Brown bear population density on Togiak National Wildlife Refuge and BLM Goodnews Block, southwest Alaska

Patrick Walsh, Joel Reynolds, Gail Collins, Brook Russell, Michael Winfree, and Jeffrey Denton

March 2008

Togiak National Wildlife Refuge
Dillingham, Alaska

The mission of the National Wildlife Refuge System is to administer a national network of lands and waters for the conservations, management and where appropriate, restoration of the fish, wildlife and plant resources and their habitats within the United States for the benefit of present and future generations of Americans.

Suggestion Citation:

Walsh, P, Reynolds, J., Collins, G., Russell, B., Winfree, M., and J. Denton. 2008. Brown bear population density on Togiak National Wildlife Refuge and BLM Goodnews Block, southwest Alaska. U.S. Fish and Wildlife Service. Dillingham, Alaska.

Brown bear population density on Togiak National Wildlife Refuge and BLM Goodnews Block, southwest Alaska

---

Patrick Walsh, Joel H. Reynolds, Gail Collins, Brook Russell, Michael Winfree, and Jeffrey Denton[1]

Abstract

Brown bear (*Ursus arctos*) population density was estimated for a 21,178 km^2 study area in southwest Alaska. Estimates were obtained using an aerial line transect method that allows for peak detection to be both off the transect line and < 100%. Data collection required five small aircraft with two-person crews. Surveys were flown in 10-day windows to capture the period after den emergence but prior to full green-up. Surveys were flown in two consecutive years in order to detect sufficient bear groups to support the estimation. The survey detected 197 bear groups (330 bears) in 969 aerial transects averaging 24.8 km in length and with an effective strip width of 728 m. Estimated population density in the study area was 40.4 bears/1000 km^2, with a 95% confidence interval of 31.4 to 54.5 bears/1000 km^2; estimated density of independent bears was 27.3 bears/1000 km^2, with a 95% confidence interval of 21.4 to 34.4 independent bears/1000 km^2.

Keywords: *Ursus arctos*, population estimate, double count, contour transects, distance estimation, gamma detection function, aerial line transects, bootstrap.

Introduction

The brown bear (*Ursus arctos*) is the largest member of the order Carnivora in southwest Alaska. It occupies the uppermost position in a complex food chain, plays a primary role in the distribution of nutrients from aquatic systems to terrestrial systems (Helfield 2001), and is a continuing source of human interest, both positive and negative. It occurs in habitats ranging from mountain tops to coastal beaches, equally at home in lowland wet grasslands, alpine tundra, coniferous and hardwood forests. It ranges from areas of deep wilderness virtually untouched by humans, to villages, fishing camps, and garbage dumps.

Efforts to estimate Alaskan brown bear populations have been evolving since the 1930's (Dufresne 1967). Brown bear populations are difficult to monitor due to their low population density, low detectability and winter inactivity (Kansas 2002). Estimation methods have included relative abundance indices based on incidental observations (Elgmork 1991) or track counts (Valdmann et al. 2001), mark-recapture using visual observation (Swenson et al. 1994,

---

[1]**Authors:** Patrick Walsh and Michael Winfree are biologists with the U.S. Fish and Wildlife Service, Togiak National Wildlife Refuge, PO Box 270, Dillingham, Alaska 99576; Patrick_Walsh@fws.gov, Michael_Winfree@fws.gov. Joel Reynolds and Brook Russell are biometricians with the U.S. Fish and Wildlife Service, Alaska Regional Office, 1011 E. Tudor Road, Anchorage, Alaska 99503; Joel_Reynolds@fws.gov. Gail Collins is a biologist with the U.S. Fish and Wildlife Service, Sheldon Hart National Wildlife Refuge, P.O. Box 111, Lakeview OR 97630; Gail_Collins@fws.gov. Jeffrey Denton is a biologist with U. S. Bureau of Land Management, Anchorage Field Office, Anchorage, Alaska; Jeff_Denton@ak.blm.gov.

Miller et al. 1997) or genetic signature (Boulanger et al. 2002, Bellemain et al. 2005), total counts with sightability corrections (Barnes and Smith 1998), and more recently, distance estimation methods (Quang and Becker 1997).

Brown bear population density was first estimated in this study area as part of a statewide population assessment (Miller 1993) that classified Alaskan brown bear populations into three density classes: low density (<40 bears/1000km^2), medium density (40-175 bears/1000km^2), and high density (>175 bears/1000km^2). Probable brown bear population density was mapped statewide by extrapolating from 17 study areas. The present study area was included in the low density category. More recently, a demographic study in the Kuskokwim Mountain portion of the Togiak and Yukon Delta National Wildlife Refuges and Wood-Tikchik State Park encountered 52 known independent bears, providing a minimum brown bear population size for the area equating to a density of 18.2 independent bears/1000 km^2 (Van Daele et al. 2001). However, the researchers suspected that actual density was nearly twice that size (Van Daele et al. 2001).

In recent years, concerns have been regularly voiced during local village meetings, state Fish and Game Advisory Committee Meetings, and Federal Subsistence Regional Advisory Council meetings, that brown bear populations are increasing, and this increase has adversely impacted wildlife populations targeted by subsistence hunters. The lack of quantitative information on bear abundance has prevented resource managers from adequately addressing these concerns.

This project was initiated to (i) obtain statistically sound estimates of current brown bear abundance and population parameters in the study region and (ii) assess the feasibility of the aerial line transect survey method as a cost-effective approach to regular brown bear monitoring. The objectives were to:

1. Estimate the number of brown bears, and its associated uncertainty, throughout Togiak National Wildlife Refuge and the Bureau of Land Management (BLM) Goodnews Block.
2. Report time and expense requirements to conduct this survey and discuss feasibility as a monitoring method.
3. Estimate demographic parameters of brown bears throughout Togiak Refuge and the BLM Goodnews Block.

Study area

The study area consists of Togiak National Wildlife Refuge, the BLM Goodnews Block (Bureau of Land Management lands in the vicinity of Goodnews Bay), and various private and native corporation lands enclosed within the outer boundary of the two federal land units (Fig. 1). The study area was approximately 2.12 million ha. Land forms in the study area were dominated by the Ahklun Mountains, which occupied approximately 80% of the area. The remainder consisted of low elevation graminoid and lichen tundra areas forming the Nushagak and Kanektok Lowlands at the northwest and southeast edges of the study area. The area included approximately 1,120 km of coastline at the confluence of the Bristol and Kuskokwim Bays of the Bering Sea. It included all or portions of 35 major rivers, 25 major lakes, and extensive smaller water resources (USFWS 1990).

The study area climate was subarctic maritime near the coast, transitioning to subarctic continental toward the interior. From 1971-2000, the mean monthly maximum and minimum temperature averaged -6.3 and -11.3^{o} C in February, the coldest month, and 11.9 and 8.4^{o} C in

August, the warmest month (NCDC, Western Regional Climate Center, data for Cape Newenham Air Force Site in the southwest corner of the study area). Precipitation averaged 90.1 cm annually and total snowfall averaged 197.8 cm annually during the period 1953-1984.

The marine and aquatic environments are highly productive of fish, especially the five species of Pacific salmon, over 1,000,000 of which return annually to spawn in study area waters (USFWS 1990). Brown bear reproductive success, population density, and body size have all been correlated to the availability of high-quality food sources such as salmon (Hilderbrand et al. 1999).

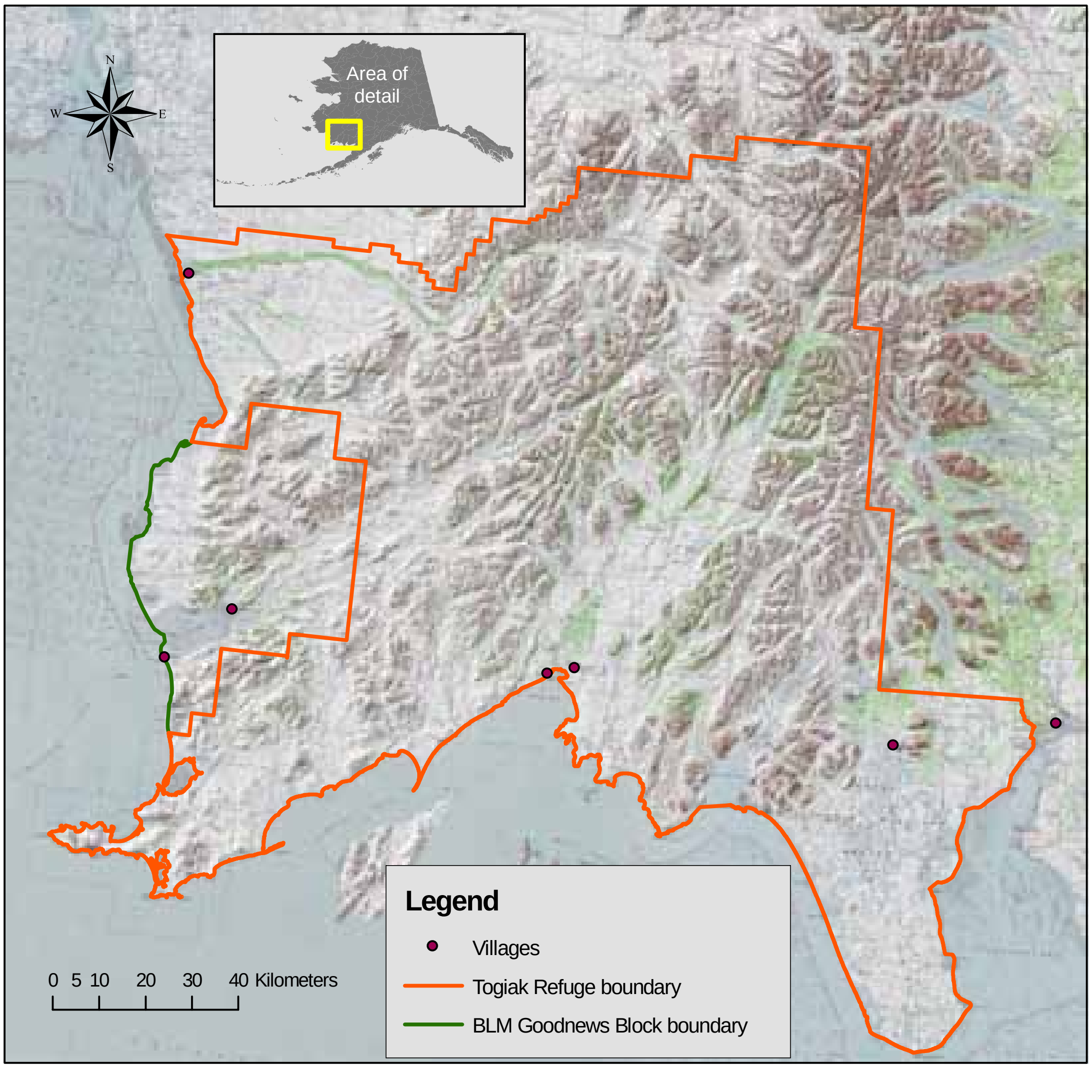

Figure 1. Study area.

The study area was relatively undeveloped, with most human development restricted to seven villages (Fig. 1) with a total human population of approximately 5,000. There was no network of roads between villages. There were villages located at the mouths of the majority of the largest rivers. Additionally, these rivers sustained the bulk of the boat traffic, and thus summertime human activity, occurring in the study area. The boat traffic supported recreational and subsistence activities from both study area residents and people residing outside the study area.

However, during the time of the survey, there was virtually no human activity on the refuge, save that associated with villages and aircraft overflights.

Brown bear den emergence in the study area averaged mid-May (Collins et al. 2005). Of 231 location observations of radio-collared female brown bears followed in the springs of 1994 through 2003 in a study area that included the north-central portion of the current study area, 22 (9.5%) were recorded as still in their dens between 25 May and 6 June and 17 (7.4%) were known or estimated to emerge between 1-13 June (Togiak National Wildlife Refuge unpublished data). During the year that this study was initiated, one of 21 radiocollared bears was in its den on 19 May (Togiak National Wildlife Refuge unpublished data); it had emerged when located one month later.

Methods

Overview

The study used the double-observer aerial line transect method (Quang and Becker 1999; Becker and Quang, in press). The method combines distance sampling and double observer techniques to allow maximum probability of detection ('peak detection') to occur off the transect centerline and be less than 100%. Survey effort is driven by the need for sufficient detections to support formulation and estimation of the detection function(s) (Buckland et al. 2001).

Survey Design

Surveys were performed from tandem 2-seater aircraft (Piper Supercub and Aviat Husky) capable of slow speed and high maneuverability. Transects, generally 25 km in length, were flown at an altitude of 90 m above ground level at a speed of approximately 95 -125 km/hr. Pilot and backseat passenger both served as observers, but will henceforth be referred to as "pilot" and "observer." Prior to the survey, pilots and observers were briefed on the survey protocol and underwent a mock survey on the ground to gain familiarity with the data recording protocol and use of the data collection software on portable computers.

Survey Transect Selection

Transect mid-points were randomly selected throughout the study area at all elevations up to 1,067 m following Alaska Department of Fish and Game protocol (E. Becker pers. comm.). In flat terrain, transects followed straight paths with a random angle at the mid-point in order to better fit into a partially-mountainous landscape. In mountainous terrain transects followed the contours of the land to maintain a constant altitude (Quang and Becker 1999). When a continuous 25 km transect was not possible at a given elevation (such as in the case of a lone mountain), the transect was paused when the mountain was circled, then resumed on the nearest unsurveyed mountain. In cases where there were no nearby areas of the appropriate elevation, transects shorter than 25 km were flown.

In total, 1200 transects were randomly selected from across the study area. Transects were randomly sorted without regard to location, then the first 100 transects were surveyed, then the next 100, etc., in order to avoid confounding of location and survey date.

Both individuals observed to the same side of the aircraft when flying a transect. In flat terrain, the side was randomly chosen by flipping a coin; on contour transects, observations were made on the uphill side.

Survey Timing

Surveys were timed to commence after brown bears emerged from their dens, based on den emergence information from Collins et al. (2005), and conclude prior to when full vegetation leaf-out reduced detectability. Continuing den emergence during the survey would violate the assumption that all bears were available to be detected, resulting in density estimates that were biased low. Similarly, advancing leaf out during the survey would violate the assumption of a temporally constant detection probability and require further modeling to account for the heterogeneity.

Survey Protocol

Location of flight path and transect attributes (start point, end point, deviations from the transect) were recorded by a portable computer interfaced with a GPS using a custom application for ArcPad ver. 6.0 (ESRI 2002) developed by R. Strauch (Alaska Department of Fish and Game). The observer operated the computer, recording covariates describing the bear group, surrounding area, and transect information (Table 1). Vegetation cover and snow cover were estimated in comparison to a reference card illustrating cover levels at 10% increments.

Table 1. Covariates recorded at the observation of each bear group.

Covariate	Response
Transect ID	Unique number designating each transect
Search side	Right or left
Bear ID	Unique number assigned to each bear group
Number of bears	Total number of bears in group
Group type	One of the following: Male Female Breeding pair Subadult(s) Female with cub(s) of the year Female with yearling offspring Female with two year old or greater offspring
Activity type	One of the following: Bedded Sitting Standing Feeding Walking Running
% Cover within 10m	Estimated percentage of area within 10 m of bear group that would obscure bear group visibility
% Snow	Estimated percentage of area within 10 m of bear group covered with snow
Who observed?	One of the following: Pilot Observer Both
Repeatability	The estimated number of times out of 10 one would have seen the bear group under similar conditions

Additionally, at each bear group observation, an estimate was made of the furthest distance being actively searched at the time of the observation (referred to as the effective search distance, or ESD). Effective search distance records the instantaneous width of a person's active search area. The covariate is expected to change with both terrain and habitat; it is expected to be shorter on contour transects in high gradient terrain due to visual blocking by the wings, and shorter in denser vegetation due to slower search rates hence narrower search area for a fixed flight speed. ESD was recorded for the person who detected the bear group; when both parties detected the group, an agreed-upon common ESD was recorded. Bear group and ESD locations were recorded via GPS by having the aircraft deviate from the transect and fly directly over the bear group (or the initial point of observation if the group had since moved) and the ESD point. Additional covariates continuously recorded while on a survey transect included time of day, speed, GPS location accuracy, and aircraft elevation.

Pilot and observer maintained independent observations of each bear group until the aircraft had passed the group, then exchanged information to determine who saw the bear group: pilot only, observer only, or both. A visual barrier was placed between pilot and observer to ensure independence of observations.

Data Processing

Data files were downloaded from each field computer daily during the survey. A running total of transects completed and bear groups observed was maintained in a Microsoft Access™ database. All flight path data, including portions on and off transects, were imported into ArcView GIS ver. 3.3 and examined for errors or problems caused by incorrect computer operation or computer crash. Errant data were corrected through consultation between analyst and observer/pilot team. At the conclusion of the survey, all flight path data underwent a cleaning procedure, at which time flight path segments not associated with transects were removed so that the remaining spatial files contained only the flown transects, bear group locations and ESD points.

Each GIS cleanup operation required multiple steps, including:

1. Data files were transferred from field computers to a central processing computer. This consisted of tabular data containing all survey covariates, as well as spatial files containing location of flight path, which were broken into segments that corresponded to survey action (e.g., flying to the start point of transects, flying on transect and observing for bear groups, flying off transect to record bear group locations, and flying between transects.)
2. For each transect, all associated off-transect flight segments were deleted, leaving just the flight path of the actual surveyed transect.
3. Bear group and ESD points were inspected to ensure that they were not plotted in incorrect locations (such as on the wrong view side, or the ESD point being closer to the transect than the bear group). When errors were found, the flight path was printed, the flight crew was consulted on correct location, and the point location was changed as necessary.
4. Summary tables were created of all covariates by transect, locations of bear groups and ESD points, and distances from transect to bear groups and ESD points.

To prevent data degradation, a second analyst double-checked all data cleanup steps. Following data cleanup, the perpendicular distance from each bear group to its associated transect, and from the ESD to the transect, were calculated in ArcInfo ver. 9.0 using a macro developed by R. Strauch (Alaska Department of Fish and Game). As an accuracy check, all such distances were also measured by hand in Arc View using the ruler tool. Differences greater than 1% between computer-generated and hand-calculated distances were investigated by re-examination of the flight path files to determine the cause of discrepancy.

Sample Size

The minimum sample size to achieve estimates of adequate precision was estimated to be 150 bear groups (E. Becker, Alaska Department of Fish and Game, personal communication). The survey was scheduled to continue a second year if necessary to achieve this goal.

DENSITY ESTIMATION

The density estimate for the study region was obtained by (i) estimating a detection function, thus providing estimates of each bear group's probability of detection, then (ii) using the probabilities of detection and observed bear group sizes to estimate bear group density in the searched region (Becker and Quang in press; Buckland et al. 2004). By sampling design, this also estimates bear density in the study area.

The uncertainty of the resulting density estimate is driven by two components. Foremost is the uncertainty in the fitted detection functions, predominantly driven by the total number of groups detected and the sources of systematic variation in the detection probability. The other component is variation in group size, which only comes into play in phase (ii) of the estimation.

Total area searched also only comes into play in phase (ii), estimating the bear density in the search region. In this context, interest is in the total area actively searched – if a particular transect is flown twice in the course of the survey, its search area is counted twice. Thus transects overlapping in space but not time, repeated observations of the same bear group at different times (on different transects), etc., do not invalidate the method or introduce bias. Bears can move around within the study region as long as the speed at which the survey transect is traversed is at least two to three times faster than the average bear movement speed (Hilby 1986). All detections made by the pilot are used to estimate the shape of the pilot's detection function; all detections made by the observer are used to estimate the shape of the observer's detection function. The combined pilot-observer data are used to estimate the two apex parameters, i.e., maximum prob(detection | Pilot) and maximum prob(detection | Observer).

Fitting Detection Functions

Detection functions were estimated by fitting a gamma distribution kernel to the observed detection distances using maximum likelihood methods (Becker and Quang, in press). For flexibility, the scale parameter was modeled as the product of two components: $b * \lambda$, where b was a function of the shape parameter r (see below) and λ was allowed to be a log-linear model of observed covariates (see below) (ibid). Thus, covariates could influence the 'scale' of the detection function, stretching the function to the right or left, but not the overall shape (for example, see Figure 7).

Detection functions were fit separately for the pilot and observer positions to allow for varying covariate effects and inherent differences in detection. Following Becker and Quang (in press), detection functions were modeled as:

$$\mathrm{Pr}_{\mathrm{detect}}(dist\ y \mid h_j, r_j, \lambda_j) = \frac{h_j}{\Gamma(r_j) b_j} \left(\frac{y}{\lambda_j b_j}\right)^{r_j - 1} \exp\left(\frac{-y}{\lambda_j b_j}\right),$$

where y is the perpendicular distance from the transect to the detected object, j distinguishes between the detection parameters of pilot and observer, h is the unknown maximum detection probability at the function's apex, r is the unknown shape parameter, λ is a nonlinear function of the observed covariates (below), and the scale parameter is given by $b^* \lambda$. The component b is defined to be:

$$b = \frac{1}{\Gamma(r_j)} \left(\frac{r_j - 1}{e} \right)^{r_j - 1},$$

where e is the natural logarithmic base, i.e., ln(e)=1. Covariates were incorporated via the log-linear model

$$\ln(\lambda_j) = \beta_{jo} + \beta_{j1} x_1 + \ldots + \beta_{jk} x_k ,$$

where the x_i's are the covariates associated with the i^th^ group detected by observer *j*, i.e. the pilot or the observer.

The suite of plausible detection functions, or models, was identified using a three step process outlined below. Final density estimates were obtained from the best model as identified by model selection using AIC (Burnham and Anderson 2002).

Model Selection Step 1: Covariate Screening
Categorical covariates (Table 1) were reviewed, independent of the response observations (i.e. detection distances), and modified if necessary to reduce the total number of unknown parameters requiring estimation (see **Results**). Quadratic effects of survey date were considered, in addition to linear effects, in order to represent any influence of systematic temporal changes in den emergence, green-up, searcher experience, and searcher exhaustion on detection rates. Interactions between survey year and date were allowed in order to account for changes in phenology, emergence, or participants across years.

Consideration was only given to models whose (total number of covariate parameters requiring estimation)/(the number of detected bear groups) was ≤ 10 (van Belle 2002). Note that for fitting, say, the pilot detection function, the relevant number of detected bear groups was the number detected by the pilot and both pilot and observer. All covariates associated with models with delta AIC values < 10, for either the pilot or observer model suites, were considered further.

Model Selection Step 2: Independent fitting of pilot and observer models
All single covariate detection functions were fit separately for pilot and observer and their AIC values and weights calculated (Burnham and Anderson 2002). To limit the potentially large number of resulting models, only the top four single covariates from each analysis (pilot/observer) were additively combined, along with interactions between year and date, to form models for further analysis. These were fit for pilot and observer separately and their AIC values and model weights calculated.

Each model's goodness of fit was assessed by first transforming the detected bear groups to observations expected to be from a uniform [0,1] distribution using the fitted detection functions and the probability integral transform as described in Becker and Quang (in press). The transformed observations were visually assessed for departures from the expected uniform distribution and quantitatively assessed using a Kolmogorov-Smirnov test. A Monte Carlo simulation procedure was used to account for some of the parameter uncertainty in the test's null reference distribution (Tadikamalla 1990), though the method did not fully account for the uncertainty introduced by the embedded scale parameter model.

Model Selection Step 3: AIC model selection for top combined model
The AIC values and model weights were calculated for each combination of plausible pilot and observer models. The resulting best model combined the best pilot model and the best observer model.

Estimating peak detection
Estimates of pilot and observer peak detection probabilities were obtained from the double-count data using maximum likelihood methods described in Becker and Quang (in press).

Temporal trend in detection
At least four different causes could produce a within-year temporal trend in bear group detections: 1) increasing numbers of bears available for detection due to survey initiation prior to 100% den emergence, 2) increasing detectability due to increasing observer experience; 3) decreasing detectability due to increasing vegetation green-up; and 4) decreasing detectability due to increasing observer exhaustion. Temporal trends in bear group detections were assessed by regressing each day's bear group encounter rate (number bear groups detected / total length of transects flown) against the survey date using weighted regression (weights proportional to total length of transects flown per day). Each year was assessed separately.

Density Estimation
Having identified the best combined detection function model, the number of bears in the searched area was estimated using a Horvitz-Thompson estimator (Becker and Quang in press). Bear density was estimated by dividing the estimated number of bears by the total area searched. Each transect's search area was estimated as the area perpendicular to the transect out to the effective strip width distance, less a blind strip of 22 m directly alongside the transect and hence underneath the airplane (Becker and Quang, in press). The effective strip width was defined as the upper 95th percentile of the observed detection distances (Buckland et al. 2001). For curvilinear transects, area that was lost or gained due to transect curves was calculated using GIS macros written in ArcInfo ver. 9.0 by R. Strauch (Alaska Department of Fish and Game). Total search area was estimated as the sum of the transect search areas. Because of the random transect selection design, the estimated density in the searched area was also the estimated density for the whole study area. The density estimation process was repeated after setting group size to 1 for all 'sow with offspring' categories to estimate the density of independent bears.

Standard Errors and Confidence Intervals
Nonparametric bootstrap resampling was used to estimate standard errors and 95% confidence intervals for all major model parameters and estimates. Percentile and bias-corrected adjusted confidence intervals were both calculated (Lunneborg 2000).

Software
Transect selection and estimation of detection distances and search areas were performed using an Avenue application developed by R. Strauch (Alaska Department of Fish and Game) for ArcView 3.2 (ESRI 1996). This application was modified from an application originally developed by Susan Huse, National Park Service.

All graphs and analyses were conducted in the freeware statistical analysis environment R (version 2.2.0, R Development Core Team 2005). The analyses used code originally created by Becker and Quang (in press) for S-Plus (Insightful, Inc., Seattle, WA) and converted to R by A.

Christ (Alaska Department of Fish and Game). The code was extensively investigated, documented, and in some cases modified by J. Reynolds and B. Russell (U.S. Fish and Wildlife Service), and is available from J. Reynolds upon request. Maximum likelihood estimates were obtained using the R numerical optimization package trust (Geyer 2005). Multiple starting points were used to assess convergence of the numerical optimizations. Bootstrap standard error and confidence interval estimates were obtained using the R package boot (Canty and Ripley 2005).

SEX AND AGE COMPOSITION

In the case that detection was found to be independent of group type or size, then bear groups could be justifiably considered a random sample of the brown bear groups in the study area and simple summaries calculated of bear demographics, group sizes and activities. However, there was no assessment of observer accuracy in classifying bears to age or gender. Thus, although all bear group classifications are reported as recorded by observers, demographic inferences are restricted to females with offspring as we assume the size difference between sows and their offspring resulted in low classification error rates.

Results

Survey Effort

The survey was initiated in 2003, at which time 99 bear groups were detected. As this was fewer than the desired minimum sample size of 150, the survey continued in 2004, resulting in a survey total of 197 bear groups (Table 2, Fig. 2). A total of 969 transects were flown (Fig. 3), with survey effort fairly evenly distributed across years (Table 1). Average survey speed was 118 km/hr (range in average of individual transects: 47 – 181 km/hr).

Table 2. Summary of annual survey effort and detected bear groups.

	2003	2004	Total
Survey dates	19 – 29 May	24 May – 02 June	
Surveys flown	474	495	969
Average transect length (km)	24.87	24.72	24.79
(standard deviation)			(1.46)
Total survey length (km)	11,789	12,237	24,026
Transects with detected bear groups	83	82	165
Percent transects with detected bear groups	17.5%	16.6%	17.0%
(standard deviation)	(2%)	(2%)	(2%)
Bear groups detected	99	98	197
Total bears detected	163	167	330
Average bears/group	1.65	1.74	1.70
(standard deviation)	(0.94)	(0.84)	(0.89)

Confounders with Survey Timing

No significant trends were detected in daily bear group encounter rate (trend p values > 0.30).

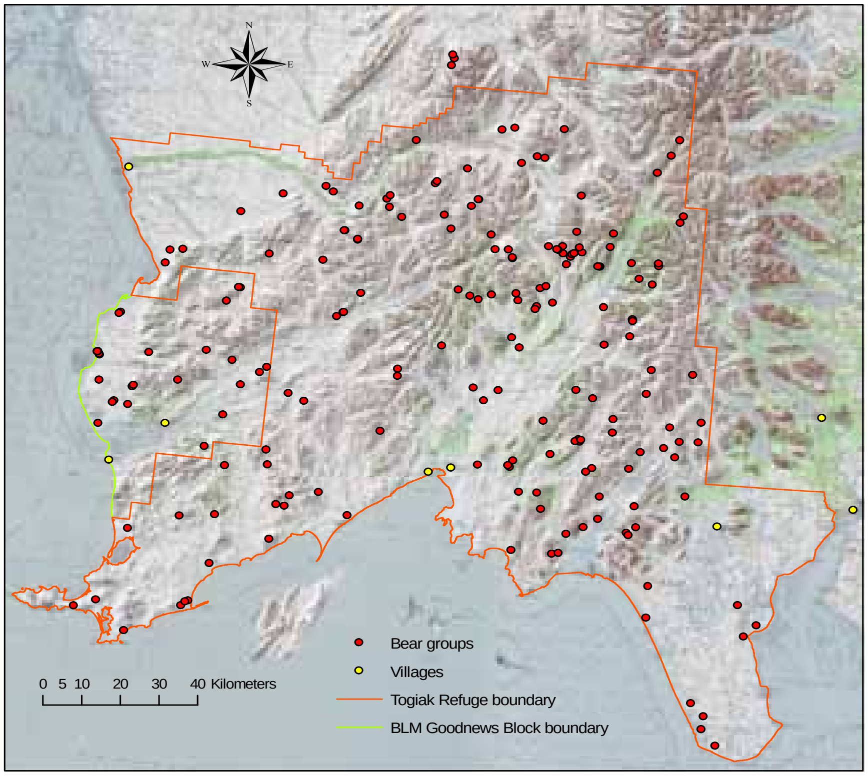

Figure 2. Location of bear groups observed during spring 2003 and 2004.

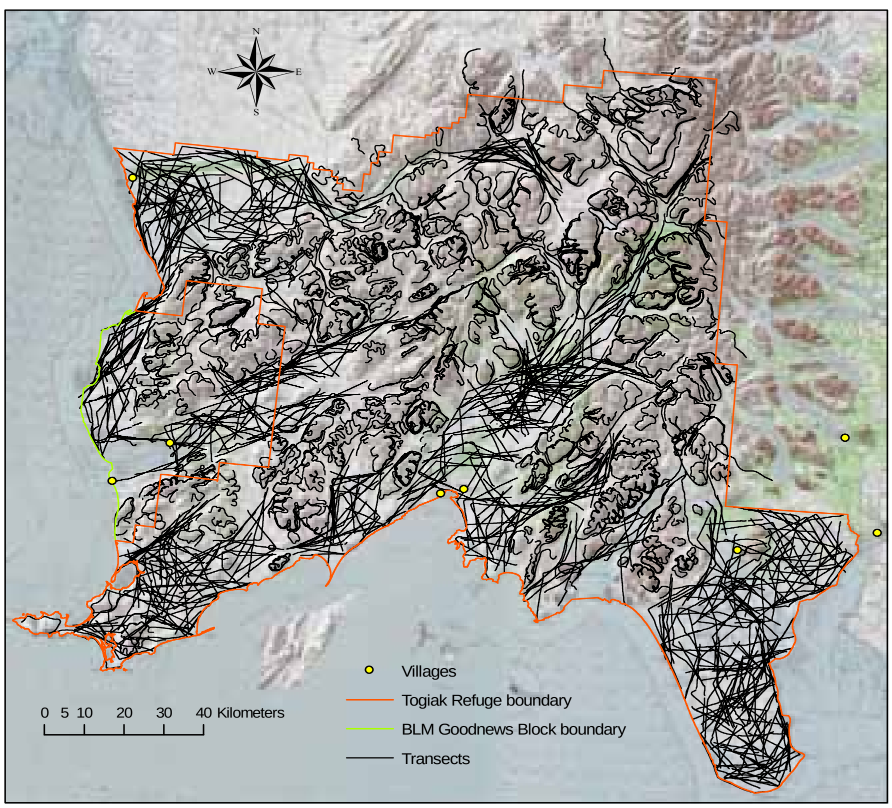

Figure 3. Location of transects flown during 2003 and 2004.

Data Screening

There were discrepancies between the distances calculated using the ArcInfo macro and those calculated by hand. The errors were not due to problems in the automated code, as the program worked flawlessly. These errors (Table 3) were due to incorrect actions on the part of the field data collectors. The automatically calculated distance to transect did not match the hand calculated value on 17 of 197 detected bear groups and 27 of 197 ESDs (Table 4). Although a few of the individual distances were wildly divergent (e.g., one bear group was calculated by computer as 1,787m while the hand calculated distance was 104m), most differences were small (Table 4). The mean difference for bear groups was 8% while the mean difference for ESDs was -1%.

Table 3. Common problems in data recording and corrective action taken during data cleanup stage.

	Problem	Correction	n*
1	Bear group or ESD point placed in incorrect location or not recorded.	Bear group (n = 3) or ESD point (n = 25) replotted on map after consultation with air crew.	28
2	Transect not drawn or incompletely drawn. This occurred when computer lost power or crashed due to memory overload.	Use the computer-generated flight path as actual flight path after consulting with air crew to ensure there were no major deviations.	22
3	Transect number or covariate (e.g., percent cover, activity) keyed in incorrectly.	Correct using value from hand written data sheet.	12
4	During cleanup, not all extra "off transect" segments were removed from the final flight path, or flight segments were accidentally deleted.	Second cleanup technician corrected the error and removed or replaced flight path segments.	9
5	Transects incorrectly labeled	Relabel transects.	7
6	Viewside recorded incorrectly.	Change viewside	5
7	Transect aborted before completion, such as when forced by weather.	Discard transect data.	4
8	Bear recorded on wrong side of transect.	Verify that aircraft was in steep banked turn and bear was seen from proper side of aircraft.	2

*n = sample size for 2004. Problems were not recorded in 2003.

The computer program generally failed to calculate the correct distance when: 1) The flight path passed in close proximity to a bear group, but the bear group was concealed by terrain until the aircraft continued to a greater distance from the bear group, such as when taking a curving path around a mountain. In such cases the true distance was underestimated because the nearest distance to the flight path was not the point from which the bear was detected and was instead a point from which the group could not have been detected, e.g. due to intervening mountains. 2) The observer cued the computer to change flight segments prior to passing the bear group, in which case the nearest point measured to the bear was actually longer than that from the perpendicular point. In such cases the true distance was overestimated. In addition to errors caused by incorrect data recording, errors were also a result of computer crashes and errors made during the general data cleanup procedures (Table 3).

Table 4. Differences in automatic and hand-drawn distance to transect calculations.

	Bear Group			ESD		
	2003	2004	Total	2003	2004	Total
n	99	98	197	99	98	197
% differing > 1 m	9.3	9.2	9.2	12.1	15.3	13.7
mean of differences (m)	24.0	2.3	14.0	-3.4	-6.6	-5.1
standard deviation of differences	174.2	38	127.9	57	76	67.3
mean % difference	19.3	1.1	8.0	-0.3	-1.4	-1.0

Detection Function Estimation and Selection

Effective Strip Width
Eliminating the largest 5% of the observed distances (Buckland et al. 2001) gave an effective strip width estimate of 750 m (Fig. 4). Only bear groups whose detection distances were less than this value were considered in the detection function estimation process, though all detected bear groups were considered in the demographic summaries.

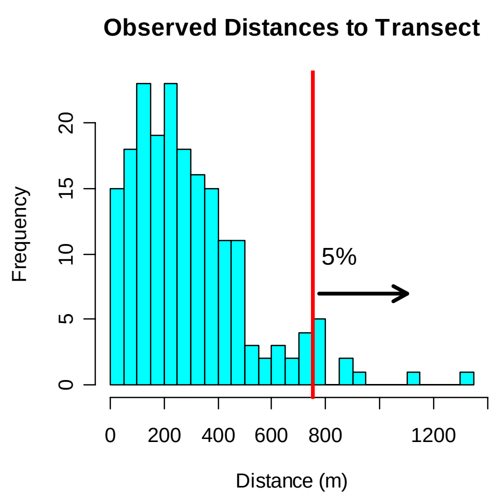

Figure 4. Observed detection distances and resulting effective strip width estimate.

Covariate Screening
Eight covariates were initially considered for use in fitting the scale function λ (Table 5), addressing survey timing (Date, Year), habitat or terrain surrounding the detected bear group (Effective Search Distance, Visual Index), and bear group characteristics (Type, Size, Activity). Some categorical variables were simplified to reduce the number of unknown parameters requiring estimation or when too few observations were available within a given level to support estimation (Tables 5, 6). Percent snow and percent vegetation cover were combined into a

single variable assessing difficulty of detection after reviewing a scatter plot of the two variables (Fig. 5, Left). Bear encounter rates did not vary with elevation, so elevation was not considered further (Fig. 5, Right**):** 42 groups were detected at altitudes between (0**,** 200m), 59 between (200, 400m), 53 between (400, 600m), and 22 between (600, 800m).

Table 5. Covariates considered for modeling the scale parameter of the detection function, their original measurement levels, and revised levels used in the fitting.

Covariate	Scale or Original Levels	Revised	Parameters
Effective Search Distance (ESD)	Continuous		1
Date (linear term)	Continuous		1
$Date^2$ (quadratic term)	Continuous		1
Year	2003, 2004		1
Date:Year	Interaction term		1
Group Activity	Bedded, Sitting, Feeding, Standing, Walking, Running	Alternative 1: Low (Bed, Sit) Med. (Feeding, Standing) High (Walk, Run);	2
			or
		Alternative 2: Low (Bed, Sit, Feeding, Standing) High (Walk, Run)	1
Group Size	1, 2, 3, 4	1, 2, 3+	2
Group Type	Adult Male, Adult Unknown gender, Sub-adult, Breeding pair, Sow w/ cub, Sow w/ yearling, Sow w/ 2 yr olds.	Adult Male, Sow w/ young, Other	2
Visual Index combining Snow and Vegetation Cover (Fig. 5)		High (snow>=30%, vegetation<=20%), Medium (all others) Low (snow<=10%, vegetation>=40%)	2

Table 6. Frequency of occurrence of covariate levels among activity and group size of detected bear groups.

	Covariate	Frequency
Activity	Bedded	29
	Feeding	4
	Running	11
	Sitting	13
	Standing	68
	Walking	71
Group size	1	108
	2	52
	3	27
	4	9
	5	1

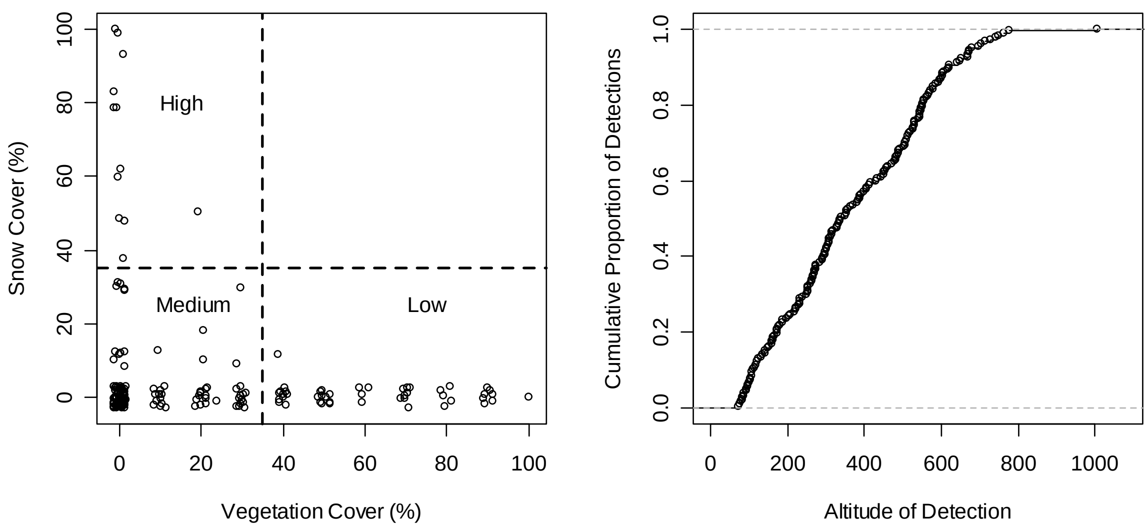

Figure 5. (Left) The ordinal vegetation and snow cover covariates were combined into a three-level visual contrast index (labeled regions). (Right) The cumulative distribution of altitudes (=elevation+aircraft height) at which bear groups were detected (unadjusted for height of plane above ground level).

In both years green-up rapidly advanced throughout the survey period, with leaf out beginning at low elevations and on southern exposures and rapidly moving upslope. By the end of each survey period, green-up had advanced to the point that visibility declined by more than 50% in riparian areas and on alder (*Alnus* spp.) slopes. Date was therefore allowed to enter into the scale function as both linear and quadratic terms in order to represent, if appropriate, an increasing then decreasing temporal trend in detection independent of any other covariates. To avoid numerical problems, Date was converted to Julian date form (e.g., 19 May 2003 = 138) and centered on the survey calendar date mid-point (Julian date – 145.5).

For both pilot and observer models, the logarithm of the effective search distance, ln(ESD), was the most important covariate when considering just single-covariate models (Table 7). In addition to ln(ESD), the top four single covariates for pilot were Date, Year, and Group Activity (Revised, Alternative 2). For observer the additional top covariates were Group Activity (Revised, Alternative 2), Group Activity (Original), and Date. Of these last two, only Group Activity (Revised, Alternative 2) was retained given its better performance than the original six-category covariate (Table 5). Analysis then focused on models with additive combinations of the covariates ln(ESD), Group Activity (Revised, Alternative 2), Date, and Year.

Table 7. Change in AIC (ΔAIC) among suite of single covariate models for the scale parameter, for Pilot and Observer data fit separately. Covariates are defined in Table 5. Ln = natural logarithm.

Covariate	Pilot ΔAIC	Observer ΔAIC
Intercept Only	32.0	47.19
ln (ESD)	0	0
Date	29.22	45.79
Year	30.48	47.63
Group Activity (Original)	32.86	43.88
Group Activity (Revised, Alternative 2)	31.92	42.46
Group Size	33.41	47.56
Group Type	35.00	47.78
Visual Index	34.28	47.70

In addition to the sixteen models formed from all possible additive combinations of these four covariates, consideration was also given to (i) the eight models formed by taking the models with a linear Date term and adding a quadratic term, $Date^2$, and (ii) the eight models formed by including an interaction between Year and Date or $Date^2$. Each of the resulting thirty-two possible additive models were fit independently to each of the two data sets (pilot, observer). The same eleven models exhibited AIC model weights greater than 0.001 for both the pilot and observer data sets (Table 8).

Maximum Probability of Detection

Pilots and observers exhibited similar probabilities of detection (Table 9, Fig. 6). As a proportion of the total number of bear groups seen by pilot/observer teams, pilots detected an average of 69.9 +/- 13.4%. Observers detected an average of 71.0 +/- 12.1%. Individual detections ranged from 25 to 100%. Thus, although there was a wide range in individual detection ability, this range was similar in both pilots and observers. The maximum probability of detection and shape parameters for the best detection functions were relatively precisely estimated from the observations (Table 10). The coefficients for modeling the scale parameters as functions of the covariates were less precisely estimated (Table 10).

Table 8. Top eleven additive covariate models out of the 32 considered, Pilot and Observer data fit separately. Models are ordered by Pilot model weight. Effective search distance is the dominant covariate, with the Pilot and Observer data sets differing in the best additional covariate (Date or Year). Ln = natural logarithm.

Covariates	Pilot ΔAIC	Pilot model weight	Observer ΔAIC	Observer model weight
ln(ESD) + Date	0	0.263	1.82	0.125
ln(ESD) + Yr	1.10	0.152	0	0.309
ln(ESD) + Date + Yr	1.23	0.142	1.77	0.128
ln(ESD) + Date + Activity	1.80	0.107	2.26	0.100
ln(ESD) + Date + $Date^2$	1.97	0.098	3.82	0.046
ln(ESD) + Date + Yr + Date:Yr	2.33	0.082	3.60	0.051
ln(ESD) + Date + Yr + Activity	3.15	0.055	2.84	0.075
ln(ESD) + Date + Activity + $Date^2$	3.75	0.040	4.24	0.037
ln(ESD) + Date + Yr + Activity + Date:Yr	4.19	0.032	4.22	0.037
ln(ESD)	5.16	0.020	3.55	0.052
ln(ESD) + Activity	6.91	0.008	4.15	0.039

Table 9. Summary counts of bear group detections by Pilot vs Observer, by year.

		2003		2004	
		Observer			
		Yes	No	Yes	No
Pilot	Yes	44	18	41	26
	No	21		27	

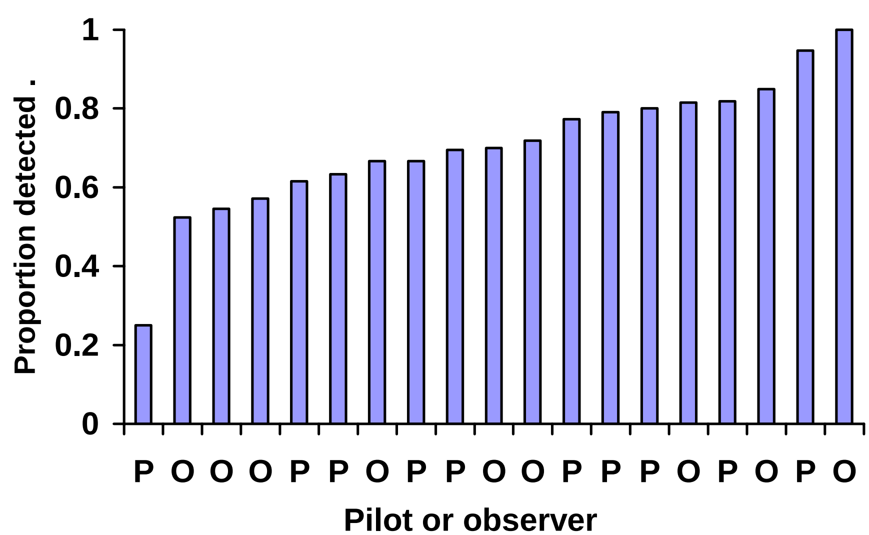

Fig. 6. Proportion of bear groups seen by individual pilot or observer in relation to the total number seen by pilot/observer team, ordered from lowest to highest. Data restricted to pilots and observers performing >30 transects.

Table 10. Parameter estimates for final detection model, with standard errors and coefficients of variation (CV) estimated from 2000 nonparametric bootstrap replicates of the observed transect data. The 'Date' covariate did not occur in the Observer model; Year did not occur in the Pilot model. Ln = natural logarithm.

Parameter	Pilot Estimate (Standard Error)	Pilot CV	Observer Estimate (Standard Error)	Observer CV
Intercept	1.12 (0.65)	0.6	0.06 (0.66)	11.5
ln(ESD)	0.75 (0.11)	0.1	0.90 (0.11)	0.1
Date	0.045 (0.016)	0.4		
Year effect for 2004			0.27 (0.10)	0.4
Shape parameter of detection function	2.96 (0.58)	0.2	3.08 (0.48)	0.2
Maximum Prob(Detection)	0.89 (0.06)	0.1	0.87 (0.06)	0.1

Combined Pilot / Observer Models

All possible combinations of the best eleven pilot models and the best eleven observer models were fit and their AIC values and weights calculated. The best scale parameter model (Table 10, Figures 7 and 8) was formed from the best pilot model and the best observer model (Table 8), and in turn used to derive the final brown bear density estimates. The other models gave almost identical density estimates and confidence intervals (Figure 9), obviating any value in conducting multi-model inference (Burnham and Anderson 2002). All parameter estimation calculations converged and no computational problems were encountered.

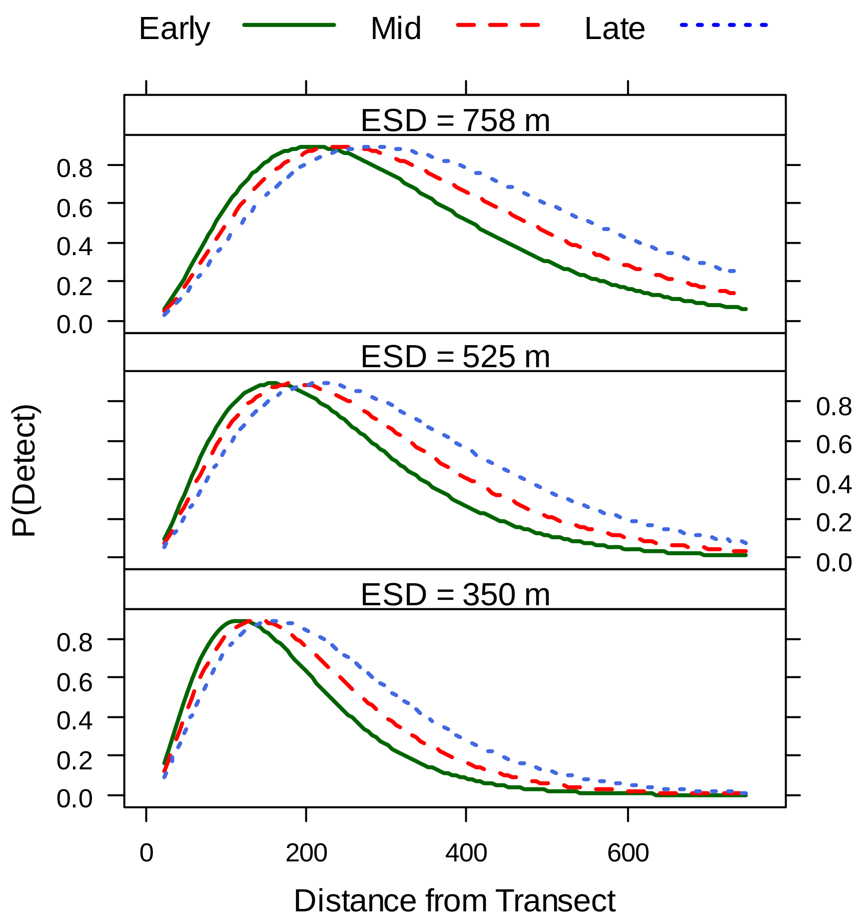

Figure 7. Fitted detection function for pilots (Table 8). Estimated probabilities of detection are plotted at three different effective search distances (the 25th, 50th, and 75th percentiles of the observed effective search distances, corresponding to 350 m, 525 m, and 758 m), illustrating that the peak detection probability increased in distance as did the search distance. The detection model also varied systematically with survey date (classified as Early, Mid, and Late, corresponding to dates 25%, 50% and 75% through each year's survey period), illustrating that peak pilot detection increased in distance from the transect during the course of the survey period.

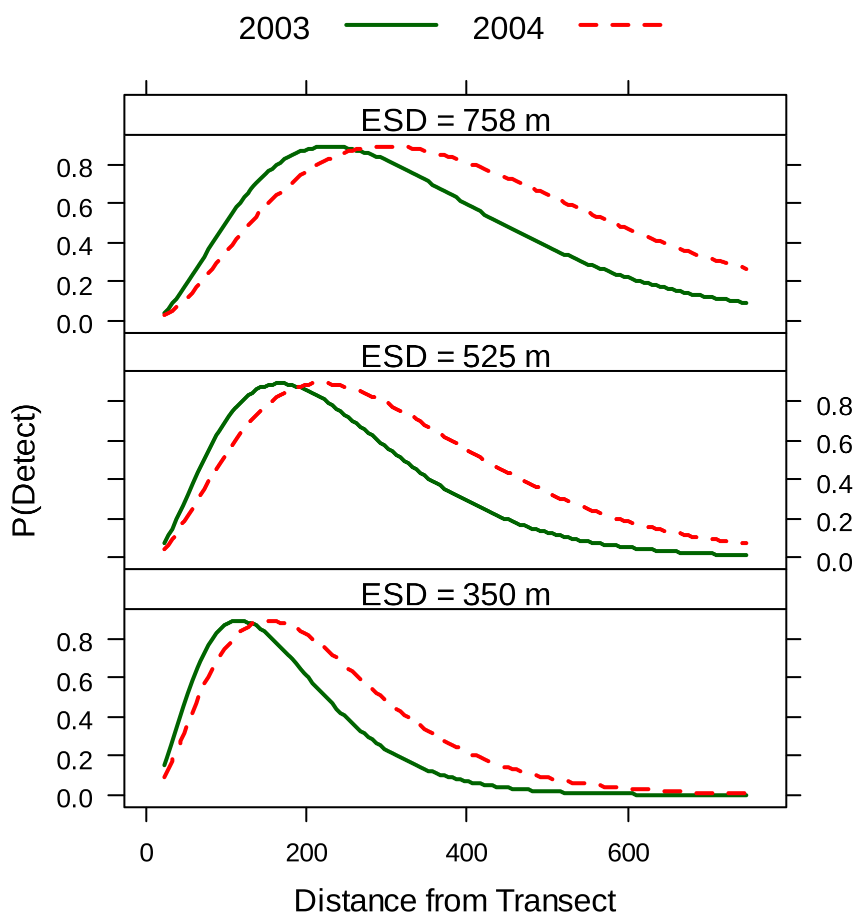

Figure 8. Fitted detection function for observers (Table 8). Actual bear group detection distances are plotted at three different effective search distances (the 25th, 50th, and 75th percentiles of the observed effective search distances, corresponding to 350 m, 525 m, and 758 m), illustrating that the peak detection probability increased in distance as did the search distance. The detection model also varied systematically with survey year, illustrating that peak observer detection occurred at greater distances in 2004 than in 2003.

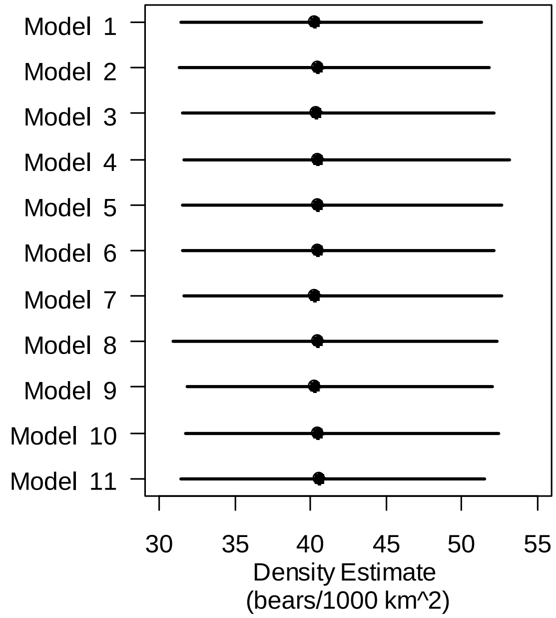

Figure 9. Density estimates and 95% confidence intervals from the top eleven combined models.

Total Area Searched
Accounting for transect curvature, the total area searched was estimated to be 16,544.42 km^2. Failing to account for transect curvature would overestimate total search area by 5.7%, thus underestimate total density by 1/1.057 = 0.054 or 5.4%. The total study area was 21,178 km^2.

Density Estimation
Brown bear population density was estimated as 40.4 bears per 1,000 km^2 with a 95% confidence interval of 31.4 to 54.5 (standard error of 5.1, CV of 13%). The population density of independent brown bear, defined as all independent bears 3 years or older, was estimated as 27.3 bears per 1,000 km^2 with a 95% confidence interval of 21.4 to 34.4 (standard error of 3.2, CV of 12%).

Demographics
Since no covariates describing group characteristics occurred in the final detection function, the observed bear groups were considered a simple random sample of the bear population. Female and offspring groups constituted 26% of the detected groups (Table 11). These were composed of approximately 26% females with cubs of the year (bootstrap standard error 6.2%), 34% females with yearling cubs (bootstrap standard error 6.6%), and 40% females with cubs 2 years old or older (bootstrap standard error 7.1%). No inferences are made on demographics of the other bear group types reported in Table 11, as we are uncertain of the accuracy of these classifications.

Time and expense requirements
The time necessary for design, implementation, and analysis for this survey totaled approximately 3,300 hours (Table 12). This included approximately 560 hours of one-time costs for debugging, modifying, and documenting the analysis code. The total complement of personnel directly involved in this survey was ten pilots, nine biologists, one computer technician, and two biometricians.

Table 11. Composition of brown bears groups detected during the survey, by year. Standard errors (SE) for Percent of Total are from 2000 nonparametric bootstrap resamples; standard errors for average number of offspring per female are from usual formula for a sample mean.

	2003	2004	Total	Percent of Total (SE)
Large males	21	9	30	15 (2.6)
Unknown adult bear groups	27	26	53	27 (3.1)
Breeding pairs	12	17	29	15 (2.5)
Sub-adult bear groups	11	24	35	18 (2.8)
Female with 2+ year old cub groups	10	10	20	10 (2.2)
Female with 1 year old cub groups	8	9	17	9 (2.0)
Female with cub-of-the-year groups	10	3	13	7 (1.8)
Average number 2+year olds/female	2.0	1.7	2.0	
(standard error)	(0.33)	(0.21)	(0.20)	
Average number yearlings/female	1.8	2.2	2.0	
(standard error)	(0.25)	(0.15)	(0.15)	
Average number cubs/female	2.1	1.7	2.0	
(standard error)	(0.23)	(0.33)	(0.20)	

Time and expense requirements

The time necessary for design, implementation, and analysis for this survey totaled approximately 3,292 hours (Table 12). At an average of $26/hour, salary costs totaled $85,592. Time requirements included approximately 200 hours of one-time costs for debugging, modifying, and documenting the analysis code. The total complement of personnel directly involved in this survey was ten pilots, nine biologists, one computer technician, and two biometricians.

The total cost to perform this survey was $202,514. After salary costs, the greatest individual expense was the cost of aircraft, which totaled $79,547. The remaining operating expenses were composed of equipment purchases ($11,881), fuel ($11,746), travel, food, lodging ($7,699), and overtime ($6,049).

Table 12. Survey time requirements by activity.

Activity	Description	Person hours
Initial training	Participation in similar survey on Alaska Peninsula	112
Survey design	Establish transects	30
	Develop maps, transect lists, instruction sheets,	20
	Purchase and assembly of survey materials, setup of survey computers	80
Logistics coordination	Establish fuel caches	30
	Coordinate availability of aircraft and survey crews	34
	Training survey personnel	16
Field operations	Air crews flying surveys	1,760
	Reviewing and summarizing data daily during survey	120
Analysis	Cleaning data, calculating distances and transect lengths	280
	Learning, documenting, debugging, modifying analysis software	200
	Analyzing data	280
Reporting	Preparing survey report	330
Total		3,292

Discussion

Consistency with previous density estimates

The population density estimate derived here generally agrees with previous work in the area, though these are the first formal estimates including standard errors. Miller (1993) suggested that the study area population density was < 40 brown bears/1000 km^2; Van Daele et al. (2001) hypothesized that the population density of the north central portion of the study area was approximately 36 bears/1000 km^2.

Demographics - Reproduction

Younger cubs are likely harder to detect because of both size and behavior, and thus potentially suffer an unknown amount of underestimation, though note that no consistent impact of group type on the detection function scale parameter was found (Table 8). Underestimation appears to have occurred in applications of this method to other brown bear populations (E. Becker, Alaska Department of Fish and Game, personal communication).

The composition point estimates for offspring per female is opposite that expected in a steady-state population: cubs of the year - 26% (standard error 6.2%), yearling cubs - 34% (standard error 6.6%), and cubs 2 or more years old -40% (standard error 7.1%). However, the estimates are not distinguishable given their associated uncertainties, limiting further interpretation.

Such bias would also affect the estimated average number of offspring per female (Table 11). The lack of any consistent trend from cubs to yearlings to 2+ year olds, either overall or within a survey year, suggests that any bias is negligible relative to the precision of the estimates (Table 11).

Negligibility of any bias against detecting cubs is also suggested by comparison of the current estimates to those from similar areas or time periods. The average spring litter size for cubs-of-the-year, for the years 1993 – 2003, at an area including the north-central portion of the current study area was 2.0 (SE = .08) (Kovach et al. 2006). Litter sizes from seven other interior Alaska study areas ranged from 1.8 - 2.2 (ibid). The current survey's estimate of 2.0 (standard error 0.20) strongly agrees with both sets of results (Table 11). The current survey's estimated mean litter sizes for yearling and 2+-year olds, respectively, 2.0 (standard error 0.15) and 2.0 (standard error 0.20) are somewhat higher than those reported by Kovach et al. (2006), 1.6 (SE = 0.08) for yearlings, 1.6 (SE = 0.09) for 2-year-olds, and 1.5 (SE = 0.19) for 3-year old, though not distinguishable considering the associated uncertainties.

Survey timing and implementation

The survey may have been initiated prior to full den emergence given that brown bear sows in the Kuskokwim Mountains of southwest Alaska have been recorded in dens up through May 31 (Togiak National Wildlife Refuge unpublished data) and that in 2003 one of 21 radio-collared sows remained in her den by 19 May (Togiak National Wildlife Refuge unpublished data). Because of the rapid changes in plant phenology in late May and early June, delaying the survey would have resulted in decreased detectability, and thus a greater time investment necessary to attain the minimum sample size.

Extending the data collection in this survey across two years introduced the unavoidable possibility of population change across years, and thus formally invalidating the closed-population assumption. The resulting density estimate is an average for the period. Given that bears are long-lived and have low rates of reproduction, we do not expect rapid changes in population sizes to occur in this short of a time period. This is reinforced by the almost identical bear group encounter rates and sizes across survey years (Table 2), suggesting any changes were minor relative to the precision of the estimates.

Logistics and data management

Learning requirements for conducting this survey entailed a significant investment of time. This survey required advanced knowledge of GIS and database applications, training in survey operations as well as data management, and access to numerous proprietary computer applications developed by the Alaska Department of Fish and Game. The analysis requires a Master's level familiarity with statistical models, model selection, numerical algorithms, and bootstrap methods.

Feasibility as a monitoring tool

The uncertainty in the density estimates stems from three factors – uncertainty in fitting the detection function (Table 10), the bear group encounter rate (Table 2), and variation in bear group size (Table 6). Uncertainty in the detection functions will likely decrease through time as encounters from *all* surveys, current and past, can be used in the model selection and fitting. For example, if the survey is repeated at a future date and another 200 groups detected, then all 397 detections can be used in the fitting process. Unfortunately, we have no control over encounter rate or variation in bear group size.

The expense in conducting this survey makes it feasible only at a return interval of at least five years. However, in order for this method to be considered feasible as a monitoring tool, it must have reasonable power to detect relatively small changes (i.e., changes of ~20% or less over five years). Power analyses should be conducted to assess the number of detections required to obtain density estimates of sufficient precision to provide this power for detecting change.

Acknowledgements

This project was funded by the Togiak National Wildlife Refuge (NWR) and the BLM Anchorage Field Office. We appreciate the guidance provided throughout the project by E. Becker and R. Strauch, Alaska Department of Fish and Game (ADFG). In-kind support, including equipment and personnel, was provided by: Alaska Peninsula/Becharof NWR, Arctic NWR, Izembek NWR, Kodiak NWR, Selawik NWR, and Yukon Delta NWR. Survey aircraft were piloted by E. Akola (USFWS), L. Ayers (Selawik NWR), G. Dobson (USFWS), K. Fox (Izembek NWR), S. Gibbens (Quicksilver Air), M. Hinkes (Togiak NWR), P. Liedberg (Togiak NWR), D. Sailors (Husky Aviation), D. Sowards (Arctic NWR), and P. Valkenburg (Quicksilver Air). We thank observers A. Aderman (Togiak NWR), S. Kovach (Yukon Delta NWR), P. Perry (ADFG), M. Robinson (Togiak NWR), and J. Woolington (ADFG). Thanks to L. Andrew (Togiak NWR) for computer support. Finally, our thanks go to E. Becker and S. Kovach for providing reviews of the manuscript.

References

Barnes, V. G. and R. B. Smith. 1998. Estimates of brown bear abundance on Kodiak Island, Alaska. Ursus 10:1-9.

Becker, E. F., and P. X. Quang. (In Press) A gamma-shaped detection function for line-transect surveys with double-count and covariate data. Journal of agricultural, biological, and environmental statistics.

Bellemain, E., J. E. Swenson, D. Tallmon, S. Brunberg, and P. Taberlet. 2005. Estimating population size of elusive animals with DNA from hunter-collected feces: four methods for brown bears. Conservation Biology 19: 150-161.

Boulanger, J., G.C. White, B.N. McLellan, J. Woods, M. Proctor, and S. Himmer. 2002. A meta-analysis of grizzly bear DNA mark-recapture projects in British Columbia, Canada. Ursus 13:137-152.

Buckland, S. T., D. R., Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas. 2001. Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press, New York, New York, USA.

Burnham, K. P., and D. R. Anderson. 2002. Model Selection and multimodel inference: a practical information-theoretic approach (2nd ed). Springer, New York, New York, USA.

Canty, A. and B. Ripley. 2005. boot: Bootstrap R Functions. R package version 1.2-24. URL http://cran.r-project.org/.

Collins, G. H., S. D. Kovach, and M. T. Hinkes. 2005. Home range and movements of female brown bears in southwest Alaska. Ursus 16:181-189.

Dufresne, F. 1967. My way was north; an Alaskan autobiography. Holt, Reinhart, and Winston, New York, New York, USA.

Elgmork, K. 1991. Estimation of brown bear (*Ursus arctos* L.) populations by means of reports from moose hunters in central south Norway 1966-68 and 1976-78. Fauna 44:269-274.

Environmental Systems Research Institute 1996. ArcView version 3.3. Environmental Systems Research Institute, Inc., Redlands, California, USA.

Environmental Systems Research Institute 2002. ArcPad version 6.0. Environmental Systems Research Institute, Inc., Redlands, California, USA.

Geyer, C. 2005. trust: Trust Region Optimization. R package version 0.1. http://www.stat.umn.edu/geyer/trust.

Helfield, J. M. 2001. Interactions of salmon, bear and riparian vegetation in Alaska. Doctoral dissertation, University of Washington, Seattle, Washington, USA.

Hilderbrand, G. V., C. C. Schwartz, C. T. Robbins, M. E. Jacoby, T. A. Hanley, S. M. Arthur, and C. Servheen. 1999. The importance of meat, particularly salmon, to body size, population productivity, and conservation of North American brown bears. Canadian Journal of Zoology 77:132-138.

Kansas, J. L. 2002. Status of the grizzly bear (*Ursus arctos*) in Alberta, Alberta Wildlife Status Report No. 37. Alberta Sustainable Resource Development, Fish and Wildlife Division, and Alberta Conservation Association, Edmonton, Alberta, Canada.

Kovach, S. D., G. H. Collins, M. T. Hinkes, and J. W. Denton. 2006. Reproduction and survival of brown bears in southwest Alaska, USA. Ursus 17(1):16-29.

Laake, J. 1999. Distance sampling with independent observers: reducing bias from heterogeneity by weakening the conditional dependence assumption. In G. W. Garner, S. C. Amstrup, J. L. Laake, B. F. J. Manly, L. L. McDonald, and D. G. Robertson, eds, Marine mammal survey and assessment methods. A. A. Balema, Rotterdam, Holland. pp 137-148.

Lunneborg, C. E. 2000. Data Analysis by Resampling: concepts and applications. Duxbury Press, Pacific Grove, California, USA.

Miller, S. D. 1993. Brown bears in Alaska: a statewide management overview, Wildlife Technical Bulletin. #11 Alaska Department of Fish and Game, Juneau, AK, USA.

Miller, S. D., White, G. C., Sellers, R. A., Reynolds, H. V., Schoen, J. W., Titus, K., Barnes, V. G., Smith, R. B., Nelson, R. R., Ballard, W. B., and C. C. Schwartz. 1997. Brown and black bear density estimation in Alaska using radiotelemetry and replicated mark-resight techniques. Wildlife Monographs, No. 133.

Quang , P. X., and E. F. Becker. 1997. Combining line transect and double count sampling techniques for aerial surveys. Journal of Agricultural, Biological, and Environmental Statistics. 2:230-242.

Quang, P.X., and E.F. Becker. 1999. Aerial survey sampling of contour transects using double-count and covariate data. Pages 87-97 *in* G.W. Garner, S.C. Amstrup, J.L. Laake, B.F.J. Manly, L.L. McDonald, and D.G. Robertson, editors. Marine Mammal Survey and Assessment Methods. Balkema Press, Rotterdam, Netherlands.

Quang, P. X. 2005a. The 2004-2005 bear survey of Region 9A. Misc. report prepared for Lake Clark National Park, National Park Service, AK, USA.

R Development Core Team. 2005. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Swenson, J. E., F. Sandegren, A. Bjarvall, A. Sonderberg, P. Wabakken, and R. Franzen. 1994. Size, trend, distribution and conservation of the brown bear *Ursus arctos* population in Sweden. Biological Conservation 70:9-17.

Tadikamalla, P. R. 1990. Kolmogorov-Smirnov type test-statistics for the gamma, Erlang-2 and the inverse Gaussian distributions when the parameters are unknown. Communications in Statistics: simulation and computation 19:305-314.

U. S. Fish and Wildlife Service. 1990. Fishery Management Plan, Togiak National Wildlife Refuge. U. S. Fish and Wildlife Service, Anchorage, AK, USA.

Valdmann, H., U. Saarma., and A. Karis. 2001. The brown bear population in Estonia: current status and requirements for management. Ursus 12:31-36.

van Belle, G. 2002. Statistical rules of thumb. Wiley, New York, New York, USA.

Van Daele, L. J., Morgart, J. R., Hinkes, M. T., Kovach, S. D., Denton, J. W., and R. H. Kaycon. 2001. Grizzlies, Eskimos, and biologists: cross-cultural bear management in southwest Alaska. Ursus 12:141-152.