

A MAGNESIUM-DRIVEN HYPOTHESIS OF DALL SHEEP MINERAL LICK USE: PRELIMINARY TESTS AND MANAGEMENT RELEVANCE

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Abstract: A major collection and analysis of soil and "mineral lick" samples throughout North America and a review of the literature relating to geology and mineral nutrition by Jones and Hanson (1985) has produced a magnesium-centered hypothesis which appears to have as viable a physiological rationale as the more commonly accepted sodium model. Central to the magnesium model was rediscovery that the aldosterone mechanism decreases magnesium absorption from the gut. Mineral lick use data from 2 licks in Interior Alaska were reanalyzed to test some predictions of the magnesium hypothesis which may be relevant to Dall sheep population monitoring at mineral licks. Results were inconclusive. However, when considering mitigation of mineral lick loss, the more comprehensive physiology associated with the magnesium model suggests inclusion of magnesium (and possibly other divalent cations) may be significantly more beneficial than providing only sodium.

Many wild ungulates eat soil from specific sites at certain times. The sight of wild animals, particularly those sought as human food, eating dirt (geophagy) has always interested humans. Early hunters found these sites were good places to take game, and modern hunters also found animals at licks were relatively easy prey.

It seems likely the first human investigation involved eating some of the soil. At least one early "taste tester" in eastern North America used the word, LICK, in reference to, "A salt spring...furrowed out in a most curious manner by the buffalo and deer which lick that earth on account of the saline particles with which it is impregnated," (Imlay 1792 quoted in Jakle 1969:688). This report probably reflected common usage and interpretation or coined the term "salt lick." It is the first recorded speculation as to why North American ungulates eat dirt. Subsequently, more sophisticated chemical analyses were employed in an effort to understand why animals ate dirt or licked rocks at these special places. The subject eventually developed a rich literature (Jones and Hanson 1985, Tankersley 1987). Implicit in efforts to understand "why" has been the assumption that mineral lick using species eat dirt because they have a physiological need for some nutrient it holds. As Seton (1901) wrote:

"...But all went listlessly after the Wise One, whose calm decision really inspired confidence. When far below the safety-line, the leader began to prick up her ears and gaze forward. Those near her also brightened up. They were neither hungry nor thirsty, but their stomachs craved something which they felt was near at last. A wide

slope ahead appeared, and down it a white streak. Up to the head of this streak the Wise One led her band. The needed no telling; the bank and all about was white with something that the Sheep eagerly licked up. Oh! it was the most delicious thing they had ever tasted! It seemed they could not get enough; and as they licked and licked, the dryness left their throats, the hotness went from eye and ear, the headache quit their brains, their fevered itching skins grew cool and their stomachs sweetened, their listlessness was gone, and all their nature toned. It was like a most delicious drink of life-giving cordial, but it was only common salt.

This was what they had needed--and this was the great healing Salt-lick to which the leader's wisdom had been their guide.

A corollary assumption, that the beneficial mineral nutrients attract the users to the lick, appears to have also played a major part in the speculation concerning why ungulates use licks.

This thinking has been evident in experimental approaches to answering the "why" question. Experimental efforts have included "cafeteria style" feeding trials (Stockstad et al. 1953, Fraser and Reardon 1980), as well as composition analyses of mineral lick materials by numerous authors (see Hanson and Jones 1985). Many of these observations have been interpreted as supportive of sodium ion as the major attractant and functional nutrient in ungulate mineral licks.

Sodium is certainly a required nutrient and is necessary for many physiological functions in the mammalian body (Forbes 1962). Furthermore, the role ascribed to sodium as the major attractive-nutritional component of mineral licks appeared increasingly certain with the inference from Epstein (1972) that herbivore diets are likely to be low in sodium because few if any plants require or store this element. This perspective gained additional support from the writings of Hebert and Cowan (1971) and Weeks and Kirkpatrick (1976) relating sodium/potassium homeostasis to the high potassium load herbivores receive when consuming emerging vegetation in spring. Hebert and Turnbull (1977) proposed a sodium flow model based on mountain goat (Oreamnos americanus) sodium intake and fecal loss in spring-summer. These authors used data from moose, deer, and domestic livestock sodium flux, and suggested that mountain goats can become sodium deficient during this period. Similarly, Thompson (1982) reported accelerated sodium loss from mountain goats during the spring-summer period exceed the plausible intake from available sources. However, he also reported that sodium requirements for mountain goats appear to be far below recommended levels for comparable domestic ruminants.

However, the lack of readily identifiable, specific symptoms of sodium deficiency in wild or domestic ungulates, the seeming abundance of available sodium in wild ungulate habitats (cured winter forage burns with a characteristic yellow "sodium flame"), its apparent absence from some licks, and the spectacular capacity for sodium retention by the mammalian kidney lead several authors to discount sodium as the prime nutritional component in mineral lick soils (French 1945, Cowan and Brink 1949, Murie 1951, Heimer 1974).

Some investigations have centered on nutritional function, while others focused on the search for an attractant in mineral lick soils. These differences in approach have led to some confusion, and even some contention about the most reasonable justification for protecting ungulate mineral licks in wildlife management. Protection is often justified simply on the basis that the level of use mineral licks sustain obviously demonstrates their nutritional necessity. This approach has minimum acceptability with developers who argue there is no proof of nutritional dependence.

Whatever the reason animals are attracted to licks, I suggest the model produced by Jones and Hanson (1985) as well as the literature reviewed above presents a consistently strong case for nutritional necessity. I further suggest that the case for nutritional dependence on mineral licks holds the greatest potential for their preservation for wildlife use in the face of human development.

The work done by Jones and Hanson (1985) suggests a significant addition to the sodium model for mineral lick attraction and ungulate benefit. These authors analyzed samples collected by a variety of unspecified methods from 276 ungulate mineral licks throughout North America, characterized the solid types within the regions surrounding these mineral licks, and reviewed the literature of plant physiology relating to mineral content as well as the physiological literature about mammalian ion regulation. They concluded magnesium was the most important functional nutrient in lick soils, and appeared to ascribe the role of attractant to it as well.

The Magnesium Model

In the mammalian body, magnesium functions primarily inside cells, most notably as an enzyme activator and/or a cofactor in energy metabolism. There is no known body reserve of magnesium. Consequently, it is not difficult to produce low serum magnesium levels in domestic livestock (colloquially referred to as grass tetany, milk fever, or wheat poisoning depending on circumstances) because herbivore diets and environments are seldom rich in available magnesium. Captive bighorn sheep also showed decreasing concentrations of serum magnesium from October through May (Hebert, unpubl. data). In captive bighorn sheep maintained on forage gathered from their seasonal and winter ranges, mean serum magnesium levels in these bighorn sheep declined from an average of about 2 mg per 100 ml to 0.3 mg per 100 ml throughout the winter months. The data Hebert so generously provided did not indicate whether bighorns recovered their early winter magnesium levels without magnesium supplements. Still, the measured decrease in serum magnesium concentration was striking, and appears to demonstrate the absence of homeostatic mechanisms for magnesium in bighorn sheep.

Jones and Hanson (1985) present strong arguments that support their working hypothesis that North American ungulates get magnesium, which prevents tetany caused by low serum magnesium levels, from mineral licks. I am unaware of any reports of tetany in wild ungulates; however, several gross symptoms associated with many accounts of "capture myopathy" mimic those of grass tetany in domestics. These symptoms include ataxia,

inability to stand, and death. Consequently, it is possible that hypomagnesemic tetany may be more common in wild ungulates than we have appreciated because it might easily be misdiagnosed as "capture myopathy."

In recent years, the term "capture myopathy" has become synonymous with vitamin E-selenium deficiency or White Muscle Disease. This unfortunate confusion in terms (the first clinical report of a capture myopathy in bighorn sheep was not synonymous with White Muscle Disease; Spraker 1976) has shifted thinking toward selenium deficiency whenever a captured animal fails to walk away after handling. There could be simpler and more treatable causes; hypomagnesemic tetany could be among them.

Potassium intake affects magnesium homeostasis.--Effects of the generally limiting magnesium levels in sheep diets are amplified by its low concentration relative to potassium in forage. High levels of potassium in emerging spring forage lead to imbalances of sodium and potassium in the body fluids of mineral lick-using species (Weeks 1974).

Normally, potassium and sodium are kept in balance in the mammalian body through chemoreceptors which monitor the ratio of these 2 ions in cerebro-spinal fluid. When this balance is tipped in favor of potassium (potassium ingestion or sodium loss), a hormone called aldosterone is secreted by the adrenal cortex. This hormone acts to restore balance by increasing active transport of sodium ions back into the body from plasma filtered in the kidney. Aldosterone increases activity of the sodium/potassium exchange pump in the distal convoluted portion of the nephron (Ruch and Patton 1965). Because the sodium/potassium pump exchanges sodium ions in the filtered plasma for potassium ions from body fluids, urinary potassium excretion increases as sodium is retained. That is, the mammalian system is adapted to conservation of sodium through the renal aldosterone mechanism. Mechanisms for potassium homeostasis apart from sodium have not been found.

Unfortunately, sodium-potassium homeostasis leads to magnesium loss because aldosterone has the side-effect of limiting magnesium absorption from the gut (Levin 1976). Hence, when spring herbivore diets (which are rich in potassium) distort the sodium/potassium ratio in spinal fluid, magnesium balance is compromised. Sheep appear to rectify this imbalance by eating sodium- and magnesium-rich soils at mineral licks. Ingestion of sodium acts to restore the sodium/potassium ratio and lower aldosterone levels. High magnesium intake counters decreased absorption caused by increased aldosterone and sets the stage for rapid recovery once aldosterone secretion returns to normal levels.

Jones and Hanson (1985) cite work by Grunes et al. (1970) that demonstrates forages with high amounts of potassium relative to magnesium and calcium lead to net magnesium and calcium loss in domestic ungulates. This appears to occur through the mechanism reviewed above. Consequently, lowered serum magnesium follows with the danger of metabolic dysfunction (which produces the symptoms of grass tetany common in metabolically stressed domestic livestock) due to lowered enzyme activity resulting from insufficient quantities of intracellular magnesium. Threshold levels have not been determined for wild ungulates. Jones and Hanson suggest that North American ungulates, including Dall sheep (Ovis dalli), have adapted

to seasonal mineral lick use to forestall these potentially fatal symptoms. Among Dall sheep, mineral lick use typically coincides with emergence of spring vegetation (and a presumed potassium load) as well as parturition and the onset of lactation (which require expenditure of copious quantities of magnesium and calcium as well as sodium). Thus, Hanson and Jones (1985) suggested mineral lick drive is best understood as a result of acute or impending magnesium deficiency. A broader view would also include sodium loss even though specific symptoms are less striking.

Mineral licking drive may vary with plant ionic composition.--The ratio of potassium to magnesium-plus-calcium in emerging vegetation varies even though measurable soil concentrations are constant. Thomas and Hipp (1968) report empirical evidence that the ratio of potassium to magnesium-plus-calcium in plant tissue decreased with declining soil moisture. When soil moisture is high, the relative chemical activity (chemically active concentration), of monovalent cations, such as potassium with an oxidation state of plus 1, increases. Consequently, plants absorb more potassium. In drier circumstances, the chemical activity of the divalent cations (magnesium and calcium with higher oxidation states) is relatively greater, and absorption of these cations is favored. This is due to a factor called the dilution effect which occurs in the outer layers of the soil colloidal system (Wicklander 1964).

Other hypotheses involving low soil temperatures and subsequently elevated concentrations of ammonium ions in the soil during early plant growth have also been suggested as causative factors in lowering magnesium plus calcium concentrations in plant tissue (Wilcox and Hoff 1974). These mechanisms are consistent with low Alaskan soil temperatures and the general paucity of nitrogen-fixing bacteria in Alaskan alpine soils. These postulated mechanisms may contribute to hypomagnesemia as well.

Model Synopsis and Relevance

I think the physiological and empirical evidence supporting the magnesium hypothesis argues that wildlife managers should include emphasis of magnesium in nutritional justifications for mineral lick preservation. Sodium may well be the attractant, and ingestion of sodium concentrates will act to re-establish sodium/potassium ratios in spinal fluid and reduce aldosterone secretion. This will have the added beneficial effect of allowing increased absorption of the magnesium concentrates from the sheep gut.

Wildlife biologists have been divided over the importance of "attractants to" and "nutritional function of" mineral licks for many years. Historically, the attractant school has prevailed, and sodium has been the "ion of choice". There is little doubt that Dall sheep in Alaska prefer salt blocks to the soil of all mineral licks where salt (NaCl) blocks have been made available. Still, the evidence supporting involvement of the divalent cations, particularly magnesium, suggests managers should adopt a more comprehensive view of mineral nutrition when justifying protection of mineral licks for ungulate use.

In summary, the magnesium hypothesis predicts that the ratio of potassium to magnesium-plus-calcium in sheep forage varies with available

moisture at the time of plant emergence. In drier years, the ratio of these alkaline earth cations to potassium will favor magnesium absorption and licking drive should be reduced. Hence, the hypothesis predicts that mineral lick use, if a constant, linear function of magnesium-generated licking drive, should always be less in drier years.

Mineral Lick Use by Dall Sheep Has Been Predictable

Seasonal use of mineral licks by Dall sheep in Alaska has been particularly well documented (Heimer 1973, Curby 1981, Spindler 1983, Tankersley 1984). Heimer (1973) shows a minimum of 94% fidelity among ewes to the mineral lick where they were marked. He suggests this predictability could be exploited for population monitoring purposes.

If magnesium homeostasis drives Dall sheep mineral lick use, lick drive should vary with moisture availability to plants. If so, population monitoring at mineral licks would only be effective in years when high potassium to magnesium-plus-calcium ratios occur in plants. That is, during dry springs or after winters with little snow, high mineral lick fidelity might not be expected among Dall sheep. The purpose of this paper, besides advocating a broader view of mineral nutrition as it is influenced by mineral licks, is to explore this possibility and discuss its management relevance to using Dall sheep fidelity to mineral licks for population monitoring.

MATERIALS AND METHODS

Dall ewes were captured and marked at the Dry Creek and Robertson River mineral licks in Interior Alaska from 1967 to 1984 (Erickson 1970, Heimer et al. 1980, Heimer and Watson 1986). Returns of marked ewes were documented using various schedules of observation which were dependent on project objectives and funding. The return percentage for ewes known to be alive each year (either by sighting that year, or in subsequent years) was calculated. Observations were terminate after 1985 in the Robertson River and 1986 in Dry Creek, so both final year return frequencies are possible maximums. Percent sightings for each year were then regressed as functions of winter snow accumulation, spring precipitation up to the typical onset of peak mineral lick use and combined water equivalent (assuming 0.3 inches of water per inch of snow in April). Correlation coefficients were calculated and probability values determined using standard statistical tables.

RESULTS

In the data from Dry Creek, there was some suggestion that mineral lick use, as reflected by observed return of marked ewes, decreases with precipitation (as the hypothesis predicts) between the last week of May and the first week in June ($n = 7$ years, average ewe return = 81%, $r = 0.731$, $P < 0.10$, Table 1), but the correlation was not significant at $P > 0.05$. There was no suggestion of correlation between percentage ewe return and winter snow accumulation or total water equivalent.

In the Robertson River, sheep mineral lick-use trends suggested that mineral lick use may decrease with increasing total water equivalent ($n =$

5 years, average ewe return = 95%, $r = -0.8186$, $\underline{p} < 0.10$, Table 2). The correlation was not significant at $\underline{p} > 0.05$. There was no suggestion of correlation between lick use and winter snow depth or early spring precipitation. The hypothesis did not predict, even qualitatively, in this case.

Table 1. Percent of living ewes returning to the Dry Creek lick, spring precipitation, winter snow depth, and combined precipitation, Alaska Range, Alaska, 1973-86.

Year	% return observed	Spring precipitation (inches)	Winter snow depth (inches)	Combined water equivalent (inches)
1973	89	0.65	24.3	8.20
1974	75	0.84	17.3	6.03
1982	75	0.10	22.5	6.85
1983	79	1.00	18.3	6.49
1984	88	1.20	12.5	4.95
1985	93	1.20	22.7	8.01
1986	70	0.25	16.3	5.14
		$r = 0.7031$	$r = -0.1277$	$r = 0.1228$
		$\underline{p} < 0.10$		

Table 2. Percent of living ewes returning to the Robertson River mineral lick, spring precipitation, winter snow depth, and combined water equivalent, Alaska Range, Alaska, 1981-85.

Year	% return observed	Spring precipitation (inches)	Winter snow depth (inches)	Combined water equivalent (inches)
1981	100	2.1	8.8	4.74
1982	96	0.1	22.5	6.85
1983	93	1.0	18.3	6.49
1984	95	1.2	12.5	4.95
1985	89	1.2	22.7	8.01
		$r = 0.3166$	$r = -0.7273$	$r = -0.8186$
			$\underline{p} > 0.10$	$\underline{p} < 0.10$

DISCUSSION

The differences in sign of correlation coefficient between Dry Creek and the Robertson River suggest several possibilities. First, measurements of moisture may have been too crude to be relevant to the question.

Second, differences could have been due to human factors. Experienced observers were present at the Robertson River lick throughout June each year while observers kept incomplete or variable schedules at Dry Creek. Had observers been at the Dry Creek lick at all times, as was the case at the Robertson River lick, it is possible that return percentages would have been uniformly higher. Still, years with continuous observer presence in Dry Creek gave differing percentage returns of living ewes, and most sheep visit the lick several times during the month. The suggested relationship may not be spurious.

Third, lick drive may not be equally variable in both populations. Plant species compositions in winter diets of these 2 populations are different (Heimer 1983), and it is possible that the Robertson River ranges chronically supply less magnesium with respect to potassium than the Dry Creek ranges.

Finally, it is possible that the hypothesis has no relevance to measurable mineral lick use. It is also possible that sheep visit mineral licks for reasons other than physiological prophylaxis.

It should also be noted that the final years of observation, 1985 for the Robertson River and 1986 in Dry Creek, are maximum estimates of return because continuous observations were discontinued after those years. Hence, living ewes who "skipped" those years could not have been resighted subsequently. Whatever the case, mineral lick observations still appear to offer considerable promise for population monitoring. Better testing of the predictions of the magnesium hypothesis should include careful, on-site measurement of soil moisture, plant calcium plus magnesium to potassium ratios, serum magnesium values from sheep, and mineral lick use. I think return of marked animals to the mineral lick each year is the best present indicator of mineral lick use.

I realize that evaluation of the predications of the magnesium hypothesis is not an immediate management concern. However, the prospect of mitigating loss of mineral licks is. I think the magnesium hypothesis is a sufficiently satisfactory model from physiological and nutritional perspectives that sheep populations will be better served by recommending nutritionally balanced supplements in addition to sodium. Tankersley (1987) recommends establishment of replacement licks with substrate and ionic composition as similar as possible to the original lick.

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