EFFECTS OF SAMPLE SIZE ON ACCURACY AND PRECISION OF BROWN BEAR HOME RANGE MODELS

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Abstract: We equipped 9 brown bears (*Ursus arctos*) on the Kenai Peninsula, Alaska, with collars containing both conventional very-high-frequency (VHF) transmitters and global positioning system (GPS) receivers programmed to determine an animal's position at 5.75-hr intervals. We calculated minimum convex polygon (MCP) and fixed and adaptive kernel home ranges for randomly-selected subsets of the GPS data to examine the effects of sample size on accuracy and precision of home range estimates. We also compared results obtained by weekly aerial radiotracking versus more frequent GPS locations to test for biases in conventional radiotracking data. Home ranges based on the MCP were 20–606 km^2 ($\bar{x}$ = 201) for aerial radiotracking data (n = 12–16 locations/bear) and 116–1,505 km^2 ($\bar{x}$ = 522) for the complete GPS data sets (n = 245–466 locations/bear). Fixed kernel home ranges were 34–955 km^2 ($\bar{x}$ = 224) for radiotracking data and 16–130 km^2 ($\bar{x}$ = 60) for the GPS data. Differences between means for radiotracking and GPS data were due primarily to the larger samples provided by the GPS data. Means did not differ between radiotracking data and equivalent-sized subsets of GPS data ($P > 0.10$). For the MCP, home range area increased and variability decreased asymptotically with number of locations. For the kernel models, both area and variability decreased with increasing sample size. Simulations suggested that the MCP and kernel models required >60 and >80 locations, respectively, for estimates to be both accurate (change in area ≤1%/additional location) and precise (CV ≤ 50%). Although the radiotracking data appeared unbiased, except for the relationship between area and sample size, these data failed to indicate some areas that likely were important to bears. Our results suggest that the usefulness of conventional radiotracking data may be limited by potential biases and variability due to small samples. Investigators that use home range estimates in statistical tests should consider the effects of variability of those estimates. Use of GPS-equipped collars can facilitate obtaining larger samples of unbiased data and improve accuracy and precision of home range estimates.

Ursus 11:139–148

Key words: brown bear, home range, kernel, minimum convex polygon, *Ursus arctos*

During recent decades, radiotelemetry commonly has been used to study movements of secretive species such as brown bears. Large areas occupied by individual bears and logistical constraints imposed by remote and rugged terrain may limit the conditions under which radiotracking data can be obtained using conventional VHF transmitters. Studies of brown bear home ranges have accepted such limitations because no alternatives were available (e.g., Judd and Knight 1980, Mace and Waller 1997). Sample size may greatly influence estimates of home range size for some models (Boulanger and White 1990); however, empirical data to quantify these effects are limited. Although animal movements may vary according to time of day, weather, or other external influences (Gese et al. 1990), telemetry data collected by field personnel often cannot be obtained at random or even systematic intervals (e.g., because of inability to obtain locations at night or under adverse weather conditions). Thus, in many cases, it is impossible to obtain an unbiased sample of animal movements using conventional radiotracking methods.

The availability of animal collars that contain GPS receivers presents the opportunity to obtain data more frequently and at specified intervals, independent of time, weather, and remoteness (Rempel et al. 1995, Moen et al. 1996, Obbard et al. 1998). However, in 1998 the cost of GPS-equipped collars exceeded that of conventional transmitters by a factor of >10 (e.g., US $4,000 for the GPS collars described herein). This cost differential may preclude the widespread use of GPS collars and encourage investigators to continue to use established radiotracking techniques. Our objectives were to model brown bear home ranges using data collected by GPS collars to estimate minimum sample size necessary for accurate and precise home range estimates and to determine whether data obtained through conventional VHF radiotracking methods would produce unbiased estimates of home range area.

STUDY AREA AND METHODS

The study was conducted on the Kenai Peninsula, located in south-central Alaska and bounded by Prince William Sound, the Gulf of Alaska, and Cook Inlet. The peninsula is approximately 23,310 km^2 and is connected to the mainland to the north by an isthmus 17.8 km wide. Approximately 14,600 km^2 are federal lands, including the Kenai National Wildlife Refuge, Chugach National Forest, and Kenai Fjords National Park (Peterson et al. 1984). Most non-federal land is located along the west-

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ern side of the peninsula. The eastern two-thirds of the peninsula consists of the Kenai Mountains, which rise to 1,800 m and are dominated by numerous glaciers and 3 large icefields. In contrast, the western third of the peninsula is predominantly lowlands, with rolling hills rising to 150 m (Spencer and Hakala 1964, Peterson et al. 1984, Schwartz and Franzmann 1991). Lowland forests are dominated by black and white spruce (*Picea mariana* and *P. glauca*) on mesic soils and by combinations of white birch (*Betula papyrifera*), aspen (*Populus tremuloides*), and black cottonwood (*P. trichocarpa*) in drier areas. Higher areas are characterized by white spruce and mountain hemlock (*Tsuga mertensiana*) or shrublands of willow (*Salix* spp.) and alder (*Alnus* spp.) Elevations >500 m are mostly shrubland, alpine tundra, rock, or ice. Since the 1950s, much of the forested area on the Kenai Peninsula has been affected by an outbreak of spruce bark beetle (*Dendroctonus rufipennis*). During this study, approximately 1,600 km^2 were infested (Hennon et al. 1994), and mortality of mature spruce was nearly 100% in many areas.

Brown bears were captured using immobilizing darts fired from low-flying helicopters (Taylor et al. 1989). Bears were immobilized using a mixture of equal parts tiletamine hydrochloride and zolazepam hydrochloride (Telazol®, Fort Dodge Laboratories, Fort Dodge, Iowa, USA) at dosages of 6–10 mg/kg body weight. Nine adult females were equipped with collars containing both conventional VHF transmitters and GPS receivers (Telonics Inc., Mesa, Arizona, USA). Bears were captured initially during April or May and recaptured in October to recover the collars. We monitored 1 bear during 1996 and 8 during 1997. To ensure that sampling periods were similar for all bears, we used only data obtained between 1 June and 30 September of either year, and no bears provided data for both years. One additional bear, monitored from July–October 1996, was excluded from this analysis because of the shorter monitoring period. GPS units were programmed to attempt to determine a position every 5.75 hours, beginning at midnight (Greenwich Mean Time) following the time the collar was activated. GPS positions were stored in non-volatile internal memory until the collar was recovered, 4–6 months after deployment. Performance and relative costs of these collars were evaluated by Schwartz and Arthur (This Volume). Following the initial capture, each bear was located at approximately weekly intervals using conventional aerial radiotracking procedures from small, fixed-wing aircraft (Mech 1983). These locations were obtained opportunistically during daylight hours when weather conditions were favorable.

We modeled home ranges using the MCP model (Hayne 1949) because this has been commonly used in studies of many species and is the easiest model to compare across studies. The MCP ranges were modeled using a modification of the program described by White and Garrott (1990:Appendix 7). We also modeled home ranges using fixed and adaptive kernel models with the program KERNELHR (Seaman and Powell 1996, Seaman et al. 1998). We defined kernel home ranges as the areas encompassing 95% of the utilization distributions estimated from the animal locations.

We examined the relationships between home range area and sample size for the 3 home range models using subsets of the GPS data. For each combination of bear and sample size, 1,000 replicate data sets were drawn randomly without replacement. Sample sizes ranged from 10–100 locations in increments of 10. To reduce spatial autocorrelation between sequential locations (Swihart and Slade 1985) and to more closely simulate conventional radiotracking data, we restricted the selection process so that a maximum of 1 location/day could be selected. Selections within each day also were random. GPS collars did not always operate as programmed (Schwartz and Arthur This Volume), and 3 bears were located on <100 different days. Thus, the maximum sample size for these bears was 70 (1 bear) or 90 (2 bears). We estimated home range area for each data set using the 3 models and plotted the relationships between mean range area and sample size. We also examined the relationships between precision of the home range estimates and sample size for each model by plotting the coefficients of variation (CV) of range area versus sample size.

Home range area estimated with the MCP method increases asymptotically with number of locations used for the estimate (Odum and Kuenzler 1955). There is no widely-accepted method to determine the minimum number of locations necessary for an accurate estimate, but Odum and Kuenzler (1955) suggested that sample size should be sufficient so that estimated area increases by ≤1% for each additional location. Recently, home range models based on kernel density functions have received much interest among biologists (e.g., Worton 1989, 1995). Seaman and Powell (1996) reported that kernel models with small samples tend to overestimate range size. Although these models also are expected to improve as the number of locations is increased (Hansteen et al. 1997), standards for determining minimum sample sizes have not been presented. Following Odum and Kuenzler (1955), we defined the minimum sample size needed for an accurate estimate as the minimum sample for which range area changed by ≤10% with the addition of 10 locations. We arbitrarily chose CV ≤50% as an acceptable level of precision. For other studies, minimum acceptable precision will depend on the studies' objectives and methods.

Because our radiotracking data were obtained only during daylight hours and with favorable weather, these locations might not represent movements of bears at other times. To test whether these data were unbiased, except for the relationship between sample size and home range area, we simulated radiotracking data for each bear using 1,000 subsets of the GPS data (drawn randomly, without replacement, and with a maximum of 1 location/bear/day) of size equal to the radiotracking data. Using the 3 models, we determined home range area for each subset and compared these results to estimates from the actual radiotracking data. To examine effects of different sample sizes, we created a data set consisting of 1,000 subsets for each bear, with each subset comprising 1 randomly-chosen GPS location/day (OLPD) for each day the bear was located. We compared ranges modeled with these data to ranges modeled with the simulated radiotracking data (SRD). Finally, we compared estimates from the OLPD to estimates made using the entire set of GPS data for each bear (our best estimates of true home range area). We used paired *t*-tests to compare means of all bears between data types, with $\alpha = 0.05$ for each test, and either *z* or 2-sample *t*-tests to compare results for each individual bear. Because the tests of individual bears involved 9 simultaneous comparisons, we used a critical level of $\alpha = 0.01$ for each comparison so that the error rate over each set of 9 comparisons would be <0.10. Because MCP estimates are unlikely to decrease when sample size is in-

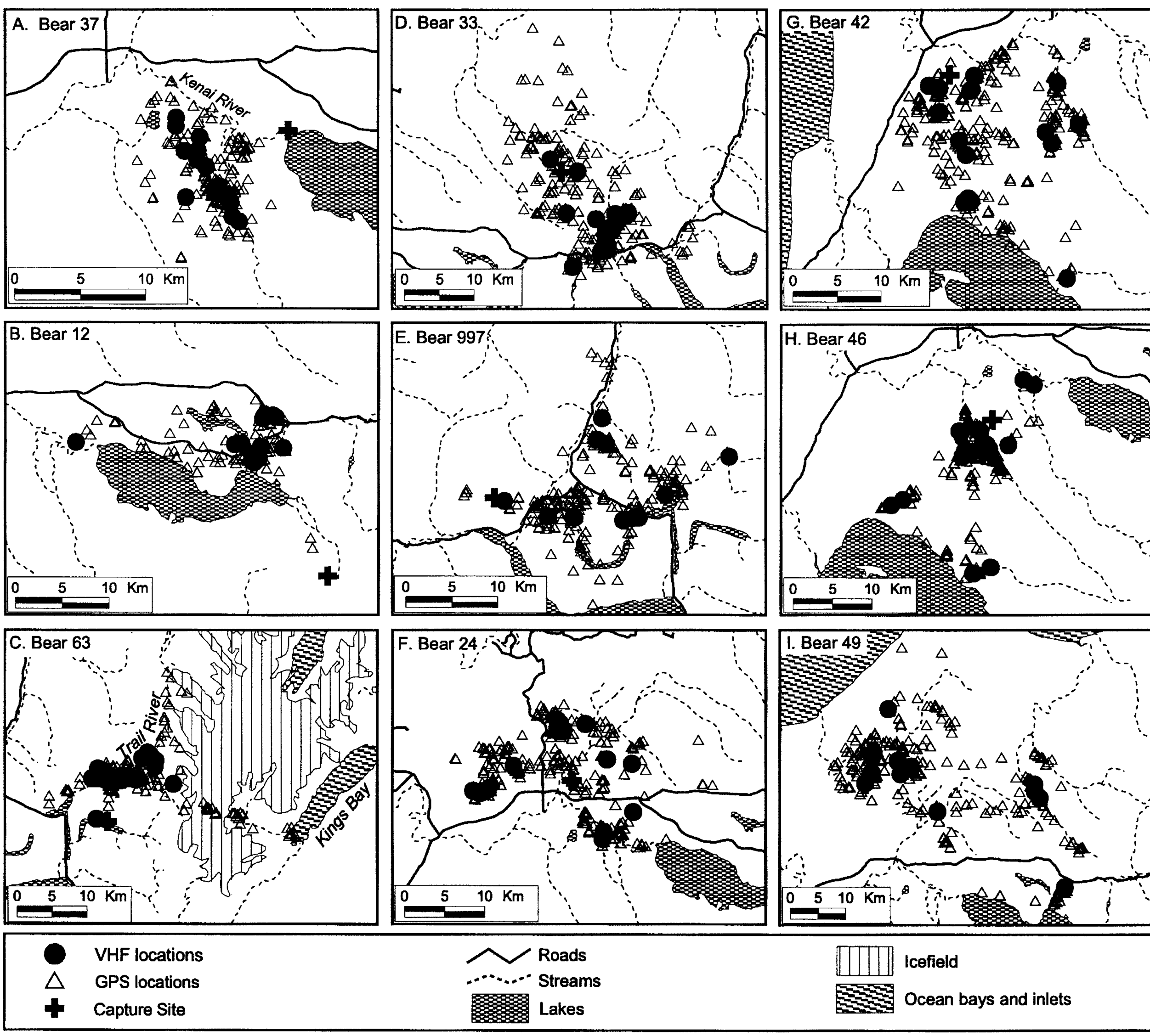

Fig. 1. Locations of brown bears on the Kenai Peninsula, Alaska, Jun–Sep 1996 (A) and 1997 (B through I), determined by radiotracking or by GPS collars.

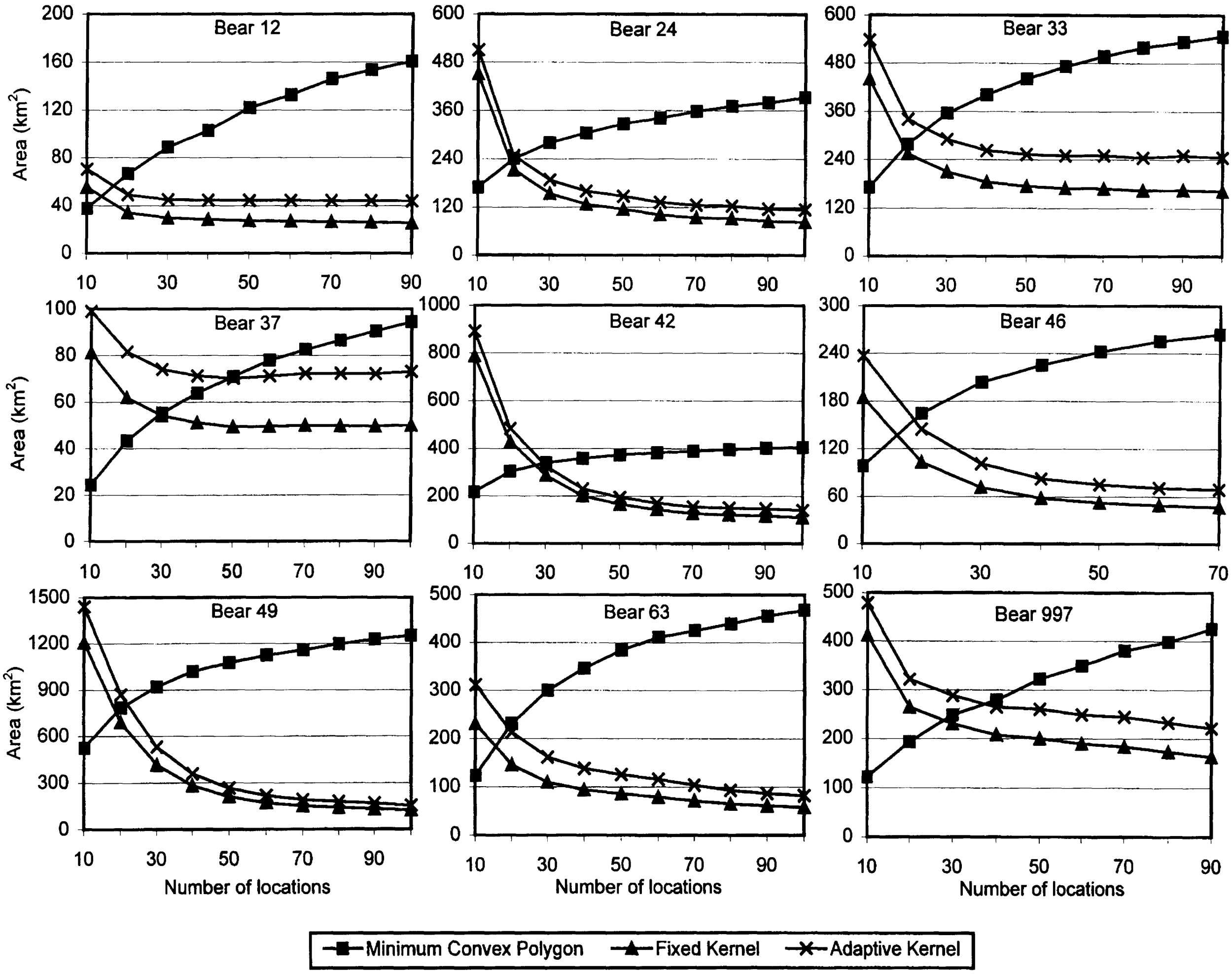

Fig. 2. Effect of sample size on estimates of home range area (km²) for brown bears on the Kenai Peninsula, Alaska, Jun–Sep 1996 (bear 37) and 1997 (all other bears). Data for each bear and sample size are means of 1,000 simulations using randomly chosen subsets of data from GPS collars.

creased (Odum and Kuenzler 1955), comparisons of MCP ranges between SRD and OLPD and between OLPD and all GPS data were 1-tailed. All other comparisons were 2-tailed.

These methods measure the ability of simple random sampling to approximate the distribution of locations shown by the GPS data. To draw inferences regarding the ability of such sampling to depict home ranges of bears, we assumed that the set of GPS locations for a particular bear was the universe of locations occupied by the bear during the time it was monitored. Although a bear may have occupied an infinite number of locations between any 2 GPS data points, these data were collected at sufficiently short intervals so that we believe it is unlikely that reducing our sampling interval would have revealed any movements beyond the ranges produced by the GPS data.

RESULTS

We obtained samples of 12–16 radiotracking locations/bear (maximum of one/bear/day) and 200–466 GPS locations representing 71–117 of the possible 152 days during the period (Fig. 1). For every combination of bear and sample size, mean home range area was larger for the adaptive kernel than for the fixed kernel (Fig. 2). For small samples, area estimates using the MCP were smaller than with the kernel methods, but the reverse was true for larger samples (Fig. 2). Coefficients of variation were smallest for the MCP for all sample sizes and were simi-

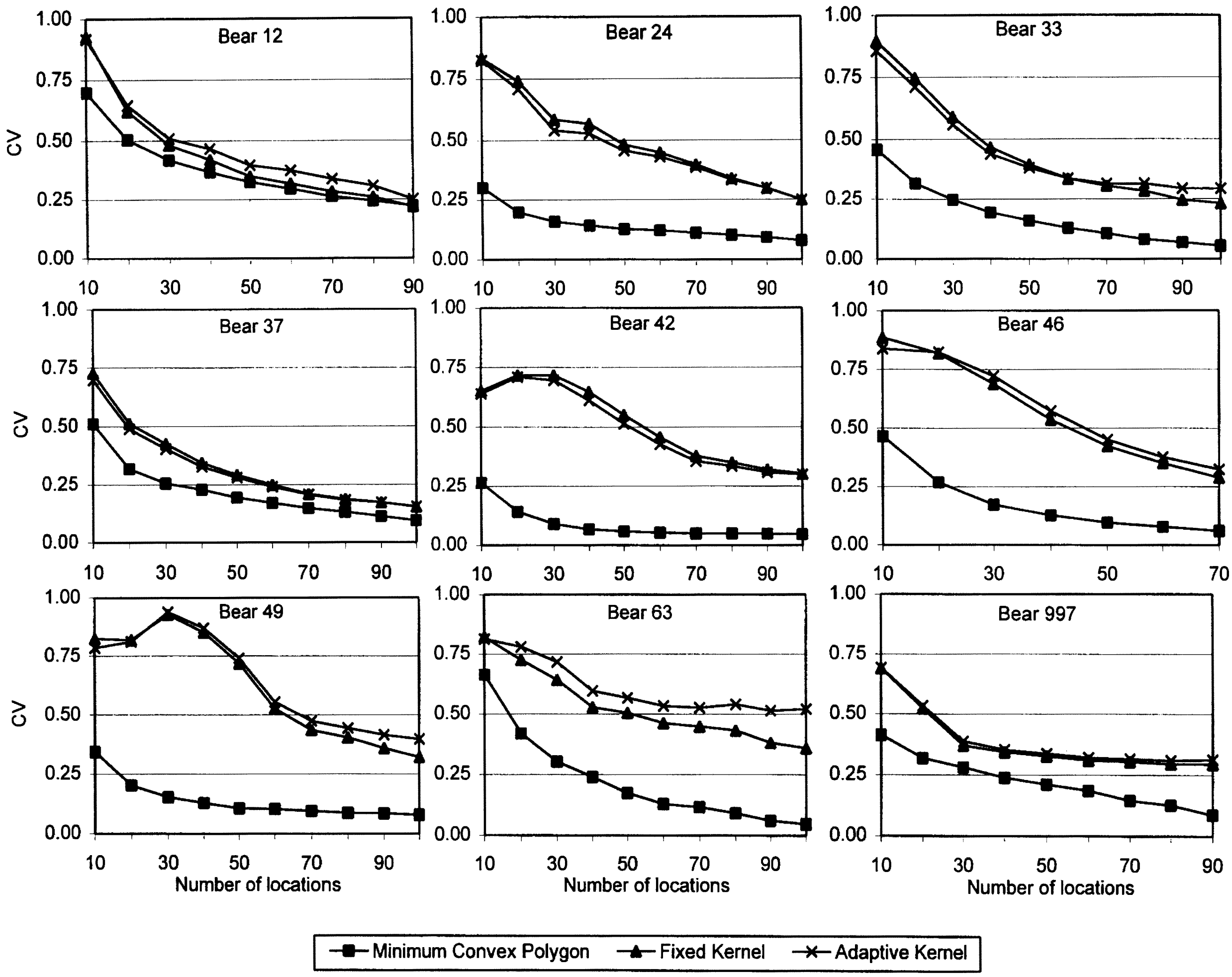

Fig. 3. Effect of sample size on coefficient of variation (CV) of home range estimates for brown bears on the Kenai Peninsula, Alaska, Jun–Sep 1996 (bear 37) or 1997 (all other bears). Data for each bear and sample size are results of 1,000 simulations using randomly chosen subsets of data from GPS collars.

lar between fixed and adaptive kernel methods (Fig. 3). Because of the consistent results between fixed and adaptive kernel models, we used only the MCP and fixed kernel models in the remaining comparisons.

As predicted, mean home range area increased asymptotically with sample size for the MCP model (Fig. 2). A minimum of 40 locations was required so that the increase in area was ≤1%/additional location (Fig. 4). However, ranges of only 2 bears reached this point with 40 locations; 3 bears required ≥50 locations and 4 bears required ≥60 locations. Conversely, mean area for the kernel models decreased with increasing sample size (Fig. 2). Three bears required ≥40 locations for the change in area to be ≤1%/additional location, whereas 4 bears required ≥50 locations and 2 bears required ≥80 locations (Fig. 4). Variability of the home range estimates decreased with increasing sample size for the MCP model (Fig. 3). A similar relationship was evident for the kernel estimates; however, this relationship was not as consistent across sample sizes as for the MCP model (Fig. 3). The MCP model required ≥30 locations and the fixed kernel required ≥70 locations for CV to be <50% for all bears (Fig. 4).

Our data suggest that some of the differences in variability among individuals may have been due to differences in home range area. Using the MCP with small samples (n = 10–20 locations), variability seemed to decrease as home range area increased. In contrast, variability of fixed kernel home ranges seemed to increase with area, but only for intermediate sample sizes (n = 30–60 locations; Table 1). Although regressions of CV versus area were not statistically significant for any sample size ($P > 0.10$; Table 1), these tests likely had low power due to the small number of bears in our study. According to the method of Zar (1984:314), ≥27 bears would have been required to find any of these relationships significant at the 0.05 level.

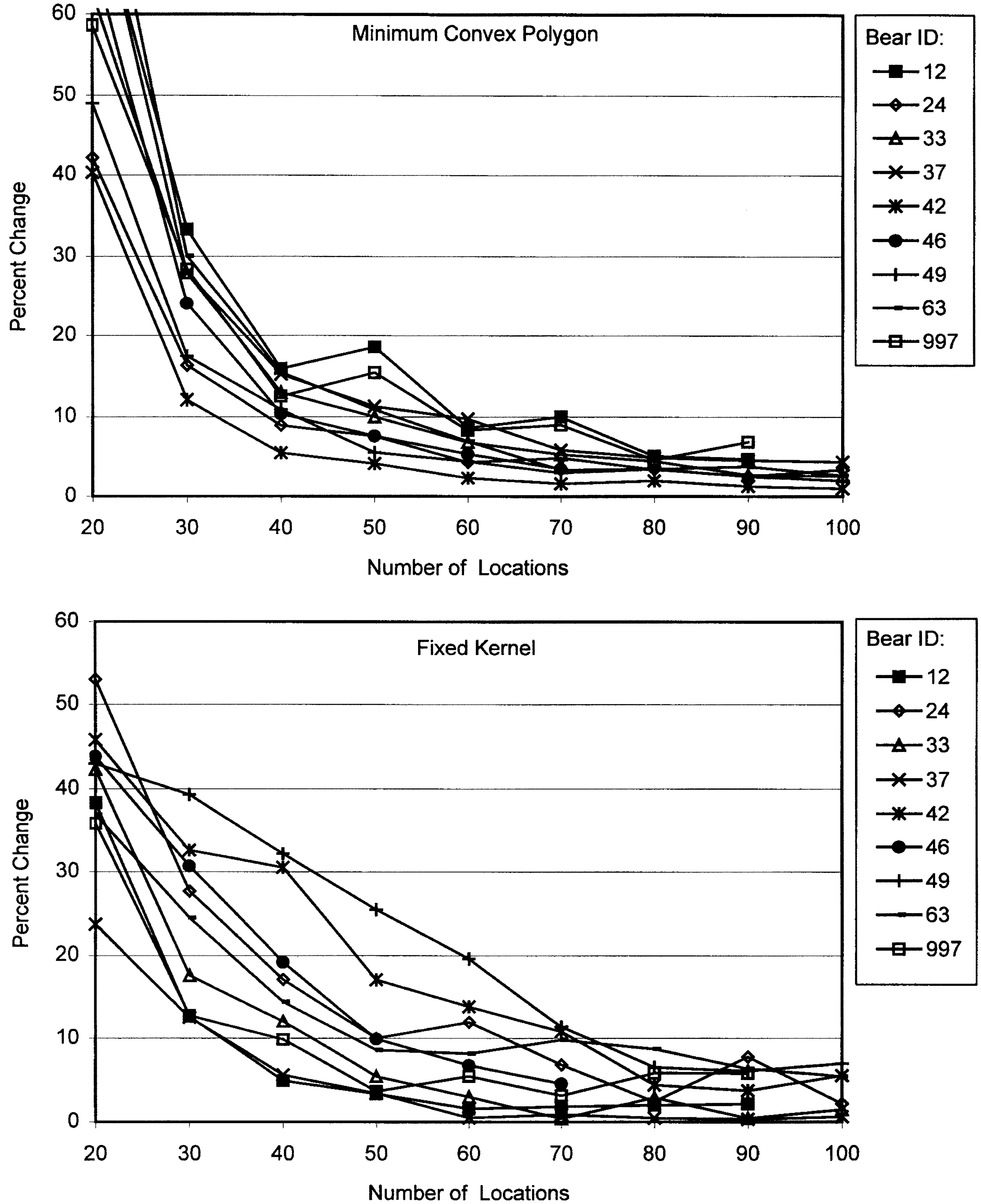

Fig. 4. Percent change in mean home range area associated with increasing number of locations for brown bears on the Kenai Peninsula, Alaska, Jun–Sep 1996 (bear 37) or 1997 (all other bears). Change is in comparison to mean range size estimated by models using 10 fewer locations. Data for each bear and sample size are results of 1,000 simulations using randomly chosen subsets of data from GPS collars.

Using the radiotracking data, MCP home ranges were 20–606 km^2 ($\bar{x}$ = 201 km^2), whereas mean area for the SRD ranged from 32–612 km^2 ($\bar{x}$ = 212 km^2; Table 2). Means for all bears did not differ between radiotracking data and SRD (paired $t = 0.41$, $P = 0.69$). Similarly, separate z-tests comparing data types for each bear indicated no differences between methods for any bear (all $P \geq 0.02$; Table 2). The fixed kernel model produced similar results: mean estimates from the radiotracking data ($\bar{x}$ = 224 km^2, range = 34–955) did not differ from the SRD ($\bar{x}$ = 317 km^2, range = 44–927, paired $t = 1.70$, $P = 0.13$), and there were no differences between data types for any individual bear (all $P \geq 0.11$; Table 3).

For the MCP model, estimates of home range area increased significantly between the SRD (n = 12–16 locations/bear) and the OLPD simulations (n = 71–117 locations, $\bar{x}$ = 457 km^2, range = 97–1288 km^2, paired $t = 4.5$, $P = 0.002$, Table 2). Comparisons between data types for each bear also differed significantly (2-sample t-tests, all $P < 0.001$). Using the fixed kernel model, ranges modeled with the OLPD data ($\bar{x}$ = 88 km^2, range = 25–156 km^2) were smaller than ranges modeled with the SRD (paired $t = 2.7$, $P = 0.03$; Table 3). This difference also was true for individual bears (2-sample t-tests, all $P < 0.001$). Mean area of home ranges modeled with all available GPS data (n = 245–466 locations/bear) differed significantly from the mean of ranges modeled with the OLPD data for the MCP model (paired $t = 3.3$, $P = 0.01$; Table 2), but not the fixed kernel (paired $t = 0.4$, $P = 0.73$; Table 3). Considering each bear separately, MCP home ranges using all data differed significantly from OLPD data for 7 bears (z-tests, all $P \leq 0.01$), but not for 2 bears ($P > 0.02$; Table 2). Fixed kernel models

Table 1. Regressions of coefficient of variation of home range area versus mean area for samples of 10–100 locations of brown bears on the Kenai Peninsula, Alaska, Jun–Sep 1996 (1 bear) and 1997 (8 bears). Sample size for each regression is the number of bears used.

		Minimum convex polygon			Fixed kernel		
Locations	Bears	Slope (%)	r^2	P	Slope (%)	r^2	P
10	9	-0.05	0.30	0.13	-0.01	0.07	0.48
20	9	-0.03	0.27	0.16	0.02	0.19	0.24
30	9	-0.02	0.23	0.19	0.08	0.39	0.07
40	9	-0.01	0.21	0.21	0.11	0.35	0.09
50	9	-0.01	0.2	0.22	0.09	0.24	0.18
60	9	-0.01	0.17	0.28	0.05	0.11	0.39
70	9	-0.01	0.14	0.33	0.04	0.08	0.46
80	8	-0.01	0.21	0.26	0.03	0.05	0.58
90	8	-0.01	0.15	0.34	0.04	0.09	0.48
100	6	0.00	0.00	0.93	0.02	0.01	0.84

Table 2. Home range areas (km^2) estimated with the minimum convex polygon method for brown bears on the Kenai Peninsula, Alaska, Jun–Sep 1996 (bear 37) and 1997 (all other bears).

Bear	Radiotracking data		Simulated radiotracking data[a]			1 GPS location/day/bear[b]			All GPS data		Radiotracking versus simulated		Simulated versus 1/day		1/day versus all GPS data	
ID	n^c	Area	n^c	$\bar{x}$	SD	n^c	$\bar{x}$	SD	n^c	Area	z	P^d	t^e	P^f	z	P^f
12	13	66.3	13	47.5	29.3	97	168.0	33.4	245	212.1	0.6409	0.522	8.1424	<0.001	1.3218	0.093
24	14	212.0	14	204.3	48.5	117	408.4	22.5	348	470.4	0.1583	0.874	11.4597	<0.001	2.757	0.003
33	16	101.8	16	237.9	81.9	113	561.5	20.8	294	618.3	1.6621	0.097	11.4907	<0.001	2.7282	0.003
37	13	19.9	13	31.5	13.5	109	97.4	7.8	252	115.5	0.8624	0.388	12.6855	<0.001	2.3209	0.010
42	16	288.9	16	280.0	47.7	110	410.8	19.4	329	457.9	0.1864	0.852	7.6120	<0.001	2.4285	0.008
46	16	251.7	16	145.5	46.2	78	271.0	14.7	466	309.3	2.3003	0.021	7.7745	<0.001	2.6085	0.005
49	13	606.3	13	611.7	182.0	117	1287.5	90.7	345	1504.9	0.0296	0.976	9.9712	<0.001	2.3965	0.008
63	17	79.0	17	205.2	97.4	102	469.7	20.4	247	510.4	1.2954	0.195	7.9703	<0.001	1.9991	0.023
997	12	184.7	12	141.5	55.2	96	438.3	24.1	261	501.8	0.7826	0.434	14.7885	<0.001	2.6383	0.004
$\bar{x}$		201.2		211.7			456.9			522.3						
Comparison of means for all bears											0.4103[g]	0.692	4.5047	0.002	3.3402[g]	0.01

[a]Data from 1,000 sets of randomly-selected GPS locations with n = number of radiotracking locations obtained for each bear.
[b]Data from 1,000 sets consisting of 1 randomly-selected GPS location/day for every day each bear was located.
[c]Number of locations used for the model.
[d]Two-tailed test.
[e]Test statistic for 2-sample t-test comparing data for each bear or paired-sample t-test comparing means for all bears.
[f]One-tailed test.
[g]Paired-sample t-test comparing means for all bears.

Table 3. Home range areas (km²) estimated with the fixed kernel method for brown bears on the Kenai Peninsula, Alaska, Jun–Sep 1996 (bear 37) and 1997 (all other bears).

Bear	Radiotracking data		Simulated radiotracking data[a]			1 GPS location/day/bear[b]			All GPS data		Radiotracking versus simulated		Simulated versus 1/day		1/day versus all GPS data	
ID	n^c	Area	n^c	$\bar{x}$	SD	n^c	$\bar{x}$	SD	n^c	Area	z	P^d	t^e	P^f	z	P^f
12	13	33.7	13	44.3	36.4	97	24.7	5.0	245	14.5	0.2908	0.771	1.5953	<0.001	2.0468	0.041
24	14	124.8	14	291.6	247.7	117	80.1	17.5	348	62.0	0.6733	0.501	2.5550	<0.001	1.0366	0.300
33	16	84.4	16	311.1	240.8	113	160.0	33.0	294	111.2	0.9412	0.347	1.8644	<0.001	1.4784	0.139
37	13	75.8	13	73.0	48.2	109	50.4	6.8	252	33.4	0.0589	0.953	1.3955	<0.001	2.4953	0.013
42	16	191.2	16	547.9	372.9	110	106.1	28.1	329	57.4	0.9564	0.339	3.5442	<0.001	1.7342	0.083
46	16	315.1	16	133.2	113.5	78	44.6	12.8	466	15.8	1.6029	0.109	2.3289	<0.001	2.2556	0.024
49	13	955.0	13	926.7	767.1	117	113.1	30.7	345	129.5	0.0369	0.971	3.1795	<0.001	0.5345	0.593
63	17	101.0	17	165.7	124.4	102	56.6	19.8	247	56.2	0.5200	0.603	2.5973	<0.001	0.0197	0.984
997	12	135.8	12	363.0	235.7	96	156.2	44.2	261	60.2	0.9640	0.335	2.5879	<0.001	2.1714	0.030
$\bar{x}$		224.1		317.4	278.0		88.0	48.9		60.0						
Comparison of means for all bears											1.6957[f]	0.128	2.7139	0.026	2.5331[f]	0.035

[a]Data from 1,000 sets of randomly-selected GPS locations with n = number of radiotracking locations obtained for each bear.
[b]Data from 1,000 sets consisting of 1 randomly-selected GPS location/day for every day each bear was located.
[c]Number of locations used for the model.
[d]Two-tailed test.
[e]Test statistic for 2-sample t-test comparing data for each bear or paired-sample t-test comparing means for all bears.
[f]Paired sample t-test comparing means for all bears.

differed significantly between data sets for only 1 bear ($P < 0.001$, for other bears $P \geq 0.04$; Table 3).

DISCUSSION AND CONCLUSIONS

Our simulations suggest that, for Kenai brown bears, 60–80 locations are needed to model home range area using either the MCP or kernel methods. Furthermore, increasing the number of locations changed home range estimates for several bears even when the difference in sample size was due only to increasing the number of observations obtained/day (our OLPD versus all GPS comparison). This illustrates the sensitivity of these models to sample size and suggests that comparing home range estimates from different studies should be done cautiously.

Even with samples of >50 locations, variability of home range estimates was high (CV > 10% for MCP and >30% for fixed kernel). Studies that estimate home range areas should also estimate the variability of those estimates (e.g., through bootstrapping). To date, few (if any) studies incorporating home range models have reported the variability of the models' results or the effects of that variability on the studies' conclusions. For example, studies of habitat selection may define habitats used by or available to an animal as those within the boundaries indicated by a home range model (e.g., MacCracken et al. 1997, Craighead 1998). Differences between proportional use and availability of habitats are then assessed using a statistic that is assumed to follow the χ^2 distribution (e.g., Neu et al. 1974, Marcum and Loftsgaarden 1980, Aebischer et al. 1993, Arthur et al. 1996). However, if habitat use or availability are measured imprecisely, then the χ^2 distribution may be a poor approximation to the true distribution of the data, and the Type 1 error rate may be larger than what is indicated by the test statistic (Link and Karanth 1994). Samuel and Kenow (1992) described how to account for measurement error in analyses of habitat selection. Similar techniques are needed when home range models are used to estimate use or availability of habitats.

Studies using radiotracking data commonly omit outlier locations, because these tend to have large effects on estimates of home range area (White and Garrott 1990:151–152). The rationale for eliminating outliers is that these locations represent occasional, brief excursions by an animal outside of its usual home range (Burt 1943). However, when samples are small (<50 locations for Kenai brown bears) there is no basis for deciding what constitutes an outlier. Eliminating any of our radiotracking locations would have further reduced our ability to estimate home range areas. For example, radiotracking data for 3 of the bears we monitored exhibited single locations >15 km from any other radiotracking location (Fig. 1B, G, and I). Eliminating these locations would have reduced MCP home range estimates by 74, 41, and 38% for bear numbers 12, 42, and 49, respectively. However, GPS data confirmed that these areas were used regularly by the bears and should be included in home range estimates. In fact, the supposed outlier locations corresponded to salmon (*Oncorhynchus* spp.) spawning streams that likely were important food sources for the bears. Thus, we suggest that eliminating outliers is of questionable value unless sample size is sufficient to distinguish exploratory movements from short-term use of important resources. Also, the criteria for identifying outliers should be based on knowledge of a species' behavior and not just on characteristics of a set of location data (e.g., eliminating an arbitrary percentage of locations without regard to why the animal may have been at each location).

Radiotracking data for 2 other bears also failed to indicate the importance of some feeding areas. Bear 37 was captured 0.25 km from the Kenai River, but all subsequent radiotracking locations were ≥2 km from the river (Fig. 1A). Without the capture site, the radiotracking data would have suggested that this bear did not use the riparian areas along the Kenai River. However, 35 (14%) of 252 GPS locations were <2 km and 25 (10%) were <1 km from the river. Many brown bears frequent the banks of the Kenai River during July–October when salmon are present. However, the river is used intensively for human recreation, and bears likely move away from the river during the day to avoid contact with humans. This might be why our diurnal radiotracking locations failed to indicate the importance of this food source to bears. For bear 63, radiotracking locations encompassed 79.0 km^2 centered around the Trail River (Fig. 1C). However, GPS data revealed that the bear made ≥2 trips to the head of Kings Bay, 20 km to the east and across a 1,000-m glacier-covered mountain pass. Most likely, these movements were in response to the presence of spawning salmon in streams feeding into Kings Bay, but use of this resource was not indicated by the radiotracking data.

Although our estimates of home range area were similar between radiotracking data and SRD, the variability of estimates using 12–16 locations was so great that these estimates may not represent any biologically meaningful parameter. Furthermore, if an animal's movements are affected by circadian cycles, weather patterns, or other factors that also limit a researcher's ability to obtain telemetry locations, the resulting data most likely will be biased, even if the bias is not statistically detectable. By using GPS-equipped collars, it is possible to obtain locations at programmed intervals regardless of weather or the location of an animal (unless local features interfere with reception of GPS radio transmissions [Schwartz and Arthur This Volume]). This capability enables researchers to obtain larger samples with less chance of bias than previously was possible. In some situations, the cost of the collars may be offset by reduced costs for data acquisition, especially if radiotracking must be done by aircraft. However, in many instances, the higher cost of the GPS collars will limit the number of animals that can be studied. Thus, researchers planning such studies must weigh the relative merits of obtaining large samples of unbiased data from a few animals versus using a larger group of animals but obtaining data of lesser quality. Increasing the number of observations/animal likely will require reducing the interval between locations, which may preclude the assumption of independence among observations (Swihart and Slade 1985). However, with an appropriate sampling schedule this assumption may not be necessary (Otis and White 1999). Alternatively, if locations are obtained at sufficiently short intervals so that movements between them are considered trivial, the data can be treated as a census, rather than a sample. This may allow new analytical methods to be developed that do not require the assumption of an underlying probability distribution or density function. Methods that attempt to model the path or trajectory of an animal (e.g., Bovet and Benhamou 1988, Gautestad and Mysterud 1993) seem especially promising.

ACKNOWLEDGMENTS

This study was part of a cooperative effort involving several agencies and individuals. Members of the Interagency Brown Bear Study Team (including L. Suring, B. Shuster, T. Bailey, R. Ernst, M. Chase, M. Tetreau, and G. Del Frate) helped in developing research priorities and securing funding. Field assistance was provided by G. Hilderbrand, T. Spraker, P. Del Vecchio, R. Davis, L. Lewis, and E. Sochat. Pilots R. Ernst, J. DeKreeft, C. Lofstead, B. Lofstead, C. Saloy, T. Cambier, and J. Larrivee were instrumental in capturing and radiotracking bears. S. Tomkiewicz and associates at Telonics, Inc., developed the collars and provided the GPS data. B. Strauch provided geographic databases used for some of the analyses. Major funding was provided by the Alaska Department of Fish and Game (Federal Aid in Wildlife Restoration Project W-24-4), U.S. Fish and Wildlife Service (Kenai National Wildlife Refuge), and U.S. Forest Service (Chugach National Forest). Additional support was provided by Wildlife Forever, Safari Club International, and The Alaska Bowhunters Association.

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