Mineral Lick Visitation by Mountain Goats, *Oreamnos americanus*

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Many species, including Mountain Goats (*Oreamnos americanus*), are known to visit mineral licks, but the extent and duration of use are poorly understood because most studies consist of observations at licks. I studied the movements to, from, and near mineral licks of 11 mountain goats in Washington wearing Global Positioning System (GPS) collars for a total of 169 goat-months of tracking and evaluated chemical composition of six mineral licks compared with reference soil samples. I recorded 101 mineral lick visits to 13 mineral licks. Each GPS fix was classified as moving toward a mineral lick, in the vicinity of a lick, on an excursion from a lick, moving away from a lick, or not associated with lick use. Depending on annual movement patterns associated with lick use, each Mountain Goat was classified as a Migrant (single lick visit of long duration, $n = 3$ Mountain Goats), Sojourner (few visits of short duration, $n = 2$), Commuter (many visits of short duration, $n = 5$), or Resident (lick within normal range of movements, $n = 1$). Most mineral lick visits took place 01 June–15 August with peak visitation about 14 June–29 July. Migrants typically stayed in the vicinity of licks about a month (but as long as 51 days) whereas other mountain goats visited licks for 0.1–8 days (median = 1 day). Migrants also tended to take longer and move farther than other Mountain Goats when on movements to and from licks. Most Mountain Goats moved toward mineral licks faster (km/hr) than they moved away from licks. All licks had higher concentrations of sodium than reference samples (1.5–27 times as high), although concentrations of calcium, potassium, and sulphate tended to be higher as well, whereas magnesium was not. Mineral lick visitation has costs (energetics of travel, reduced forage, and predation risk). Depending on the importance of these costs, mountain goats evidently use various strategies for exploiting mineral licks as exemplified by the movement types (migrant, sojourner, commuter, or resident). Notably, most of the Mountain Goats in this study crossed national forest, county and Washington Department of Fish and Wildlife region boundaries to another to visit mineral licks. Thus, coordination among administrative units is needed in management of Mountain Goats and mineral licks they use.

Key Words: Mountain Goats, *Oreamnos americanus*, Global Positioning System (GPS), mineral lick, movements, Washington.

The use of mineral licks has been documented for numerous species (Klaus and Schmid 1998), especially ungulates (Jones and Hanson 1985; Kreulen 1985; and many others) including mountain goats (*Oreamnos americanus*, e.g., Hebert and Cowan 1971; Singer and Doherty 1985; Poole and Heard 2003; Turney and Blume 2004; Poole et al. 2010). Most studies have emphasized chemical composition of lick soils (e.g., Kennedy et al. 1995; Tracy and McNaughton 1995, Dormaar and Walker 1996; Ayotte et al. 2006) or monitored visitation to licks (e.g., Tankersley 1984; Moe 1993; Atwood and Weeks 2002; Turney and Blume 2004) and provide at most, anecdotal accounts of movements to and from mineral licks (Heimer 1974; Tankersley 1984; Hnilicka et al. 2002). One exception to this is the study of movements of White-tailed Deer (*Odocoileus virginianus*) visiting licks in Indiana (Wiles and Weeks 1986).

Although there has been considerable discussion of the potential benefit from mineral licks (Kreulen 1985; Klaus and Schmid 1998), for ungulates in seasonal environments, the preponderance of evidence points to sodium as the constituent primarily associated with licks (Kennedy et al. 1995; Klaus and Schmid 1998; Atwood and Weeks 2002). Sodium concentrations in lick soils were consistently much higher than in reference soil samples and were deficient in forage (Klein and Thing 1989; Ayotte et al. 2006; Mincher et al. 2008). Also, during the time of greatest lick use (late spring and early summer), sodium requirements are high as this corresponds to late gestation and early lactation for many species and elevated potassium in forage plants at that time increases the need for sodium (Weeks and Kirkpatrick 1976; Atwood and Weeks 2002). Foley et al. (1995) indicated that sodium may be important in mediating the acidification resulting from detoxification of forage secondary compounds. Others have suggested that magnesium is a key component of lick soils (Jones and Hanson 1985; Heimer 1988; Klaus and Schmid 1998).

Despite these evident benefits, visiting mineral licks incurs costs. These are in the form of energetic costs of movement, potentially increased risk of predation in unfamiliar terrain and suboptimal habitat lacking escape terrain, and loss of foraging opportunity due to time budget constraints and potentially reduced forage availability due to poor habitat or high levels of use in the vicinity of the lick. Because the costs and benefits vary among licks and among individuals, patterns of mineral lick use can be expected to vary depending on the quality of the lick, distance to the lick, terrain that must be traversed to visit the lick, mineral content of the soils and vegetation in the "normal" home range of the individual, and habitat in the vicinity of the lick.

Prior to this study, knowledge of mineral lick use by Mountain Goats in Washington was limited. Wright (1977) reported Mountain Goats using a mineral lick on the flanks of Mt. Baker (exact location not specified). Representatives of the Sauk-Suiattle Tribe determined that the early summer aggregation of mountain goats on Gamma Ridge (Glacier Peak) was associated with the use of a mineral lick (D. Graupman personal communication 2001). To increase our understanding of the use of mineral licks by Mountain Goats in Washington, the objectives in this study were to identify mineral licks used by Mountain Goats, and to describe movements of GPS collared Mountain Goats visiting mineral licks. Because there are few comparable studies of mineral lick visitation by Mountain Goats, I described the frequency with which individuals visit mineral licks, the distances they travel in doing so, to further our understanding of how they balance the trade-offs between costs and benefits of mineral lick use. I also evaluated the chemical constituents of mineral licks mountain goats used.

Materials and Methods

Study Area

I studied Mountain Goat mineral licks in the Cascade Range in Washington State where topography extends as high as 4267 m on several volcanic peaks, but most terrain is below 2100 m. In this area, Mountain Goats typically inhabit elevations between 600 and 2400 m, which have six broad classes of vegetative cover (derived from Comer et al. 2003): Bare (1510–4270 m), which includes bedrock, scree, talus, and dwarf shrubs; Grassland (1170–2190 m); Parkland (1180–2080 m); Woodland (600–1840 m); Forest (600– 1470 m); and Shrubland (600–1380 m).

Capture and Collaring

I captured 46 Mountain Goats in the Cascade Mountain Range between 26 September 2002 and 2 July 2007 (Rice and Hall 2007) and fitted them with GPS tracking collars (Vectronic GPS Plus-4, Vectronics Aerospace, Berlin, Germany). All captures were in compliance with Washington Department of Fish and Wildlife Policy on Wildlife Restraint or Immobilization (M6003). The primary purpose of these captures was to provide locations for studies of movements and habitat selection (Wells 2006) and to provide marked groups for sightability modeling for surveys (Rice et al. 2009). Only the 11 collared mountain goats known to visit mineral licks are included in this study (Table 1). Seven of these were captured near the licks on Gamma Ridge (Glacier Peak) in 2006 to improve our understanding of movements of Mountain Goats associated with mineral licks and Gamma Ridge in particular. One capture took place in the vicinity of the Deadhorse Point lick. Because our overall study emphasized females, only 1 of the 11 mountain goats that visited mineral licks was an adult male (038GMM) and the extent to which his mineral lick use reflected his sex (Hebert and Cowan 1971; Ayotte et al. 2008; Poole et al. 2010) or that he had a mineral lick within his normal range is an open question. 051GPM was also a male, but was captured at 1 year of age, and, in terms of lick visitation, probably behaved more like the adult females during the 13 months he was tracked.

Most Mountain Goats in this study captured prior to 2006 (033GPF, 034GPF, 037HRF, 045MRF, and 038GMM) were set on a 3 hr fix interval. The exception was 024KRF which was on a 5 hr rotating schedule from 13 September 2003 to 28 June 2004, and subsequently on a 3 hr interval. The collars for the 2006 captures (051GPM, 052GPF, 053GPF, 054GPF, and 055GPF) were on a 5 hr rotating schedule most of the year but on a 1 hr interval 07–21 June and 25 July–20 August, when movements to and from Gamma Ridge were expected. I removed outlier fixes by visually screening locations beyond the continuous distribution of distances of all fixes from the median for each individual and by visual inspection of travel paths (usually single fixes separate from temporal clusters, Rice 2008). The median estimated location error (Lewis et al. 2007) for fixes used to determine movements to mineral licks and habitat was 9.6 m (central 95% = 5.9–129.8, $n = 9165$).

Identifying Licks

Mineral licks used by collared Mountain Goats were identified in three ways: on the basis of previous knowledge; field observations; and in two cases, movement records from GPS collars which were to clusters of fixes 4-5 km outside the range of movements for that individual. Other mineral licks probably occurred within areas of movement for some collared mountain goats. Such licks might or might not be associated with clusters of collar fixes as this was variable for known licks. Within the usual movements for an individual, it was not feasible to distinguish clusters of fixes associated with licks from those associated with other locations of high use (e.g., favored resting sites) without independent information on the location of the lick. Field observations were made on mineral lick use on Gamma Ridge on 25 and 26 July 2007, during which six new mineral lick sites were identified by observing mountain goat use.

Movements

I identified five states for mountain goats determined by movements relative to mineral licks: (1) At Lick, (2) moving Toward the lick, (3) moving Away from the lick, (4) on an Excursion from the lick, and (5) None (none of the above), collectively termed Lick State. A Mountain Goat was considered At Lick if the fix was within the vicinity and within a specified distance from the lick (same as region 2 of Hebert and Cowan 1971). This distance varied among the Mountain Goats and was determined by examining time series graphs of distance from the lick and between-

TABLE 1. Mountain Goats visiting mineral licks tracked with GPS collars in Washington. Sex is indicated by the last letter of the individual designation (F = female, M = male). Age is at time of capture. Max distance is the maximum distance from the nearest mineral lick when At Lick (m).

Type	Goat	Age	Area	Dates		Fixes	Months	Visits	Max
				Minimum	Maximum		tracked		distance
Migrant	033GPF	4	Gamma Ridge	9 July 2004	6 June 2005	2036	11	1	1400
	034GPF	4	Gamma Ridge	9 July 2004	22 September 2006	3200	26	5	1400
	051GPM	1	Gamma Ridge	29 June 2006	25 July 2007	2025	13	2	2475
Sojourner	024KRF	3	French Cabin Creek	13 September 2003	14 November 2005	4711	26	5	400
	037HRF	3	Deadhorse Point	10 July 2004	10 February 2006	3055	19	7	1275
Commuter	045MRF	5	Mineral Mountain	3 September 2004	10 August 2005	1841	11	11	850
	052GPF	6	Gamma Ridge	29 June 2006	5 September 2006	780	2	4	700
	053GPF	5	Gamma Ridge	29 June 2006	30 May 2007	1549	11	3	1150
	054GPF	4	Gamma Ridge	29 June 2006	19 September 2007	3067	15	13	1050
	055GPF	2	Gamma Ridge	30 June 2006	14 March 2007	1319	8	5	850
Resident	038GMM	3	Gardner Mountain	10 July 2004	9 September 2006	5022	26	45	625
	All			13 September 2003	19 September 2007	28605	169	101	

fix paths for each lick area. Generally, starting and ending fixes of movements Toward and Away were clearly evident in time series graphs of distance from the lick, but when questions arose, I used the rule that the movements were considered continuous if the distances for the fixes in question covered a period of < 2 days. Excursions were movements Away immediately followed by movements Toward which did not reach the typical distances of Toward and Away for that individual.

Based on the Lick States, I calculated the Duration of each State, and the change in Distance to the lick (in km) between the first and last fixes in each State. I defined the Interval between mineral lick visits as the difference (in days) between the start of movement Toward and the end of the previous movement Away for each visit and partitioned these Intervals into those that were within a given year and those between years (over winter).

Based on movement records, I classified each individual as one of four Types: Migrant, Commuter, Sojourner, or Resident. Migrants moved to the lick and stayed for an extended period (>2 weeks). Commuters moved to and from the lick frequently within a season. Sojourners visited the licks briefly, and if they visited a lick more than once in a season, visits were separated by >2 weeks. The Resident visited a lick located within his normal range of movements.

Analysis

To test for differences in measures of mineral lick use among visitor Types and Lick States, I included individual identity as a random effect because multiple visits are repeated measures on the same individual and used the Tukey test for multiple comparisons of the means of the different groups (Zar 1996). To address distribution considerations (skewness of pooled samples = 0.813–4.121), I log-transformed Durations, Intervals, Distances and movement rates. For movement rate analysis, I adjusted for the fact that collars were programmed with varying fix intervals and that not all fix attempts were successful by including realized fix interval (in hours) as a categorical nuisance variable. Statistical analysis was conducted with JMP (v7.0, SAS Institute 2007).

Lick Sampling and Analysis

Soil samples were collected at two mineral licks on Gardner Mountain and five licks on Gamma Ridge (Figure 1). At each site, reference samples were collected 50 m upslope, downslope, and to each side of the site. Each sample was analyzed for chemical constituents frequently referenced in the earlier reports (e.g., Kennedy et al. 1995; Ayotte et al. 2006): Sodium (Na), Calcium (Ca), Potassium (K), Magnesium (Mg), and sulphate (SO_4) which were assayed by Kuo Soil Labs (Othello, Washington). Because the distributions of chemical concentrations were skewed, I log-transformed all values. Te evaluate if chemical concentrations differed between lick and reverence samples, I used a nested ANOVA design (lick vs reference within site). I also checked that reference samples from the downslope of the site did not differ from other reference samples with a 1- sided *t*-test, in case drainage from the lick site may have elevated concentrations for the downslope sample.

Results

Movements

Of the eight Mountain Goats captured near mineral licks, three were Migrants, one was a Sojourner, and four were Commuters. The Migrants stayed in the vicinity of the lick a median of 38.6 (range 23.9-38.7) days after capture. The Sojourner stayed 5.9 after capture, and the Commuters stayed in the vicinity a median of 2.8 (range 2.6-3.5) days after capture. It would appear that capture did not have much effect on lick visitation (see below).

Mountain Goats generally followed mountain ridges when moving Toward and Away from mineral licks (Figure 2). However, this was only partially true for Migrants, which followed ridges initially when moving toward the licks, but then crossed the Suiattle River valley rather than detour along the ridge to the south (paths in the upper half of box for Gamma Ridge, Figure 2). Also, 045MRF crossed the lower part of the Winthrop Glacier on her many trips Toward and Away.

Movements Toward and Away from mineral licks by Mountain Goats were usually decisive (Figure 3), but there were exceptions. For instance, in 2006, 034GPF stopped her movement 6 km from the Gamma Ridge mineral licks, retreated to 11 km from the licks for four days, resumed her movement toward the lick, but paused again at 6 km for 2.5 days before moving to the licks (Figure 3). In 2005, 034GPF turned and ascended along the Suiattle River 4 km over two days before continuing to the licks. Although the mineral licks for the Resident (038GMM) was enclosed by other areas he visited, the radial nature of his Toward and Away moments suggests that the lick was the main reason he visited the area of the lick (Figure 2).

Most (90%) mineral lick visits took place 1 June–15 August but this varied among Types. Apart from a few early visits to mineral licks, Migrants, Sojourners, and Commuters, all started lick visits in mid-June (14 June, 14 June, and 17 June, respectively, Figure 4). The Resident started regular lick visits on 29 April, and activity increased on 25 May (Figure 4). All Types ceased regular visits near the end of August (Migrants-24 August, Sojourners-19 August, Commuters-26 August, and Resident 21 August) although there were gaps in visitation for Sojourners (13 July–02 August), Commuters (09–17 August), and the Resident (26 July–11 August). Altogether, peak visitation was about 14 June–29 July. Early and late visits to mineral licks also occurred, especially for the Resident, but also for other Types except Migrants (Figure 4). Typical number of days At Lick in a year was highest for Migrants (44), intermediate for the Resident and Commuters (28 and 21), and lowest for Sojourners (13).

Migrants typically stayed At Lick >1 month per visit (Table 2), which was significantly longer than other Types (Table 2, $F_{3,6} = 10.251$, $P = 0.009$). Sojourners were usually At Lick 2–3 days and not more than about one week whereas Commuters usually stayed at lick about one day or one week at the most. The Resident's visits were shorter (Table 2), although differences among Sojourners, Commuters and Resident were not significant. The Duration of movements Toward were less than Away (Table 2, $F_{1,124} = 9.793$, $P = 0.002$, Table 2).

Within a given year, Commuters and the Resident had similar Interval between mineral lick visits, which was much shorter than those for Sojourners ($F_{2,49} = 5.816$, $P = 0.005$, Table 3). Between year Interval observations were too sparse for meaningful testing (Table 3).

The longest Distance a Mountain Goat moved Toward or Away from a mineral lick was 29.4 km and the shortest Distance was 0.6 km (Table 4). Typical movements for Migrants were >15 km, whereas those for Sojourners and Commuters were more variable (4–17 km), with the Resident's movements usually much shorter although these differences were marginally not significant (Away $F_{3,6} = 4.526$, $P = 0.059$; Toward ($F_{3,5} = 5.409$, $P = 0.050$). Generally, Distance moved was slightly greater Toward than Away ($F_{1,122} = 6.245$, $P = 0.014$).), movement rate (m/hr) was highest during Toward, nearly three times the rate when in lick state None and Away was also higher than lick state None (Table 5, $F_{4,\ 8395} = 101.941$, $P < 0.001$). This demonstrates the energetic costs of mineral lick movements. Movement rates did not vary significantly among Types ($F_{3,\ 7} = 0.492$, $P = 0.699$).

Soil Samples

Sodium concentrations were significantly higher in lick soils than in reference soils at all licks and were >20 times higher for two licks (GAM1 and GAM3, Table 6). Other chemicals had significantly higher concentrations at some licks (K at 3 licks, Mg at 1, and SO_4 at 1). Despite the lack of consistently significant differences, concentrations of Ca, K, Mg, and SO_4 were generally higher at licks than in reference samples. Downslope samples were not significantly higher than the other reference samples at each site for any chemicals with regards to either concentration of difference from the site sample ($t_{1–2} = 0.016–0.984$, 3 of 70 tests were with $P < 0.05$).

Discussion

We tracked 46 Mountain Goats distributed over a wide geographic range in Washington (Rice and Hall 2007; Rice 2008), but only 11 exhibited pronounced movements associated with mineral licks and eight of these were captured while visiting known licks. The results show that there is wide variation in the details of mineral lick visitation among individuals in terms

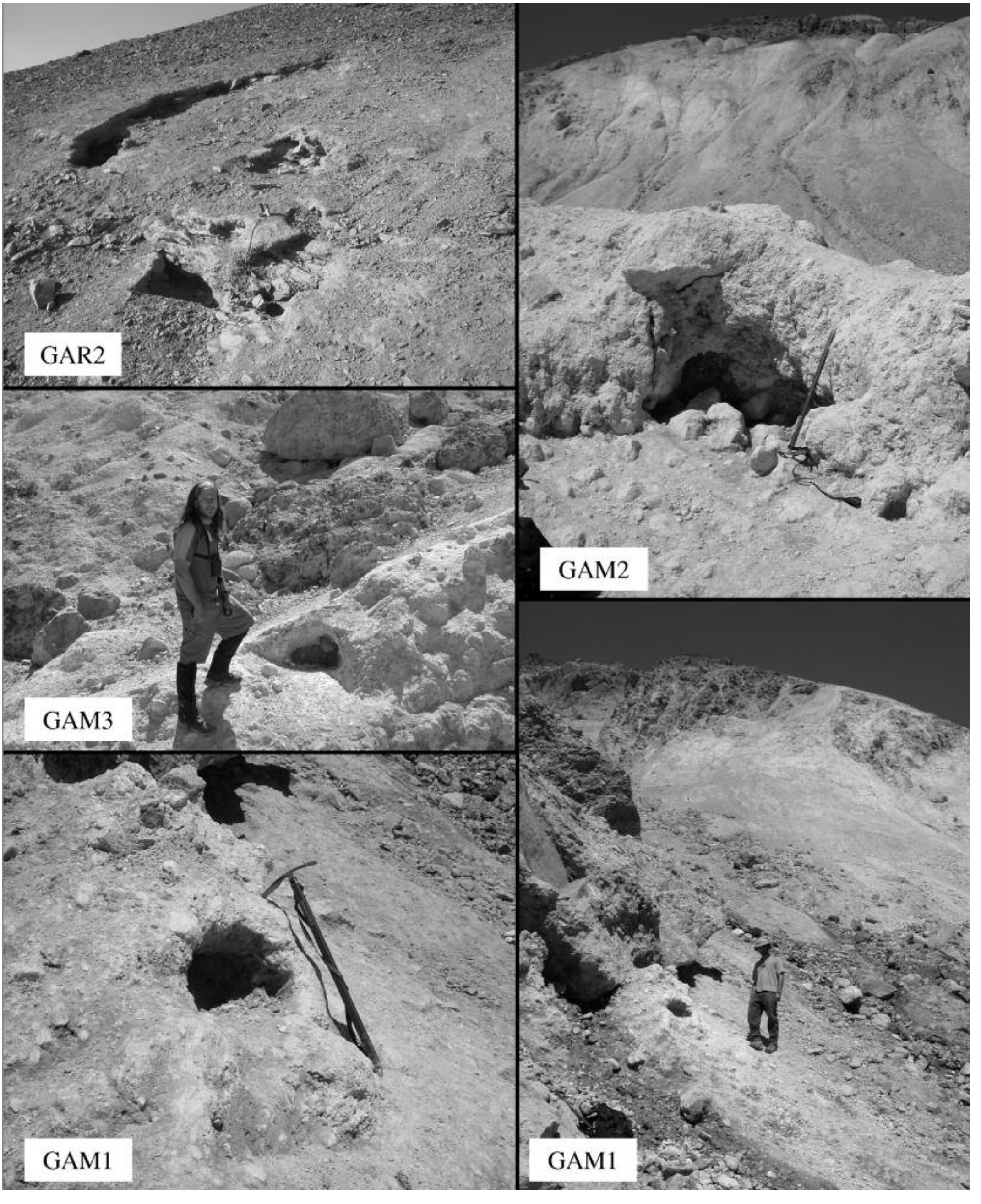

FIGURE 1. Examples of Mountain Goat mineral licks in Washington, 13 September 2003–19 September 2007.

of number of visits, distance traveled, and time spent in the vicinity of licks leading to the categorization of lick visitation into four types. As with other species, lick use was decidedly seasonal for Mountain Goats. None of the licks we visited were at the bases trees, in contrast to those investigated by Poole et al. (2010) in southeastern British Columbia.

Those Mountain Goats that visited mineral licks did so every year they were tracked. Poole et al. (2010) assert that most populations of Mountain Goats make extensive use of natural licks and detected extra-range lick visitation in about 70% of their collared Mountain Goats in two populations. They also noted the difficulty in documenting lick use from GPS collar records

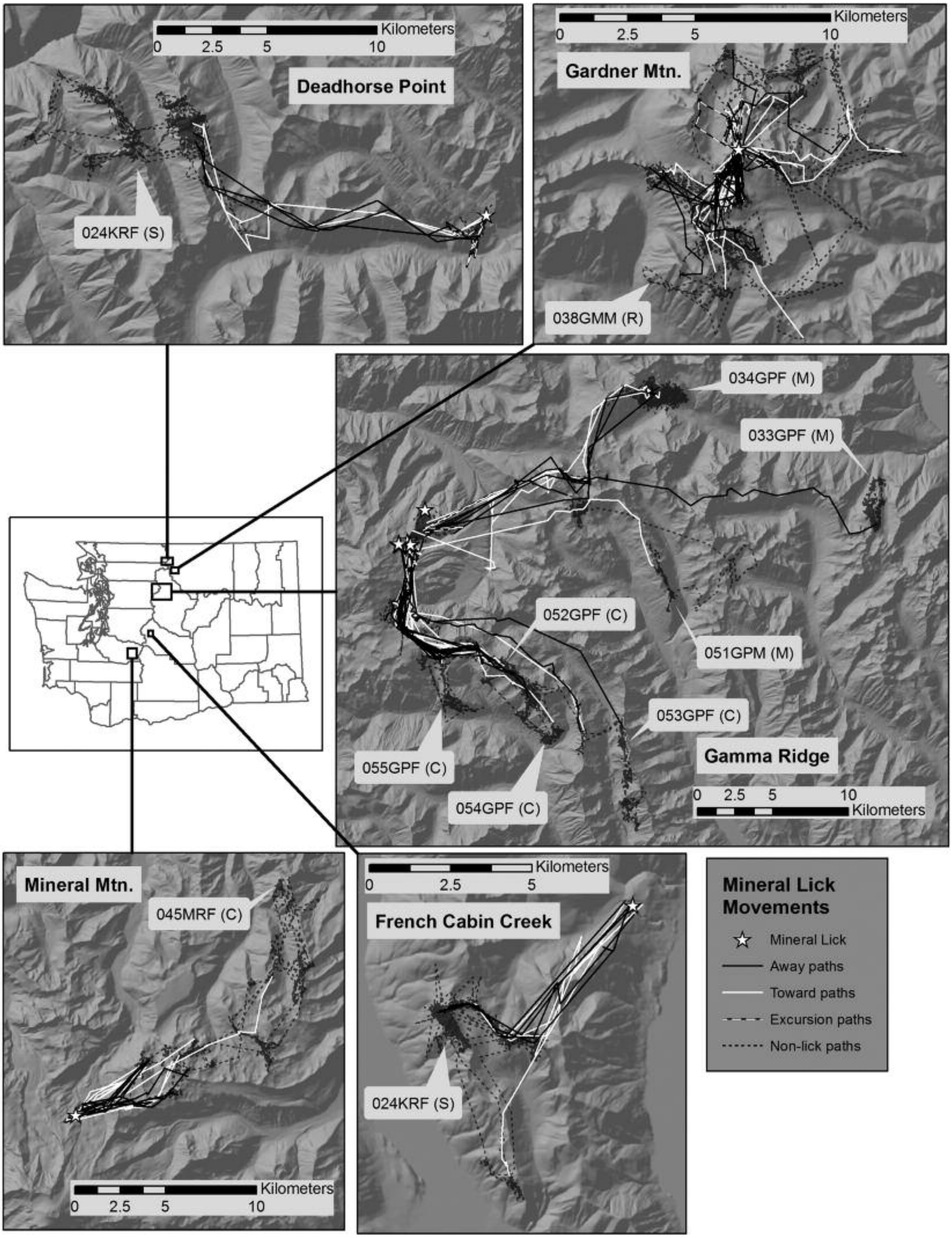

FIGURE 2. Movements of GPS-collared mountain goats toward and away from mineral licks in Washington, 13 September 2003–19 September 2007. Non-lick paths for each Mountain Goat are indicated by callout boxes giving the goat name and Type in parenthesis (M = Migrant, S = Sojourner, C = Commuter, and R = Resident).

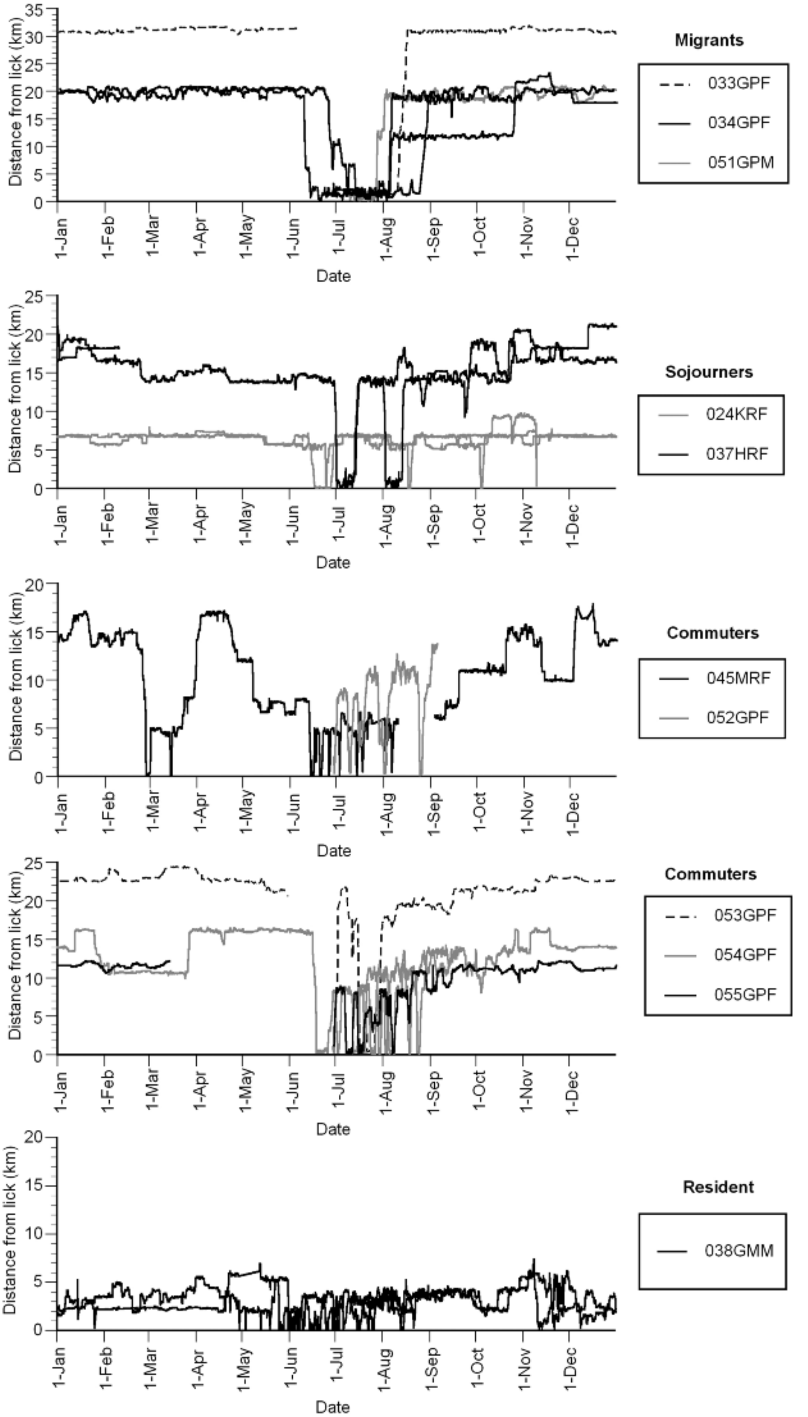

FIGURE 3. Distance from their respective mineral licks for 11 Mountain Goats in Washington, 13 September 2003–19 September 2007. Multiple lines for an individual indicate multiple years of tracking.

TABLE 2. Median, maximum, and minimum Duration of Lick States (moving Toward lick, At Lick, Excursion from lick, and moving Away from lick) in days for individual Mountain Goats in Washington, 13 September 2003–19 September 2007.

Type	Goat	Toward				At Lick				Excursion				Away			
		Median	Min	Max	n	Median[1]	Min	Max	n	Median	Min	Max	n	Median	Min	Max	n
Migrant	033GPF	.	.	.	0	31.8	31.8	31.8	1	.	.	.	0	6.3	6.3	6.3	1
	034GPF	9.2	4.1	14.3	2	18.3	0.5	51.5	5	3.8	5.1	2.5	2	5.1	2.4	7.0	3
	051GPM	2.2	2.2	2.2	1	35.0	33.0	37.1	2	.	.	.	0	1.0	1.0	1.0	1
	All	4.1	2.2	14.3	3	32.4[a]	0.5	51.5	8	3.8	5.1	2.5	2	5.1	1.0	7.0	5
Sojourner	024KRF	1.0	0.3	4.0	5	1.5	0.1	7.9	5	.	.	.	0	2.1	1.5	2.8	5
	037HRF	1.7	1.6	1.8	2	2.4	2.0	5.4	7	0.5	3.0	0.3	4	3.1	1.9	3.6	3
	All	1.6	0.3	4.0	7	2.4[b]	0.1	7.9	12	0.5	3.0	0.3	4	2.1	1.5	3.6	8
Commuter	045MRF	0.3	0.1	2.4	10	0.4	0.1	2.0	11	0.8	0.8	0.8	1	1.0	0.3	1.6	10
	052GPF	1.5	1.3	4.1	3	1.1	0.4	1.7	4	.	.	.	0	3.1	1.7	6.3	4
	053GPF	1.0	1.0	1.0	1	2.5	0.2	7.5	3	2.3	2.3	2.3	1	3.7	2.5	4.9	2
	054GPF	0.9	0.4	2.3	11	1.5	0.6	7.6	13	0.2	0.2	0.2	1	1.7	0.5	4.6	12
	055GPF	1.1	0.8	1.5	3	1.6	1.3	4.0	4	1.7	1.7	1.7	1	1.5	1.3	2.0	3
	All	1.0	0.1	4.1	28	1.3[b]	0.1	7.6	35	1.2	2.3	0.2	4	1.5	0.3	6.3	31
Resident	038GMM	0.5	0.1	3.0	26	0.8[b]	0.1	2.9	45	0.5	2.3	0.1	19	1.0	0.1	4.9	26
All	All	1.0	0.1	14.3	64	1.0	0.1	51.5	100	0.5	5.1	0.1	29	1.5	0.1	7.0	70

[1]letters indicate statistically significant differences between Types.

within a Mountain Goat's normal range of movements. Thus, just how many of the 35 mountain goats we tracked for which we could not document mineral lick use did not use licks and how many used licks we did not detect remains an open question, but my subjective assessment is that a number of them did not use licks. Notably, Festa-Bianchet and Côté (2008) did not report any natural mineral lick use over 15 years of study of the Caw Ridge (Alberta) Mountain Goat population and Fox et al. (1989) indicated that lick use was not evident in Mountain Goats in southeast Alaska. It may be that the generally high rates of use of mineral licks by Mountain Goat populations is a consequence of the availability of licks in mountainous terrain and the lack of lick use is due to the lack of availability.

The seasonal nature of mineral lick use has been reported in other species (e.g. Weeks and Kirkpatrick 1976; Tankersley 1984; Atwood and Weeks 2002) and Mountain Goats (Hebert and Cowan 1971; Turney and Blume 2004). For mountain ungulates, the period of greatest visitation was similar to those of this study (Heimer 1974; Tankersley 1984; Turney and Blume 2004; Poole et al. 2010). The earlier onset and decline in mineral lick visitation by the Resident in this study may be due to the fact that he was a resident, that he was the only adult male in my study, or to particular characteristics of the licks and associated terrain. Notably, other reports have documented earlier lick use for males: for Mountain Goats (Hebert and Cowan 1971; Poole et al. 2010; J. Mainguy, personal communication, 2008); Moose (*Alces alces*), Fraser and Hristienko 1981; Tankersley and Gasaway 1983; and Dall Sheep (*Ovis dalli dalli*), Tankersley 1984. In mountain environments, snow may impede and hence delay long-distance movements compared to lower elevations and may explain the later peak in mineral lick visitation by Migrant Mountain Goats.

Although I did not find significant differences among Types for Durations of States other than At Lick, it seems likely that this was due to low statistical power (given the small sample sizes) rather than the lack of actual differences. For States of Toward and Away, Sojourners had Durations approximately half those of Migrants, Commuters had Durations approximately half those of Sojourners, and the Resident had Durations approximately half those of Commuters (Table 2). A similar progression was evident in the non-significant Distances, except that Sojourner and Commuter Distances were approximately equal (Table 4).

Mineral lick use can be considered in a cost-benefit framework, in which the benefit is the chemical constituents available from the lick (Kreulen 1985; Klaus and Schmid 1998) and the costs are the energetic costs of traveling Toward and Away, reduction of foraging opportunity, and increased predation risk associated with travel and remaining in the vicinity of the lick. Foraging opportunity was probably reduced in the vicinity of most licks. The Deadhorse Point and French

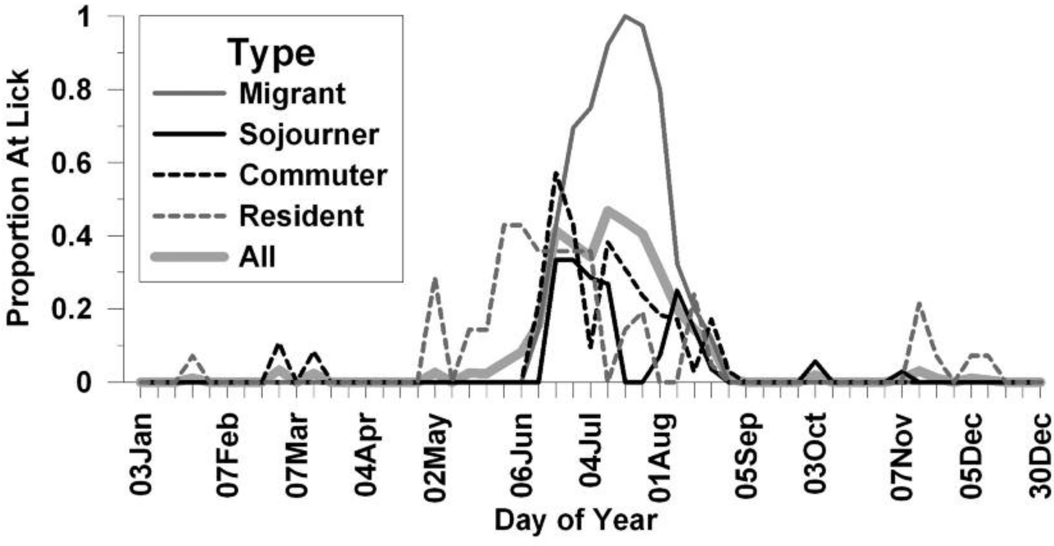

FIGURE 4. Weekly means of the daily proportion of Mountain Goats At Lick for each Type in Washington, 13 September 2003–19 September 2007.

TABLE 3. Median, minimum, and maximum Intervals (difference, in days, between the start of Toward and the end of the previous Away) between mineral lick visits by Mountain Goats taking place in the same year and between years (over winter) in Washington, 13 September 2003–19 September 2007.

		Same year				Between years			
Type	Goat	Median	Min	Max	*n*	Median	Min	Max	*n*
Migrant	033GPF	.	.	.	0	.	.	.	0
	034GPF	.	.	.	0	316.7	312.4	321.0	2
	051GPM	.	.	.	0	317.8	317.8	317.8	1
	All	.	.	.	0	317.8	312.4	321.0	3
Sojourner	024KRF	64.8	51.0	78.5	2	237.4	224.5	250.2	2
	037HRF	16.4	16.4	16.4	1	318.9	318.9	318.9	1
	All	51.0[a]	16.4	78.5	3	250.2	224.5	318.9	3
Commuter	045MRF	5.5	0.9	89.6	9	.	.	.	0
	052GPF	15.5	6.3	16.9	3	.	.	.	0
	053GPF	12.9	12.9	12.9	1	.	.	.	0
	054GPF	6.0	1.5	16.2	10	290.5	290.5	290.5	1
	055GPF	5.2	1.7	16.5	3	.	.	.	0
	All	6.3[b]	0.9	89.6	26	290.5	290.5	290.5	1
Resident	038GMM	3.1[b]	0.4	93.5	23	143.1	124.5	161.6	2
All	All	5.6	0.4	93.5	52	290.5	124.5	321.0	9

[1]letters indicate statistically significant differences between Types

Cabin Creek licks were in timbered areas which may have less forage available than open areas, although this was not the case with the subalpine licks (Gardner Mountain, Gamma Ridge, and Mineral Mountain). Also, it is highly likely that forage in the vicinity of licks is over-utilized by high concentrations of visiting Mountain Goats (Cowan and Brink 1949). For Mountain Goats, predation risk probably increases in unfamiliar terrain and with restricted visibility in forested habitats (Cowan and Brink 1949; Festa-Bianchet et al. 1994; Côté and Beaudoin 1997). As such, predation risk would be considered higher for visits to Deadhorse Point and French Cabin Creek licks, but less for the subalpine licks. Also, Gamma Ridge differed from the other lick areas in that extensive alpine meadows and escape terrain occurred in the vicinity of the licks. However, Migrants visiting the Gamma Ridge licks traveled though timbered terrain on route to the subalpine licks there. The artificially high concentrations of Mountain Goats in the vicinity of licks may also increase predation risk. The tradeoffs in these factors have apparently resulted in the lick visit Types, where the Mountain

TABLE 4. Median, maximum, and minimum Distance (km) and movement rate (km/hr) for individual mountain goats moving Toward and Away from a mineral lick from the first fix of the movement to the last in Washington, 13 September 2003–19 September 2007.

		Distance						Movement Rate						n	
		Toward			Away			Toward			Away				
Type	Goat	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Toward	Away
Migrant	033GPF	.	.	.	29.4	29.4	29.4	.	.	.	0.20	0.20	0.20	0	1
	034GPF	18.0	17.6	18.3	17.9	15.9	18.2	0.12	0.05	0.18	0.13	0.11	0.31	2	3
	051GPM	15.6	15.6	15.6	7.9	7.9	7.9	0.29	0.29	0.29	0.32	0.32	0.32	1	1
	All	17.6	15.6	18.3	17.9	7.9	29.4	0.18	0.05	0.29	0.20	0.11	0.32	3	5
Sojourner	024KRF	5.5	5.5	8.9	6.4	5.3	6.7	0.22	0.06	0.92	0.13	0.10	0.16	5	5
	037HRF	13.7	13.4	14.0	12.5	12.1	12.9	0.34	0.33	0.34	0.16	0.15	0.28	2	3
	All	5.6	5.5	14.0	6.7	5.3	12.9	0.33	0.06	0.92	0.14	0.10	0.28	7	8
Commuter	045MRF	4.6	4.1	12.8	4.7	4.2	6.5	0.61	0.22	1.45	0.19	0.13	0.73	10	10
	052GPF	10.1	8.1	10.3	8.7	7.7	12.1	0.23	0.10	0.34	0.12	0.08	0.20	3	4
	053GPF	16.8	16.8	16.8	17.1	16.1	18.2	0.67	0.67	0.67	0.22	0.14	0.30	1	2
	054GPF	8.0	7.3	15.1	7.9	6.7	12.9	0.40	0.26	0.86	0.23	0.10	0.62	11	12
	055GPF	7.7	7.3	8.1	7.4	4.8	7.6	0.26	0.21	0.40	0.18	0.14	0.25	4	4
	All	7.8	4.1	16.8	7.5	4.2	18.2	0.40	0.10	1.45	0.19	0.08	0.73	29	32
Resident	038GMM	2.3	1.5	6.9	2.0	0.6	5.1	0.23	0.04	0.75	0.10	0.01	0.50	26	26
All	All	5.5	1.5	18.3	5.3	0.6	29.4	0.30	0.04	1.45	0.16	0.01	0.73	65	71

TABLE 5. Rate of movement (m/hr) by State and Type during the lick season (01Jun-15Aug) for mountain goats visiting mineral licks.

Effect	Level	Mean[1]	95%CI	*n*
State	Toward	70.9[a]	54.9–91.5	547
	Away	52.0[b]	40.6–66.5	787
	Excursion	34.1[bcd]	23.5–49.4	95
	At Lick	27.1[c]	21.5–34.3	1864
	None	23.7[d]	18.9–29.8	5131
Type	Commuter	44.1	33.5–58.1	3655
	Migrant	37.8	27.4–52.2	2097
	Resident	36.9	22.2–61.6	1179
	Sojourner	34.3	23.4–50.5	1493

[1]letters indicate statistically significant differences

Goat may: (1) visit the lick infrequently and remain in the vicinity for an extended period because the costs of travel are high and habitat in the vicinity of the lick is acceptable (Migrant); (2) visit the lick infrequently and remain in the vicinity for a short period because the costs of travel are high and habitat in the vicinity of the lick is unacceptable (Sojourner); or (3) visit the lick frequently and remain in the vicinity for a short period because the costs of travel are low (Commuter and Resident).

Given the low number of Mountain Goats and licks in this study, it is difficult to be certain whether these Types are artificial divisions along a continuum of responses or natural categories emerging from the trade-offs discussed above. However, other accounts of mineral lick visitation suggest they can be fit into these Types. Hebert and Cowan (1971) indicated Mountain Goats visited licks briefly once a year, which would be Sojourners. Singer and Doherty (1985) described frequent visits by Mountain Goats from Glacier National park (Commuters) but suspected that Mountain Goats coming from Flathead National Forest visited only once per year for < 2 weeks (Sojourners). The Bighorn Sheep (*Ovis canadensis*) studied by Hnilicka et al. (2002) made fortnightly visits to the lick throughout the summer (Commuters), whereas Dall Sheep (*Ovis dalli*) in Alaska visited the licks primarily during the transition from winter to summer range (Heimer 1974; Sojourners). Adult Moose (*Alces alces*) studied by Fraser and Hristienko (1981) were evidently Sojourners and Commuters, while young male Moose were Migrants. White-tailed Deer (*Odocoileus virginianus*) studied by Wiles and Weeks (1986) had licks within their usual ranges (Residents) or traveled frequently to nearby licks (Commuters).

Comparisons of licks soils across studies can be difficult due to inconsistent choices of which constituents to measure and differing methods of measurement (Klaus and Schmid 1998). Some of my measurements can be compared with those reported by Jones and Hanson (1985) for the geometric mean of 18 mineral licks used by Mountain Sheep and Mountain Goats: Na = 1.67; Ca = 27.85; Mg = 5.69. The significantly

TABLE 6. Mean concentrations of Calcium (Ca), Potassium (K), Magnesium (Mg), Sodium (Na), and sulphate (SO_4) in mineral lick (Site) and reference (Ref) soil samples in Washington and *t*–test evaluations of differences for each lick. Means are back transformed estimates from the average of log–transformed values. Effect is the difference in the averages of the log–transformed values (site – reference) and the *t*–test evaluates the hypothesis of site > reference. meq = milliequivalents.

Chemical	Mineral Lick	Concentration Site	Concentration Ref	Samples Site	Samples Ref	Effect	*t*	*P*
Ca (meq/100g)	GAM1	7.49	10.10	2	4	–0.300	0.706	0.757
	GAM2	6.77	5.96	3	3	0.127	–0.317	0.377
	GAM3	5.70	6.60	1	4	–0.146	0.267	0.604
	GAM5	6.80	4.83	1	4	0.343	–0.627	0.268
	GAR1	3.12	2.49	2	8	0.224	–0.579	0.284
	GAR2	4.71	2.82	2	8	0.512	–1.322	0.098
K (ppm)	GAM1	245.73	138.05	2	4	0.577	–1.927	0.032*
	GAM2	191.00	133.47	3	3	0.358	–1.271	0.107
	GAM3	317.00	127.17	1	4	0.913	–2.365	0.012*
	GAM5	90.00	75.40	1	4	0.177	–0.458	0.325
	GAR1	97.86	55.35	2	8	0.570	–2.086	0.023*
	GAR2	47.29	53.93	2	8	–0.131	0.481	0.683
Mg (meq/100g)	GAM1	4.05	5.71	2	4	–0.343	1.037	0.846
	GAM2	4.79	4.76	3	3	0.007	–0.022	0.491
	GAM3	4.60	3.54	1	4	0.261	–0.612	0.273
	GAM5	1.10	1.01	1	4	0.082	–0.193	0.424
	GAR1	0.39	0.22	2	8	0.582	–1.930	0.032*
	GAR2	0.30	0.24	2	8	0.203	–0.672	0.253
Na (meq/100g)	GAM1	2.39	0.12	2	4	3.003	–11.267	<0.001*
	GAM2	0.87	0.15	3	3	1.764	–7.020	<0.001*
	GAM3	4.75	0.17	1	4	3.305	–9.605	<0.001*
	GAM5	0.54	0.22	1	4	0.888	–2.580	0.008*
	GAR1	0.22	0.12	2	8	0.621	–2.554	0.008*
	GAR2	0.26	0.17	2	8	0.427	–1.755	0.045*
SO_4 (ppm)	GAM1	208.94	35.87	2	4	1.762	–2.205	0.018*
	GAM2	98.11	29.14	3	3	1.214	–1.611	0.059
	GAM3	143.13	27.32	1	4	1.656	–1.605	0.059
	GAM5	32.13	20.87	1	4	0.431	–0.418	0.339
	GAR1	5.13	4.71	2	8	0.085	–0.116	0.454
	GAR2	2.58	1.31	2	8	0.674	–0.923	0.182

*Significant at $\alpha = 0.05$

higher concentrations of Na at licks and higher concentrations, but less extreme differences for other chemicals are similar to the results of other studies (e.g. Weeks and Kirkpatrick 1976; Tankersley 1984; Klein and Thing 1989; Tracy and McNaughton 1995; Klaus and Schmid 1998; Mincher et al. 2008). This supports the conclusion that Na is the main reason the mountain goats in this study visited mineral licks. My results do not support the hypothesis that Mg is a chemical sought after at licks (Jones and Hanson 1985; Heimer 1988; Klaus and Schmid 1998). The preponderance of visits to mineral licks in the late spring and early summer suggests that the detoxification/acidosis function of Na (Foley et al. 1995) is not the driver for mineral lick visitation because secondary compounds are more prevalent in browse than grasses and forbs (Festa-Bianchet 1988), and Mountain Goat diet is typically mostly forbs and graminoids in the summer with the most browse consumed in the winter (Fox et al. 1989).

It is noteworthy that all seven Mountain Goats visiting Gamma Ridge (Migrants and Sojourners) crossed the crest of the Cascade Range during the movements Toward and Away from the licks (Figure 2). While doing so, they also crossed from one national forest to another, from one Department of Fish and Wildlife administrative region to another, and from one county of Washington to another. 037HRF also crossed region and county boundaries during mineral lick visits. Consequently, coordination among administrative units is a necessary part of managing these Mountain Goats and the mineral licks they use. Nevertheless, little is known about the degree to which disturbances (logging, recreation, road construction, trail development) may impact mineral lick movements and this may vary among Mountain Goat populations. Poole et al. (2010) gave anecdotal accounts of logging modifying, but not inhibiting Mountain Goat lick visitation, but at a road inhibited movements for about a year. It would seem prudent to limit logging operations and road building along known mineral lick travel routes to avoid times of high lick visitation.

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