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Wolf and Wolverine Density Estimation Techniques

by
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SUMMARY

During this study we successfully conducted three wolf (*Canis lupus*) density estimates in Game Management Unit 13. We systematically sampled 12 26.2-km, 16 33.1-km, and 35 26.2-km long transects in the Alphabet Hills, Lake Louise and the Alphabet Hills Two study areas, respectively. The number of wolves that crossed the transects and the distance the wolves moved perpendicular to the transects were determined and provided the basis for the following density estimates: 14.7 wolves/1000 km^2 (80% confidence interval of 8.3-24.1 wolves/1000 km^2) in the Alphabet Hills study area; 9.4 wolves/1000 km^2 (5.6-21.8 wolves/1000 km^2) in the Lake Louise study area; and 23.3 wolves/1000 km^2) (14.4-32.3/1000 km^2) in the Alphabet Hills Two Study Area. During these surveys, no technique assumptions were detected to be invalid. In 1991, we attempted a wolf survey consisting of 35 26.2-km transects, however, no estimate was obtained because three model assumptions were violated. Weather conditions and an on going wolf hunt caused the failure. Six systematic samples consisting of 3 38.9-km-long transects were aerially surveyed for wolverine (*Gulo gulo*) in the Talkeetna Mountain study area. We estimated wolverine densities at 4.69/1,000 km^2 (80% confidence interval of 4.44-5.59/1,000 km^2). We detected no departures from the model assumptions used to obtain the wolverine density estimate. Recommendations to improve the technique and decrease the variance are discussed.

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BACKGROUND

Wolves (*Canis lupus*) and wolverine (*Gulo gulo*) in Alaska inhabit large home ranges, occur in low densities and are secretive in nature. This makes them difficult and expensive animals to monitor. Diverse public desires for these species calls for precise population estimation. Previous methods used to estimate wolf population levels have been: howling responses (Harrington and Mech 1982), wolf track and trapper surveys (Gasaway et al. 1983), and radio telemetry data and harvest reports (Ballard et al.. 1987). All these methods provided an estimate of abundance but all had inherent biases making results difficult to interpret and compare (Becker 1991). Before 1988, wolverine population densities were estimated by using calculated home range sizes of radio-collared individuals (Gardner and Ballard 1981, Whitman and Ballard 1983, Magoun 1985, Banci 1987) and mark and recapture data (Hornocker and Hash 1981). Both methods required assumptions that were not valid which makes the accuracy of the estimates uncertain.

Wolf management in Alaska has become very controversial. No longer can managers afford to have ambiguous population data. Recent studies have shown that moose, and to a lesser extent caribou, are predator limited (Gasaway et al. 1991). As the human population in Alaska has grown, so has the consumptive and nonconsumptive demands for moose and caribou. In the past, wolf reduction programs were used to enhance ungulate population growth for human use (Gasaway et al. 1983; Ballard et al. 1987). In 1991, a statewide wolf management plan was adopted. The plan stresses public input into management goals for wolf population size and requires more intensive wolf management data, which should be scientifically collected and include statistically defensible estimates of population status.

Wolverine populations have declined throughout southcentral Alaska (ADF&G harvest records). Wolverines, because of their valuable pelt are a sought after furbearer. Their scavenging lifestyle and large home ranges lead them to be easily trapped. Under heavy trapping pressure, wolverine populations can decline over a large area, because of naturally low densities and low reproductive potential (Hornocker and Hash 1981; Van Zylle de Jong 1974). In Alaska, population trends are monitored through harvest sealing documents, which is slow and insensitive in recognizing population changes. Banci (1987), Magoun (1985) and Gardner (1985) all pointed out that a technique that gives a precise estimate of population status is essential to wolverine management.

During March 1988, Alaska Department of Fish and Game (ADF&G) biologists estimated the wolverine population in a portion of the Chugach Mountains in Game Management Subunit 13D (Becker 1991). A sampling design (Horvitz and Thompson 1952, Becker 1991) based on the probability of observing wolverine tracks crossing a transect was used to obtain the estimate. An estimate of 5.4 wolverine/1000 km^2 with an 80% confidence limit of 4.0 to 7.5 wolverine/1000 km^2 was obtained. The survey technique worked well and it appeared that it could provide precise estimates for both wolf and wolverine. However, during the initial study, the inherent assumptions of the technique were not adequately tested. This project was designed to test the assumptions for both wolf and wolverine population estimates.

OBJECTIVES

Job 1. Estimate wolf population density within 2 study areas in Unit 13 using a transect intercept probability (TIP) sampling scheme.

Job 2. Test the assumptions of the technique for surveying wolves.

Job 3. Estimate wolverine population density in 2 study areas in Unit 13 using the TIP sampling scheme.

Job 4. Test the assumptions of the technique for surveying wolverines.

Job 5. Test different sampling intensities and increasing length of time between end of snowfall and initiation of the survey on the precision of the wolf and wolverine estimates.

Job 6. Prepare a final report.

METHODS

Job 1. Wolf Density Estimation

In 1990, we conducted three wolf surveys in Unit 13. Four systematic samples consisting of 3 26.2-km transects were used to estimate wolf density in the Alphabet Hills 1 study area; four systematic samples consisting of four 33.1-km transects were used to estimate wolf density in the Lake Louise study area; and seven systematic samples consisting of five 26.2 km transects were used to estimate wolf density in the Alphabet Hills 2 study area. In 1991, we conducted one wolf survey in Unit 13. We used seven systematic samples consisting of five 26.2-km transects to estimate wolf density in the Alphabet Hill 2 study area.

We used the TIP estimator (Becker 1991) to estimate wolf densities. Study areas were surveyed by 2-3 teams made up of a pilot skilled as an aerial wolf tracker, and a biologist flying in a Piper Supercub (PA-18). Two to four days after a 7.5 cm or greater snowfall teams flew systematic groups of randomly selected transects and followed all wolf tracks which intersected the transects. The distance each wolf pack traveled perpendicular to the transect was used to generate the probability of observing that pack (Horvitz and Thompson 1952, McDonald 1980, Kaiser 1983, Becker 1991). We used this inclusion probability to generate a population estimate for each systematic sample. The population estimate is the mean of the systematic sample population estimates. This technique assumes:

1) all wolf tracks made since the last snowstorm and intersect the transect are observed;
2) all fresh tracks can be back tracked to the pack's location at the end of the snow storm and forward tracked to the pack's present location;
3) pack movements can accurately be recorded on a map;
4) all wolves move some distance after the end of snowfall and leave tracks;
5) all wolf tracks are continuous, or occur in segments that can be followed and ascribed to the correct pack.

Confidence intervals assume a t-distribution and the lower limit was adjusted to the minimum number of wolves seen during the survey if this number was larger than the original limit.

Job 2. Assumption Testing - Wolf Survey

We tested assumptions 1, 2, and 3 by flying each transect twice and by flying the area between transects, following and mapping any wolf tracks encountered, to determine if tracks that crossed transects were missed by the transect teams. At the end of the survey, we compared maps illustrating track and wolf locations and the number of wolves observed between teams. Assumption 4 was tested indirectly during intensive searches between the transects. Assumption 5 we tested while tracking the individual packs.

Job 3. Wolverine Density Estimation

We surveyed the Talkeetna Mountains study area with three pilot-biologist teams in Piper Super Cubs (PA-18) 48 hours after a 7.5 cm or greater snowfall. We followed wolverine tracks that intersected a transect and the distance each wolverine moved perpendicular to the transect was used to generate the probability of observing that individual. We used this inclusion probability to generate a population estimate for each systematic sample. We used the mean of the systematic sample population estimates as the population estimate.

Job 4. Assumption Testing - Wolverine Survey

We tested assumptions of the technique following the same procedures outlined above for wolves.

Job 5. Sampling Intensity and Timing

Time between the end of snowfall and when the survey started was extended in latter surveys by approximately 15 hours for wolves and 30 hours for wolverine. In addition, we increased sampling intensity in latter wolf surveys. To test the feasibility of the technique for estimating wolf densities in large areas we planned to use Subunits A, B, and C as study areas. We were unable to obtain all the field data required to complete this objective because of unsuitable weather conditions.

Using 30 hour wolf movement data from the first Alphabet Hills estimate, coupled with educated guesses as to the number, location, and movements of packs which have traditionally inhabited this area (Ballard et al. 1987) as well as guesses as to what the 60 hour movements would have been, a population of wolves and their movements was created. Simulations, 1,000 replications each, were performed to examine the effect of increased movements, and sampling effort on the precision of the population estimates.

RESULTS AND DISCUSSION

Jobs 1 and 2. Wolf Density Estimation and Assumption Testing

Success of the density estimate depends on a 7.5 cm or greater snowfall, calm winds and good flying conditions for a 2- to 4-day period. During late February and March 1990, several snow storms hit the Copper River Basin and we completed three wolf surveys.

We conducted the first survey on 15 February 1990 approximately 30 hours after a 46-51 cm snowfall in the 4,556 km^2 Alphabet Hills Study Area. Two Super Cubs were used to fly four systematic samples consisting of three 26.2-km long transects oriented in a north-south direction (Fig. 1). An additional Super Cub searched the most probable wolf travel routes between transects to determine if any wolf tracks originating in these areas had crossed a transect but were missed by the transect planes. We also flew each transect twice to verify if we missed any wolf tracks.

We observed three packs containing 38 wolves, resulting in a study area estimate of 66.9 wolves (Table 1) (SE=26.02) with an 80% confidence interval of 38 to 109.6 wolves. The study area's density was 14.7 wolves/1,000 km^2 (SE=5.71), with an 80% confidence interval of 8.3 to 24.1 wolves/1,000 km^2. The average pack consisted of 12.7 wolves (SE=3.67) and the average travel distance perpendicular to the transect, weighted by pack size, was 14.5 km (SD=4.13). The average inclusion probability, weighted by pack size, was 0.213 (SD=0.053).

All wolf tracks were continuous and successfully tracked to the animals except for a pack of two wolves whose tracks had become covered by drifting snow when they crossed a 3-km long ridge. The tracks were still faintly visible but might have been missed or would have been recorded as being deposited before snowfall if the transect had crossed them on the ridge, and as a result, this section of track was not used in calculating the X-axis distance traveled by this pack. Once the wolves left the ridge their tracks were again obviously fresh and were followed to the carcass of a dead moose that had been used during the past 30 hours by a pack of 18 wolves. These two wolves were combined with the 18 to form a network and calculations were based on the inclusion probability of a network (Becker 1991, p732) of 20 wolves. The network approach was unavailable for the first analysis (Becker and Gardner 1990). This approach eliminated the subjectivity of determining where the group of two wolves travelled, increased the 1990 point estimate by 1.1 wolves and appreciably increased the precision of the estimate from the 1990 standard error of 35.42 wolves (Becker and Gardner 1990).

Five moose, two being a cow/calf pair were used by three different wolf packs (id: 2,3, & a pack of 11 just outside the east boundary) (Table 1) since snowfall. These packs had traveled an average of 8.7 km (SD = 1.70 km).

Reflying the transects produced no new tracks. The team, which did not fly transects but searched likely habitat for wolves, found three wolf packs which crossed at least one transect. All these packs had been observed by the transect teams. Mapping wolf travel routes and number of wolves/pack corresponded closely between spotter teams.

We conducted the second survey on 20 February 1990, 54 hours after a snow storm in the 5,201 km^2 Lake Louise Flats Study Area. Two Super Cubs were used to fly four systematic samples consisting of four 33.1-km long transects oriented in a east-west direction (Fig. 2). An additional Super Cub was used to search areas between transects to determine if any wolf tracks were missed by the transect planes. After completing their transects, the two transect teams did localized searches between transects and tracked any recent wolf tracks to determine if any had crossed the transects and were unobserved.

Three packs coı. ıining 29 wolves were observed resulting in an estimate of 49.1 wolves (SE=39.25) with an 80% confidence interval of 29 to 113.4 wolves. The study area density was 9.4 wolves/1000 km^2 (SE=7.55) with an 80% confidence interval of 5.6 to 21.8 wolves/1,000 km^2. Average pack size was 8.0 wolves (SE=4.04) and the average distance traveled perpendicular to the transects, weighted by pack, was 8.1 km (SE=1.03 km). The average inclusion probability, weighted by pack size, was 0.207 (SD=0.026).

Tracks of the three packs were continuous and successfully backtracked to the animals. Kills of one moose and one caribou were utilized by two packs (id: 1,2) (Table 2) since snowfall. The two packs had traveled a weighted mean distance of 9.9 km (SE=0.39 km) since snowfall.

Flying the areas adjacent to transects resulted in identifying one pack of three wolves that had crossed the transect but was missed during the regular transect search. Aerial observation of these tracks revealed the pack had followed Tolsona Creek, but before creek/transect intersection, the wolves had turned into a thick spruce (*Picea*) stand and followed a caribou trail. This pack was included in the estimate and treated as though it was found during the initial transect survey. The third Super Cub, which searched likely habitat for wolves, found three wolf packs, but none had crossed a transect.

Survey conditions between the Lake Louise and Alphabet Hills study areas were different and warrant comments. The increased density and height of the overstory and larger number of caribou in the Lake Louise Study Area made it more difficult to survey. It is necessary when surveying through low sightability areas such as dense overstory, ungulate tracks, overflow, and hard snow that the survey team spend more time inspecting the difficult areas and does not move on until they are sure no wolf tracks are being missed. In areas with large expanses of low sightability, the estimation technique would not produce accurate results because the assumptions that all tracks that cross the transects are observed and all tracks can be followed would surely be violated. Decreasing the length of time between the ends of snowfall and the initiation of the survey would help reduce tracking problems because of caribou, however, the probable reduction in the inclusion probabilities will cause a loss of precision.

We conducted a third survey on 16 March 1990, 48 hours after a partial snowstorm in the 5,335 km^2 Alphabet Hills 2 Study Area. The eastern boundary of the Alphabet Hills Study Area was moved to include several more packs. We used three Super Cubs to fly 7 systematic samples consisting of 5 26.2-km long transects oriented in a north-south direction (Fig. 3). In addition to flying transects, localized searches for wolf tracks between transects were conducted to determine if all wolf tracks which intersected the transect were observed.

We observed eight packs containing 77 wolves, resulting in an estimate of 124.2 wolves (SE=32.82) with an 80% confidence interval of 77 to 172.46 wolves. The study area's density was 23.3 wolves/1,000 km^2 (SE=6.15) with an 80% confidence interval of 14.4

to 32.3 wolves/1,000 km^2. Average pack size was 9 wolves (SE=2.29) and the average distance traveled perpendicular to the transects, weighted by pack size, was 16.9 km (SD=5.22 km). The average inclusion probability, weighted by pack size, was 0.531 (SD=0.170).

Tracks of the eight packs were continuous and successfully backtracked to the animals. Twelve moose kills, three of which were outside the study area, were used by wolves since snowfall. Of the five packs observed on kills, three (id. 3,4,5) (Table 3) had traveled a mean distance, weighted by pack size, of 28.2 km, (SD=10.96) perpendicular to the transects, while the other two packs (id 6,7) only moved 2.4 km (SD=0.58). Pack 8 consisting of a lone wolf traveled primarily parallel to the transects and only traveled 2.1 km perpendicular to the transects. Observers saw one wolf, dead of unknown causes. All planes flew areas between the transects and no additional packs were observed.

The tremendous range of distances (1.9 to 36.4 km) traveled by wolves during this survey was mainly because of differences in the timing of snowfall. Some packs spent the entire period on, or very near, a kill. The eastern portion of the study area had received the most snowfall (7.5 cm) 48 hours before the survey. Snowfall was less in the south-central portion of the study area and ended approximately 60 hours before the survey. The northwest section of the study area did not receive any new snow, and tracks were at least one week and possibly one month old. The distances wolves traveled were greatest in the areas that received little to no snowfall.

On 14 March 1991, a wolf survey was conducted 69 hours after a 7.5 cm snowfall in the 5,335 km^2 Subunit 13B study area. Three Super Cubs were used to fly 7 systematic samples consisting of five 26.2-km long transects oriented in a north-south direction (Fig. 4). Our localized searches between transects did not find any wolf tracks that had intersected the transects and had not been observed.

We did not obtain an estimate from this survey because three of the technique's assumptions outlined by Becker (1991) were violated. The assumptions violated were: 1) pre- and post-snowstorm tracks can be distinguished, 2) all animal tracks are continuous, and 3) all animals can be tracked to both their current location and location at the end of the snowstorm. Weather, light conditions, and an ongoing wolf hunt caused the failure. In parts of the study area, the light was too flat and the delay between end of snowfall and the survey was too long for the snow conditions. The 7.5 cm snowfall came after three weeks of no snow and the ungulate and canid track density in the area was high. This minimum amount of snow was not enough to adequately cover old tracks and we had great difficulty following the packs, especially through trees when the animals followed one of their own trails or a moose trail. Also, before the survey in the northern part of the study area, a strong wind blew erasing tracks for long distances causing us to lose the tracks of two packs. In concert with the difficult tracking conditions, there were obvious impacts from the ongoing wolf hunting season. The wolves were very difficult to see as they were very secretive, travelling long distances in dense timber and also, several packs were scattered because they had recently been hunted. In total, we found tracks of six packs but only observed wolves in three of the packs observed.

Based on the results from these surveys, it is extremely important that only pilots with excellent tracking skills be used for this technique to work. The pilot has the best visibility and the best chance of detecting tracks. The biologist should also be able to recognize tracks to ensure that no tracks are being missed, but because of lower visibility in the back seat, the biologist's primary duties are: to ensure that the plane is correctly flying the transects, that areas of low sightability are being adequately surveyed; to map wolf movements and locations of kills accurately; and to take notes on pack size, pack color composition, and tracking conditions.

We found that this estimator is difficult to use in areas with high caribou densities, since wolf tracks can resemble caribou tracks and also, because wolves will follow caribou trails and may be missed. If the study area has low caribou densities, we recommend that all caribou tracks which intersect the transect be followed for a short distance to avoid missing wolf tracks. Our data suggest that the assumption that all wolves which cross the transect are observed is reasonable, especially if intensive searches are conducted in areas of low sightability along the transect.

To obtain a useful wolf density estimate, careful attention must be given to weather conditions, the amount of human disturbance, timing of the survey, and transect orientation. Factors that need to be considered in determining the timing of the survey are: 1) the amount of snowfall and whether it was consistent over the entire study area; 2) survey time will increase if snowfall was light (at least 7.5 cm) and heavy track deposition occurred before snowfall; 3) normal weather patterns for the area, i.e. the chance for strong winds or significant cloud cover; 4) the habitat of the area; 5) ungulate densities and 6) the intensity wolves are being hunted in the study area. Orienting transects to run perpendicular to major wolf travel routes will increase precision. The use of this technique is greatly reduced in areas with volatile weather patterns, dense overstory, or occupied by high densities of caribou, because of the likelihood of either missing tracks or not following tracks accurately.

After completing four wolf surveys in Unit 13, we believe that for areas between 5,000 and 6,000 km^2 that seven systematic samples with five transects is the **minimum** sampling intensity that should be used. Approximate cost including flying the area between the transects is $1,900 to $2,600 per survey ($135.00/hr Super Cub cost).

<u>Job 3 and 4. Wolverine Density Estimation and Assumption Testing</u>

The Talkeetna Mountain wolverine study area, totalling 2,700 km^2, was surveyed 47 hours after a 15 cm snowfall on 27 February 1991, using six systematic samples consisting of three 38.9 km transects oriented in an east-west direction (Fig 5). After completing the transects each survey team searched between transects to check if all wolverine tracks crossing the transects were observed. The additional searches revealed no missed tracks.

We followed 11 wolverine tracks (Table 4) to the animal or to its hiding place under snow or rocks, and estimated 12.66 wolverines (SE = 1.64), with an 80% confidence interval of 12.0 to 15.09 wolverines. Wolverine density was estimated at 4.69 wolverine/1,000 km^2 (80% confidence interval of 4.44-5.59/1,000 km^2). We followed one other wolverine but it had not crossed a transect. The average group distance travelled perpendicular to the transects was 9.74 km (SE = 1.85). Two groups of two wolverines travelled together and both were associated with moose carcasses. One group observed on a moose carcass had travelled around 10 km together since the end of snowfall. The other group had used a common carcass but had separated by survey time. Since the end of snowfall, the two animals had travelled about 17 km and 33 km, respectively.

Based on the length of movements and the amount of track crossing and backtracking done by these wolverines in 47 hours we believe that 48 hours is the maximum time a wolverine survey should be conducted after an adequate but shallow snowfall (7.5 to 20 cm). The sampling intensity of 6 systematic samples and three transects for a 2,700 km^2 area with a 48-hour delay between end of snowfall and the survey gave a reasonable population estimate that could be used in management decisions.

Job 5. Sampling Intensity and Timing

Three general methods to increase precision of the population estimate are: 1) use of a better sample design; 2) increase inclusion probabilities by increasing the time between the end snow fall and the initiation of the of survey; and 3) increase sampling effort.

Assuming inadequate information to stratify, and a tendency for home ranges not to overlap, a repeated systematic sample design should be close to optimum (Becker 1991, p732). Simulation results, using known and guesstimated 30 hour wolf and guesstimated 60 hour movements within the Alphabet Hills 1 Study Area, indicates that the configuration of the systematic sample design, given that sampling effort is fixed, can impact the precision of the estimate. The movement data was collected when during a year in which "land and shoot" by aerial hunters was prohibited. The following discussion of optimal results assumes that confidence intervals which can potentially use the number of wolves seen during the survey are superior to the traditional confidence intervals in a decision making context. Optimal sample designs will be based upon the widths of the modified confidence intervals.

Based on the results of simulating each systematic sample design 1,000 times, and assuming the above 30 hour movement patterns, optimal systematic sample designs for two, three, and four plane surveys in a 5,335 km^2 study area were five systematic samples of five transects (Fig. 6), seven systematic samples of five transects (Fig. 7), and two systematic samples of 24 transects (Fig. 8), respectively. A four plane design of 5 systematic samples of 10 transects each did almost as well as the one above (Fig. 8) and was felt to be more robust to changes in movement patterns, and as a result, is preferred over the two systematic samples of 24 transects design. These results assume transect lengths and light conditions that allow 2, 3, and 4 airplane surveys to search approximately 24, 36, and 48 transects respectively. Based on this movement data, precision increases linearly as survey effort increases from 2 to 4 planes (Fig. 9).

For 60 hour movement patterns, optimal systematic sample designs for 2, 3, and 4 plane surveys in a 5,335 km^{2} study area were 5 systematic samples of 5 transects (Fig. 10), 2 systematic samples of 18 transects (Fig. 11), and 2 systematic samples of 24 transects (Fig. 12), respectively. Based on these movement data, precision appears to increase linearly as survey effort is increased from 2 to 4 planes (Fig. 13).

The most dramatic increase in precision occurred by increasing sampling effort. Allowing more time for animals to move and using optimal designs also produced marked increases in precision. Allowing more time for animals to move increases the chances of detrimental weather conditions and/or tracks from other species to obscure tracks, and may result in failure of model assumptions.

The time period between end of snowfall and the survey was 29 to 35 hours longer in the 1991 wolverine survey than that of the 1988 survey (conducted 12 to 18 hours after snowfall). The gain in precision, based on differences in the 80% confidence interval half width expressed as a percentage of the point estimate, was 14.1% (33.3 to 19.2%). Since sampling intensity, as measured by transect density, was similar (1 transect/150 to 155 km^2) for both surveys and the median of the observed inclusion probabilities were similar (0.479 in the earlier survey and 0.435 in 1991), the increase in precision was mainly a result of the reduction in the standard error because of a larger sample size.

RECOMMENDATIONS

In the absence of detailed wolf movement data to simulate, the simulation results provide insights for sample design and effort decisions. The presence of aerial hunting of wolves may alter the utility of the simulations results since wolf movement patterns in years when land and shoot by aerial hunters was legal, was substantially different in the amount of pack splintering and use of more heavily forested habitat. This can make wolves harder to track. Aerial hunting may decrease the utility of increasing the amount of time between the end of snow fall and initiation of the survey beyond 72 hours by producing conditions in which packs can not be adequately tracked. Additional sample effort and choice of a better sample design should increase the precision of the estimate, even if aerial hunting is occurring. The availability of good pilot/observer tracking teams may be a limiting factor to increasing sampling effort. Performing wolf surveys in the fall, prior to aerial hunting, should help increase the precision of the estimator. High ungulate concentrations in the study area will require a shorter time frame between the end of snowfall and beginning the survey, and the amount of snowfall required to initiate the survey may be increased to ensure the elimination of old tracks.

Following the general approach we used in the Talkeetna Mountains wolverine estimate, we believe excellent wolverine estimates can be obtained. If adequate numbers of radio-collared wolverines become available, an additional wolverine survey coupled with locating and backtracking the radio collared wolverine, would provide an excellent test of the assumption that all of the wolverine which cross the transect are observed.

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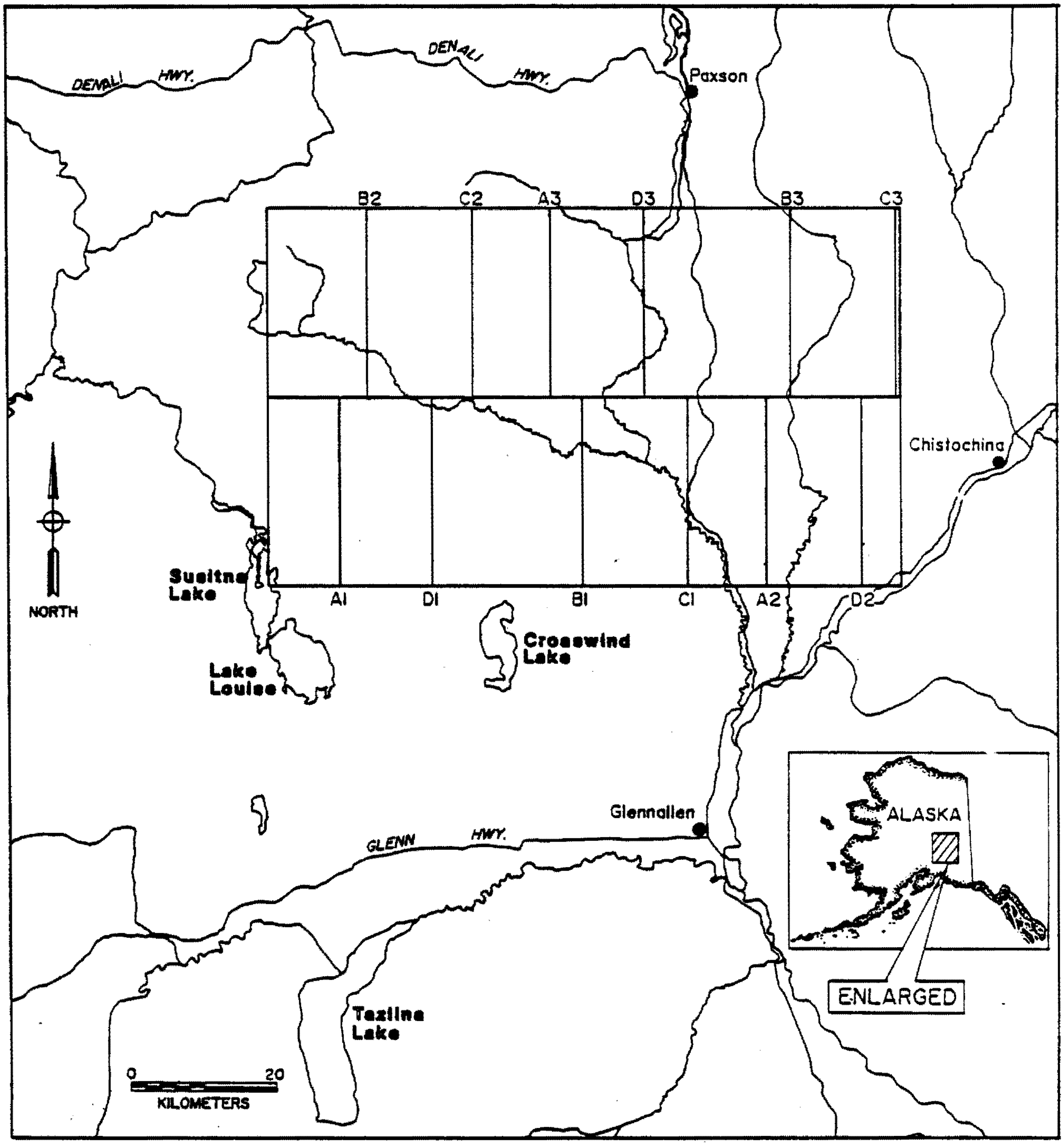


Figure I. Alphabet Hills wolf study area for the 15 February survey. Study area boundaries and location of 4 systematic samples (A-D) with 3 transects per sample (I-3) are shown.

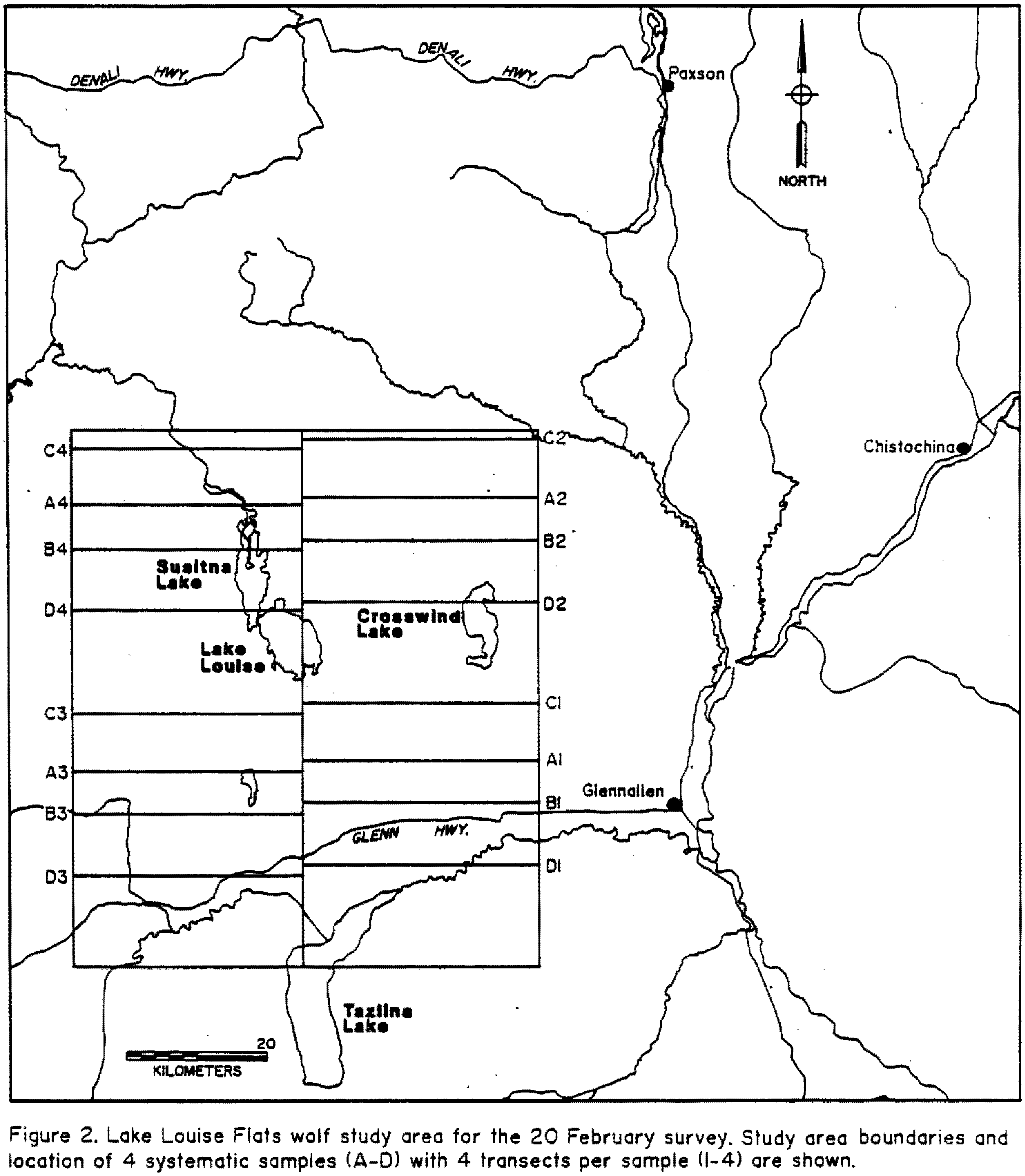


Figure 2. Lake Louise Flats wolf study area for the 20 February survey. Study area boundaries and location of 4 systematic samples (A-D) with 4 transects per sample (1-4) are shown.

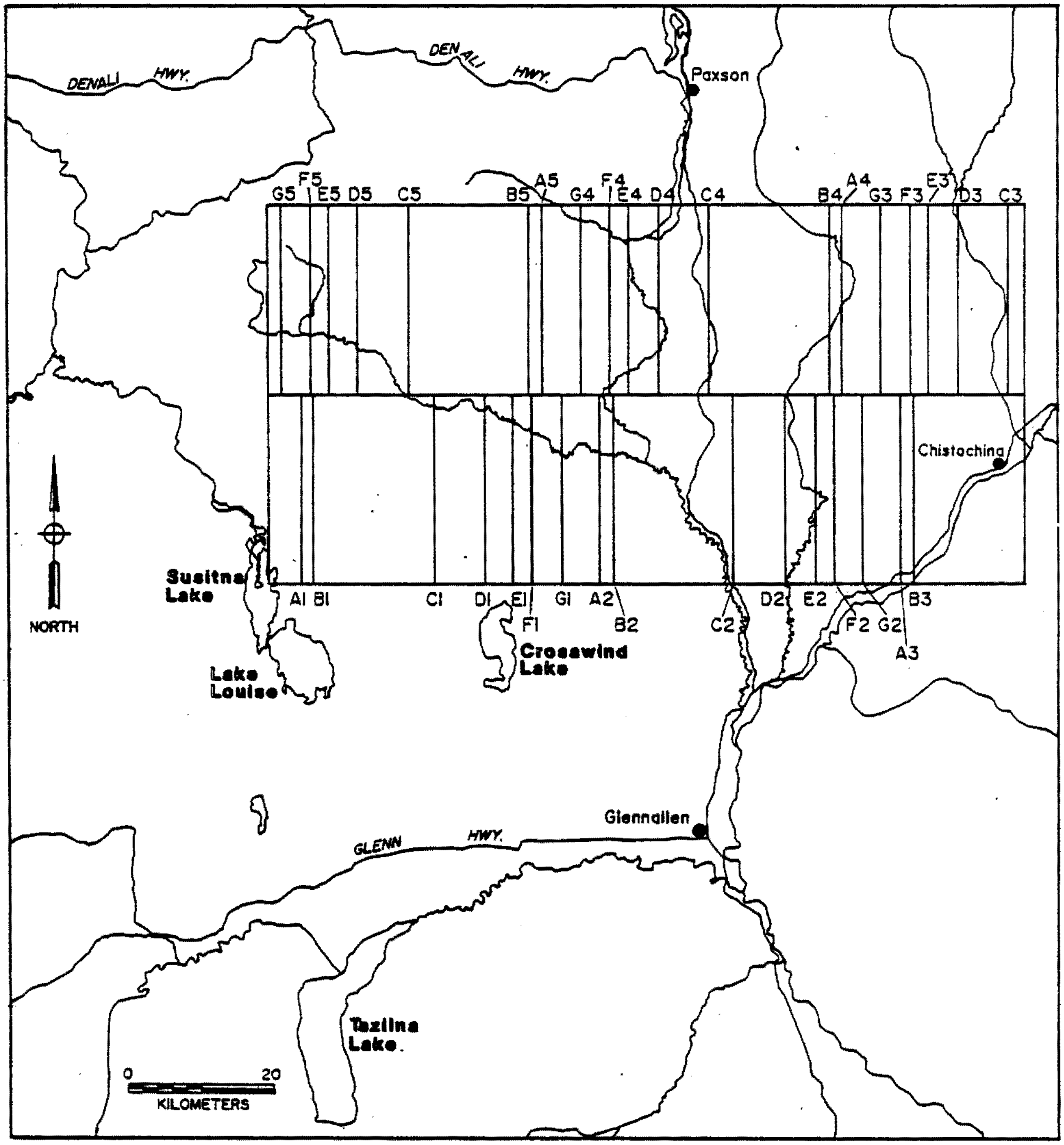


Figure 3. Alphabet Hills wolf study area for the 16 March survey. Study area boundaries and location of 7 systematic samples (A–G) with 5 transects per sample (1–5) are shown.

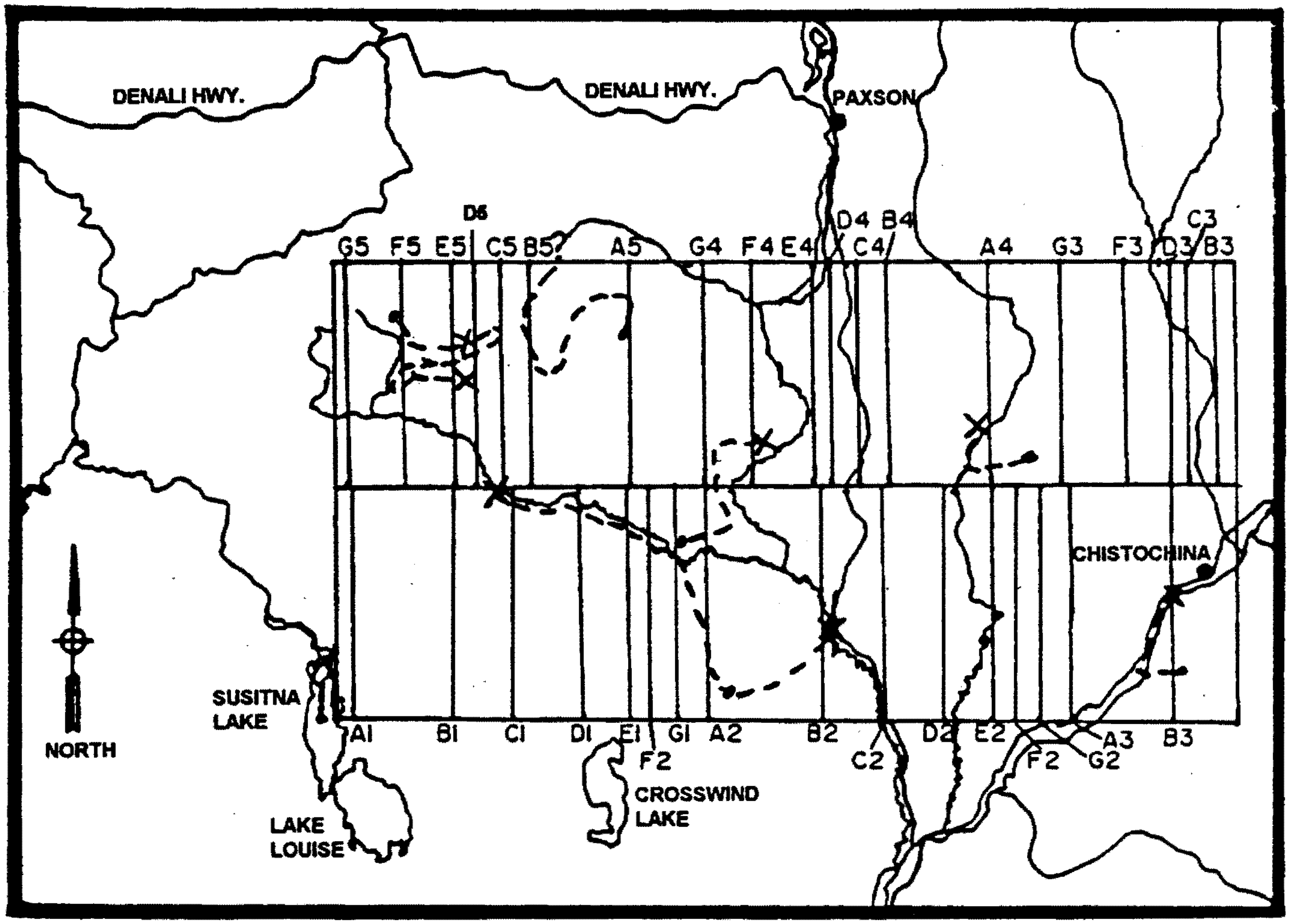


Figure 4. Alphabet Hills wolf study area for the 14 March 1992 survey. Study area boundaries and location of 7 systematic samples (A-G) with 5 transects per sample (1-5) are shown.

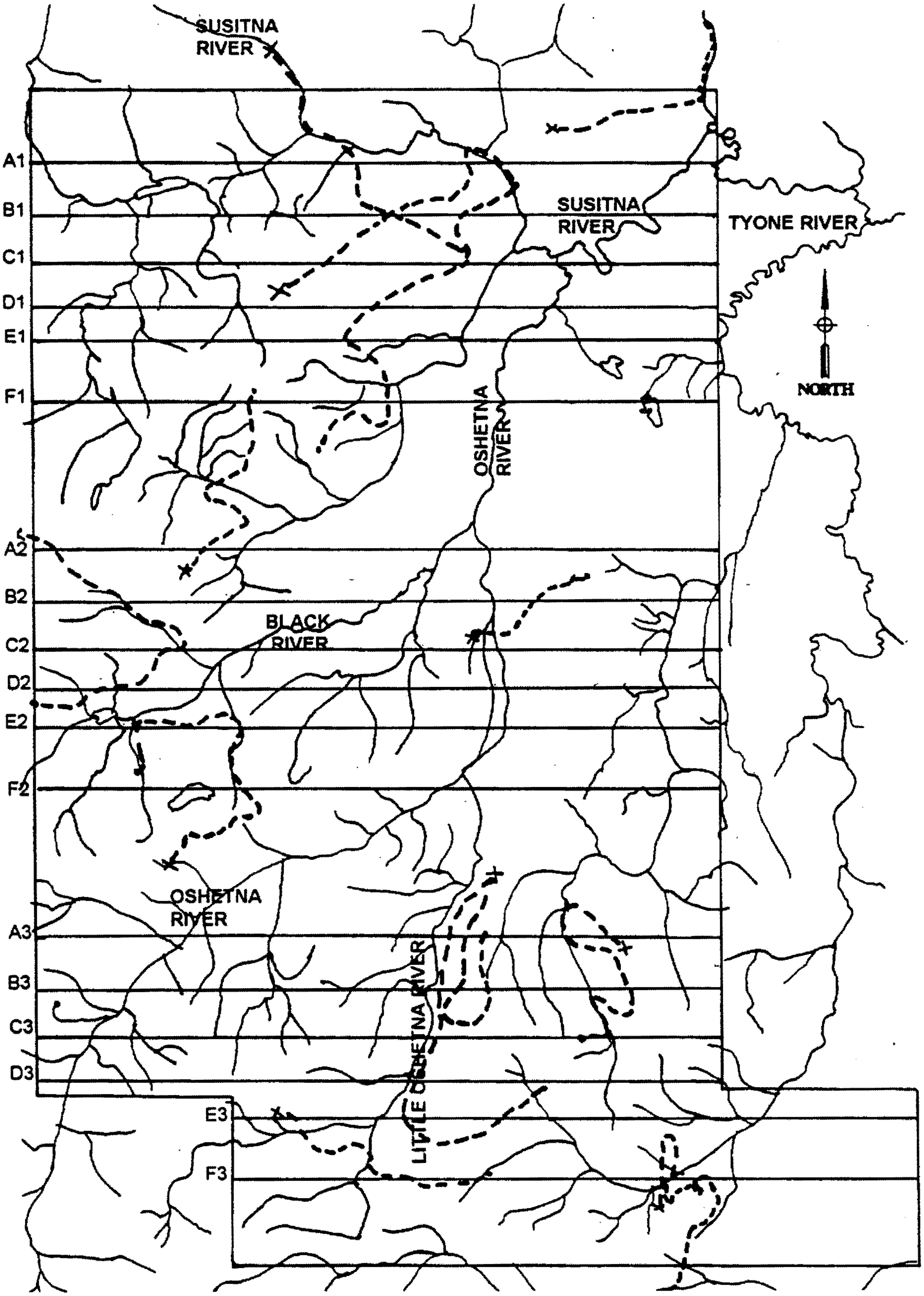


Figure 5. Talkeetna Mountains region wolverine study area for 2 February 1991. Survey study area boundaries, location of 5 systematic samples (A-F) with 3 transects per sample (1-3), wolverine movements (--), and location (X) are shown.

Fig. 6. Simulation results of confidence interval width for 2 airplane surveys on a population of 77 wolves with 30 hour movements.

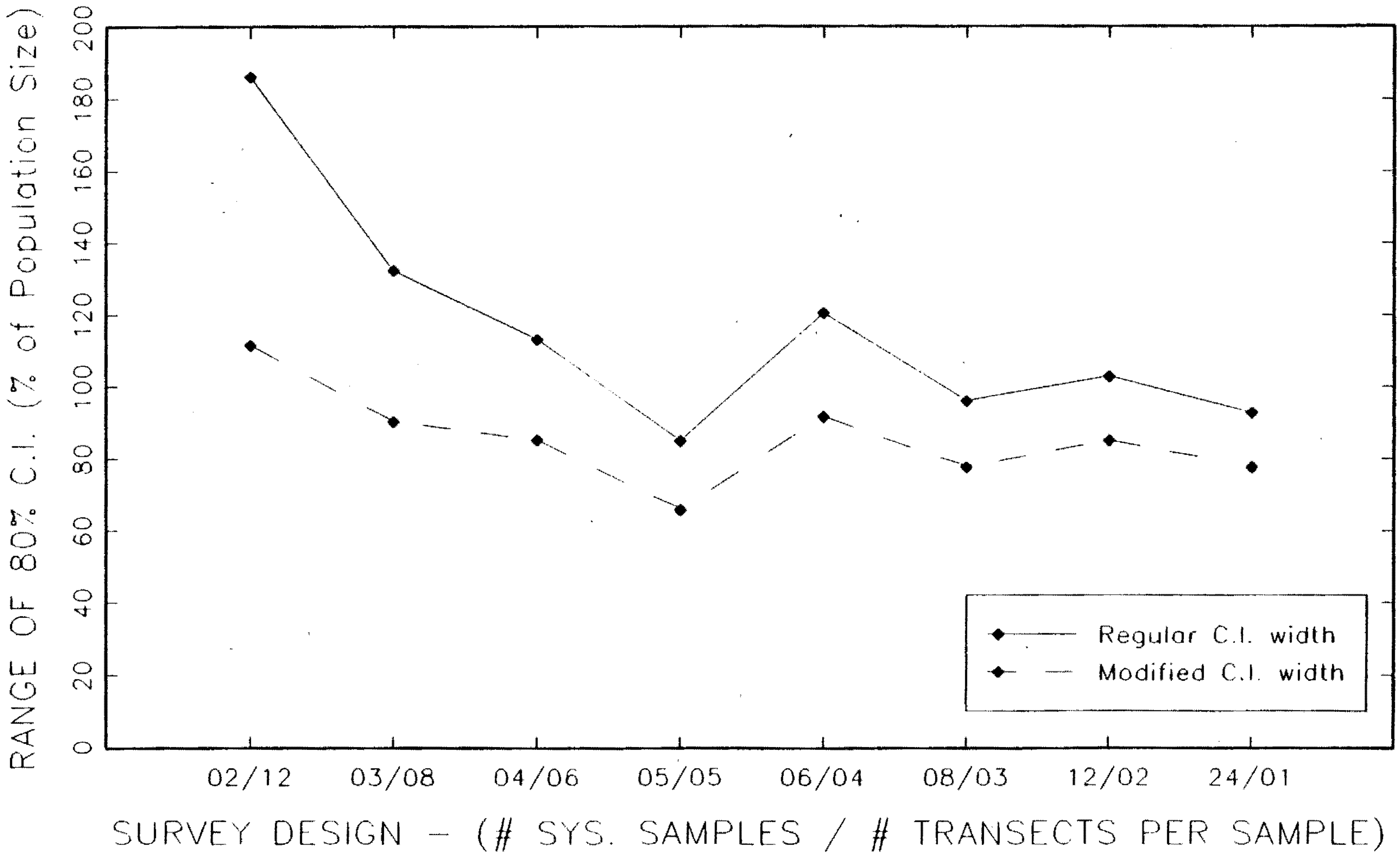


Fig. 7. Simulation results of confidence interval width for 3 airplane surveys on a population of 77 wolves with 30 hour movements.

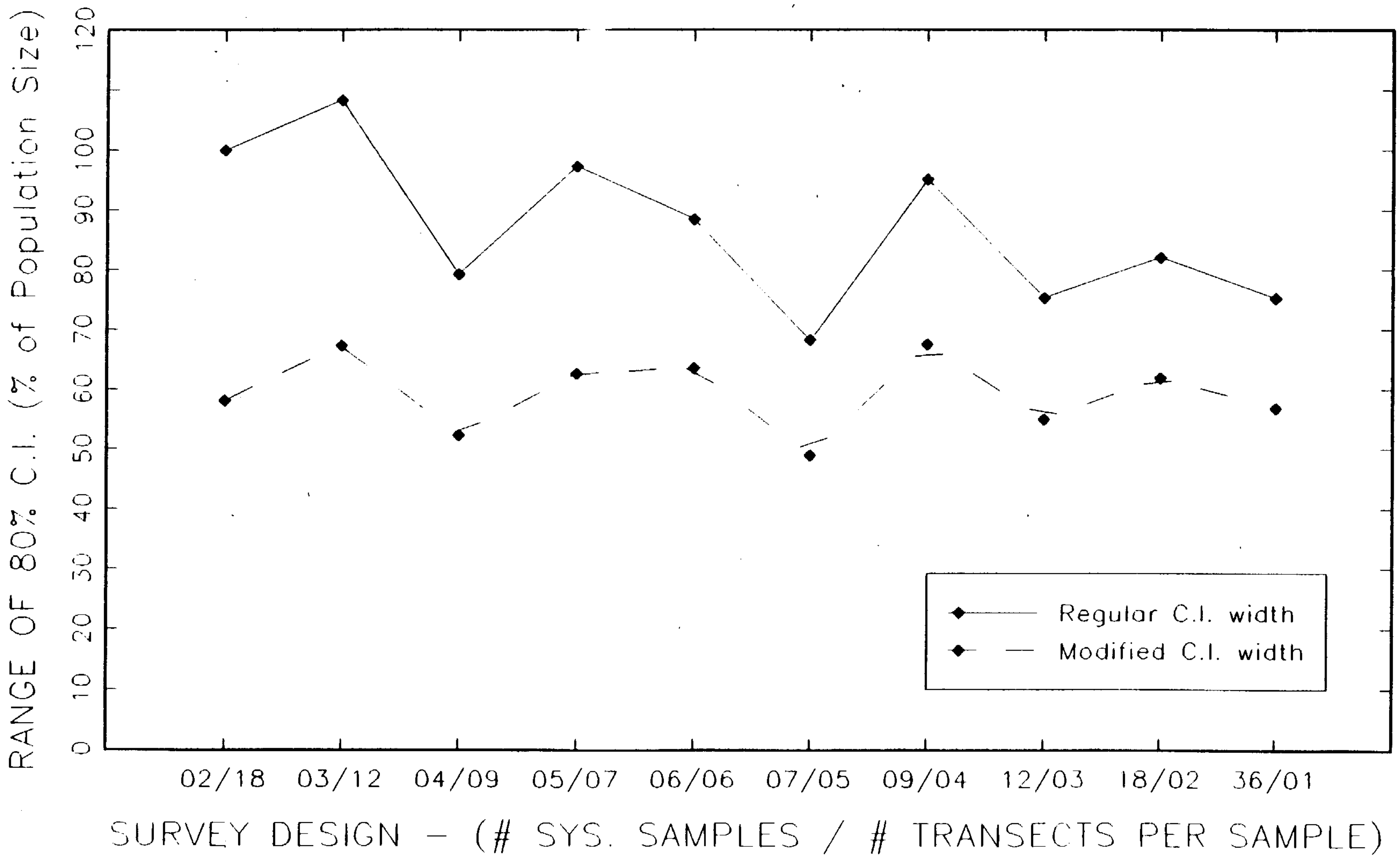


Fig. 8. Simulation results of confidence interval width for 4 airplane surveys on a population of 77 wolves with 30 hour movements.

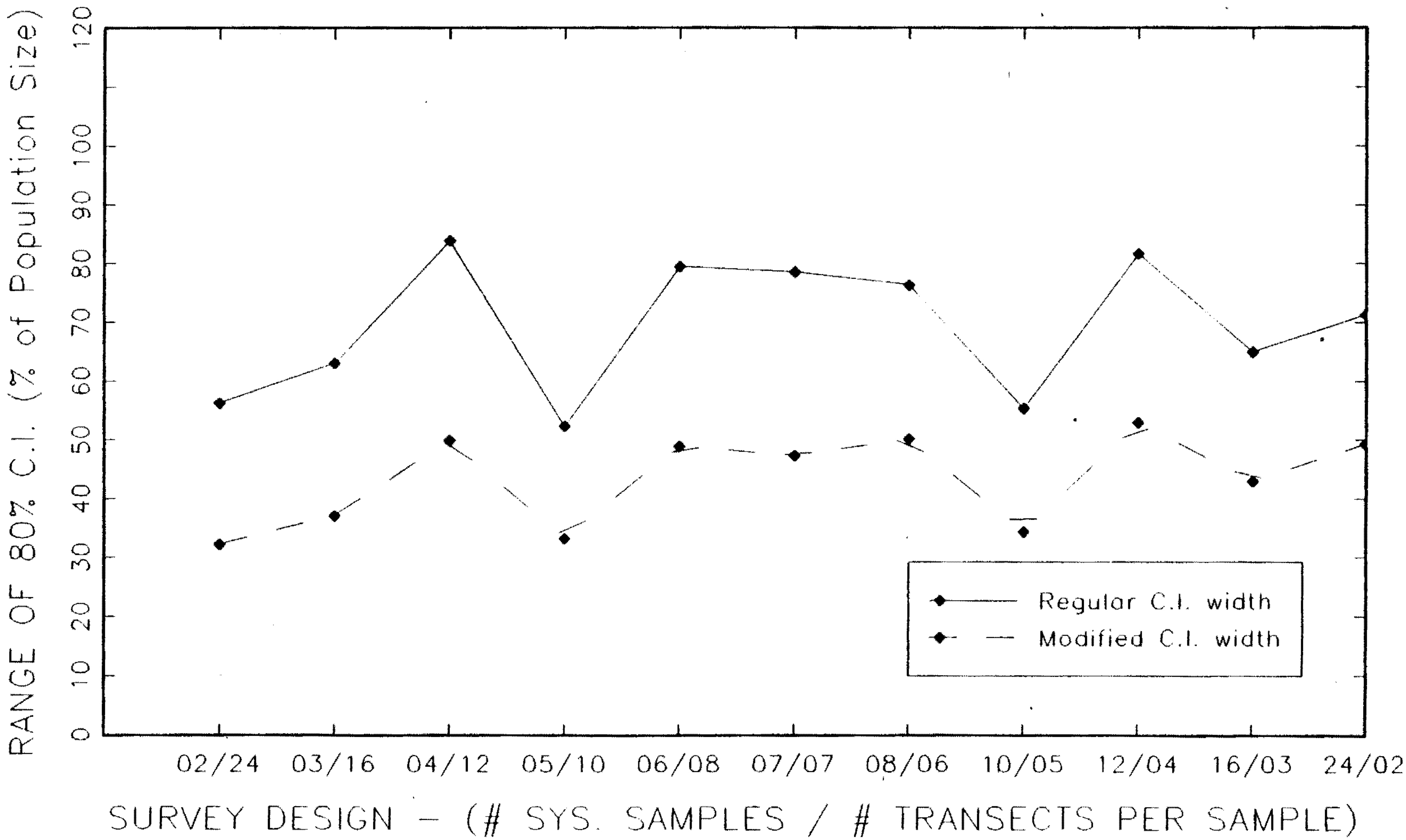


Fig. 9. Simulation results of confidence interval width for optimal 2, 3, and 4 airplane surveys on a population of 77 wolves with 30 hour movements.

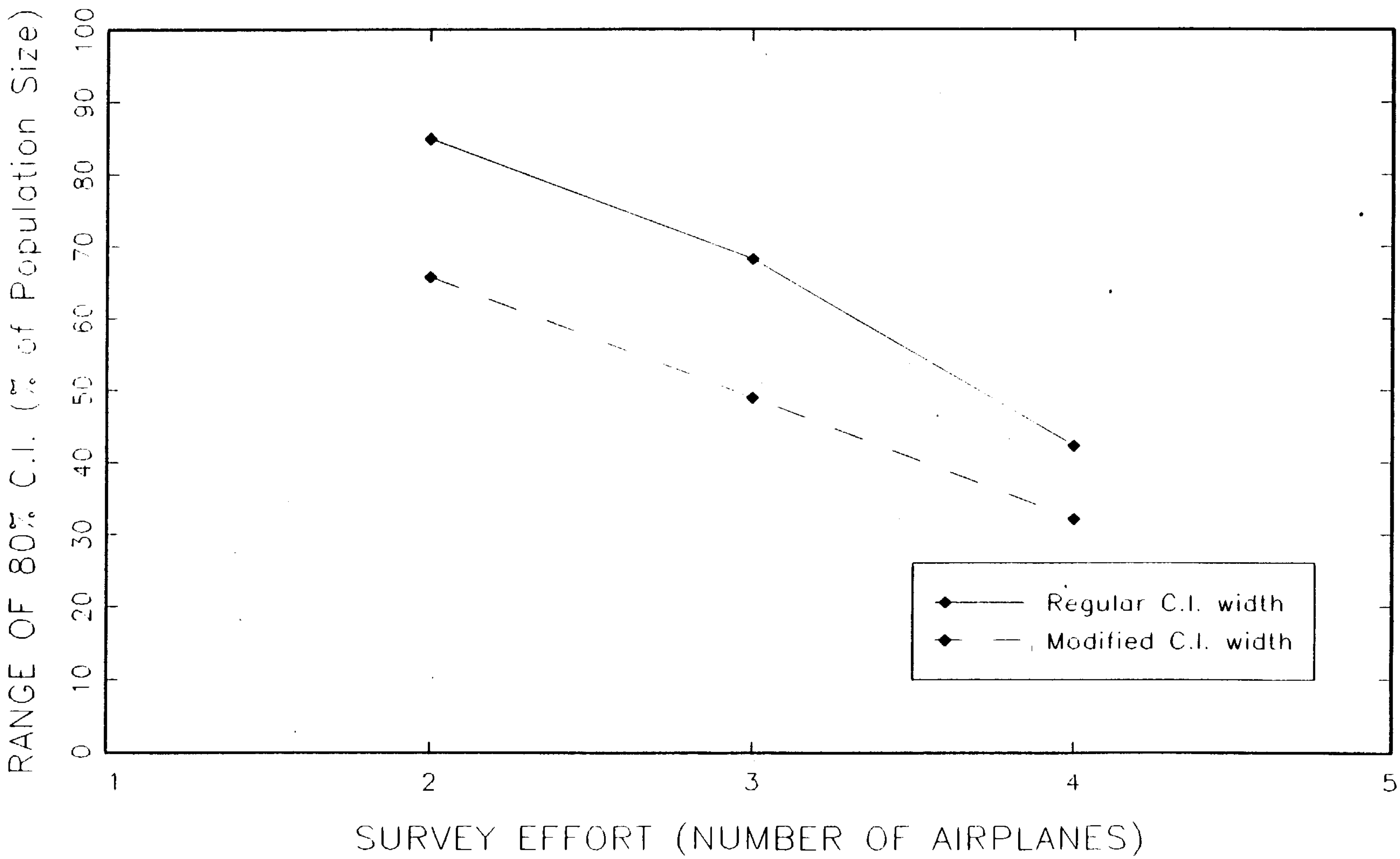


Fig. 10. Simulation results of confidence interval width for 2 airplane surveys on a population of 77 wolves with 60 hour movements.

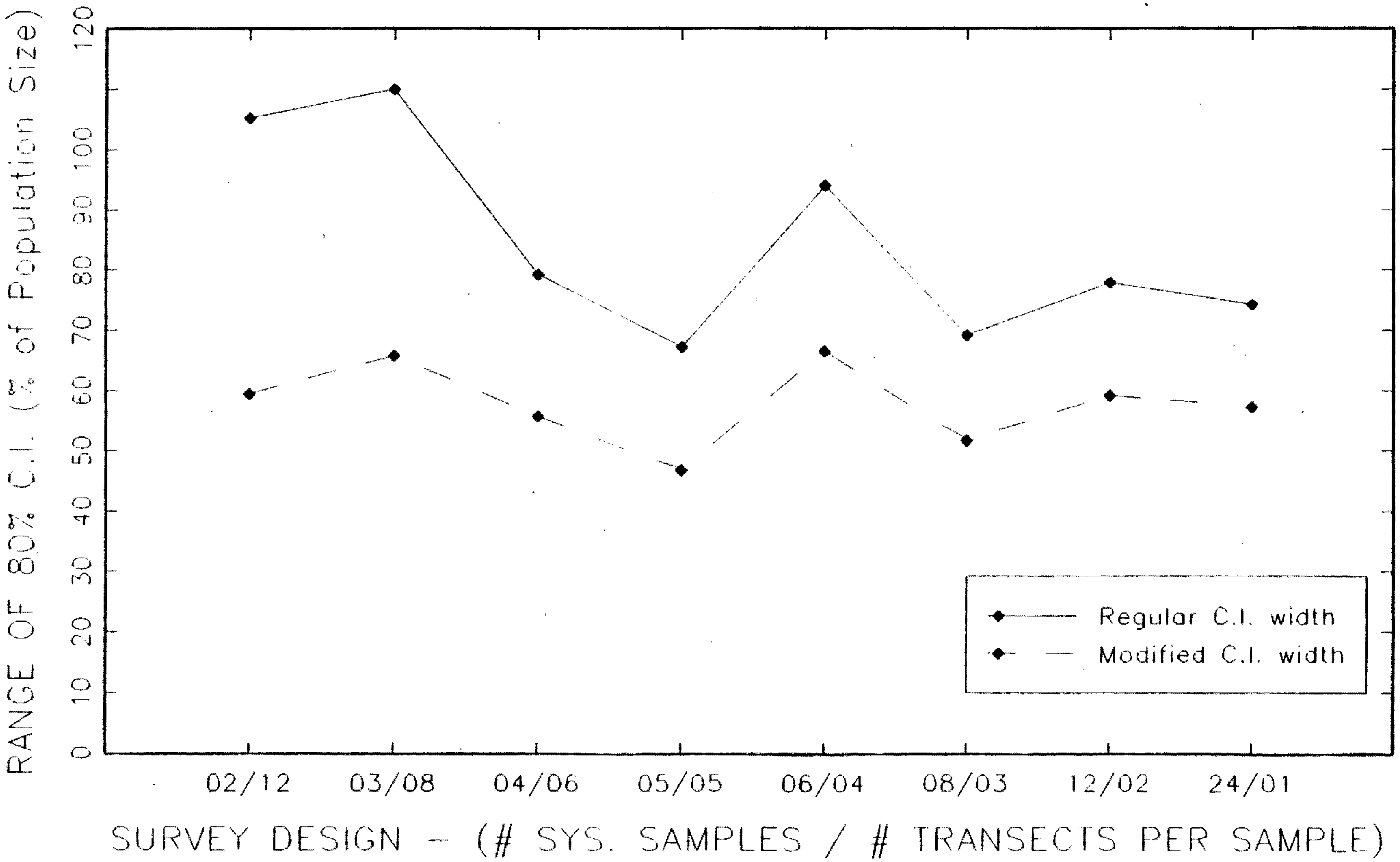


Fig. 11. Simulation results of confidence interval width for 3 airplane surveys on a population of 77 wolves with 60 hour movements.

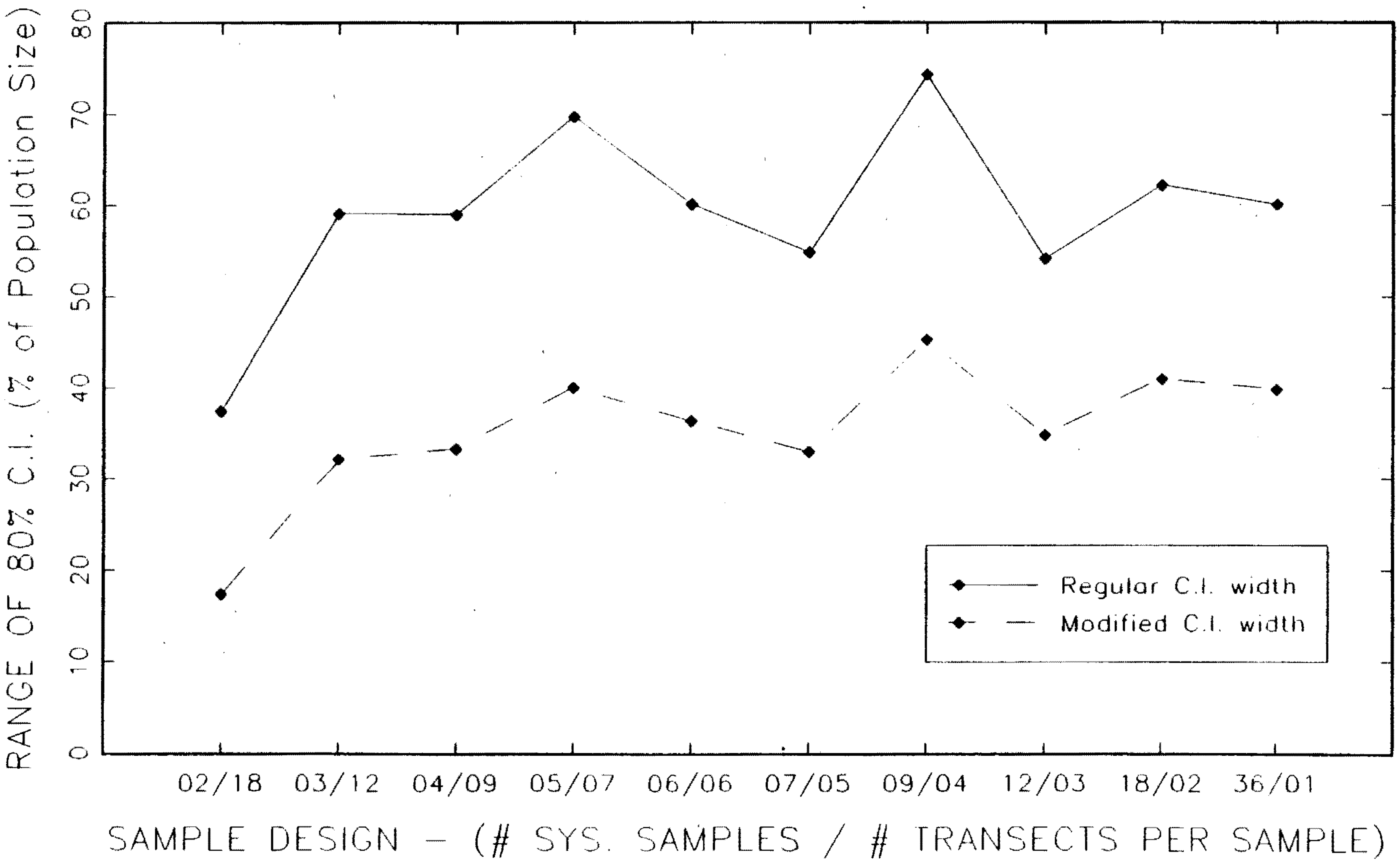


Fig. 12. Simulation results of confidence interval width for 4 airplane surveys on a population of 77 wolves with 60 hour movements.

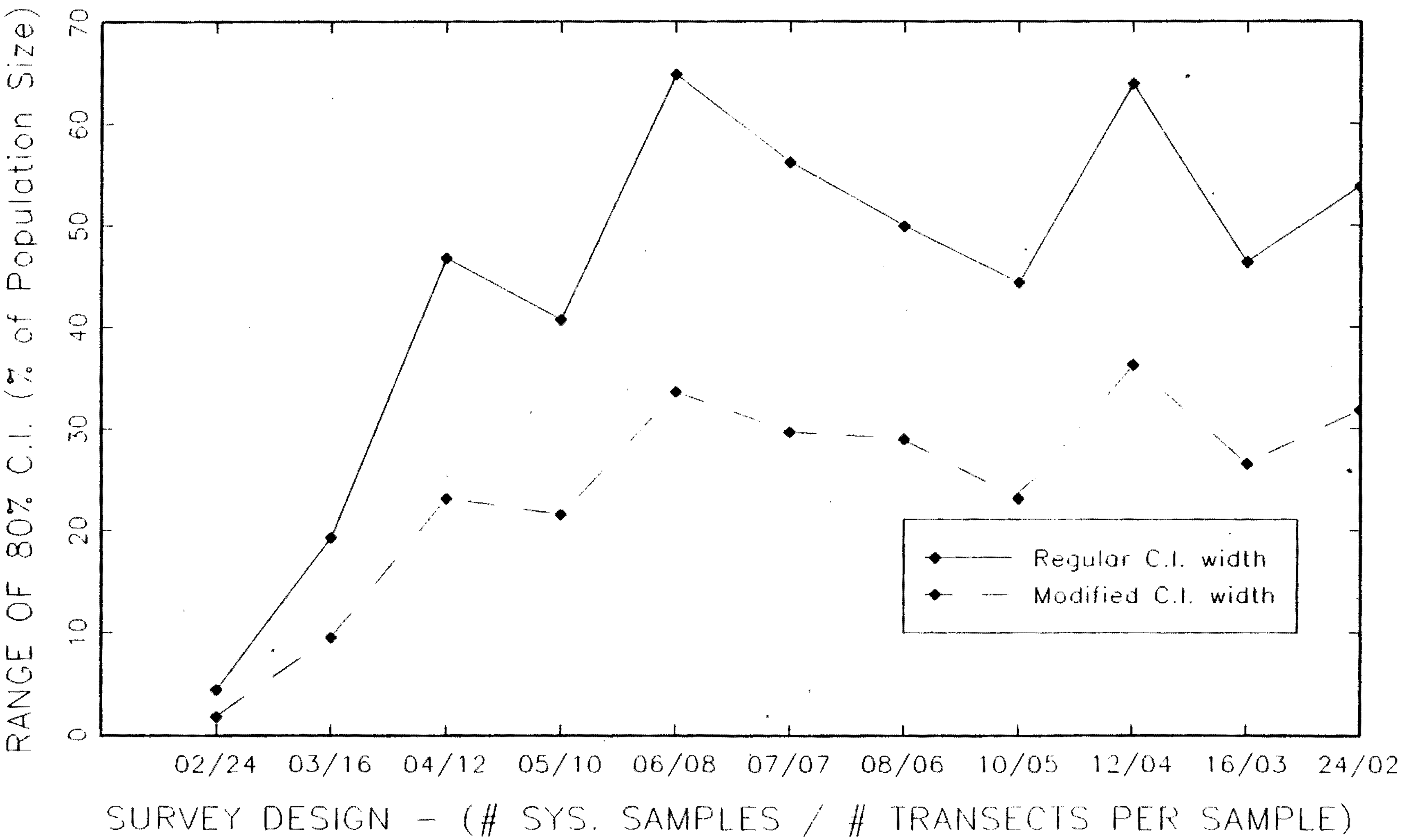


Fig. 13. Simulation results of confidence interval width for optimal 2, 3, and 4 airplane surveys on a population of 77 wolves with 60 hour movements.

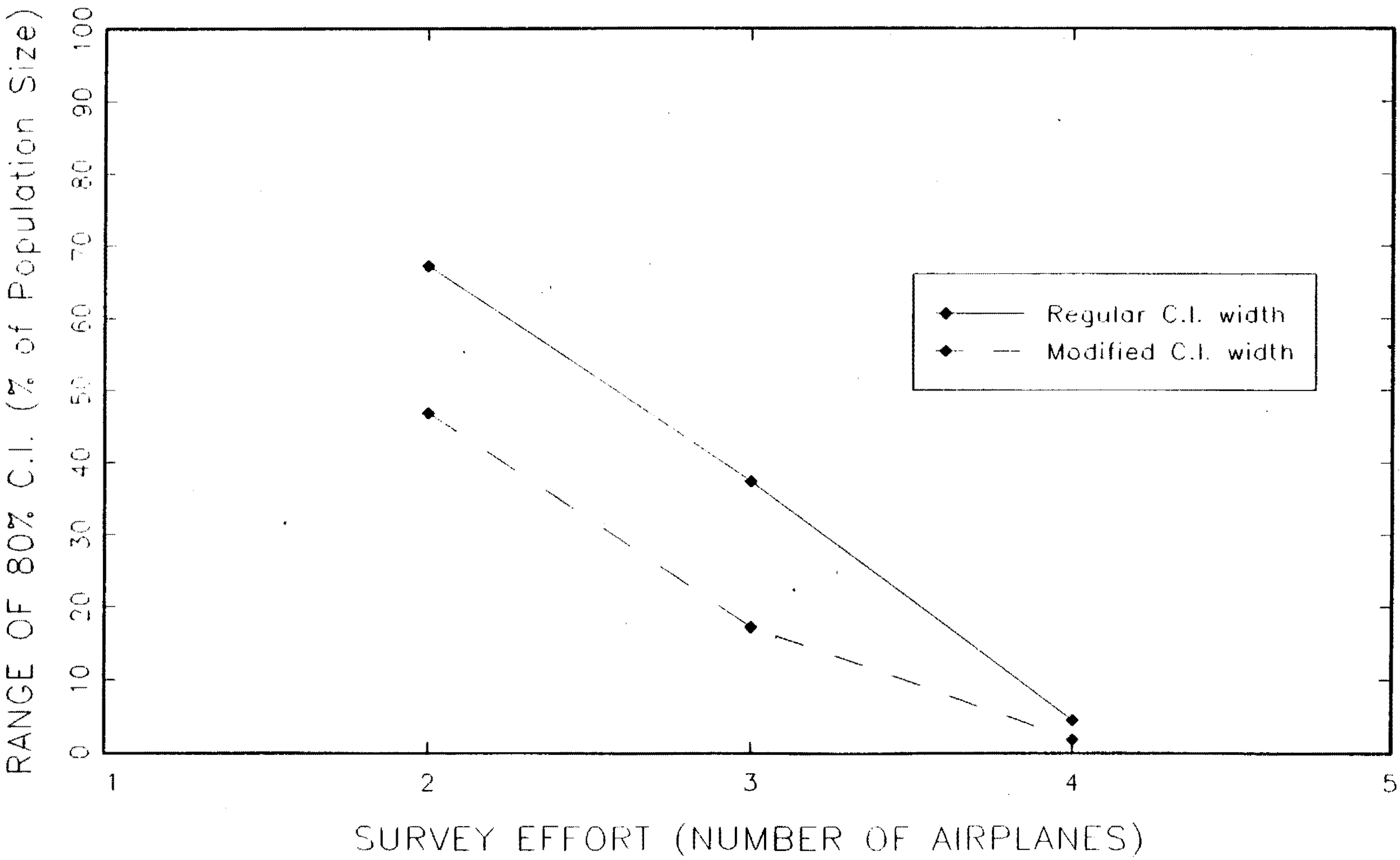


Table 1. Wolf survey data for a 4,556 km^2 area in the Alphabet Hills region of Subunit 13A, collected on 15 February 1990, approximately 30 hours after snowfall.

Sample/ Transect Id.	Pack Id.	# of Wolves	X_u	π_u	T_{yij}	$T_{yi.}$
A1	1	9	10.14	0.172	52.35	
A2		0			0	
A3	2	9	7.10	0.120	74.79	
						127.14
B1		0			0	
B2	3	20	19.77	0.285	70.26	
B3		0			0	
						70.26
C1		0			0	
C2	3	20	19.77	0.285	70.26	
C3		0			0	
						70.26
D1		0			0	
D2		0			0	
D3		0			0	
						0

X_u - denotes the distance the pack traversed perpendicular to the transect (km.).
π_u - denotes the inclusion probability (probability this pack is observed in a systematic sample).
T_{yij} - denotes the contribution to the ith estimate.
$T_{yi.}$ - denotes the population estimate based on the ith systematic sample.

Table 2. Wolf survey data for a 5,201 km^2 area in the Lake Louise flat region of Subunit 13A, collected on 20 February 1990.

Sample/ Transect Id.	Pack Id.	# of Wolves	X_u	π_u	T_{yij}	$T_{yi.}$
A1	1	3	9.38	0.240	12.53	
A2		0			0	
A3	2	5	10.14	0.259	19.31	
A4		0			0	
						31.84
B1		0			0	
B2		0			0	
B3		0			0	
B4		0			0	
						0
C1		0			0	
C2	3	16	6.59	0.168	95.08	
C3	4	5	10.14	0.259	19.31	
C4		0			0	
						114.39
D1		0			0	
D2		0			0	
D3		0			0	
D4		0			0	
						0

X_u - denotes the distance the pack traversed perpendicular to the transect (km.)
π_u - denotes the inclusion probability (probability this pack is observed in a systematic sample)
T_{yij} - denotes the contribution to the *i*th estimate
$T_{yi.}$ - denotes the population estimate based on the *i*th systematic sample

Table 3. Wolf survey data for a 5338 km^2 area in the Alphabet Hills region of Subunit 13A, collected on 16 March 1990.

Sample/ Transect Id.	Pack Id.	# of Wolves	X_u	π_u	T_{yij}	$T_{yi.}$
A1	1	12	4.67	0.122	98.64	
A2	0	0				
A3	2	14	13.76	0.359	39.01	
A4	3	18	24.96	1.000	18.00	
A5	4	15	36.39	1.000	15.00	
A5(cont.)	5	3	6.29	0.164	18.27	
						188.92
B1	1	12	4.67	0.122	98.64	
B2		0			0	
B3	2	14	13.76	0.359	39.01	
B4	3	18	24.96	1.000	18.00	
B5	4	15	36.39	1.000	15.00	
						160.65
C1		0			0	
C2	6	6	3.03	0.079	75.88	
C3	7	8	1.87	0.049	164.40	
C4		0			0	
C5	3	18	24.96	1.000	18.00	
C5(cont.)	4	15	36.39	1.000	15.00	
						273.28
D1		0			0	
D2		0			0	
D3		0			0	
D4	4	15	36.39	1.000	15.00	
D5	3	18	24.96	1.000	18.00	
						33.00
E1		0			0	
E2	8	1	2.09	0.036	27.40	
E3		0			0	
E4		0			0	
E5	3	18	24.96	1.000	18.00	
E5(cont.)	4	15	36.39	1.000	15.00	
						60.40

Table 3. (continued)

Sample/ Transect Id.	Pack Id.	# of Wolves	X_u	π_u	T_{yij}	$T_{yi.}$
F1		0			0	
F2	2	14	13.76	0.359	39.01	
F3		0			0	
F4	4	15	36.39	1.000	15.00	
F5	3	18	24.96	1.000	18.00	
						72.01
G1	5	3	6.29	0.164	18.27	
G2	2	14	13.76	0.359	39.01	
G3		0			0	
G4	4	15	22.61	1.000	15.00	
G5	3	18	15.51	1.000	18.00	
						90.28

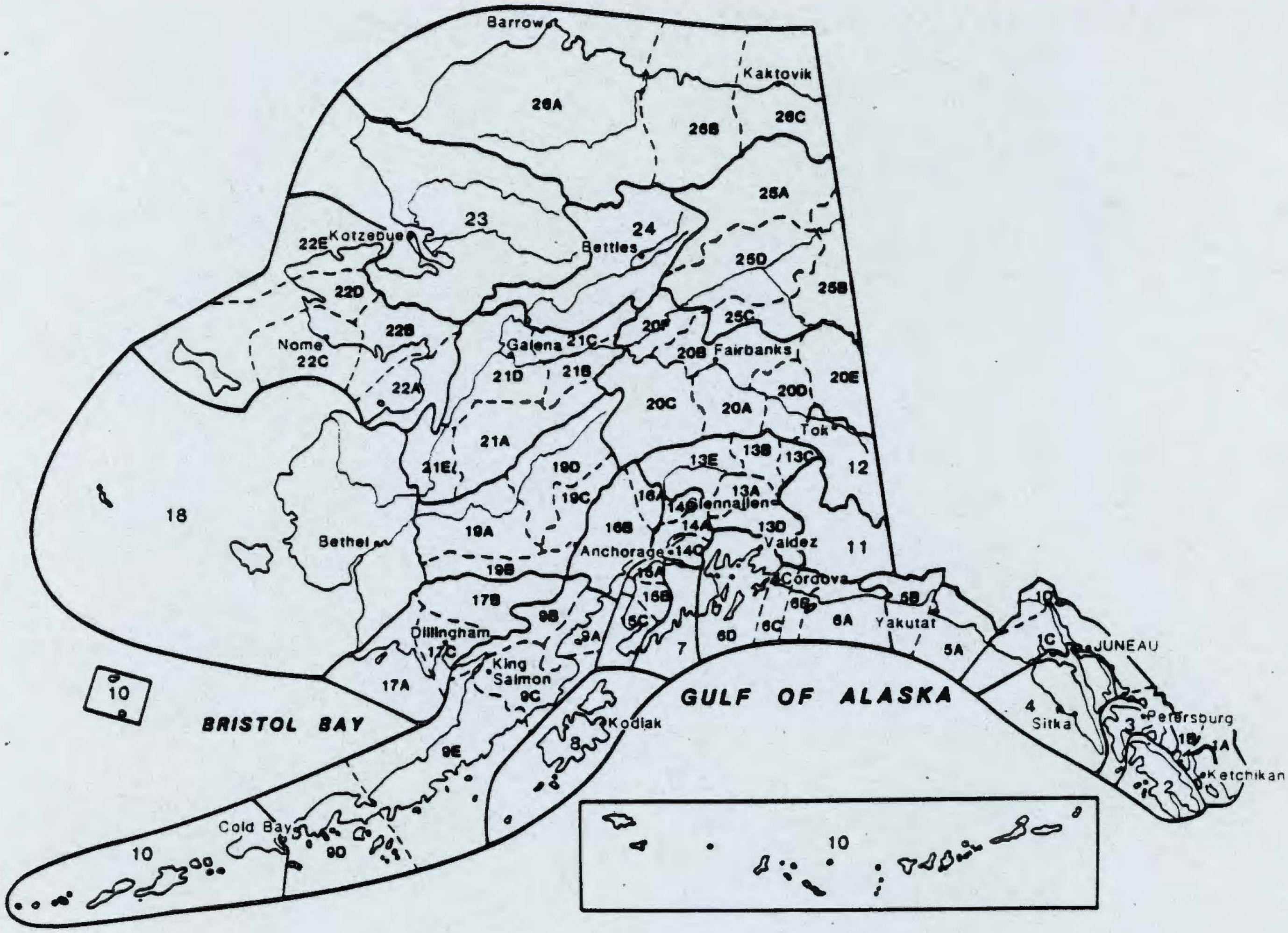
X_u - denotes the distance the pack traversed perpendicular to the transect (km.)
π_u - denotes the inclusion probability (probability this pack is observed in a systematic sample)
T_{yij} - denotes the contribution to the *i*th estimate
$T_{yi.}$ - denotes the population estimate based on the i the systematic sample.

Table 4. Wolverine survey data for a 2,700 km² area in the Talkeetna Mt. region of Unit 13, collected on 7 February 1991.

Sample/ Transect Id.	Group Id.	# of Wolverine	X_u[a]	π_u[b]	T_{yij}[c]	$T_{yi.}$[d]
A1	1	2	20.75	0.926	2.16	
A2	2	1	9.75	0.435	2.30	
A2 (cont.)	3	1	10.38	0.463	2.16	
A3	6	1	15.25	0.680	1.47	
A3 (cont.)	7	2	7.69	0.343	5.83	
						13.92
B1	1	2	20.75	0.926	2.16	
B2	3	1	10.38	0.463	2.16	
B2 (cont.)	4	1	2.25	0.167	5.99	
B3	6	1	15.25	0.680	1.47	
B3 (cont.)	7	2	7.69	0.343	5.83	
						17.61
C1	1	2	20.75	0.926	2.16	
C2	3	1	10.38	0.463	2.16	
C3	6	1	15.25	0.680	1.47	
C3 (cont.)	7	2	7.69	0.343	5.83	
						11.62
D1	1	2	20.75	0.926	2.16	
D2	3	1	10.38	0.463	2.16	
D3	6	1	15.25	0.680	1.47	
						5.79
E1	1	2	20.75	0.926	2.16	
E2	5	1	9.75	0.435	2.30	
E3	6	1	15.25	0.680	1.47	
E3 (cont.)	8	1	4.13	0.184	5.43	
						11.36
F1	1	2	20.75	0.926	2.16	
F1 (cont.)	2	1	9.75	0.435	2.30	
F2	5	1	9.75	0.435	2.30	
F3	8	1	4.13	0.184	5.43	
F3 (cont.)	9	1	7.75	0.346	2.89	
						15.08

[a] X_u denotes the distance traveled perpendicular to the X-axis (km) by the *u*th group of wolverines;
[b] π_u denotes the inclusion probability for the *u*th group of wolverines;
[c] T_{yij} denotes the contribution to the *i*th population estimate;
[d] $T_{yi.}$ denotes the population estimate based on the *i*th systematic sample.

Alaska's Game Management Units



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