Sampling designs matching species biology produce accurate and affordable abundance indices

Wildlife biologists often use grid-based designs to sample animals and generate abundance estimates. Although sampling in grids is theoretically sound, in application, the method can be logistically difficult and expensive when sampling elusive species inhabiting extensive areas. These factors make it challenging to sample animals and meet the statistical assumption of all individuals having an equal probability of capture. Violating this assumption biases results. Does an alternative exist? Perhaps by sampling only where resources attract animals (*i.e.* targeted sampling), it would provide accurate abundance estimates more efficiently and affordably. However, biases from this approach would also arise if individuals have an unequal probability of capture, especially if some failed to visit the sampling area. Since most biological programs are resource limited, and acquiring abundance data drives many conservation and management applications, it becomes imperative to identify economical and informative sampling designs. Therefore, we evaluated abundance estimates generated from grid and targeted sampling designs using simulations based on geographic positioning system (GPS) data from 42 Alaskan brown bears (*Ursus arctos*). Migratory salmon drew brown bears from the wider landscape, concentrating them at anadromous streams. This provided a scenario for testing the targeted approach. Grid and targeted sampling varied by trap amount, location (traps placed randomly, systematically or by expert opinion), and traps stationary or moved between capture sessions. We began by identifying when to sample, and if bears had equal probability of capture. We compared abundance estimates against seven criteria: bias, precision, accuracy, effort, plus encounter rates, and probabilities of capture and recapture. One grid (49 km2 cells) and one targeted configuration provided the most accurate results. Both placed traps by expert opinion and moved traps between capture sessions, which raised capture probabilities. The grid design was least biased (-10.5%), but imprecise (CV 21.2%), and used most effort (16,100 trap-nights). The targeted configuration was more biased (-17.3%), but most precise (CV 12.3%), with least

effort (7,000 trap-nights). Targeted sampling generated encounter rates four times higher, and capture and recapture probabilities 11% and 60% higher than grid sampling, in a sampling frame 88% smaller. Bears had unequal probability of capture with both sampling designs, partly because some bears never had traps available to sample them. Hence, grid and targeted sampling generated abundance indices, not estimates. Overall, targeted sampling provided the most accurate and affordable design to index abundance. Targeted sampling may offer an alternative method to index the abundance of other species inhabiting expansive and inaccessible landscapes elsewhere, provided their attraction to resource concentrations.

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INTRODUCTION

Wildlife biologists often rely on photographs or DNA in a capture-mark-recapture (CMR)

framework to estimate the abundances of sparsely distributed animals inhabiting expansive,

heavily vegetated and inaccessible terrain (*Karanth & Nichols, 1998; Boulanger et al., 2002;*

Harris et al., 2010; Kindberg et al., 2011). At issue is how to sample effectively and

economically under such conditions. In particular, are there alternative sampling designs to the

conventional grid?

Grid-based designs operate by enveloping study sites with a uniform cell size and sampling

within each cell (*e.g. Woods et al., 1999; Poole et al., 2001; Boulanger et al., 2002; Williams et*

al., 2002; Boulanger et al.,2004; Kendall et al., 2009). Although the approach is popular, grid

sampling harbors logistical challenges, and when improperly used, methodological flaws (see

below). An alternative sampling design could sample only at biologically important locations that

attract the target species (hereafter "targeted sampling"; *Karanth & Nichols, 1998; Sawaya et al.,*

2012). Obvious resistance to this approach stems from the biases introduced if some individuals

in the population failed to visit the sampling area.

While abundance estimation forms a cornerstone of wildlife biology, the size of many study sites,

challenging terrain and elusiveness of the target species makes acquiring abundance data

expensive. Yet most biological programs receive little funding, requiring professionals to pursue

33   economical methods to estimate abundance, while maintaining informative and scientifically

34   defensible designs. Given this reality, we evaluated the targeted sampling design by comparing it

35   to conventional grid sampling. If targeted sampling generates abundance estimates affordably

36   and precisely, with low bias and effort, then it could offer an informative and economical

37   alternative to estimating abundances of sparsely distributed animals inhabiting heavily vegetated

38   or topographically complex environments, provided the species attraction to resource

39   concentrations. Globally, many species having these characteristics are of high conservation

40   concern (*e.g. Fuller, 1995; Weber & Rabinowitz, 1996; Shackleton, 1997*). Often, abundance

41   data for such species are deficient, unable to inform population status, threat assessments, or

42   provide direction for properly conserving and managing populations of these animals.

43   **Grid and targeted sampling**

44   Grid sampling aims to ensure that all individuals within the population have the same probability

45   of capture (*Nichols & Karanth, 2002; Williams et al., 2002*). While the theory is sound,

46   implementation has at least 3 disadvantages. First, to ensure that all individuals encounter traps,

47   users often scale grid cells to match the average home range size of the target species (*Boulanger*

48   *et al., 2004a; Boulanger et al., 2006*). Problems arise when biologists lack home range

49   information for their population under study, home range sizes vary between surveys, or home

50   range sizes vary widely within a population. When home range data are lacking, then

51   practitioners can rely on home range sizes from the same or related species elsewhere, hoping

52   that the cell size used is appropriate (*Boulanger et al., 2006*; *Sawaya et al., 2012*). If animals

53   change their behavior in response to concentrated or dispersed resources, making their home

54   ranges shrink or expand, then home range sizes will vary between years (*i.e.* surveys). This

55   makes it challenging for a defined grid size to always be appropriate. If home range sizes have

56   much variation in the population, then a mean value has little biological relevance (*McNab,*

57   *1963; Powell, 2000; Boulanger et al., 2006*). By relying on the home range mean, a segment of

58   the population will have home range sizes below the cell size, so traps may not be available to

59   capture them. In each case, using home range data to guide the size of the grid cell may result in

60   the grid being too large, causing an unequal probability of capture. This raises capture

61   heterogeneity, thereby increasing error in the CMR approach (*Williams et al., 2002; Boulanger et*

62   *al., 2004)*. Since many studies sampling with grid configurations do not biologically justify the

63   grid resolution chosen, they lack information to evaluate this heterogeneity violation (*e.g. Woods*

64   *et al., 1999; Boulanger et al., 2004; Mowat et al., 2005; Boulanger et al., 2008a; Kendall et al.,*

65   *2008)*.   In any event, for grid sampling, the solution relies on using small cell sizes to ensure that

66   all individuals have a chance of being captured.

67   Of course, this begs the question of how small cell sizes must be. Although we discuss this point

68   later, it invokes the second issue. Many study sites are large (10,000s of km^2) and include areas

69   difficult to access, due to vegetation types, terrain, or insecure political situations. Sampling in

70   these areas is logistically difficult or unsafe, and when using small cells sizes, the projects can

71   become prohibitively expensive (*Kendall et al., 2009; Harris et al., 2010; Sawaya et al., 2012*).

72   A third issue with grid sampling is the same trapping effort covers an entire study area that varies

73   in species densities. This seems inefficient. Overall, these problems risk generating ineffective

74   and expensive sampling designs, which can discourage project implementation (*Woods et al.,*

75   *1999; Boulanger et al., 2002; Kendall et al., 2009*).

76   Resources influence a species' distribution, by attracting animals from the wider landscape into

77   relatively smaller areas. Therefore, places that concentrate important biological resources often

78   contain a high density of the target species (*MacArthur, 1972; Karanth et al., 2002*). Hence,

79   targeted sampling focuses effort in high use areas (places that attract the target animal), which

80   may reduce the amount of area to sample, number of traps, and sampling logistics (*e.g.* scent

81   marking stations, water holes, trails; *Karanth & Nichols, 1998; Sawaya et al.,2012*). Each of

82   these factors lowers project costs. Because the sampling design matches species biology and

83   more animals are sampled in less area, it should increase capture probabilities (*Karanth et al.,*

84   *2002*). Further, targeted sampling may facilitate sampling insecure study sites, if the resource

85   concentrations – and hence high densities of the target species – occur in safer areas where they

86   can be sampled.

87   The estimator would fail if numerous individuals in the population did not frequent the sampling

88   area, or if the proportion that visited changed over time. Then, traps in a targeted configuration

89   would not be available to all individuals equally, in amounts that could vary between surveys,

90   causing bias. This would render the sampling assumptions unreasonable, and the final abundance

91   estimates unreliable (*Karanth & Nichols, 1998, Williams et al., 2002*). Further, changes in

92   abundances between years would reflect behavioral responses of the species, or an artifact of

93   sampling design, and not actual variation of the species abundances. The sampling techniques

94   would not generate estimates, but indices. Of course, these are the same issues encountered when

95   sampling animals with grids, when home range sizes vary between surveys, or when cells are too

96   large, so traps fall outside of some animals' home ranges rendering them unavailable for capture.

97   Our goal is to identify sampling designs that provide accurate, affordable and defensible

98   abundance estimates. Therefore, we compared abundance estimates generated from grid and

99   targeted sampling designs against a known population size. Our evaluations relied on geographic

100   positioning system (GPS) location data from female brown bears (*Ursus arctos*) inhabiting the

101   Kenai Peninsula of south-central Alaska, USA. Here, migratory salmon drew brown bears from

102 the wider landscape, concentrating them at anadromous streams (*i.e.* streams containing

103 anadromous fish). This provided a scenario for testing the targeted sampling approach (*Miller et*

104 *al., 1997; Hilderbrand et al., 1999; Boulanger et al., 2004b; Mowat et al., 2005*). Because

105 comparisons between designs would be nearly impossible to accomplish in the field, we

106 simulated all sampling in a geographical information system (GIS).

107 We began by determining the optimal dates to sample. Next, we evaluated if all bears were

108 available for capture during that period. For the targeted scenario, bears must be near streams

109 with anadromous fish. For grids, traps must occur within each bears home range. Therefore, we

110 compared brown bear home range sizes to grid cells of varying extent, to inform the cell sizes

111 used for sampling. For grid and targeted sampling, we sampled during the optimal periods, and

112 evaluated each design against seven criteria: bias, precision and accuracy in the population

113 estimates, effort required to obtain estimates (trap-nights) and encounter rates. We also evaluated

114 capture and recapture probabilities, since the best way to reduce capture heterogeneity is by

115 maximizing them (*Lukacs, 2009*).

116 When biologists estimate the abundance of animal populations, their sampling considerations

117 include logistics: the number of traps to deploy, how to place traps, and whether to move traps

118 between capture sessions. Their constraints are time and costs. Therefore, designs with fewer

119 traps and systematic placement are preferable, provided they produce unbiased abundance

120 estimates at the required precision. Similarly, since moving traps between capture sessions adds

121 considerable expense, it makes sense to move traps only if the improvements in accuracy

122 outweigh those costs. Hence, our sampling designs varied by trap amount, location (*i.e.* traps set

123 randomly, systematically or located by expert opinion), and traps stationary or moved between

124 capture sessions.

METHODS

Study Area

We studied brown bears on the Kenai Peninsula, of south-central Alaska, USA (23,310 km^2). The
western third of the Peninsula consists of thickly forested plains (approximately sea level), while
ice fields and precipitous mountains dominate the remaining landscape. Mountains peak at
≈2,000 m, and we never sampled areas covered by water or ice (Fig. 1). During summer, schools
of anadromous salmon (five species) leave the sea and spawn in the Kenai's freshwater
tributaries. These migrating salmon form a resource pulse for brown bears and other wildlife
(*Hilderbrand et al., 1999*).

GPS Telemetry

Data representing bear movements came from GPS telemetry of female brown bears acquired on
the Kenai Peninsula. During 1995 – 2003, the Alaska Department of Fish and Game captured
female brown bears throughout the entire Peninsula. Captures occurred in mid-Spring, before
deciduous trees leafed and salmon entered streams. Bear captures were geographically dispersed
(excluding glaciers) and each bear received a GPS collar. Only females were collared, since
males and cubs experience rapid weight gain throughout a season, making the collars either too
loose or tight, thereby increasing the risk of injuring (or killing) the bear. All field and capture
methods were approved by Alaska Department of Fish and Game, Animal Care and Use
Committee, Assurance No. 06-03. GPS collars recorded geographical location, and associated
date and time, at intervals ranging from 15 minutes to 13 hours. We only used data with 3-D

145 accuracy, and resampled these GPS data to 13 hours. Resampling kept the first GPS location for

146 each bear, and each 13-hour fix thereafter. Data for some bears spanned multiple years,

147 generating 51 bear/year combinations. Most data covered 1 June through 30 September of a

148 given year (period of most bear activity, after winter denning).

149 **Trapping Period**

150 CMR studies often use 4 to 5 sampling sessions (*Karanth & Nichols, 1998; Boulanger et al.,*

151 *2008a; Boulanger et al., 2008b; Sawaya et al., 2012*). We followed this practice, and simulated 5

152 sessions, each lasting 10 days (50 total days). We determined when to sample by identifying the

153 period between 1 June and 30 September that bears would most likely encounter traps.

154 We examined 3 approaches to identify the sample period for the grid-based designs. First, we

155 hypothesized that bears leaving dens would explore the landscape and encounter traps. For bears

156 in Alaska, this period began 1 June and ended 20 July. Next, we presumed that greater

157 movements would cause more trap encounters. Therefore, we found the contiguous window of

158 50 days, when the average movement rate for brown bears between successive GPS fixes was

159 maximized. Lastly, we examined long-range movements by identifying the contiguous window

160 of 50 days that maximized the average distances between the furthest-apart GPS fixes for each

161 bear.

162 To calculate the movement metrics, we divided the 1 June through 30 September period into 10-

163 day brackets. This generated 122 different intervals (day 1–10, day 2–11, etc.). We then

164 quantified the mean and standard error of brown bear movements in each of the intervals. We

165 retained the 5 contiguous intervals that maximized bear movements (50 contiguous days).

166   The targeted design hinged on salmon being an important food resource that attracted brown

167   bears to anadromous streams (*Hilderbrand et al., 1999; Beier, 2005*). Therefore, we used the

168   same 122, 10-day intervals to quantify the proportion of GPS fixes ≤500 m of an anadromous

169   stream for each bear. We chose the 5 contiguous 10-day intervals that maximized this proportion.

170   Targeted simulations occurred during those dates.

171   **Availability for Capture**

172   We quantified the sizes of brown bear home ranges, to inform the selection of appropriate cell

173   sizes for the grid-sampling frame. The objective was to ensure that all bears were available for

174   capture. Our method examined the relationships between grid-cell size (km), and the proportion

175   of bears with home range sizes below that cells area. We also calculated the number of traps

176   within each bears home range, to determine if it contained at least one trap. For each bear, home

177   range calculations used GPS data spanning 1 June through 20 July of a given year, to match when

178   grid sampling occurred (see Results). To estimate home range, we used 95% fixed-kernel and

179   least-squares cross-validation to calculate the smoothing parameter (*Hooge & Eichenlaub, 2000*).

180   Data represented home range sizes of different classes of bears (females without cubs, females

181   with cubs of the year, and females with cubs over one year old). In practice, biologists often do

182   not know in advance what classes, or numbers of individuals within those classes would be

183   trapped, so they usually rely on the average home range size to inform the area of the sampling

184   cell (*Boulanger et al., 2004a; Boulanger et al., 2006*). To test the notion of using an average

185   home range size to inform grid cell area, we averaged the sizes of all home ranges together (n =

186   42 bears with GPS data spanning the 1 June through 20 July period). We also reported the home

187   range size of just females with cubs (n = 29).

188   For targeted sampling, we also determined the proportion of bears available for capture. We

189   relied on the GPS data to evaluate if each bear was within 500 m of an anadromous stream during

190   the sampling period. We then examined the proportion of bears within this sampling frame, for

191   every year of GPS data. The sampling frame was about 3,500 km^2, or 22% of the grid-sampling

192   frame ($\approx$16,000 km^2).

193   **Sampling Designs**

194   For grids, we simulated traps in a GIS by dividing the peninsula into 3 sets of square cells, with

195   areas of 49, 81 and 121 km^2 (Table 1). These cell areas were informed by the home range

196   analysis, and similar cell sizes are often used to estimate brown and grizzly bear population sizes

197   (*e.g. Boulanger et al., 2002; Beier et al., 2005; Mowat et al., 2005; Boulanger et al., 2008b;*

198   *Kendall et al., 2008*). Traps were stationary between capture sessions and located using 3

199   different configurations: traps in cell centers, traps placed randomly in the cell, or traps placed by

200   expert opinion in each cell. Expert opinion relied on our knowledge of bear behavior to locate

201   traps (in the GIS) where bears would most likely intercept them, were the traps actually set on the

202   ground. This included locations along streams, ravines and similar topographical features that

203   can attract or funnel moving bears.

204   We simulated the targeted designs using two methods, each with effort (trap-nights) comparable

205   to or less than the grid configurations (Table 1). First, traps were systematically spaced in the

206   GIS, with 17 and 19 km spacing.   Second, trap locations were identified in the field, by expert

207   opinion. We located these places by ground and plane reconnaissance, based on the

208   characteristics of shallow water or narrow reaches, since these attributes facilitate a bears' ability

209   to catch fish. Trap coordinates were input into the GIS. The traps placed by expert opinion had

210   two configurations that varied by effort.

211   Previous studies suggested that moving traps between captures sessions increases capture

212   probabilities and the number of individuals captured (*Boulanger et al., 2002; Boulanger et al.,*

213   *2004; Boulanger et al., 2006*). This should reduce bias and error in abundance estimates. We

214   tested this advice for brown bears using grid and targeted sampling designs, with traps placed by

215   expert opinion. For grids, we began by simulating 5 different sets of trap locations within each

216   cell. Trap locations were identified with aerial photography of the study area, and the coordinates

217   input into a GIS. We examined 30 scenarios of stationary traps (for each cell size). For five of

218   these scenarios, we held each of the trap sets (sets 1–5) constant across all capture sessions. For

219   the remaining 25 scenarios, we randomly picked a trap in each cell, and held this set constant

220   across all capture sessions (Table 1).

221   When traps were moved between capture sessions, a different trap set (1 of the 5) was used once

222   for each capture session. For example, trap set 3 in capture session 1, then trap set 4 in session 2,

223   etc. We randomly selected 30 of the 120 possible permutations of moved traps within each cell

224   (separately for grids of 49, 81, and 121 km^2; Table 1).

225   For targeted scenarios, we iteratively picked every 5th trap from the set of expertly located traps,

226   to ensure a different trap was used each session (140 traps/session). A second configuration of

227 targeted sampling halved this number of traps (70 traps/session). Permutations of stationary and

228 moved traps followed the same procedure outlined above (Table 1).

229 Lastly, we generated a hybrid technique. This design had traps expertly placed along streams, and

230 traps in a grid formation at 9 km spacing, located ≥15 km from anadromous streams.

231 **Abundance estimation and evaluation**

232 For each sampling configuration, we recorded a capture when a bear's GPS location occurred

233 ≤500 m of a trap. All abundance estimates were then calculated with closed capture models in

234 the program MARK (version 6.2; *White & Burnham, 1999*). We fit 8 models under the "full

235 closed captures with heterogeneity" data type. The first model was M_o, which assumed no

236 variation in capture probability associated with individuals or occasions (only one capture

237 probability, p). Model M_t assumed variation in capture probability between sampling sessions,

238 but not among individuals within a session. Model M_h (heterogeneity) permits different capture

239 probabilities for individuals, which remains the same over all sampling occasions regardless of

240 the capture history (*Karanth et al., 2002*). The fourth model, M_b, allows bears to demonstrate

241 behavioral responses (*e.g.* trap happy or shyness), an effect which can exist in simulations

242 (*White, 2008*). The remaining models allowed for combinations of the previous models (M_{th}, M_{tb},

243 M_{bh}, M_{tbh}).

244 We used the program MARK to estimate abundance and the related metrics, based on the models

245 receiving the most parsimonious fit. We used second-order Akaike's Information Criterion

246 (AIC$_c$) for model selection and treated models with $\Delta AIC_c \leq 2$ as competitive (*Anderson &*

247   *Burnham, 2002; Burnham & Anderson, 2002*). We model averaged competitive models based on

248   model weights.

249   We evaluated abundance estimates for each grid and targeted sampling design against 7 criteria.

250   First, we calculated average bias (how close the population estimate was to the true abundance

251   value) as:

252   $Bias\ (\hat{N}) = \dfrac{1}{n}\sum_{i=1}^{n}(\hat{N}_i - N)$

253   with $\widehat{N}$ $\hat{N}$ representing the abundance estimate, *N* the true abundance, and *n* the number of

254   simulations (30). We reported this as a relative score, by dividing bias by true abundance (*N* =

255   42). Next, we examined precision, the degree to which an individual estimate is repeatable or

256   reproducible. We reported coefficient of variation (CV) as a proportional measure of error in the

257   abundance estimates

258   $CV\ (\hat{N}) = 100 * \dfrac{SD(\hat{N})}{\hat{N}}$

259   Accuracy is a combination of these metrics (*Williams et al., 2002*), calculated as:

260   $RMSE\ (\hat{N}) = \sqrt{\dfrac{1}{n}\sum_{i=1}^{n}(\hat{N}_i - N)}\,_2$

261   $RMSE\ (\hat{N})$ was reported relatively, by dividing by true abundance (*N* = 42). We also reported

262   encounter rates, capture probabilities, and recapture probabilities. Encounter rates described the

263   number of GPS fixes considered captures, divided by the total number of GPS fixes (for each

264   bear). Capture probabilities were the number of bears caught divided by the total number of

265   known bears. Recapture probabilities were calculated as the number of bears caught more than

266   once, divided by the total number of bears captured. We used 2-sample *t*-tests to compare the

267   number of bears captured and recaptured between stationary and moved traps for each scenario

268   (*Zar, 1999*). If Levene's test for equality of variances indicated unequal variances, we used *t*-tests

269   where equal variances were not assumed (*SPSS, 2010*).

270   We also calculated the amount of effort (trap-nights) required to acquire population estimates as a

271   surrogate for cost. This value was the number of traps multiplied by the number of days sampled.

272   Lastly, we used program TRENDS to determine the number of survey years required to detect a

273   given population change or trend (*Gerrodette, 1993*). Parameters were $\alpha = 0.05$, 1-β (power) =

274   0.8, CV($\widehat{N}$) $\propto$ $\sqrt{\overline{N}}$, with a linear change over time. This exercise assisted with interpreting

275   the influence of CV ($\widehat{N}$) on the effectiveness of each scenario for monitoring abundance

276   changes.

277   **RESULTS**

278   **Sampling Periods**

279   We analyzed data from 42 female brown bears to evaluate the grid and targeted sampling designs.

280   We based the grid simulations during the 1 Jun–20 Jul period, since the greatest number brown

281   bears encountered traps in spring. There was an average of 57.0 GPS fixes per bear (SD 11.0)

282   during this time. The targeted scenarios occurred between 10 July through 28 August, when

283   brown bears had most location fixes <500 m of anadromous streams. On average, there were 58.0

284   GPS fixes per bear (SD 20.1) during this sampling period.

285   **Availability for Capture**

286   For grid-based and targeted sampling to produce reliable population estimates, all individuals in

287   the population must have traps available to capture them. To accomplish this with grids,

288   practitioners recommend that cell area match the average home range size of the target species

289   (*Boulanger et al., 2004; Boulanger et al. 2006; Sawaya et al., 2012*). Therefore, we calculated

290   home range sizes for the brown bears we sampled. The mean value was 149.7 km^2 (SD 149.8

291   km^2). When considering home range sizes of females with cubs, the mean home range size was

292   141.3 km^2 (SD 145.8 km^2). A 12 x 12 km cell approximates either area (Fig. 2).

293   Sixty-seven percent of the bears had home range sizes below this value. A cell size of 25 km^2

294   would miss <5% of bears yet the effort involved in employing such a grid is logistically

295   untenable (30,050 trap-nights) and would be exorbitantly costly for a study site this large. We

296   evaluated grids with edge lengths of 7, 9 and 11 km, and the following proportions of bears had

297   home range sizes below each of these areas, respectively: 26%, 49% and 63%.

298   However, traps (especially when expertly placed) may occur within the animals' home range,

299   even if it is smaller than the cell size employed. Therefore, for each grid scenario (expertly

300   placed traps) we determined if each bear had a trap within its home range. The average number

301   of bears without traps in their home range for stationary traps was 4.4 (SD 1.9; 49 km^2), 9.5 (SD

302   3.2; 81 km^2), and 14.8 (SD 2.1; 121 km^2). Moving traps between capture sessions reduced these

303   values, whereby the following numbers of bears never had a trap within its home range 1 (49

304   km^2), 1 (81 km^2), and 3 (121 km^2).

305   For targeted sampling, the sampling frame was the area within 500 m of an anadromous stream.

306   All bears were located within 500 m of anadromous streams during the sampling session, except

307   for 1997, when 2 bears were unavailable (although these bears were ≤500 m of streams after the

308   sampling session; Table 2).

309   Because one to three bears were always unavailable for capture, by definition, grid-based and

310   targeted sampling generated population indices, not estimates (hereafter termed indices). As

311   indicated, moving traps attenuates the problem of ensuring that all bears have equal opportunity

312   of encountering traps, but did not fix it.

313   **Evaluation of Sampling Configurations**

314   For each sampling configuration, we evaluated abundance indices, encounter rates, capture

315   probabilities, recapture probabilities, and the effort required to acquire them. For grids, the

316   configurations with traps in cell centers or randomly placed produced the lowest capture

317   probabilities, and generated abundance indices with high bias and error. Targeted sampling with

318   traps systematically placed also generated inaccurate abundance indices, and the hybrid

319   configuration provided results similar to targeted sampling alone. Therefore, we did not present

320   or consider these sampling designs further.

321 We focused on configurations with traps expertly placed in each cell (Table 3). Within each

322 configuration, sampling with traps moved between capture sessions always provided more

323 accurate population indices than sampling with stationary traps, mainly because moving traps

324 halved bias. Moving traps always increased precision for targeted sampling, but inconsistently for

325 grids (Table 3).

326 Sampling with traps moved between capture sessions using 49 km^2 cells and targeted sampling

327 generated the most accurate population indices (Table 3). The 49 km^2 grid had least bias (-

328 10.5%) and low precision (CV 21.2%), while targeted sampling had more bias (-17.3%) and most

329 precision (CV 12.3%). Their accuracy was nearly equivalent (RMSE = 21.7% and 20.0%

330 respectively; Table 3).

331 Grid-based sampling with moved traps in 81 km^2 cells and with stationary traps in 49 km^2 cells

332 also generated similar accuracy (RMSE = 26.5% and 25.6%). The 81 km^2 configuration had less

333 bias (-13.0), and more error (CV 26.6%), while stationary traps in the 49 km^2 grid had greater

334 bias (-21.5) and less error (CV 17.8%). Sampling in the 121 km^2 cells or with half the amount of

335 targeted traps (stationary) generated the most inaccurate indices, due to combinations of high bias

336 and imprecision (Table 3).

337 Usually, the techniques used to estimate or index abundance should be robust enough to identify

338 a specified level of change, be it the time necessary to quantify a given population trend, or the

339 time required to measure a set difference between individual surveys. For example, on the Kenai

340 Peninsula, this brown bear population has a growth rate (λ) of 1.04 (S. Farley, unpublished data).

341 At best, it would take $\geq$16 years to detect this trend with grid-based sampling (49 km^2 grids with

342 stationary traps). The targeted configuration required 12 years (moved traps; Table 4). A

343 doubling of population size is detectable in 19 or 28 years using a grid of 49 km^2 with traps

344 stationary or moved, respectively. Targeted sampling required 10 years (moved traps). Were a

345 population to halve in size, the same grid scenarios would require 6 and 7 years to detect it, while

346 targeted sampling would take 4 years (Table 4).

347 **Encounter rates, capture probabilities, recapture probabilities and effort**

348 Encounter rates within each grid and targeted configuration remained identical between traps

349 stationary or moved (moving traps reduced variability). Encounter rates for the targeted scenario

350 (moved traps) was 4 times greater than the best grid scenario (49 km^2; Table 5).

351 Within each configuration, moving traps always resulted in higher capture probabilities than

352 stationary traps. The increases were between 10 and 33% (Table 6). Targeted sampling generated

353 the highest capture probabilities. With moved traps, capture probabilities were 11% higher than

354 sampling within the 49 km^2 grid ($t = -5.1$, $df = 52.2$, p-value < 0.001).

355 Within a given configuration, moving traps always reduced recapture probability. The result was

356 significant for every configuration except when sampling within 49 km^2 grids (Table 7). The

357 recapture probabilities declined with increasing cell size (49 km^2 and 81 km^2 grids), or with

358 fewer targeted traps. For grids, recapture probabilities were greater for 121 km^2 cells with

359 stationary traps, because the scenario caught fewer bears more often (Table 7). We found that

360 targeted sampling with moved traps had higher recapture probabilities than sampling in 49 km^2

361 grids (t = -13.2, df = 58, p-value < 0.001).

362 Lastly, effort (measured by trap-nights) was highest for grid sampling with 49 and 81 km^2 cells,

363 as these scenarios expended 16,100 and 9,750 trap-nights each. Effort for the targeted

364 configuration was 57% less than the 49 km^2 grids and 28% less than 81 km^2 grids (7,000 trap-

365 nights; Table 1).

366 **DISCUSSION**

367 Establishing defensible and economical sampling methods to obtain species abundances will

368 inform conservation measures and management actions for many species inhabiting large, remote

369 or complicated landscapes. Therefore, we used a CMR framework and evaluated sampling

370 designs which varied by configuration, effort (trap amount) and complexity (stationary or

371 moved). The goal was to identify informative and affordable sampling designs that biologists

372 could use for estimating or indexing abundance.

373 For grid-based sampling, it is often recommended that cell size corresponds to the average area of

374 an animal's home range, or smaller, to reduce capture heterogeneity (*Boulanger et al., 2004;*

375 *Boulanger et al., 2006; Sawaya et al., 2012*). However, animal home ranges usually have much

376 variability, which can change within and across seasons based on resource pulses and their

377 distribution (*McNab, 1963; Boulanger et al., 2006, Nielsen et al., 2010*). Therefore, a value

378   describing the average home range size may not be biologically meaningful, making it risky to

379   justify grid resolution on this metric. In our case, cell sizes of 49, 81 and 121 km^2 seemed

380   appropriate since female brown bears had home range sizes averaging 149.6 km^2. Yet these cell

381   sizes were still too large for grid sampling to provide population estimates, since some bears were

382   not available for capture.

383   When grid configurations are used, justification for the cell size should not rely on the average

384   home range size of the target species. Instead, justification falls on making cell size as small as

385   project costs allow. However, to make studies affordable, the temptation is for fewer traps to be

386   employed, and therefore, increased cell size. Yet we found that as the grid cells became larger,

387   less numbers of traps caught fewer bears, which lowered encounter rates, capture and recapture

388   probabilities (Tables 5, 6 & 7). This produces results with more bias and imprecision (Table 3).

389   Given this information, how does one know when cell sizes are too large?

390   Unless preliminary work provides information for understanding a species use of the landscape,

391   then the cell size chosen will be a speculation. As a result, the abundance estimate generated may

392   indicate an estimate or an index, or be completely uninformative.

393   Previously, many projects that estimated brown bear abundance operated in places spanning

394   ~2,000 - 8,000 km^2 (*e.g. Poole et al., 2001; Boulanger et al., 2002; Mowat et al., 2005;*

395   *Boulanger et al., 2006, Kendall et al., 2008*). Our site spanned 16,000 km^2. For areas of this

396   size, small grids grow prohibitively expensive to use. In our case, cell size should be <49 km^2,

397   requiring > 322 traps and >16,100 trap-nights (>0.02 traps/km^2). Checking these traps in remote

398   locations usually requires the use of helicopters, which often exceed $700.00 per flight hour.

399 Project costs can easily approach $1,000,000.00 in such large areas, when sampling in grids at or

400 below this resolution. In any event, grid sampling places many traps in low density, to sample

401 low densities of animals across an expansive area. It seems costly and inefficient.

402 For the targeted design, species biology informed the sampling frame, as anadromous streams

403 attracted bears from the wider landscape. The technique was more efficient, by operating 140

404 traps in a 3,500 km^2 area (0.04 traps/ km^2). It sampled higher densities of animals in a smaller

405 area with less traps, generating the highest capture and recapture probabilities (Tables 6 & 7). Its

406 accuracy was equivalent to the grid index (49 km^2; Table 3).

407 For brown bears in Alaska, the targeted configuration is easier and cheaper to operate in the field

408 for at least three reasons. First, it required half the effort of the 49km^2 grids. Second, since traps

409 occur along streams, they are more accessible by walking or rafting. Third, the lure (fish) is

410 provided naturally, reducing time, expense and costs for trap set-up, and concerns that the target

411 species may lose interest in the trap over time (*Boulanger et al. 2004a; Boulanger et al. 2008b*).

412 The conventional assumption is that moving traps raises capture probabilities, by increasing the

413 proportion of bears captured, and therefore reducing bias (*Boulanger et al.,2002; Boulanger et

414 al., 2004a; Boulanger et al., 2006*). Our simulation confirmed this assumption for grid and

415 targeted sampling, as moving traps always increased capture probabilities. Moving traps between

416 capture sessions raised capture probabilities, because moving traps to new areas increased their

417 availability to more bears that would otherwise not have the opportunity to encounter them.

418 However, moving traps also caused a decline in recapture probabilities. This makes sense, as

419 moving traps takes them from a location where they already sampled bears, and places them

420 someplace new. Then, it becomes more difficult to recapture those same bears already caught, as

421 the trap is more likely to be moved to a spot where they do not occur. The 49 km^2 grid had most

422 traps, which may explain why the effects of relocating traps was not as marked.

423 For indexing species abundances, the most accurate results occurred with traps moved between

424 capture sessions, and traps placed by expert opinion. Moving traps reduced capture heterogeneity,

425 by increasing the number of animals in the sampling frame with a nonzero probability of

426 encountering a trap (*Williams et al., 2002; Lukacs 2009*). Unfortunately, moving traps did not

427 ensure trap availability to all bears, and therefore did not completely alleviate the sampling bias

428 caused by using too large a cell, or sampling at anadromous streams. All individuals in the

429 population must visit the sampling area to generate valid estimates of abundance. Hence, the final

430 abundances generated from both sampling designs represented population indices. Providing

431 population estimates would require smaller grid cells, or more traps in the targeted design.

432 **Sampling synopsis**

433 The most accurate configurations, targeted and grid-based sampling with 49 km^2 cells, had

434 tradeoffs in bias, precision and effort (costs). Targeted sampling was more biased and precise

435 while the 49 km^2 grid was less biased and less precise. Because abundances gained from grid

436 sampling tend to be imprecise, some projects incorporate ancillary information (*i.e.* covariates) to

437 increase precision, or data from captures gained elsewhere (*Boulanger et al., 2008b; Kendall et*

438 *al., 2009; Sawaya et al., 2012*). Many applications to index abundance for bears and other

439 species will not have such ancillary data available, and therefore we did not include covariates in

440 our analyses.

441   Often, management applications center on evaluating trends in abundances over time. Because

442   this exercise requires high precision, most wildlife surveys aim for a CV $\leq$ 20% (*Boulanger et*

443   *al., 2002; Williams et al., 2002*). Otherwise, it takes unacceptably long to measure population

444   changes and trends in time for managers to act. The most accurate targeted scenario met the

445   criteria, by generating a CV of 12%, while the most accurate 49 km^2 grid did not.

446   When using the program MARK, the most competitive models for grids (moved traps) typically

447   contained M_o models (80% 49 km^2, 86% 81 km^2), and rarely M_h based models. This outcome is

448   indicative of grid sampling reducing heterogeneity between capture sessions. However, M_o based

449   models are sensitive to violations in the underlying model assumption of homogenous capture

450   probabilities (*Otis et al., 1978*). For the targeted approaches, we anticipated variation in capture

451   probability among individuals, and found that all targeted configurations (moved traps) used M_h

452   based models. The M_h models are robust to violations in underlying model assumptions,

453   providing greater confidence in those abundance estimates (*Burnham & Overton, 1978; Otis et*

454   *al., 1978; Karanth et al., 2002*).

455   Given this synopsis, targeted sampling provides results with accuracy comparable to grid

456   sampling, only more affordably. Hence, targeted sampling opens opportunities for indexing

457   abundances of animal populations for many conservation and management projects, provided that

458   the species are attracted to resource concentrations. Often, these projects are cost limited, large in

459   geographical size, focus on rare and sparsely distributed species, and cover locations with

460   challenging access. The abundance indices gained would contribute toward understanding

461   population changes between periods and measuring the trajectory of populations over time, for

462   many species whose current information is deficient.

Encounter distance and use of lure

464 The effective distance that a bear would be attracted to a scent or visual lure is unknown. The

465 distance depends on the type of lure used, amount of elapsed time since lure deployment (more

466 time dilutes lure effectiveness), topography, weather (*e.g.* aridity, precipitation), wind speed and

467 direction, bear gender, experience and behavior (*i.e.* waning interest in lure; *Boulanger et al.,*

468 *2004a; Boulanger et al., 2008b; Sawaya et al., 2012*). Potentially, future studies aimed at

469 quantifying this distance could leverage off projects that estimate population sizes of lions

470 (*Panthera leo*) and hyenas (*Crocuta crocuta*) using call playbacks as lure (*Mills et al., 2001;*

471 *Kiffner et al., 2008*).

472 Our simulation considered distances between a bears GPS location and hypothetical trap < 500 m

473 as encounters. The actual distance used is essentially irrelevant for the simulation. What matters

474 is bear density in a given area. Areas with high bear density will get more captures than a place

475 with low density, regardless of the distance between bear and trap. In our example, targeted

476 sampling occurred in a confined area, defined as places within 500 m of anadaramous streams.

477 Since all bears visit this relatively small area – about 88% smaller than the grid area – then traps

478 placed here catch more bears more often. The wider landscape has lower density of bears, so

479 traps placed there catch fewer bears less often. Preliminary work with a 100 m encounter

480 distance generated similar outcomes to those presented here, only with less encounters and

481 captures (G. Harris, unpublished data). Seemingly, by considering larger encounter distances, it

482 would generate more encounters and captures.

483 Because our effort is a simulation, it did not account for baiting traps, a common practice to

484 attract bears when field sampling (*e.g. Woods et al., 1999; Boulanger et al. 2002; Sawaya et al.*

485 *2012*). Were a field study to occur, with traps baited, then we would expect encounter

486 probabilities to increase, for grid and targeted sampling alike. Both sampling designs can have

487 lure associated with them (*Sawaya et al., 2012*). Therefore, in the simulation, since data are

488 handled identically, there is no more attraction for a bear to visit a targeted snare any more so

489 than a grid snare. Additionally, the behavioral responses measured in the modeling can reflect

490 survey configuration (*White, 2008*).

491 As above, what differs is bear density in an area. The targeted sampling frame matched species

492 biology by relying on animals' attraction to resource concentrations (*Karanth et al., 2004*). This

493 outcome enabled targeted sampling to provide accurate abundance indices. The targeted approach

494 is not new, and has been used elsewhere to provide abundance data with informative results, be it

495 rub trees to collect bear hair (*e.g. Mowat et al., 2005; Kendall et al., 2008; Kendall et al., 2009;*

496 *Sawaya et al., 2012*) or to gain photographs of tigers along trails (*Karanth & Nichols, 1998*).

497 **Spatial capture-recapture models**

498 We relied on closed capture models in the program MARK (*White & Burnham, 1999*) to quantify

499 abundances, instead of other approaches such as spatially explicit capture-recapture models

500 (SECR; *Efford et al., 2009; Efford, 2011; Royle et al., 2011*). While the SECR approach can

501 apply to grid sampling, and we applaud the innovation, there are five reasons why we employed

502 MARK. First, MARK is a proven method and appropriate for estimating animal abundances.

503 Second, this project is a simulation, with all bears completely within the study frame, and the

504 population closed (based on the GPS location data). This eliminated any ambiguity over the

505 effective sampling area, which the SECR models rigorously address for the purposes of density

506 estimation. Third, when grid cells exceed home range size – as encountered herein – then not all

507 individuals are available for capture. SECR models do not solve this bias. Fourth, the SECR

508 models rely on information describing where and when a given animal is trapped (session

509 number) to identify each individual animals "activity center". The probability of detection for

510 each trap is modeled as a function of the distance from the activity center to traps in the array. If

511 the method relies on animal movements to estimate home range centers (*Royle et al., 2009*), then

512 SECR requires multiple captures. Yet, over one-third of these bears had only one capture (each,

513 for 49 km^2 and 81 km^2 grid cells with moved traps). This renders the SECR technique less

514 effective. Fifth, some SECR models assume that activity centers are uniform and symmetric

515 (*Efford et al., 2009; Efford, 2011; Royle et al., 2011*). Unfortunately, this assumption is untenable

516 for brown bears inhabiting the Kenai Peninsula. Home range sizes varied widely in area (Fig. 2),

517 and spatially, as bears often moved linearly within mountain valleys and through passes, thereby

518 defying the notion of a symmetrical home range (G. Harris and S. Farley, unpublished data).

519 Unfortunately, SECR models are not yet designed for data gained by a targeted approach (J. A.

520 Royle, pers. comm. 2013). If activity centers were built for bears trapped at streams, it would

521 imply that bears only occurred there. This would severely bias the true distribution of bear's

522 activity centers across the landscape. In reality, bear movements follow a general pattern

523 whereby they periodically visit streams as they wander throughout the wider landscape (G. Harris

524 & S. Farley, unpublished data). Therefore, by using MARK to compute abundance indexes, it

525 ensured that each of the scenarios contained similar sampling and quantitative assumptions.

526 **Density estimation**

527   An important part of abundance estimation is defining the sampling area, and determining if that

528   area is open or closed to species movement. For targeted sampling, defining the study area

529   requires knowing the "attraction distance" of the species to the resource concentrations (where

530   sampling occurs). We do not know the attraction distance of brown bears to anadromous streams.

531   However, in our study, all bears spanning the peninsula visited anadromous streams. Because the

532   attraction distance was not exceeded for these bears, a targeted sampling design actually

533   conducted on the Kenai Peninsula could estimate density. Obviously, this is not the case for

534   many other species and locations. For them, additional work will probably be required to

535   determine the attraction distance, which would in turn define the sampling frame. Fortunately,

536   there is precedence for such efforts, as biologists on the African continent estimate abundance of

537   lions and hyenas based on their attraction to vocalization lures. Biologists quantified the

538   attraction distance of these carnivores to the lure, to estimate species density (*Ogutu & Dublin,*

539   *1998*).

540   **CONCLUSIONS**

541   When sampling cryptic animals inhabiting thickly vegetated and expansive areas, with DNA,

542   camera traps or other CMR methodology, it can challenge abilities to produce accurate and

543   affordable abundance indices. Yet targeted sampling met these criteria, by sampling where

544   individuals gathered in smaller areas, at biologically important places and times. It generated

545   encounter rates four times higher than grid sampling, capture probabilities 11% higher, and 60%

546   higher recapture probabilities. This reduced capture heterogeneity (*Williams et al., 2002; Lukacs,*

547   *2009*). By generating a CV of 12%, targeted sampling was precise. Better precision enables

548   measuring changes in abundances quicker, with trends more likely to reflect true changes in the

549   population and not sampling or biological artifacts. Lastly, targeted sampling was more

550   economical, as it used half the effort of the grid.

551   Since our simulation had a known number of bears, it enabled us to evaluate the veracity of the

552   grid and targeted designs. Hence, our simulation provided insight into sampling approaches and

553   assumptions for grid and targeted sampling that would be difficult to provide with field studies.

554   However, conducting field studies to test and verify our findings, or refine methodologies, forms

555   a logical next step. Fortunately, for targeted sampling, some field studies already provide insight.

556   For instance, Saway et al. (2012) found that collecting hair from bear rubs generated higher

557   detection rates and capture probabilities than traps in grids, for all classes of bears. Kendall et al.

558   (2009) also relied on collecting hair on bear rubs and from physical captures to improve capture

559   probabilities, as samples gained from grid traps alone provided inaccurate results.

560   Grids blanket entire study areas under the guise of ensuring equal probability of capture. This

561   approach should work, provided the cells are small enough to encapsulate home ranges of all

562   individuals. This requires home range data, which can be expensive and laborious to procure. If

563   the average home range size is used, or were cell size based on home range data gained

564   elsewhere, or home range sizes changed between surveys, then cell sizes may be too large. Then,

565   users of grid sampling may assume that their techniques meet the sampling assumptions required

566   to estimate population abundance, when in actuality, not all individuals are available for capture.

567   Worryingly, many studies have not confirmed that the cell sizes they employ are appropriate (*e.g.*

568   *Woods et al., 1999; Boulanger et al., 2004; Mowat et al., 2005; Boulanger et al., 2006;*

569   *Boulanger et al., 2008; Kendall et al., 2008; Sawaya et al., 2012).* Therefore, their results may

570   represent estimates or indices, and if the latter, how the index relates to the estimate is unknown.

571 Criticism of the targeted approach centers on subjective or convenience sampling, largely

572 regarded as poor practice. As with grids, to ensure that subjective sampling does not occur,

573 studies should demonstrate that individuals have a nonzero probability of capture (to produce

574 estimates). Unfortunately, other studies using targeted sampling have not justified if all

575 individuals in the sampling frame have a nonzero probability of capture, so whether these studies

576 meet this assumption also remains unknown (*Karanth et al., 1998; Kendall et al., 2009; Sawaya*

577 *et al., 2012*).

578 We found that grid and targeted sampling of brown bears on the Kenai Peninsula had a few

579 individuals with zero probability of capture, and therefore did not meet this assumption. The

580 extent that serious problems in wildlife management or conservation stem from studies sampling

581 with grids or targeted designs and presenting estimates that could represent indices remains

582 uncertain.   However, in keeping with our results, the biases are likely to be negative, thereby

583 erring conservatively. Although, the trends for grids would likely be less informative than the

584 trends reported from targeted designs, because the grid designs were more imprecise, which

585 could mask population changes when they occur.

586 The targeted approach relied on identifying biologically important resource concentrations, and

587 sampling at those sites. For bears, salmon runs may change in timing between periods, so bears

588 could visit them outside the sampling period. Or, some resource concentrations may be unknown,

589 and therefore not sampled. If so, the cost of inadequately covering all resource concentrations is

590 larger bias. However, population indices from the targeted design maintained precision,

591 rendering them useful for evaluating trend (provided traps were moved between sessions).

592 Therefore, the outcome of heterogeneity in animal captures for trend analyses manifests in grid

593 sampling losing utility as trap density declines (via larger grid cells), while trends from targeted

594 sampling remained useful.

595 Biologists must weigh the theoretical robustness of sampling and modeling procedures with the

596 logistical constraints of a given sampling design. Clearly, both grid and targeted sampling have

597 benefits and flaws. Before employing these designs, practitioners should evaluate their sampling

598 assumptions, the methodological drawbacks, and the utility of the results generated. The grid and

599 targeted designs are not appropriate for all species in every situation. Neither approach is a

600 panacea.

601 Targeted sampling could assist with indexing abundance of other species that concentrate at

602 biological resources – be it trails, water holes, mineral licks, or animal latrines (*Karanth et al.,*

603 *2004*). For example, travel routes and trail intersections draw tigers (*Karanth & Nichols, 1998*).

604 The thick lowland forests of the Southwestern Amazon contain sparsely distributed macaws.

605 Macaws gather by the hundreds to take clay from exposed riverbanks (*Diamond, 1999*).

606 Similarly, burned patches in lowland Nepal attract axis deer (*Axis axis*) from forests (*Moe &*

607 *Wege, 1997*), while alpine ibex (*Capra ibex*) and bighorn sheep (*Ovis canadensis*) vacate rugged

608 terrain to frequent natural and anthropogenic sources of salt and minerals (*Schmidt et al., 1978;*

609 *Watts & Schemnitz, 1985; Bassano et al., 2003*). Walruses (*Odobenus rosmarus*) aggregate at

610 terrestrial haul-out sites (*Lydersen et al., 2008*) and elephants congregate at water sources (*Harris*

611 *et al., 2008*).

612 Globally, many species inhabit expansive and inaccessible areas, and have sparse distributions

613 within them. Because these species are difficult to sample, data describing their abundances are

614 often deficient. Many of these animals are of high conservation concern. Biologists require

methods to sample these animals effectively and economically, for indexing abundance and

reporting trends, to subsequently conserve and manage their populations. In extensive areas

where animals concentrate in confined locations, targeted sampling could provide such an

approach.

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Sampling configurations.

Characteristics of the sampling configurations used to simulate capture-mark-recapture of brown bears on the Kenai Peninsula, south-central Alaska, USA. Attributes included the timing of the simulation (period), position of traps (placement), whether traps were stationary or moved between capture sessions, cell area (km^2) or trap spacing apart (km), the number of traps in each of 5 capture sessions, and effort (trap-nights).

Table 1

Sampling Configuration	Period	Placement	Stationary (S) or Moved (M)	Cell Area or Spacing	No. Traps per Capture Session	Total Effort (Trap-Nights)	
Grid	6/1–7/20	Cell Center	S	49, 81, 121	322, 195, 135	16,100, 9,750, 6,750	
Grid	6/1–7/20	Random	S	49, 81, 121	322, 195, 135	16,100, 9,750, 6,750	
Grid[a]	6/1–7/20	Expert opinion	S	49, 81, 121	322, 195, 135	16,100, 9,750, 6,750	
Grid[a]	6/1–7/20	Expert opinion	M	49, 81, 121	322, 195, 135	16,100, 9,750, 6,750	
Targeted	7/10–8/28	Systematic	S	17, 19	324, 312	16,200, 15,600	
Targeted[a]	7/10–8/28	Expert opinion	S	N/A	140, 70	7,000, 3,500	
Targeted[a]	7/10–8/28	Expert opinion	M	N/A	140, 70	7,000, 3,500	

[a] These configurations were analyzed and compared (each configuration had 30 simulations). The other configurations produced inaccurate abundances.

Availability for capture.

The total number of bears on the Kenai Peninsula during the sampling period for the targeted scenario, along with the number of bears present within the sampling frame (< 500m of an anadromous stream) during that period, for each year of sampling.

Table 2

Year	Total No. Bears In Sampling Period	No. Bears Within Sampling Frame
1996	2.0	2.0
1997	14.0	12.0
1998	4.0	4.0
1999	8.0	8.0
2000	6.0	6.0
2003	5.0	5.0
2004	3.0	3.0

Table 3 <small>(on next page)</small>

Comparison of sampling configurations.

Results describing the bias, precision and accuracy of abundance estimates generated from the grid and targeted sampling configurations, with trap placement stationary or moved between capture sessions ($N = 42$ for each configuration).

Table 3

Configuration	Placement	n[a]	$\widehat{N}$[b]	SD[c]		% Bias[d]	% RMSE[e]	CV[f]
Grid 7km	Stationary	30	32.98	5.88	-21.48	25.63	17.82	
	Moved	30	37.59	7.98	-10.51	21.70	21.22	
Grid 9km	Stationary	30	29.96	10.57	-28.67	38.16	35.30	
	Moved	30	36.56	9.72	-12.95	26.51	26.58	
Grid 11km	Stationary	30	19.49	9.76	-53.60	58.42	50.10	
	Moved	30	32.21	17.45	-23.31	47.63	54.16	
Targeted	Stationary	30	28.23	4.22	-32.77	34.28	14.94	
	Moved	30	34.75	4.26	-17.27	20.02	12.26	
Targeted(1/2)	Stationary	30	20.36	5.00	-51.51	52.87	24.56	
	Moved	30	27.42	4.32	-34.71	36.20	15.75	

[a] Sample size

[b] Mean estimated abundance

[c] Standard deviation of mean estimated abundance.

[d] Percent relative bias

[e] Percent relative root mean squared error (accuracy)

f Coefficient of variation (precision)

Time required to measure population change.

Time (years) required to measure a lambda of 1.04, and a doubling or halving of overall population size, from 5 different sampling configurations with traps stationary (S) or moved (M) between capture sessions. Calculations relied on CVs reported in Table 3.

Table 4

Sampling Configuration	T_λ[a]	T_d[b]	T_h[c]
Grid 7km (S)	16	19	6
Grid 7km (M)	19	28	7
Grid 9km (S)	34	61	17
Grid 9km (M)	23	43	11
Grid 11km (S)	48	82	36
Grid 11km (M)	54	106	41
Targeted (S)	14	13	4
Targeted (M)	12	10	4
Targeted(1/2) (S)	21	36	9
Targeted(1/2) (M)	15	16	5

[a] Number of years required to detect a yearly growth rate (λ) of 1.04.

[b] Number of years required to detect a doubling of the overall population size

[c] Number of years required to detect a halving of the overall population size

Encounter rates.

Mean and standard deviation of encounter rates (number of GPS locations considered captures / total number of GPS locations) for all bears in the sampling period, for 5 grid and targeted sampling configurations, with traps stationary or moved between capture sessions (N= 42 bears, with 30 simulations for each configuration).

Table 5

Configuration	Stationary $\overline{X}$ [a]	SD	Moved $\overline{X}$ [a]	SD
49 km² grid	0.03	0.01	0.03	0.00
81 km² grid	0.02	0.01	0.02	0.00
121 km² grid	0.01	0.01	0.01	0.00
Targeted	0.12	0.03	0.12	0.01
Targeted (1/2)	0.06	0.02	0.06	0.01

[a] Encounter rates

Comparison of capture probabilities.

Mean and standard deviation of capture probabilities for 5 sampling configurations. We used a *t*-test to compare capture probabilities.

Table 6

Configuration	Stationary Traps			Moved Traps			Levene's Test		t-test		
	$\dot{p}$ [a]	SD($\dot{p}$) p-value		$\dot{p}$ [a]	$\sigma(p)$	SD($\dot{p}$)	F	p-value		t	df
49 km² grid	0.60	0.08		0.66	0.07		2.82	0.099	-2.92	58.0	0.005
81 km² grid	0.44	0.09		0.52	0.06		2.56	0.115	-3.95	58.0	0.000
121 km² grid	0.32	0.07		0.38	0.07		0.20	0.656	-3.31	58.0	0.002
Targeted	0.61	0.07		0.73	0.05		2.74	0.103	-8.16	58.0	0.000
Targeted(1/2)	0.43	0.10		0.57	0.05		10.61	0.002	-7.008	44.78	0.000

[a] Capture probability

Comparison of recapture probabilities.

Mean and standard deviation of recapture probabilities for 5 sampling configurations. We used a *t*-test to compare recapture probabilities.

Table 7

_	Stationary		Moved		Levene's Test			t-test
Configuration	$\acute{c}^a$	$\bar{c}_R$	SD($\acute{c}$)		$\acute{c}^a$	SD($\acute{c}$)	F	p-value
	t	df	p-value					
49 km² grid	0.47	0.13	0.43	0.08	4.05	0.049	1.19	49.17
	0.241							
81 km² grid	0.42	0.12	0.34	0.10	0.11	0.747	2.79	58.0
	0.007							
121 km² grid	0.48	0.10	0.29	0.10	0.01	0.934	7.36	58.0
	0.000							
Targeted	0.75	0.08	0.69	0.06	1.48	0.230	3.73	58.0
	0.000							
Targeted(1/2)	0.70	0.09	0.53	0.08	0.17	0.678	7.52	58.0
	0.000							

_

[a] Recapture probability

Figure 1

Study Location.

We simulated and compared capture-mark-recapture using grid-based and targeted sampling designs for brown bears (*Ursus acrtos*) inhabiting theKenai Peninsula (center, with elevation shaded from low [light gray] to high [black]), south-central Alaska, USA (inset). The grid-based design used cells with an area of 49 km 2 , 81 km 2 (pictured in gray), and 121 km 2 . The targeted design sampled places where important biological resources concentrated the target species (*i.e.* bear's attraction to anadromous streams; black lines).
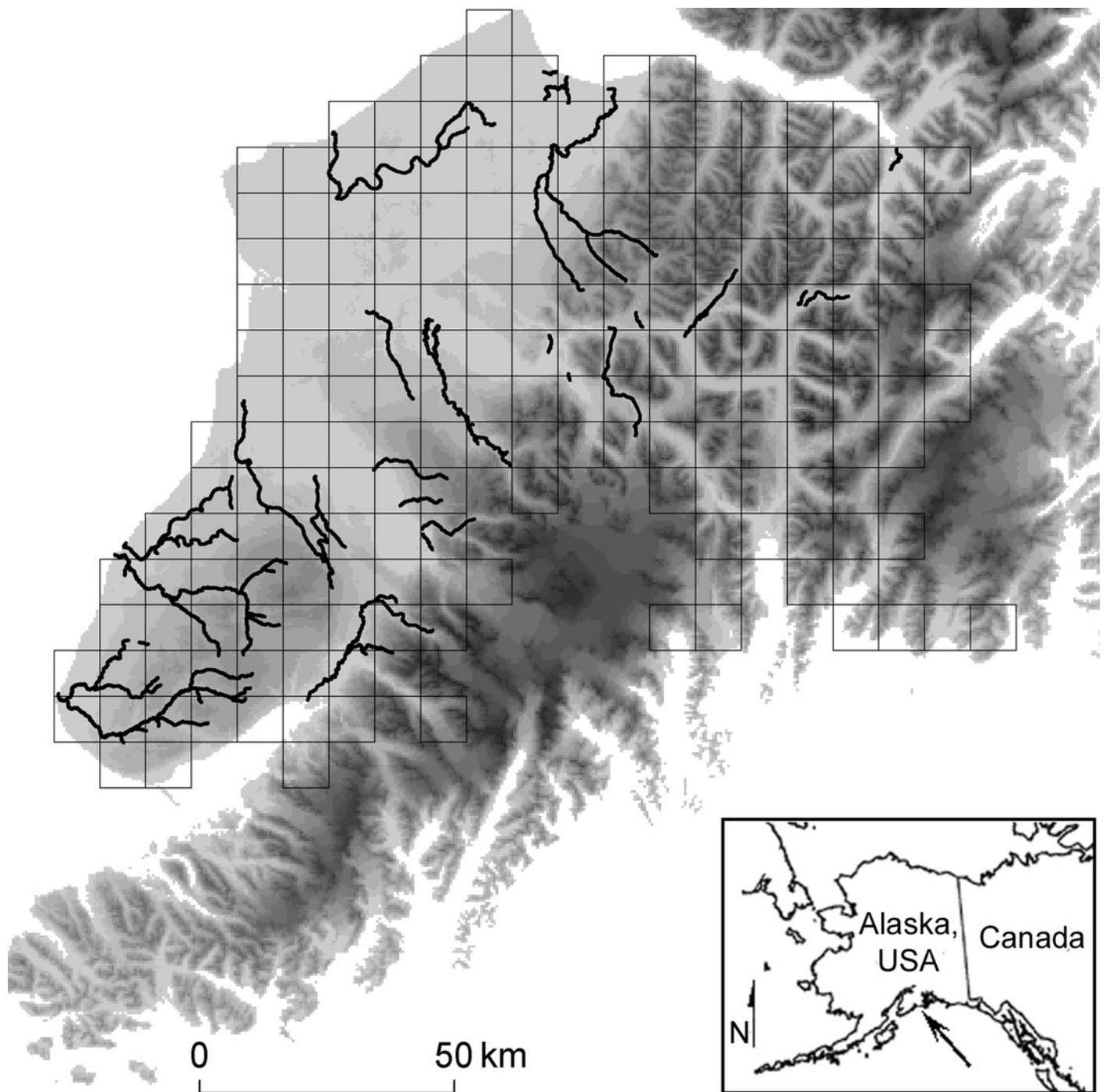
Figure 2

Brown bear home range sizes.

Distribution of home range sizes of brown bears ($n = 42$) during 1 June through 20 July on the Kenai Peninsula, south-central Alaska, USA. Mean home range size (M) was 149.6 km 2 (SD = 149.7 km 2). Sixty-seven percent of bears had home ranges smaller than the mean.