Use of Line-Intercept Track Sampling for Estimating Wolf Densities

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During spring 1990 and spring 1991 we tested the use of line-intercept sampling of tracks for estimating wolf densities f known wolf population occupying a 6,464 km^2 study area in northwest Alaska, and for a population estimated by traditic aerial reconnaissance in a 5,011 km^2 survey area in interior Alaska. In each study area we used seven randomly cho samples, each consisting of five systematically spaced transects. Based upon telemetry studies, the minimum number of wo known to occupy the northwest Alaska study area was 48. The population estimated based upon line-intercept sampling 50.7 (80% ci = 33.4 to 67.9). The biological confidence interval was 43 to 68. The estimated numbers of wolves occup the interior survey area, based upon aerial reconnaissance surveys, was 41. The population estimate based upon line-inter sampling was 33.4 (80% ci = 23.2 to 43.6). The biological confidence interval was 25 to 44. Advantages of the line-inter procedure over other survey methods include objectivity, repeatability, speed, reduced cost, reasonable accuracy, measurable precision.

Introduction

Obtaining accurate and precise estimates of wolf (*Canis lupus*) population density is costly and time consuming because of relatively low density and secretive behavior of the species. Since the early 1970's a number of state, provincial, and federal governments have attempted to monitor the status of wolf populations regularly. Methods included harvest statistics (Rausch 1967), howling surveys (Harrington and Mech 1982b), hunter observations to assess trend (Crete and Messier 1987), a variety of aerial reconnaissance surveys (Stephenson 1978, Gasaway et al. 1983, Crete and Messier 1987), and radiotelemetry studies (cf. Ballard et al. 1987, Fuller and Snow 1988). A number of problems exist with each method.

Howling surveys are time consuming, expensive, require road access, are limited to relatively small areas, and are imprecise (Crete and Messier 1987, Fuller and Sampson 1988b). Estimates obtained from hunter observations are also relatively imprecise and require a large sample of hunters (Crete and Messier 1987), which is not practical for many areas of North America. Aerial track counts using transects were evaluated and found unsatisfactory by Crete and Messier (1987).

Aerial reconnaissance surveys (Stephenson 1978, Gasaway et al. 1983) are widely used in western Canada and Alaska for assessing wolf densities. This method differs considerably from the aerial track counts evaluated by Crete and Messier (1987); smaller and slower aircraft are used, pilots and observers are experienced wolf trackers, and transects are flown only in homogeneous habitats. Varying intensity searches are conducted of habitats frequented by wolves (e.g., ridges, shorelines, and streams). When wolf tracks are encountered they are followed until wolves are observed and the number and color composition of the pack are determined. Pack size is estimated from tracks if wolves are not observed. Tracks, wolves observed, and prior knowledge of wolf pack locations are used to form a mosaic of wolf pack areas. Numbers of wolves in each area are estimated from the survey data resulting in best, low, and high estimates that are not estimates of precision. This method appears to work well in Alaska with resident wolf packs, but may not in areas where part or all of the wolf population is migratory and/or wolves exist in relatively low densities. The method was evaluated on a cursory basis by Stephenson (1978), who determined that in one area the method provided a good estimation (within 80–96%) of wolf density in relation to what was estimated from radiotelemetry studies. W.B. Ballard (Alaska Dept. Fish and Game, unpubl. data) had similar results with a test of a pilot-observer team that was "current" (fewer than five years since last wolf survey) at wolf tracking. However, results were 50% lower with a pilot-observer team that was experienced but not current (more than five years since last wolf survey).

To date, the best method for estimating wolf population density involves use of radiotelemetry to estimate pack territories and-sizes, and the numbers of wolves in each pack. While the resulting density estimates are accurate and repeatable (Fuller and Snow 1988), they are also expensive and time consuming to obtain, and do not contain measures of precision. High cost makes this method impractical for routine management.

A cost-effective and practical method of surveying wolves over large geographic areas would ideally be accurate and have a high degree of precision. Becker (1991) reported a method for estimating lynx (*Felis lynx*) and wolverine (*Gulo gulo*) densities in Alaska using a line-intercept track sampling method that we have termed the track intercept probability estimator (TIP survey). The greatest potential advantage for use on wolves is that it provides a measure of precision not previously available. The TIP survey method has been used for surveying wolves (Becker and Gardner 1990, Gardner and Becker 1991), but its accuracy and precision within a known population of wolves has not been assessed, nor have the results been compared with those from traditional aerial reconnaissance surveys. This study compares TIP survey (Becker 1991) estimates to a radiotelemetry-based estimate (Kobuk study area) and to an estimate based upon aerial reconnaissance surveys (Minto study area). We discuss advantages and disadvantages in relation to other available survey methods.

Study Area and Methods

The Kobuk study area included the winter range of the western Arctic caribou (*Rangifer tarandus*) herd and portions of Kobuk Valley National Park, Selawik National Wildlife Refuge, and Koyukuk National Wildlife Refuge in northwest Alaska. Within the 12,279 km^2 wolf study area (Ballard et al. 1990), we selected a 6,464 km^2 TIP survey area (Fig. 1) where radio contact had been maintained with three wolf packs during the previous three years. Two additional packs without collared members (uncollared packs) were observed within the TIP survey area before the survey, and their numbers were determined by direct count prior to the survey. Territory boundaries of instrumented packs were estimated using outermost radio-relocations (Mohr 1947). Territories of uncollared packs were estimated based upon their spatial relationship to collared packs, wolf sightings, and mapped travel routes observed during capture and monitoring flights.

During spring 1991, we conducted aerial reconnaissance surveys (Stephenson 1978) in the Minto study area to determine wolf densities (Fig. 2). Surveys were conducted during clear weather, one to five days following fresh snowfalls ≥ 75 mm. One to three aircraft (Piper Supercub or Bellanca Scout) searched 1,000–2,500 km^2 search blocks on each of five survey days. We resurveyed search blocks on different days and concentrated search efforts on probable wolf travel routes. Once encountered, wolf tracks were followed until wolves were sighted or pack size could be estimated from tracks. We backtracked wolves until tracks appeared old and plotted all track segments on 1:250,000 scale U.S. Geological Survey maps.

The aerial reconnaissance estimate of wolf numbers included wolves observed plus track estimates. Individual packs were identified by size and color composition. Relative timing of track observations, hunter and trapper sightings, and repetitive surveys of search blocks helped differentiate between observed packs and those estimated from tracks. No correction factor was applied for single wolves because we had no basis for estimating single wolves. Before completing the aerial reconnaissance survey we conducted a TIP survey within a 5,011 km^2 portion of the Minto study area to provide an alternate estimate of wolf numbers and to compare the TIP survey estimate with that obtained from the aerial reconnaissance survey.

For both study sites, the TIP survey areas were designed as rectangles and positioned on a 1:250,000 scale map so that randomly selected transects would have a high probability of crossing wolf travel routes (e.g., ridges and streams). Locations of surveyed transects were selected using a randomly repeated systematic sample design (Becker 1991). Each sample unit consisted of five systematically spaced transects that were 38.6 km long in the Kobuk study area and 25.2 km long in the Minto study area. A random sample of seven of these sample units was selected by randomly choosing the starting point on the x-axis for the first transect in each systematic sample. The randomization was restricted by forcing a minimum spacing of 1.6 km between any two adjacent transects. Other combinations of numbers of samples and transects can be used, but previous experience indicated that seven samples composed of five transects was a desirable sampling scheme (Gardner and Becker 1991). We calculated 80% confidence intervals (CI) for each estimate. We chose 80% CIs to prevent making a Type II error of falsely concluding that there was no change in the population.

General procedures for conducting the survey were described by Becker (1991), Becker and Gardner (1990), and Gardner and Becker (1991). The mathematical equations, sampling theory, and model assumptions are detailed in Becker (1991). Becker (1991) outlined four assumptions necessary when line-intercept track surveys are conducted from fixed-wing aircraft: 1) all wolves in the study area move and deposit tracks prior to the survey; 2) all wolf tracks that cross a transect are detectable and identifiable; 3) tracks encountered can be followed to the wolf's present location and backtracked to where it had bedded down during the snowstorm or where the tracks can be classified as "old"; and 4) the distance wolves traveled parallel to the x-axis since the last snowstorm can be determined by tracking. Field

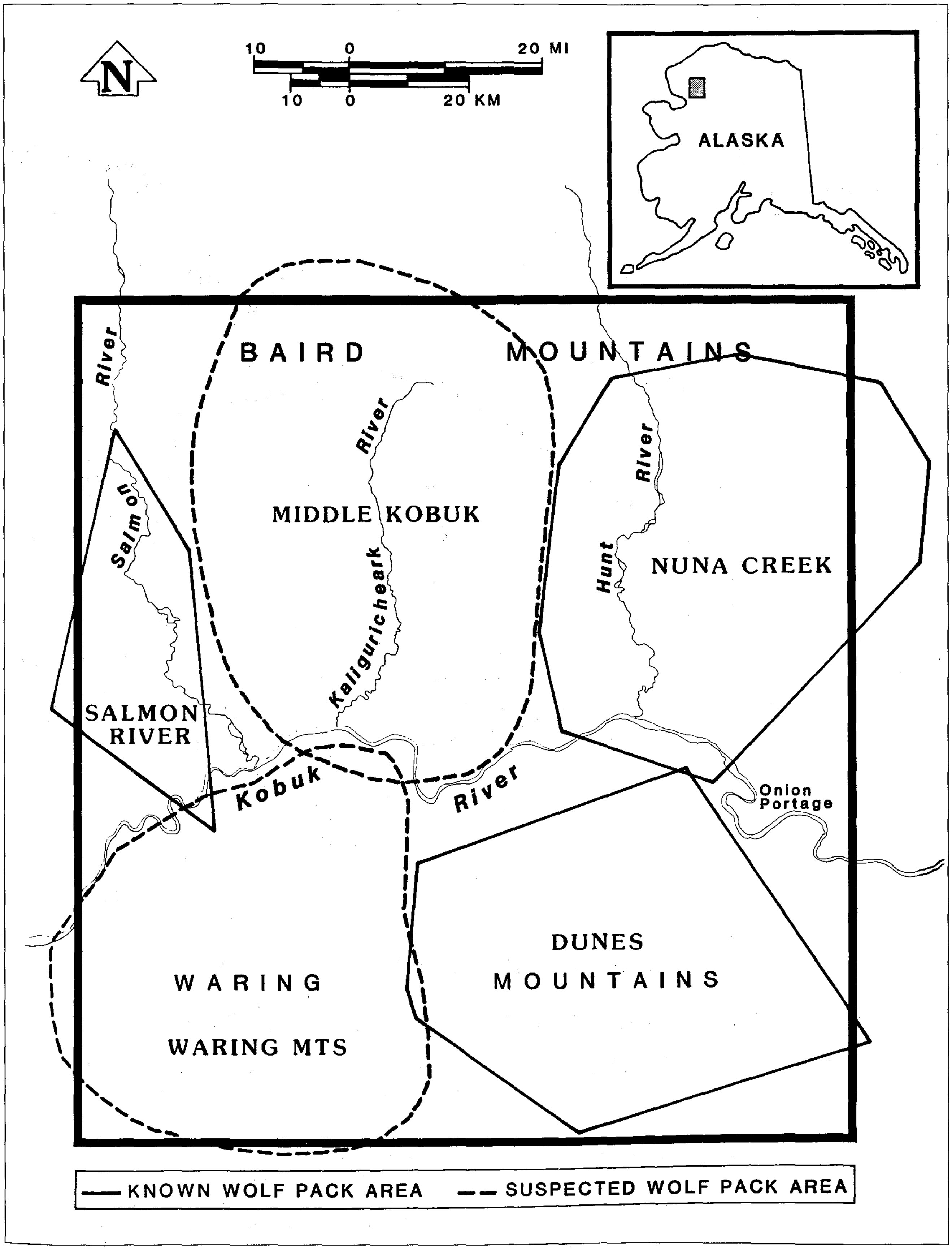

Fig. 1. *Boundaries of wolf survey area in relation to observed and suspected wolf pack territory boundaries in northwest Alaska.*

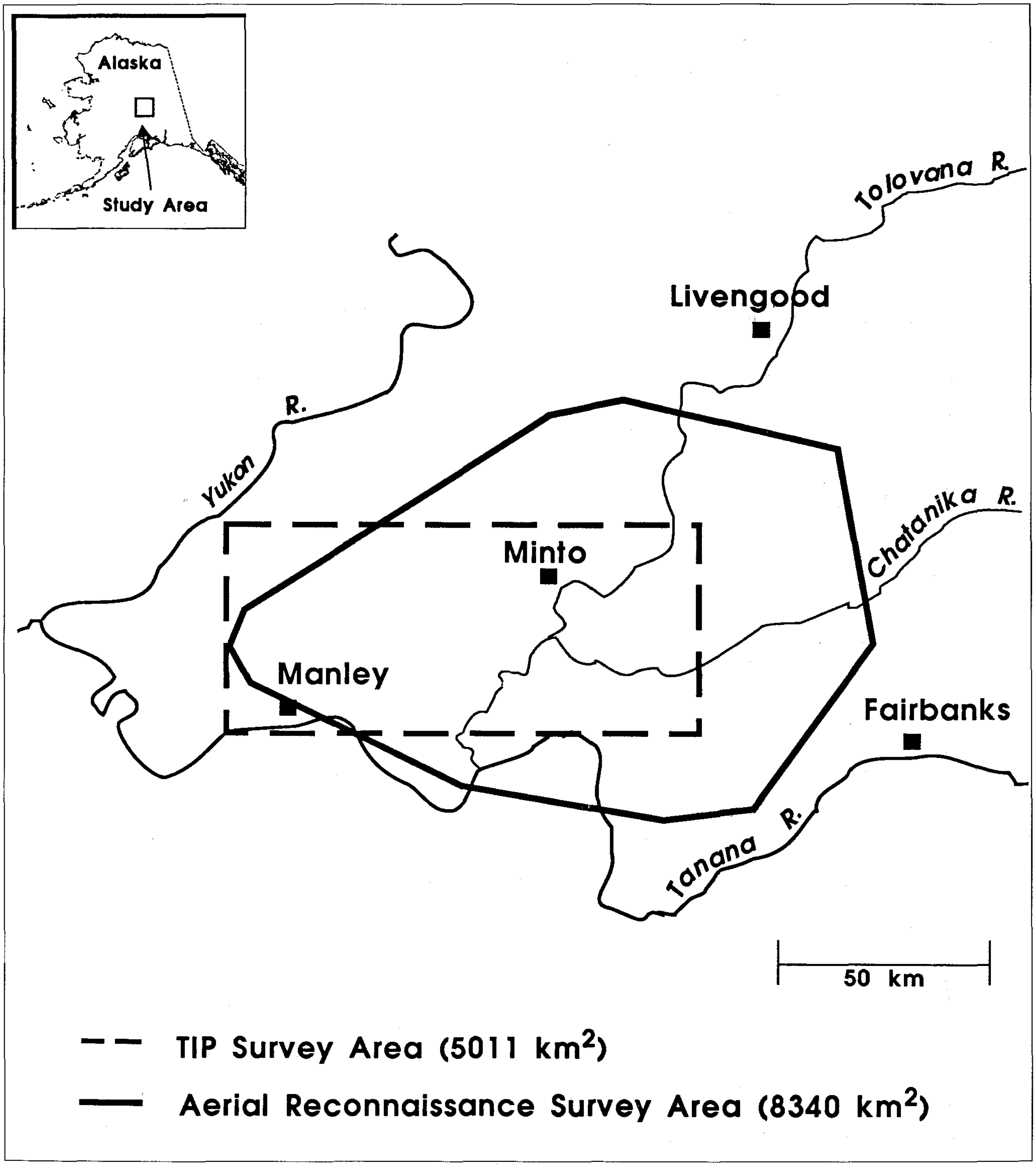

Fig. 2. *Relative position of aerial reconnaissance and TIP survey areas in the Minto study area in interior Alaska.*

procedures were designed to ensure compliance with these assumptions and to verify their validity.

Each survey aircraft (Piper Supercubs and Bellanca Scout) was assigned seven transects. Transects were initiated from the western boundary of both study areas. Following completion of all assigned transects, each aircraft flew irregular searches (herein referred to as renegade searches) between transect lines to check if any wolf tracks had been missed. Survey aircraft maintained airspeeds of approximately 90–130 km/hour at altitudes of 60–160 m.

Before and after the survey in the Kobuk study, a separate aircraft (Piper Supercub) that did not participate in the survey used radiotelemetry to locate and backtrack all radio-collared wolves associated with the study. This allowed us to determine if all radio-collared wolves were in the study area and were available for counting. It also provided an opportunity to determine if the survey aircraft could locate, backtrack, and estimate pack sizes for packs of known numbers.

Topography of the survey area ranged from flat (30 m) along the Kobuk River and along the southern boundary of the area to the gently sloping north- or south-facing slopes from the crest (536 m) of the Waring Mountains. North of the Kobuk River, which runs through the area from east to west, several steep ridges (1,100 m) run from north to south.

Vegetation of the area ranged from thick black (*Picea mariana*) and white (*P. glauca*) spruce forests along the Kobuk River and its major tributaries, grading into sparser stands of spruce and mixed shrub consisting of willow (*Salix* spp.), alder (*Alnus* spp.), and birch (*Betula glandulosa*, *B. nana*, and *B. papyrifera*). Higher elevations were dominated by mat-cushion and upland tundra and bare rock.

The area has a maritime climate during snow-free periods. Winter and summer temperatures average -11.5° and 9.4°C, respectively. The area is often snow-covered from October through May. Annual precipitation averages 680 mm, half of which occurs during July and August.

The Minto study area ranges in elevation from 90 to 1,400 m. The southern portion of the study area is characterized by flat terrain with numerous lowland lakes interspersed with mixed birch, both black and white spruce, and wet marshlands. North of Minto Flats, the terrain rises through rolling, forest-covered hills to a prominent east-west alpine tundra ridge along the northern boundary of the area. Drainages flow south into the Tanana River.

Climate of the area is continental. Annual precipitation averages 310 mm, half of which occurs during June, July, and August. Accumulated snow depths average 480 mm on 1 March and average daily temperatures range from 15.3 °C in July to -21.8 °C in January.

Results

Kobuk Study Area

A snowstorm from 26–28 April 1990 brought 48 mm of fresh snow to the study area, adding to 64 cm already on the ground. An earlier storm from 21–23 April resulted in 310 mm of fresh snow, so survey conditions were excellent on 1 May. On 1 May 1990, approximately three days after the storm, five fixed-wing aircraft flew seven systematic samples consisting of five, 38.6 km long transects (Fig. 3). We expended 36.6 hours flying transects and renegade searches. During the approximate 5–7.5 hours of renegade searches four of five aircraft found no additional wolf sign. One aircraft missed a pack of three wolves (Waring Mountain pack) that had crossed the southernmost transect on two occasions.

Forty-eight wolves were accounted for during the survey (Table 1): 43 wolves observed and tracks of five others. All five packs known to occur within the study area were located.

All wolves encountered were successfully tracked and backtracked. However, there were discrepancies between pack size estimates during the survey and those obtained before and after the survey. For example, the radio-tracking aircraft could only account for 10 wolves in packs from the Salmon River and middle Kobuk River, but the survey crew counted 11 in each. The Dunes pack contained five individuals that had been observed daily during the preceding two-week period, while the survey crew (based upon track counts) estimated six to seven wolves. The Nuna Creek pack numbered 18 wolves the morning before the survey, but during and after the survey only 16 wolves were counted in the pack. Some time during the survey two radio-collared wolves split away from their pack and died and were missed during the survey. Subsequent observations revealed that a rabies enzootic was in progress (Brand et al. this volume). Although no lone wolves were radio-collared, losses from some instrumented packs over the previous three-week period (Nuna Creek pack originally had numbered 21 individuals) suggested some lone wolves were either in the area, had been killed by local hunters, or died of rabies.

Wolves were encountered on several of the systematic samples (Table 1). Average group size was 8 ± 5.6 (SD) and average distance moved perpendicular to the transects since the last snowstorm was 18.9 ± 9.3 (SD) km per wolf group. The resulting wolf population estimate based upon the transects was 50.7 with an 80% confidence interval (CI) of 33.4–67.9 (Table 1). The density estimate was 7.8 wolves/1,000 km^2 (80% CI = 5.2-10.5 wolves/1,000 km^2).

Minto Study Area

We flew 50.5 hours on aerial reconnaissance surveys in the Minto study area between 12 March and 2 April 1991. The best estimate was 61 wolves (7.3 wolves/1,000 km^2) composed of 12 packs within the 8,340 km^2 study area (Table 2). We calculated low and high estimates of 55 and 71 wolves, respectively, by excluding or including packs whose separate identities could not be clearly established. Among the 12 packs included in the best estimate, pack sizes ranged from two to 12 wolves and averaged 5.1 wolves per pack.

Deriving estimates from aerial reconnaissance surveys requires subjective decisions because complete home ranges are not known and estimates are often based upon tracks rather than observed wolves. Searching the survey area repeatedly after consecutive snowfall events helped us differentiate between adjacent packs because we gained additional wolf movement information after each fresh snowfall. For example, during aerial reconnaissance searches on 21 March, three days following a 75 mm snowfall, we encountered wolf tracks in the northeastern corner of the study area

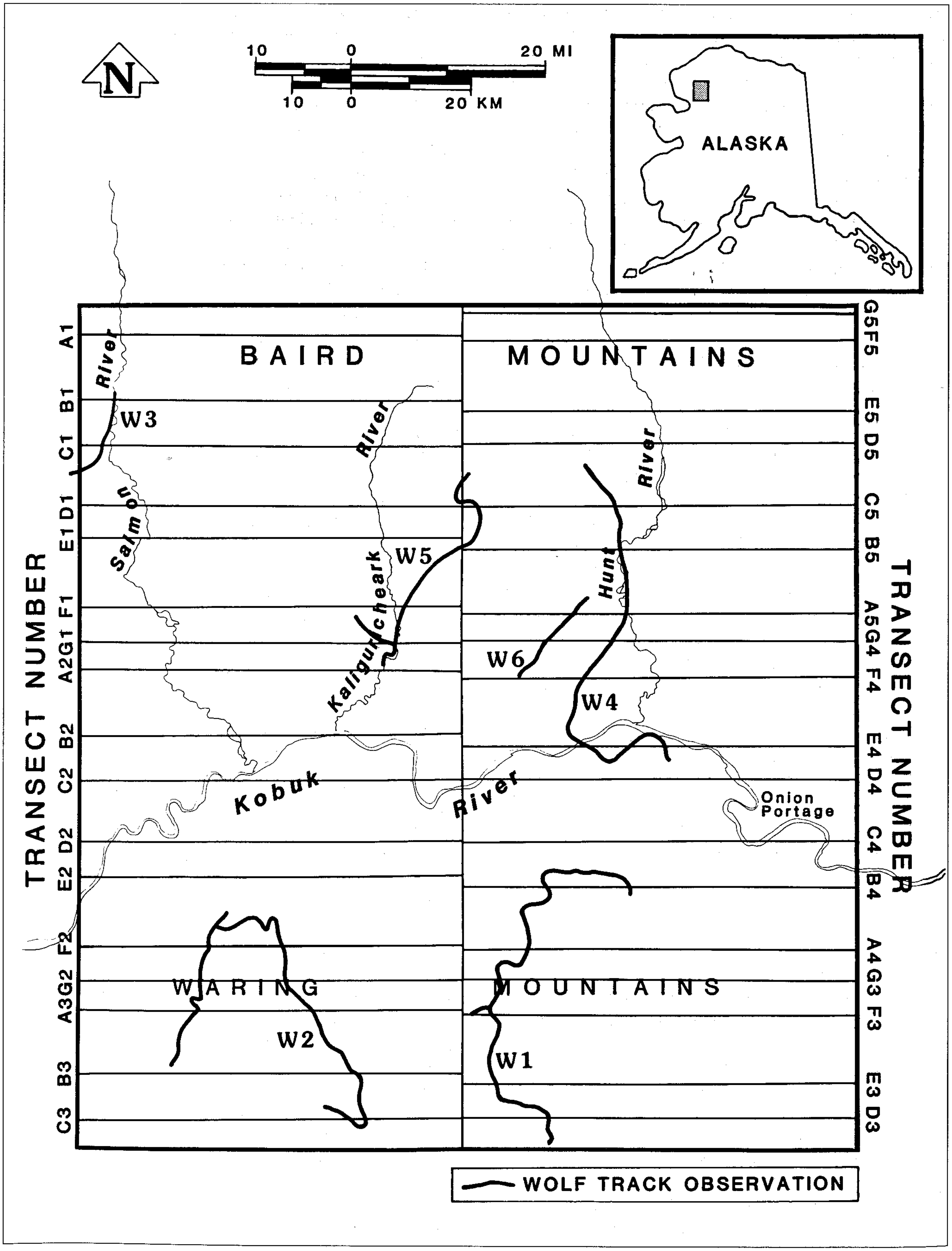

Fig. 3. *Location of transects in northwest Alaska used to survey wolves on 1 May 1990 and observed wolf travel routes.*

Table 1. Wolf survey data obtained on 1 May 1990 and calculations used to estimate population size within a 6,464 km^2 study area, northwestern Alaska.

Wolf group	*Pack Name*	*Est. no. wolves (no.obs.)*	*Known no. wolves*	*Dist. move (km)*	P[1]	*T*[2]
W1	Dunes	6(2)	5	27.3	0.8258	7.27
W2	Waring	3(2)	3	21.8	0.6591	4.55
W3	Salmon	11(11)	11[3]	8.0	0.2424	45.38
W4	Nuna	16(16)	18	29.3	0.8864	18.05
W5	Kobuk	11(11)	11[3]	19.1	0.5758	19.10
W6	single	1(1)		7.8	0.2348	4.26

Samp. ID	*Wolf groups*	*Pop. est. based on ith sample = sum T for each group*
A	W1, W2, W4, W6	34.13
B	W1, W2, W3, W4, W5	94.35
C	W2, W3, W4, W5	87.08
D	W1	7.27
E	W1, W4	25.32
F	W1, W2, W4, W5, W6	53.23
G	W1, W2, W4, W5, W6	53.23
	Total	354.61[a]

a Total Population Estimate = 354.61/7 = 50.66; 80% Confidence Interval = 33.38 to 67.94
1 Probability observed (P) = distance moved perpendicular to transect/x-axis X no. of transects.
2 T = pack size/P.
3 Ten wolves were observed in each pack prior to survey.

that led us 90 km along an open ridge to the northwestern corner of the study area. Two aircraft encountered the track segment and although only six wolves were sighted, each search team independently estimated 10–14 wolves from tracks. Later, on 1 and 2 April, after fresh snowfall covered the tracks observed on 21 March, we saw three packs totalling 19 observed wolves in the vicinity of the track segment observed on 21 March.

Although resurveying the study area following consecutive snowfalls enhanced our aerial reconnaissance survey estimate, at some time during aerial reconnaissance surveys money or weather preclude further efforts and subjective decisions enter into the final estimate. In this case, of the 55 wolves estimated in the low estimate, only 39 wolves were actually observed and, hence, the minimum estimate could be construed as 39 wolves (4.7 wolves/1,000 km^2).

On 31 March, two days after a large storm deposited 580 mm of snow, we flew a TIP survey within a 5,011 km^2 rectangle within the Minto study area (Fig. 4). Three aircraft (two Supercubs and one Bellanca Scout) flew seven systematic samples consisting of five, 25.2-km transects. We flew 19.5 hours to complete transects and to conduct renegade searches between transects. The entire TIP survey area had been searched by aerial reconnaissance surveys on 20 and 21 March, but all tracks observed during those surveys had been covered by snow between 24 and 29 March.

During the TIP survey, we encountered tracks of four wolf packs totalling 25 wolves that crossed transects. We successfully tracked three packs until wolves were sighted, the fourth pack (two wolves) was tracked to where the wolves were concealed by thick spruce. A fifth pack (Baker pack) was found between transects during the renegade search, but that pack had moved only a short perpendicular distance and failed to cross survey transects. The following day, during aerial reconnaissance surveys, a sixth pack (Hut-

Table 2. Estimated-size and color composition of wolf packs identified within the 8,340 km^2 Minto study area on aerial reconnaissance surveys, 12 March–2 April 1991.

Pack ID#	*Pack name*	*Estimated number of wolves (no. observed)*	*Color composition*
M1	C.O.D.[1]	2(0)	Tracks only
M2	Tolovana[1]	6(6)	1 black, 5 gray
M3	Swanneck[1]	12(12)	11 black, 1 gray
M4	Dugan[1]	5(3)	1 black, 2 gray
M5	Baker[1]	7(7)	5 black, 2 gray
M6	Hutlinana[1]	6(6)	4 black, 2 gray
M7	Globe	3(0)	Tracks only
M8	Tatalina	8(0)	Tracks only
M9	Chatanika	3(3)	3 black
M10	Minto Lakes	2(2)	1 black, 1 gray
M11	Manley[1]	3(0)	Tracks only
M12	Standard	4(0)	Tracks only
M13	Wolverine Mountain	2(0)	Tracks only
M14	Uncle Sam[1]	2(1)	1 black
M15	Deadman	2(1)	1 black
M16	Dunbar	4(0)	Tracks only
		Best estimate[2]	61 (39) = 7.3 wolves/1000 km^2
		Low estimate[3]	55 (39) = 6.6 wolves/1000 km^2
		High estimate[4]	71 (41) = 8.5 wolves/1000 km^2

1 Denotes packs observed within the TIP survey area.
2 Best estimate included packs M1-M12.
3 Low estimate excluded packs M7, M11, M13-M16.
4 High estimate included all packs M1-M16.

linana pack) was successfully tracked within the TIP survey area. Again, the entire track segment lay within the TIP survey area, but had not crossed any of the survey transects. Therefore, we did not detect two wolf packs totalling 13 wolves during the TIP survey. Because those packs did not cross survey transects, they did not enter into calculations of the TIP wolf population estimate. We continued aerial reconnaissance surveys through 2 April, but found no additional packs.

Wolves were encountered on all seven systematic samples within the Minto TIP survey area (Table 3). Average group size was 6.3 ± 4.2(SD) and average distance moved perpendicular to the transects since last snowfall averaged 13.1 ± 5.7 (SD) km per group. The TIP wolf population estimate within the 5,011 km^2 survey area was 33.4 with an 80% confidence interval (CI) of 23.2 to 43.6 (Table 3). The density estimate was 6.7 wolves/1,000 km^2 (80% CI = 4.6 - 8.7 wolves/1,000 km^2). In comparison, the best estimate from the aerial reconnaissance survey for the TIP survey area (5,011 km^2) was 41 wolves, and the density estimate for the entire Minto study area (8,340 km^2) from aerial reconnaissance surveys was 7.3 wolves/1,000 km^2. Therefore, similar wolf population and density estimates were obtained from the aerial reconnaissance and TIP surveys.

Discussion

The TIP survey method is objective and repeatable, and appears to alleviate the problem of dealing with the proportion of lone wolves in the population estimate (Fuller and Snow 1988). Other methods rely on estimates from the

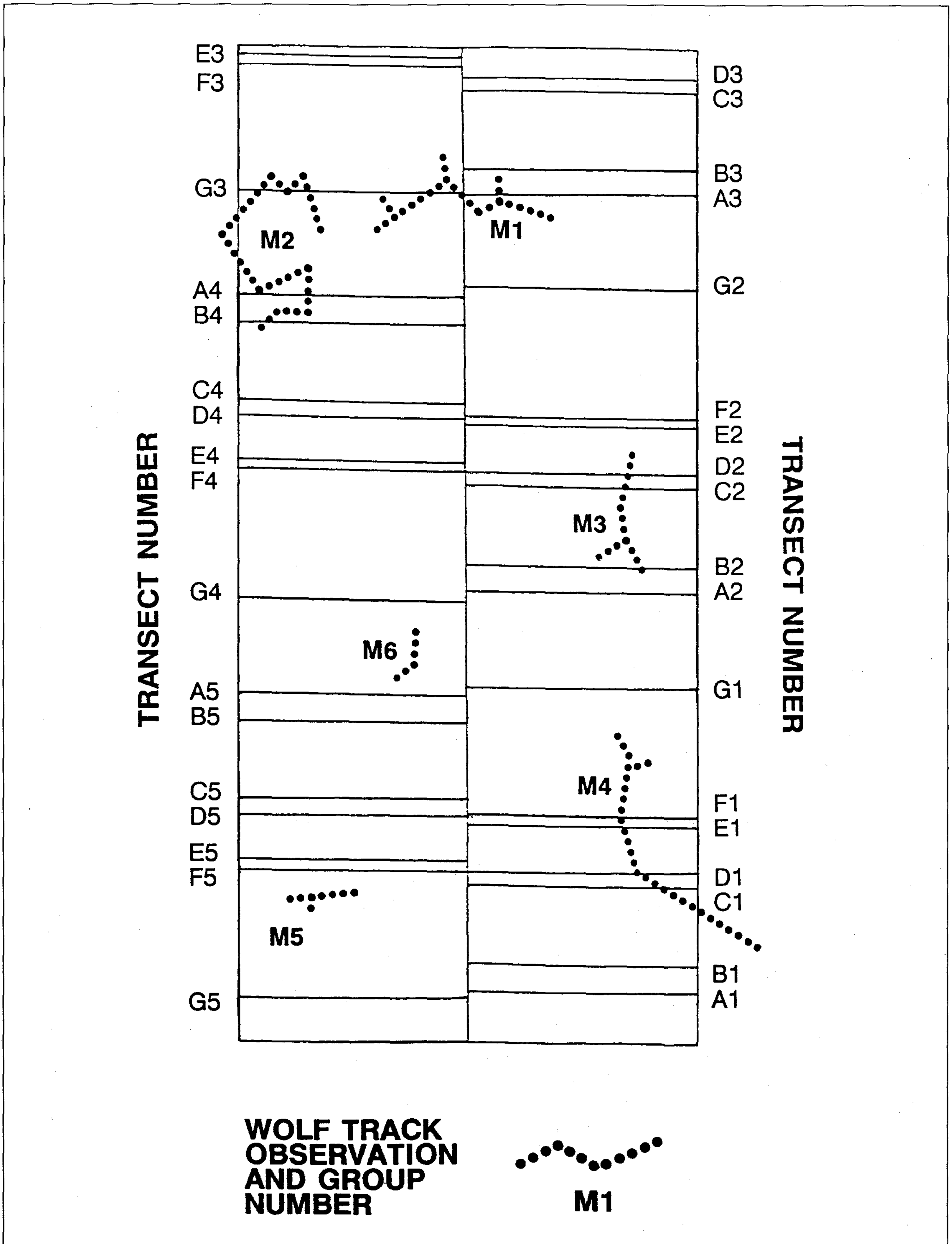

Fig. 4. *Distribution of observed wolf tracks in relation to randomly spaced transects in the Minto study area in interior Alaska.*

Table 3. Summary of wolf survey conducted on 31 March 1991 and calculations used to estimate population size within the 5,011 km^2 Minto study area, interior Alaska.

Wolf group	*Pack name*	*Estimated number of wolves (no. observed)*	*Distance moved (km)*	P[1]	*T*[2]
M1	C.O.D.	2(0)	6.45	0.162	12.35
M2	Tolovana	6(6)	12.98	0.326	18.40
M3	Swanneck	12(12)	12.50	0.314	38.22
M4	Dugan	5(3)	20.32	0.511	9.78

Sampling ID	*Wolf groups encountered*	*Population estimate based on i^{th} Sample = sum T for each group*
A	M1, M2	30.75
B	M2, M3	56.62
C	M3, M4	48.00
D	M3, M4	48.00
E	M4	9.78
F	M4	9.78
G	M1, M2	30.75
TOTAL		233.6

Total population estimate = 233.68/7 = 33.38

80% confidence interval = 23.21 - 43.55

1 Probability observed (P) = distance moved perpendicular to transect/x-axis X number of transects.

2 T = pack size / P.

literature or costly radiotelemetry studies. With the line-intercept method, the proportion of lone wolves included within the estimate is determined by actual survey data.

The maximum size of a survey area for application of the TIP survey method is limited primarily by the number of aircraft and available flight time per aircraft. Factors that affect how aircraft are utilized include: 1) numbers and lengths of transects to be surveyed; 2) target animal densities and movement rates and patterns since last snowfall, which influence time necessary for forward- and backtracking; and 3) commute times between aircraft facilities and the study area, ferry times between transects, and the availability of cached fuel in or near the study area. Because the survey method is dependent upon the distance moved by target animals perpendicular to the transects, surveying the entire area quickly is important. While all tracks of target animals intercepting a transect must be detected and tracked, all target animals in the survey area need not be detected by having their tracks intercept a transect.

The size of our study areas (6,464 km^2 and 5,011 km^2) was limited by available aircraft, logistics, and in the Kobuk study by the desire to evaluate the assumption of track detectability, which required a high probability that tracks made by instrumented packs would be intercepted by more than one transect. The aircraft were assigned 270 km and 294 km of transects to search and averaged 7.3 hours and 6.5 hours of survey effort (not including ferry time) in the Kobuk and Minto study areas, respectively. Each aircraft's time budget was allocated approximately two hours of commute time, about 6–6.5 hours to fly the transects and follow intercepted tracks, and about 0.5–1 hour for renegade searches. Because of the potential for pilot fatigue, maximum flight time per survey day should not exceed 8.0 hours. Study areas ranging from 4,556 to 10,343 km^2 have been surveyed with this method (Becker and Gardner 1990; Gardner and Becker 1991; G. Carroll, Alaska Dep. of Fish and Game, unpubl. data; this study). The study areas could have been doubled in size with modest increases in commute time. However, doubling would have required less intensive sampling (fewer transects or fewer samples), less time per aircraft for renegade searches, and probably would have resulted in decreased precision. The sampling intensity we used provided increased precision because most packs crossed several transects; therefore, data from most packs were included in more than one systematic sample.

The survey method has a number of potential problems, most of which are common to all aerial survey techniques. Spotting wolf tracks in the snow from aircraft and then tracking and backtracking requires a higher level of pilot expertise than for most other wildlife surveys. Use of inexperienced pilots would undoubtedly result in underestimates of wolf population sizes. Although experienced observers are helpful, most of the spotting and tracking depends on the pilot.

Based upon computer simulations, Gardner and Becker (1991) recommended conducting TIP surveys four to five days following a snowstorm. That recommendation assumed a snowfall of more than 70 mm and relatively low caribou densities. Our surveys were conducted on the second or third days following a snowstorm and accurately estimated the numbers of wolves relative to known or estimated numbers inhabiting the area. More research is necessary to determine the optimum period for conducting TIP surveys on wolves.

Lack of population closure (i.e., failure of all wolves whose home ranges overlap the study area to be within the study area during the survey) may also affect density estimates derived from aerial reconnaissance or general line-intercept surveys, because survey area boundaries often cut through portions of several wolf pack territories. The aerial reconnaissance survey method can greatly overestimate wolf densities when wolves are observed in the area, but only a small portion of their home range occurs there. In one instance, a wolf population was overestimated by the aerial reconnaissance method by 16% in a 8,671 km^2 area. One wolf pack that had less than 10% of its territory within the count area was included in the estimate (W.B. Ballard and J.S. Whitman, Alaska Dept. of Fish and Game, unpubl. data).

Becker (1991) suggested that during TIP surveys intercepted tracks be completely tracked forward and backward, so the distance wolves traveled parallel to the x-axis could be accurately mapped. Then, if $\geq 50\%$ of that distance was traveled within the study area, the data for that pack would be included in wolf estimate calculations. An alternative method would include only data from wolves that were in the study area during the aerial survey. If wolves made tracks in the study area but then left prior to the survey, data from those packs would not be considered. The latter method would provide a better estimate of wolves in the study area on the day the survey was flown, but it could yield extreme, imprecise estimates when a wolf pack was found shortly after it had entered the study area. We recommend using Becker's closure rule because it would tend to provide a better-behaved precision estimate and a better overall seasonal estimate of wolf density. During our surveys, we used Becker's (1991) recommendations in those instances when wolves were tracked outside the study area (Figs. 3 and 4). Closure rules are necessary to prevent biased wolf density estimates.

Gardner and Becker (1991) reported that an ongoing wolf-hunting season affected use of the method in their study area. Apparently wolf packs had been hunted (aircraft assisted) immediately before the counts were initiated, and packs and individual pack members were scattered over large areas. Hunting regulations over most of Alaska until recently allowed hunters to use aircraft to spot wolves and then land to shoot. This practice became illegal in many areas of the state beginning 1 July 1992; consequently, this factor should be less important in future surveys.

Tracking wolves through dense forest from fixed-wing aircraft is difficult, time consuming, and requires good snow conditions. Becker and Gardner (1990) suggested accurate counts would not be expected in large areas with low sightability, such as those with dense forests. If sightability was low, the assumption that all tracks could be detected and followed would probably be violated. The Kobuk study area contained thick stands of spruce along riparian areas, yet survey conditions were near ideal because dense vegetation only occurred in relatively narrow strips surrounded by open habitat types. In contrast, the Minto study area contained large forested areas. We did not fail to detect wolf tracks in the forested habitats, based on renegade searches and on subsequent aerial reconnaissance surveys. But more testing, using radio-collared wolves, is needed to evaluate sightability in closed habitats under varying conditions of light, snow, and wolf densities.

Wolf packs stay close to ungulate kills for two- to five-day periods (Ballard et al. 1987) and for as long as eight to 15 days (Messier 1985a, Ballard et al. 1987). Consequently, some packs may not move between the last snowstorm and the time the survey is conducted. The point estimate of population size if these packs are encountered may be unreasonably high and could have low precision. For example, if the Baker Creek pack of seven wolves (Minto survey area) had crossed a transect with its perpendicular distance of only 1.0 km, the estimate would have been 72.8 wolves rather than 33.4, and the 80% Confidence Interval would have been $\pm$ 64% of the estimate rather than $\pm$ 30% of the estimate. Lengthening the period between end of snowfall and initiation of the survey will decrease the chance that such packs occur, as apparently was the case for Becker and Gardner (1990).

Our original intent was to develop a wolf census method for use on the wintering grounds of the western Arctic caribou herd. Because the TIP method is highly dependent on good wolf tracking conditions, it cannot be used in areas of high ungulate density, particularly on caribou winter range. No accurate and precise methods currently exist for surveying wolves on caribou winter range, other than radiotelemetry. Although no caribou were present in our Minto study area and only small, scattered groups were encountered in our Kobuk study area, large numbers would greatly complicate survey attempts.

In spite of the above potential problems, the TIP method contains a measure of precision not obtained with other aerial survey methods. Equally important, the method is objective, repeatable, fast, and appears to provide reasonably accurate population estimates. Unlike aerial reconnaissance surveys, investigators are not required to distinguish between different wolf packs, or to detect all wolf packs within the survey area. Currently, statistical precision obtained with the TIP method is low. The biological precision (number observed and the upper 80% limit), however, is a large improvement over other wolf-survey methods. We hope to further improve precision by experimenting with different transect orientation designs and by more closely defining optimum survey periods following snowfall.

The TIP method is less expensive than telemetry studies. Total costs for such surveys ($135/hour/aircraft) exclusive of manpower ranged from $1,900–$2,600 (U.S. dollars) in south-central Alaska (Gardner and Becker 1991) to $3,250 in the Minto study area and $11,100 in the Kobuk study area. The Kobuk study costs represented an extreme because of difficult logistics that required aircraft and personnel from outside areas. The actual Kobuk survey cost was $4,758, the remainder being transportation costs. Gardner and Becker's (1991) costs represent the low end because experienced pilots and observers were located close to the study areas and commute times were minimal.

Accurate and precise density estimates may allow extrapolation of survey results to larger areas of management significance. Simple extrapolations to obtain population estimates may be appropriate if study area boundaries contain representative proportions of habitat for the larger area of interest. Extrapolation may otherwise have to be based upon habitat types, prey densities, or other criteria. Survey areas can also serve as trend count areas to monitor long-term population status.

This study demonstrated that the track intercept probability estimator can provide useful, relatively accurate, and precise wolf population estimates. Further refinement of the technique is needed to improve precision, but useful estimates are now attainable if proper conditions exist and experienced personnel are used.

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