Alaska Department of Fish and Game
Division of Game
Federal Aid in Wildlife Restoration
Research Progress Report

DEVELOPMENT OF POPULATION ASSESSMENT TECHNIQUES FOR LYNX

by
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Job 7.14
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SUMMARY

Because of poor weather conditions this winter, only one lynx (Lynx canadensis) density estimate was conducted during this report period. Twelve 2-mi transects were sampled systematically, and the number of different lynx tracks in each one were counted. This information provided the basis for a density estimate: 5.07 lynx/100 km^2 (an 80% confidence interval of 3.71-7.81 lynx/100 km^2). Aerial transects were conducted on eight of the 12 ground transects with comparable results. Simulation modeling indicated that the best sampling design for the density estimate would be achieved with 4 systematic samples, each one containing 3 transects. Five additional lynx were captured and radio-collared for studies next year. Recommendations for improvement of the study design are included.

Key Words: census techniques, density estimate, lynx, Lynx canadensis

CONTENTS

BACKGROUND

Lynx (*Lynx canadensis*) population dynamics and subsequent management decisions throughout Alaska are affected by population cycling, exploitation rates, and other factors. Research in the past decade has shown that lynx cycles follow that of the snowshoe hare (*Lepus americanus*), which is their primary prey. Brand et al. (1976), Brand (1979), and Parker et al. (1983) have shown that trapping can play a significant role in the dynamics of a lynx population. After reviewing the demographic characteristics of the lynx population on the Kenai National Wildlife Refuge (KNWR), Bailey et al. (1984) suggested that lynx numbers were lower than the amount these habitats could support; they based this conclusion on measured densities of snowshoe hare as well as information available in the literature. Bailey et al. (1984) implied that trapping and other causes of mortality during periods of low densities in the hare population were, in turn, the major causes for low densities in the lynx population.

The Alaska Department of Fish and Game (ADF&G) closed lynx trapping in Subunit 15A in 1984 and reduced the season from 126 to 47 days in the remainder of Units 15 and 7; ADF&G also is responsible for monitoring resident fur-bearer populations and recommending trapping seasons and bag limits to the Board of Game. To properly manage the lynx population on the Kenai Peninsula and elsewhere in Alaska, the trapping season should be shortened or closed during periods when the lynx population is low and reopened when lynx and hare numbers have increased and lynx kittens have been recruited into the population for at least 2 years. To accomplish this objective, changes in lynx densities must be monitored.

The exploitation rate of a healthy lynx population could range up to 30% annually and, theoretically, could continue for at least 2 years after the population has peaked; this would allow for the harvest of surplus lynx produced during peaks in the hare population. Following this harvest, Brand (1979) recommended that further harvests be severely restricted or eliminated to conserve the remaining adults within the population and to allow for an adequate increase when the hare population rebuilds.

In order to manage lynx in accordance with this strategy, we need to know 2 important parameters for determining the stage of the population cycle and the applicable rate of harvest: (1) an accurate estimate of lynx density and (2) an assessment of kitten production and survival. Additionally, information on the abundance and population trend of hares would allow us to determine the stage (highs or lows) of the hare cycle and assist us in making management decisions concerning harvest levels for lynx (Brand 1979). If we can establish an accurate estimate of lynx density within a specific study area, we should be able to apply the technique to larger areas. This technique will also allow us to get an early winter estimate of kitten production, since track surveys will provide information on family groups within the study areas.

The KNWR is currently conducting lynx research in 2 study areas: (1) in the lowlands near the ADF&G Moose Research Center (MRC) and (2) in the mountains between Skilak and Tustumena Lake (Tustumena Bench). Their objectives specifically address lynx ecology but provide for the opportunity to concurrently test a census technique. Their study objectives mandate that attempts be made to radio-collar every adult lynx within the study areas. In the fall of 1986 there were 5 and 4 adult lynx collared in the MRC and Tustumena Bench areas, respectively.

During the winter of 1984, ADF&G biologists, KNWR staff, and local trappers attempted to estimate the lynx population density north of the Sterling Highway (Mystery Hill area). A probability sampling design (Horvitz and Thompson 1952) involving the observation of lynx tracks crossing a transect was used to obtain a population estimate. This estimation procedure is similar to King's grouse estimator (Hayne 1949); however, the flushing radius is replaced with the perpendicular distance that the lynx moved to the transect. In order to calculate the probability of observing a lynx crossing the transect 24 hrs after a snow fall, lynx tracks that were encountered on the transect were backtracked to the bed the lynx occupied during the snowstorm. Backtracking determined the distance the lynx had moved on the x-axis (the axis perpendicular to the transect) between the bed and the transect. Based on a Taylor-series approximation, this distance could be used to estimate the probability of encountering that lynx during the survey (Becker, unpubl. data). Unfortunately, the procedure to estimate the probability of encountering a particular lynx can result in unstable estimates, since transects intersecting lynx tracks close to their bed will produce unrealistically large population estimates. During the 1984 sample, this estimator became unstable when 1 lynx traveled only a short distance (<100 m) resulting in the overestimation of the lynx population. Subsequent reassessment of this survey using radio-telemetry information generated during 1985 by personnel of the KNWR has provided a lynx density estimate of 10.83 lynx/60mi^2 (18.05/100 mi^2), a value that refuge and ADF&G biologists find reasonable. This method assumes that there is a radio-collared subset of the population that is representative of that population; e.g., if distance moved by lynx are a function of the animals' age and/or sex, then the radio-collaring of lynx should be proportional to the sex and/or age composition of the population of interest. This project fits the needs of managers because it may provide a useful tool for estimating lynx numbers within a specific area, thus providing a data base for management recommendations.

OBJECTIVES

Job 1.

To estimate lynx population density within 2 study areas on the Kenai Peninsula using line transect surveys.

Job 2.

To test the feasibility of aerial surveys to estimate lynx density based on track counts.

Job 3.

To test a lynx population density estimator using simulation modeling.

Job 4.

To prepare a final report.

METHODS

Job 1. Density Estimates

In the fall of 1986, 5 and 2 radio-collared lynx were within the MRC and Tustumena Bench study areas, respectively.

Systematic density estimates were made using a probability sampling design (Horvitz and Thompson 1952). Details of the mathematical model, statistical calculations, and sampling procedure have been prepared for publication and are listed in Appendix A. The design called for surveys to be conducted for 24-96 hrs after a fresh snowfall so that old lynx tracks would be eliminated. The surveys were repeated 4 times within the MRC study area to determine variability with time. Existing roads, trails, and lakes provided access to the study area. Two surveys were conducted in the Tustumena Bench study area using helicopter support.

Since the key to developing a population density estimator relies on establishing a relationship of a known number of lynx to a defined area, we will base our estimate of lynx density within the 2 study areas on information from the radio-collared lynx. Since the distance traveled by each collared lynx is critical to the estimator, aerial surveys will be conducted continuously over a 24- to 96-hr period after snowfall. Flights will rely on weather conditions and range from 1 to 4 times/day. These flights will enable us to determine the distance traveled by each collared lynx and to pinpoint their locations prior to the ground survey. Lynx tracks identified during the ground survey will then be classified as follows: (1) a known marked animal, based on location, or (2) an unmarked animal. Radio-tracking surveys will provide us with the information needed to determine the number of marked individuals within the area; this, as well as the number of observed unmarked individuals (tracks), will provide a minimum estimate to compare with the line transect estimator.

Job 2. Aerial Surveys

Because of the expense and limited usefulness of applying the density estimator technique to remote areas, we propose to conduct simultaneous aerial surveys using a Piper Supercub. We want to determine if a relationship exists between between ground and aerial surveys. If a statistical relationship (correlation/regression) can be established, aerial lynx surveys may become an important management tool for indexing densities. Because aerial tracking is difficult, particularly identification of lynx tracks, we intend to use one pilot (Chuck Rogers, Fish and Wildlife Protection) and one observer (Ted Spraker, ADF&G) for all aerial surveys. Since both individuals are highly skilled aerial observers, this hopefully will eliminate the potential for observer bias.

Job 3. Simulation Modeling

Computer simulations will be used to check the reliability and precision of the estimator. A random-number generator will be used to establish transect lines within a theoretical study area. Lynx movements will be determined from existing data available from the USFWS. Repeated simulations (1000 or more) will be run to determine the ability of the estimator to correctly provide the number of lynx within the area. Repeated runs will allow us to determine the optimal sampling strategy and the distribution of the estimator so that confidence intervals can be calculated.

RESULTS AND DISCUSSION

Job 1. Density estimates

Success of the density estimate was tied to snowfall and reliable weather conditions after each storm. During the fall of 1986 and winter of 1987, weather conditions were very unsuitable for applying the technique. Many snowstorms were followed by high winds and freezing rain that prevented radio-tracking of collared lynx; moreover, warming conditions often melted snow soon after the storms passed. We attempted to conduct several surveys from November through April, but were successful in completing only one.

A snowstorm hit the Kenai Peninsula on 4 January 1987; on 10 January it stopped snowing, and the radio-tracking aerial surveys of marked lynx occurred from 11 to 13 January, the day of the census. On 13 January, personnel from the USFWS and ADF&G assembled at the KNWR Headquarters for a briefing on the census technique and to receive maps of their transect. Each person then went to the starting point of their transect and walked the designated 2 mi. Access to the 12 transects was provided as follows: four by automobile, one by snowmachine, and the remaining seven by ski plane. Observers walked their transects and counted each set of lynx tracks encountered. If more than one set of tracks was observed, the recorder determined if the tracks were from the same lynx or from a different one. If this determination was not feasible at that time, additional tracking was conducted the following day. Observers also recorded tracks of other carnivores and snowshoe hares. A total of 18 lynx tracks were counted; 12 sets of tracks were from different lynx (Table 1). Six transects had tracks of a single cat, 1 transect had two different cats, and 1 transect had a family group of four individuals. In addition, 2 transects (C3 and D2) had 2 sets of tracks that were made by a single cat. In all cases where there were multiple tracks, additional backtracking was required; this was done the following day. One ground observer missed a set of tracks on a transect (D3) that had been made in an old set of moose tracks on a lake; this was determined and confirmed by the aerial observer. The ground transect crossed the area where the cat had walked in the moose tracks, and it was almost impossible to detect the foot print of this lynx. The aerial observer was able to determine that this lynx had crossed the transect because he detected the tracks some distance from the lake and followed them to the place where the cat began to walk in the moose tracks. One of the assumptions of this technique is that all tracks are counted. This instance indicated that even close ground inspection can lead to an underestimation of the total number of tracks.

In addition to counting lynx tracks, observers counted the tracks of coyote, wolf, and snowshoe hare; however, four of the 12 observers failed to tally hare tracks. This was due, in part, to the fact that the data form (Fig. 1) issued during the briefing did not contain a specific space for hare tracks. This form will be modified next year to include them.

In addition to completing the 12 transects (Fig. 2), it was necessary to determine the movements of the radio-collared lynx during the survey period. Initially, there were 5 radio-collared lynx in the study area; by January, 2 of these marked animals had disappeared. A 3rd cat was illegally trapped during the survey, reducing our sample of marked animals to 2 individuals. We radio-tracked these 2 cats from 11 January until the end of the census (13 January). Movements prior to the 11th and between radio locations on 12 and 13 January were determined by ground tracking on 14 and 15 January. Details of the aerial locations and subsequent locations indicate that there was movement by the cats between locations, which if not confirmed by ground observation would have biased the estimator (Fig. 3). Both the female (No. 610) and male (No. 170) were located on the south shore of Clam Lake on 12 and 13 January, respectively, but tracking information indicated that their movements between these location points were well to the south of Clam Lake, increasing the distance traveled by almost 50% for the male and 30% for the female lynx. The x-axis distances moved by the 2 radio-collared lynx were determined to be 4.71 and 2.72 mi for the male and the female, respectively. The best estimate of the average distance moved on the x-axis by the marked population was 3.64 ± SE 0.93 mi. The x-axis distances moved by the population for the 4 systematic samples were at 55.0, 73.3, 55.0, and 36.7 mi for samples A through D, r-espectively. The best estimate of x-axis distance moved by the population was therefore 55.0 ± SE 7.48 mi. Our best estimate of $\underline{N}$ was therefore calculated to be 14.45 lynx for the 110-mi^2 study area, or 5.07 lynx/100 km^2. The 80% confidence interval was 3.71-7.81 lynx/100 km^2.

Based on the radio-telemetry survey, the estimate (i.e., 14.45 lynx/110 mi^2) was higher than expected. One radio-collared female (No. 500) whose radio was dead at time of survey was later trapped in the area (March) with 5 kittens. Other radio-collared lynx accounted for include 1 female without kittens (No. 610), 2 males (Nos. 170 and 551), and 1 female (No. 689) with 3 kittens. There were also 2 unmarked lynx whose tracks were encountered on transect C2 at Grebe Lake and transect C1 at Dollyvarden Lake. The female lynx (No. 689) and her 3 kittens and 1 male (No. 551) were not within the study area at the time of the survey. A total of 10 lynx were known or suspected to be in the study area during the census. An additional adult male was subsequently captured in the southeast part of the study area during trapping operations in March; he possibly entered the census area during the survey. We located lynx tracks at Mallard Lake (transect A3) and at Swan Lake (transect D3) that could not be accounted for; possibly male No. 170 had traveled into that area sometime between 10 and 11 January. His radio location was provided on 11 January, and we sent one ground tracker to that radio location to determine if he had moved into the area prior to the 11th, but no tracks were detected coming from the Swan Lake area. We suspect that this was an unknown, unmarked lynx. At the time of the census, we can therefore account for 10 to 11 lynx in the 110-mi^2 study area. Our 80% confidence interval of 10.58-22.26 lynx, which was determined from the census, overlaps the 10-11 lynx we accounted for; however, the confidence interval appears to err on the high end.

Overestimation can result because (1) our best assessment of the movements of marked lynx underestimated the movements of the population or (2) the number of individual lynx tracks encountered on the transects was greater than what would be normally observed. We spent 2 days confirming the distance moved by the marked individuals, so our best estimate of movement of the marked individuals is probably accurate. Our sample size of marked animals was very small ($\underline{n}$ = 2), and it probably did not reflect movements of the population. Additional marked animals will be required to accurately determine the average distance moved. We verified multiple crossings of each transect to be sure that we did not overestimate individual crossings, and we feel that this estimate was accurate.

Job 2. Aerial Survey

Ideal conditions for aerial surveys of tracks require sunlight and no wind. Conditions on the day of the survey were not ideal. There was an overcast sky, poor light, and 10- to 15-knot winds. Even with the poor conditions, the survey crew completed 8 transects. They observed lynx tracks on 5 of the 8 transects (A1, A3, C3, D2, D3) and no tracks on 3 transects (A2, C2, D1) (Table 1). Ground observers detected the same lynx tracks on A3, C3, D2 but also observed tracks on transect A2 that were missed by the air-survey team. Likewise, the air team sighted a set of tracks on transect A1 that the ground observer did not encounter. These tracks probably did not cross the ground transect. The air team surveyed a zone, rather than the lines that the ground observers walked. The air team also observed a set of tracks on transect D3 that the ground observer missed. Ground observers crossed tracks on transects A2 and C2 that the air crew missed. The air crew was correct on transect C3, which was where no tracks were encountered by the ground observer. If we exclude transect A1 (where the tracks observed by the air crew were probably not on the ground transect), then the air crew was correct 5 out of 7 times; the ground crew was correct 6 of the 7 times. Although there were discrepancies between lynx tracks either observed or missed between the ground observer and the air crew, the possibility of using aerial surveys is promising. Conditions during the aerial survey were poor. Under ideal conditions, it is likely that the air crew could approximate the number of tracks on each transect. Since the air crew detected a set of tracks that the ground observer missed, it is also recommended that aerial overflights continue to aid ground observers in both detecting lynx tracks and, when multiple crossings are encountered, determining if the tracks represent the same or different individuals.

Prior to the start of the 1986-87 field season, there were 2 radio-collared lynx in unit 15B (i.e., Tustumena Bench study area). By early winter one lynx had left the area, leaving an insufficient number of individuals to initiate a census. During the month of February, we paid 2 trappers to capture study animals in this area. The trappers were able to successfully capture 5 lynx: 2 kittens (male and female) and 3 adults (2 males and 1 female). One kitten died later in the winter because of injuries sustained from trapping, but the remaining four are still in the area. We hope to use these lynx as part of our marked population next year.

Job 3. Simulation Modeling

Budgetary and manpower constraints restricted the sampling effort to 12 transects. In order to obtain as precise a population estimate as possible, various sample designs were simulated on a hypothetical lynx population using a fortran program (i.e., Snowrap.for). For each sample design, the program computed a population estimate and variance as well as a variance estimate on the distance moved by the population using the formulas given in the Appendix. The systematic samples-transect combinations were constrained because the number of transects did not exceed 12. The hypothetical lynx population was based on the best available estimate of the number of lynx in the study area and their hypothetical movement patterns during the 48 hrs following a midwinter snowstorm.

Using the program on a hypothetical population of 7 lynx (Figure 4) inhabiting the study area, the sample design resulting in the smallest 80% confidence interval for the estimated distance (perpendicular to the x-axis) moved by the population would be one containing 4 systematic samples with 3 transects per systematic sample (Table 2). For future surveys, we recommend that the simulation program be run on a hypothetical lynx population that represents our best estimate of the number of lynx and their movement patterns over a given time period following a snow storm.

RECOMMENDATIONS

We recommend that the study be continued for at least one more year. Because of weather conditions, we only completed one census during this report period. The USFWS has placed additional radio-collared lynx in the MRC study area, and there are currently 8 lynx with functioning transmitters. This is a substantial gain over the 2 marked individuals we had this past year. Likewise, there are 5 radio-collared lynx in the Tustumena Bench area, so we also have an adequate sample of marked lynx to conduct a census. We recommend that the aerial surveys be continued to aid ground observers in locating lynx and sorting out multiple tracks crossing a single transect. We further recommend that additional studies be initiated to determine when kitten production and recruitment occurs. Last year, there was one family group in the study area during the census. Another family group that was located on the northern end of the study area was not in the study area during the census. It is likely that routine line transects will detect family groups.

ACKNOWLEDGEMENTS

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Table 1. Number of tracks encountered during 4 systametic samples with with 3 transects per sample (n = 12) during a lynx density estimate on 13 January, 1987, at the Moose Research Center study area, Kenai Peninsula, Alaska.

Systematic sample (transect)	Lynx tracks encountered		Total tracks			Lynx tracks encountered on aerial survey	
	Total	Individuals	Wolf	Coyote	Hare	Total	Individual
A(1)	0	0	0	0	70	11	1
A(2)	1	1	0	0		0	0
A(3)	2	2	0	3	--	2	2
B(1)	0	0	6	10	76	Not surveyed	
B(2)	8	4	0	7	58	Not surveyed	
B(3)	0	0	0	1		Not surveyed	
C(1)	1	1	0	2	113	Not surveyed	
C(2)	1	1	0	0	9	0	0
C(3)	2	1	0	10	73	2	1
D(1)	0	0	0	3		0	0
D(2)	2	1	0	7	34	?	0
D(3)	1[a]	1[b]	0	7		1	1
Total	18	12	6	50	433		

[a] Tracks may not have crossed ground transect.
[b] Track was missed by the ground observor but detected by aerial survey team.

Table 2. Simulation results[a] of a comparison of different sample designs with the size of the confidence interval on an estimate of the total distance moved by the population ($\hat{T}x$), perpendicular to the X-axis.

No. systematic samples	No. transects per cluster	df	$SE(\hat{T}x)$[b]	One-half the width of an 80% CI[b]
12	1	11	247.46	337.29
6	2	5	247.87	365.86
4	3	3	189.69	310.71
3	4	2	180.71	340.82
2	6	1	120.89	372.10

[a] based on 2500 trials/design
[b] distance in miles

KENAI LYNX SURVEY

TRANSECT____________________ DATE_____________________

OBSERVER____________________ START TIME_______ END TIME_____

YOU ARE REQUESTED TO TABULATE THE TOTAL NUMBER OF LYNX TRACKS YOU ENCOUNTER ON THE TRANSECT, WHICH REPRESENTS EACH SET OF TRACKS THAT CROSSES YOUR TRANSECT LINE. THIS REPRESENTS TOTAL TRACKS ENCOUNTERED. YOU ALSO MUST DETERMINE THE NUMBER OF DIFFERENT INDIVIDUALS THAT WERE ENCOUNTERED ON THE TRANSECT. THIS NUMBER REPRESENTS THE INDIVIDUAL NUMBER OF LYNX ENCOUNTERED.

TOTAL LYNX TRACKS ENCOUNTERED ________

DIFFERENT LYNX TRACKS ENCOUNTERED _______

WE ALSO NEED TO KNOW IF YOU ENCOUNTERED A FAMILY GROUP, AND HOW MANY INDIVIDUALS WERE IN THIS GROUP.

IF YOU OBSERVED MORE THAN ONE SET OF DIFFERENT LYNX TRACKS, WAS IT A FAMILY GROUP OR DIFFERENT SINGLE ANIMALS?

FAMILY GROUP______, TOTAL NUMBER IN GROUP ______

DIFFERENT INDIVIDUALS ______

WE ALSO WANT TO TABULATE THE NUMBER OF TRACKS FROM OTHER SPECIES THAT YOU ENCOUNTER ON THE TRANSECT.

WOLF ___________ TOTAL TRACKS ________ DIFFERENT TRACKS ________

COYOTE _________ TOTAL TRACKS ________ DIFFERENT TRACKS ________

OTHER _________ TOTAL TRACKS _________ DIFFERENT TRACKS ________

Figure 1. Field data form used during 1987 lynx census on the Kenai Peninsula.

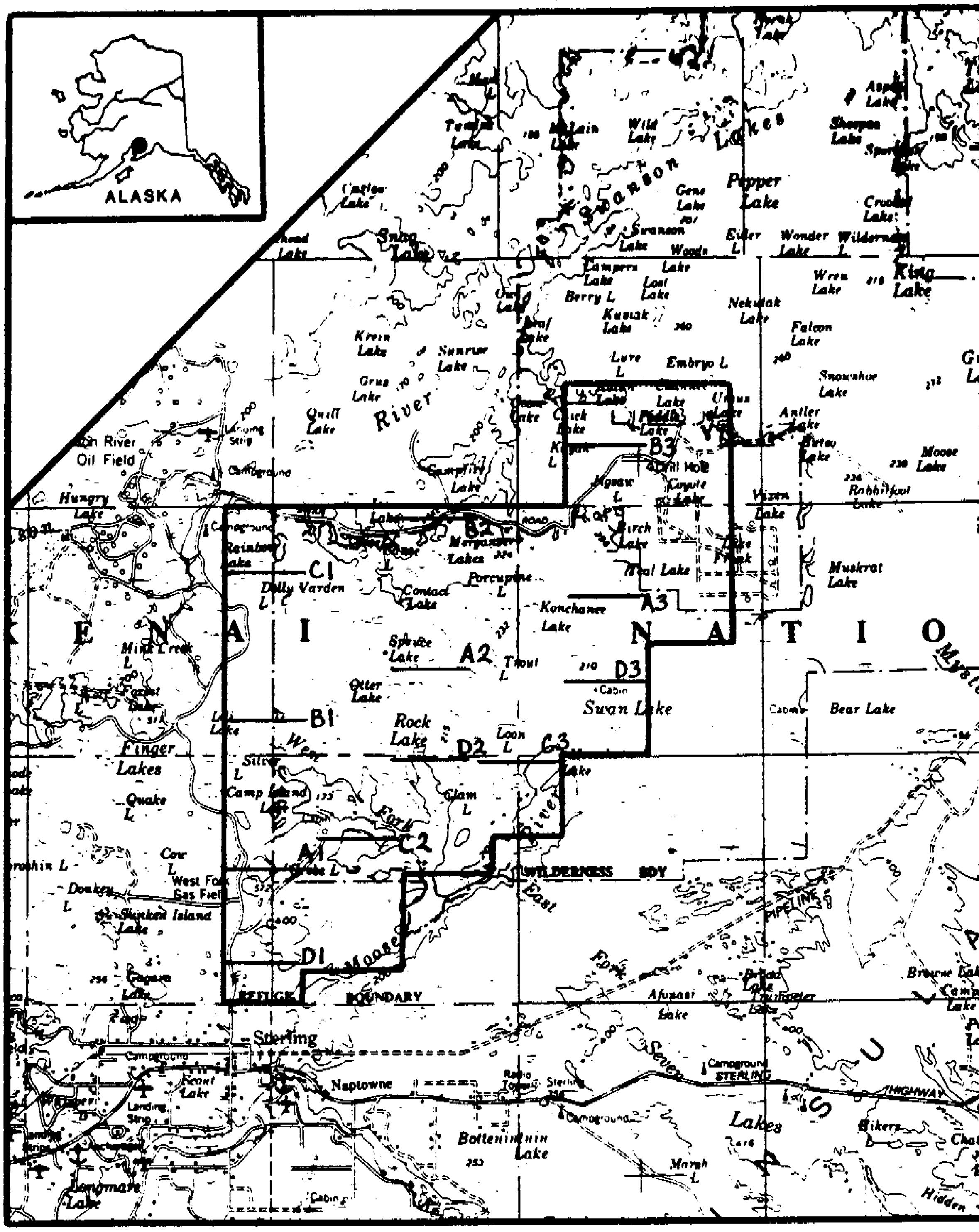

Figure 2. Moose Research Center study area located in the northcentral portion of the Kenai Peninsula lowlands. Study area boundaries and location of the 4 systematic samples (A-D) with the 3 transects per sample (1-3) are shown.

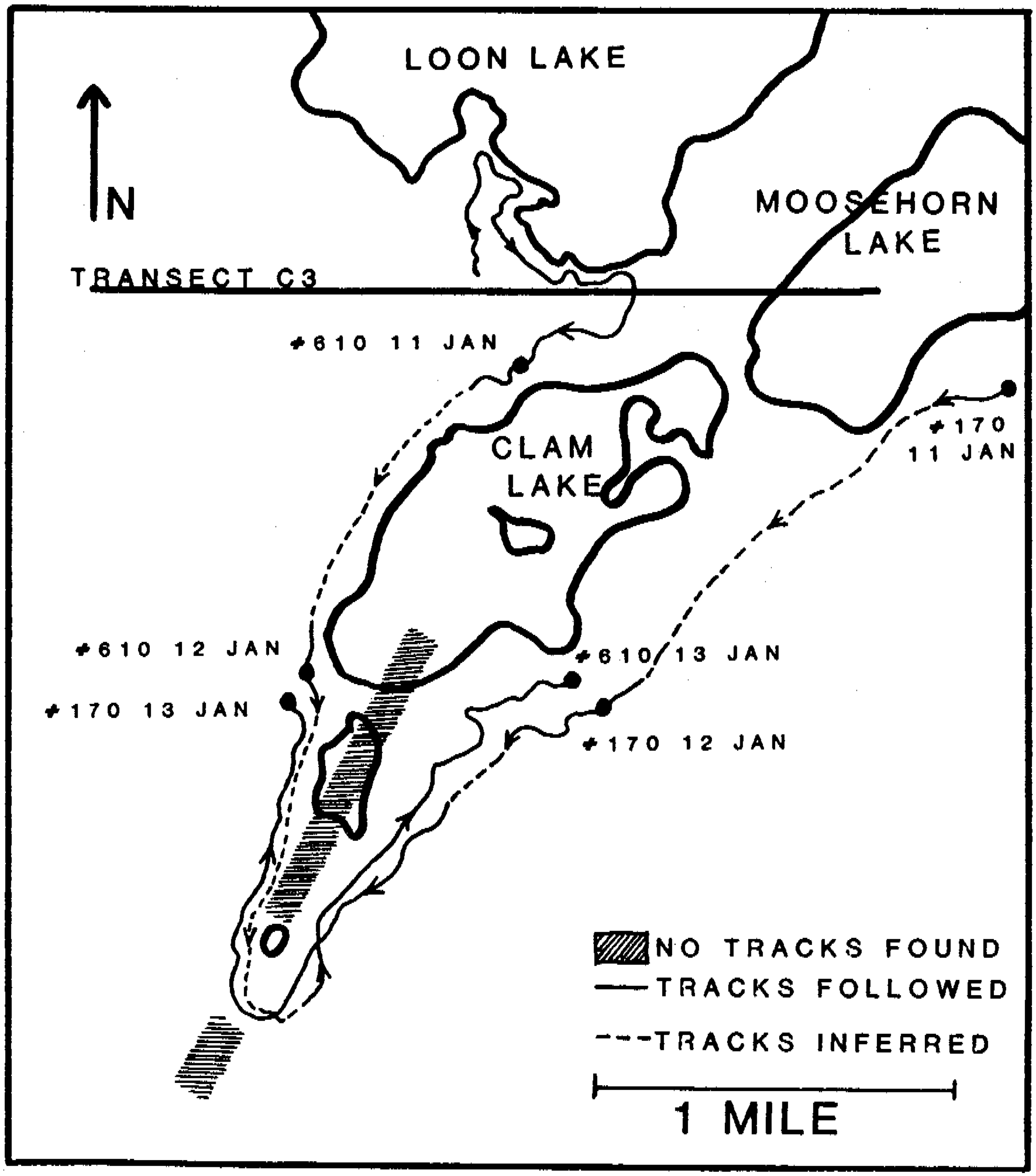

Figure 3. Details of radio-locations and movements for 2 radio-collared lynx from 11 to 13 January, 1987. For reference to the location, see Fig. 2 and note where transect C3 crosses between Loon and Clam Lakes.

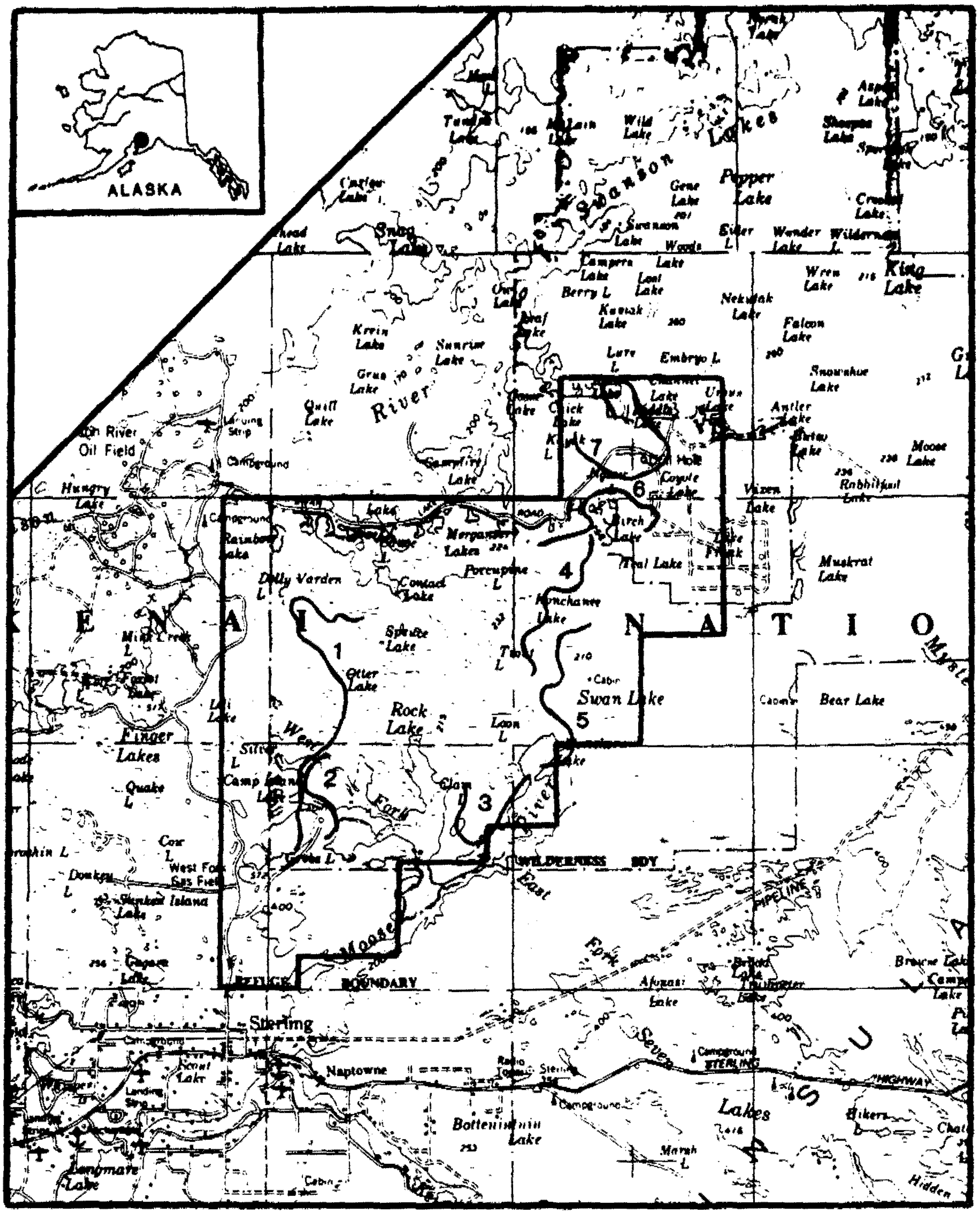

Figure 4. Details of the movement patterns of the hypothetical lynx population used to simulate various sample designs.

Appendix

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A Terrestrial Furbearer Estimator Based on Probability Sampling

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SUMMARY

A new method of estimating furbearer abundance based upon probability sampling results is proposed. This method requires that good snow conditions be present during the course of the study and that all animal tracks encountered during the sampling process are observed. Two general sampling designs are presented, the first assumes that animal tracks can be observed and backtracked from aerial observation, while the second assumes that the number of different animals encountered along a set of transects can be determined and that it is possible to get movement data from a random sample of animals which are radio collared.

1. Introduction

Terrestrial furbearers, such as lynx (*Lynx canadensis*), bobcat (*Lynx rufus*), wolf (*Canis lupes*), wolverine (*Gulo gulo*), coyote (*Canis latrans*), mountain lion (*Felis concolor*), fisher (*Martes pennanti*), and marten (*Martes americana*) occur at low densities, are secretive and often nocturnal. Increases in trapping pressure and loss of habitat has resulted in increased demands to monitor furbearer population levels more precisely as furbearer management becomes more intensive.

Previous methods used to monitor furbearer population levels include mark and recapture experiments (Smith et al. 1984), total trapper harvest reports (Keith 1963), trap night indexes (Wood and Odum 1964), track counts (Linhart and Knowlton 1975, Roughton and Sweeny 1982, Van Dyke et al. 1986), mail surveys (Lemke and Thompson 1960), and howling responses (Harrington and Mech 1982). In the past, these methods have proven difficult to implement or have given unsatisfactory results. Due to small population sizes and low capture probabilities, mark and recapture experiments are not appropriate (White et al. 1982). Trapper harvest tends to be confounded with socio-economic conditions

(Gilpin 1973, Weinstein 1977, Winterhalder 1980). Track count indexes can be confounded by changes in movement patterns (Ward and Krebs 1985). Mail surveys provide, at best, an index to animal abundance and are difficult to interpret. Howling responses provide an index of the number of wolf packs, is biased towards large packs, affected by topography and weather, and can not be accurately used to estimate total wolf abundance (Harrington and Mech 1982).

The purpose of this paper is to present a method of obtaining population estimates based on the probability of observing animal tracks in the snow. Two different applications will be presented, one assumes that animal tracks can be readily seen from a slow, low flying airplane, while the second assumes that a random sample of the population can be fitted with radio collars and that observers can walk randomly selected transects in the study area and observe all animal tracks which cross the transect.

2. Proposed Technique

2.1 Introduction

Several papers (Hayashi, 1978, 1980, Hayashi et al. 1979) have examined ways to use tracks in fresh snow to estimate hare (Lepus brachyurus angustidens) population size in northern Japan. For the most part these methods are suited for smaller study areas than practical here in Alaska.

The idea of using the probability of observing animal tracks to obtain a population estimate is similar to the King grouse estimator (Hayne 1949). The flushing radius is replaced by the projected distance moved by the animal, perpendicular to the orientation of the transect.

2.2 General Sample Design Requirements

Using the probability of observing animal tracks in the snow to generate a population estimate requires the following :

(i) good snow conditions are present;
(ii) all animals move during the course of the study;
(iii) all animal tracks, of the species of interest, are easily recognizable;
(iv) all animal tracks are continuous;
(v) animal movements are independent of the sampling process;
(vi) the animal of interest beds down during a snowstorm;
(vii) all animal tracks which cross sampled transects are observed;
(viii) the study area is rectangular in shape;
(ix) all the transects are oriented perpendicular to a 'X-axis'

Good snow conditions are defined to be fresh snow of sufficient depth that allows the ready distinction between pre-snowfall and post-snowfall animal tracks. In addition, wind conditions during and after the snow storm should be moderate enough that fresh tracks are not blown away. The condition that animal tracks be continuous can be relaxed if a 1-1 correspondence exists between the tracks and the population of interest. If possible, the X-axis should be oriented parallel to animal movement patterns, if they are known. For purposes of this paper, it is assumed that the transects to be sampled are selected using a replicated systematic sample design.

3. Technique for Aerial Observation of Animal Tracks

3.1 Sample Design.

Use of a slow, low flying airplane to sample transects requires the following :

(i) animal tracks, for the species of interest, are readily identifiable from the air;
(ii) the animal tracks can be backtracked to both the animal's present location and the 'bed' from which the animal waited out the snowstorm;
(iii) the distance the animal travels parallel to the X-axis can be determined by backtracking.

The beginning location of the track is usually a bed, but if one doesn't exist, then the point at which the animal track would be classified as 'old' could be used in place of the bed location.

The following notation will be used :

- U - collection of animals of interest (Universe);
- S_i - the i th systematic sample;
- Y - a random variable of the population of interest, $Y: U \rightarrow y$;
- T_Y - population total;
- p_u - probability that the u th animal is contained in the sample;
- x_u - distance, parallel to the X-axis, traveled by the u th animal;
- D - the length of the X-axis.

Repeated systematic sampling of the transects should be close to the optimal sampling design. Since spreading the transects out over the study area should maximize the information gain, and it is reasonable to expect the variance within systematic samples (clusters) to be greater than the variance between clusters. Assuming a repeated systematic sample is used with equal length transects, and letting $y_u = 1$ for every element of the universe, then :

$$T_Y = \sum_{u \in U} y_u \ .$$

Now by the Horvitz-Thompson Theorem (1952) :

$$\hat{T}_{yi} = \sum_{u \in S_i} y_u/p_u = \sum_{u \in S_i} 1/p_u \text{ is unbiased for } T_y,$$

where i (i = 1,2,...r) indexes the systematic sample, j (j = 1,2,...q) indexes the number of transects per systematic sample, and

$$p_u = \begin{cases} x_u/(D/q) & \text{for } x_u \le (D/q) \\ 1 & \text{otherwise.} \end{cases}$$

Then $\hat{T}_y = \sum_{i=1}^{r} \hat{T}_{yi}/r$ is an unbiased estimate of T_y, and an estimate of the variance of $\hat{T}_y$ is :

$$V(\hat{T}_y) = [\sum_{i=1}^{r} (\hat{T}_{yi} - \hat{T}_y)^2]/[r(r-1)].$$

If the transects are of unequal length, then the estimation and variance formulae should be changed so that T_{yi} is weighted by the sum of the transect lengths used to obtain the estimate, the weighting should be done using ratio to size formulae (Cochran, 1977).

3.2 Simulation Results for Aerial Sampling Design

A simulation of this sampling design was used to estimate a population of 12 wolverines. The movement data (Figure 1) represented wolverine movements in the spring. The movement data reflect differences in movement patterns by sex, 48-72 hours following a snowstorm. The simulated study area was 5869.6 km^2 (64.75 x 90.65 km). All transects were 64.75 km in length, and the X-axis was 90.65 km in length. Based on the results of 1,000 trials, using 4 systematic samples each consisting of 3 transects, the mean population estimate was 11.98 with a standard error of 2.12 wolverine. From the 80% confidence intervals presented in Table 1, it would appear that an adjusted t-distribution with $2/3\alpha$ in the lower tail and $1/3\alpha$ in the upper tail would produce the best confidence intervals. The distribution of T_y is skewed to the right.

Table 1. Simulation results, based on 1,000 trials, for 80% confidence intervals for a population of 12 wolverine.

Distribution	Lower Limit	Upper Limit	% Low	% High	True Coverage
N(1/2α, 1/2α)	9.26	14.69	18.6	10.6	70.8%
T(1/2α, 1/2α)	8.51	15.45	14.9	7.0	78.1%
T(2/3α, 1/3α)	9.09	16.31	12.1	10.1	77.8%
T(3/4α, 1/4α)	9.33	16.96	8.7	11.7	79.6%

df = 3.

4.0 Technique for Ground Observations of Animal Tracks

4.1 Sample Design

In situations where it is unreasonable to assume that all animal tracks can be seen and accurately backtracked from the air, the general sampling design is modified to incorporate data from walking the transects. Due to the logistical difficulties with trying to backtrack animal tracks from the ground and the potential for the sampling process to influence animal movement patterns, just the number of different individuals encountered in each systematic sample will be recorded. This data will be used to obtain an estimate of the distance moved by the population, with regard to the X-axis. Radio telemetry data will be used to determine the average X-axis distance moved by a group of radio collared animals. The population estimate will be based upon the ratio of two estimates, the estimated distance moved by the population, with regard to the X-axis, over the estimated average X-axis distance moved by an individual. In order to estimate the distance moved by the population, with regard to the X-axis, the following assumptions on the ground transect data need to be met :

(i) systematic samples are constructed so that animal tracks intersecting 1 transect will not intersect other transects within the same systematic sample;

(ii) the number of different animals encountered in each systematic sample can be determined.

To estimate the average X-axis distance moved by an individual of the population, a random sample of animals will be fitted with radio collars and their locations plotted as often as possible for the period following the snowstorm to the completion of sampling the transects. On the following day, the tracks of the radio collared animals will be backtracked from the beds used to wait out the snowstorm to their last locations. These tracks are plotted on a map and this information is used to generate a measurement of the X-axis distance moved by each radio collared animal. If a random sample of animals is not possible, the group of animals selected to be collared should be representative of a simple random sample of animals, and reflect possible differences in movement patterns by sex and (or) age.

Additional notation that will be used is:

T_x - the total X-axis distance moved by the population;

n_i - the number of different animals encountered in the i^{th} systematic sample;

μ_x - is the average x-axis distance moved by an individual of the population.

Then by definition $T_x = \sum_{u \in U} x_u$.

Assuming systematic sampling, as before, then based on the above assumptions $\max\{x_u\} \le D/q$ and $p_{ui} = (x_u q/D)$. Based on the Horvitz-Thompson Theorem

$\hat{T}_{xi} = \sum_{u \in S_i} x_u/p_u = Dn_i/q$ is unbiased for T_x and

$\hat{T}_x = \sum_{i=1}^{r} \hat{T}_{xi}/r$ is an unbiased estimate of T_x with variance :

$$V(T_x) = \{\sum_{i=1}^{r}(\hat{T}_{xi} - \hat{T}_x)^2\}/\{r(r-1)\}.$$

If the transects are of unequal length, then the above formulae can be adjusted to weight the data proportional to transect length (Cochran 1977).

An estimate of μ_x is : $\hat{\mu}_x = \sum_{u \in S_R} x_u/n_R$, where S_R denotes the sample of radio collared animals and n_r is the number of animals in that sample. The variance can be estimated by :

$$V(\hat{\mu}_x) = \{\sum_{i=1}^{n_r}(x_u - \hat{\mu}_x)^2\}/\{n_r(n_r-1)\}.$$

Then

$\hat{T}_y = \hat{T}_x/\hat{\mu}_x$ is an estimate of T_y with approximate variance

$V(\hat{T}_y) \approx (\hat{T}_x/\hat{\mu}_x)^2 \; \{[V(\hat{T}_x))/((\hat{T}_x)^2)] + [V(\hat{\mu}_x)/((\hat{\mu}_x)^2)]\}$ based upon a second order Taylor-Series approximation. The bias of the point estimate is approximately:

$[\hat{T}_x/(\hat{\mu}_x)^3]\ V(\hat{\mu}_x)$, which is usually negligible since $[\hat{T}_x/(\hat{\mu}_x)^3] = [\hat{T}_y/(\hat{\mu}_x)^2]$ is usually much smaller than 1.

4.2 Simulation Results for Ground Sampling Design

This sampling technique was simulated on a population of 7 lynx, 3 with radio collars. A sampling design consisting of 4 systematic samples of 3 transects each is used. The hypothetical study area is 160 km (4 x 40 km) with the X-axis being 40 km in length. Based on the results of 33,000 trials, using all possible combinations of 3 radio collared animals except all male or female data sets, the average estimate of T_y was 7.01, with an average standard error of 2.97 and an average bias of 0.13 lynx. The hypothethetical movement data is shown in figure 2. Based on simulation results for 80% confidence intervals (Table 2), it would appear that an adjusted normal distribution with $2/3\alpha$ in the lower tail and $1/3\alpha$ in the upper tail would produce the best confidence interval. The distribution of T_y is skewed to the right.

Table 2. Simulation results, based on 33,000 trials, for 80% confidence intervals for a population of 7 lynx, 3 of which were radio collared.

Distribution	Lower Limit	Upper Limit	% Low	% High	True Coverage
$N(1/2\alpha,\ 1/2\alpha)$	3.27	10.83	15.6	5.4	79.0%
$N(2/3\alpha,\ 1/3\alpha)$	3.72	11.55	13.6	7.9	78.4%
$N(3/4\alpha,\ 1/4\alpha)$	4.00	12.00	10.1	12.4	77.5%
$T(1/2\alpha,\ 1/2\alpha)$	2.14	11.96	12.5	2.1	85.4%
$T(2/3\alpha,\ 1/3\alpha)$	2.97	13.19	9.6	4.7	85.7%
$T(3/4\alpha,\ 1/4\alpha)$	3.30	14.11	7.8	5.7	86.5%

df = 3, since $V(T_x) >> V(\mu_x)$.

6.0 Discussion

At the present time, the technique of generating furbearer estimates based on the probability of encountering the track along a transect appears promising. However, several problems must be addressed before this technique is considered fully developed. The present method of generating confidence intervals is unsatisfactory; hopefully bootstrap confidence intervals will solve this problem. Another area of concern is insuring that no animal tracks which intersect a transect are missed. This problem can be addressed through some replicate sampling to get an estimate of the observer error. It may be possible to model this error term into the estimation procedure along the lines suggested by Pollock and Kendall (1987).

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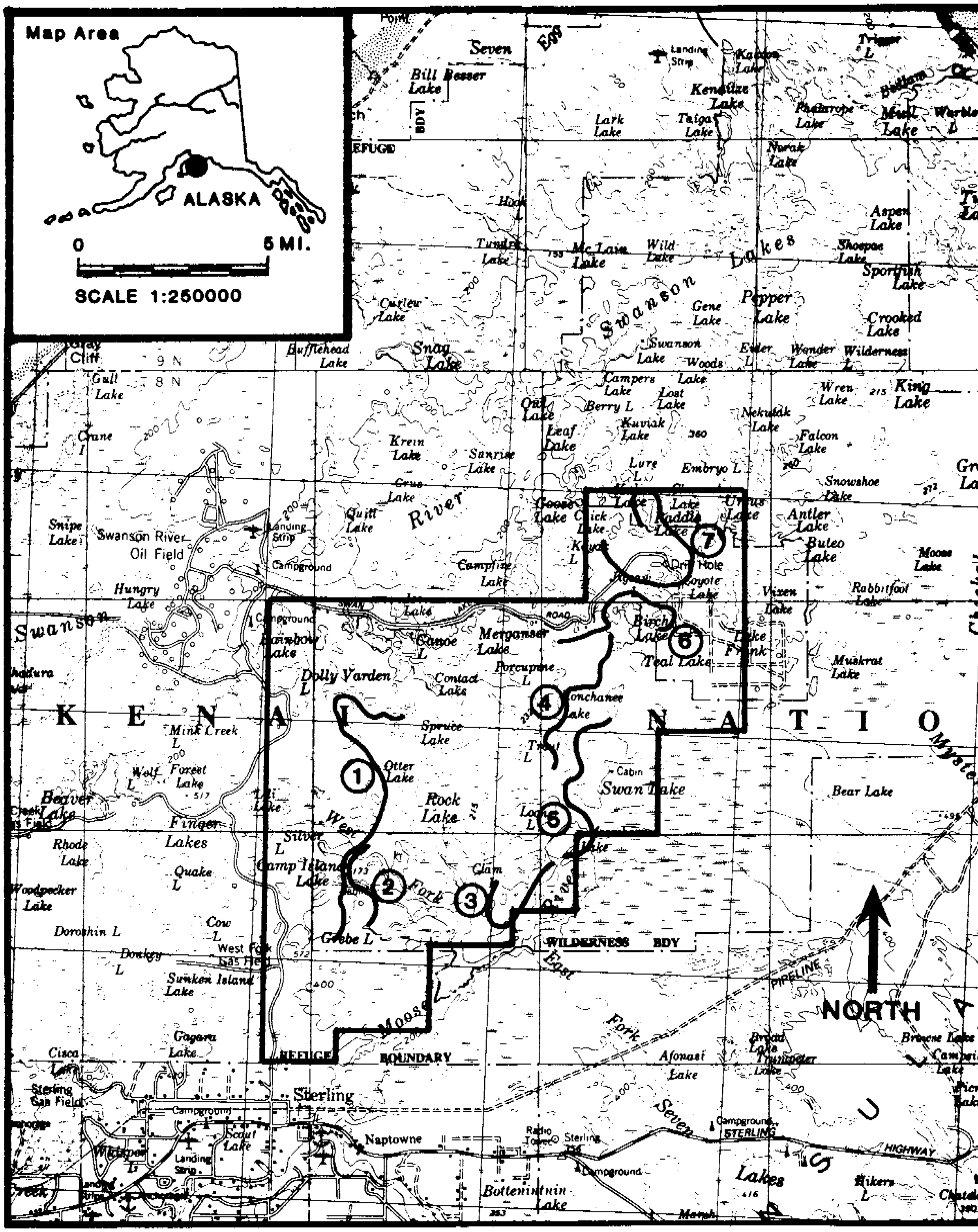

Figure 1. Hypothetical 48 hour movements of 7 lynx within a 285 sq. km. study area on the Kenai Penninsula.

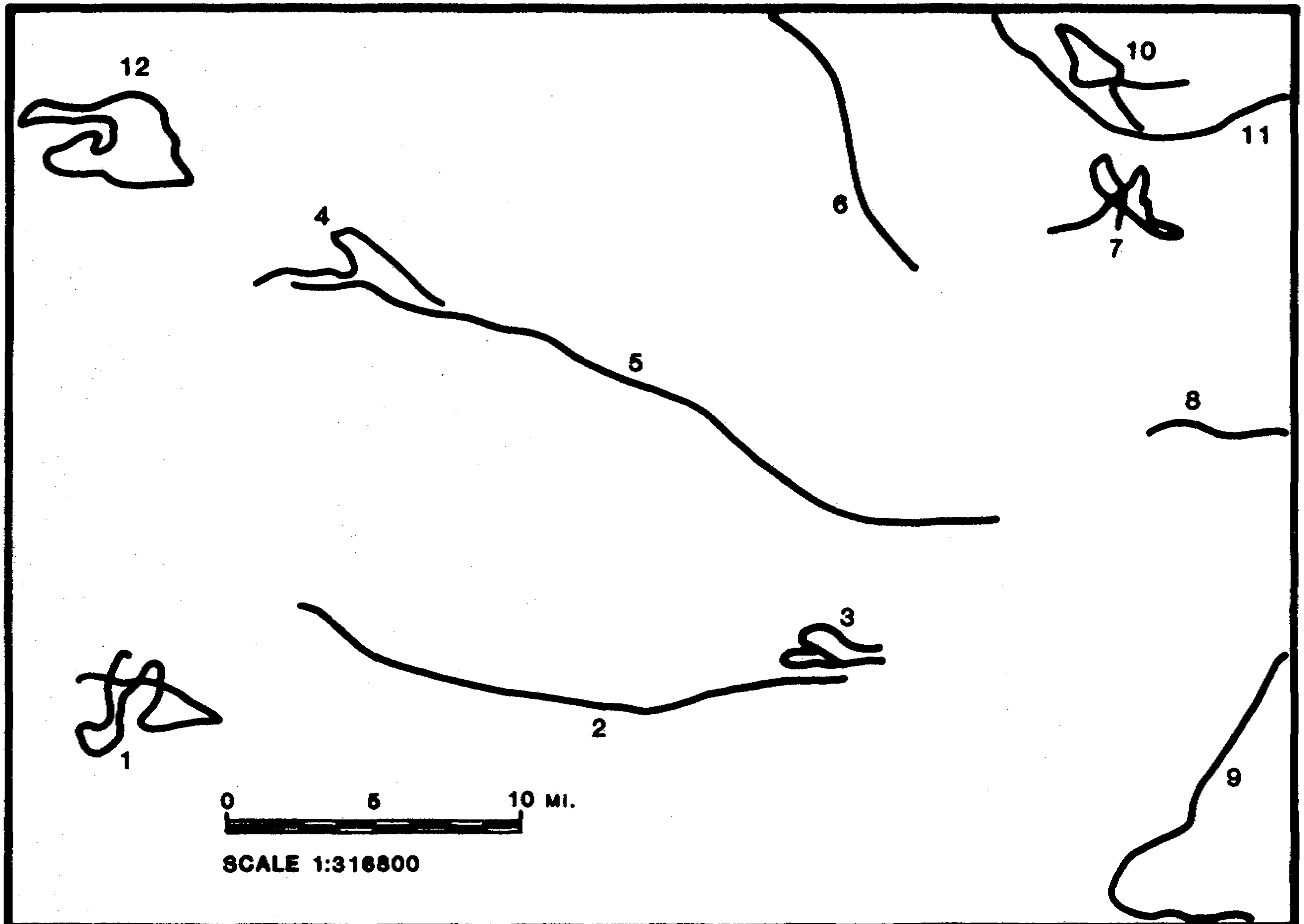

Figure 2. Hypothetical 48 hour movements of 12 wolverine within a 5870 sq. km. study area.

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