PREGNANCY RATE AND EARLY LAMB SURVIVAL OF CALIFORNIA BIGHORN SHEEP (OVIS CANADENSIS CALIFORNIANA, DOUGLAS 1871) IN THE ASHNOLA WATERSHED, BRITISH COLUMBIA.

By

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ABSTRACT

The Flatiron Mountain population of bighorn sheep [Ovis canadensis], with a history of low lamb recruitment, was studied to determine the timing of offspring losses, the nutritional and disease status of females, and the significance of suckling behaviour, weather, and predation on lamb survival. Pregnancy rate, determined by Doppler ultrasound diagnoses, was 100% in 10 adult females captured in mid to late gestation. Mortality of lambs belonging to tagged females was 64%, all occurring in the first month postpartum. Of the five females that were observable throughout the lambing period, three lost their offspring when the lamb was between five and 21 days old. Adult females from Flatiron Mountain were heavier and had higher body condition scores than a captive research herd with higher lamb production, suggesting energy status of Flatiron females was sufficient for lamb survival. Concentrations of selenium, copper, and zinc in the blood serum of Flatiron females in winter were marginally deficient, based on domestic sheep values. The one 9-month old lamb captured had very low levels of some blood minerals. Liver and kidney concentrations suggest that selenium in adult males was the only trace mineral marginally deficient in this population. The only important pathogen isolated from nasal swabs was parainfluenza type-3 virus, which was found in 50% of the 12 females sampled in late winter. Although several storms involving freezing temperatures and snowfall occurred during the lambing period, females with newborn lambs frequented lower elevations characterized by a milder microclimate, and there was no obvious correlation between inclement weather and periods of high lamb mortality. The suckling behaviour of Flatiron lambs was similar to that of other populations which, on average, had double the lamb production of Flatiron females. Analysis of predator scats, mainly coyote, revealed 24% by volume of their spring diet consisted of bighorn lambs. Based on the lack of significant nutritional, disease, or climatic factors, and considering the timing of lamb losses, coyote predation was hypothesized to be the most likely factor limiting lamb survival on Flatiron Mountain. Research effort should be directed towards testing this conclusion before management prescriptions are applied.

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"When we consider... how soon some fishes would fill the ocean if all their ova became full grown fishes, we are tempted to say that every organism, whether animal or vegetable, is contending for possession of the planet... Nature opposes to this many obstacles, as climate, myriads of brute and also human foes, and of competitors which may preoccupy the ground. Each suggests an immense and wonderful greediness and tenacity of life... And each prevails as much as it does, because of the ample preparations it has made for the contest..."

- Henry David Thoreau

March 22, 1861.

INTRODUCTION

Background and Objectives

The numbers of California bighorn sheep (*Ovis canadensis californiana*) in the Ashnola watershed before the arrival of white men are unknown, but were probably larger than the present population, based on reports from early naturalists. An Indian village was located near the confluence of the Ashnola and Similkameen Rivers and its inhabitants hunted the various populations of bighorn in the area. Led by Indian guides, the first white men to visit the area in 1886 and 1887 remarked on the great abundance of bighorn observed (Allen 1912; Buechner 1960). When word of this spread internationally, unregulated hunting, until 1909, drastically reduced the Ashnola population (Blood 1961). Brooks (1923) attributes the extirpation of mountain sheep in the dry interior of B.C. to the introduction of rifles to the Indians and the introduction of diseases from domestic sheep on bighorn range. During the period from 1909 until 1955, with the exception of a short season in 1947, all hunting of bighorn was forbidden in the southern interior of B.C. and surviving bighorn populations increased. This increase continued after a male-only hunting season was introduced, and the population peaked at a minimum of 217 bighorn on Flatiron

Mountain in 1967 (Scheffler 1973). After 1967, classification counts indicated that the population began to decline, primarily as a result of low lamb production (Ramsay 1980).

In the past 30 years many management strategies have been applied to the Ashnola bighorn, with the objective of increasing the population to the level estimated to have existed before the arrival of white men (R.C. Lincoln pers. comm.). These included cattle removal, fall and spring burning, predator control, winter feeding, mineral supplementation, water supplementation, and anti-helmintic treatment (Table 1). The reasons for applying these treatments were often due to retroductive reasoning, which is not always reliable because alternate hypotheses can be generated from the same set of facts (Romesburg 1981). During the period from 1970 to present, when most of these treatments were applied, production of lambs generally decreased and classification counts averaged only 26 lambs per 100 adult females (n=13 years, Table 2). While there is great variation in lambing success among North American mountain sheep populations, 50 lambs per 100 females is generally considered adequate for population growth (Lawson and Johnson 1982). During this period of low lamb production, the maximum number of adult females on Flatiron Mountain declined at an average rate of 1.7 per year (Figure 1).

Bighorn sheep and their range habits have been studied in

Table 1. Recent history of the Ashnola bighorn population.

Date	Factors affecting the bighorn sheep on Flatiron and Crater Mts.	Source
1861	wagon road up the Ashnola R.	Blood 1961
early 1880'S	start of cattle grazing on bighorn winter ranges	Blood 1961
1887	start of unregulated sport and market hunting	Blood 1961
1909	bighorn herds closed to hunting	Blood 1961
1912	start of domestic sheep grazing on winter ranges	Blood 1961 & Demarchi 1965
1913	O.I.C. Grazing Reserve for bighorn on South Slope and Cliff's Ridge	Harper 1980
1919	start of horse grazing on bighorn winter ranges	Demarchi 1965
1922	"virus" from domestic sheep causing disease in bighorn	Brooks 1923
1924	domestic sheep removed from winter ranges	Demarchi 1965
1914-1950	600 cattle on all Ashnola winter ranges	Demarchi 1965
1928	400 cattle on South Slope alone indicates overstocking	Blood 1961
1947	short hunting season	Blood 1961
1951-52	coyote control by poison bait	Blood 1961
1952	cattle numbers reduced to 150	Blood 1961
1955	male only hunting season begins (3/4 curl regulation)	Demarchi 1965

Table 1. Continued.

1955	cattle numbers increase to 300	Blood 1961
1957	poison baits dropped by aircraft on mountain ranges	Blood 1961
1957-68	cattle numbers stabilize at 340-345	Blood 1961 & Demarchi 1965
1969-76	cattle removed	Morrison 1972
1973	predator control by poison bait, trapping and shooting	Webster unpubl. field notes
1974-83	open season is replaced by Limited Entry Hunting	Ramsay 1980
1976-80	spring burning on South Slope	Ramsay 1980
1977	mineral blocks (300lbs)and anti-helmintics (50 lbs) fed to bighorn on South Slope	Harper 1980
1977	cattle returned to Ashnola ranges (350 head) but do not graze on South Slope	Crater-Juniper C.R.M.P.
1978-81	300-800 kg of pelleted food supplements and anti-helmintics on South Slope	Ramsay 1980
1981	fall burning of South Slope and surrounding ranges	Min. of Environ. files, Penticton.
1982	additional pelleted food supplement to make up for burned winter range, no anti-helmenthics, but mineral mix added to feed.	Min. of Environ. files, Penticton
1983	pelleted food supplements but no minerals or anti-helmenthics	Min. of Environ. files, Penticton
1984	Number of permits for Limited Entry Hunting increased but a 3/4 curl restriction is now enforced	B.C. Limited Entry Hunting Synopsis 84/85

Table 2. Summary of yearly maximum classification counts on Flatiron Mountain since 1950. See Figure 1 for graphical representation of number of adult females and lamb:female ratios.

Year	Lambs	Yearl.	Females 2yr+	Males 2yr+	Lambs per Female	Yearl. per Female	Source
1950	16	11	43	-	.37	.26	Cowan 1951
1951	23	5	38		.60	.13	Cowan 1951
1960	35	15	54	71	.65	.28	Blood 1960, 1961, 1963.
1963	23	16	53	79	.43	.30	Demarchi 1965
1964	30	17	72	53	.42	.24	Demarchi 1965
1967	49	34	107	51	.46	.31	Scheffler 1973
1968	28						Silver 1971
1969	27						Silver 1971
1970	28	-	99	62	.28	-	Spalding 1971
1971	27	13	93	65	.29	.14	Webster unpubl
1972	14	16	80	61	.18	.20	Webster unpubl
1973	12	7	67		.18	.10	Ramsay 1980
1974	20	9	75		.27	.12	Ramsay 1980
1975	10	10	80		.13	.13	Ramsay 1980
1976	16	8	84		.19	.10	Ramsay 1980
1977	10	15	62		.16	.24	Ramsay 1980
1978	27	17	58		.47	.29	Ramsay 1980
1979	19	29	56		.34	.52	Ramsay 1980
1980	17	18	53		.32	.34	Ramsay 1980
1982	23	17	81	38	.28	.21	Harper 1984
1983	20	19	82	44	.24	.23	Harper 1984

Average lamb:female (1970 to 1983) = 0.26
Average yearling:female (1971 to 1983) = 0.22

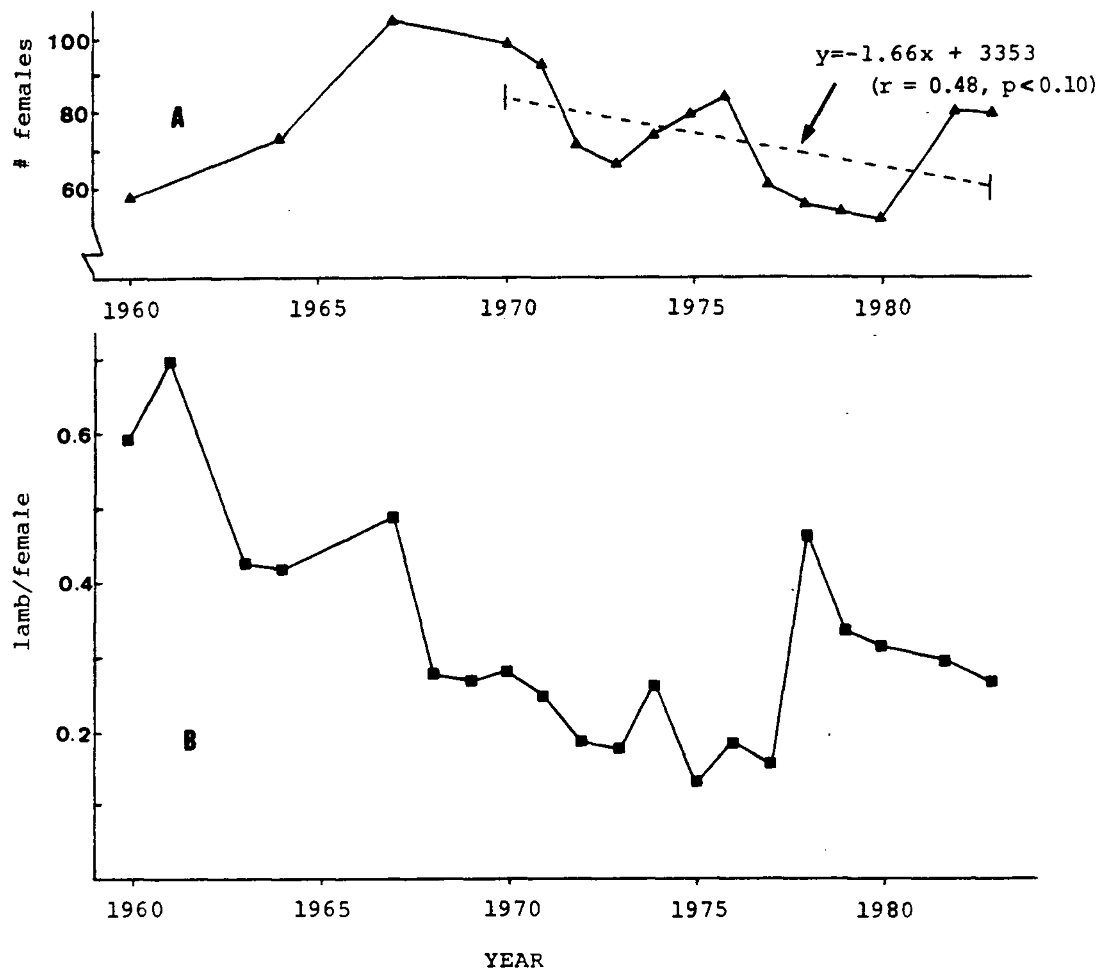


Figure 1. (A) Yearly maximum counts of females (2 years and older) on Flatiron Mountain from 1960 to 1983. (B) Ratio of lambs per adult female from 1960 to 1983 based on yearly maximum counts. See table 2 for actual values.

the Ashnola watershed since 1960 (Blood 1961, 1963, 1967; Sugden 1961; Demarchi 1965, 1968; Harper 1969; Silver 1971; Morrison 1972; and Scheffler 1973). These studies were mostly general ecological investigations of animal food habits and habitat characteristics, and as such have provided limited information applicable to bighorn management. While there have been several investigations of the Ashnola habitat, there has been no satisfactory documentation of the reproductive, nutritional, or disease status of these bighorn. Ramsay (1980) studied aspects of the reproductive biology of Ashnola bighorn, and recognised the importance of determining pregnancy rate as a method of investigating the cause of the low lamb recruitment. He was, however, unable to capture female bighorn in late gestation to meet this objective.

Previous work on various populations of bighorn sheep has suggested three major periods of bighorn lamb mortality. The first, neonatal mortality, occurs between birth and a few days postpartum (Geist 1971). A second period of high lamb mortality occurs in lambs one to four months old, attributable to a lungworm/pneumonia complex (Woodard et al. 1974; Horesji 1976; Spraker and Hibler 1982). The third period of high lamb mortality occurs during the lambs' first winter (Blood 1961; Demarchi 1965; Geist 1971). A fourth period, early postnatal mortality, was considered in this study. Early postnatal mortality occurs after the neonatal period but before the lambs reach one month of age.

Although mortality of lambs in the Flatiron herd between one month and one year of age was greater than 25% for four years from 1960 to 1964 (Demarchi 1965), classification counts since 1970 indicate lamb mortality in their first winter has not recently been that high (Table 2). Accordingly, this study focussed on determining the number of bighorn offspring conceived and their survival during the neonatal and early postnatal periods. Secondly, this study focussed on evaluating from available data, the factors affecting pregnancy rate and offspring survival.

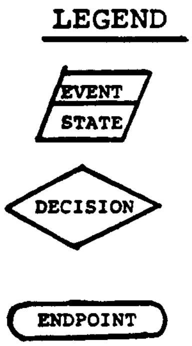
The number of offspring born depends on a series of events beginning with ovulation, and continuing through fertilization, cleavage and development to the blastocyst stage, implantation, placentation, successful gestation, and parturition. A variety of factors affect each of these critical events and ultimately determine the efficiency of reproduction (Nalbandov 1976). Based on previous studies of domestic sheep (Thomson and Thomson 1953; Munro 1962; Belschner 1965; Leathem 1966; Alexander and Williams 1968; Butterworth and Blore 1969; Henne 1975; Nalbandov 1976; Webster 1976; Underwood 1977; Hidiroglou 1980; Puls 1981; Dubeski 1983; Shamberger 1983), wild sheep (Geist 1971; Shackleton 1973; Horesji 1976; Fairaizl 1980; Bunnell 1982), and wild cervids (Verme 1965, 1977; Thorne et al. 1976; Blix and Steen 1979; Steigers and Flinders 1980), the process of, and possible factors affecting, the production and survival of lambs to one month of age are summarized in Figure 2. Figure 2 illustrates the progression of the female through various physiological states and events, during the development of her offspring to 30 days postpartum, based on the format of a computer program flowchart.

No successful studies of pregnancy rates in living bighorn sheep had previously been accomplished, and the only available data were fortuitous and of limited value for general application (e.g. Spalding 1966). Pregnancy rate determination was the first sampling point during the development of bighorn offspring that was used to meet the first objective, which was:

1. To identify the stage in development when most offspring mortality is occurring.

As shown in Figure 2, there are a number of stages where production failures can occur. However, a pivotal point for a practical study may be recognized according to whether or not females are pregnant. If pregnancy rate is low then subsequent work must concentrate on those events and factors prior to gestation. Alternatively, if pregnancy rate is high one can concentrate on late prepartum and postpartum factors.

In order to meet objective 1 concerning the timing of offspring losses the following null research hypothesis was tested:



Sources

1. Alexander and Williams 1968.
2. Belschner 1965.
3. Blix and Steen 1979.
4. Bunnell 1982.
5. Butterworth and Blore 1969.
6. Dubeski 1983.
7. Fairaizl 1980.
8. Geist 1971.
9. Hart et al. 1961.
10. Henn 1975.
11. Hidiroglou 1980.
12. Horesji 1976.
13. Leathem 1966.
14. Munro 1962.
15. Nalbandov 1976.
16. Puls 1981.
17. Shackleton 1973.
18. Shamberger 1983.
19. Steigers and Flinders 1980.
20. Thomson and Thomson 1953.
21. Thorne et al. 1976.
22. Underwood 1977.
23. Verme 1965.
24. Verme 1977.
25. Webster 1976.

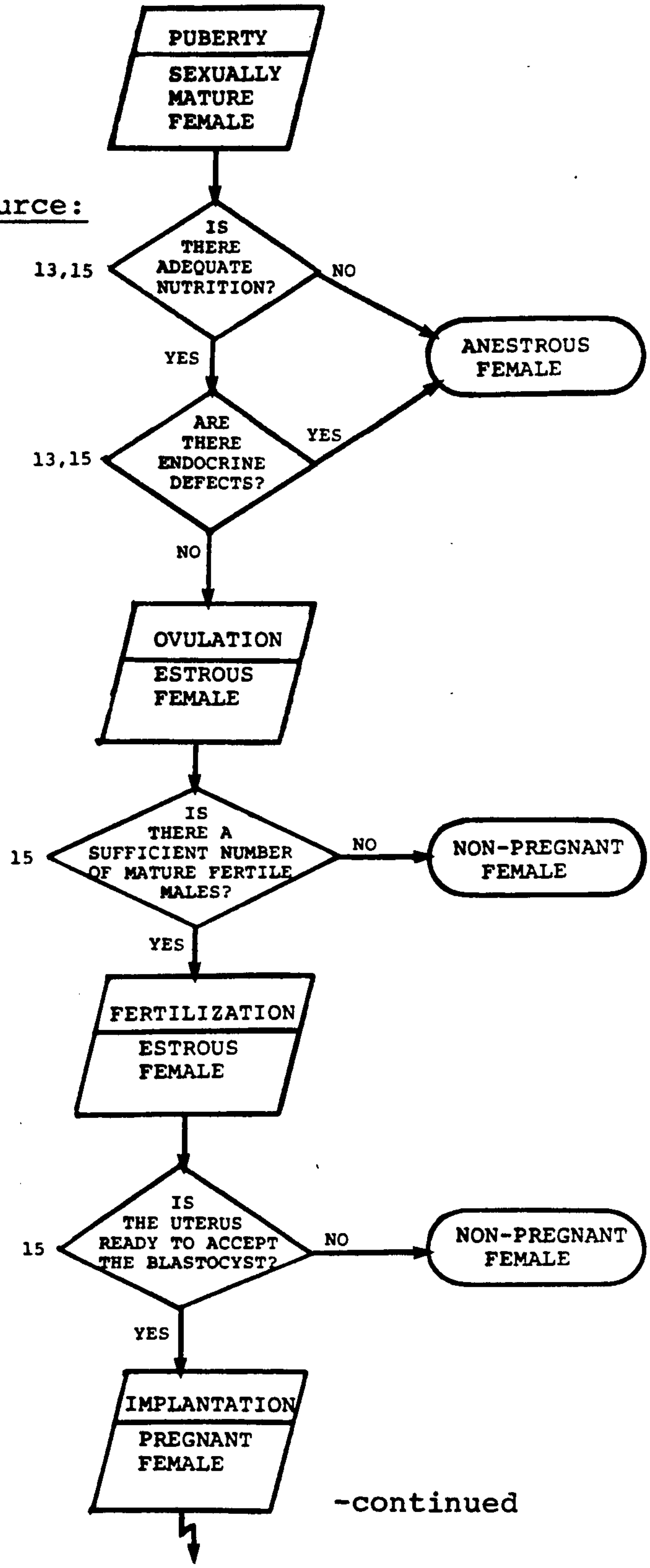


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Figure 2. Schematic diagram representing the process of, and factors affecting, production and survival of bighorn lambs to one month of age.

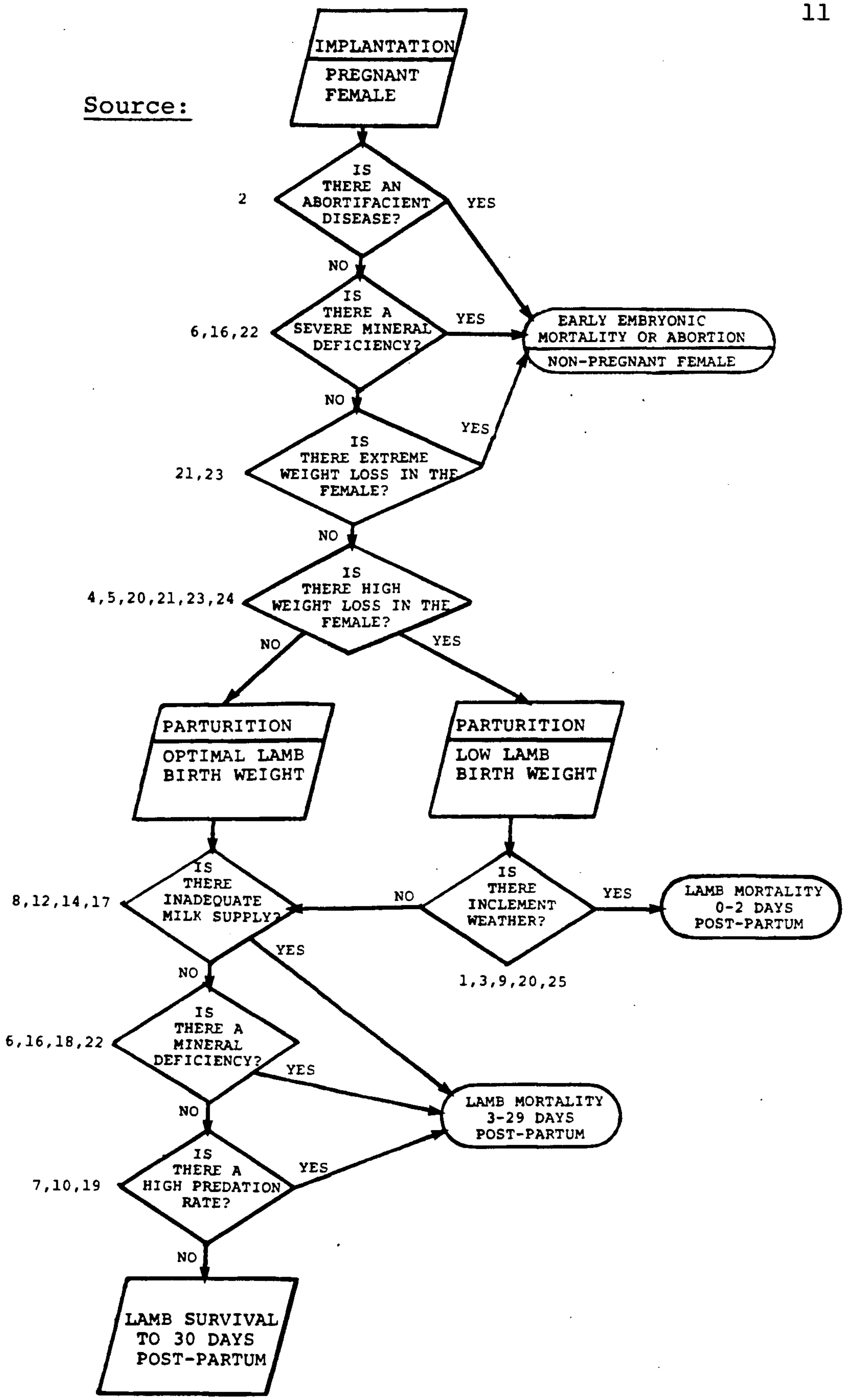


Figure 2. Continued.

Ho: There is no difference between the pregnancy rate and lamb production rate of Flatiron Mt. females.

Ha: The pregnancy rate is higher than the production rate.

Data required to test this hypothesis is the pregnancy rate of the population, based on a sample of captured females. Additional data, required to meet objective 1, are the survival rate of lambs belonging to individually identified females, and the timing of any lamb mortalities. Neonatal mortality is defined as occurring at parturition or within 2 days postpartum (Verme 1965,1977; Geist 1971; Lent 1974). Early postnatal mortality is defined as occurring after 2 days and before 30 days postpartum.

To study the factors involved in the successful progress from gestation through parturition and lactation (Figure 2), the second objective formulated was:

2. To investigate the nutritional and disease status of females prior to lambing and the effects they have on the survival of offspring.

Studies of domestic sheep have shown that the female's body weight is significantly affected by her nutritional level (Peart 1968). Subsequently, ewe body weight has a significant effect on lamb birth weight (Butterworth and Blore 1969; Peart _et_ _al_.

1975) which may affect lamb survival (Thomson and Thomson 1953)(see Figure 2). Smith (1970) reviewed methods for estimating physical condition in ungulates, and concluded the kidney fat index was the most useful in terms of accuracy and field applicability. In white-tailed deer (Odocoileus virginianus) the kidney fat index has been shown to accurately predict (r^2=0.75) the percent total body fat (Finger et al. 1981). Other techniques for measuring nutritional status usually involve estimating the amount of deposited fat reserves, although Bandy et al. (1956) suggested a technique based on the relationship between body weight, chest girth, and hindfoot length. The difficulty with kidney fat indices and most other direct measures of fat reserves is that they involve measuring dead animals, and thus are not feasible for small threatened populations.

Considering the limitations of working with live animals, the three most feasible techniques for determining nutritional status in living bighorn sheep are body size (Bandy et al. 1956), subcutaneous fat reserves (Russel et al. 1969), and blood chemistry (Franzmann and Thorne 1970; Hebert 1978; Peterson and Bottrell 1978). Nutrition through the last third of gestation has a direct effect on domestic lamb birth weights; for example an average 4.3 kg birthweight results when feed is adjusted to minimize catabolism of fat stores, versus 3.0 kg when blood free fatty acids and ketones indicate adipose tissues are being mobilized (Peart 1967). Similar findings have been reported by other researchers in domestic sheep (Wallace 1948; Russel et al. 1967; Butterworth and Blore 1969), and wild cervids (Verme 1965, 1969; Thorne et al. 1976).

Certain infectious diseases, of both viral and bacterial origin, can cause sterility and impaired fertility in a variety of ungulates (Belschner 1965; Nalbandov 1976). Disease status in living bighorn can be assessed by nasal swab (Parks et al. 1972; Marshall et al. 1983) and serum antibody titre (Parks and England 1974; Turner and Payson 1982).

In order to meet objective 2, the nutritional status of females from Flatiron Mt. can be compared to a captive research herd at the Okanagan Game Farm in terms of body condition and liveweight. Objective 2 can also be addressed by comparing differences in weight, body condition score, blood minerals, and disease affliction among females on Flatiron Mt. to the survival of their offspring. Thus, any differences in the nutritional or disease status between those females that produce viable lambs, and those that lose their lambs, should become apparent.

The third objective of the study related to the influence of weather on the survival of lambs, since newborn ungulates are sensitive to thermoregulatory stress (Blix and Steen 1979).

3. To document the severity of weather during the lambing period relative to the survival of bighorn lambs.

Lambs which are subject to nutritional stress during gestation will have lower birth weights, mineral deficiencies, or both, and thus are more susceptable to acute cold stress after they are born (Figure 2). Likewise, lambs that do not receive adequate milk supplies after they are born will be more susceptable to hypothermia. However, severe inclement weather in the presence of adequate nutrition could conceivably cause mortality directly, if the energy drain were severe enough to exceed the lambs' summit metabolism.

In order to avoid a negative energy balance, a 5 kg domestic lamb must elevate its metabolism to 350 $W.m^{-2}$ at -10 C in a 5.5 m/s wind; however, summit metabolism of a 5 kg domestic lamb is only 360 $W.m^{-2}$ (Webster 1976). The lower critical temperature in still air of adult bighorn in winter pelage is -20 C (Chappel and Hudson 1978). The lower critical temperature of newborn domestic lambs in still air is much higher, ranging from +22 to +32 C when wet, and +12 to +22 C when dry (Webster 1976). It is apparent that although bighorn lambs are probably better adapted to cold than are domestic lambs, temperatures encountered during the lambing period on Flatiron Mountain could result in an energy cost for thermoregulation. For example, in caribou calves (Rangifer tarandus) the resting metabolic rate was doubled at 0 C in still air, and elevated to five times resting rate when inclement weather was sufficient to cause hypothermia and death (Hart et al. 1961).

The increased metabolic demand required to maintain body temperature during inclement weather is met by two homeostatic feedback systems. The autonomic system involves catabolising brown adipose tissue reserves. However, these brown fat energy reserves, with which the neonate is born, are easily exhausted if the lamb does not suckle soon after birth (Alexander 1962). At birth, brown adipose tissue accounts for 40% of the heat generated at summit metabolism, but only 5% at 30 days postpartum (Alexander and Williams 1968). The other thermoregulatory system in young lambs involves the somatic shivering response. At summit metabolism this accounts for 60 and 95% of the heat generated in newborn and 30 day old domestic lambs respectively (Alexander and Williams 1968).

Data required to meet objective 3 are the daily minimum and maximum temperatures, humidity, and precipitation on the South Slope lambing grounds during the lambing period. These data can then be compared to counts of lambs during the lambing period to determine if inclement weather during the lambing period is associated with an increase in the mortality of lambs.

Whereas nutrition through gestation has been determined to have a significant effect on the birth weight of domestic lambs, it has marginal effect on subsequent milk production (Barnicoat *et al.* 1949, 1957; Peart 1967; Butterworth and Blore 1969), providing energy and protein intake during lactation is adequate (Butterworth *et al.* 1968; Peart 1968; Forbes 1969). The energetic requirement of lactation in domestic sheep is two and one half times that of maintenance, and exceeds the cost of fetal production (NRC 1975). As such, it would be expected that a protein/energy deficiency in Ashnola females would manifest itself in a lower milk production. In domestic sheep 71% of the daily weight gain of lambs is directly dependent on the milk yield of their dams (mean coefficient of determination of eight studies: Wallace 1948; Barnicoat *et al.* 1949, 1957; Owen 1957; Munro 1962; Butterworth *et al.* 1968; Forbes 1969; Peart *et al.* 1975).

Work with bighorn sheep has found differences in the duration of the suckling bout between species (Geist 1971), between populations (Shackleton 1973), and between years in the same population (Horesji 1976). These differences were related to lamb production and population quality (Geist 1971). The fourth objective was to determine if lactation production was sufficiently low to be limiting the survival of lambs.

4. To assess the lactation production of females in the first month after parturition relative to populations with known lamb production.

Data required to meet objective 4 are the duration and frequency of suckling bouts of Flatiron Mt. lambs of different ages, under the assumption that these variables are indicative of milk production (Shackleton 1973). These data can then be compared to other studies to determine if Flatiron Mt. lambs receive relatively less milk than populations that have higher lamb production.

Predation is the third main factor which may affect the survival of bighorn lambs in the first four weeks after parturition (Figure 2). However, while predation may act independantly of the other two factors, lambs which had been subject to nutritional stress during gestation or lactation would be much more susceptible to predator attacks. Likewise severe inclement weather could weaken lambs and make them easier prey.

There are several potential predators of bighorn sheep in the Ashnola watershed. Three members of the family Felidae inhabit the area, the cougar (Felis concolor), the lynx (Lynx lynx), and the bobcat (Felis rufus). All three are known to prey on young ungulates, with the cougar being the largest at approximately 46 kg, followed by the bobcat at 16 kg, and the lynx at 8 kg (Cowan and Guiguet 1956).

Two members of the family Canidae occur in the study area. The coyote (Canis latrans) is the largest at 13 kg and is also the most abundant based on tracks and observations. The red fox

(*Vulpes vulpes*) is much smaller at 5 kg (Cowan and Guiguet 1956) and is probably present in lower densities.

Black bears (*Ursus americanus*) and golden eagles (*Aquila chrysaetos*) are also relatively abundant in the study area and can be considered to be potential predators.

The fifth objective of the study was:

5. To determine if bighorn sheep constitute a major component (25% or greater) of the diet of predators during the lambing period.

Data which can be obtained to meet objective 5 are observations of interaction between lambs and predators, and the proportion of bighorn remains which occur in predators scats.

STUDY AREA

The focus of this study was the population of bighorn inhabiting Flatiron Mountain in the Ashnola watershed, totalling approximately 165 to 175 animals (Figure 3). Field work conducted between April 1982 and August 1983 concentrated on Flatiron Mountain, because its unique topographic characteristics allowed all age-sex classes of bighorn to be easily observed. For comparative purposes additional data on the pregnancy status, weights, and condition of females were collected from; 1) a captive population of research bighorn on native range at the Okanagan Game Farm, and 2) a free ranging population that winters east of Vaseux Lake in the Okanagan Valley.

Occurring in a transition zone between the Cascade Mountains to the south, and the Thompson Plateau to the north, the Ashnola watershed consists of a highly dissected plateau, varying in elevation from approximately 1500 to 2100 m above sea level (Figure 3). The Ashnola experiences a rainshadow effect common to the southern interior of British Columbia, and thus the low precipitation results in development of semi-arid, grass steppe plant communities.

The south side of Flatiron Mountain (South Slope) and its environs was where observations of tagged and untagged females were made (Figure 3). South Slope (400 ha) is frequently used by

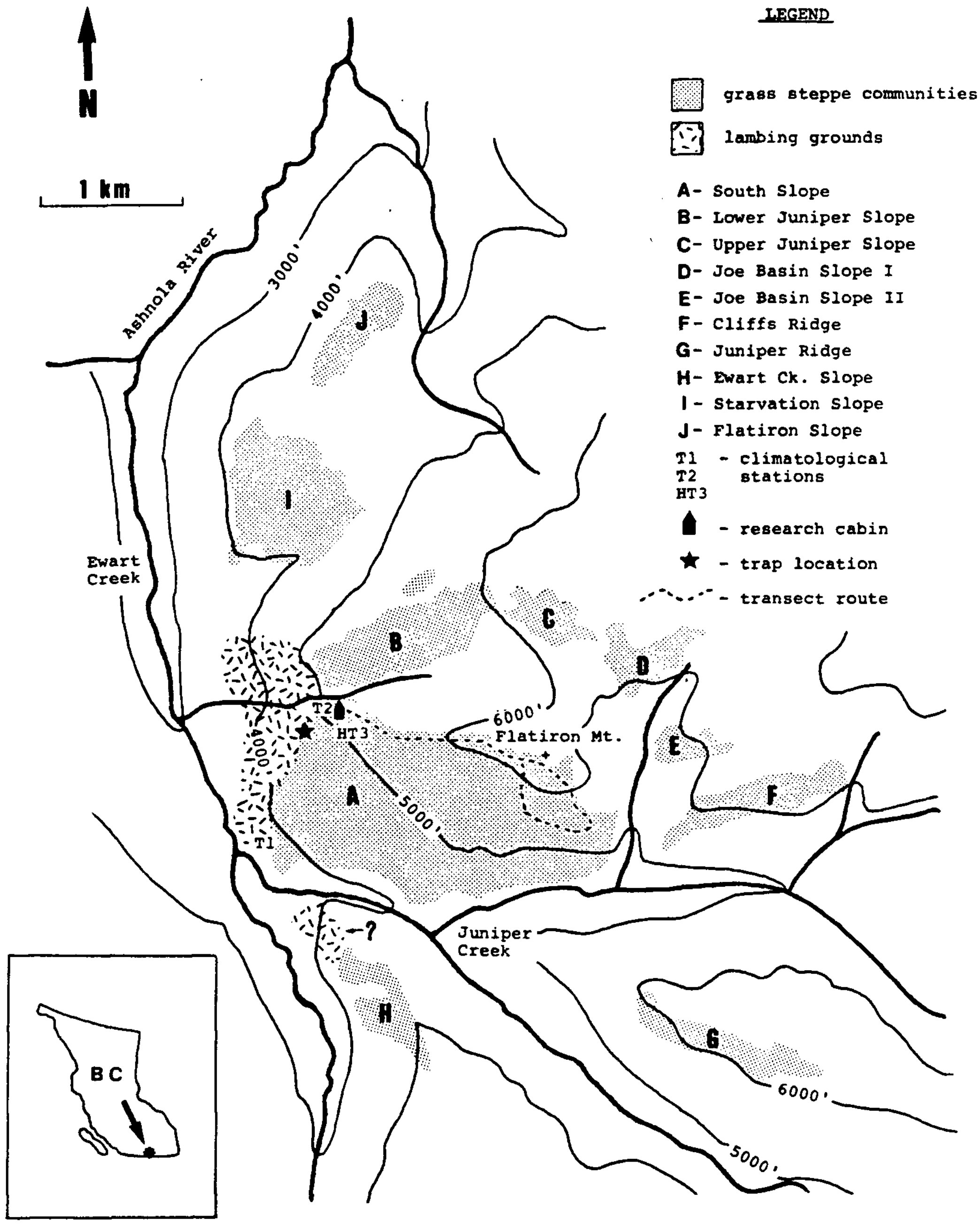


Figure 3. The study area on Flatiron Mountain in the Ashnola River watershed.

sheep, and consists of a mixture of continuous grass steppe communities rising from an elevation of 1000 m to 2100 m at the top of Flatiron Mountain (Figure 3), while Juniper Slope (100 ha) rises from 1700 to 2000 m elevation and is little used by bighorn. To the west of South Slope and Juniper Slope a rugged cliff terrain of small plateaus and ledges is used by some females for lambing. Cliffs Ridge (50 ha) to the east of South Slope is a steep south facing slope frequented mainly by rams. Together, these make up most of the winter-spring habitat of the Flatiron Mountain population of bighorn.

Detailed descriptions of the topography and botanical composition of the grass steppe communities of the Ashnola watershed are available elsewhere (Blood 1961; Demarchi 1965; Harper 1969; Scheffler 1972; Harcombe and Kowall 1982). Vascular plant neomenclature is after Taylor and MacBryde (1977). The grass steppe, bighorn habitat occurs in several large (50 to 400 ha) islands surrounded by climax Douglas-fir (Pseudotsuga menziesii) parkland and fire successional lodgepole pine (Pinus contorta) communities between 1000 and 2300 m elevation. The grass steppe is a mixture of several community types, with Agropyron spicatum - Koelaria macrantha type being the most common due to xeric conditions on the steep south-facing slopes (Harper 1969). Mesic soil moistures occur in areas of less slope, and Agropyron spicatum - Festuca idahoensis communities predominate. Forage production on these first two communities varies between 500 and 1200 $kg.ha^{-1}$, depending primarily on soil moisture variations due to slope (Demarchi 1965; Harper 1969). In hygric areas with little or no slope a productive community (up to 2000 $kg.ha^{-1}$) occurs where *Poa pratensis* is the dominant grass species (Harper 1969; Scheffler 1973).

METHODS

Capture and Data Collection

A total of 12 bighorn females were captured during February and March, 1983, in a trap located at 1400 m elevation on the west end of South Slope (Figure 3). The population has been fed winter supplements in the form of a pelleted ration since 1977, and this was used as bait for the trapping program. Minimal amounts of bait were used to avoid confounding the nutritional status of the population. A corral-type trap was constructed 3 to 4 m high and 25 m in diameter from mesh fishing net covered with burlap to form a visual barrier. A gate 3 m high and 5 m wide was released, either manually, or electrically, when bighorn were inside the corral.

Once captured, the sheep were quietly driven into a corner chute which led to two plywood handling crates. The far end of the handling crates was covered in netting so there was no visual barrier. When the sheep were in the crates, plywood doors at the ends were closed. Based on experience with the Okanagan Game Farm research population, the sheep were left at least 1 h before handling. The last five sheep captured on two different occasions were also given a low dose ($<1 mg.kg^{-1}$) of xylazine (manufactured by Rogar/STB under the label Rompun) as a sedative to facilitate handling and reduce stress.

Pregnancy Diagnosis

Pregnancy status was diagnosed, based on the presence or absence of fetal and maternal tissues of pregnancy, by ultrasonic scanning using a Doppler Ultrasound Pregnancy Detector (Medata Systems Ltd., The Parade, Pagham, West Sussex, England, PO21 4WT). Doppler ultrasound has been used accurately to detect pregnancy in domestic sheep by several authors (Lindahl 1971; Hulet 1973; Deas 1977; Wani and Sahni 1981; Trapp and Slyter 1983). The technique is also effective for bighorn sheep, and in a preliminary test of the technique with the captive research population at the Okanagan Game Farm, the accuracy was 100% (Harper and Cohen, in press). This is the first time that ultrasound has been used to determine pregnancy rates in free ranging bighorn sheep. Specific details of this technique are given in Appendix 1.

Blood and Tisssue Samples

To determine trace mineral status of individual sheep, six blood samples were obtained by jugular venipuncture using 20 gauge needles and 15 ml vacutainers. Once the blood had coagulated, serum was separated by centrifugation, or when not possible, by letting the blood stand overnight. The serum samples were then kept on ice until they could be frozen (within

5 days), and submitted to the Veterinary Pathology Laboratory at Abbotsford, B.C. for trace element analysis and disease antibody titres.

A total of 25 liver and 17 kidney samples were obtained from hunter-harvested rams, road killed ewes and lambs, and one trapping mortality. Samples were submitted to the Veterinary Pathology Laboratory, Abbotsford, for determination of iron, selenium, zinc, copper, and manganese concentrations.

Aerobic Bacteria and Virus Sampling

Nasal swabs were inserted 15 cm into the external nares and rotated to collect samples for culture. After extraction the swabs were immediately placed in sterile fixative and kept cool until submitted to the Provincial Veterinary Pathology Laboratory at Abbotsford, B.C.. Culturettes (manufactured by Canlab), a sterile culture collection system containing 0.5 ml of modified Stuart's bacterial transport medium, were used to collect bacterial samples. For viral samples the Virocult collection system was used (Medical Wire and Equipment Co. Ltd.).

Weights and Measurements and Body Condition Scores

Liveweight was determined with a dial spring scale, accurate to 0.5 kg, with the animals held in a small plywood box. Body measurements to, 1.0 mm, taken with a flexible steel tape, included: hind foot length, total body length, chest girth, (Bandy *et al.* 1956; Blood *et al.* 1970). The level of fat deposition in bighorn females was estimated by a modification of Body Condition Scoring (Russel *et al.* 1969); a common technique used in domestic sheep research. This provided a way of standardizing a subjective assessment of fatness in live animals based on certain physical characteristics, which vary according to the level of fat deposition in the lumbar region. A Body Condition Score, ranging from 0 to 5, was assigned to each female based on a descriptive scale (Appendix 2). All the animals examined by this technique fell into one of three broad categories, score 1, score 2 and score 3. Some animals did not fit exactly to the scores described in Appendix 2 and were therefore given intermediate values.

Identification Collars and Eartags

Before being released, the adult females were fitted with a permanent, nylon, identification collar (n=10). Five animals, including a lamb, were given individual plastic eartags (Duflex, manufactured by Fearing).

Observation and Census of the Population

Census Technique

A standardized transect, developed by B.C. Ministry of Environment personnel and employed during a previous study of the population (Ramsay 1980), was the most frequently used route for classification counts of the population (Figure 3). Other transects used during field observations were designed to maximize the number of different bighorn observed. Only those classification counts in which all of South Slope and Juniper Slope were thoroughly scanned are included in estimates of the total size and age-sex composition of the population. If there was any possibility that the same animal was counted twice, the census was repeated or the data discarded.

Age-sex classes and marked individuals were identified using 7X50 binoculars and a spotting scope with 20X or 40X eyepieces. Bighorn were classified as lambs (less than 1 year old), male and female yearlings (1 to 2 years old), adult females and adult males (greater than 2 years old). The adult males were additionally classified into one of four age classes based on horn size (Geist 1971).

Suckling Behaviour

Suckling behaviour of lambs of both tagged and untagged females was quantified as an indirect estimate of lactation production. Observations of suckling included data on the duration of the suckling bout, the number of bunts during the suckling bout, and the frequency of nursing when known individuals were observed continuously for two or more consecutive bouts. Suckle durations to the nearest 0.1 s were timed using a stopwatch, and the terminator of the bout was recorded.

Since lambing occurred over a period of approximately one month, lambs of many different ages were present in the nursery groups at any one time. To quantify the age of the lamb the height of its back relative to the belly of its dam was recorded along with the behavioural information. By observing five marked females of known parturition dates, the size of lambs relative to their dams was correlated to age, and assuming an equal growth rate for all lambs, the relationship was used to age lambs of unmarked females. Lambs were classified into three categories (less than belly height, equal to belly height, and greater than belly height), which corresponded to three age groups respectively: 2 to 10 days, 11 to 25 days, and 26 to 50 days.

Climatological Stations

The temperature, humidity, and precipitation were monitored using two ground level thermographs located at different elevations, and one hygrothermograph in a Stevenson Screen located 1.5 m above the ground (Figure 3). The lower (1065 m elevation) ground level thermograph (T1) was located on a ledge in the South Slope lambing grounds shaded by a rock and white plywood sheet. The upper (1585 m elevation) ground level thermograph (T2) was located in the shade of the research cabin, less than 100 m from the top of the South Slope lambing grounds. The hygrothermograph in a Stevenson Screen (HT3) was also at 1585 m elevation and was less than 200 m from the South Slope lambing grounds. Relative humidity on the hygrothermograph (HT3) was corrected using a sling psychrometer. Two storage raingauges were located at the HT3 station.

Predator Food Habits

To determine if bighorn lambs were a significant component of the early spring diet of predators, 81 scats were collected from April 20 to June 20, in 1982 and 1983. Efforts were made to collect only fresh scats, but since the collections were done in early spring, some scats may have been deposited in the previous winter and may have just recently thawed. Most collections were made on trails which were frequently cleared of all predator scats, so the approximate age of most scats was therefore known.

The scats were sterilized against *Echinococcus granulosus* by drying in an oven at 110° C for 8 h, and then were washed over 1 mm and 0.5 mm sieves to remove all material except for hair, bone, and insect exoskeleton. Identification of prey species was accomplished, using a 50X and 100X light microscope, from the characteristic scale patterns on guard hairs (Adorjan and Kolenosky 1969; Moore *et al.* 1974). Bighorn lamb hair was distinguished from adult hair when diameters of the guard hair shafts were less than 130 u.

Statistical Analysis

All means are given +/- the standard deviation. Two-tailed Student's t-tests for samples of unequal size and variance were used to detect differences between group means for lamb suckling bout rate and temperatures at two different elevations on the South Slope lambing grounds. Chi-square analysis of body condition scores was used to determine if the ranked scores came from the same statistical population. The 5% level of probability was selected *a priori* for tests of hypotheses.

One-way Analysis of Variance was used to determine the effect of population on the liveweight of adult females sampled at the same time of the year. Data on the suckling behaviour of lambs were also analysed by one-way ANOVA to determine the effect of age on both the duration of the suckling bout and the rate of bunting. The distribution of suckle durations was skewed, therefore a natural log transformation was used to normalize these data. One-way ANOVA was accomplished using the BMD:10V statistical package (UCLA Medical School, Los Angeles, California). The following linear model was used:

$$Y_{ij} = \mu + A_i + E_{j(i)} \qquad 1$$

where,

Y_{ij} = suckling bout duration, or bunt rate, or liveweight.

μ = overall mean.

A_i = effect of lamb age, or population (3 levels).

$E_{j(i)}$ = error term.

Significant differences among means were determined using Duncan's Multiple Range test with the _a priori_ probability level set at 5%.

RESULTS

Timing of Offspring Losses

Pregnancy Rate

All 10 adult females captured live on Flatiron Mountain between January 29 and March 24, 1983, were diagnosed pregnant by Doppler ultrasound. The one capture mortality was also pregnant with a single fetus. Thus, for the sample of bighorn 4.5 years and older, the pregnancy rate was 100% (Table 3). Based on a gestation period for (O. c. californiana) of 174.2 +/- 1.7 days (Shackleton et al. 1984), and the estimated dates of parturition for each female, the mean fetal age at the time of diagnosis was 105.8 +/- 18.5 days (range 73 to 130 days, Table 3). Serum progesterone concentrations of four adult females diagnosed pregnant by ultrasound averaged 15.3 +/- 7.8 $ng.ml^{-1}$, while that of the female lamb was 0.2 $ng.ml^{-1}$ (Table 4).

Survival of Lambs from Tagged Females

Of the total estimated population of 82 adult females, 10 tagged females and one naturally marked female could be individually identified and observed through the lambing period. The pattern of isolation showed five of them (Category I) gave birth on the cliff escape terrain at the west end of South Slope

Table 3. Pregnancy diagnosis, weights, and measurements of bighorn females captured on Flatiron Mountain in 1983.

I.D.	AGE years	DATE OF DIAGNOSIS	FETAL AGE days	BASIS OF DIAGNOSIS[a] (Doppler ultrasound) FHR	FM	PC	UA	WEIGHT kg	BODY COND. SCORE	TOTAL LENGTH mm	HINDFOOT LENGTH mm
01	0.5	n/a						25.5	1.50	1280	-
02	4.5	07/03	128[b]	132	+	+		56.7	1.75	1650	380
03	6.5	21/02	102[c]	168	+		+	58.0	2.00	1560	364
04	6.5	06/03	122[c]		+		+	59.4	3.00	-	385
05	6.5	21/02	95-105[d]		(autopsy)			64.9	3.00	1570	405
06	7.5	07/03	119[c]	126	+	+	+	57.6	2.00	1470	410
07	7.5+	06/02	87[c]		+			67.1	2.50	1670	420
08	7.5+	29/01	86[b]		+			68.0	3.00	-	400
09	8.5+	06/02	73[b]		+	+		59.0	2.00	1630	375
10	8.5+	24/03	130[c]	108	+	+	+	64.4	1.75	1620	400
11	9.5+	07/03	105[c]		+			61.2	1.75	1600	395
12	9.5+	26/02	112[b]	162	+	+		-	2.50	1700	390

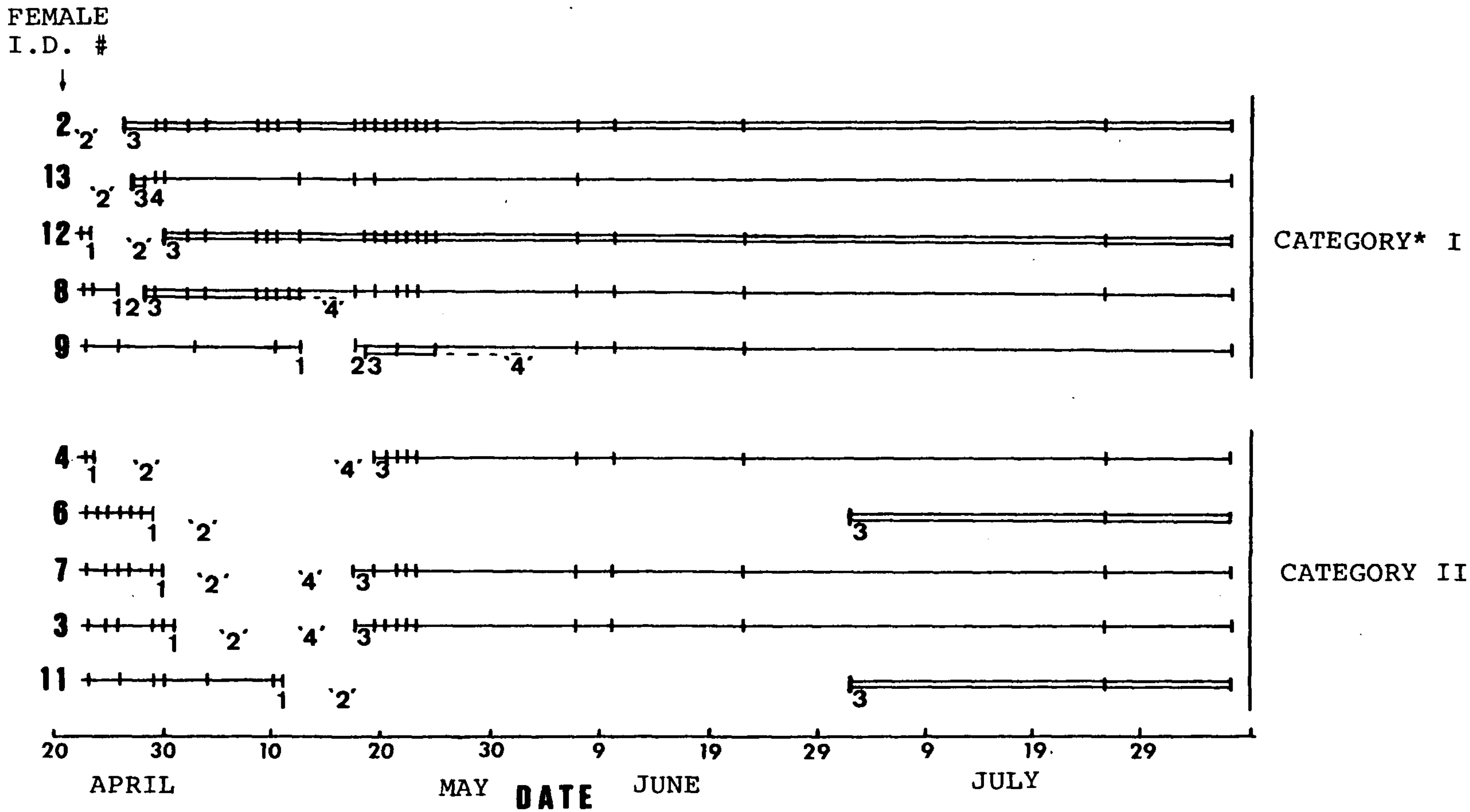
a - FHR=fetal heart rate (bpm); FM=fetal movement; PC=placental circulation; UA=uterine artery. b - Fetal age estimated from observations of newborn lambs. c - Fetal age estimated from dates when females isolated themselves. d - Fetal age estimated from the mean birthdate of the population.

Table 4. Blood chemistry of female bighorn from Flatiron Mountain.

Serum Constituent	Units	Concentration in Blood Serum: Adult females $\bar{x}$	SD	n	Lamb female n=1
Trace elements-					
Selenium	$mg.kg^{-1}$	.090	.034	5	.046
Copper	$mg.kg^{-1}$	.69	.08	4	.35
Zinc	$mg.kg^{-1}$	.52	.19	4	.25
Iodine (total)	mcg%	5.3	1.3	4	5.0
Macro elements-					
Calcium	mg%	8.95	.41	4	9.7
Magnesium	mg%	1.95	.57	4	1.28
Phosphorus	mg%	3.25	.73	4	5.9
Reproductive hormone-					
Progesterone	$ng.ml^{-1}$	15.3	7.8	4	0.2

(Figure 3), and five of them (Category II) gave birth at an undetermined location. Although female #10 had been diagnosed pregnant, she was consistantly observed on South Slope, but never with a lamb of her own. Since it could not be determined if and when she isolated herself, she was placed in neither category.

Of the five females in Category I observed on the South Slope lambing grounds, only two (#2 and #12) had lambs which survived until early August (Figure 4). The other three females in Category I were observed with lambs, but they lost them when the lambs were between 5 and 21 days old. The females in Category II left South Slope for periods ranging from approximately 16 to 60 days. There was considerable variation in the date they left and in the time they spent away from the main winter-spring range. As with the females which remained on and near South Slope, only 2 of the 5 females in Category II returned with lambs. Based on the date when they isolated themselves and the date when they returned to South Slope without a lamb, the unsuccessful females in Category II lost their lambs when they were less than 20 days old. The females in Category II which lost their lambs, returned to South Slope between May 10 and May 20. Those which did not lose their lambs returned more than one month later in early July (Figure 4).



*Category I - those females which used the South Slope lambing grounds.
Category II - those females which left South Slope to lamb in an unknown area.

female observed without a lamb on South Slope.

female observed nursing a lamb on South Slope.

vertical bars indicate at least one observation per day.

1 - isolation
2 - parturition
3 - reappearance on South Slope.
4 - loss of offspring.
' ' - numbers in quotes are estimated dates.

Figure 4. Pattern of birth and survival of lambs from identified female bighorn on Flatiron Mountain.

Nutritional and Disease Status of Females in Late Gestation

Weights, Measurements, and Body Condition Scores

Mean weights and lengths (+/- SD) of adult females from Flatiron Mountain were as follows: liveweight 61.6 +/- 4.1 kg (range 56.7 to 68.0 kg), total length 1608 +/- 69 mm (range 1470 to 1700 mm), and hindfoot length 393 +/- 16 mm (range 363 to 420 mm) (Table 3). The mean chestgirth of adult females was 1011 +/- 41 mm (n=11), and the chestgirth of the female lamb was 775 mm. Liveweight was significantly correlated with chestgirth (r^2=0.79). The mean liveweight of 17 adult females from Vaseux Lake was the same as Flatiron females at 61.6 kg (Table 5). Female liveweights of nine Okanagan Game Farm research bighorn in early spring were significantly lower than the free-ranging populations at 46.8 kg (Table 5). The Okangan Game Farm bighorn originated from the Vaseux Lake population in 1977 (Eccles and Shackleton 1979).

Body condition scores of 11 Ashnola females varied from 1.5 to 3.0 with a mean score of 2.3 +/- 0.5 (Table 3). The female lamb had the least lumbar fat reserves and scored 1.5. The mean score value of 2.3 was significantly larger than the mean score of 1.8 +/- 0.4 (Harper unpubl.) found in the Game Farm adult females (chi-squared = 2.78). Although 27% of the Ashnola females ranked at the uppermost scale of 3.0, none of the Game Farm females ranked so high. At the other end of the scale 10% of the

Table 5. Weights of California bighorn sheep from south-central British Columbia.

Population	Month/Year	Weight in kg x	sd	n	Homogeneous Subsets
Flatiron Mountain	03/83	61.6	4.1	10	a
Vaseux Lake	03/84	61.6	3.9	17	a
OK Game Farm	04/83	46.8	3.8	9	b

Game Farm females ranked 1.0, but none of the females from Flatiron Mountain had such a low score.

Blood and Tissue Chemistry

In blood serum from Flatiron bighorn, adult female trace element levels were twice that of the female lamb for selenium, copper, and zinc (Table 4), but the serum concentration of iodine, calcium, and magnesium did not differ appreciably between the adults and the lamb. Inorganic phosphorus concentration in the lamb serum was almost twice the mean level of the adult females (Table 4).

In liver and kidney tissue, adult male trace element concentrations were apparently lower than the mean of non-males (female #5, her fetus, and a newborn lamb) for iron, zinc, and selenium (Table 6). Conversely, copper levels were apparently higher in adult male liver and kidneys. Manganese levels were not consistently different in both tissues, with kidney levels being higher in the males, and liver levels being higher in the non-males (Table 6). In order to establish some baseline levels of trace elements in bighorn liver and kidney tissue, data from the Vaseux Lake, Crater Mountain, Flatiron Mountain, and Big Bar populations were combined (Appendix 3). Compared to the overall means for south-central B.C., iron, zinc, and selenium liver levels were lower in Flatiron males. Non-males from Flatiron, however, had relatively higher levels of liver iron and kidney

Table 6. Trace mineral concentrations of liver and kidney tissue on a wet weight basis from male and female bighorn from Flatiron Mountain.

		Liver ($mg.kg^{-1}$)			Kidney ($mg.kg^{-1}$)		
Element	Sex*	x	sd	n	x	sd	n
Iron	Males	55	12	7	64	26	4
	Non-males	173	38	3	91	27	3
Copper	Males	81	19	7	4.5	1.1	4
	Non-males	67	45	3	3.8	1.1	3
Zinc	Males	33	6	7	22	6	4
	Non-males	71	35	3	32	14	3
Manganese	Males	3.2	0.7	7	2.0	0.9	4
	Non-males	4.0	1.3	3	1.2	0.3	3
Selenium	Males	0.18	0.06	7	-	-	-
	Non-males	0.27	0.09	3	-	-	-

* Males were all hunter-harvested adults. Non-males consisted of one adult female trapping mortality (I.D. #5, table 2), her 95-105 day old fetus, and one road-killed newborn female lamb.

zinc compared to the overall means in Appendix 3. Both copper and manganese kidney level were lower in Flatiron non-males than the south-central B.C. average. All the other tissue levels in the Flatiron population were similar to the average for south-central B.C. (Appendix 3).

Disease Incidence

Analysis of the nasal swabs indicated the presence of four species of bacteria and one species of virus. A 30 to 50% incidence of the following three non-pathogenic bacteria was found: *Flavobacter spp.*, non-hemolytic *Corynebacterium spp.*, and alpha-*Streptococcus*. Two of six nasal swabs isolated hemolytic *Staphylococcus aureus*, a potentially pathogenic bacterium. All 12 nasal swabs were negative for the presence of *Pasteurella spp.* and hemolytic *Corynebacterium pyogenes*. Viral nasal swabs were all negative for bovine viral diarrhea (BVD), infectious bovine rhinotracheitis (IBR), and adenovirus. However, six of twelve bighorn females were infected with parainfluenza type-3 (PI-3) virus at the time of sampling. The Rapid Plate Test on six serum samples for *Brucella spp.* antibodies were all negative, as were serological tests for the presence of *Leptospira spp.* antibodies.

Production and Survival of Offspring During the Lambing Period

Classification Censuses of the Flatiron Mt. Population

Periodic censuses of Flatiron Mountain from April 23 to June 11, 1983, showed that the number of females observed on the winter-spring range of Flatiron Mountain declined from 70 in late April to 50 animals by May 3 when females were leaving the herd presumably to give birth (Figure 5B). The number of females observed remained at approximately 50 until May 10, after which it increased to 58 by May 21. The number of females observed did not return to pre-lambing period levels until May 24, and then remained at approximately 70 females until at least June 11. This exodus of animals from South Slope for a period of one month coincided with a steady increase in the number of lambs observed (Figure 5A).

The pattern of lamb observations through the lambing period indicated that parturition occurred over a period of approximately 1 month between April 22 and May 22 (Figure 5A). Assuming that the observation of additional newborn lambs represents further parturitions, and the pattern of lamb survival does not vary appreciably throughout the lambing period, the mean "birthdate" (+/- SD) of lambs in 1983 was May 7 +/- 11 days. The actual mean birthdate was probably a few days earlier because most lambs were not observed until they were 2 to 4 days old. Less frequent surveys in 1982 indicated a steady increase in lamb

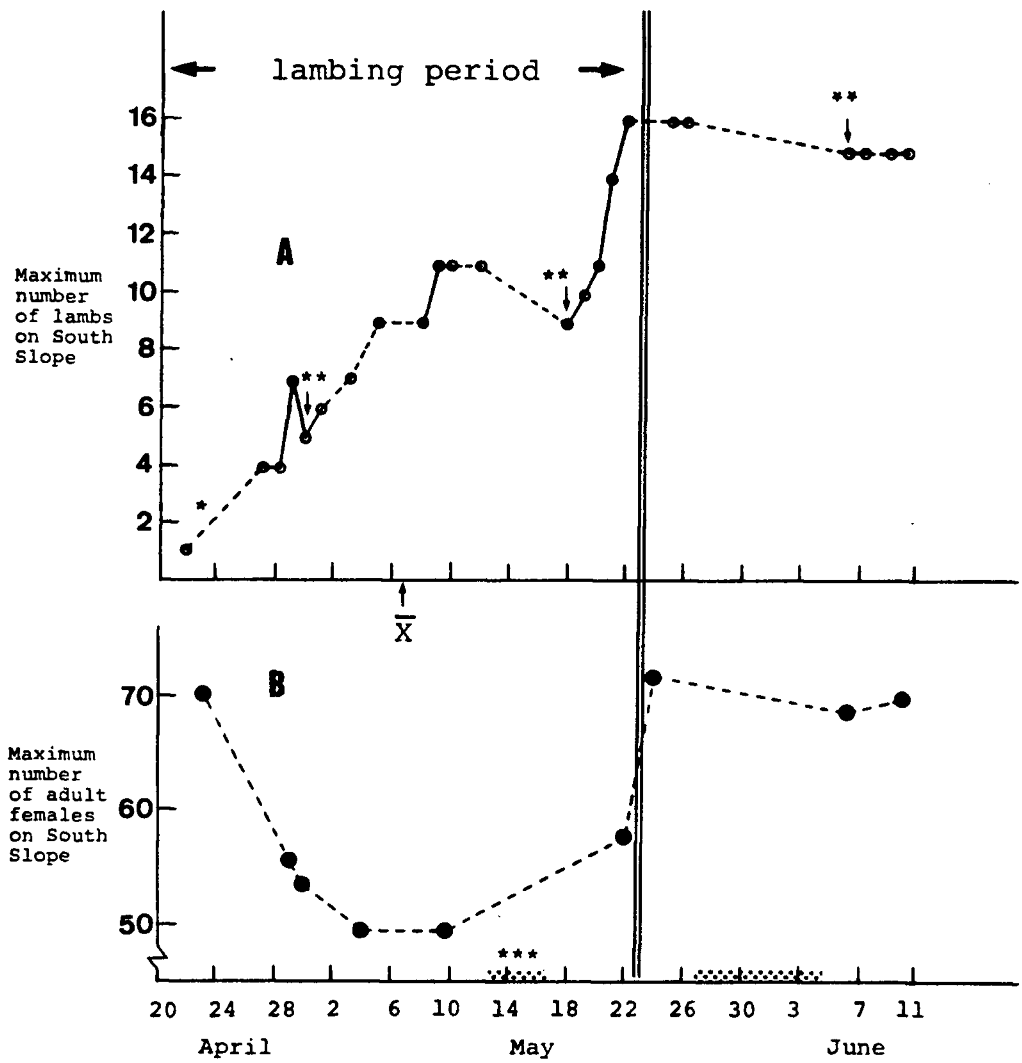


Figure 5. (A) Pattern of observation of newborn lambs on Flatiron Mountain in 1983. (B) Pattern of observation of adult females on Flatiron Mountain in 1983 indicating isolation of pregnant females during the lambing period.

* broken lines indicate full counts of lambs were not obtained.

** arrows indicate periods when total number of lambs observed declined due to known losses.

*** shaded areas indicate periods when there were no observations.

$\bar{X}$ = mean "birthdate" of lambs (May 7).

numbers through late April to early May. When lamb production was censused more frequently in 1983, and 13% of the females were tagged, three periods where the number of lambs decreased were identified. These were April 28 to 30, May 12 to 18, and May 26 to June 6 (Figure 5A). The maximum counts of lambs were 23 on June 18, 1982 and 20 on July 26, 1983. Using the maximum count of females 2 years and older (Table 7), the lamb to female ratios for 1982 and 1983 were 0.28 and 0.24 respectively. Lamb production in 1984 was less than either of these years with a maximum count of only 14 lambs (Ministry of Environment files, Penticton).

Once the bighorn lambs reach approximately one month of age then their subsequent survival rate is high. Maximum counts of lambs from June, 1982 to May, 1983 of the following year indicate an overall survival rate of 82%, with losses being evenly distributed throughout the year (Figure 6). Seventeen of the 20 lambs produced in 1983 survived to May of 1984, a survival rate of 85%.

Vocalization and Search Behaviour of Females

Early in the lambing period it was possible to identify individually the seven females which were leading lambs. Two of them were collared, one had a uniquely light-coloured pelage (#13), and the remaining four were in different stages of the moult, varying from a full winter coat to a full summer coat. On

Table 7. Monthly maximum classification counts of bighorn sheep on the Flatiron Mountain transect in 1982 and 1983. Ratios in parentheses of lambs, yearlings and adult males to adult females are also shown based on yearly maxima.

	LAMBS		YEARLINGS		FEMALES 2YR+		MALES 2YR+		TOTAL		NUMBER OF SURVEYS	
MONTH	82	83	82	83	82	83	82	83	82	83	82	83
FEB	-	19	-	-	-	82	-	06	-	107	-	4
APRIL	7	7	16	19	58	70	22	35	103	131	3	4
MAY	21	16	17	14	46	72	26	44	110	147	8	6
JUNE	23	15	11	15	81	70	1	44	116	144	4	5
JULY	23	20	15	9	66	48	4	1	108	78	6	1
AUG	-	20	-	-	-	67*	-	2	-	89	-	3
OCT	17	-	-	-	62*	-	5	-	83	-	4	-
NOV	20	-	-	-	92*	-	38	-	150	-	3	-
DEC	20	-	-	-	86*	-	37	-	143	-	4	-
YR MAX	23	20	17	19	81	82	38	44	161~	165~	32	23
RATIO	(.28)	(.24)	(.21)	(.23)			(.49)	(.54)				

* - counts of females in late summer and fall include yearlings.

~ - yearly maximum total numbers of sheep are calculated by summing yearly maxima for each age-sex class.

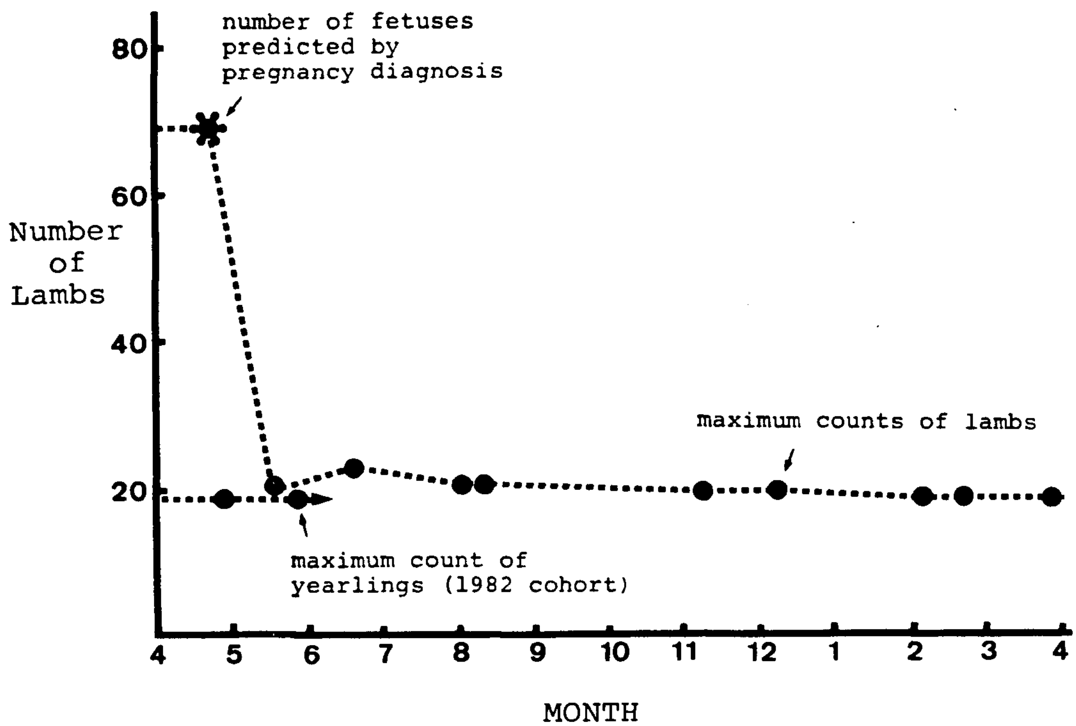


Figure 6. Survival of bighorn lambs on South Slope from June, 1982 to May 1983 based on pregnancy diagnosis in 1983, and maximum counts of lambs and yearlings.

April 30, 1983 one of these seven females, individually identified the previous day by its pattern of winter coat moult, was observed by herself running back and forth on South Slope, stopping frequently in a head-up alert posture, and vocalizing loudly and constantly. At this time there were no other sheep in sight and this female was not followed by a lamb. Later the same day a different female, this time in the company of two other uncollared females, was seen to approach a group of females and yearlings while vocalizing constantly. The same afternoon, female #13 was observed vocalizing constantly and travelling at a steady pace while in the company of two other females. Thus a total of three different females were observed to exhibit the unusual behaviour of travelling and constant vocalizing on April 30, 1983. It was dusk before the nursery group, consisting of six females (two tagged) and five lambs, was sighted. The lamb count for April 30 was therefore two less than the count on April 29, this difference being accounted for by the loss of lambs belonging to two identified females (Figure 5A).

On May 9, 1983 another solitary female was observed travelling and vocalizing for a period of 30 min. This female was vocalizing at a rate of 0.8 $.min^{-1}$, grazing very infrequently, and was almost constantly maintaining a head-up alert posture. On May 10, 1983 another travelling, vocalizing female was observed. This female vocalized at a rate of 16 $calls.min^{-1}$, travelled with a head-up alert posture, and only infrequently stopped to graze.

After not being observed for 26 days, female #4 returned to South Slope on May 20, 1983, and was observed vocalizing and travelling extensively among groups of sheep, sniffing other females' lambs. On two occasions within 1 h she ran to groups of lambs, sniffing a total of five lambs during one 8 min period. The lambs in each case usually fled to their dam. Activity sampling indicated she spent less than 30% of her active time grazing, instead she maintained a head-up alert posture, and vocalized while travelling or standing. Two separate samplings revealed female #4 vocalized at a rate of 10.9 and 12 calls.min^{-1} when in the head-up alert posture. The following day female #4 did not exhibit the vocalizing and lamb sniffing behaviour. She did, however, associate with the nursery group at least until May 26, but was not with them on June 6, 1983.

On June 7, 1983 four adult females including female #12 were observed travelling rapidly and vocalizing as part of a group of 5 females, 2 yearlings, and 1 lamb. They approached another group of 3 females and 1 lamb, whereupon 3 of the females sniffed that lamb. The group then quickly returned over the ridge only to return 10 min later with an additional 3 females and 7 lambs. It appeared that these females had found their lambs because no further vocalization and travelling behaviours were observed that day.

Potential Factors Affecting Lamb Survival

Weather During Lambing

Climatological records covered an "extended" lambing period of 39 days from April 23 to May 31, 1983 to document any affects weather might have on the survival of lambs to two weeks of age (the last documented parturition occurred on May 18). There was considerable variation in the climatic variables recorded at HT3 during the lambing period of 1983 (Figure 7). However, periods of high lamb mortality were not associated with the freezing temperatures and precipitation of April 23 to 26, and May 8 to 10, which resulted in an accumulation of 6 to 7 cm of snow at the upper elevations of the lambing grounds. Of the three periods where lamb numbers noticably declined (Figure 5A), two occurred during and after periods of increasing temperatures, declining humidity, and no precipitation (Figure 7). The known decline in lamb numbers that occurred between May 12 and 18 was, however, associated with a storm which resulted in 9 mm of precipitation, but temperatures were not as cold as those associated with the first two storms. While postnatal mortalities were probably occurring throughout the lambing period, there certainly was not a pattern which reflected a response to inclement weather. In fact, more lambs were observed after the most severe storm of April 23 to 26, than were observed before it. Also, based on observations on the lambing grounds, the females and newborn

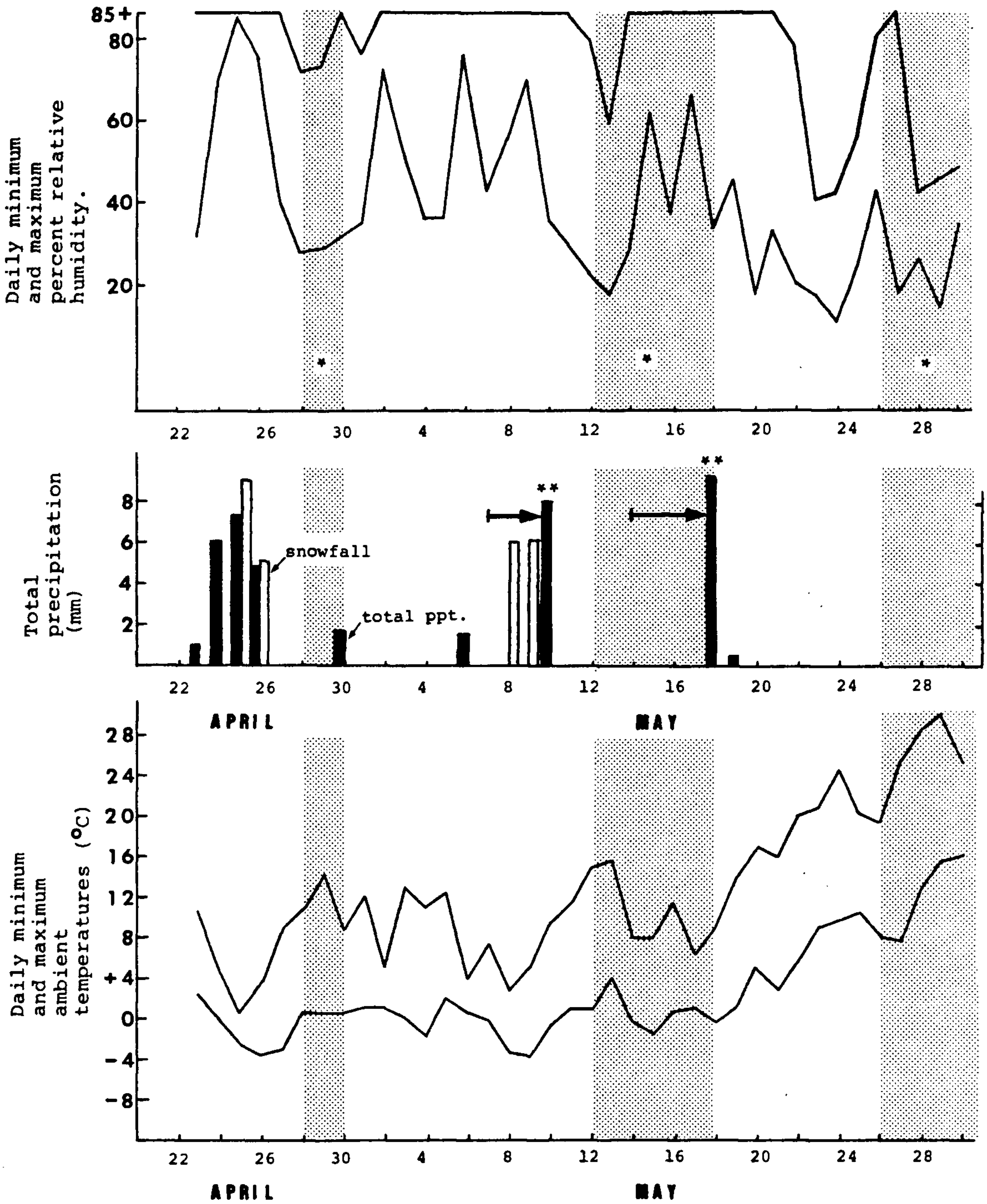


Figure 7. Weather patterns in the Ashnola at 1585 m (HT3) during the 1983 lambing period.

* shaded areas indicate periods when the total number of lambs declined due to known losses (See Figure 5A).

** Vertical bars showing total precipitation accumulated over the period covered by the preceding horizontal arrow.

lambs made considerable use of shelter in the form of cliff overhangs, shallow caves, and mature Douglas-fir trees. This behavioural thermoregulation would have moderated some of the thermal stress experienced by neonatal and early postnatal lambs.

The South Slope lambing grounds vary in elevation from 1050 m to 1585 m. Ground level temperatures were significantly warmer at 1065 m (T1) compared to 1585 m (T2). The mean minimum and maximum temperatures from April 23 to May 31, 1983 at 1065 m elevation were +7.1° and +16.2°C respectively. At 1585 m the mean minimum and maximum temperatures were +1.7° and +12.6° C respectively. Mean minimum and maximum temperatures at the lower elevation of the lambing grounds were 5.4° and 3.6° C warmer respectively. The lower part of the South Slope lambing grounds was an area where females with newborn lambs were frequently observed.

Since the microclimate that newborn lambs experience at ground level could be different than that higher above the ground, temperatures at ground level(T2) and temperatures 1.5 m above the ground in a Stevenson screen (HT3) were compared at an elevation of 1585 m. Overall, for the extended lambing period, ground level minimum and maximum temperatures were 1.1° and 0.6°C colder respectively. However, further analysis revealed that ground temperatures were colder only during periods free of

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precipitation. During the 15 days of the extended lambing period that precipitation fell, ground level minimum and maximum temperatures at 1585 m were 0.8° and 0.7° degrees C. warmer than those in the Stevenson screen. It was during those days of precipitation that temperatures were lowest and thermal stress on the neonate would be highest.

Suckling Behaviour

A total of 195 suckling bout durations were timed on Flatiron Mountain from late April to early June, 1983. The mean suckle duration was 21.9 +/- 9.9 seconds. Only lambs less than 10 days old terminated suckling bouts, and these accounted for 22 (11.3%) of the suckling bouts timed. The remaining suckles were terminated by females stepping over their lambs' heads and breaking contact with the udders.

One-way ANOVA of the effect of lamb age on the duration of the suckling bout revealed two homogeneous subsets. Lambs less than 10 days old suckled significantly longer on average (x=24.3 s) than the other two age-classes (F=11.67, Table 8). The second subset, included female terminated suckling bouts with lambs both 11 to 25, and 26 to 60 days old, and averaged 19.2 s and 18.4 s respectively. There were no a significant differences among mean durations of tagged and untagged females, regardless of whether they lost their lambs or not (One-way ANOVA, F=0.85).

Table 8. Suckling behaviour of bighorn lambs for the Flatiron Mountain population between April 27 and June 11,1983.

Estimated Age (days)	Suckle Duration (s)			Suckle Rate ($bouts.h^{-1}$)	Total Suckle Duration Rate ($s.h^{-1}$)	Bunt Rate ($bunts.s^{-1}$ of suckling)		
	x	sd	n	x	x	x	sd	n
1–10	24.3_a	1.6	60	3.2_a	75	0.30_a	.26	18
11–25	19.2_b	1.4	51	2.0	29	0.45_b	.18	25
26–60	18.4_b	1.3	84	0.7_b	14	0.44_b	.19	42

Means within columns with different subscripts are significantly different.

The suckle rate of lambs 1 to 10 days old was 3.2 bouts.h^{-1} and was significantly more frequent than the bout rate of 0.7 bouts.h^{-1} for lambs 26-60 days old. The sample size of suckle rates for lambs 11 to 25 days old was insufficient to allow statistical comparisons. The bunt rate of 5 lamb terminated suckles was 0.14 bunts.s^{-1} and was significantly different from the bunt rate of 80 female terminated suckles that was 0.43 bunts.s^{-1} (One-way ANOVA, F=10.2). The mean bunt rate of lambs 1 to 10 days old was also significantly less at 0.30 bunts.s^{-1} compared to lambs 11 to 60 days old which averaged 0.45 bunts.s^{-1} (One-way ANOVA, F=3.5, Table 8).

Direct Observations of Predators

Golden eagles were observed on three occasions attacking groups of sheep which contained juveniles. On April 25, 1982, an immature eagle was observed diving at and hovering one to two meters above a group of females and yearling bighorn for a period of 15 min before flying away. The sheep gathered in a tight group but did not flee, with the yearling appearing to obtain protection by crouching beside the adult females. On May 6, 1982, the main nursery group was observed fleeing to escape terrain pursued by two mature eagles in rapid, low level flight. All the lambs were able to keep up with the adult females, but the outcome of this pursuit was unknown. On May 24, 1983, a mature eagle was observed diving on a group of lambs bedded on a large flat rock. The eagle came within 1 m of striking one of the lambs, whereupon the entire nursery group fled immediately to cliff escape terrain and remained standing in a tight group for 10 min before bedding down. These eagle-bighorn interactions were unusual because golden eagles were observed often, throughout the year and during the lambing period, in the proximity of bighorn without either species reacting to the presence of the other.

Black bear sightings were quite common in the study area. A B.C. Ministry of Environment crew observed five different bears on Juniper Slope in the summer of 1982, based on variations in the colour phase and size of these bears. Black bears were observed as early as the first week of May so they could potentially prey on newborn lambs. Bears were observed more often on Juniper Slope, an area not used by bighorn in the spring, in both 1982 and 1983. No bear-bighorn interactions were observed.

A single red fox was observed on the South Slope lambing grounds on May 22, 1984. A solitary female bighorn, that was on the travel route of the fox, hid below some rock bluffs until the fox had passed. The fox did appear to be aware of the presence of the bighorn.

Although a total of only seven coyotes were observed during the course of field work (three individuals, and one group of four), coyote tracks were common at all times of the year on the bighorn winter-spring range. Based on tracks and scent posts to indicate activity centers, a minimum estimate of three family groups of five coyotes each occurred in the vicinity of Flatiron Mountain. On South Slope single coyotes were observed on two occasions in close association with bighorn. On March 28, 1983, a coyote was observed approximately 70 m from two adult females that were bedded on open range near the forest edge. The coyote appeared to be aware of the bighorn as it approached, since it went into the trees when it had reached a position where the bighorn could see it on the open range. On April 29, 1983, a single trotting coyote was observed to make a brief attack on two adult female bighorn running towards a large group of sheep on South Slope. The coyote and the bighorn were heading straight towards each other, and when the coyote tried to cut the bighorn off, they changed direction to avoid the coyote and accelerated their run. The coyote then slowed to its brisk trot and disappeared over the ridge in the opposite direction of the bighorn.

Contents of Predator Scats in Spring

A total of 81 predator scats were collected, most of which were coyote scats, since none were associated with scrapes. However, it is possible that some Felid or Canid scats other than coyote were included in the sample. Twenty-four percent of the total volume of scats collected consisted of hair and bone fragments of bighorn lambs, while adult remains amounted to 10% by volume. Thus, approximately 34% the predators' early spring diet consisted of bighorn sheep.

On a frequency occurence basis, 38 of the 81 scats (47%) contained the remains of either lambs or adult bighorn. Twenty-nine percent contained only lamb hair, 12% contained only adult hair, and 6% contained both adult and lamb remains. Of those scats which contained lamb hair, the average volume was 68%. The proportion of adult bighorn in the diet of coyotes may have been overestimated because some of the scats collected may have recently thawed from the previous winter, and thus would not represent predator food habits in early spring. The proportion of lambs in the predators' diet could not be biased by inclusion of old scats however, because none of these were greater than nine months old when collected.

DISCUSSION

Timing of Offspring Mortality

Pregnancy Rate

Assuming the sample of 11 females is representative of the population as a whole, the 100% pregnancy rate in mid to late gestation clearly leads to rejection of the hypothesis that there is no difference between the pregnancy rate and the rate of lamb production. The cause of low recruitment is therefore not low conception. The assumption that the sample is representative is open to some question, because it is possible that the increased energy requirement of gestation may have differentially attracted pregnant females to food used as bait in trapping. When adult females were trapped in 1977 for the Okanagan Game Farm study, from the Vaseux Lake population, all 16 gave birth to viable lambs, with two producing twins (Eccles and Shackleton 1979). My estimate of pregnancy in 1984 for another trapped sample of the Vaseux population was 93%, based on serum progesterone and Doppler ultrasound diagnosis (Harper unpubl.). While age-sex classes other than adult females were also captured, in both cases food was used to lure sheep into the traps. However, in a mixed road-kill and shot sample of Vaseux females collected in 1965 and 1966, Spalding (1966) found a pregnancy rate of 91% with

4 cases of twins in 11 females. Also, in a large sample of Dall's sheep (Ovis dalli dalli) females shot and autopsied in the Northwest Territories, 78% of females 2-years and older, and 3 of 7 female yearlings were pregnant, (Simmons et al. 1984). All eighteen adult female Dall's sheep autopsied in Alaska were pregnant (Nichols 1978) and wild Asiatic sheep (Ovis orientalis) autopsied in Iran also showed a 100% pregnancy rate in females 3-years and older (Valdez 1976). It would therefore seem that pregnant females are probably not differentially attracted to baited traps, and it is common for females in wild Ovis populations to have high pregnancy rates.

Although a 100% pregnancy rate was determined, senescent domestic ewes may not conceive near the end of their reproductive life (Nalbandov 1976). Similarly, it is probable that few of the 2-year old females would have attained sufficient weight to conceive as yearlings (Geist 1971). Observation of marked Dall's sheep females indicated natality was >80% in females 5-years and older, but only 50% of the 4-year olds and none of the 3-year olds gave birth to live lambs (Bunnell and Olsen 1981). Maximum counts in 1983 indicated the Flatiron Mountain population consisted of 82 females two years and older (Table 7). Using 50% of the yearlings in 1982 to estimate the number of 2-year old females as 9 in 1983, results in an estimate of 73 females of reproductive age (3-years and older). Assuming 5% of these mature females were beyond their reproductive life further reduces the estimate of pregnant females in the population to 69. So, in the population of 82 females 2-years and older, only an estimated 69 females 3-years and older, based on my pregnancy rate, would have given birth to 69 lambs. However, the maximum summer lamb count was only 20 in 1983.

Survival of Lambs from Tagged Females

Observations of marked females indicate 3 of 5 Category I females lost their lambs when the lambs were between 5 and 21 days old. Low lamb production was not due to high neonatal mortality since all lamb losses of Category I females occurred when lambs were greater than 3 days old. Low lamb production was due to high early postnatal mortality in Category I females. Circumstantial evidence, based on the fact that unsuccessful Category II females were away from South Slope from 18 to 26 days after first isolating themselves, suggest Category II females did not lose their lambs in the first few days after parturition either. This is based on the assumption that Category II females isolated themselves a few days before parturition as the Category I females did, and returned to South Slope within a few days of losing their lambs. The fact that female #4, upon her return to South Slope, exhibited the vocalization and search behaviour typical of dams searching for missing lambs, supports this idea. This behaviour should only be exhibited for a few days after the loss of an offspring.

Lamb production from identified females was four of 11 or 36% in 1983 (Figure 4). Using the above estimated 69 pregnant females in the population, lamb production from unmarked females 3-years and older is then 16 of 58 or 28%. This difference could be due to random variation in lamb survival among females, or may suggest there are more non-pregnant females in the population than is predicted by the sampled pregnancy rate.

Survival rates of lambs after they reached one month of age were high in 1983 and 1984, at 82% and 85% respectively. The survival rates of lambs from one month to one year of age were lower in the early 1960's, being 73% in 1961 (Blood 1961) and 71% in 1964 (Demarchi 1965).

Nutritional and Disease Status of Females in Late Gestation

Weights, Measurements, and Body Condition Scores

Liveweights of Ashnola females were 32% higher than females from the Okanagan Game Farm research herd, yet they produced fewer lambs than that captive population in both 1982 and 1983 (28% and 24% versus 64% and 82%). Similarly body condition scores of Ashnola females were 28% higher than Okanagan Game Farm females. Flatiron Mt. females are in a better state of nutrition than Game Farm females. Thus the nutritional status of Flatiron Mt. females in mid to late gestation should not affect lamb production. Within the Flatiron Mt. sample, the lowest weight female was the lamb, which also had the lowest body condition score and the lowest concentration of certain blood minerals. In fact if body condition scores of the Flatiron Mt. females are equivalent to scores in domestic sheep, they are in good fat condition. Using the regression relationship (r^2=0.88) determined for domestic sheep (Russel et al. 1969), the chemical fat in the fleece-free empty body should approximate 20% for a body condition score of 2.3. Thus lamb birthweights from the Ashnola and Vaseux populations should be above a level which would cause the high neonatal mortality that is related to low birthweights described by workers on domestic sheep (Thomson and Thomson 1949), and wild cervids (Verme 1965, 1977; Thorne et al. 1976).

Compared to published weights of O. c. californiana the weights of the females captured in this study are heavier than the mean of 53 kg given by Blood et al. (1970). However, their sample size was small (n=4), and the range of weights given was high (48 to 66 kg). The mean weight of adult females from the Vaseux Lake population in winter of 1965-66 was 58.7 kg (n=9, Ministry of Environment files, Penticton). Both the Ashnola and the Vaseux populations are winter fed which may account for the higher weights obtained in the 1980's compared to the 1960's. Linear measurements of the Flatiron Mt. females were also larger than published mean measurements of Ovis canadensis with total length being 81 mm longer and hind foot length being 45 mm longer

(Lawson and Johnson 1982).

Blood and Tissue Chemistry

While there are no published data on the trace mineral levels of bighorn sheep, there are several studies which give the concentration of the macrominerals calcium, phosphorus, and magnesium in bighorn serum. Although data on their lamb production is not given, blood mineral levels in other populations of bighorn indicate how they differ from the Flatiron Mountain herd. Serum calcium in Flatiron females is similar to that reported by Franzmann (1971, 1972), Franzmann and Thorne (1970), Hickey (1976), and Peterson and Bottrell (1978) for Rocky Mountain and California bighorn. Free ranging desert bighorn (*O. c. nelsoni, O. c. mexicana,* and *O. c. cremnobates*) however, have serum calcium concentrations ranging from 9.8 to 11.0 mg% which is slightly higher than the Flatiron females (Bunch *et al*. 1980; McDonald *et al*. 1981; Deforge and Scott 1982). Dall's sheep also have slightly higher serum calcium levels at 9.6 mg%. (Foreyt *et al*. 1983).

Whereas there was little variation in the published values of serum calcium, inorganic phosphorus concentrations varied from a low of 3.3 mg% in wild bighorn after handling (Franzmann and Thorne 1970), to a high of 7.0 mg% in captive bighorn (Woolf and Kradel 1970). Most studies of wild sheep on native forage give levels of serum inorganic phosphorus varying from 4.0 to 5.4 mg%

(Franzmann and Thorne 1970; Franzmann 1971, 1972; Hebert 1972; Hickey 1976; Peterson and Bottrell 1978; Bunch et al. 1980; MacDonald et al. 1981; Deforge and Scott 1982; Foreyt et al. 1983). One population of O. c. nelsoni however, had lower than average inorganic phosphorus serum levels of 3.6 mg% (McDonald et al. 1981). At 3.25 mg%, Flatiron adult females had lower serum inorganic phosphorus than that reported in the literature. It is interesting to note that the despite having lower levels in most serum minerals, the female lamb had almost twice the concentration of serum inorganic phosphorus of adult females. In humans, phosphorus is known to decrease with increasing age, as its concentration in blood is correlated to the rate of bone growth (Hillman 1983).

Chemical composition of the principal forage species on the South Slope bighorn winter range has been determined to contain sufficient crude protein, fat, fiber, ash, nitrogen-free extract, and calcium for maintenance (Demarchi 1968). Phosphorus, however, was considered to be deficient, especially among grasses, since it declined in dry matter concentration from ranging from 0.06% to 0.12% in August to 0.01% by March of the following year (Demarchi 1968). However, in a review by Cohen (1980), it was stressed that phosphorus in rangeland ruminant nutrition cannot be considered an isolated nutrient and panacea for ill-thrift and infertility. While rangeland cattle respond well to phosphorus supplements, there are few reports of positive responses to phophorus supplementation in domestic sheep (Cohen 1980). It is not clear what effects low phosphorus in bighorn winter forages and pregnant female serums had on the productivity of Flatiron bighorn, but deficiencies will affect growth and skeletal development (Cohen 1980). However, domestic sheep are able to supply the fetus with phosphorus in direct relation to its size and need, and back transfer represents only 7% of the transfer from female to fetus (Garel 1983). It is possible that the low phosphorus in serum of pregnant females is a response to high fetal demand.

Magnesium levels were higher than baseline levels established by Franzmann (1971,1972) and Franzmann and Thorne (1970), but were lower than Rocky Mountain bighorn from south-eastern B.C. (P. Davidson pers. comm.).

Serum trace element concentrations were obtained as a first step toward establishing baseline levels to allow comparison among populations. The only comparable data comes from south-eastern B.C. (P. Davidson pers. comm.), where serum concentrations of selenium and copper were similar to Flatiron Mt. females, iodine was lower, and zinc levels were almost 4 times higher.

Although energy status of the Flatiron Mt. females appeared to be adequate during gestation, blood serum levels of copper, zinc, and selenium, may be marginally deficient based on the adequate levels which have been established for domestic sheep (Puls 1981). However, iodine, calcium, and magnesium appear normal based on values for domestic sheep (R. Puls pers. comm.). Phosphorus in blood serum of adult females was lower than most published bighorn levels and the normal level established for domestic sheep.

Concentrations of trace elements in liver and kidney tissue are better indicators of status than blood serum because they are storage tissues for many of these elements, whereas blood is a homeostatic tissue which will tend to maintain a constant concentration despite the presence of dietary deficiencies. Tissue levels of Flatiron male and non-male bighorn suggest they had adequate levels of the trace elements copper, zinc, manganese, and iron for growth and reproduction. This is at odds with the suggestion from serum levels that the Flatiron adult females were marginally deficient in copper and zinc. However, based on baseline levels established for domestic sheep liver, it is possible the Flatiron bighorn were marginally deficient in selenium, which agrees with the serum selenium results. Alfalfa forages grown in central B.C. and Washington State have been determined to be inadequate in selenium with a mean concentration of 0.047 ppm on a dry weight basis (Cathcart et al. 1980). As with serum trace elements there are no published studies of tissue trace element levels in bighorn sheep.

Selenium/vitamin E deficiency in sheep causes white muscle disease (Hidiroglou 1980) which affects domestic lambs between birth and weaning; and losses may be as high as 65% (see review in Dubeski 1983). White muscle disease in domestic lambs is characterised by first a reluctance to walk, then a stiffness of the hind limbs, and then an arched back stance (Shamberger 1983). The disease may also result in mortality from cardiac arrest, but correct diagnosis can be difficult since visible symptoms, such as partial paralysis of hind and front legs, are not always apparent (Dubeski 1983). Despite intense observation of nursery groups in 1983 for white muscle disease, clinical symptoms were not observed either in lambs that survived, or in those that died. This does not, however, preclude the possibility of cardiac failure in some of those lambs which died. The possibility of a significant interaction between predator activity, and acute cardiac failure as a result of the stress of prolonged pursuit cannot be ruled out. However, any mineral deficiencies which resulted in the estimated 70% lamb mortality found in the Flatiron herd would probably be so severe that clinical symptoms would be very apparent. In addition, if this were the case it would be expected that blood and tissue levels would be significantly lower than those that were found.

Disease Incidence

The 50% incidence of PI-3 virus isolated from the nasal swabs was the most interesting result of disease analyses. This suggests that approximately half the population may have been suffering from influenza during the February and March sampling period. However, three of the four lambs which survived the lambing period belonged to dams infected with PI-3. PI-3 is a paramyxovirus and common upper respiratory disease of domestic cattle (McLean and Doane 1971), and domestic sheep (Fischman 1967). The high incidence of PI-3 in these otherwise healthy Flatiron females, and the fact that PI-3 infection had no effect on reproduction, suggests that it may not be as pathogenic as has previously been suspected (Parks et al. 1972).

Serologic tests on 73 Dall's sheep revealed only one positive antibody titre for PI-3 (Foreyt et al. 1983) and antibody titres on 11 penisular desert bighorn (O. c. cremnobates) were all negative for PI-3 (Turner and Payson 1982). However, high incidences of antigenic response to PI-3 in bighorn have been documented in Colorado and Wyoming (62%, Parks and England 1974) and California (69% to 77%, Deforge et al. 1982). It would appear that PI-3 is a common virus of mountain sheep in areas where they are in contact with domestic animals.

The inability to isolate BVD, IBR, adenovirus, Corynebacterium pyrogenes, and Pasteurella indicate the Flatiron bighorn are not in an acute disease situation. Pasteurella spp. and Corynebacterium pyogenes have been found in bighorn which died of bacterial bronchiopneumonia and pleuritis after association with domestic sheep (Foreyt and Jessup 1982). The presence of alpha hemolytic Streptococcus, Corynebacterium spp., Flavobacter spp., and Staphylococcus aureus, on nasal swabs from Flatiron females is not thought to be significant to the assessment of pathogenic diseases in these sheep (Dr. R. Lewis, Veterinary Pathologist, pers. comm.). Although all six female sera tested negative for the presence of antibodies for Brucella spp. and Leptospira spp., these diseases have been isolated in other wild sheep (Foreyt and Jessup 1982; Foreyt et al. 1983), and both are highly pathogenic organisms which are capable of causing late term abortions (Belschner 1965).

Although the sample size of identified females which successfully reared offspring was low (n=4), they had no obvious advantage in weights, body condition scores, trace minerals, or disease affliction, compared to those females which lost their lambs. In fact, six of seven serum minerals measured higher in three unsuccessful females than the one blood sampled female which successfully reared an offspring (Appendix 4). Unsuccessful females were also heavier, and had higher body condition scores than successful females, but there was little difference in total length or hindfoot length (Appendix 4). It was therefore apparent that nutrition and disease did not affect lamb survival among the tagged females on Flatiron Mt. in 1983.

Production and Survival of Offspring During the Lambing Period

Lambing Chronology and Production in Previous Years

The lambing period on South Slope began early in the spring with the observation of a single lamb soon after mid-April. Early dates of observations of the first lamb are as follows; April 22, 1971 (est. born April 17), April 18, 1972 (newborn), April 17, 1983; and April 18, 1984. Observations for 1971 and 1972 are from Webster (unpubl. field notes), and for 1983 and 1984 from a record book maintained by the Keremeos-Cawston Rod and Gun Club.

The temporal pattern of lamb appearance on South Slope has been investigated previously by Blood (1967) and Ramsay (1980). The majority of lambs were born on Flatiron Mountain before May 30 in all years except 1960 (Figure 8). Rapid increases in the number of lambs observed occurred in early June, 1960, and late May, 1961 (Figure 8). Ramsay (1980) found rapid increases in the number of lambs observed occurred earlier than in the early 1960's, with most lambs being born in the first two weeks of May in 1978, 1979, and 1980. Lamb numbers did not increase as rapidly in 1982 and 1983 as previous researchers had found, but the chronology of births was similar to the late 1970's, with the majority of lambs being born in the first two weeks of May.

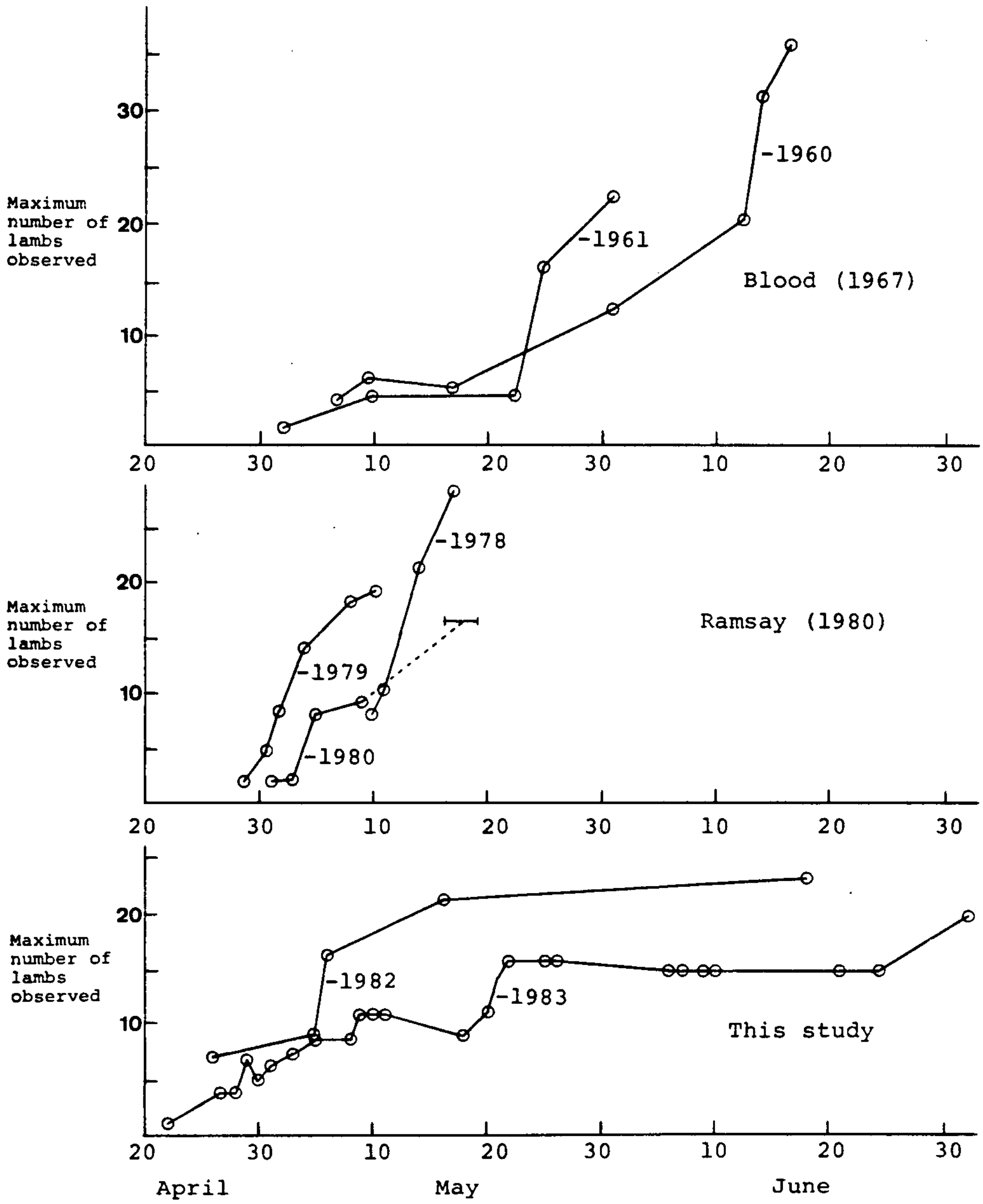

Figure 8. Pattern of observation of newborn lambs on Flatiron Mountain in seven different years.

There has been considerable variation in the pattern of lamb sightings on Flatiron Mountain during the lambing period (Figure 8). This may be due to differences among years in birth dates, in the pattern of female isolation, in survival of lambs, in the effort and ability of the observer, or in some combination of these. In view of the fact that some females with lambs stayed away from South Slope for up to 60 days in 1983, the difference observed between the early 1960's and recent years is not neccesarily due to a change in the breeding season. Variation in the lambing chronology of Dall's sheep between years was small when actual parturitions were observed (Bunnell 1980).

Total numbers of lambs observed range from a high of 49 in 1967 (Scheffler 1973) to a low of 10 in 1975 and 1977 (Ramsay 1980 and Table 2). Declines in the maximum number of adult females observed in the 1970's corresponded to low lamb:female ratios (Figure 1). From 1978 to 1980 lamb:female ratios were over 0.30 but the number of females continued to decline. Classification counts conducted as part of this study (Table 8) indicate an increase in the number of females in the population from 1980 to 1982. If the additional number of females in 1982 were due to relatively higher lamb production in 1978 then these should have been censused as an additional 14 two year old females in 1980, which was not the case (Table 2). Only if all the estimated 32 female lambs produced in 1978, 1979 and 1980 survived, and the mortality rate of all adult females was zero for these three years, could the rate of lamb production explain the increase in adult females from 53 to 81 in just two years.

One of the implications of the observed pattern of female isolation (Figure 5B) is that to obtain maximum counts of adult females population censuses must be done either before or well after the lambing period. If censuses are done just during the lambing period from April 15 to June 15 then the number of females and lambs in the population may be underestimated. Even if counts are made in late June some of the females may not have returned to the main winter-spring range. In 1983, a group of seven females (two tagged), two yearlings, and five lambs did not return until early July. This may explain why in some years more yearlings were observed than lambs that had been counted the previous year (Ramsay 1980).

Potential Factors Affecting Lamb Survival

Weather During Lambing

The two selective forces thought to control the evolution of lambing onset in mountain sheep are climate (Geist 1971), and birthweight (Bunnell 1980), since together they determine the earliest date that a newborn lamb can survive cold stress. Temperatures dropped below freezing on three separate occasions at the upper lambing ground weather station during the lambing period of 1983 (Figure 7). However, the climate of the Ashnola plateau is not particularly harsh, when compared to lambing areas at higher elevations and more northerly latitudes (e.g. Hoefs and Cowan 1979). At the lower elevations of the South Slope lambing grounds, where dams and newborn lambs were most frequently observed, the mean minimum temperature during the lambing period was 5.4° C warmer than higher on the lambing grounds. This corresponded almost exactly to the dry adiabatic lapse rate of 1° C per 100m elevation change (Miller and Thompson 1975). As such the lowest temperature recorded on the lower elevation lambing grounds was +2° C. The use of shelter, coupled with the mild climate experienced at the lower elevation lambing grounds, suggest the lambs born in 1983 did not experience any thermogregulatory stresses that could not be compensated for by catabolism of normal amounts of fat reserves.

Though the data was inconclusive, there was no increase in the mortality of lambs that was associated with inclement weather during the lambing period, based on a comparison of Figures 5A and 7. Of the three periods identified in Figure 5A when lamb losses occurred, only one was associated with inclement weather, the other two occurring during periods of warm sunny weather. It should be stressed that previous work has demonstrated that thermoregulatory stress has the greatest affect on neonatal mortality, a period that does not appear to be implicated as the major cause of lamb losses on Flatiron Mt.

Suckling Behaviour

The overall mean suckle duration of 22 s found in the Flatiron Mountain herd falls in between the levels reported by Shackleton (1973) for two populations of <u>O. c. canadensis</u>, and is similar to levels given by Geist (1971), by Horejsi (1976), and by Smith and Wishart (1978), for other populations of mountain sheep. Geist (1971) first suggested that suckle durations were correlated with lamb production in mountain sheep populations through the concept of population quality. Shackleton (1973) found lamb production positively correlated to large differences in suckle duration between two different populations. Horejsi (1976) detected differences in lamb survival among years in the same population, that was related to small variations in mean suckle duration. However, when mean suckle durations from different years and populations was correlated to the corresponding lamb:female ratios (Geist 1971; Shackleton 1973; Horejsi 1976; Smith and Wishart 1978; and this study), there was no significant relationship (r^2=0.003, n=11). The mean suckle duration of all these studies was 21 seconds, and the mean lamb:female ratio was 0.58. Compared to these other populations, the Flatiron herd had average suckle durations but less than half their average lamb production.

The suckling rate of Flatiron lambs was similar to that reported in other populations, declining from approximately 3 bout.h^{-1} in one week old lambs to less than 1 bout.h^{-1} in four week old lambs (Geist 1971; Shackleton 1973). The average bunt rate of 0.42 bunts.s^{-1} of suckle duration in Flatiron lambs is the same as that determined for highly productive populations (Shackleton 1973; Horejsi 1976), but is lower than that determined for Shackleton's low quality population. If the assumption that a high bunt rate and short suckle duration is associated with low milk production is correct (Shackleton 1973), this suggests the milk production of Flatiron females is greater than Shackleton's low quality population that had slightly higher lamb production.

The suckling behaviour of Flatiron Mt. lambs, in terms of suckling duration, suckling rate, and bunt rate is similar to that of other populations where lamb production is higher. It does not appear that milk production is limiting the survival of lambs on Flatiron Mountain. The fact that Flatiron females had relatively high live weights and body condition scores in late gestation also suggests that lactation production should not be limiting lamb survival.

Predation

There is little doubt that 65 to 70% of the lambs produced each year are subject to mortality between parturition and three weeks postpartum. This is evidenced by a high estimated pregnancy rate, coupled with a low survival of offspring and the presence of females exhibiting a vocalization and search behaviour. Observations to determine the timing of lamb mortality eliminated prenatal and neonatal mortality, and suggested early postnatal mortality as the reason for low lamb production. What is still in doubt is the cause of this high early postnatal mortality. Available data have eliminated the likelyhood of nutritional and disease status of pregnant females, inclement weather during lambing, and milk production as estimated by suckling behaviour of lambs, as factors affecting high early postnatal mortality.

Scat contents indicate that, depending on the technique used, bighorn lambs either constituted 24% (volume analysis) or 35% (frequency occurence) of coyotes early spring diet. Adult bighorn constituted either 10% (volume analysis) or 18% (frequency occurence) of the coyotes early spring diet. Percent volume analysis tends to underestimate the contribution of large animals because of their smaller surface area to mass ratio relative to smaller animals. However, frequency occurence may well overestimate the proportion of bighorn in the diet of coyotes, since the remains of one meal may be present in more than one scat.

Starting with the estimated number of pregnant females on Flatiron Mountain in 1983 (69), and subtracting the maximum count of lambs (20), results in an estimated 49 lambs that apparently died between birth and three weeks of age. Using a mean birthweight of bighorn lambs of 4.0 kg (Bunnell 1982), and the pattern of linear weight gain reported for domestic lambs (Spedding 1965; Peart *et al.* 1975), a growth rate of 0.2 $kg.day^{-1}$ is predicted to achieve the mean weight of 5 month old lambs given by Blood *et al.* (1970) and Bunnell (1982). According to this, bighorn lambs on Flatiron Mountain should weigh approximately 6 kg at 10 days, 8 kg at 20 days, and 10 kg at 30 days. Assuming a mean age of 10 days for lamb mortalities, the total biomass of lost lambs is 294 kg.

It was estimated that a minimum of 15 coyotes inhabit Flatiron Mountain. Messier (1979) reviewed coyote food intake rates, and found it ranged from 0.06 to 0.17 $kg.day^{-1}.kg^{-1}$ body weight. A mean food requirement of 0.12 $kg.day^{-1}.kg^{-1}$ body weight was assumed for both his calculations and this study. Using the mean weight of a large sample of B.C. coyotes (11.36 kg, K. Atkinson pers. comm.) predicts an intake rate of 1.36 $kg.day^{-1}$ for each coyote. Lambs were lost from April 20 to May 20, 1983, a period of 30 days, thus the total estimated food intake of the 15 coyotes during this lambing period would be 613 kg. If coyotes ate all the lamb biomass available then bighorn lambs should represent 48% of their diet (294kg/613kg), which is higher than either estimate based on scat contents, but certainly indicates that a relatively small coyote population in the area could ingest all the lambs estimated to be lost each year.

Without direct observations of predation, it is difficult to determine if coyotes are actually preying on healthy lambs, or merely scavenging dead and dying lambs. Inductive reasoning leads one to reject the idea that lambs are born in a weak or sickened condition, based on the good condition of their dams and their lack of significant disease organisms or mineral deficiencies. Also, of those lambs which were born to marked females, none showed any behaviour indicative of a weakened condition, including those which subsequently died.

Bighorn sheep, especially lambs, were a major component of the diet of predators during the lambing period. Furthermore, based on circumstantial evidence and inductive reasoning, it appears coyote predation of otherwise healthy lambs could be the source the high early postnatal mortality documented in this population.

Despite much searching, no carcasses of dead lambs were found on Flatiron Mountain, but this is not surprising since predator scats contained large bone fragments indicating the entire lamb was ingested. Direct observation of coyote-lamb interactions were not observed, perhaps because the kills were made in the predawn hours as was the case on a Montana domestic sheep ranch (Henne 1975). Coyotes have not been reported to be major predator of bighorn offspring before, however, seven of 11 coyote scats in Wyoming contained bighorn remains (Thorne 1976 in

Lawson and Johnson 1982). Isolated observations of successful predation by coyotes on bighorn lambs has been reported by Bowen (1978), and Shank (1977).

Coyotes have been reported to be major predators of the offspring of other large ungulates. The finding that Flatiron Mountain females lose their lambs up until three weeks of age is consistent with mule deer fawn mortalities due primarily to coyote predation (Steigers and Flinders 1980; Salwasser 1978). Cook et al. (1971) used radio telemetry, and determined that the high mortality of white-tailed deer fawns was due to coyote predation. Coyote predation was responsible for the mortality of more than 50% of marked pronghorn fawns when they were between 4 and 57 days old (Barrett 1984). There have not yet been any intensive studies on the effect of predation on the survival of bighorn lambs.

Predator control on Flatiron Mountain was attempted by the B.C. Ministry of Environment in the first four months of 1973 (B. Webster unpubl.). Two bobcat, 2 coyote, 2 bear, 3 cougar, and 4 lynx were trapped or shot. In addition, approximately 35 to 40 poison baits (1080) were ingested, primarily by coyotes based on track evidence, between March and May, 1973. Despite these efforts, predator sign during the lambing period indicated not all the Canid and Felid predators were killed, and lamb production was lower than usual with a maximum count of only 12 lambs in 1973.

One of the difficulties in evaluating the effectiveness of past management prescriptions has been the inability to show cause and effect relative to changes in lamb production. If predation was in fact the factor most limiting lamb survival, one might expect either a random fluctuation in yearly predator success, or a correlation with predator numbers and alternate prey abundance. Since none of these parameters have ever been measured, the mechanisms behind variations in yearly lamb survival relative to predation remain unknown. To understand fully those factors limiting lamb survival, future research should concentrate on the behaviour and food habits of the coyote, particularly its interaction with bighorn lambs in early spring.

CONCLUSIONS

The following conclusions correspond to the objectives presented in the Introduction.

1. Low lamb production was not due to a low pregnancy rate or a high neonatal mortality, but high early postnatal mortality accounted for 60 to 70% of lamb losses.

2a. The nutritional status of Flatiron females, as determined by liveweight and body condition, was above a level that would have affected lamb production.

2b. There was no difference between Flatiron females that produced viable lambs and those that lost their lambs in terms of liveweight, body condition score, blood minerals, or disease affliction.

3. Preliminary information indicated no apparent increase in the mortality of lambs that was associated with inclement weather during the lambing period.

4. The suckling behaviour of Flatiron lambs indicated they did not receive less milk than populations that had higher lamb production.

5. Bighorn sheep (especially lambs) constituted a major component of the diet of predators during the lambing period.

RECOMMENDATIONS

Management of California Bighorn in the Ashnola

Food, Mineral and Water Supplementation

Winter feeding should be maintained at the current level for three reasons. Firstly, to insure that the condition of animals remains at its current level so as to minimize mortality among adult females, and secondly to maintain lamb birth weights at such a level that will minimize neonatal mortalities. Thirdly, to test the hypothesis that coyote predation is limiting lamb production, all other factors should be held as constant as possible to avoid confusing the interpretation of a response to predator manipulation.

Results indicate mineral supplementation should not have a major effect on lamb survival, however, the possibility of a significant interaction between a marginal selenium status and lamb vulnerability to predation cannot be ruled out. Any contemplated mineral supplementation should be undertaken in consultation with a nutritionist.

Snow provides a source of water well into the growing season, after which the water content of spring forages is high enough to meet bighorn requirements. Water limitations are probably highest in summer and early fall, when winter-spring range forages become desicated. However, this is also the period when the bighorn migrate to alpine areas where delayed phrenology results in forages of higher water content. Water is therefore probably not a limiting factor for the bighorn of Flatiron Mountain.

Range Burning

Since preparturant females do not appear to be nutritionally stressed, it is unlikely that range burning will increase lamb production. However, fall burning of south-facing forested habitat adjacent to existing grass steppe bighorn ranges may well be able to increase the area of bighorn winter-spring habitat. Thus, if increased lamb survival resulted in population growth, this increased range might allow a higher overall carrying capacity for bighorn on Flatiron Mountain.

Predator Manipulation

The most common method for reducing predator pressure on a prey species is to remove the predators by trapping or poisoning. Aside from a potential adverse public reaction, predator be can cost ineffective. A poisoning and trapping program on Flatiron Mountain in 1973 required much effort, yet some predators remained after the program, and lamb survival did not increase (B. Webster unpubl.).

Instead of trapping, shooting, and poisoning predators one could provide coyotes with an attractive food source as an alternative to bighorn lambs. Large quantities of red meat, obtained from road-killed mule deer, placed in strategic locations could potentially draw predators away from the Flatiron Mountain lambing grounds. If the predators were satiated by this alternate food source during the 6 week period when lambs are vulnerable (April 15 to May 31), then they may be less inclined to hunt bighorn lambs. Based on my rough estimate of coyote population size and their food requirement approximately 1000 kg of meat would be required to cover the 6 week period. An increase in lamb survival of only 10% to 15% is all that is required to allow the bighorn population to stabilize.

One potential drawback to supplementary feeding of predators on Flatiron Mountain would be allowing the predator population to increase. However, for coyotes at least, there should be no increase in their population, as the critical period for pup survival occurs in the fall (F. Messier pers. comm.), and spring food supplementation for a short period in the spring should not increase pup survival.

Future research efforts should be directed towards coyote food habits, behaviour, and interactions with bighorn lambs, before management prescriptions aimed at reducing coyote numbers are implemented.

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Appendix I. Paper submitted to the Journal of Wildlife Management (in press).

ACCURACY OF DOPPLER ULTRASOUND IN DIAGNOSING PREGNANCY IN BIGHORN SHEEP

Keywords: Doppler, ultrasound, pregnancy diagnosis, bighorn sheep, Ovis canadensis.

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A reliable estimate of the proportion of females that successfully conceive is an important piece of information that is required to fully understand the population dynamics of a species. This is especially important when the population of offspring is low. These data are generally unavailable for wildlife populations so female production estimates usually are based upon counts of offspring for the year. These counts often are made after the early postnatal period during which significant mortality can take place. In addition, counts of offspring give no indication of prenatal reproductive failures. The main constraint in estimating pregnancy rates has been one of methodology. Either the techniques are difficult to use and subject to error when a single sample is obtained, or they require sacrificing large numbers of females for reliable estimates to be made by autopsy.

Many techniques have been developed to diagnose pregnancy in domestic animals. These include hormonal assays, rectal palpation, radiography, vaginal biopsy, laparotomy, and ultrasound (Memon and Ott 1980). Of these techniques, some have been used with wild species; for example progesterone assay (Ramsay and Sadleir 1979; Whitehead and McEwan 1980; Rehbinder et al. 1981), rectal palpation (Follis and Spillet 1974), ultrasound (Barrett 1981; Smith and Lindzey 1982), and laparotomy (Turner 1983). Assaying for hormones is relatively expensive and does not give immediate results, and since the levels of circulating progestrone vary erratically between individuals, as well as through gestation, this technique can be subject to misinterpretation (Whitehead and McEwan 1980). Rectal palpation is suitable only for larger mammals and requires extensive experience for accurate results. Memon and Ott (1980), reviewed the techniques available for pregnancy diagnosis in domestic sheep and goats, and concluded that Doppler ultrasound was the most accurate and reliable method.

There are two types of ultrasound devices currently available for diagnosing pregnancy in wild animals: the Doppler, and the pulse-echo. External Doppler ultasound was 92% accurate in determining pregnancy in a large sample of domestic ewes, under field conditions (Wani and Sahni 1981). Pulse-echo ultrasound, (also known as amplitude depth or A-scan), has been used to reliably diagnose pregnancy in mule deer (Odocoileus hemionus), but the accuracy of this method decreases after mid-gestation (Smith and Lindzey 1982). The objectives of this study were to evaluate the accuracy of Doppler ultrasound for diagnosing pregnancy in captive bighorn sheep (Ovis canadensis), and to compare these data with those from domestic sheep, with the ultimate goal being the use of this technique on free-ranging bighorns.

METHODS

EQUIPMENT

A portable (0.61 kg) Medata Doppler Ultrasound Pregnancy Detector, (Medata Systems Ltd., The Parade, Pagham, West Sussex, England, PO21 4WT), was used on 23 bighorn and 59 domestic sheep. This device operates as follows: an external transducer, consisting of transmitting and receiving piezoelectric crystals, is placed in contact with the skin. A thin layer of mineral oil or Vaseline between the transducer and the skin serves to exclude air which will block the transmission of sound waves. A continuous sinusoidal wave of low power ultrasound (2 MHz; $10 mW.cm^{-2}$) is directed into the body cavity from the transmitting crystal. When the sound wave strikes various tissues it is reflected back to the receiving crystal.

The Doppler shift principle (Rose and Goldberg 1979) is used to detect tissue movements associated with pregnancy. Depending on the direction of tissue movement, the reflected wave is displaced to a higher or lower frequency, and once received is analysed electronically, and the resultant signal broadcast on a speaker system. In the Medata Pregnancy Detector the electronics and the speakers are part of the headphone apparatus, and operate on a 12 volt transistor battery.

ANIMALS AND MEASUREMENTS

The sample of bighorn females was captive and came from two locations; the Okanagan Game Farm, Penticton, B.C. (n=20, O.c. californiana), and the Animal Care Facility, University of British Columbia, Vancouver, B.C. (n=3, O.c. canadensis). Bighorn females were tested between 110 and 150 days gestation; full term is 174 days (Shackleton et al. 1984). Individuals were identified, and the accuracy of pregnancy diagnosis was confirmed at lambing. The sample of domestic ewes came from a research herd at the Dept. of Animal Science, University of British Columbia (n=9), and a commercial herd at Aldergrove, B.C. (n=50). The ewes from the University herd were tested between 90 and 120 days of gestation (term = 145 days). Forty one of the ewes from the commercial farm were examined between 74 and 94 days of gestation and another 9 ewes were between 118 days and term.

The external transducer head was placed on the abdomen both anterior and posterior to the teats and between 5 and 15 cm. either side of mid-line. It was then manipulated to scan the abdominal cavity in search of the sounds characteristic of pregnancy. Identification of one or more of the characteristic sounds generated by the uterine artery, placental circulation, fetal movement, umbilical artery, or fetal heart, was considered positive evidence of pregnancy. If none of the characteristic sounds was detected within 5-10 minutes, the animal was diagnosed as nonpregnant. Positive diagnosis of pregnancy often took as little as 30 seconds, especially with females in the last third of gestation.

The only other sounds which could be detected were the peristaltic movement in the lower intestines, and the interference associated with friction between the transducer and the subject. There was no difficulty in recognising the difference between these sounds and those associated with pregnancy.

Parentage of lambs was determined from lambing records for the domestic herds and the captive bighorn at the University of British Columbia. Successful suckling of a lamb confirmed parentage in the Okanagan Game Farm bighorn herd.

RESULTS

PREGNANCY DETERMINATION OF BIGHORN

All 3 female bighorn at the University of British Columbia were diagnosed pregnant in April, 1982 and produced lambs in June (Table 1). Eight of the 11 captive bighorn females at the Okanagan Game Farm research herd were diagnosed pregnant in April, 1982 (Table 1). These sheep lambed around the last week in May and 7 lambs were observed on June 13, 1982. When the herd was recaptured in June all 8 females that were diagnosed pregnant were apparently lactating, based on the swollen condition of the mammary glands. However, observation of the herd revealed that one of the animals which had been diagnosed pregnant, and had a swollen udder, was not suckling a lamb. Later that year the remains of a lamb were discovered. The lamb had been killed or scavenged by coyotes. These remains were assumed to be that of the lamb from the aforementioned ewe.

The following year 9 of the 11 bighorn ewes at the Okanagan Game Farm were captured and tested with Doppler ultrasound on April 12, 1983. Eight of these were diagnosed pregnant (Table 1). By June 12, there were 7 lambs and by July 25 there were 9 lambs. Parentage of the collared lambs was determined on August 7 by observing suckling bouts, and the diagnosis of pregnancy was confirmed for all 8 females. Two of these did not lamb until after June 12, indicating that the pregnancy diagnosis occured when the fetuses were less than 114 days old. The other females were diagnosed when the fetuses were approximately 130-140 days old. The gestation period of California bighorn sheep has been determined to be 174.2 +/- 1.70 days (Shackleton _et al_. 1984). The animal that was diagnosed as non-pregnant was not seen suckling a lamb.

Pregnancy determination of female bighorns was 100% accurate for both diagnosis of pregnancy (n=19), and diagnosis of non-pregnancy (n=4), (Table 1).

PREGNANCY DETERMINATION OF DOMESTIC SHEEP

Of the 9 domestic ewes tested at the University of British Columbia, 7 were diagnosed pregnant and 2 were diagnosed non-pregnant. These diagnoses were confirmed when the ewes lambed. In the second sample of 50 ewes from a commercial farm a total of 6 errors in diagnosis occured, all the result of diagnosing pregnant animals as non-pregnant. Thus the accuracy for domestic sheep was 100% for positive diagnosis and 54% for negative diagnosis (Table 1). The overall accuracy of both positive and negative diagnoses was 90%.

DISCUSSION

The results of this study indicate that the the Doppler ultrasound technique, using an external probe, is both practical and effective for diagnosing pregnancy in bighorn sheep. The overall accuracy of pregnancy diagnosis was higher for bighorn females than for domestic sheep. There are two possible explanations for this. Firstly, the bighorn were tested in the last third of gestation whereas the majority of the domestic sheep were in their second trimester. No errors occurred in those domestic ewes tested in their third trimester. The larger fetal mass present later in gestation makes it less likely that a pregnancy would be overlooked during ultrasonic scanning. A second explanation may be that the maximum number of bighorns processed at one time was 11. This allowed more time to be spent diagnosing each female. The 6 errors occurred when 50 domestic ewes were processed at one time, and might have been avoided if more time had been spent in the diagnosis of non-pregnancy.

Doppler ultrasound is accurate in the positive diagnosis of pregnancy. Misdiagnosis of pregnancy in a non-pregnant individual is unlikely unless extraneous sounds are misinterpreted as being associated with fetal tissue. However, error in the diagnosis of non-pregnancy (prediction of non-pregnancy in a pregnant female) is possible, because the absence of sounds characteristic of pregnancy can be due to improper probe placement and operator inexperience. It is significant that the only errors in this study occured as a result of processing a large number of animals in a short period of time.

Errors in the diagnosis of non-pregnancy could probably be reduced by testing females diagnosed as non-pregnant on two separate occasions. The accuracy of predicting non-pregnancy in domestic ewes improved considerably when the animals were examined twice (Lindahl 1972). It also may be possible to reduce error by using an intrarectal probe, which is more accurate in early gestation (Deas 1977). Unfortunately,accuracy with the intrarectal probe decreases after mid-gestation, and there is a possibility of causing injury, peritonitis, and abortion (Trapp and Slyter 1983). The probablility of such injury could be even greater in wild species.

In conclusion, it appears that Doppler ultrasound should be a useful technique for determining pregnancy rates in wild bighorn sheep populations, provided that the females are at least 110 days pregnant. In addition to being an accurate technique, an important advantage is the immediate diagnosis of reproductive status, a consideration for some field studies. In this study, a compact weather resistant instrument, which used 2MHz ultrasound from an external transducer, accurately and rapidly determined the pregnancy rate of captive bighorn females.

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Table 1. Accuracy of both positive and negative diagnoses of pregnancy in bighorn females and domestic ewes

	LOCATION AND YEAR						
	BIGHORN FEMALES				DOMESTIC EWES		
	UBC 1982	OKGF 1982	OKGF 1983	Total Bighorn	UBC 1982	Hunt Farm 1983	Total Domestic Ewes
# tested with ultrasound	3	11	9	23	9	50	59
# diagnosed pregnant	3	8	8	19	7	39	46
# nursing lambs	3	7+(1)*	8	18+(1)*	7	39	46
% correctly diagnosed pregnant	100%	100%*	100%	100%	100%	100%	100%
# diagnosed non-pregnant	0	3	1	4	2	11	13
% correctly diagnosed non-pregnant	n/a	100%	100%	100%	100%	45%	54%
% overall accuracy	100%	100%	100%	100%	100%	88%	90%

- Number

* - assuming one female which was diagnosed pregnant, was lactating, but was not observed nursing, was the dam of a mortality discovered.

UBC - University of British Columbia, Vancouver, B.C.

OKGF - Okanagan Game Farm, Penticton, B.C.

Appendix 2. Description of the characteristics used to define the Body Condition Score scale used in this study (after Russel *et al*. 1969).

SCORE 0: Extremely emaciated and on the point of death. It is not possible to detect any muscular or fatty tissue between skin and bone.

SCORE 1: The spinous processes are felt to be prominant and sharp. The transverse processes are also sharp, the fingers pass easily under the ends, and it is possible to feel between each process. The eye muscle areas are shallow with no fat cover.

SCORE 2: The spinous processes still feel prominent, but smooth, and individual processes can be felt only as fine corrugations. The transverse processes are smooth and rounded, and it is possible to pass the fingers under the ends with a little pressure. The eye muscle areas are of moderate depth, but have little fat cover.

SCORE 3: The spinous processes are detected only as small elevations; they are smooth and rounded, and individual bones can be felt only with pressure. The transverse processes are smooth and well covered, and firm pressure is required to feel over the ends. The eye muscle areas are full, and have a moderate degree of fat cover.

SCORE 4: The spinous processes can just be detected, with pressure, as a hard line between the fat covered eye muscle area. The ends of the transverse processes cannot be felt. The eye muscle areas are full, and have a thick covering of fat.

SCORE 5: The spinous processes cannot be detected even with firm pressure, and there is a depression between the layers of fat in the position where the spinous process would normally be felt. The transverse processes cannot be detected. The eye muscle areas are very full with very thick fat cover. There may be large deposits of fat over the rump and tail.

Appendix 3. Trace mineral concentrations of liver* and kidney** tissue on a wet weight basis from bighorn sheep from south-central British Columbia.

Element	Liver ($mg.kg^{-1}$) x	sd	n	Kidney ($mg.kg^{-1}$) x	sd	n
Iron	99	58	25	73	38	17
Copper	68	47	25	4.8	1.6	17
Zinc	37	18	25	23	8.0	17
Manganese	3.4	1.3	25	1.6	0.6	17
Selenium	0.27	0.08	25	-	-	-

* Liver samples came from Vaseux Lake (n=12), the Ashnola (n=12), and Big Bar (n=1). Seventeen were from males, five from females, two from fetuses, and one from a newborn lamb.

** Kidney samples came from Vaseux Lake (n=8), and from the Ashnola (n=9). Nine were from males, four from females, two from fetuses, and two from lambs.

Appendix 4. Comparison of the characteristics of those tagged females which successfully reared a lamb to three months old, to those that lost their lambs when they were less than one month old.

Variable	Successful Female* Mean (n)	Unsuccessful Female** Mean (n)
Liveweight (kg)	58.5 (3)	62.6 (6)
Chestgirth (mm)	1009 (4)	1011 (6)
Total Length (mm)	1605 (4)	1620 (4)
Hindfoot Length (mm)	394 (4)	391 (6)
Body Condition Score	2.0 (4)	2.4 (6)
PI-3 infection	75% (4)	50% (6)
Serum selenium($mg.kg^{-1}$)	0.08 (2)	0.10 (3)
Serum copper ($mg.kg^{-1}$)	0.77 (1)	0.66 (3)
Serum zinc ($mg.kg^{-1}$)	0.48 (1)	0.53 (3)
Serum iodine (mcg%)	5.00 (1)	5.33 (3)
Serum calcium (mg%)	7.70 (1)	7.77 (3)
Serum phosphorus (mg%)	2.80 (1)	2.97 (3)
Serum magnesium (mg%)	1.55 (1)	2.09 (3)

* females whose lambs survived to three months old.

** females whose lambs died before they were one month old.