MARK-RECAPTURE FOR ESTIMATION OF ROOSEVELT ELK NUMBERS AT BIG LAGOON, HUMBOLDT COUNTY, CALIFORNIA

by

Frank L. Galea

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Frank L. Galea

Approved by the Master's Thesis Committee

[redacted] 10 Feb. 90

Richard T. Golightly, Chairman Date

[redacted] 12 Feb. 90

Barry R. Noon Date

[redacted] 10 Feb. 90

Terry Hofstra Date

[redacted] Feb 12, '90

Director, Natural Resources Graduate Program Date

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Approved by the Dean of Graduate Studies

[redacted] 3/12/'90

Robert Willis Date

ABSTRACT

Methods for estimating numbers, relative densities, home range and group dynamics of Roosevelt elk (Cervus elaphus roosevelti) were studied near Big Lagoon, Humboldt County, California from 1 July 1985 to 30 June 1987. An aerial mark-recapture model was used to estimate the number of elk groups; groups with telemetry-equipped members were considered as marked and groups without telemetry-equipped members were unmarked. The average group size per survey was multiplied by the estimated number of groups to yield an estimate of elk numbers. Thirteen aerial surveys were conducted within a 10 km^2 area where a mark-recapture census model was applicable. Eight surveys, where four or more marked elk groups were available, provided an estimate of 140.6 (95% CI = 68.7 - 212.5) elk for an approximate 10 km^2 area. The precision of the abundance estimate may be acceptable where other methods provide less reliable estimates and indicated the necessity for averaging results from repetitive surveys.

The relationship between group size and density in elk was examined within a 23 km^2 area to determine the feasability of using group size as an indicator of relative density. Average elk group size decreased as

distance increased from a point of greatest elk density, which indicated group size as a possible indicator of relative density.

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This study is dedicated to the memory of my loving Father, Frank J. Galea, who passed away before we could together share in the completion of this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

INTRODUCTION

Roosevelt elk (<u>Cervus elaphus roosevelti</u>) were once distributed throughout northern California but are now restricted (excluding transplants) to a coastal strip from the Little River in Humboldt County to the Oregon border. From the late 1930's when Roosevelt elk naturally recolonized Boyes Prairie (presently within Prarie Creek Redwoods State Park) in Humboldt County (Bentley 1959) to the present the number of elk in Del Norte and Humboldt counties have not been quantitatively estimated.

Elk populations on huntable lands have apparently not reached numbers great enough to warrant yearly elk hunts (H. Pierce, Calif. Dept. Fish & Game, Eureka, CA 95501). In 1963, 1964, 1967, 1974 and 1976 hunts were conducted on private timber-company lands to reduce a percieved threat to planted conifer seedlings by depredating elk (Obrien 1974). Limits of elk taken during these hunts were determined from information obtained by ground reconniassance and from local foresters (Hofsted 1961) and these estimates of numbers were only guesses.

Estimates of elk population size were made either by direct observation (Harn 1958, Hofsted 1961, Mandel 1979) or by extrapolation of numbers observed within a sampled area, where a random distribution of elk groups was assummed (Lemos 1971). Dasmann (1964) and the California Department of Fish and Game (Anon. 1963) estimated 2,000 elk in Humboldt and Del Norte counties in 1963. This figure was based on numbers of elk counted in limited areas and extrapolated to a larger area. For Roosevelt elk, techniques had not been developed to determine exact numbers or population trends, primarily because Roosevelt elk occupy dense, coniferous forests (Harper 1971).

From the 1930's to the 1970's Roosevelt elk populations may have experienced an increase in numbers (Obrien 1974, Wertz 1982). After 1937 large tracts of old-growth forest had been removed by clear-cut logging, especially in the 1960's, which may have provided elk with greater amounts of forage than was previously available (Mandel 1979, Harper et al. 1987). Mandel (1979), however, later surveyed elk in and around Redwood National Park and estimated 1,000 to 1,300 elk in Humboldt and Del Norte counties. Although his figures are based on sightings using non-marked elk, if correct they would demonstrate a decline in elk numbers from earlier estimates. Since the early seventies most of the elk range in the area had been in a seral stage of forest succession not optimum for elk recruitment (Mandel 1979, Harper et al. 1987): this could account for decreased elk numbers.

Previously special-hunted, timber-producing property incorporated into State or National Parks are no longer open to hunting. The remaining private timber lands with elk populations were opened only twice to elk hunting (1984, 1988) within the last decade. A primary concern was that without adequate knowledge of elk numbers, it would be difficult to establish the number of elk to be taken without risk of overharvesting (B. Morris, Louisiana Pacific Corporation, Eureka, CA 95501). A method of accurately determining elk numbers was needed. In addition, an understanding of geographic variation in elk densities would be useful to distribute hunting pressure.

Sport hunting was not the only reason new methods of determining Roosevelt elk densities was needed. In 1978 Redwood National Park was expanded to include the western portion of the Redwood Creek drainage. Before Redwood National Park took possession, timber was harvested by clear-cutting, temporarily providing increased forage (Harper et al. 1987). After the park expansion, vehicular access became limited, hunting was not allowed and law-enforcement increased. After a possible increase in elk numbers in Redwood Creek drainage due to increased forage, greater numbers of elk contributed to current elk depredation problems in nearby agricultural areas (personal observation). To anticipate and manage for future fluctuations in elk numbers, Park wildlife managers would require a census technique for monitoring elk populations.

Numerous techniques have been attempted for estimating densities of cervids in the Pacific northwest. Pellet group surveys provide a measure of relative abundance or indicate trends (McConnel and Smith 1970, Edge and Marcum 1989) in relatively open habitats. However, the lack of adequate calibration of defecation rates to habitat use limits the technique for estimating numbers (Rowland et al. 1984). Also, the technique would be difficult in the Pacific northwest because pellets decompose rapidly (Fairbanks 1978) and are difficult to locate in thick vegetation (personal observation).

Spotlighting deer (Harestad and Jones 1980) has been used to provide relative estimates of abundance, but not actual estimates of population size.

Aerial censusing is presently the most common census method used for elk (Samuel 1984). Rocky Mountain elk (C. e. canadensis) were censused during aerial surveys since 1932 (Anderson 1958) using direct count methods *(Hanscum 1949, Buechner et al. 1951). Aerial survey* methodologies increased in complexity and accuracy after Siniff and Scoog (1964) used stratified random sampling to census caribou (*Rangifer tarandus*) in Alaska. Rice and Harder (1977) utilized aerial surveys in a mark-recapture census of white-tailed deer (*Odocoileus virginianus*). Recent evaluations of aerial surveys (Caughley 1977) and their inherent inaccuracies have led to numerous, specific studies of aerial surveys and their ability to accurately describe elk populations (Rounds 1980, Samuel 1984, Houston et al. 1987).

Presently a number of models exist for approximating the true number of elk for a given area from aerial survey sampling (Cook and Martin 1974, Cook and Jacobson 1979, Maxim et al. 1981, Routledge 1981, Samuel 1984, Pollock and Kendall 1987) (for a more exaustive review of aerial survey methodologies, see Samuel 1984). However, most of these methods are limited to elk utilizing relatively open or semiopen habitats, such as Rocky Mountain or Tule elk (*C. e. nannodes*). The primarily open habitats of Tule elk allow for efficient aerial and ground surveys where total numbers of elk for a given area can be determined (D. Koch, Calif. Dept. Fish & Game, Sacramento, CA 95814). The migratory nature of the Rocky Mountain elk creates large, concentrated winter populations in relatively open terrain allowing efficient ground or aerial census (Thomas and Toweill 1982, pp. 375-376). Both Rocky Mountain and Tule elk normally associate in large groups (Thomas and Toweill 1982), a factor which may also be dependent upon habitat type. Thus, censusing populations of Rocky Mountain or Tule elk can be accomplished relatively efficiently.

In contrast to other North American elk, the Roosevelt elk occupy habitats with dense vegetation, making detectability of elk groups difficult (Harper 1971). In addition to the dense vegetation, Roosevelt elk behaviors, such as small group size (Clutton-Brock 1974, Franklin et al. 1975) and initial intolerance to human activity (personal observation), may decrease detectability relative to other elk subspecies. Aerial censusing of Roosevelt elk has been used primarily to collect population trend data rather than attempt to determine actual densities or numbers mainly because of visibility bias caused by dense vegetation (Harper et al. 1987). Visibility bias (the failure to observe all animals) has been cited as the primary cause of inaccuracy in aerial surveys (Cook and Martin 1974, Caughley 1974, Cook and Jacobsen 1979, Samuel 1984).

Radio-telemetry equipment has been utilizied to study Roosevelt elk habitat, food, or population dynamics (Jenkins 1979, Witmer 1981, Jenkins and Starkey 1982, Witmer and deCalesta 1985, McCoy 1986). The difficulties involved in capturing and handling elk usually limit the number of elk that are telemetry-equipped. A limited number of telemetry-equipped elk may be sufficient, however, for use in mark-recapture. The first objective of this study was to determine the feasibility of censusing Roosevelt elk in second-growth habitat utilizing a limited number of radio-collared animals in an aerial mark-recapture experiment. A mark-recapture census model was chosen as a technique for compensating for visibility bias and estimating true numbers of elk groups in dense vegetation from the air. This was possible when a proportion of the groups were identifiable (marked). Individual identification of elk was accomplished using radio-collars. Ear tags and colored neck-bands were alternatives, but ear tags would be difficult to detect (especially in dense Roosevelt elk habitat) and, regardless of the mark used, both provide less information than radio-collars considering the difficulties of capturing and handling elk.

By using telemetry-equipped elk to identify a proportion of the elk groups as marked, elk groups instead of individual elk became the unit used in a mark-recapture census. Mark-recapture calculations therefore estimated number of elk groups. Concomittantly, numbers within groups were observed during surveys and the average group size was multiplied by the estimated number of groups to estimate number of elk. The mathematics involved were a derivation of the Peterson (1896) model for mark-recapture (Caughley 1977:141-145) which required that the following assumptions be met; 1) that no marks were lost (2) the probability of observing individuals was equal for all within the population and (3) there were no additions to the population and loss of individuals is equal for both marked and unmarked segments of the population.

Resources required to collect data of the type used by Samuel (1984) are normally not available for routine use. My study attempted to confine methods to those which utilized resources available to most wildlife managers.

A second objective of this study was to explore the use of group size as an indicator of relative density. Group size of gregarious animals has been suggested as an index of density (Christie and Andrews 1964, Caughley 1977). Theoretically, the mean size of social groups of gregarious animals tends to increase as density increases. Though the determining factor for group size may not be density itself, the relationship of group size to density may provide an index for making comparisons of relative densities. If this were true for Roosevelt elk then relative densities could be determined from the simple technique of sampling group size. Christie and Andrews (1964) utilizied this method for determining relative densities of Himalayan Tahr (*Hemitragus jemlahicus*) in New Zealand. Group size of elk can be obtained relatively quickly and therefore, inexpensively. Sampling elk group size could also be accomplished without capturing or handling elk. Other than this study, this technique has not yet been attempted for Roosevelt or other North American elk.

STUDY AREA

The study area was within the 26,800 ha Big Lagoon Timber Tract owned by Louisiana Pacific Timber Company in Humboldt County, California (Figure 1). The timber tract represented a major portion of existing Roosevelt elk range outside the boundaries of national and state parks in California. The Big Lagoon timber tract consists of two main drainages, Maple Creek drainage to the north and Little River drainage to the south. The study area was located in the western half of Maple Creek drainage, around the Big Lagoon lumber mill, associated mill pond and log decks. The study area was bordered by Highway 101 to the west, the balance of Maple Creek drainage to the east and the Little River drainage to the south. North of the study area is the Redwood Creek expansion portion of Redwood National Park.

The Maple Creek drainage was logged during the past 40 years and therefore was in various stages of vegetative succession. Approximately 50 percent of the drainage was logged less than 20 years ago. Most of the area has been silviculturally managed for coast redwood (*Sequoia sempervirens*) and Douglas-fir (*Pseudotsuga menziesii*) (personal observation). Large stands of red

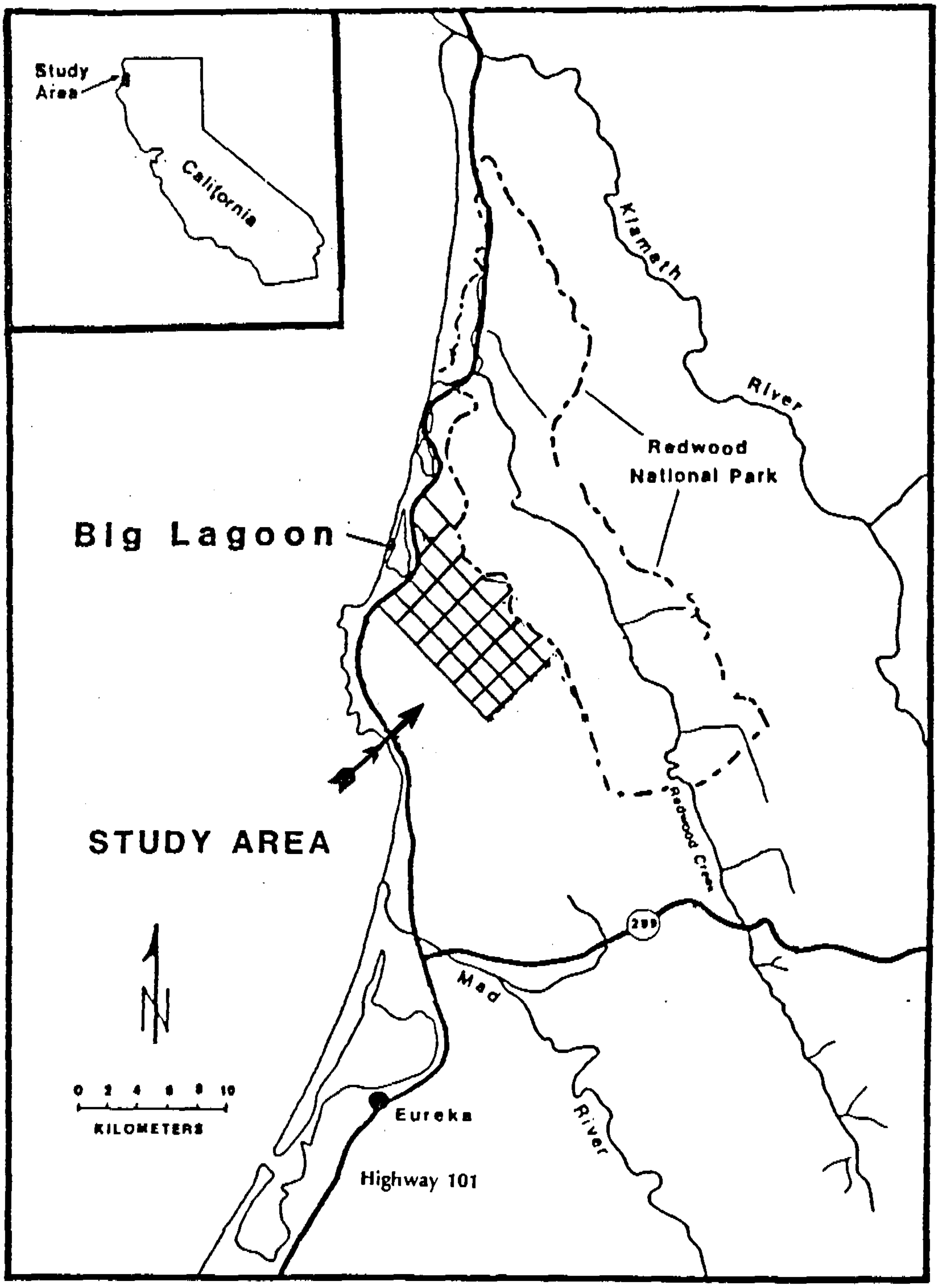

Figure 1. Big Lagoon Study Area for Roosevelt Elk Census, July 1986 to May 1987, delineated by hatched section, within Humboldt County, CA.

alder (Alnus rubra) dominate mid-seral logged areas. Recently (2-10 years) logged areas of the Maple Creek drainage were identifiable by dense growth of pampas grass (Cortaderia jubata); an introduced species which elk of the area frequently consumed (personal observation). The area is characterized by long ridges with steep to moderately steep slopes and many creeks and elevations ranging from sea level to 950 meters.

The climate is temperate with cool (0-10 C), wet winters and mild (10-22 C), dry summers. Fog occurs at any time of year but was more common in summer. Rainfall was heaviest between November and April and averaged 190.5 cm per year (1985-1987, Redwood National Park South Operations Center Files, Orick, CA 95555).

METHODS

Capture and immobilization of elk was required to place telemetry collars on individuals in order to have identifiable groups. Boundaries of the area where aerial mark-recapture was applicable was defined by the home ranges of telemetry-equipped elk. A measure of association between elk and their associated groups was required to determine group stability and mutual home range use. Group size observations were utilized in the aerial mark-recapture model and for analyzing the relationship between group size and density. Estimates of home range, degree of association and average group size were determined utilizing radio-telemetry equipped elk and random observations of elk, telemetry equipped or otherwise.

Trapping and Immobilization

Elk were captured in corral traps as described by Mace (1971) or were darted and immobilized while in open terrain near the Big Lagoon mill, during the period 28 October 1985 to 15 October 1986 (see Golightly and Hofstra 1989). Radio-transmitter collars (model 500, Telonics Inc., Mesa, AZ 85201) and ear tags were placed on eight cow elk. Captured bull elk were not telemetry-equipped because their assumed solitary nature (Thomas and Toweill 1982:231) would have provided less population and group size data than cow elk. All collars were color-coded with color duct-tape and were adapted with a break-away design to prevent accidental choking and to allow for the eventual loss of the collar from the animal. Radio-collared cow elk are hereafter identified by the order of their capture; the first caught being cow #1 and so forth.

Home Range Estimates

A radio-receiver (model TR-2, Telonics Inc.) and a two element hand-held yagi antenna were used to approximate locations of telemetry-equipped elk; they were then approached on foot to attempt visual observation and determine exact location, size and composition of the associated group. Locations verified visually were plotted on 1:24000 topographic maps using UTM coordinates. Telemetry-equipped elk were located at least once every seven days between 24 November 1985 and 20 June 1987. To avoid a time-of-day-bias, locations of collared elk were determined during one of three daily periods; early morning, midday, or late afternoon. Attempts to locate elk were rotated systematically between the three daily periods.

Counts of total number of elk and composition of each group were determined from successful visual observations. When it was suspected that not all members of a group were detected, the greatest number of elk observed was recorded with a notation that additional elk were probably present. Only presumed accurate counts (when number of elk recorded was assummed accurate within ± two individuals) were used for calculating group size and composition.

All telemetry-facilitated locations and random sightings of collared elk were combined for determining home ranges. Home range was estimated using the modified minimum area method (Harvey and Barbor 1965), which Burger (1985) preferred in comparisons with other home range models. Home range estimates from two other models, the minimum convex polygon model (Eddy 1977) and the minimum concave polygon model, both available on the microcomputer program McPaal (Stuwe and Blohowiak 1981), were calculated for comparison with results from other studies.

Coefficient of Association Estimates

The percentage of locations where one marked elk was located in the same group as another marked elk was referred to as their degree of association (Jenkins 1979). Previous elk research where associations were described

(Knight 1970, Jenkins 1979, Witmer 1981) used coefficient of coincidence (first proposed by Dice, 1945), though results were reported as coefficients of association (CA). Cole (1949) was erroneosly cited by Knight (1970), Jenkins (1979), and Witmer (1981) as the source for the CA formula. For the purpose of uniformity, levels of association reported here were labelled as CA's although they are actually coefficients of coincidence (Dice 1945). CA's were calculated as:

$$CA = 2h / a + b \qquad (1)$$

where h was number of locations where individuals a and b were observed together, a was the total number of observations for individual a, and b was the total number of observations for individual b. The CA varies from a value of 0 (no association) to 1 (complete association).

Bull Elk

Sightings of bull elk which were not in cow groups were excluded from mark-recapture calculations because bull elk had not been radio-collared. Male elk in association with cows were counted as part of the group. Reconniassance flights indicated that mature bull elk occupied habitats in the Little River drainage, south of the study area, during part of the year. Thus an estimation of bull elk numbers additional to male elk that were associated with cow groups was not attempted.

Group Size and Density Relationship

To investigate the relationship between group size and density, the study area was divided into concentric zones with a common center point at the Big Lagoon mill, near the Lagoon (Figure 2). Early reconniassance suggested elk numbers decreased as distance increased from the Lagoon area. The mill was chosen as the point from which distance was measured because of it's central position to the presumed greatest elk density.

All ground observations of cow groups during the period from August 1985 to 20 June 1987, whether telemetry-assisted or random, from each zone were combined to determine average group size per zone. Four zones were examined, all group observations within 1 km distant of the center point were collectively considered as belonging to the first zone, all observations between 1 and 2 km distant the second zone, all observations between 2 and 3 km distant the third zone and all observations between 3 and 4 km distant the fourth zone.

Group size was measured both from the ground and from the air, although observations were not synchronous. Air and ground results were tabulated separately for

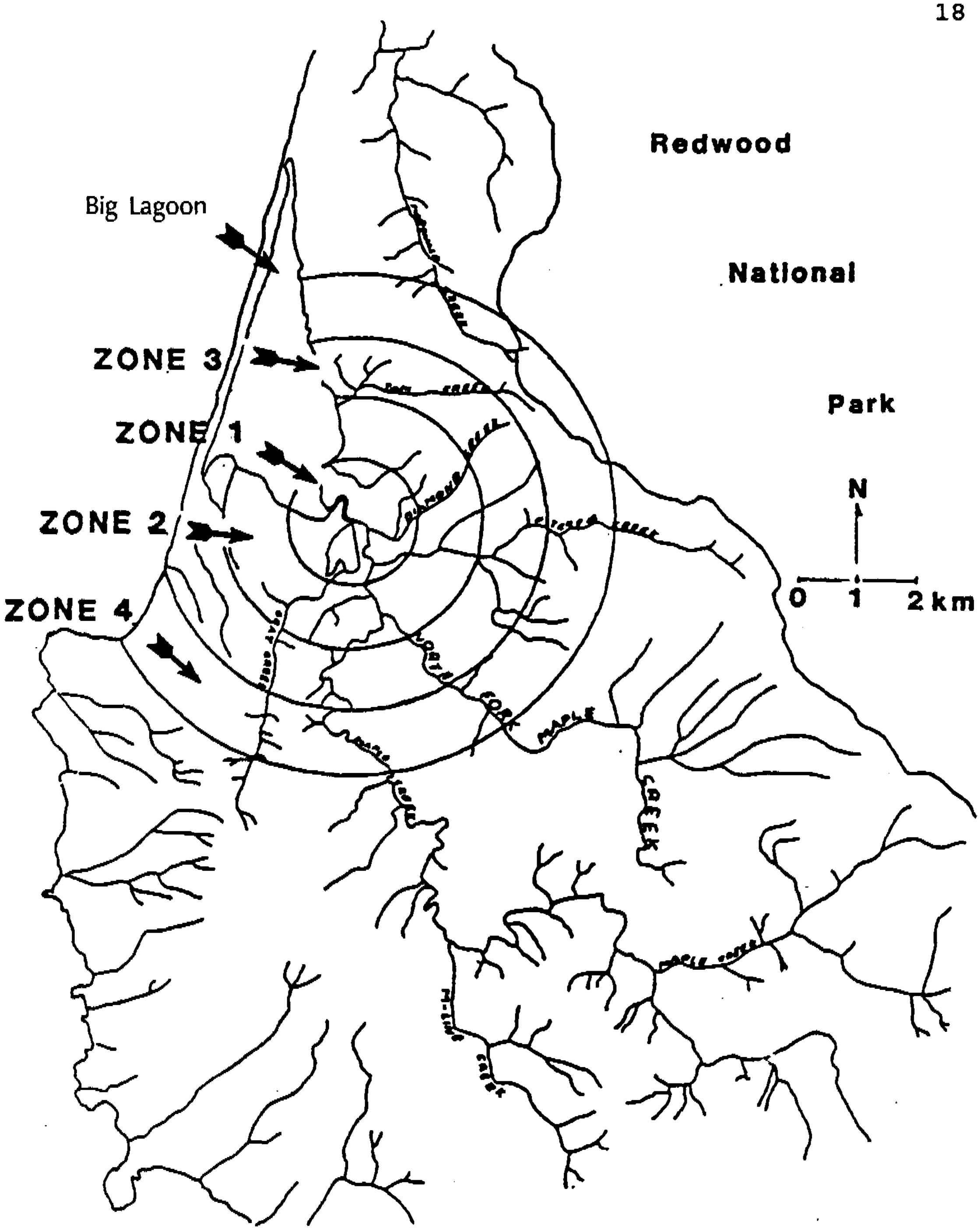

Figure 2. Location of Zones 1-4 used in Elk Group/Zone index for Relative Density estimates. Big Lagoon Study Area, Humboldt County, CA.

comparison. An assumption of the technique was that group sizes were estimated with constant absolute accuracy ($\pm$ one or two elk) regardless of visibility or true group size. In some instances when observing elk on the ground additional efforts were necessary to facilitate an accurate count. For example, after initial observation of an elk group, I would make my presence known, often causing the appearance of several additional elk which were previously undetected.

Aerial Surveys

Aerial surveys were conducted using either a fixed-wing Cessna 182 or a Bell Jet-Ranger helicopter. Five reconnaissance flights over the study area were conducted between 26 November 1985 and 17 April 1986. The first was flown without any systematic flight plan. The next three were experimental flights used for designing future aerial surveys. The fifth flight was used for reconnaissance only.

Exclusive of the aforementioned five flights, thirteen aerial surveys, twelve using fixed-wing aircraft and one with a helicopter, were completed. Aerial surveys were completed in a systematic manner using alternating east-west and west-east transects spaced at approximate 60m intervals and following elevational contours.

Transects were flown in an area of approximately 23 km^2 around the Big Lagoon mill (Figure 3).

During aerial surveys the radio-telemetry reciever in the aircraft was turned off until a group was sighted. When an elk group was sighted, investigators circled above and estimated group size and composition. The reciever was then activated to determine if radio-collared elk were within the group. Groups were considered marked (and recaptured) if they contained a radio-collared elk as a member; the group was unmarked if they did not include a radio-collared elk. If two or more radio-collared elk were present, the group was considered as one radio-collared group (note that the total number of available marked groups for the survey was then decreased). Locations of elk groups were determined ($\pm$ 50 m) using visible roads and obvious geographic features. Positions of elk groups were recorded on topograghic maps (scale = 1:24000). After all transects had been completed, those radio-collared elk which had not been detected were located using telemetry equipment. If their location was outside the aerial survey area they were excluded as potential marks from mark-recapture calculations for that survey.

For each survey the number of elk groups present was estimated using the Peterson (1896) model for mark-

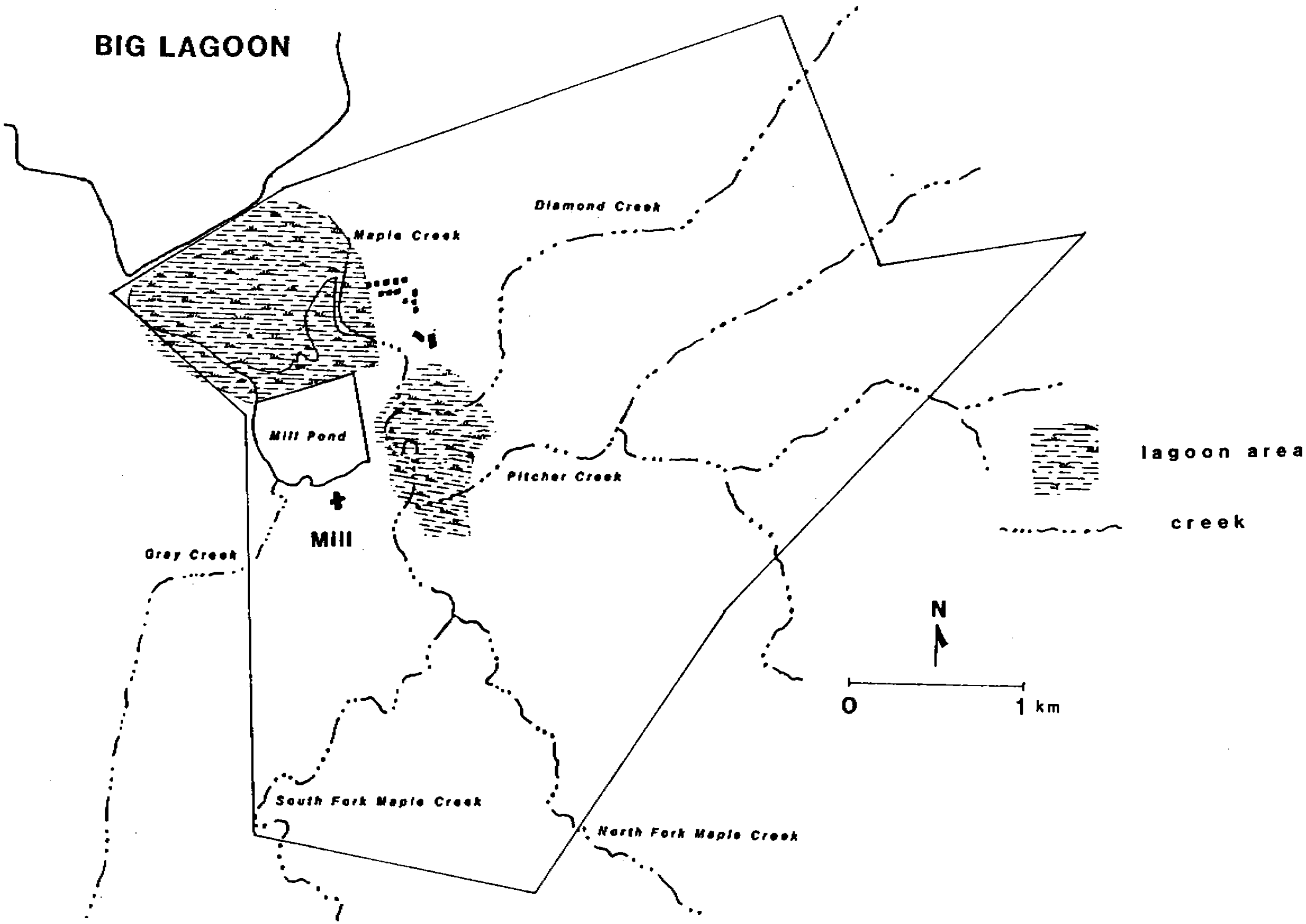

Figure 3. Area around Big Lagoon Mill censused using aerial mark-recapture surveys. Big Lagoon study area, Humboldt County, CA.

recapture calculations (Caughley 1977:141). Strandgaard (1967) in a similar experiment utilizied the Bailey (1951) modification to the Peterson model but found no difference in the results. Average number of elk per cow group was determined per survey and multiplied by the estimated number of groups present to calculate total number of elk in cow groups (including associated male elk). Standard error of the product was calculated according to Goodman (1960:710).

RESULTS

Trapping and Immobilization

Using two traps, 570 trap-days were accummulated between 28 October 1985 and 15 October 1986. Ten trap sites were used and elk were caught at five sites. Twenty-three elk were captured in traps, but eleven subsequently escaped, three were released for immobilization of another elk and one mortality occurred. Two cow elk were immobilizied without the use of corral traps. Seven radio-collars were successfully placed on elk.

Home Range Estimates

Each home range model estimated different shape and size home ranges for each elk (Table 1). Results from each model are presented for comparison with other studies which may have used the same model or software. The modified minimum area model was used for estimation of home ranges in defining boundaries of sampled areas.

Average home range size for radio-collared elk was 381.1 ± 32.5 (± one standard error) ha. All collared elk except one utilizied common core areas (containing > 75

Table 1. Home Range Estimates (ha) from Minimum Convex Polygon, Minimum Concave Polygon Models (Stuwe and Blohowiak 1981) and Modified Minimum Area Model (Harvey and Barbour 1965) for Radio-Collared Elk, Maple Creek Drainage, Big Lagoon Study Area, Humboldt County, CA.

		Method		
Elk Number	Number Locations	Minimum Convex	Minimum Concave[b]	Modified Minimum Area
1	64	321	199	338
2a	64	1047	403	595
3a	54	1045	289	682
4	60	232	177	180
5	23	124	68	156
6	26	139	126	162
7a	20	701	320	555

aAreas included the 32 ha area Mill and Mill pond which were not utilizied by elk.
bThis method as configured in Stuwe and Blowhowiak (1981) did not perform reliably.

percent of all observations) with two other collared elk (Appendix A). Three collared elk shared a core area north of the mill, three collared elk used a core area around the mill and one cow utilizied a home range core area within the lagoon. For ease of explanation these three core areas will be hereafter referred to as the Hill, Mill and Lagoon areas, respectively (Figure 4).

Coefficient of Association Estimates

Coefficients of Association were calculated for each radio-collared elk (Table 2). The greatest CA calculated (CA = 0.50) was for cows #3 and #7 from the Mill area. No associations were observed between elk from Hill and Mill areas (though individual elk home ranges from the two areas slightly overlapped). No associations were observed between elk from the Hill and Lagoon areas.

Group Size and Density Relationship

Ground observations of 352 cow groups were utilizied to determine average group size per zone, with each sequential zone having a smaller average group size (Table 3). Zone 1 had the greatest average group size and zone 4 the least. Average group size for all zones was significantly different (Kruskall-Wallis single factor Anova by ranks, $p < 0.05$, Zar 1984:177). A similar trend

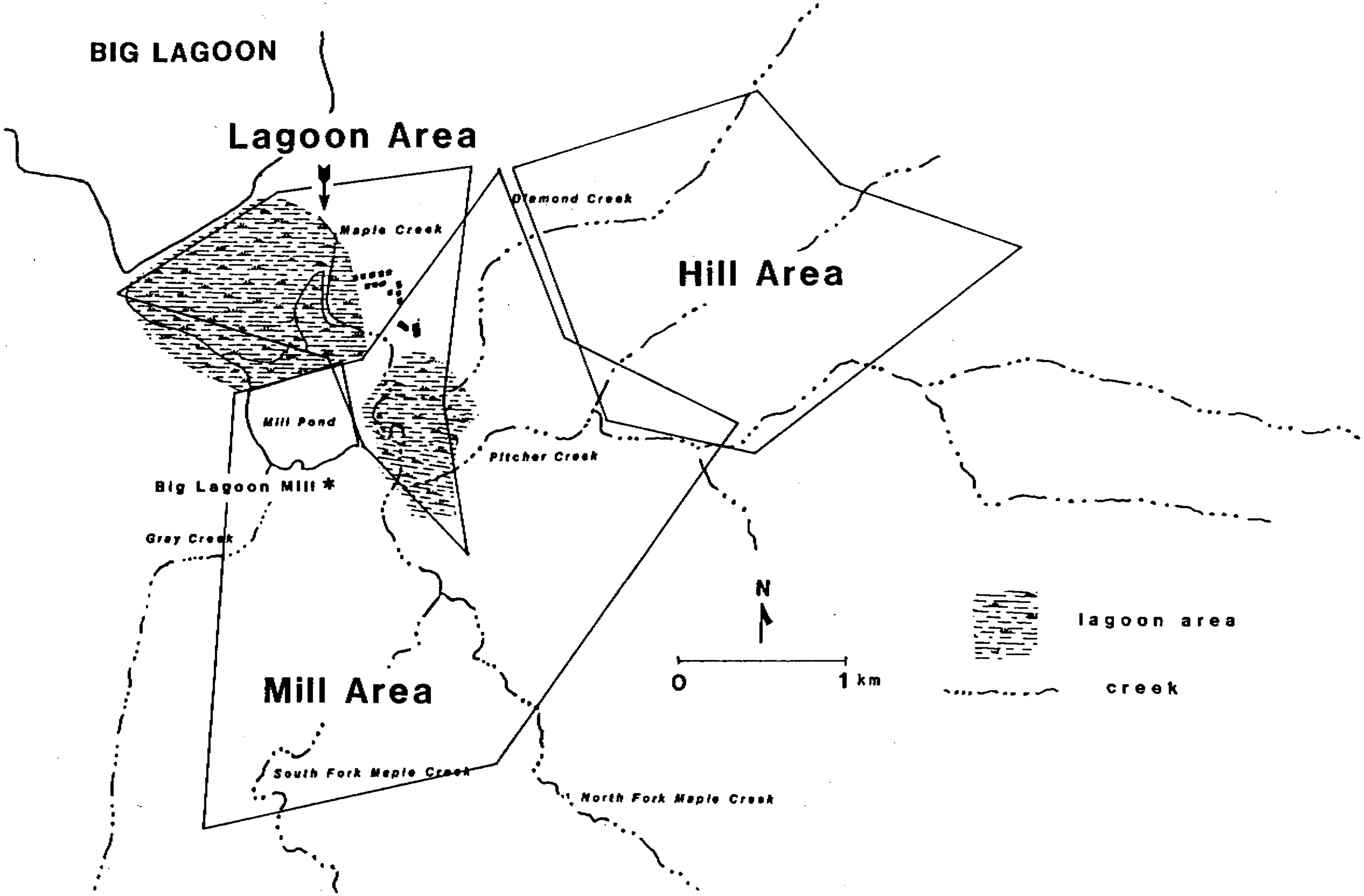

Figure 4. Location of mill, Hill and lagoon Core Home Range areas within the Big Lagoon study area, Humboldt County, CA, based on telemetry results of collared elk.

Table 2. Coefficient of Association Estimates for Radio-Collared Elk, Big Lagoon Study Area, Humboldt County, CA.

Area	Elk Number	Elk Number					
		1	2	3	4	5	6
Hill	1						
Mill	2	0.00					
Mill	3	0.00	0.32				
Lagoon	4	0.00	0.00	0.06			
Hill	5	0.05	0.00	0.00	0.00		
Hill	6	0.14	0.00	0.00	0.00	0.23	
Mill	7	0.00	0.44	0.50	0.00	0.00	0.00

Table 3. Mean Group Size Per Zone for Elk at Big Lagoon Study Area, observed from the ground and from the air. Humboldt County, CA.

	ZONE 1		ZONE 2		ZONE 3		ZONE 4	
	Ground	Air	Ground	Air	Ground	Air	Ground	Air
Mean	20.4	12.7	12.1	7.5	6.5	5.0	4.4	2
S.E.	0.9	1.8	0.8	0.9	0.5	1.4	1.0	0
n[a]	128	49	125	43	72	5	16	1

a Number of groups observed.

for mean group size per zone was observed from the air (Table 3) except the mean group size was smaller than results obtained on the ground.

Average group size associated with radio-collared elk for the entire study period was 15.0 $\pm$ 4.5 and ranged from 7.9 $\pm$ 0.7) for cow #1 to 26.5 $\pm$ 0.9 for cow #4 (Table 4). Variance around the mean for group size per collared elk indicated that radio-collared elk did not remain in cohesive groups, but rather fluctuated in group size and membership.

Aerial Surveys

Flights were conducted under varying weather conditions and at different times of the day. Number and experience of observers differed with a minimum of one observer and a maximum of three.

A helicopter reconniassance flight on 24 March 1986 (before mark-recapture flights began) resulted in 112 elk counted within the mark-recapture area. A helicopter survey flight on 7 Febuary 1987 resulted in a count of 106 elk within the same area. Two days later 106 elk were again observed from a fixed-wing aircraft.

Radio-collars on elk were not visible from the air upon initial observation of elk groups, therefore collars did not increase the visibility of marked groups over unmarked groups. Collars became visible and identifiable

Table 4. Average Group Size ($\bar{X} \pm$ standard error) for Radio-Collared Elk. Big Lagoon Study Area, Humboldt County, CA.

Home Range Area	Cow Number	Average Group Size	Home Range Area Average Group Size	n
Hill				
	1	7.9 ± 0.7		37
	5	11.3 ± 1.5		11
	6	11.1 ± 1.7		11
			10.1 ± 1.1	
Mill				
	2	17.4 ± 1.2		47
	3	17.6 ± 0.9		40
	7	13.5 ± 1.7		17
			16.2 ± 1.3	
Lagoon				
	4a	26.5 ± 0.9		48

a One group in home range area.

by color upon a search following determination of their presence using radio-telemetry. Elk did not react to overflights by fixed-wing aircraft but would move a short distance because of low flights by helicopters, although not more than 100m unless pursued.

Aerial mark-recapture surveys were limited to the area delineated by the combined home ranges of telemetry-equipped elk. Using the modified minimum area model (Harvey and Barbour 1965), this resulted in an area of 10 km^2.

Results from two mark-recapture survey attempts were excluded, one because of untrained observers and the other because of strong winds which hampered observation. Three surveys were not utilizied for final calculations because the number of marked elk groups available (three or less) were inadequate for mark-recapture calculations.

Results for density calculations were based on 8 surveys, all of which had four or more marked groups available (Table 5). For aerial surveys with four or more marked groups, the number of marked groups available per flight ranged from four to six, with an average of 5.1 ± 0.8 ($n = 11$). Number of groups detected per flight (marked and unmarked) averaged 5.1 ± 1.3 with a range of three to seven groups. During one survey (25 Febuary

Table 5. Detections for Mark-Recapture Aerial Surveys, Big Lagoon study area, Humboldt County, California.

Survey Number	Date (d/m/y)	Time Began	Number of Observers	Number Marked Groups	Number Groups Detected	Marked Groups Detected
1	17/4/86	1010	2	2	3	1
2	16/6/86	0920	2	3	10	3
3	17/7/86	0900	2	4	7	1
4	2/9/86	1640	2	5	5	2
5	30/10/86	1100	2	6	3	2
6	7/2/87	0850	3	4	5	2
7	9/2/87	0943	1	5	6	4
8	25/2/87	1245	3	6	6	6
9	26/3/87	0920	3	3	3	1
10	29/4/87	1300	1	6	4	4
11	26/5/87	1205	2	5	5	1

1987) only marked elk groups were observed (n = 6); this result was treated as a complete count of elk groups.

Estimates for number of elk in cow groups within the mark-recapture area for eight surveys ranged from 81.0 ± 36.3 to 225.0 ± 98.7 (Table 6). The average estimate for all aerial surveys was 140.6 ± 36.7 (95 % CI = 68.7 - 212.5) which provided an estimate of 0.12 elk/ ha (elk in cow groups).

Number of marked groups available was not correlated with estimated number of elk ($r = 0.28$, $p > 0.05$, $n = 11$, Zar 1984:308). There was also no significant correlation between number of groups observed per survey and estimated number of elk ($r = .09$, $p > 0.05$). For all surveys combined the estimated percentage of elk groups in the mark-recapture area which were marked was 50 percent ± 0.09.

Table 6. Results of Mark-Recapture Aerial Surveys, Big Lagoon study area, Humboldt County, CA. ($\bar{x} \pm$ standard error)

Survey Number	Date (d/m/y)	Number Elk Observed	Estimated Number Groups	Average Group Size	Estimated Number Elk
1a	17/4/86	52	6.0 ± 4.9	13.0 ± 13.0	78.0 ± 35.9
2a	16/6/86	56	10.0 ± 4.8	7.4 ± 6.2	74.0 ± 22.4
3	17/7/86	43	28.0 ± 25.9	6.1 ± 4.4	170.8 ± 74.0
4	3/9/86	52	12.0 ± 6.9	10.4 ± 11.6	130.0 ± 70.5
5	30/10/86	54	9.0 ± 3.7	13.5 ± 12.0	121.5 ± 59.8
6	7/2/87	106	10.0 ± 5.5	17.5 ± 11.1	175.0 ± 60.9
7	9/2/87	106	7.5 ± 2.4	15.1 ± 8.7	113.6 ± 29.7
8	25/2/87	90	6.0 ± 0.0	18.0 ± 11.0	108.0 ± 29.5
9a	26/3/87	19	9.0 ± 7.4	6.3 ± 5.5	57.0 ± 36.9
10	29/4/87	54	6.0 ± 0.0	13.5 ± 12.1	81.0 ± 36.3
11	26/5/87	45	25.0 ± 22.4	9.0 ± 12.0	225.0 + 152.4

a Excluded from mark-recapture values reported in text because only 3 or fewer marked groups available.

DISCUSSION

Home Range

Mean home range estimates calculated from radio-telemetry results were the smallest reported for Roosevelt elk (381 ha) and included the smallest reported home range (180 ha). Franklin and Lieb (1979) reported smaller average home ranges (300 ha) for Roosevelt elk at Prairie Creek Redwoods State Park but their results were not based upon telemetry-assisted data. Logsdon (1965), utilizing an elk marking system, estimated elk home ranges at Boyes Prairie and Gold Bluffs Beach (both within Prairie Creek Redwoods State Park) as 202 and 338 ha, respectively. Witmer (1981) reported similar values (<400 ha) for Roosevelt elk in the Coos Bay area of Oregon derived from a bivariate ellipse home range model, which he suggested tended toward overestimation. Jenkins (1979) reported average home range estimates of 1,064 ha for Roosevelt elk in Olympic National Park, also based on a bivariate ellipse model. Janz (1980) reported an average of 520 ha for Roosevelt elk in British Columbia, using a modified minimum area model.

Average home range size estimates for radio-collared elk from the Mill area were 202 percent greater than for cow elk of the Hill area and 379 percent greater than for elk from the Lagoon area. Elk using the Mill area apparently used a much larger home range, although most of the area they occupied appeared to be good Roosevelt elk habitat (a flat, grassy area associated with fluvial activities) according to studies of Roosevelt elk habitat in other areas (Jenkins 1979, Witmer 1981, Raedeke and Taber 1982, Irwin and Peek 1983).

Greater elk density in the Mill area may have caused more dynamic interactions and movements between groups; this was supported by greater CA values for radio-collared elk of the Mill area than was observed for elk from the other areas. Greater heterogeneity of habitat may also have been a factor; the Mill area included non-productive mill sites and log-storage decks and seasonally flooded swamps.

Radio-collared elk demonstrated great fidelity to their respective home ranges. Radio-collared elk were rarely located in a core area other than their own and then only within an area of overlap with a home range from an adjacent core area (Appendix A). Logsdon (1965) reported a similar pattern for elk at Prairie Creek Redwoods State Park. Although elk from the Lagoon home range occasionally entered the western edge of the Mill area, they did so only during flooding of the lagoon. When this occurred elk from the Mill area moved to eastern portions of their home range.

A border existed between the Hill and Mill home ranges as elk from either were rarely observed within the range of the other. Although telemetry-equipped elk (and associated groups) from either area were sometimes located within a shared border (along a creek) no association between collared elk from the Mill and Hill areas occurred.

Group Size and Density Relationship

Mean group size decreased as distance increased from a central point (the Big Lagoon mill). The number of elk groups encountered, per zone, during ground and aerial surveys also supported the hypothesis that density of elk decreased as distance from the center point increased, although these data were not collected systematically. Beyond Zone 4 and outside of the study area was the remainder of the Big Lagoon Timber tract, which I often traversed during the course of this study. Few elk were ever encountered outside of the study area and these were either single males or groups of three or fewer cows.

Visibility of elk observed from the ground may have differed per zone, but was not measured quantitatively. Qualitatively, zone two was as open as zone one, yet mean group size for the former was less than for the latter. An assumption of the technique was that group size was determined with relative accuracy regardless of the visibility; if this was not accomplished the sighting was not used.

Groups within the study area remained within a limited range, based on home-range affinity demonstrated by radio-collared elk. Thus, elk groups observed in more distant zones (3 and 4) were assummed to be within their respective home ranges and not dispersing from inner zones. The same affinity to home range in Roosevelt elk was noted by Mandel (1979) in California and by Harper (1964) in south-west Oregon, where tagged elk rarely were observed more than 1.6 km from their point of capture (including bull elk). Starkey et al. (1982) reported Roosevelt elk to be faithful to traditional home range areas and did not readily colonize new areas. Therefore, I assumed that observed mean group size per zone results were based on groups which did not range widely.

Variation in group size in elk has often been related to season (Franklin 1968, Knight 1970) and has been noted for non-migratory Roosevelt elk in California

(Franklin and Lieb 1979). Mandel (1979), however, found no seasonal variation in group size for non-migratory Roosevelt elk in and around Redwood National Park. If group size was seasonally affected in this study, each zone would be influenced equally by all 21 months of group size data (assuming seasonal affects were constant across all zones).

Cow elk 2, 3 and 7 shared a core home range area within Zone 1 and demonstrated a high degree of association. Cow elk 1, 5 and 6 shared a smaller core home range area within Zone 2, yet had far less association and smaller average group size. This suggests a difference in social structure between the two areas, perhaps in response to different relative densities of elk in the two areas.

Increased elk group size may correspond to increased use of open areas (Knight 1970, Franklin et al. 1975, Marcum 1975), although Knight (1970) and Fischer (1987) noted decreased group size in migratory elk in open areas in spring when use of open habitats (such as meadows) increased. Mandel (1979) reported larger group sizes in open versus intermediate or closed habitats, but found no difference between mean group sizes for intermediate or closed habitats.

A regular change in group size associated with marked elk was observed in this study. Similarly, Harper (1971) noted changes in elk group size while working on the Millicoma tree farm in Oregon; conversely Franklin et al. (1975) did not observe changes in group size while studying elk at Prairie Creek Redwoods State Park in California. Though no data were presented, Franklin (1968) suggested the difference in group stability between Roosevelt elk herds in California and southern Oregon was due to differences in the stage of social development (length of time together to develop social bonds), with elk herds on cutover lands in Oregon having a lower stage of social development than those on undisturbed land in California. Unhunted elk groups in unmanaged forests, such as those at Prairie Creek Redwoods State Park (Franklin and Lieb 1979) and Olympic National Park, Washington (Jenkins and Starkey 1982) formed stable, long-lasting relationships. Hunted populations inhabiting silviculturally managed forests in south-west Oregon formed relatively small bands with greater interchange (Harper 1964, Witmer 1982). Though not legally hunted on a regular basis, poaching and irregular hunts may have led to some degree of social instability for elk in this study. More research into the relationship between these variables is warranted to better understand the interaction of elk densities and group associations.

Aerial Surveys

Aerial surveys with three or less marked elk groups available provided inaccurate estimates of elk numbers. The greatest estimate under such conditions was 78 elk, yet three aerial surveys (two were conducted within two days of each other and the other 11 months previous) provided direct counts of at least 106 elk observed. I commonly counted 70 or more elk in one evening in the Mill and Lagoon areas alone. Therefore, I assummed that for the 10 km^2 mark-recapture area there were a minimum of 106 elk.

All surveys (except one) which did not estimate at least 106 elk had three or less marked groups available. This suggests that less than four marked groups available per survey is an inadequate sample size. Detecting a relatively greater number of elk groups (as occurred in survey 2) apparently did not compensate for having an inadequate number of marked groups.

Lack of a sufficient number of marked groups per survey was primarily caused by more than one marked elk in the same group. On three occasions marked elk were within a canyon not navigable by aircraft and therefore outside of the survey area, which also contributed to a reduced number of marked groups. The loss of the canyon as part of the survey area, because it was part of the home range for three marked elk, violated the assumption of a closed study site. Based upon the movements of collared elk, unmarked elk within the survey area were assummed to utilize limited home ranges and violation of the closed study area was probably limited.

The assumption of equal detectability was maintained as the process of capturing elk for marking was a one-time occurrence, and during recapture episodes (aerial surveys) elk were not harrassed; therefore I assummed no conditioning to recaptures occurred. No collars were lost, thus the assumption was valid that marks were not lost.

The proportion of a population which should be marked for a mark-recapture estimate has been estimated at greater than 45 percent (Bartmann et al. 1986). Strandgaard (1967) marked 75 percent of a roe deer (Capreolus capreolus) population in a mark-recapture experiment while McCullough and Hirth (1968) found that having 68 percent of a population marked did not guarantee accuracy. These studies, however, dealt with the individual as the basic marked unit; utilizing groups instead of individuals may be different in terms of required sample size.

Only survey number 10 provided an estimate (81.0) below 106 elk when an adequate number of marked elk groups were available. For this survey only marked elk groups were detected, thus the number of marked groups equalled the total number of groups detected and the estimated number of groups equalled the number of marked groups available. For surveys number 10 and 8 this occurred, providing the lowest estimate for number of groups (n = 6) and the two lowest estimates for number of elk (108 and 81) for surveys with four or more marked elk groups available. Having only marked groups detected could occur when all or almost all elk groups in the area are marked. However, the percentage of marked to unmarked groups detected in other aerial surveys indicates not all elk groups were marked and results from survey 8 and 10 may have been a sampling artifact.

Fluctuating group size may cause variance for estimated number of groups calculated for aerial surveys. During one aerial survey I observed 52 elk in one group, the largest group size recorded during the study. Within three hours I reobserved the same area, but the 52 elk had split into four groups, each moving in a different direction. Such combining and subsequent splitting of groups during the study was verified using coefficients of association for collared elk. The factors causing such behaviours are unknown, but the behaviour demonstrates the need for surveys to be conducted quickly and efficiently, making aircraft essential.

Because surveys were not consistent, elk were sampled under various conditions, many of which (such as time of day, weather and temperature) may be a factor in elk group size. McCoy (1986) observed greater use of open areas by Roosevelt elk in California during periods of low temperatures, high winds, or precipitation, while using forest and riparian habitats during periods of decreased cloud cover and increased ambient temperature. He also noted activity peaks one hour after sunrise or sunset. Future surveys may reduce the amount of bias introduced by group size fluctations and overall visibility by using consistant sampling regimes.

For social ungulates such as elk, a survey can count either individuals or groups. Individuals are assummed to be equally detectable. When, however, the group and not the individual is the unit being surveyed, the bias of unequal detection for differing group size occurs (Samuel 1984). Larger groups should have a greater probability of detection than smaller groups, thus causing an overestimation of group size and an underestimation of number of groups (Cook and Martin, 1974). Samuel (1984) used group size as an independent variable (as well as percent vegetation cover, behavior, study area, search rate, percent snow cover and observers) for a logistic regression analysis to determine which variables impacted detectability of elk groups most. To accomplish this, Samuel (1984) located the groups missed during a survey, counted group size and compared these to group size of previously detected groups. This required utilizing the helicopter's maneuverability to observe the missed groups sufficiently for a proper count. Group size and percent vegetation cover had the greatest influence on detectability and he developed models which corrected for both.

Opportunities to quantitatively assess the relationship between vegetation and detectability were not available for this study because I was usually limited to fixed-wing aircraft which cannot be utilizied to count elk in dense vegetation. A helicopter was used for only one survey and, of the two marked groups missed, only one was later observed and counted. For eleven aerial surveys, 24 marked elk groups were missed and only six were later sufficiently observable to count. Usually, missed elk groups were within thick second-growth redwood-Douglas fir stands which hid them completely.

Samuel and Pollock (1981) attempted to measure and compensate visibility bias due to group size for sea otters (Enhydra lutris) off the coast of California. By utilizing data on group size collected on shore (and assummed to be more accurate than aerial survey data) group size detectability was estimated and a model for correction calculated. This was not feasable for this study because ground visibility of elk groups was minimal.

I assumed that smaller (1-5 elk) groups had a decreased probability of detection than larger groups (Cook and Martin 1974, Samuel 1984). This would cause an underestimation of the number of groups in the area. However, at the same time group size was overestimated because the smaller elk groups were not detected and did not contribute to average group size. Thus the decreased detectability of smaller groups affected the variance in two opposite directions, but they may not necessarily have compensated for each other.

Detectability of elk groups missed by mid-day surveys because they were utilizing thermal cover (characterized by relatively greater canopy cover [Witmer 1981] reducing detectability from the air) might have been increased had time of all survey flights been in early morning when elk groups were more likely to be actively feeding in the open. Because the study was conducted next to the ocean, evening surveys would have been less desireable because of visual interference caused by reflected sunlight.

Although confidence intervals around individual aerial surveys were great, the combined estimates from eight aerial surveys provided an average estimate of 140.6 elk (95 percent confidence interval of 68.6 - 212.6). Because minimum direct-counts had at least 106 elk, a more realistic range for the estimated number of elk would be 106 to 212 elk. The accuracy reported here may be acceptable as a population estimate for management purposes; other estimates of the population (Mandel estimated 55 elk for the area in 1979, based upon limited observations) may be little more than guesses. Guesses such as these are often utilized by managers in closed vegetation; the methodology presented here represents a significant technical improvement.

The mean of the eight corrected counts was assummed to be a minimum corrected count, because number of elk observed per group during aerial surveys was always a minimum. Only those elk observed were recorded, no effort was made to approximate number of elk not detected. Therefore average elk group size per aerial survey was probably a minimum, as possibly was the corrected estimate.

This study suggests that aerial surveys can be utilized to census elk groups in second-growth forest even with relatively few collared elk available. Elk radio-equipped as part of a translocation attempt, habitat or population study can be utilized to conduct similar surveys and provide managers with a population size estimate.

Management Recommendations

The objective of this study was to determine the feasability of censusing elk populations using a mark-recapture technique with a minimum number of telemetry-equipped elk, and to determine relative density utilizing group size. It was possible to obtain useful estimates of elk densities using these methods. Seven elk equipped with telemetry-collars were sufficient for conducting aerial mark-recapture estimates within a 10 km^2 area. A greater area could be surveyed using this technique provided (1) an adequate number of collared elk were utilizing the majority of the study area (2) collared elk distributed themselves among elk groups and (3) vegetation cover allowed some degree of visibility.

Greater precision could be obtained with greater numbers of marked elk and increased consistency in data collection. Aerial surveys can be conducted at the same time of day, preferably early morning. Number of observers and type of aircraft should be constant. Number of repeat surveys would depend upon number of marked elk available, percent vegetation cover (visibility of elk from the air) and success of previous surveys, plus finances available to the investigator.

Results from this study suggest a relationship between elk group size and relative density. This technique may be acceptable to provide the manager with an index of elk densities. More research into this relationship is warranted in view of its implication for establishing estimates of elk densities with little expenditure.

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APPENDIX A. Locations of collared elk home ranges within the Big Lagoon Study Area, Humboldt County, CA.

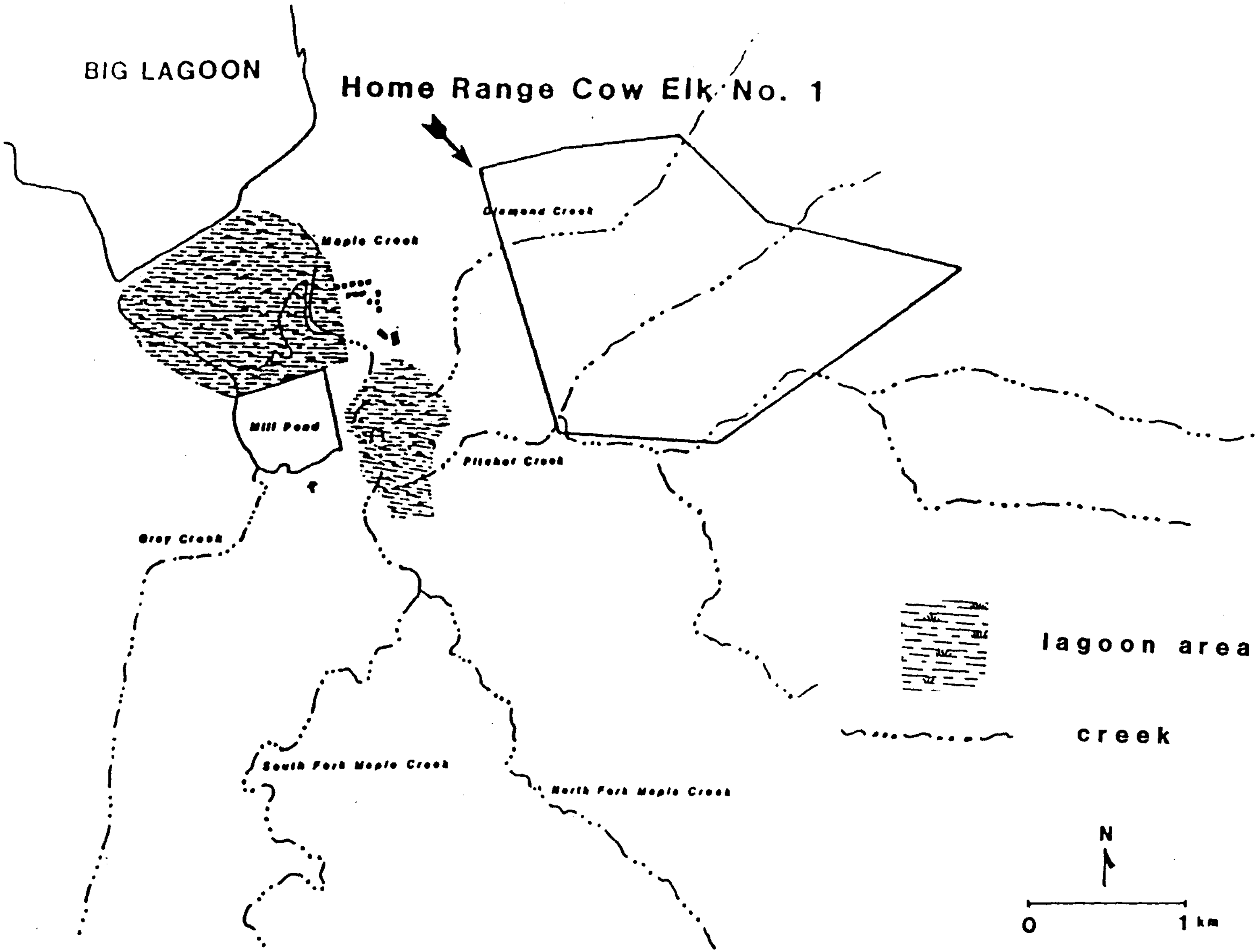

Figure 5. Location of Home Range for Radio-Collared Cow Elk Number 1, Big Lagoon Study Area, Humboldt County, CA.

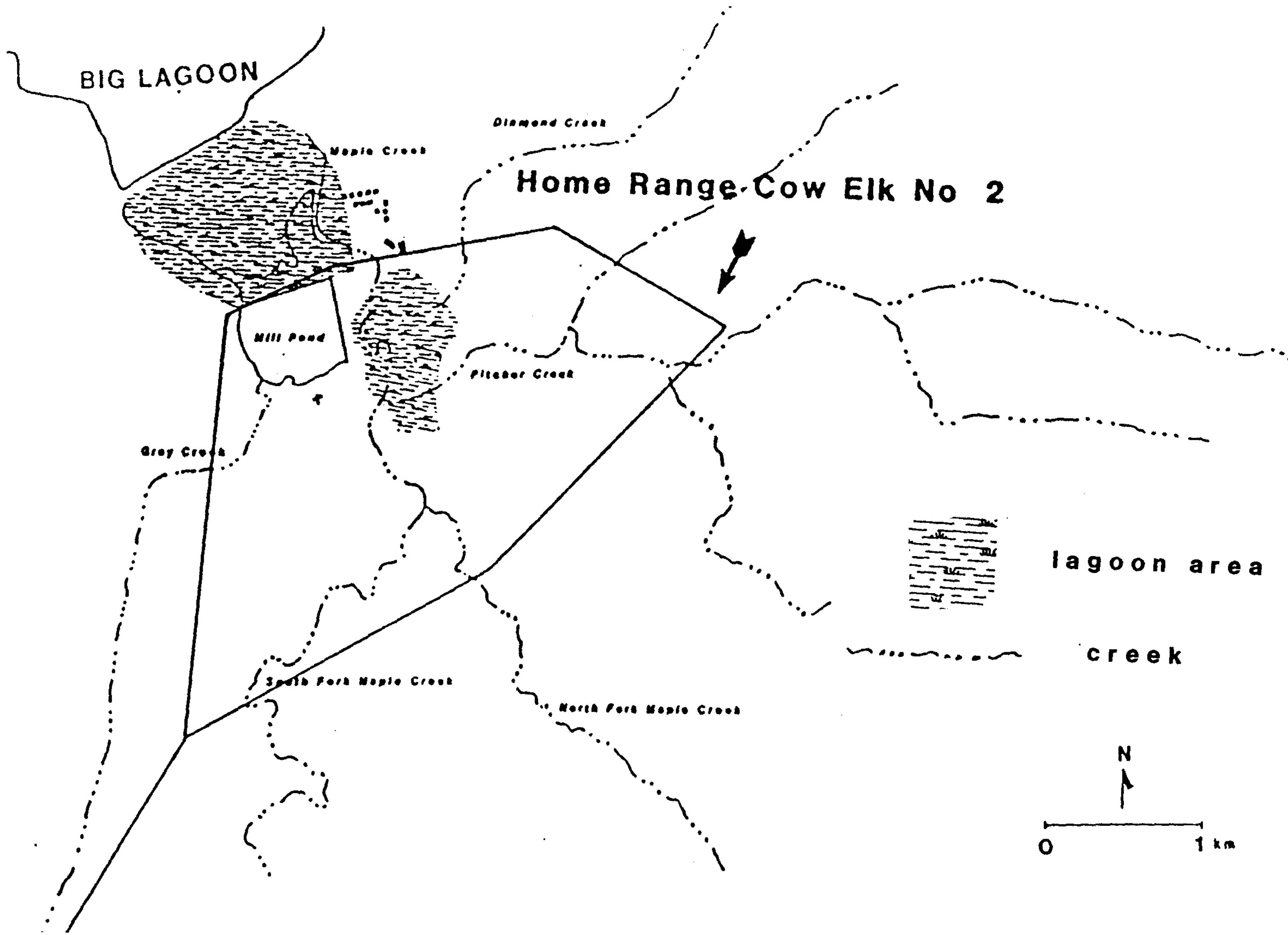

Figure 6. Location of Home Range for Radio-Collared Cow Elk Number 2, Big Lagoon Study Area, Humboldt County, CA.

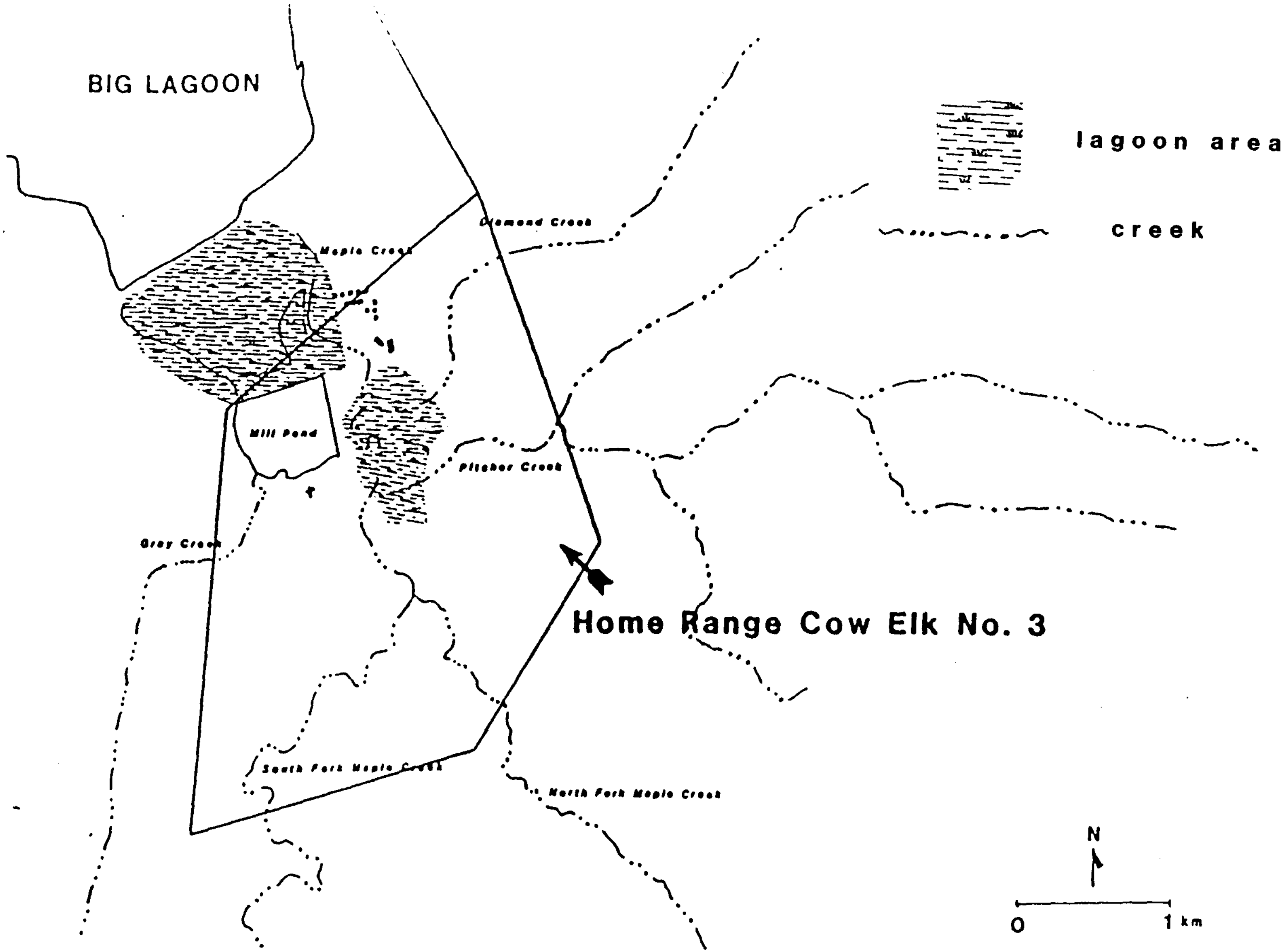

Figure 7. Location of Home Range for Radio-Collared Cow Elk Number 3, Big Lagoon Study Area, Humboldt County, CA.

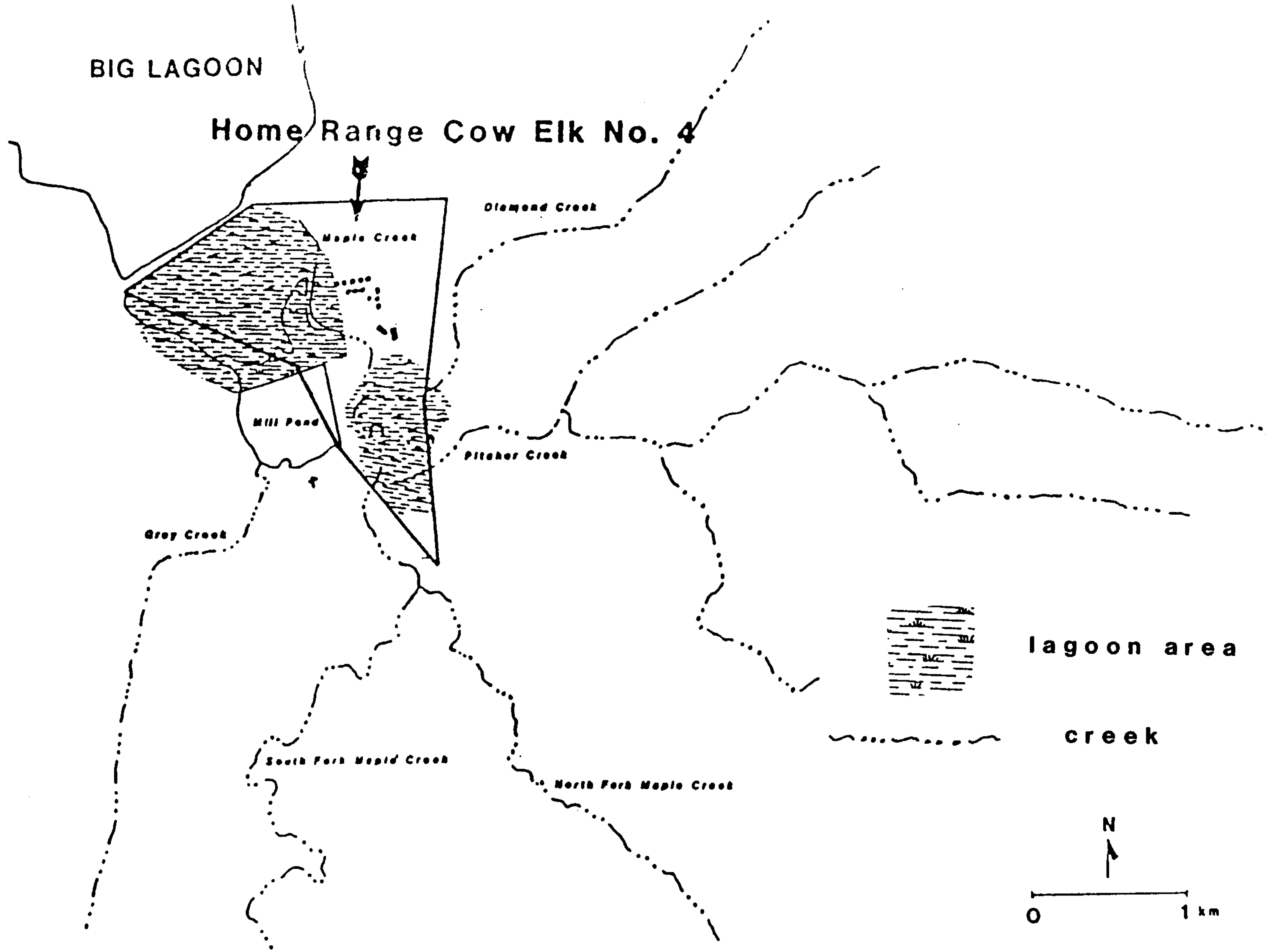

Figure 8. Location of Home Range for Radio-Collared Cow Elk Number 4, Big Lagoon Study Area, Humboldt County, CA.

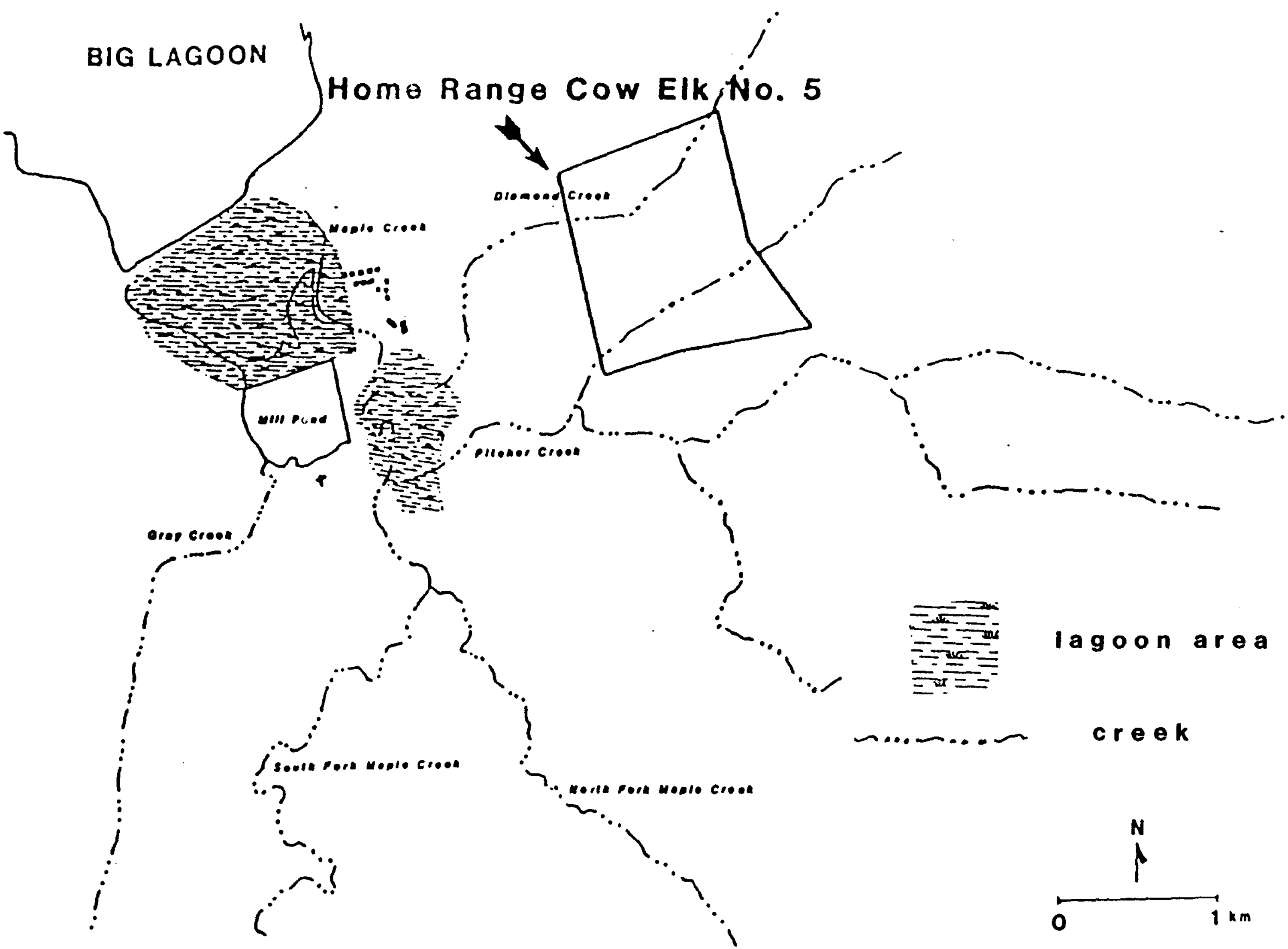

Figure 9. Location of Home Range for Radio-Collared Cow Elk Number 5, Big Lagoon Study Area, Humboldt County, CA.

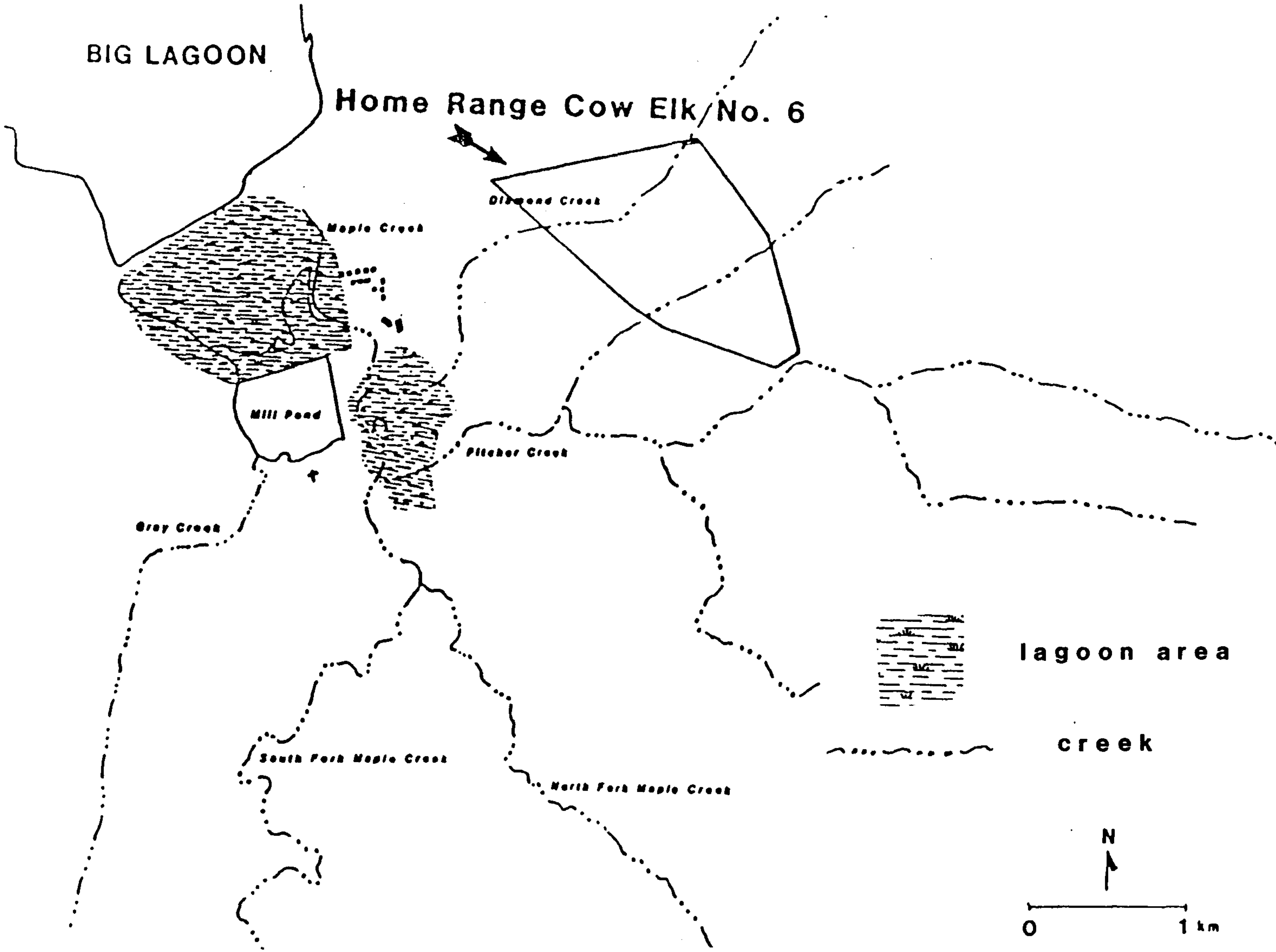

Figure 10. Location of Home Range for Radio-Collared Cow Elk Number 6, Big Lagoon Study Area, Humboldt County, CA.

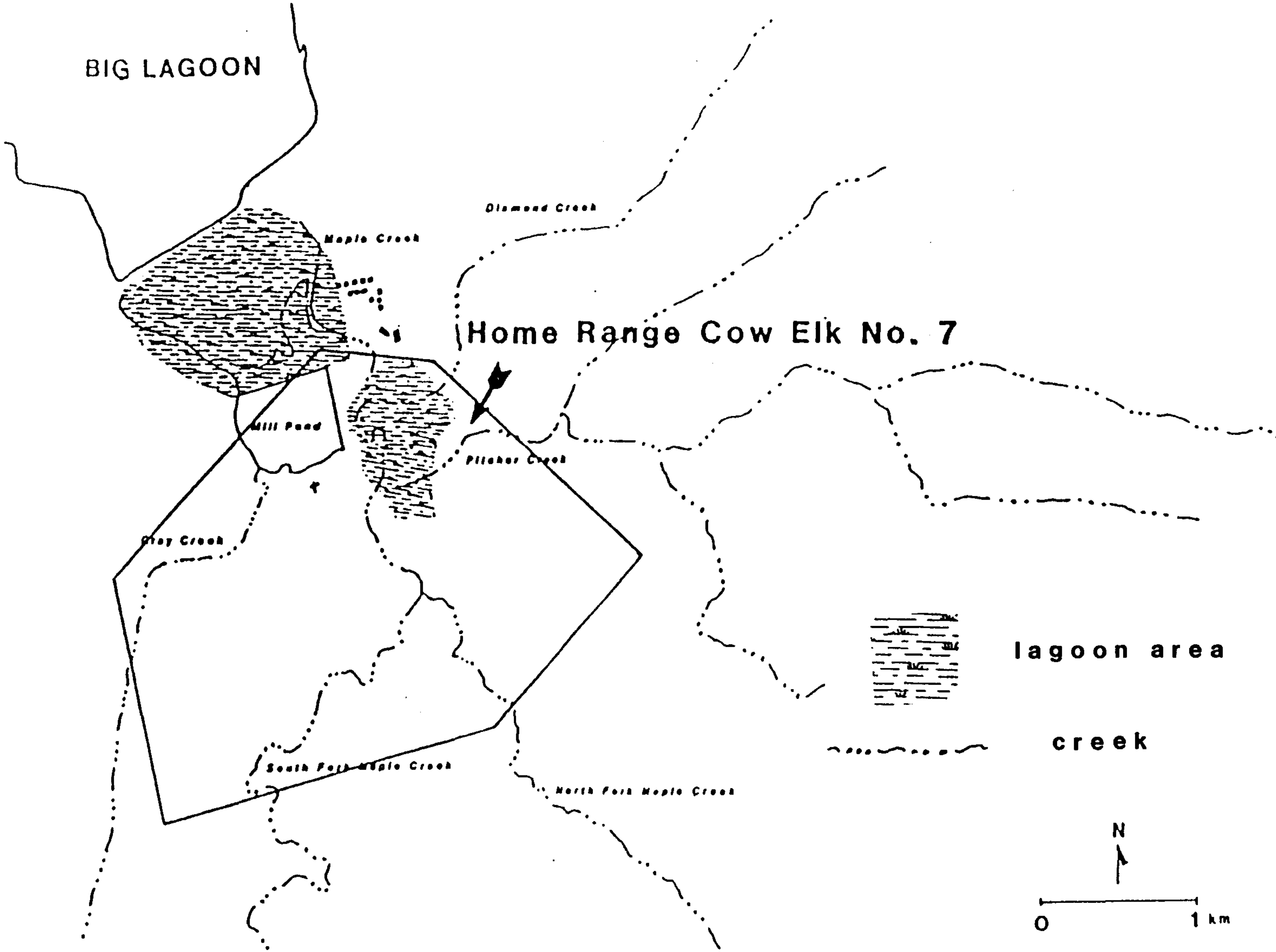

Figure 11. Location of Home Range for Radio-Collared Cow Elk Number 7, Big Lagoon Study Area, Humboldt County, CA.