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BACKGROUND

The lynx (Lynx canadensis) is the only wild felid that occupies the boreal forests of Alaska and much of Canada. Lynx are recognized as a valuable wildlife species and an economically important furbearer. Lynx population dynamics are intimately linked with their major prey, the snowshoe hare (Lepus americanus), and its population cycles (Elton and Nicholson 1942). More recently, work by Brand et al. (1976), Brand (1979), and Parker et al. (1983) have clearly shown that trapping plays a significant role in the dynamics of a lynx population. Quinn and Parker (1987) summarized the findings of Brand and Keith (1979) and listed 3 important points of their research. First, lynx populations decline because of a complete failure of recruitment, and the harvest of a declining population will contain few, if any, young. Second, trapping mortality is additive, not compensatory, to natural mortality, and lynx populations are vulnerable to overharvesting during population declines. Third, lynx populations can be protected, and long-term harvests may actually be increased by suspending trapping during the 3- to 4-year decline in the population cycle.

Brand and Keith (1979) suggested that the exploitation rate of increasing lynx populations can range up to 30% annually and continue for at least 2 years after the population has peaked. Recruitment of kittens to winter populations decreases dramatically 2 years after the peak in lynx fur harvest, and it remains near zero during the next 3 to 4 years. Harvest should then be severely restricted or eliminated during the population decline to conserve remaining adults that will allow for adequate population increases when the hare cycle renews.

Demographic characteristics of the lynx population on the Kenai National Wildlife Refuge (KNWR) indicated that lynx numbers were lower than habitats could support (Bailey et al. 1986), based on measured snowshoe hare densities and information available in the literature. The Alaska Department of Fish and Game (ADF&G)

closed lynx trapping on part of the Kenai Peninsula in 1984 and the remainder in 1986. To properly manage lynx according to the recommendations of Brand and Keith (1979), ADF&G needed (1) an accurate estimate of lynx densities and (2) an assessment of kitten production and survival.

Quinn and Parker (1987) reviewed the methods of estimating lynx densities, concluding that "the complete count, or census, of lynx in regional populations is impossible." Becker (In press) reviewed several techniques for estimating furbearer abundance; he concluded that large terrestrial furbearers were difficult to count because of their secretive and often nocturnal nature.

Becker (In press) described 2 furbearer estimators. The first assumed that each furbearer intersecting a transect could be tracked at the end of a recent snowstorm to both its present location and its location prior to the storm. His estimator used probability sampling results (Horvitz and Thompson 1952, McDonald 1980, Kaiser 1983) to obtain a population estimate. The process was analogous to replacing flushing radius in King's grouse estimator (Hayne 1949) with projected distance moved by furbearers perpendicular to the transect. The second furbearer estimator assumed that it was possible to determine the number of individual furbearers that intersected the transect and that a random sample of furbearers was radio-collared. Probability sampling results were used to generate an estimate of distance traveled by individuals in the population; locations of radio-collared animals provided an estimate of the average distance moved. The ratio of the 2 estimates was used to predict population size. Since lynx cannot be tracked on the ground to their present location, we tested Becker's second estimator. This study tested the feasibility of this technique to accurately estimate the densities of lynx within a defined area. Additionally, it was possible to get information about early winter kitten production, since track surveys provided information on family groups within the study areas.

Key words: Alaska, census, density, lynx, *Lynx canadensis*, population estimation.

CONTENTS

METHODS

Study Area

Our 283-km^2 lynx study area was located on the northcentral Kenai Peninsula lowlands (Fig. 1). Detailed descriptions were presented by Kesterson (1988) and Schwartz and Franzmann (1991). The area supported a typical northern coniferous forest containing a mixture of white spruce (Picea glauca), black spruce (Picea mariana), black cottonwood (Populus trichocarpa), quaking aspen (Populus tremuloides), and paper birch (Betula papyrifera). On dry upland sites the mature forest vegetation was white spruce, paper birch, quaking aspen, or some combination of these species; whereas, black spruce dominated poorly drained sites (Lutz 1956, Spencer and Hakala 1964). The deciduous tree species represented successional stages of revegetation after fire. Within the study area there were 3 successional stages of forest: (1) overmature old growth (>100 yrs), (2) midsuccessional forest burned in 1947, and (3) a small tract of early successional forest burned in 1969. The area was characterized by a high interspersion of habitat types and typified good lynx habitat on the Kenai lowlands. The study area coincided with that of an ongoing long-term lynx population dynamics study conducted by the U.S. Fish and Wildlife Service on the KNWR (Bailey et al. 1986, Kesterson 1988).

Census Procedures

We tested the radio-collar technique to estimate furbearer abundance described by Becker (In press). We conducted each census from 2 to 4 days after a snowstorm sufficient enough to obliterate all old tracks. The method required (1) good snow conditions during the study, (2) movement of lynx during the study, (3) lynx tracks that were identifiable and continuous (not interrupted), (5) movements of lynx that were independent of the sampling process, (6) lynx bedded down during the snowstorm, (7) all lynx tracks crossing transects observed, (8) systematic samples constructed so that animal tracks intersecting 1 transect did not intersect other transects within the same systematic sample, and (9) a determinate number of different animals encountered in each systematic sample. In addition, the technique required a rectangular-shaped study area with all transects oriented perpendicular to an x-axis. The x-axis was oriented parallel to the predominate axis of lynx movements to increase the probability of lynx crossing the transects. Based on previous work (Kesterson 1988), we knew that general travels for lynx in our study area were in a north-northeast to south-southwest direction, so our transects were layed out east to west.

Manpower constraints limited the number of participants in a survey to no more than 12, and short periods of daylight restricted us to transects no longer than 3.2 km. We used simulation modeling to determine that a study design containing 4 systematic samples, each with 3 transects, provided the smallest 80% confidence interval for the population estimate (Schwartz and Becker 1988). Replication was necessary to obtain a variance for the population estimate.

We divided our study area into a series of 3.2-km-wide strips oriented N-S (x-axis direction) that followed existing section lines on a 1:63,360 map. The total length of these strips was 88.5 km; thus for the purpose of the census, our study area could be visualized as one strip measuring 88.5 x 3.2 km. Each systematic sample consisted of a set of 3 evenly spaced 3.2-km transects positioned randomly within the strip.

Lynx were captured and fitted with radio collars as part of a comprehensive study of lynx ecology (see Kesterson 1988). To determine precensus movements, all radio-instrumented lynx were located from the air several (2-4) times daily, beginning immediately after the storm and continuing throughout the day of the census. Whenever possible, the trail of each animal was backtracked from the air or on the ground to determine the complete extent of movements during the interval from the end of the storm to the morning of the census. Locations were plotted on 1:63,360-scale topographic maps.

Basically, a population estimate was generated from a ratio of the expected x-axis distance traversed by the population and the mean x-axis distance traversed by the group of radio-collared lynx. For each systematic sample, the distance traveled by the population was determined using probability sampling results. In our case, the expected distance traveled by any lynx to cross a transect was equal to the x-axis length of study area divided by the number of transects. This expected distance traveled times the number of different lynx crossing any transect within a systematic sample provided an estimate of the distance traveled by the population. A variance estimate for total distance traveled by the population was generated from the 4 systematic samples.

For purposes of comparison, we were able to derive estimates of the minimum number of lynx in the study area during the census periods by combining the number of radio-collared lynx known to be there with the number of individual lynx tracks encountered that could not be attributable to collared animals (Table 1). Comparative estimates of density were also obtained because virtually every resident lynx within the study area was radio-collared, and tracks of uncollared lynx were identified during routine tracking surveys.

We tested for positive correlation between (1) the minimum known number of animals in the study area, (2) total lynx tracks crossing all transects, and (3) different lynx tracks crossing all transects and our population estimate using a Spearman rank correlation (Steel and Torrie 1960) and the following hypothesis: H_0: $\rho \leq 0$, H_a: $\rho > 0$. A t-test for Spearman rank correlations (Steel and Torrie 1960) was used as the test statistic and an alpha of 0.05 was used as the critical value. Where multiple estimates occured (Table 1), we used the mid-point of the range for the test.

RESULTS AND DISCUSSION

From 1987 to 1990 we completed 4 censuses within the study area (Table 1). Lynx density estimates derived with the line transect technique were well correlated ($\underline{r} = 0.949$, df = 2, t = 4.257, $\underline{P} = 0.025$) with independent estimates of lynx within the study area (Kesterson 1988; W. Staples, pers. commun.). In all years that we censused the lynx, our estimates obtained with the line transect survey were close to the number of lynx suspected to be in the area, according to radiotelemetry and ground-tracking information. It appeared that the technique accurately estimated lynx density.

The census technique required adequate snowfall to distinguish old and new tracks and reasonable weather following the storm to complete the tracking. It was our original intention to conduct at least 4 surveys/year; however, because it was very difficult to get adequate survey conditions, we only were able to successfully complete 1 survey/year.

We generally had adequate snowfall during the winter to attempt several surveys; however, most storms were followed by poor flying conditions (i.e., high wind and/or low cloud cover). We were therefore unable to obtain estimates of movements after the snowfalls for the marked population.

Access into the study area was primarily by ski plane, transporting personnel to frozen lakes. Early winter surveys were usually impossible, because many of these lakes contained insufficient ice for safe landings. Also, much of the manpower required to walk transects in early winter was unavailable because of seasonal workloads (e.g., moose composition surveys). December surveys were not considered because of the short day lengths and the possibility of personnel being stranded in the field.

During the day scheduled for the January 1989 survey, a late-afternoon snowstorm resulted in poor flying conditions. Because of heavy snow, we were unable to radio-track the marked lynx the day of the census. Consequently, we had an inaccurate estimate of the mean distance moved by the marked population. For this reason, we used our 1988 movement data, which were obtained over a similar time period.

Regarding the other assumptions, we suspect that all animals moved during the course of our study. Every radio-collared lynx moved between the snowstorm and our census.

Lynx tracks were readily identifiable in virtually all cases. Wolf tracks (Canus lupus) are of a similar size and shape at first glance, but the foot spacing and track configurations are different. A wolf tends to travel in open terrain in a generally straight line, while a lynx travels in more dense vegetation in a wandering fashion. By backtracking questionable tracks, it was generally easy to distinguish between the 2 carnivores.

Because we waited for adequate snow conditions before tracking, we met the assumption that tracks were continuous. Lynx do not travel to any great extent above ground (i.e., in the trees), and windblown tracks were seldom a problem in our study area because we did not conduct a census after a heavy windstorm.

We suspect that lynx movements were independent of our sampling process. Radio-marked lynx were residents of the study area, and many had been collared during previous years. Lynx movements following each snowstorm were determined via fixed-wing aircraft, so animals were not disturbed.

All surveys followed heavy snowstorms with >10 cm of new snow accumulation; therefore, it was usually quite easy to distinguish tracks made before a snowstorm from those made after the storm. During the census conducted in February 1990, a light snowfall occurred after the major storm and before ground transects were walked, resulting in some uncertainty in determining if 2 sets of tracks on one transect were new ones with a light dusting of snow or old tracks. We calculated densities using both counts, but based on our best estimates, we felt that 2 sets of tracks were old and should not have been counted.

We believe we were able to detect virtually all tracks crossing each transect; however, confusion resulted when several lynx traveled together and crossed a transect several times or if a lynx traveled in the tracks of another animal. One set of lynx tracks was overlooked by a ground observer on one transect; this lynx had walked in an old set of moose tracks. These lynx tracks would have been missed had not an aerial observer spotted the tracks on either side of the transect crossing, landed, and verified that the lynx had crossed the transect.

We had some difficulty determining the exact number of different lynx on some transects. When we encountered multiple crossings on any transect, we instructed the observer to try to determine if the tracks had been made by the same animal crossing the transect more than one time or if the multiple crossings had been made by different animals. In some cases little additional time was required to make such a determination; however, if multiple crossings were encountered some distance apart, it often was impossible to determine the number of lynx responsible and still complete the transect. Because completion of the transect was paramount, an observer encountering multiple crossings with inadequate time to make such a determination was instructed to flag the tracks for later examination. Usually, on the day following the census additional persons backtracked these lynx to determine the number of individuals. In most cases, backtracking clearly indicated the number of lynx involved; however, in some situations, there were still questions. When it was impossible to determine the exact number of tracks, we estimated densities using both low and high counts of tracks.

Transects were spaced far enough apart to prevent lynx from travelling across more than one of them. No observations were made of a set of lynx tracks crossing more than 1 transect during the study.

Maintaining a sample of radio-collared lynx within a study area is expensive and time-consuming. We used radio-collared lynx to determine the x-axis movements of our marked sample because of concurrent studies (Bailey et al. 1986, Kesterson 1988). Obtaining movement data was contingent upon good flying conditions, which were regularly marginal.

The other major criteria necessary for management of a lynx population is knowing when kitten production and recruitment occur. Age of first reproduction, litter size, and kitten survival have all been closely linked to the abundance of snowshoe hares (Nava 1970, Brand and Keith 1979, O'Connor, 1984). We were able to correctly detect kitten production within our study area with the line transect method in 3 of 4 years of surveys (Table 1). During the winter of 1986-87, the population was estimated to be 53% kittens (Kesterson 1988). During our 1987 census, 3 of 12 (25%) lynx tracks encountered were kitten tracks. There were no kittens in the study area in 1988 and 1990 (W. Staples, pers. commun.), and we did not observe kitten tracks. The only discrepancy occurred in 1989; there was only one known kitten produced in the area (W. Staples, pers. commun.), and we did not encounter its track.

Quinn and Parker (1987:689) suggested that "results from confined study areas may be used to estimate population densities over much larger areas based on correlations between lynx densities and the frequency of tracks." Frequencies of different lynx ($\underline{r}$ = 0.632, t = 1.155, df = 2, $\underline{P}$ = 0.184) and total lynx ($\underline{r}$ = 0.000, t = 0.000, df = 2, $\underline{P}$ = 0.500) tracks were not correlated with density estimates. These findings suggest that track counts may not provide a good index to lynx abundance, at least within the range of densities we observed.

Brand and Keith (1979) recommended curtailing trapping during the lynx population low, when kitten production is near zero. The snowshoe hare population peaked in the study area in 1984-85 (Kesterson 1988), and the lynx population peaked 2 years after the hare peak in 1986-87 (Table 1). Lynx population densities were estimated at 1.6, 3.6, and 6.8 lynx/100 km^2 in 1984-85, 1985-86, and 1986-87, respectively (Kesterson 1988). Kitten production was high in 1986-87, but it declined to near zero in the following 3 years; the line transect surveys accurately detected this trend.

SUMMARY AND MANAGEMENT IMPLICATIONS

We tested a systematic line transect technique to estimate lynx population densities. Results of 4 censuses conducted from 1987 to 1990 were highly correlated ($\underline{r}$ = 0.949, t = 4.257, df = 2, $\underline{P}$ = 0.025) with independent estimates of lynx numbers.

Surveys were conducted following adequate snowfall to eliminate old lynx tracks. Marked lynx were radio-tracked from an aircraft for several days following the snowstorm to determine distances moved. A series of systematic 3.2-km-long transects were walked, and the number of different lynx crossing the transect recorded. The population estimate was obtained from a ratio of the estimated distance traveled by lynx in the population and the estimated average distance traveled by the radio-collared lynx.

Inadequate census conditions limited our ability to conduct multiple censuses in any year during the study period (1986-87 to 1990-91). Many times, snowstorms were followed by high winds and/or low cloud cover that precluded aerial tracking of the marked population.

This population assessment provided a means of technique accurately estimating lynx densities within the study area as well as predicting kitten production. Management theory for lynx suggests that trapping should be stopped or eliminated 2 years after the peak in the lynx harvest. Trapping should remain closed during the lynx population decline, when kitten production is near zero. This technique allowed us to accurately track a lynx population through its peak and continue to track it through a population low with no kitten production. Management decisions based upon results of the line transect census would have resulted in accurate management decisions. We feel that the line transect has practical management application with limitations. Adequate access into remote areas, coupled with ideal census conditions, will determine the number of times such a technique can be conducted each winter.

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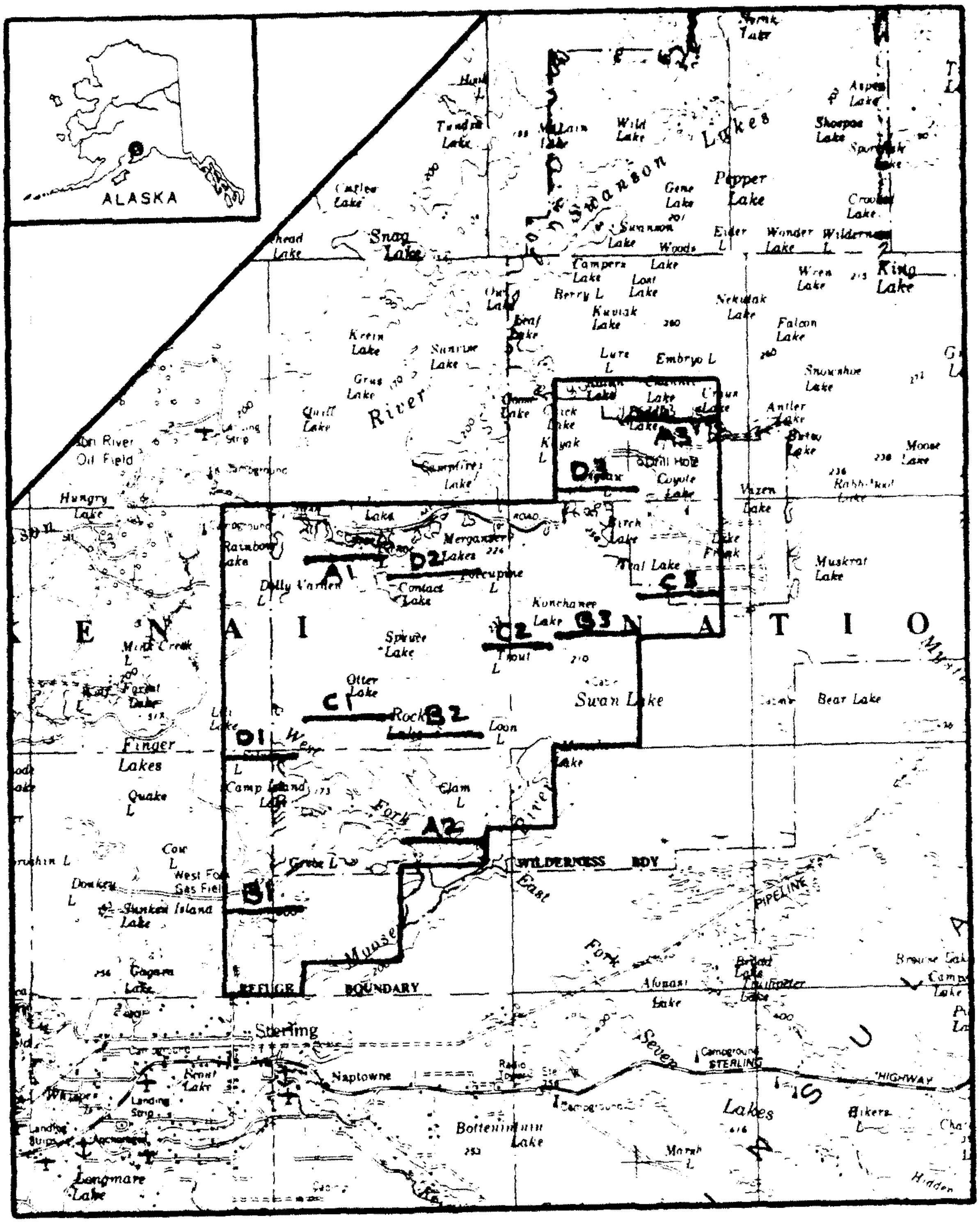

Fig. 1. Lynx study area located on the northcentral Kenai Peninsula lowlands.

Table 1. Results of 4 systematic surveys to estimate lynx density in a 285 km^2 (110 mi^2) study area on the Kenai peninsula, Alaska, 1987-90.

Date	Lynx estimate		No. lynx tracks		Distance moved		Known	Density of lynx		Kittens	Kitten
							No.	Lynx/	80%	in	tracks
mo yr	No.	80% CI	different	total	n	x (SE)	lynx	$100km^2$	CI	area	seen
Jan 87	15.1	9.5-20.7	12	18	2	3.6 (0.93)	10 or 11	5.3	3.3-7.3	Yes	Yes
Mar 88	6.0	2.4-9.5	4	17	3	3.1 (0.65)	6	2.1	0.9-3.4	No	No
Jan 89[a]	12.0		8	28			9	4.2		Yes	No[b]
Feb 90	13.5	5.1-21.9	4	6	4	1.36 (0.36)	8 or 10	4.7	1.8-7.7	No	No

[a] Do to extremely poor flying conditions, we were unable to locate the marked lynx the day of the census. Therefore, known movements of the marked sample were not known. We used movement data from the 1988 estimate,
because the time intervals were similar; for this reason, confidence intervals were not calculated.
[b] Only one kitten was known to be in the study area.

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