to housing conditions. Therefore, because of the apparent high incidence of intraspecies aggression, I would like to provide a short review of the literature regarding the social dynamics within rock hyrax communities.

First, some background definitions based on Fourie (1983). Adult rock hyrax are > two years of age; sub-adults are 13 to 24 months of age; juveniles are one to 12 months of age; and, neonates are < 1 month of age. A normal rock hyrax community in the wild can have 50 to 80 animals, but this community is divided into territories defended by a dominant male. The group defended by the dominant male includes several adult females and offspring.

Rock hyrax mature sexually at 15 to 17 months of age. Juvenile and sub-adult males of a territory do not mate with related females of their group. Sub-adult males leave the group before the next mating season to establish their own territory within a community. Seventy-five percent of sub-adult females will also leave before the next mating season. Sub-adult and adult male rock hyrax do not live in bachelor groups. Fourie (1983) reports that rock hyrax show aggression when food is scarce, against young males or against old animals but 88% of aggression is against another male of the group. In the autopsy database of captive rick hyrax, approximately 75% of the intraspecies aggression in the autopsy database was directed at young male animals. This would imply that sub-adult males are not being removed from captive colonies (or not removed in a timely manner). The dominant male may be forced to act accordingly and destroy what they perceive as a rival and interloper in their territory. Adult male rock hyrax cannot be housed together and even surgical castration does not reduce intraspecies aggression between rock hyrax males of any age (Manharth & Harris-Gerber, 2002). Therefore, we should look at the population dynamics of captive rock hyrax groups and manage them to avoid social discord, especially as related to breeding status.

Signs of aggression in rock hyrax include growling, flaring dorsal hair, chasing and biting. Aggression towards conspecifics would normally increase during reproductive season (April in the wild).

Intraspecies aggression creates an environment of stress in a rock hyrax community and such stress has health effects beyond physical trauma. Stress is a factor in hyrax stress syndrome (Omar & Magdy, 2009) and it has a role in the formation of gastric ulcers and other GIT pathology (Soma H et al, 1976).

Gastrointestinal (GIT) Obstruction

GIT obstruction in the rock hyrax includes impaction, cecoliths and, enteroliths. The overall incidence of GIT obstruction for captive rock hyrax is at least 2.9% of all autopsies and it is 5.1% of those autopsies identified with, at least, one nutritional pathology.

Most often, GIT impaction in small, herbivore hindgut fermenters like the rock hyrax is related to inappropriate diets that are too high in protein; have inappropriate protein sources (e.g., meat diets for herbivores); have a high soluble carbohydrate level (e.g., starch, sugars); and, are too low in fibre. In addition, providing environmental enrichment such as branches, hay or wood when these species are fed inappropriate diets are a factor in the development of a gastric obstruction. Fibrous dietary items such as branches, hay or wood are not digested when the herbivore gut pH is too high (alkaline). The alkaline pH is caused by inappropriate diets. The environmental enrichment (branches, hay or wood) becomes undigested fiber and these undigested fibers add to, or form, the obstruction within the GIT.

A factor in the formation of GIT obstructions unique to the rock hyrax is the effect of a decrease in ambient temperature on their GIT function. The lower metabolic rate of rock hyrax predisposes them to GIT obstruction because their physiology responds to lower ambient temperatures by furthering reducing their metabolic rate (McNairn & Fairall, 1979) and this reduction in metabolism reduces gut motility (peristalsis), (Mallet, 2002). Reduced gut motility allows food within the GIT to accumulate.

In general, a yearly examination of small, herbivore hindgut fermenters such as the rock hyrax is recommended to find GIT formations before they cause an obstruction. In most cases, palpation and/or x-ray are sufficient. If necessary, an obstruction can be removed surgically. In general, if rock hyrax reduce their feed intake and/or lose weight, GIT obstruction should be suspected. This is especially warranted if the animal has been exposed to a decrease in ambient temperatures > 2º C.

Various

Some of the autopsy records specifically stated a nutrient deficiency in the findings. However, the incidence of these statements was not sufficient to discuss individually. Therefore, I grouped these records under "various". These records include vitamin E deficiency, selenium deficiency, zinc deficiency and malnutrition. The overall incidence of various nutrient deficiencies for captive rock hyrax is at least 2.9% of all autopsies and it is 5.1% of those autopsies identified with, at least, one nutritional pathology.

The deficiencies included under "various" directly support nutrition factors for cardiomyopathy, acquired immunodeficiency and indirectly support other pathologies and/or may result from some pathologies.

Metabolic Bone Disease (MBD)

The overall incidence of metabolic bone disease (MBD) for captive rock hyrax is at least 2.6% of all autopsies and it is 4.5% of those autopsies identified with, at least, one nutritional pathology. MBD in these autopsy records include osteomyelitis, osteomalacia, rickets, hypercalcemia and, soft-tissue mineralization. All of these disease processes indicate dietary mineral imbalances (especially calcium, phosphorus and magnesium) and imbalances of vitamins A & D_3.

A key factor for the development of MBD in captive rock hyrax are diets too low in fibre. For rock hyrax, calcium metabolism is related to the amount of dietary fibre. Rock hyrax on high fibre diets had a gain of 7.8% calcium over what they consumed but rock hyrax on low fibre diets lost 20.7% more calcium than they consumed (Leon & Belonje, 1979). Part of the mechanism as explained by the researchers is that high fibre diets move slower through the rock hyrax GIT allowing a greater percentage of calcium to be absorbed and used by the animal's physiology. Diets low in fibre move quickly through the rock hyrax GIT, calcium is not absorbed and it results in a net loss for the animal.

Another factor in the development of MBD in captive rock hyrax may also be excess phosphorus. High dietary intakes of phosphorus can inhibit calcium absorption by forming insoluble calcium triphosphate. Commercial herbivore feeds designed for domestic food animals – or other exotic animals – may be a factor.

Diet Guidelines for Rock Hyrax

Despite eating seasonally, wild rock hyrax maintain a stable percent of nutrients throughout the year (Fourie, 1983) year round. Therefore, the dietary goals for captive rock hyrax include stable nutrient compositions for all seasons.

Normal Weight Range; Assessing Body Condition

Weight. The average weight of rock hyrax is 3.5 kg for female and 4.0 kg for male (Olds & Shoshani, 1982; McNairn & Fairall, 1984). Rock hyrax body weights can range from 2.3 kg to 2.8 kg (Eloff & Hoven, 1985). Obesity is not a typical finding in the autopsy database, but underweight rock hyrax are frequently reported. Therefore, monitoring body condition may be necessary to identify individuals who are underweight versus overweight individuals.

Weights should be monitored at least monthly, but this routine can be a problem with rock hyrax. Rock hyrax are easily stressed when handled. Therefore, a visual system of monitoring may be the most humane method to use for rock hyrax. If rock hyrax are weighed, one must be aware that diet can effect the weight of an animal. For example, a weight gain may not reflect an increase in body mass because the GIT system of the rock hyrax is designed to retain large amounts of fibrous ingesta. Such large amounts of fibrous ingesta can expand and the rock hyrax GIT will expand to accommodate (Eloff & Hoven, 1985). The average GIT contents in rock hyrax can be 27.7% to 37.1% of the animal's body weight (Eloff & Hoven, 1985).

Assessing Body Condition. Despite a low metabolic rate, wild rock hyrax do not store fat in the abdomen (Fourie, 1983), but they do store body fat around the kidneys and gonads (Fourie & Perrin, 1985). The literature does not appear to confirm or dispute evidence of subcutaneous fat in hyrax. One can assess body condition in the rock hyrax weighing and/or visual assessment. If weighing rock hyrax, the protocol should include a once monthly weigh-in usually before the first meal of the day and at the same time of day. Visual body condition monitoring should focus on identifying individuals with concave sides and hip bones that are easily seen. Concave sides and hip bones that are easily seen identify underweight animals.

Daily Kilocalorie (Calorie) Requirement

The metabolizable energy (ME) needs of rock hyrax are 167 kilocalorie (kcal) per day for adults and 96 kcal for juveniles (Fairall et al, 1983). ME is the net energy from a food available to an animal after digestion and absorption and the loss of some material as indigestible.

The basal metabolic rate (BMR) of an adult rock hyrax is 39.4 kilocalories $(kg)^{-0.75}$ (Rubsamen et al, 1979). BMR is the caloric needs of an animal at rest in a thermoneutral zone and essentially is the energy needed to maintain the function of normal physiology.

As with any species, there is a necessity to balance weight maintenance related to feed intake. This can be a challenge with a species such as rock hyrax with a slow metabolism. For example, Millar & Fairall (1976) found that an adult 2.8 kg hyrax fed 348 calories per day gained 268 g and an adult 2.7 kg hyrax fed only 160 calories per day lost 224 g.

Dietary Protein

The dietary protein requirements (crude protein; CP) of rock hyrax average are 8% protein DM (Fairall et al, 1983) to a range of 13.9% - 18.5% DM (Fourie, 1983). Eloff & Haven (1985) report 19.6%. Hume et al (1980) report an adult rock hyrax nitrogen requirement at a rate of 311 $mg/kg^{00.75}$ per 24 hours. The traditional nitrogen conversion factor to determine an approximate protein requirement is 6.25. The approximate conversion factor is 6.25 but, when working with nitrogen conversion factors, keep in mind that foods differ in amino acids (amount and type) and the conversion factors will differ accordingly.

In captivity, we should look at the protein levels of plant species eaten by wild rock hyrax. Table 3 lists some plant species eaten by wild hyrax and some of the nutrient composition of those plants. The DM percentages of CP are in black and range from 5.9% to 32.7%. However, the average DM CP percentage is 12.7% and I think this should be considered the lowest dietary protein level for captive rock hyrax. Typically, browsing species need a higher dietary protein level than grazers and the recommended range is 12.0% - 19% percent.

Dietary Fat

In general, the literature does not prescribe dietary fat levels for rock hyrax. However, based on nutrient analysis of some of the plant species eaten by wild rock hyrax, the dietary fat level is low (see Table 3). In addition, dietary fat should only come from plant sources. The crude fat level on a DM basis for plant species eaten by wild rock hyrax ranges from 1.4% - 3.4% with an average of 2.4% (see Table 3).

Table 3. Analysis of Some Plant Species eaten by Wild Rock Hyrax

Plant Species	Crude Protein %	Crude Fat %	Crude Fiber %	NDF (cell wall)	ADF	Cellulose %	Lignin %
Asparagus stem (*Asparagus officinalis*)	32.7[3]	3.4[3]	18.5[3]	-	-	-	-
Cross-berry (*Grewia occidentalis*)	9.6[5]	-	-	42.6[5]	-	16.9[5]	0.6[5]
Prickly Pear (*Opuntia sp*)	5.9-9.0[7]	1.42-2.4[7]	11.0-23.3[7]	-	-	-	-
Sheep brush leaves (*Pentzia* sp)	13.9[1]	25.5[1]	-	-	-	-	-
Star-apple Fruit (*Diospyros lycoides*)	0.9[2], 7.8[5]	0.1[2]	3.5[2]	41.0[5]		9.7[5]	10.3[5]
Star-apple Leaves (*Diospyros lycoides*)	12-14[2]	-	-	54.4[2]	-	-	-
Sweet thorn leaves (*Acacia karroo*)	10.5[4], 14.4[5], 12.3[6]	-	-	55.9[4], 30.7[5], 27.2[6]	46.4[4], 13.9[6]	6.2[5], 6.1[6]	3.4[5]

[1]Botha 1938
[2]Mujuru 2011
[3]Aberoumand 2010
[4]Mokoboki et al 2011
[5]Bakare 2009
[6]Basha et al 2009
[7] Hernández-Urbiola et al, 2011
Red Text = as fed
Black Text = dry matter (DM)

Fibre Requirement

For herbivores, a high dietary fibre level is important for the production of VFAs SCFAs). SCFAs provide energy, microbial protein, aid in protein synthesis, support immune function and, produce B vitamins. SCFAs also produce ammonia that is needed to conserve nitrogen and water. Most of the energy needs of rock hyrax are provided by SCFAs. SCFAs provide more than 70% of the energy needs of the rock hyrax and about 31-60% of metabolizable energy (ME) is produced in the ceca and colon (Stevens & Hume, 1998; Björnhag G et al, 1995). Eloff and Haven (1985) report that 69.9% of the BMR requirements for rock hyrax is provided by SCFAs. As a comparison, ruminant animals produce an average of 80% (Eloff and Haven, 1985) of their BMR requirements from SCFAs.

Neutral Detergent Fibre (NDF). Fourie (1983) reports that wild rock hyrax eat a diet with 50.1% - 56.7% neutral detergent fibre (NDF) DM and the variance results from eating a wide selection of plant foods on a seasonal basis. NDF is insoluble fibre and is the total cell wall that includes a measure for cellulose, hemicellulose and, lignin. It is an estimate of energy content, since the higher the NDF the lower the available energy. Available nutrient analyses of some plant species eaten by wild rock hyrax show NDF levels with a range from 27.2% to 55.9% DM (see Table 3) with an average of 40.0% DM. A diet high in NDF will have a longer GIT transit time. For the rock hyrax, a diet with 49.5% NDF had 16 hours GIT transit time (Eloff, 1983)

Acid Detergent Fibre (ADF). The dietary acid detergent fibre (ADF) requirement of rock hyrax is reported at 32.5% DM (Fairall et al, 1983). Eloff & Haven (1985) report 40.1% to 48.4% ADF (DM). ADF is also insoluble fiber, but is only a measure of cellulose and lignin. There are only two reports on the ADF content of plants eaten by wild rock hyrax. Basha et al (2009) report a 13.9% ADF level in sweet thorn leaves (*Acacia karroo*) and Mokoboki et al (2011) report a 46.4% ADF level in that plant species.

Acid detergent Lignin (ADL). The acid detergent lignin (ADL) dietary level for rock hyrax has been reported as low as 14% (Fairall et al, 1983) and as high as 29.4% (Eloff & Haven,1985) for wild hyrax. ADL consists of lignin and that is a complex polymer that gives strengths to plant cell walls. Known lignin levels in some plant species (see Table 3) eaten by wild rock hyrax range from 0.6% to 10.3% with an average of 4.8%.

Soluble Fibre. Soluble fiber includes pectins and gums that are found within plant cells (plant cell contents). The dietary soluble fibre (plant cell contents) of wild hyrax is high at 51.6%, but this is typical for a browsing species (Eloff & Haven, 1985).

Cellulose. Hemicellulose and cellulose is low in the diets of wild hyrax at 8.0% and 10.7%, respectively (Eloff & Haven, 1985). Hemicellulose and cellulose are polysaccharides found in cell walls. Low dietary cellulose levels are also typical for a browsing species. Available nutrient analyses of some plant species eaten by wild rock hyrax show cellulose levels range from 6.2% - 16.9 % DM (see Table 3) with an average of 9.7% DM.

Assessing fecal quality is one way to insure captive rock hyrax are obtaining sufficient fibres in their diet. Normal rock hyrax feces should be a round pellet, slightly moist when first excreted and about 1 cm in diameter (about ¼ to 3/8 of an inch in diameter) (Chame, 2003).

Life Stage Nutrition

Neonates. Rock hyrax neonates are precocial and will begin to ingest solid food at 1 to 2 days of age. The solid foods are usually those eaten by adults and are critical to begin establishing the gut microflora in neonates (Fourie, 1983). However, the neonates will continue to suckle even as they increase their consumption of solid food. All lactating females within a rock hyrax community will allow any young in the community to suckle (Fourie, 1983). Rock hyrax offspring are fully weaned at 10 to 12 weeks of age. Neonates and juveniles with poor nutrition will reach puberty later; males will have decreased fertility; and, females will have small litters (Millar & Fairall, 1976).

Pregnancy and Lactation. Rock hyrax can be timid and nervous animals and this may cause some difficulty identifying pregnant rock hyrax. However, in general, pregnancies last 7 to 8 months and observation of breeding should indicate possible births within 7 to 8 months. Approximately 2 months before an expected birth, rations should be increased by 30%. It is important not to only increase a nutrient such as protein in preparation for a birth and/or lactation. Increasing only a specific nutrient will create a dietary imbalance that could affect the viability of neonates and reduce the amount and quality of milk produced by the female. Dietary increases should be in total amount. For example, if an animal eats 70 g of pellets per day, then a 30% increase is 70 x 0.30 = 21 + 70 = 91 g of pellets for the 2 month period before birth. Lactating animals should be fed ad lib to provide sufficient energy for lactation and provide feed for the neonates who will increasingly eat solid foods.

A Recommended Diet

It is apparent, based on the probable incidence of nutritional pathologies, that we can make some slight changes to the diets of captive rock hyrax that will have immense health benefits. Based on the autopsy data, the current average lifespan of captive rock hyrax is 3.2 years (if one does not count neonatal deaths < 1 month of age) but it should average 10 years (Fourie, 1983). Changes in captive nutrition practice can increase the captive life span of rock hyrax and increase their quality of life during the years they do live in captivity.

Table 4 compares some recommended nutrient levels for rock hyrax with some commercial foods now used in TAG institutions. It is apparent that changes should be made to captive diets to provide nutrition similar to wild feeding ecology.

A major goal when formulating diets for herbivores is to support the gut microflora essential to providing nutrients and energy to the host animal. Gut microflora must be provided with the appropriate range and amount of dietary fibre to flourish. Since the GIT of the rock hyrax has a unique complexity for a monogastric species to digest fibre, it is apparent that the diet of the rock hyrax must be high in fibre to support the gut microflora.

The microflora in the GIT of an herbivore provides essential nutrients, energy and benefits physiological function to the host animal. Benefits of a normal, healthy gut microbial population include digestive efficiency; gut peristalsis (motility); maintaining the gut pH (acid-alkaline balance); immune system function; and, B vitamins. In addition, the SCFAs produced by gut microbes are important in the production of ATP, gut fermentation, glucose metabolism, cellular metabolism, anti-inflammatory functions and, immune function. Many of the nutritional pathologies presented in this document support the conclusion that captive rock hyrax do not have normal, healthy gut microbial populations and we can conclude that captive rock hyrax are not fed diets that establishes and maintains normal gut flora.

Based on the information provided to us from the autopsy database , these are the recommendations for diet formulation of captive rock hyrax:

1. **Reduce dietary starch and sugar**. This would decrease Type II diabetes and related pathology and reduce GIT disorders (inflammation and obstruction). Vegetables and fruit should be used with caution and/or should be eliminated from captive rock hyrax diets.
2. **Increase Dietary Fibre**. Increasing all types of dietary fibre should reduce the incidence of ISD; increase immune function (due to increased VFA production); and, decrease GIT disorders (inflammation and obstruction) and, MBD. Dietary fibre is important in the calcium metabolism of rock hyrax. For example, rock hyrax on high fibre diets had a gain of 7.8% calcium over what they consumed, but rock hyrax on low fibre diets lost 20.7% more calcium than they consumed (Leon & Belonje, 1979).
3. **Provide Sufficient and Balanced Dietary Vitamins and Minerals**. This diet change would decrease the incidence of immunodeficiency, ISD and cardiomyopathy.
4. **Increase Dietary Phytates and Tannins**. Dietary phytates and tannins reduce available iron from foods. A lack of dietary phytates and tannins is thought to be a factor in the development of ISD in captive wildlife. Foods high in phytates and tannins that should be included in the diet of captive rock hyrax include legume hay (alfalfa). Rock hyrax can digest 53.3% of DM of alfalfa hay compared to 60.8% for sheep and 43.7% for rabbits (Paul-Murphy et al, 1982). Increasing the dietary fibre will automatically result in an increase of dietary phytates and tannins.
5. **Provide Sufficient Water.** A minimum of 44 to 61 $ml/kg^{-0.82}$ of water should be provided for each rock hyrax daily (Louw et al, 1973; Rübsamen et al, 1979). Rock hyrax normally have high GIT levels of water similar to sheep and camels (Rübsamen et al, 1979) and this high GIT water level is essential to aid in the digestion of fibre and support gut microbes. For example, the total, average GIT contents (water plus ingesta) are approximately 27.7% to 37.1% of the body weight of an adult rock hyrax (Eloff & Hoven, 1985). A source of water is particularly important for captive rock hyrax that are often fed dense, dry diets such as pelleted feeds.

Basic Captive Diet for Rock Hyrax

In captivity, we cannot exactly duplicate the wild feeding ecology of rock hyrax. The wild diet of rock hyrax includes a wide variety of foods on a seasonal basis and most of these plant foods are not available in North America. However, we can formulate a diet based on known wild feeding ecology and replace the wild diet with available foods that closely match the wild diet in form and function.

Feeding Protocol. Rock hyrax should be fed twice daily - early a.m. and later p.m. Each feeding should include a pelleted feed and alfalfa hay. Drinking water must be available at all times.

Diet Transition. Most captive rock hyrax are fed diets low in fibre compared to the diet of wild rock hyrax. The recommended diet changes will include an increase in dietary fibre. However, the GIT of the rock hyrax will need to be pre-conditioned to adapt to a higher fibre level. Therefore, over a 4 weeks period, the old diet of the rock hyrax should be replaced with the new diet in transitions:

Week 1: 75% old diet and 25% new. Only if the animals are accepting the new diet and have feces that are neither dry nor loose, go on to the next transition.
Week 2: 50% old diet and 50% new diet. Only if the animals are accepting the new diet and have feces that are neither dry nor loose, go on to the next transition.
Week 3: 75% new diet and 25% old diet. Only if the animals are accepting the new diet and have feces that are neither dry nor loose, go on to the next transition.
Week 4: 100% new diet.

Any diet change must include monitoring of the animal for changes in appetite, weight and behaviour. All of these factors can signify dietary acceptance or rejection and/or the appropriateness of the food and the amount of food for the animal. For example, the recommended amounts in this document are based on the attainment and/or maintenance of a healthy weight. However, some animals are more active or sedentary than others and may require more or less in their ration. Life stages such as pregnancy and lactation may also require a change in diet amounts.

If you have questions or concerns at any time during diet transition, please contact me:
Deborah McWilliams **info@caza-narg.ca**

Pellet Feed: Pelleted feed can be a source of balanced nutrition, but it can also be a factor in the development of nutritional pathology. Pelleted feed should be a low sugar, low starch feed with high fiber levels. The pelleted feed should match – as close as possible – the nutrient levels of the wild diet as shown in Table 4. Use the following amounts for rock hyrax based on life stage as an approximate measure. Body condition assessment must be done regularly and feed amounts may have to be increased or decreased as needed.

Each day, per individual, pelleted feed should be:

Adults: 70 g pellets (+ 70 g alfalfa hay; see below)
Juveniles: 60 g pellets (+ 60 g hay; see below)
Pregnant Females: 90 g pellets (+ 90 g pellets; see below)
Lactation: ad lib mix of 50% pellets and 50% alfalfa hay.
Neonates to Weaning: ad lib mix of 50% pellets and 50% alfalfa hay.

Alfalfa Hay: Rock hyrax should be fed high quality alfalfa hay. High quality alfalfa hay is mostly green, leafy hay with very little stems. Stems in the hay must be not be coarse. The hay should not be contaminated with molds, dirt, foreign material or weeds.

Feed alfalfa hay in the same amount as the pellet feed to maintain a 50-50 ratio of pellets to hay. For example, if an adult hyrax is fed 70 g pellets, then 70 g hay should be fed. Left-over hay and/or pellets should be removed and replaced with fresh food at the next feeding.

Food Enrichment. If the animals eat all the hay at feeding time, extra alfalfa hay can be given throughout the day. If natural browse is available, fresh browse can be used.

Water. A source (or sources) of water should be supplied based on individual requirement of a minimum of 44 to 61 ml/kg$^{-0.82}$ of water daily and should be available at all times.

Table 4. Recommended Dietary Goals Compared with Commercial Feeds (DM basis) Used for Rock Hyrax in Zoological Institutions

Ingredient	Recommended Average or Range	Alfalfa Hay Avg	Timothy Hay Avg	ADF 16 Pellet	ADF 25 Pellet	Alfalfa Pellet*	Guinea Pig[2]	Hi-Fiber Primate & Sticks[2]	Kangaroo Wallaby[2]	Leafeater[2]	Rabbit[2]	Triple Crown Safe Starch	Wild[2] Herbivore Hi-fiber
Crude Protein %	12 – 19	16.25	4.20	17	12-14	14-17	18	18- 18.5	15	23.0	14	11	12
Crude Fat %	1.4 - 3.5	1.9	1.5	3	3-4	1.5-2.5	4	5 – 7.6	5	5-6.5	1.5	6	3
Calcium %	1	1.35	0.25 – 0.75	1	1	0.94	1.1	1.25	0.9	1	0.7	0.6-1.0	0.8
Phosphorus %	0.5 – 0.6	0.21	0.8	0.5-0.75	0.6	0.37	0.6	0.7	0.6	0.6	0.5	0.4	0.35
Iron ppm (mg/kg)	< 200	50+	174	310	397	300	312	255	191	100[1] 456[2]	250	180	343
ADF %	40+	39.8	34.0	15-18	25	36.3	16.3	17	8.1	13-17	43	-	34
NDF %	40+	53.0	63.5	26-30	36	48.8	26.3	29.3	21.1	21-28	27.1	-	51
Lignin %	14 – 30	10.2	10.3	-	-	-	-	-	-	-	-	-	-
Cellulose %	10.7	-	-	9.0	-	-	-	-	-	-	-	-	-
Hemicellulose %	8	-	-	-	-	-	-	-	-	-	-	-	-
Dextrose (sugar) %	< 5%	6.5	14.7	7+	7+	3.5	-	1.0	7-15	7-15	7-15	10	7-15
Starch %	< 5%	1.9	0.1	24	8.7	2.0	17.7	18.3	34.8	24	4.5	10	< 4

[1]Marion Zoological
[2]Mazuri
***Contains alfalfa hay only in a pelleted form**
****Contains only beet pulp without molasses added**

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