A COMPARISON OF BOBCAT AND COYOTE PREDATION ON LAMBS IN NORTH-COASTAL CALIFORNIA

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Abstract: We investigated predation on lambs by bobcats (*Lynx rufus*) relative to coyotes (*Canis latrans*) from June 1994 through November 1995 at Hopland Research and Extension Center (HREC) in north-coastal California, where both predators occur at equally high densities. Lamb losses during this study were typical for HREC and surrounding ranches and included 64 (5.3% of lambs pastured) confirmed predator kills and 134 (11.1%) missing individuals. Fifty-seven of the predator-killed lambs were attributed to coyotes, whereas none were assigned to bobcats. The proportion of bobcat scats containing sheep remains was small (4.2%), and occurrence did not peak in the lambing season, suggesting that sheep consumed by bobcats were scavenged. Sheep were common in coyote scats (21.4%) and occurred most frequently in scats from the winter–spring lambing season. Coyotes were responsible for all lamb kills in intensively monitored pastures for which predator species could be identified. Use of space by radiocollared bobcats was not noticeably influenced by the presence of lambs. We concluded that bobcats were not important predators of lambs at HREC and not the cause for the relatively large numbers of lambs missing and unaccounted for each year.

JOURNAL OF WILDLIFE MANAGEMENT 62(2):700–706

Key words: bobcat, California, *Canis latrans*, coyote, lamb, *Lynx rufus*, predation, sheep.

The coyote is the most important predator of domestic sheep in the western United States (Wagner 1988, Andelt 1996), but bobcats also have been known to kill domestic sheep (Young 1958, Andelt 1996). At the University of California's HREC, numbers of confirmed predator-killed sheep averaged 42 lambs and 44 ewes/year over the last 24 years, representing 3–4% of all sheep on range. The vast majority of sheep kills have been attributed to coyotes. Dogs and, more recently, mountain lions (*Felis concolor*) have also been important secondary predators of sheep. Bobcats have not been implicated in sheep kills (Scrivner et al. 1985, Timm 1990). However, numbers of missing lambs (10–12% of all pastured lambs) have been even higher than numbers of confirmed predator-killed sheep. These losses have been assumed largely due to coyotes, but it is necessary to verify this assumption for predator management to effectively target the principal predator(s).

Because bobcats are major predators of wild, neonate ungulates (Linnell et al. 1995) and are known to drag and bury prey (Young 1958, McCord and Cardoza 1982), and because coyotes and bobcats occur at equally high densities on the site (0.76/km^2; Neale 1996), we suspected bobcats might be responsible for substantial numbers of missing lambs at HREC. Coyotes select lambs over ewes, when lambs are available, but kill sheep of all sizes (Sacks 1996). Bobcats are comparatively small (F: $\bar{x}$ = 5.0 kg; M: $\bar{x}$ = 6.8 kg), weighing about half the mass of coyotes (F: $\bar{x}$ = 10.4 kg; M: $\bar{x}$ = 11.6 kg; Neale 1996); given the size of bobcats, they would likely target small lambs which, if not cached, might be wholly consumed or removed by scavenging golden eagles (*Aquila chrysaetos*; Connolly et al. 1976). To control depredation, only coyotes are regularly killed, along with offending mountain lions and black bears (*Ursus americanus*), but bobcats are not currently removed. Therefore, as part of a larger research program on the ecology of predators on sheep range (Neale 1996, Sacks 1996), we assessed the

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role of bobcats in contributing to the high numbers of missing lambs at HREC and evaluated their importance relative to coyotes in north-coastal California.

STUDY AREA

The HREC is located in southeastern Mendocino County, approximately 160 km north of San Francisco, California. This 2,168-ha area lies in the Mayacamas Mountains in the Russian River drainage, with elevations from 150 to 915 m. The site has a primarily southwest aspect; topography is hilly to rugged and includes steep, rocky drainages. Vegetation consists of 4 principal types: oak woodland, annual grassland, mixed evergreen–deciduous forest, and chaparral. Murphy and Heady (1983) provided a detailed description of plant communities at HREC. The climate is characterized by mild, rainy winters and hot, dry summers. Wild prey is abundant (Neale 1996).

The HREC has been a sheep research facility since 1951 and currently maintains the largest sheep operation in Mendocino County. Sheep are typically dispersed among several of the 32 fenced pastures that range in size from 6 to 260 ha. Fencing is usually effective at keeping sheep inside pastures but has little influence on predator movements, because of low fence height (approx 1 m in most places) and holes under fences. Sheep are checked once daily from roads. Between 900 and 1,500 mature ewes are present throughout the year; the sheep population nearly doubles in winter after lambing, which usually begins from late October to late November and is completed by mid-January. Lambs are born in the main barn–headquarters area where they are held for at least 48 hr before being put on range. Most lambs are sold by May.

METHODS

Sheep Losses

We searched pastures daily for kills and examined recovered carcasses for cause of death. Where predation was indicated (e.g., by subcutaneous hemorrhaging on the head or neck, or signs of struggle), we attempted to identify the predator. Evidence used to classify kills included size and spacing of tooth punctures on the skin, location of feeding on the carcass, tracks, scats, and other evidence described by Wade and Bowns (1982).

Analysis of Scats

We collected fresh scats of bobcats and coyotes opportunistically throughout the site and biweekly by walking 21 0.5-km dirt-road transects. We assigned scats to species of predator via size and shape (Murie 1954, Danner and Dodd 1982) as well as associated tracks and other sign (Murie 1954). We discarded scats that could not be confidently assigned to species (10–15%). Scats were processed and analyzed for food items with the techniques of Kelly (1991) and Neale (1996). We quantified occurrence of sheep remains (wool, bone) in scats for the total study period (Jun 1994–Nov 1995) and for the following seasons: summer (Jul–Sep), fall (Oct–Dec), winter (Jan–Mar), and spring (Apr–Jun). We used log-likelihood ratio contingency tables (Zar 1984:71) to determine whether occurrence of sheep remains in scats differed among seasons.

Monitoring of Lambs

Because the fate of a great number of missing lambs remained undetermined every year at HREC, we attempted to monitor all lamb losses in a subset of the flock during their first 4 weeks on range. We placed groups of 28–31 newborn lambs and their mothers into each of 4 pastures in which high numbers of missing lambs had been recorded in previous years. We established 2 groups in late November and 2 in mid-January. These groups were the only lambs (n = 119) pastured at these times. At introduction, body mass of lambs averaged 6.6 kg.

Most lambs (n = 99) were equipped with collars mounted with lightweight radiotransmitters and mortality sensors or "dummy" collars (n = 10) made of nylon webbing; 10 lambs did not have collars. In addition to routine checks for kills, we counted lambs and checked for injuries daily. Using radiotelemetry when possible, we conducted searches on foot for missing lambs, with concentrated efforts around ditches and ravines. We also monitored radiocollared bobcats (see below) near lamb pastures, especially in areas where lambs were missing or found dead, to determine if these individuals were killing lambs.

Bobcat Use of Space Relative to Lambs

We used number 3, padded-jaw leghold traps (Woodstream, Littitz, Pennsylvania, USA) to capture bobcats. We trapped along roads, ridges, and drainages throughout HREC. Traps

Table 1. Annual lamb and ewe losses due to confirmed predation and missing lambs, Hopland Research and Extension Center, 1980–95.

Parameter	16-yr total	Mean	SD	Range
Ewes killed by predators[a]	784	49.0	29.21	5–116
Lambs killed by predators[b]	766	47.9	20.21	14–83
Missing lambs	2,486	155.4	54.02	93–274

[a] Includes a small number of rams and wethers.
[b] <7 months old.

were set in trails without attractants or were baited with synthetic and natural scents and checked at least once daily. Captured bobcats were removed from traps and transported to HREC headquarters. We sedated bobcats with intramuscular injections of ketamine hydrochloride and xylazine hydrochloride (dosage for 100 mg/mL solution: 0.1 mL ketamine and 0.016 mL xylazine/kg body mass). Bobcats were examined for reproductive and overall condition, weighed, measured, radiocollared, and released at capture sites following recovery from sedation. Animal care and handling procedures were approved by the Animal Care and Use Committee at the University of California-Berkeley, Animal Use Protocol R190-0496.

Telemetry between June and December 1994 was conducted mostly from fixed tracking shelters with paired Yagi antennas and a null-peak system. By January 1995, all radiotelemetry was accomplished by truck or on foot via hand-held 2-element "H" or 3-element Yagi antennas. Universal Transverse Mercator locations based on ≥2 azimuths differing 30–150° were plotted by hand on 7.5-min U.S. Geological Survey topographic maps or in program Locate II (Pacer, Truro, Nova Scotia, Canada). Average telemetry error was estimated at 146 m, with 95% of errors <356 m (Sacks 1996). Fixed-station radiotelemetry was conducted in 4-hr sessions blocking sunrise, midday, sunset, and midnight, 8 times/week spread over 5 days. We made hourly attempts to locate each radiocollared bobcat. We conducted close-range (hand-held antenna) tracking 5–7 days/week, with most locations between 0600 and 1900. We located bobcats an average of 6.4 times/week (range of individual averages = 2.6–13.4).

To detect attraction to lambs, we evaluated home ranges and locations of radiocollared adult and subadult resident bobcats (n = 8) with respect to lamb presence. We used program CALHOME (Kie et al. 1996) to calculate adaptive kernel ranges (Worton 1989) with 90% (home range) and 50% (core) isopleths. We compared positions of home ranges and core areas between 2 periods: (1) prior to lambing (≤50 days before the initial introduction of lambs), and (2) the first 4 months of lamb presence (22 Nov 1994–22 Mar 1995). For 1 bobcat (M312), locations collected after lambs were removed from its vicinity (Apr 1995) were included in the former sample to increase sample size. We mapped adaptive kernel isopleths with the Atlas Geographic Information System (version 2.00; Strategic Mapping, Santa Clara, California, USA). For bobcats occupying home ranges overlapping lamb pastures (before or after the introduction of lambs), we evaluated attraction to lambs by comparing proportions of locations inside versus outside lamb pastures during the 2 periods. We conducted Yates-corrected log-likelihood ratio or Fisher's exact (where expected values were <5) tests of the null hypothesis that the bobcat was located inside or outside lamb pastures independently of lamb presence or absence. Significance was set at $P \leq 0.05$ for all analyses.

RESULTS

Sheep Losses

Sheep losses during this study were comparable to previous years. There were 196 confirmed predator-killed sheep between June 1994 and November 1995, including 64 lambs that represented 5.3% of the 1,207 lambs pastured. Of these 64, 57 (89.1%) were attributed to coyotes, 5 (7.8%) to dogs, and 2 (3.1%) to unknown predators (coyote, bobcat, gray fox [*Urocyon cinereoargenteus*]). Missing lambs exceeded the number of confirmed predator-killed lambs each year from 1980 through 1995 (Table 1). In 1995, missing lambs totaled 134 (11.1% of all lambs pastured) at weaning in April. Spatial distribution of missing lambs could not be precisely evaluated, because lambs were often collected from several pastures prior to counting.

Table 2. Percentage of bobcat and coyotes scats containing sheep remains, Hopland Research and Extension Center, 1994–95.

Predator	Summer (Jul–Sep)		Fall (Oct–Dec)		Winter (Jan–Mar)		Spring (Apr–Jun)		Overall Jun 1994–Nov 1995	
	%	n	%	n	%	n	%	n	%	n[a]
Bobcat	4.9	61[b]	5.0	40[b]	5.3	76	4.1	49	4.2	259
Coyote	18.4	141	14.0	121	21.3	80	30.1	103	21.4	467

[a] Samples include scats (coyote: n = 22; bobcat: n = 33) that could not be classified accurately to season.
[b] Samples represent summer 1994 (n = 34) and summer 1995 (n = 27) scats combined, and fall 1994 (n = 20) and fall 1995 (n = 20) scats combined.

Analysis of Scats

Sheep remains occurred in only 11 of 259 bobcat scats (4.2%; Table 2), and occurrence did not differ among seasons (G_3 = 0.10, P = 0.99). In contrast, coyotes ate sheep frequently (21.4% of scats). Occurrence of sheep remains in coyote scats differed among seasons (G_3 = 9.07, P = 0.03), with greatest occurrence in winter and spring, when lambs were available.

Monitoring of Lambs

Of the 119 lambs intensively monitored, 6 (5.0%) were predated, 1 (0.8%) died from exposure, and 2 (1.6%) were missing and never recovered. In addition, 1 lamb was attacked by a coyote but survived. Four of the 6 predated lambs were killed by coyotes, but we were unable to identify the responsible predator in 2 cases.

Bobcat Use of Space Relative to Lambs

None of the 8 adult and subadult resident bobcats (3 F, 5 M) radiotracked during the study were implicated in sheep predation events. Most radiocollared bobcats inhabited the higher elevations to the northeast, while lambs were pastured at lower elevations to the southwest. Nevertheless, 4 residents (M308, M312, M311, F111) occupied home ranges overlapping lamb pastures (Fig. 1), and home

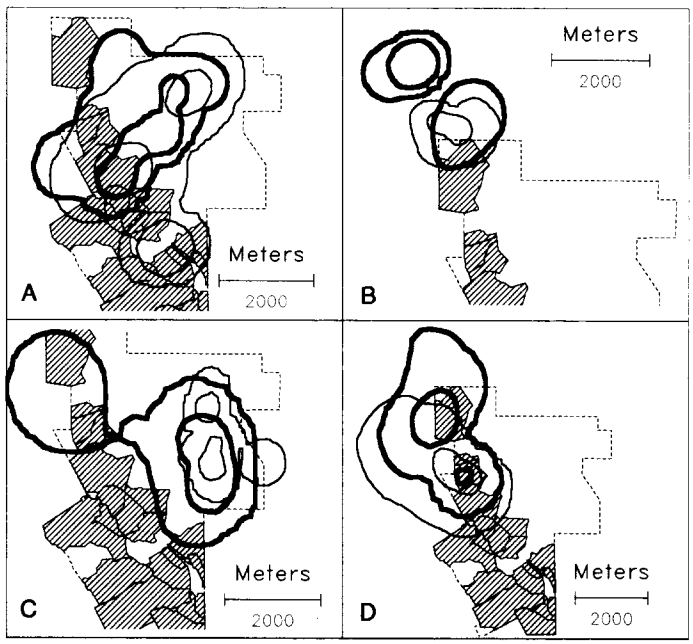

Fig. 1. Home ranges (90% adaptive kernel isopleth) and core areas (50% adaptive kernel isopleth) of 4 resident bobcats that overlapped lamb pastures (hatched) in the absence of lambs (light line) versus presence of lambs (heavy line), Hopland Research and Extension Center (dashed line), October 1994–April 1995: (A) M308, (B) M312, (C) M311, and (D) F111. Lambs were pastured from 22 November 1994 to 22 March 1995. Numbers of radiolocations (lambs absent, lambs present) used to calculate home ranges were as follows: M308 (92, 165); M312 (29, 28); M311 (193, 141); F111 (84, 29).

Table 3. Number of radiolocations of 4 resident bobcats inside and outside lamb pastures when lambs were either present or absent, Hopland Research and Extension Center, October 1994–April 1995.

Category and statistics	M308	M312	M311	F111
No. inside lamb pastures, lambs present[a]	21	4	13	8
No. outside lamb pastures, lambs present[a]	144	24	128	21
No. inside lamb pastures, lambs absent[b]	21.8	3	11.9	6.3
No. outside lamb pastures, lambs absent[b]	70.2	26	181.1	77.7
Yates-corrected *G*-statistic	4.22	[c]	0.70	[c]
P	0.039	0.283	0.404	0.006

[a] Lambs were introduced into a total of 19 pastures over 14 separate occasions, 22 November–3 March. Lamb-present radiolocations (22 Nov–22 Mar) for each bobcat were considered in or out of lamb pastures based on the current distribution of lambs in that bobcat's vicinity.

[b] Lamb-absent radiolocations were collected over 50 (M308, M311, F111) and 19 (M312) days prior to first lamb introduction: April 1995 (post-lambing season) locations were included for M312 to increase sample size. Lamb-absent radiolocations in or out of lamb pastures were calculated to reflect the relative occupancy by lambs throughout the lamb-present period as follows: for each pasture, the number of lamb-absent radiolocations falling in that pasture was multiplied by the proportion of lamb-present radiolocations that were obtained (i.e., anywhere) while lambs were in that pasture. These figures were then summed over all lamb pastures for each bobcat.

[c] Fisher's exact tests were used where expected values (not shown) were <5.

ranges of M308 substantially overlapped lamb pastures (Fig. 1A). Bobcats M308, M312, and F111 did not shift home ranges to include lambs during the lambing season (Fig. 1). However, M311 occupied a home range that overlapped lamb pastures more when lambs were present (Fig. 1C). Three other residents whose home ranges were within 1 km of lamb pastures (but did not overlap them) did not shift their space use to encompass those pastures during the lambing season. We used radiolocations of the 4 bobcats whose home ranges overlapped lamb pastures to detect finer-scale use of space relative to lambs. There were 2 significant deviations from the expected use of lamb pastures; when lambs were present, M308 used lamb pastures less than expected, and F111 used pastures more than expected (Table 3).

DISCUSSION

Scat analysis indicated that coyotes ate sheep more frequently than did bobcats at HREC. Furthermore, infrequent occurrence of sheep in bobcat scats likely represented scavenging and not predation, because the small proportion of bobcat scats containing sheep remains did not differ seasonally, as would be expected if bobcats preyed on lambs. Given the small size of bobcats at HREC, it seems unlikely they would kill ewes, which average 60–64 kg. Neale (1996) found scats of bobcats at HREC to consist mostly of small to medium-sized (<2 kg) prey. In contrast, occurrence of sheep remains in coyote scats was consistently high and peaked in winter and spring, when lambs were available. Most bobcats probably consumed no sheep at all; 8 of the 11 bobcat scats that contained sheep remains were located in a single bobcat's (M308) home range. Furthermore, several coyote-killed sheep were discovered in this area (Sacks 1996), which suggested that M308 may only have scavenged on those carcasses. On 2 occasions, M308 was located near the time of lamb predation events and in their vicinity, but evidence suggested that coyotes had made both kills; in 1 case via examination of the carcass, and in the other, a coyote pair known to frequently kill sheep was also located at the kill site near the time of the kill (Sacks 1996). Unfortunately, we had no way to quantify error in assignment of scats to predator species. However, the large difference found between the 2 diets suggests that such error was small. Furthermore, our criteria for discrimination were supported by scats collected from known individuals (e.g., at trap sites) or where tracks were visible.

Intensive monitoring of lambs also suggested that bobcats were not responsible for missing lambs. Coyotes were responsible for at least 5 of 7 lambs attacked or killed by predators in intensively monitored pastures. Without thorough searches of pastures on foot, most of the 7 losses that were recovered would not have been found (although most were found without radiotracking), because vegetation and topography precluded discovery of many carcasses. Intensive daily monitoring did not appear to reduce predation, as losses in these pastures were similar to those in other years during the same time period.

Use of space by bobcats was potentially affected by many factors. On a landscape level, scat collection and sightings suggested that bobcats were most dense at higher elevations in chaparral habitat (Neale 1996). Breeding activ-

ities and denning (females) probably influenced space use of individuals (Neale 1996). We found little evidence that bobcats shifted home ranges to include lambs. Although 1 bobcat (M311) shifted its home range closer to lamb pastures during the lambing season, this shift was probably unrelated to lamb presence because finer-scale analysis did not detect attraction to lambs. More likely, this move was related to breeding activities, as M311 was associated with F111, overlapped her home range most during this period, and maintained high use of this area well after lambs were no longer available (Neale 1996). We could not rule out attraction to lambs by F111, although she was small (4.9 kg at capture in Jul 1994). The largest (8.4 kg) bobcat (M308), and the only individual to substantially overlap lamb pastures, would have been most likely to predate lambs. However, he showed no home range shift to include more lamb pastures, and in fact used these areas less when lambs were present. In contrast, radiotelemetry of coyotes during a concurrent study (Sacks 1996) demonstrated that coyotes were responsible for the great majority of sheep damage. For example, 5 radiocollared coyotes (of 7 collared at the time) were responsible for a minimum of 44 sheep (6 ewes, 38 lambs; B. N. Sacks, unpublished data) killed between January and June 1995.

The problem of missing sheep is not unique to HREC. Predation is assumed the primary source of missing lambs on other ranches throughout the western United States (Klebenow and McAdoo 1976, Nass 1977, Tigner and Larson 1977, McAdoo and Klebenow 1978), and our results indicate such predation occurred at HREC, where predation by coyotes was likely the primary cause of missing lambs. Bobcats were not important predators of sheep at HREC and also did not appear to be major predators of black-tail deer (*Odocoileus hemionus*). Although deer occurred in 13.9% of bobcat scats annually (J. C. C. Neale, unpublished data), and at least 1 radiocollared bobcat killed a fawn (Neale 1996), occurrence of deer in scats was relatively low in spring (8.2%) and summer (9.8%), when fawns were available (J. C. C. Neale, unpublished data). Given the apparently infrequent predation on fawns by bobcats, it seems likely that most consumption of black-tail deer, like sheep, represented scavenging. Predation on lambs and fawns by bobcats also may be buffered by abundant small prey, which the mild climate and diverse landscape of HREC support.

MANAGEMENT IMPLICATIONS

Our results support the current bobcat management strategy at HREC and throughout north-coastal California: no preventive removal. Given that HREC is typical of north-coastal California sheep ranches in terms of topography, vegetation, timing of lambing, and predator composition, and that bobcat predation on sheep is rarely confirmed in the region (California Agricultural Statistics Service 1995), our conclusion that bobcats do not commonly kill lambs is likely of general applicability to north-coastal California. However, because predator size, habitat, and prey base vary throughout the western United States, additional studies may be useful in determining the relative importance of various predators to missing lambs in other regions.

ACKNOWLEDGMENTS

We thank K. M. Blejwas, J. P. Dayton, J. A. Meisler, J. Poor, Jr., and T. J. Weller for their invaluable assistance in the field. S. Ardley, J. Theade, E. Voight, and volunteers with the University Research Expedition Program also helped with fieldwork. We thank HREC personnel for their cooperation and for use of the HREC facilities. Funding and equipment were provided in large part by the U.S. Department of Agriculture's National Wildlife Research Center through cooperative agreements with the University of California at Berkeley (No. 12-34-74-0235-CA), and with the Division of Agriculture and Natural Resources of the University of California (No. 12-34-74-0224-CA). Additional support came from the graduate student fund in the Department of Environmental Science, Policy, and Management, the A. Starker Leopold endowed chair, and a fellowship (J. C. C. Neale) at the University of California at Berkeley. Comments provided by S. Knick and an anonymous reviewer greatly improved the manuscript.

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Received 4 April 1997.
Accepted 6 October 1997.
Associate Editor: Lochmiller.