Final Wildlife Research Report ADF&G/DWC/WRR–2017–1

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Alaska Department of Fish and Game Division of Wildlife Conservation

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Cover Photo: A remote trail camera photo of a female brown bear investigating a scent-baited barbed wire corral near Yakutat, Alaska. Bear hairs were snagged by the barbed wire and used to noninvasively estimate the population size.

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Abstract

Conservation of brown bear (*Ursus arctos)* populations requires managers to reliably and efficiently estimate abundance. With the recent development of spatially-explicit capture–recapture (SECR) models, bear density can now be estimated from detection parameters relative to the spatial distribution of detectors and animal movements, and abundance can be estimated within a defined survey area. Our objective was to examine brown bear population density and abundance in a 3,191 km^2 study area along the northern mainland coast of Southeast Alaska, near Yakutat, between the Gulf of Alaska and the Saint Elias Mountains. Using noninvasive sampling techniques, we collected bear hair from 15 July to 30 August 2013 to genetically identify individuals and develop capture histories for SECR models using multiple detector types: single-catch hair snares; scent-baited barbed wire corrals; and bear rub trees. We deployed 565 detectors and revisited these hair traps during 4 consecutive 9-day sampling occasions. We set 518 hair snares along bear trails adjacent to prioritized salmon streams and other frequented land cover types, such as herbaceous habitats with abundant wild coastal strawberries. To uniformly sample the landscape, we used scent lures to attract bears to 41 barbed wire corrals within 36 systematically distributed 8 km^2 grid cells. Bears also used marking trees to transmit chemical signals and we collected hair samples from 6 rub trees equipped with barbed wire. From our spatial array of these 3 detector types, we collected 849 hair samples and identified 152 unique individuals from 389 successfully genotyped detections, with 1–10 detections per individual. As part of a comprehensive study on brown bear spatial ecology and population dynamics, we captured and radiocollared brown bears and used these telemetry data to enhance the current population estimate. We incorporated 35,293 locations from 28 GPS radiocollared bears with capture–recapture data into SECR models to refine population parameters. We examined models that accounted for trap type, sex, time, site-specific behavioral changes, and integrated spatial capture histories with and without telemetry data to estimate bear density and abundance. We estimated the density of brown bears at 98.8 ± 8.2 bears/1,000 km^2, 95% CI [84.1–116.2], CV=0.08, and an abundance of 260.1 ± 21.5 bears, 95% CI [221.2–305.7]. Using the study area density, we estimated the population size for GMU 5A as 353.8. ± 29.2 bears, 95% CI [300.9–415.8], with 225 female and 129 male brown bears. We suggest integrating hair snare detectors with traditional detectors in future bear genetic mark–recapture population estimates and augmenting SECR models with telemetry data when available. The results from this study provide reliable baseline density and population estimates from which state and federal managers can successfully guide brown bear harvest management strategies in Southeast Alaska.

Key words*:* Alaska, brown bear, density, hair snare, home range, noninvasive genetic sampling, population estimation, SECR, spatially-explicit capture–recapture, telemetry, *Ursus arctos*, Yakutat

Introduction

To effectively guide brown bear (*Ursus arctos)* management in Alaska, managers need to have accurate estimates of population size, density, harvest rates, and population demographics. However, these population parameters are often costly and difficult to acquire, yet extremely important for establishing sustainable harvest guidelines. Previous population studies have shown that bear populations are slow to recover from natural or human-caused declines due to their low reproductive rates (Craighead et al. 1976, Bunnell and Tait 1981, Miller 1990 a,b, Wielgus and Bunnell 1994, Clark et al. 2010). Brown bears are valued as an important aspect of the cultural and economic resources of Southeast Alaskan communities (Titus et al. 1994, USFWS 2011), as well as integral to the functioning of ecosystems for their transport of marine-derived nutrients (Hilderbrand et al. 1999, Gende et al. 2002, Holtgrieve et al. 2009). Therefore, management agencies strive to maintain productive brown bear populations. Determining accurate population sizes and appropriate levels of harvestable surplus is warranted given the high value of this species combined with the increased demand for both hunting and viewing recreational opportunities. With accurate population demographics managers can continue developing sustainable policies.

Brown bears living in forested habitats of Alaska are often difficult to enumerate given the dense tree canopy, their elusive behavior, and wide-ranging movement patterns. Capture-mark-resight (CMR) is one proven technique to estimate animal population size (Otis et al. 1978, Seber 1982). This method estimates the number of animals in a population as a proportion of those animals caught on 1 sampling event compared to those recaptured on subsequent occasions. The density of the population is then approximated by dividing the abundance estimate by the area sampled plus a buffer along the edge to account for animal home ranges overlapping the periphery of the sampling grid. In 1993, the Alaska Department of Fish and Game (ADF&G) estimated the abundance of brown bears in Alaska based on results from 17 CMR studies conducted in Alaska (Miller 1993). Bear populations were broadly classified into 3 density classes, high (>175 bears/1,000 km^2), intermediate (40–175 bears/1,000 km^2), and low (<40 bears/1,000 km^2) density, largely dependent upon geographic location. In general, these studies spatially separated bears into different density categories, with low density populations distributed throughout the majority of interior Alaska and the northern Arctic, while the coastal areas of Southcentral and Southeast Alaska (SEAK) ranged from intermediate to high density, purportedly based on salmon abundance. Our study relies on the foundation of these fundamental CMR concepts, yet our approach with new methodologies strives to improve on the shortcomings of these traditional techniques.

Included in this statewide analysis of bear population density were several ADF&G studies conducted on Admiralty and Chichagof islands in SEAK using the traditional CMR approach (Schoen and Beier 1990, Miller et al. 1997). This technique involved extensive capture and collaring of bears, marking with ear tags, and required aerial resightings of marked animals, typically searching in the alpine above the tree line where bears were less obscured by forest cover. Density estimates from these studies were applied to the remainder of Game Management Unit (GMU) 4 in combination with expert opinion and predictions from a brown bear habitat capability model (Schoen et al. 1994). GMU 4 historically accounts for 70% of the brown bear harvest in SEAK and increasing hunting effort and harvest pressure necessitated the need for better planning and cooperation (Mooney 2013). The Alaska Board of Game (BOG) and stakeholder groups convened and developed a management strategy that recommended the 3 year average harvestable surplus be limited to 4% of the lower 95% confidence limit of the total population estimate (Unit 4 Brown Bear Management Team 2000). This GMU 4 management plan produced a sustained yield harvest strategy that has maintained stable populations for multiple user groups and provided consistent harvest opportunities.

Brown bear population estimates for the remainder of SEAK were derived by considering statewide density estimates (Miller 1993) with the habitat capability model (Schoen et al. 1994) and expert opinions. In recent years, management concerns along the northern mainland coast of SEAK in GMU 5 have risen in concert with increasing requests for additional commercial guiding opportunities. In addition, the public has submitted proposals to the BOG to increase brown bear harvest levels in GMU 5, the area surrounding the village of Yakutat. Since 1968, guided non-residents and resident hunters in GMU 5 have been allowed to harvest 1 brown bear every 4 years, in addition to federal regulations passed in 1994 that allow federally-qualified subsistence users to harvest 1 bear per year. In 1993, the brown bear population status in GMU 5A was considered stable to declining and abundance was estimated to be 522 (range 392–653) bears of all ages. Therefore, GMU 5A was classified as high density habitat with 193 bears/1,000 km^2 (522 bears/2,703 km^2 potential bear habitat). This estimation method was imprecise as no density data were available for the SEAK mainland and potential bear habitat was crudely estimated and multiplied by a density of 0.5 bears per square mile to generate the abundance estimate. Lacking more recent and definitive knowledge of brown bear population size, available habitat, spatial requirements, and harvest vulnerabilities, ADF&G has not endorsed the petitions for increased harvest.

Providing an empirical understanding of brown bear population density and abundance will enable ADF&G managers to develop sustainable brown bear management guidelines for GMU 5. Given that it is difficult to observe and estimate brown bear populations using conventional CMR techniques, advances in genetic techniques have greatly improved the ability of researchers to estimate population abundance using DNA captured from individual animals (Taberlet et al. 1997, Woods et al. 1999, Waits and Paetkau 2005, Kendall et al. 2008, Proctor et al. 2010). Use of noninvasive DNA-based hair follicle sampling can be used to confirm species, sex, and individual identification. With the recent development of spatially-explicit capture–recapture (SECR) models, bear density can now be estimated from detection parameters relative to the spatial distribution of detectors and animal movements. As well, SECR models account for individual heterogeneity in the detection process as exposure to traps is relative to animal movements (Efford 2004). Abundance estimates are more accurate as they are modeled within a defined survey area proportional to the area effectively sampled (Efford 2004). This SECR method has advantages over traditional CMR approaches which estimate population size within an undefined area and require additional measures to estimate effective trapping area which can be particularly difficult for carnivores with large home ranges and wide ranging movements. SECR models estimate density within a known sampling region and these spatial models directly estimate density and derive abundance.

In response to managers expressing a need for better population information to help guide management decisions in GMU 5A, ADF&G initiated a brown bear research project in 2009 to investigate harvest rates, spatial ecology and habitat selection, demographic parameters of survival, mortality, and reproduction, and to estimate population size and density. As part of this comprehensive study, we captured and radiocollared brown bears and used these data to augment the current population estimate. We incorporated telemetry locations from 28 brown bears equipped with GPS radiocollars and monitored during the population estimate to refine SECR model population parameters. Telemetry provides independent data on the location and presence of a sample of animals and has the potential to influence the spatial range parameter, which is especially important for those animals with limited recapture data. We also utilized this telemetry data to document brown bear home range size and movement patterns which improves our understanding of individual heterogeneity and late summer habitat spatial use patterns relative to SECR density estimation methodologies. Ultimately, assessment of telemetry data enhances SECR models and will help guide the timing and location of regulated activities.

Accurate estimates of population size and density are paramount to responsibly managing and determining appropriate harvest guidelines, especially considering the implications of reduced female survival and limited cub production in a highly exploited population. In the end, effective population management requires population demographic estimates so that harvest rates can be adapted to achieve management objectives. This report aims to provide a regional perspective on brown bear management in Southeast Alaska with recommendations for future research and management.

Study Objectives

The study's primary objective was to estimate brown bear population density and abundance for the northern mainland coast of Southeast Alaska, near Yakutat. We used a noninvasive DNA-based mark–recapture approach using hair samples and developed spatially-explicit capture–recapture models (SECR) to obtain a population estimate during late summer 2013.

Research objectives for this study included:

1. Estimating the density of brown bears in a portion of the GMU 5A study area.
2. Estimating the sex composition of brown bears detected in the study area.

3. Estimating brown bear population size in study area.
4. Estimating brown bear population size for GMU 5A, by predicting the study area density to the usable habitat identified in the subunit.
5. Computing apparent harvest rate of brown bears in GMU 5A.

Study Area

We demarcated a 3,191 km^2 study area along the Yakutat forelands on the northern mainland coast of Southeast Alaska, USA (lat 59°17'24"N, long 138°53'14"W) (Fig. 1). Situated between Glacier Bay and Wrangell—St. Elias National Parks, the study area extends 100 km east from Yakutat Bay to Dry Bay and is bounded by salt water to the south and west, and mountains and glaciers to the north and east. The majority of lands within the study area are within the United States Forest Service Tongass National Forest. A small portion of study area lands near Yakutat are owned by the State of Alaska, the City and Borough of Yakutat, and the Yakutat Native tribe, Yak-Tat Kwaan Inc. The State of Alaska manages hunting and trapping on the lands between the village of Yakutat and the Alsek River with regulations specific to GMU 5A. Yakutat is populated by more than 600 residents and road density is considered low with the main road extending 47 km to Harlequin Lake. The region has a temperate maritime climate and weather observations in Yakutat reported by the National Climatic Data Center during 1981–2015, indicate mean temperatures range from -1.9° C in January to 12.5° C in July, and mean annual precipitation totals 385 cm.

The landscape along the Yakutat forelands study area is characterized by sandy beaches, tidal mud flats, abundant wetland shrub communities, herbaceous vegetation including graminoids and forbs, recently colonized Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla)* forests, and a mosaic of deciduous trees and shrubs including cottonwood (*Populus* spp.*)*, alder *(Alnus* spp*.)*, and willow (*Salix* spp.) along the riparian margins (Shepard 1995) (Fig. 2 and 3). Glacial lakes, rivers, and streams provide important spawning and rearing habitats for fish species with 376 documented anadromous water bodies between Yakutat Bay and Dry Bay supporting 5 species of Pacific salmon (*Oncorhynchus* spp.): sockeye (*O. nerka*), pink (*O. gorbuscha)*, coho (*O. kisutch)*, chum (*O. keta*), and king (*O. tshawytscha)*, as well as steelhead (*O. mykiss*) and eulachon (*Thaleichthys pacificus*) (Johnson and Litchfield 2015). The distribution and timing of the Pacific salmon runs fluctuate annually. Peak run timing for king salmon occurs between mid-June and late July, sockeye return from late June to mid-August, pink salmon peak during August, and the greatest numbers of coho return from mid-August into October (Woods and Zeiser 2015). Brown bears are sympatric with other large carnivores (i.e., black bears and wolves) in the study area although black bear (*Ursus americanus*) spatial distribution is seasonally segregated from brown bear concentrations.

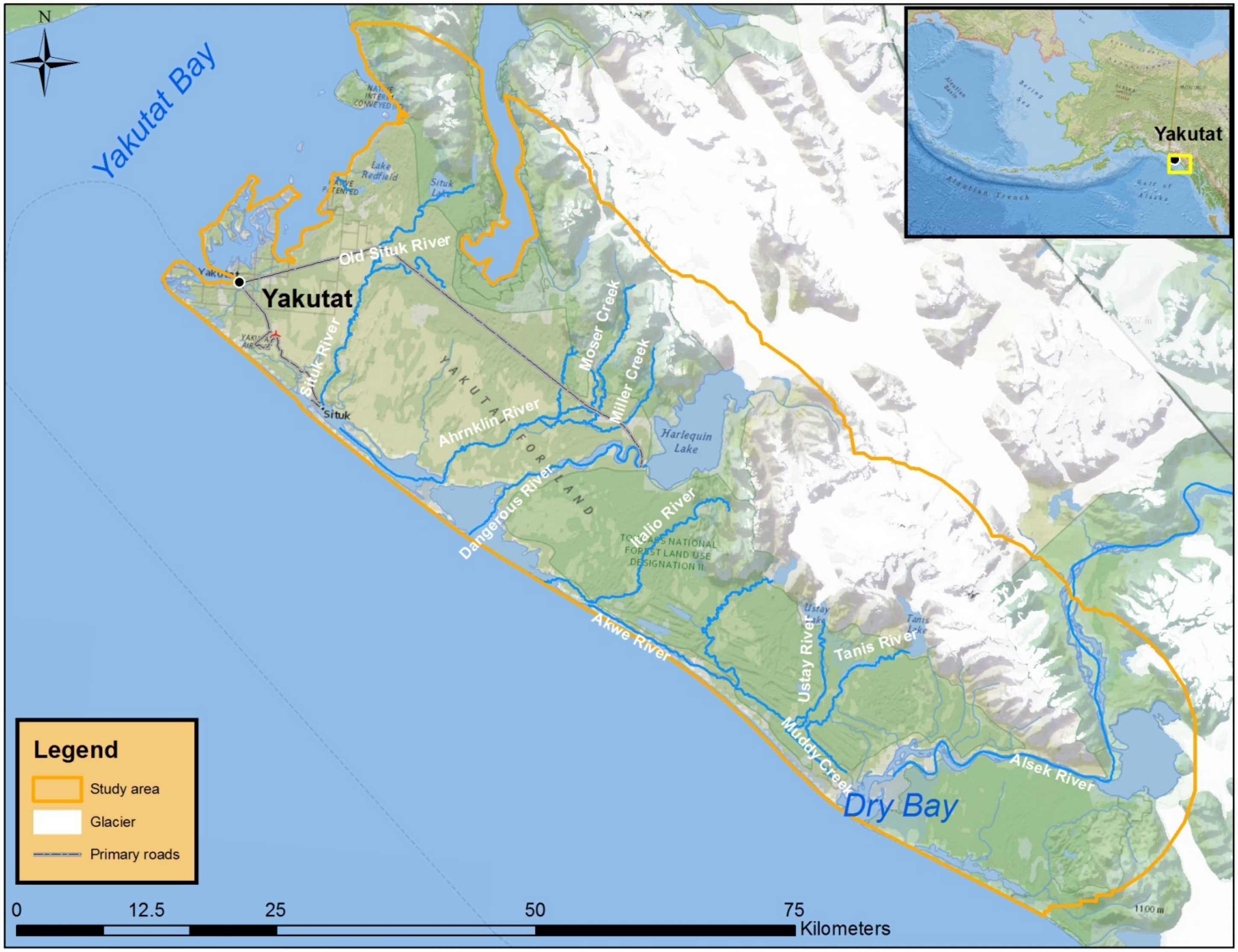

Figure 1. Study area for brown bear population estimate using noninvasive DNA-based sampling, Yakutat, Alaska, 2013.

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Figure 2. Aerial photograph of the study area near Yakutat, Alaska during an aerial telemetry survey of radiocollared brown bears.

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Figure 3. Coastal habitat of the study area near Yakutat, Alaska. In photograph from left Akwe River, strawberry beach, and Gulf of Alaska. Hair snares were set on a bear trail along the forest edge. Bears were attracted to the mesic beach habitat in late summer to forage on coastal strawberries and spawning salmon in the river.

Brown bear diet in this region is consistent with other coastal populations with the availability and abundance of resources varying seasonally (McCarthy 1989, Mowat and Heard 2006). Graminoids (i.e., grass (Poaceae), rush (Juncaceae), or sedge (Cyperaceae)), berries (i.e., blueberry (*Vaccinium* spp.), salmonberry (*Rubus spectabilis*), coastal strawberry (*Fragaria chiloensis*), dwarf nagoonberry (*R. arcticus*), devil's club (*Oplopanax horridus*), clasping twistedstalk (*Streptopus amplexifolius*)), and other herbaceous vegetation (i.e., skunk cabbage (*Lysichiton americanum*), northern rice root (*Fritillaria camschatcensis*), sea-watch (*Angelica lucida),* beach lovage (*Ligustichum hultenii*), cow parsnip (*Heracleum lanatum*)) likely balance their primary diet of salmon and terrestrial meat such as moose (*Alces alces)*. During late summer, brown bears concentrate their activities along herbaceous beach habitats that produce an abundance of coastal strawberry and strand ocean forage fishes (i.e., surf smelt (*Hypomesus pretiosus*), capelin (*Mallotus villosus*) and sand lance (*Ammodytes hexapterus*)) that have washed ashore, before moving to riparian streams to fish for spawning salmon.

We systematically sampled 3,191 km^2 of the Yakutat forelands, representing 42% of the land area in GMU 5A (7,657 km^2). We identified usable bear habitat as non-glacial habitat below 700 m, excluding the area of lakes greater than 10 acres (209 km^2). In GMU 5A this totaled 3,580 km^2. In the study area we identified 2,447 km^2 of usable bear habitat, representing 77% of the total area sampled. Therefore, we effectively sampled 68% (2,447/3,580 km^2) of the usable bear habitat in all of GMU 5A.

Methods

Animal Capture and Telemetry

Between July 2009 and September 2014, we captured brown bears along the Yakutat forelands and at the Yakutat landfill using free-range, foot snaring, and helicopter darting techniques (Jonkel 1993, Titus et al. 1999, Crupi et al. 2014). We focused bear capture efforts along the coast adjacent to the Gulf of Alaska and along salmon spawning streams in the forelands. We aimed to target a representative sample of available sex and age classes. At the Yakutat landfill we captured bears by free-range darting and using modified Aldrich foot snares set along bear trails surrounding the landfill. We checked the snares daily by visually inspecting them or listening to a snare-side VHF transmitter that indicated whether the trap had been triggered. From 2010–2012, we used a Hughes 500D or a Bell 206 Jet Ranger helicopter to opportunistically locate and dart bears near the shoreline. Captures were typically conducted in the evening during a brief summer period when strawberries ripened along open herbaceous meadows and attracted bears away from the closed canopy forest. In 2013 and 2014, we attempted to improve our understanding of the spatial variability of this population by geographically distributing our capture effort to remote alpine and riparian areas. We used a Hiller 12-E helicopter to capture bears from the air and to access areas where we captured bears with foot snares. Foot snares were monitored with a SPOT messenger device (SPOT LLC, Covington, Louisiana, USA) that was equipped to transmit the time and location of a triggered trap to orbiting satellites and then notify us via e-mail message.

Each captured bear was chemically immobilized using tiletamine HCl and zolazepam HCl (Telazol®, Fort Dodge Animal Health, Fort Dodge, Iowa, USA) at a concentration of 227 mg/ml and dosage of 7–10 mg/kg estimated body weight ("DWC Grizzly Bear Dose Protocols September 2015," ADF&G unpublished document). We administered the anesthesia by a 3–5 cc projectile dart with a 19 mm barbed, end-port needle, delivered from a Palmer Cap-Chur gun. In order to minimize the potential for harmful effects on the captured animals, staff were formally trained and followed strict ethical guidelines for capture and chemical immobilization. All animal capture and handling protocols were approved by ADF&G's Division of Wildlife Conservation Institutional Animal Care and Use Committee protocol 2013-028 and conformed to the procedures outlined by the American Society of Mammologists (Sikes et al. 2011).

Each animal was marked with a unique numbered ear tag and an ear tissue sample was collected for DNA analysis. The tissue was dried for DNA extraction and stored in a paper envelope and the remaining tissue was subsampled and preserved in 200 proof ethanol for archival storage. We collected morphometric measurements on skull length and width, neck girth, total body length, chest girth, and estimated body weight. To determine bear age, we extracted a premolar tooth for cementum analysis (Matson et al. 1993) at Matson's Laboratory (Milltown, Montana, USA). We grouped the age class of solitary bears as subadult (age class 1–4) or adult (≥ age 5), and bears that accompanied adult females as young of the year (age 0) or dependent cub (age class 1–3) (Barnes and Van Daele 2008). We determined adult female reproductive status as either solitary adult female or female with cubs, after observing cubs during capture or on subsequent telemetry flights.

We deployed GPS equipped radio collars (Telonics models TGW-3600, 3700, 3790, or 4700, Telonics, Inc., Mesa, AZ) on all captured adult brown bears and 3–4 year old subadults. The GPS collars were set to collect a location fix at 20 to 30 minute intervals from 16 April to 15 November, and then switched to an acquisition rate of 1 fix per day from 16 November to 15 April. Collars stored location, activity, and temperature data via internal memory, and some collars (model 3790) were capable of being downloaded remotely by transmitting this information to a laptop computer operated in a fixed-wing aircraft when within 1 km of the bear. Each collar was also equipped with a standard VHF beacon in the 150–151 MHz range. Collars were fitted with a release mechanism (Telonics model CR–2a) programmed to detach from the bear 10–24 months after deployment. We selected release dates that we believed would best facilitate collar retrieval, although in some instances release mechanisms failed and we did not recover the collars.

Once collars were recovered we downloaded GPS locations on a personal computer using Telonics software (TDC version 2.18). We processed the output files and converted the data to a

Microsoft Access geodatabase for analysis. We mapped the spatial distribution of all GPS locations in ArcGIS (Version 10.3.1, ESRI 2015) to determine the spatial extent of brown bear activity. We then screened GPS locations to improve location precision and eliminate locations believed to be inaccurate or impossible (D'Eon et al. 2002). We used the activity and temperature sensors in the collars to determine the actual date and time that the collar released from the animal or when the animal died.

TRAP ENCOUNTERS

Movements of male and female brown bears were investigated in relation to their distance to hair sampling detectors. High resolution spatial data recorded at frequent intervals were collected by GPS collars. We measured the minimum distances between telemetered bears and detectors to help understand animal movements in relation to the hair trap array.

SUMMER HOME RANGE ESTIMATES

Seasonal home ranges were estimated for male and female brown bears during the extent of the hair sampling session using the Geospatial Modeling Environment (GME; Beyer 2013) and ArcGIS. To estimate home range size, we used kernel density estimation (KDE) to define the probability of use by determining utilization distributions within each seasonal home range for bears with more than 10 days of locations during the study period (Worton 1989). We generated a 95% fixed kernel with a least-squares cross-validation (LSCV) bandwidth estimator and a cell size of 30 m (Seaman and Powell 1996, Gitzen and Millspaugh 2003, Horne and Garton 2006). We selected LSCV to estimate the bandwidth as it minimizes the mean integrated square error, is robust to clumped location distributions (Gitzen et al. 2006), and given our large sample size we believe this is the most biologically appropriate method for this species (Silverman 1986, Hemson et al. 2005, Kie et al. 2010). Brown bear home range estimates that extended into ocean habitats were truncated by clipping the estimated home range polygon to the defined shoreline, similar to the approach used by Goodrich et al. (2010).

To compare male and female KDE late summer home range estimates, we calculated a one-way ANOVA using PROC GLM (SAS Institute Inc., Cary, NC, USA). We performed all statistical analyses at the 95% significance level, and means are presented ± SE unless otherwise specified.

MOTION ACTIVATED CAMERAS

We deployed motion-activated digital cameras (Reconyx HC600, Reconyx, Inc., Trail Watcher 4200, Trail Watcher Game Cameras) to record bear activity at a subset of scent-baited hair traps. The cameras were positioned 3–5 m from the hair trap, attached to trees 2 m above the ground, and oriented at an approximately 30° downward angle to provide an oblique view of the trap site. The cameras were programmed to be active 24 hours per day and equipped with a passive infrared motion sensor to trigger the camera to capture up to 3 photographs within 1 minute.

Photographs and their associated time/date stamp were reviewed in the field during each trap check to determine animal activity and subsequent sample collection to minimize duplicate sampling of the same individual during each visit. Digital photos were downloaded to a PC and further inspected for evidence of cub detection.

NONINVASIVE DNA-BASED POPULATION ESTIMATION

DNA-based spatially-explicit capture–recapture (SECR) procedures were used to estimate the population abundance and density of brown bears within the Yakutat forelands study area (Woods et al. 1999, Mowat and Strobeck 2000). We followed several recommendations to increase sampling effort and potentially improve capture probability, such as including multiple detector types to maximize estimate precision, and considered seasonal movement patterns when designing the sampling strategy (Boulanger et al. 2008). We have successfully generated reliable population estimates for other brown bear populations in Southeast Alaska by setting single-catch breakaway hair snares along anadromous salmon streams (Flynn et al. 2007, 2010, 2012). Using GPS radio collar data we prioritized hair sampling sites in areas with concentrated levels of bear use. Ultimately, we wanted to maximize the number of samples collected, particularly the number of individuals recaptured, and therefore integrated both small-scale and large-scale sampling designs (Boulanger et al. 2004a). We designed a systematic sampling method to accommodate the large-scale design, and supplemented it with individual sampling devices distributed throughout the study area, particularly on trails along salmon streams, as well as other seasonally occupied habitats.

Sampling Design

We conducted 4 consecutive 9-day trapping sessions beginning 15 July and ending 30 August 2013 (Table 1). We employed a systematic approach to ensure a uniform sampling effort by establishing sampling sites within 36 grid cells across the study area (Fig. 4). We selected an 8 km^2 grid size following results of other brown bear studies (Woods et al. 1999, Mowat et al. 2005, Boulanger et al. 2002) and to provide trap spacing that overlapped the average annual female brown bear home range (± SD)(Otis et al. 1978), which in this study was 193 ± 175 km^2. Access to each grid cell was determined by the most cost efficient mode of transportation to

Table 1. Scheduled population estimate occasion dates used for sample collection and GPS collar telemetry locations, 15 July–30 August 2013 in Yakutat, Alaska. For the analysis each trap had its own set of occasion dates depending on day checked.

		Occasion			
	Deployment	1	2	3	4
Begin	7/15/2013	7/15/2013	8/3/2013	8/13/2013	8/22/2013
End	7/24/2013	8/2/2013	8/12/2013	8/21/2013	8/30/2013

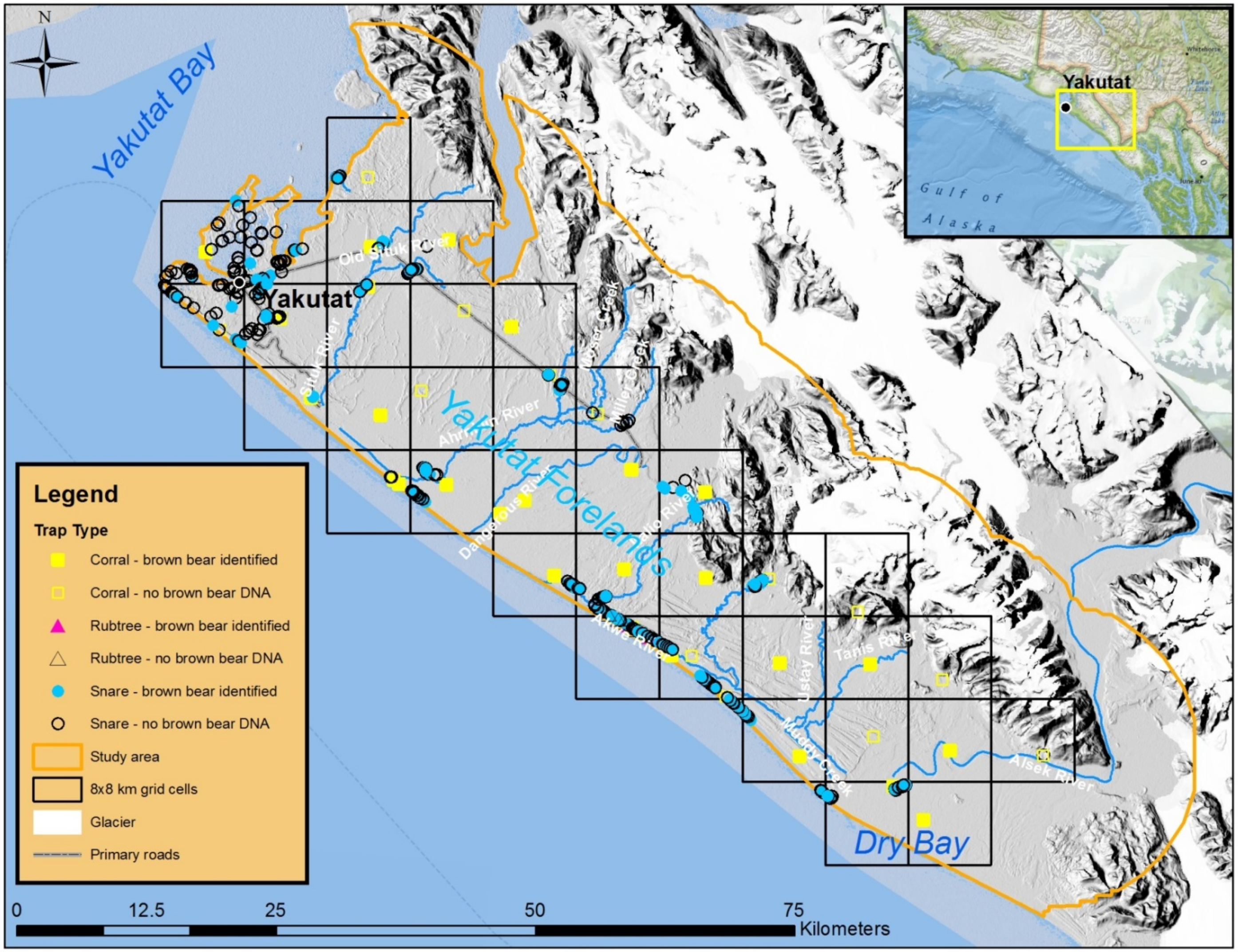

Figure 4. Sampling design and DNA genotyping success for brown bear density estimate in the Yakutat Forelands. Hair sampling corrals were systematically distributed within 36 8km × 8km grid cells, single-catch hair snares were placed in prioritized bear habitats, and rub trees were opportunistically located and sampled between 15 July and 30 August 2013.

each particular sampling site, including highway vehicle, motorized boat, fixed-wing aircraft, and helicopter. We set hair traps within each grid cell at locations that provided a suitable landing zone and evidence of seasonal bear habitat.

Three sampling methods were used to collect bear hair: 1) scent-baited hair traps placed near the center of the grid cell (Woods et al. 1999), 2) single-catch breakaway hair snares set along bear trails without lure (Beier et al. 2005), and 3) natural scent-marking rub trees used for chemical signaling (Boulanger et al. 2008, Stetz et al. 2010, Clapham et al. 2013). Hair sampling stations were deployed by and monitored by four 2-person crews. Three crews worked along the road system and the fourth crew monitored the remote trapping arrays, accessing those grids via helicopter and fixed-wing aircraft.

We devised a sampling strategy that both distributed sampling effort and focused sampling intensity on the best available seasonal habitat. All grid cells were systematically sampled with 1 scent-baited hair trap, and some were intensively sampled with single-catch breakaway hair snares. In July and August (2009–2012), we collected over 68,000 GPS collar locations and used these data to identify habitats occupied by brown bears in late summer. From these locations, we generated a kernel density estimate and 95% probability contour to characterize this high probability bear habitat. Within the majority of the grid cells (25), we prioritized the placement of 20–30 breakaway hair snares. The remaining grid cells that showed little or no bear use in July or August, were sampled by 1 scent-baited hair trap.

Scent-baited hair traps, hereafter referred to as corrals, were constructed from two 20 m lengths of 15.5 gauge double-stranded, 4-pronged barbed wire strung around 4–6 trees. Each corral consisted of barbed wire positioned at 2 heights; 20–30 cm and 60–70 cm above the ground. By placing 2 barbed wire strands at these heights we assumed we would sample bears ranging in age from dependent cubs to adults. A minimum of 1 corral was constructed in each of the 36 grid cells and we attempted to position them within 2 km of the grid cell centroid to distribute sampling effort throughout the study area. The corrals within each grid cell remained in the same location for the duration of the study. In total, we deployed 41 corrals; we established 2 corrals in 5 of the grid cells located in high probability bear habitat, because hair snares were not logistically feasible to set up and monitor.

Several scent attractants were used to encourage bears to investigate the interior of the corrals. Scents were applied to cotton balls or sheep wool and enclosed in a plastic container with holes hung from a tree approximately 3 m above the ground. We used a variety of readily available trapping lures known to attract bears, such as Mega Musk™ (Carman's Superior Animal Lures, New Milford, PA), beaver lure, Alaska salmon oil, and anise oil. Scents were replenished during each occasion and we varied the scent between the 4 lures to maintain the novelty of the site and minimize behavioral effects (Fig. 5 and 6).

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Figure 5. A remote trail camera photo of 3 brown bears investigating a scent-baited barbed wire corral set in alder habitat along the coastal beach fringe near Yakutat, Alaska. Bear hairs were snagged by the barbed wire and used to estimate the population size.

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Figure 6. Hair sample collected at a barbed wire corral set near Yakutat, Alaska. These detectors were systematically distributed throughout the study area and DNA was extracted from the hair follicles to identify individual brown bears. From these capture histories the abundance and density of the population was estimated with a spatially-explicit capture–recapture (SECR) model.

Single-catch breakaway hair snares (hereafter hair snares) were made from 3.7 m of steel cable with 3 short pieces of barbed wire clamped onto the cable to snag the hair sample. A rubber fastener was designed to release once the bear was snared and exerted enough force to break the rubber (Beier et al. 2005). Hair snares were treated with commercial dye to mask the scent and luster of the metal. Hair snares were set along seasonal bear trails to passively sample bears traversing the trail without the need for an attractant. The hair snares were anchored to trees or vegetation capable of withstanding the hair snare cinching on the bear and the resistance of the rubber fastener to its breaking point (Fig. 7).

When bear rub trees were encountered along established bear trails, we affixed a 5 m barbed wire strand to the tree to aid in the collection of hair (Boulanger et al. 2008, Stetz et al. 2010). The barbed wire was stapled to the scent marking tree with the majority of the wire configured near the rubbed portion of the tree where the bark had been scratched and/or denuded (Fig. 8).

Figure 7. LaVern Beier setting a single-catch breakaway hair snare along a bear trail in willow shrub habitat. DNA was extracted from the hairs snagged by the snare and used to estimate the size of the brown bear population near Yakutat, Alaska.

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Figure 8. Trail camera photo of a male brown bear leaving a hair sample at a rub tree detector, set with barbed wire near Yakutat, Alaska.

Genetic Sampling

Hair snares, rub trees, and corrals were checked at approximately 9-day intervals. Hair samples at rub trees and corrals were collected in the field and the barbed wire was then burned with a butane torch lighter to eliminate DNA contamination. When adjacent barbs contained hair of the same color and texture, and when motion-activated cameras indicated the detection of 1 individual, we collected only 1 sample. By design, the hair snare collects 1 sample per event and all of the adequate samples were submitted for analysis. Hair snares were processed in the field or the entire snare was retrieved and placed into individual 2-gallon plastic bags, labeled with the trap site number and date, and then returned to the office. Tripped hair snares that were collected for office processing were reset with a clean snare. Once in the office, hair samples were air dried at room temperature (15–22° C), placed in a pre-labeled paper coin envelope (3.5 × 2.25 in), and then stored in a dry environment (i.e., a cardboard container with silica gel desiccant) prior to shipment. Sample envelopes were individually identified, and the following information was recorded on a datasheet and duplicated on each envelope: sample_ID, trap_ID, staff, type of hair (guard or underfur), quantity of hair (<3, ≥3, >10), plot location (top or bottom wire and cardinal direction), waypoint, photo_ID, date, and general trap location. We screened some non-target species samples (e.g., ungulates) prior to submission to the laboratory. We did not attempt to discern between black and brown bear hair and left that determination to genetic species identification.

Genetic Analysis

Hair samples were analyzed by Wildlife Genetics International, Inc. (Nelson, British Columbia, Canada) where DNA was extracted, species was identified, and individual genotypes of brown and black bears were determined following standard protocols (Paetkau 2003). We submitted all samples for analysis that contained ≥1 guard hair follicle or ≥3 underfur hairs. All DNA extractions were performed using QIAGEN's DNeasy Tissue Kit (Qiagen Inc., Mississauga, Ontario, Canada). Brown and black bear species identification was determined using the G10J microsatellite marker with even numbered alleles classified as brown bears and odd alleles as black bears (Mowat et al. 2005). Twenty-one nuclear microsatellite loci were amplified to determine individual bears including: MU59, G10B, G1D, G10M, MU50, G10U, G1A, G10C, CXX110, CXX20, G10L, G10H, G10P, G10X, MU23, REN145 P07, MSUT2, MU51, CPH9, and MU26. These variable markers have successfully distinguished individuals in other SEAK regional genetics studies (Flynn et al. 2012, Lewis et al. 2015). Sex was determined by length polymorphism in the amelogenin sex gene (Enis and Gallagher 1994). The laboratory analysis and genotype error checking techniques utilized in this study followed rigorous protocols, reanalyzing genotypes that differed by only 1 or 2 alleles (Poole et al. 2001, Paetkau 2003, Waits and Paetkau 2005, and Kendall et al. 2008), negating the need to include genotype error rates in our models.

Population Density Estimates

We estimated the population density of brown bears using spatially-explicit capture–recapture (SECR) methods (Efford 2004, Borchers and Efford 2008). SECR is a set of mark–recapture methods used to estimate population density and abundance by incorporating the detection histories of individual animals with the spatial locations of the traps. These data are used to fit a two-part model, consisting of a space model which describes the distribution of animals' centers of activity, and an observation model that describes the probability of detecting an animal given the distance between its activity center and each individual detector. All SECR analyses were performed in the R statistical environment (version 3.3.0, R Development Core Team 2015) using maximum likelihood methods implemented in the secr package (version 2.9.4, Efford 2015).

Detection histories based on 4 sampling occasions were compiled for bears that had been uniquely identified from DNA extracted from hair. A sampling occasion was defined as the period between checks of each detector in the study area and the length of a sampling occasion was allowed to vary for each detector individually based on actual exposure time. Hair snares set along trails were single-capture detectors, while rub trees and corrals allowed for multiple detections of both the same and different individuals within the same sampling occasion. None of the 3 detector types impeded animal movement, so the same individual could be detected at multiple locations during the same occasion. As such, we set the detector type to "count", with hair snares never exceeding a single detection during any given occasion. Multiple detections of the same individual at corrals or rub trees during the same occasion were collapsed to a single detection event because it was not possible to determine if the multiple samples were deposited on a single visit, or over the course of multiple visits within the same sampling occasion. The exclusion of multiple detections at the same trap during the same sampling occasion represented only a small number of all recaptures.

A discrete analysis area mask was defined based on a 2 km grid by delineating a 15 km buffer surrounding the detector array, which was then clipped to the shoreline. The size of the buffer was selected based primarily on the maximum extent of animal movement during the study period and was selected to minimize the probability of detecting an animal in the trap array whose activity center was located outside of the study area. A secondary analysis area was defined by removing grid points that were classified as "non-habitat", which included inland bodies of water greater than 4.05 ha (10 ac), glacial ice fields, and elevations above 700 m. The 2 resulting grids encompassed a total area of 3,260 km^2 and 2,447 km^2, respectively.

To examine the effect of landscape-connectivity within the study area, we used 2 different methods to measure distance between the detectors and each grid point in the study area. First, we considered straight-line distance between detectors and activity centers. For some coordinate pairs, this line may cross over regions of non-habitat and would, therefore, underestimate the actual minimum distance a bear would have to travel to reach that particular detector from its center of activity. The second distance measure was a non-Euclidian, or ecological distance measure (Royle et al. 2013), which represents the shortest distance a bear could travel between 2 points without crossing into non-habitat or non-traversable regions, or other potential barriers to movement. This ecological distance measure may result in more realistic estimations of model parameters.

We considered a range of models with biologically-plausible covariates (Appendix A) on detection probability and space usage, including trap type (snare, rub tree, or corral) and sex. We examined the effects of behavioral responses (e.g., trap-averse or trap-happy) and site-specific changes in detector effectiveness on the detection probability and movement parameters. Sampling effort varied over time and sampling intervals were not synchronous. To take this known variation in effort into account, we modeled potential behavioral changes in terms of site-specific differences (specified using the bk parameter in SECR). There were known changes in bear distribution over the course of the study period, so we also evaluated a site-specific time coefficient, defined as the Julian day (centered and scaled) corresponding to the midpoint of each detector's sampling occasion (Efford et al. 2013). All models were repeated with the inclusion of

GPS telemetry data, by combining a capture history object containing the telemetry data with the capture-recapture data (e.g., DNA detections from hair samples), to evaluate the effect on parameter estimates. Analyses were performed using a half-normal detection function and models were ranked based on AIC corrected for finite sample size (AICc) (Burnham and Anderson 2002).

Prediction to Remainder of GMU 5A

Based on bear GPS collar location data, we generated a habitat mask for the study area to exclude areas that were considered non-bear habitat (e.g., salt water, ice, glaciers, lakes greater than 4.05 ha (10 ac), and elevations > 700 m). We examined the entire GPS location dataset collected during this project (818,435) and verified these criteria were adequate to classify the landscape as usable bear habitat or non-bear habitat. Of all bear locations, 0.3% occurred in glacial habitat and only 1% were above 700 m, typically collected in spring following den emergence as bears intersected the edges of glaciers or traversed higher elevations to get to other more productive habitats. Using these criteria, we estimated total usable bear habitat in GMU 5A as 3,580 km^2. We extended the density estimate from the study area to the remainder of the usable bear habitat (1,133 km^2) to predict the total brown bear population size in GMU 5A.

Apparent Harvest Rate

Exploitation rates were examined following procedures outlined by Miller (1993). Apparent harvest rate (AHR), or the harvest probability, was calculated using the population size point estimate and lower and upper limits of this value. We also calculated the exact 95% binomial confidence interval for the harvest rate (Clopper and Pearson 1934). Actual harvest rates would be greater if additional information was known about wounding loss, poaching, and other unreported mortalities.

Eq.1 $AHR = (x/n) \times 100$

where x is the harvest total in regulatory year 2012 (1 July 2012–30 June 2013) and n is the late summer population estimate in 2013.

Total mortality rate was calculated similarly, however total mortality includes both the number of bears harvested and additional non-hunting mortalities.

Results

Animal Capture and Telemetry

Captures

From 2009–2014, we captured and deployed GPS radio collars on 36 female and 34 male brown bears throughout the Yakutat Forelands study area, and 7 female and 15 male brown bears at the Yakutat landfill. During the time that we conducted the population estimate we monitored 28 brown bears with GPS collars; 14 female and 14 male bears from various age and sex cohorts (Table 2). Average age of female bears monitored was 9.7 years and these females were represented by the following cohorts: 6 adult females rearing cubs, 7 adult single females, and 1 subadult female. We monitored 9 adult male bears and 5 subadult males, with a mean age of 6.3 years. The oldest female radio tracked in 2013 was 18 years and the oldest male was 10 years old.

Bears monitored during the population estimate were captured through helicopter darting (22), foot snaring (4), and free range darting techniques (2). We performed helicopter captures on 16 days, over 3 years, to radiocollar the sample of bears monitored during the population estimate. During the course of the project we did not experience any direct capture related mortalities; however, while recovering from sedation, 1 bear was killed at the landfill by another agonistic bear so we attributed that mortality to research activity.

GPS Collar Locations

Between 15 July and 30 August 2013, 28 brown bears equipped with GPS collars collected 35,293 locations (Fig. 9). We used the majority of these locations in the spatial analysis of home range, movement patterns, and encounter rates. There were more female locations than male, 19,325 and 15,968 respectively. We calculated the mean daily distance traveled and found bear movement rates remained relatively stable throughout the 4 sampling occasions, ranging 6.3–7.5 km per day (Table 3). The maximum distance traveled in 1 day was 25.5 km (M740) and the minimum distance moved in 1 day was 389 m (F857).

Summer Home Range Estimates

We estimated the home range size for 21 brown bears with an adequate number of locations collected during the population estimate period (Table 4). The mean number of locations (± SD) for 10 female brown bears was 1,909.9 ± 210.8 and 1,399.9 ± 137.4 for 11 male brown bears. During the late summer period male brown bears had a mean home range size of 211.9 ± 55.7 km^2, larger than female home range size, which averaged 144.2 ± 39.3 km^2. However, sex was not a significant factor in determining seasonal home range size during this period ($F_{1,19} = 0.95$, $P = 0.34$). We mapped the home ranges of each age-sex cohort to depict the array of home range sizes and spatial locations occupied by radiocollared bears during the population estimate (Fig.

10). Adult males had the largest home range size and female bears with dependent offspring maintained the smallest home ranges (Table 4).

Male and female home range size varied throughout the duration of the study, with females occupying the largest home ranges during the second sampling occasion and male home range size doubling between the 2nd and 3rd occasion (Fig. 11). In general, radiocollared bear activity during the first occasion was concentrated near the shoreline, as strawberries were abundant and ripe, as well as near the lower reaches of the Ahrnklin, Italio, Akwe, and Alsek rivers. As spawning salmon migrated up anadromous streams, movement of telemetered bears followed.

Daily movement rates of bears did not fluctuate between occasions but the size of male and female home ranges increased, reflecting their dietary shift from vegetation to salmon, which increased their distribution while transiting between anadromous streams, primarily the Situk, Old Situk, Ahrnklin, Italio, Akwe, Tanis, and Alsek rivers and Moser Creek. Between the 3rd and 4th sampling occasions, female home range size was constant and male range size decreased slightly, while the telemetry locations indicate movement between the primary salmon spawning streams and extended moves into the upper reaches of those streams.

Similar to the GPS location dataset collected during the entire study (2009–2015), the majority of bear movement during the population estimate was concentrated in the Yakutat forelands study area, with only one foray extending beyond the study area before the bear returned to the forelands. One 6-year-old male (M740) captured at the landfill made the largest movement, traveling along the Alsek River north to the Canadian border. In the days prior to the first occasion, he traveled through a pass near Tanis Lake and foraged in the upper Alsek River near recolonizing glacial habitats, and on south facing hillsides above 450 m, presumably foraging for berries. The movement of this bear was noteworthy because it was anomalous to other bear movement patterns that remained within the sampling grid, and validates the sampling strategy used for the population estimate. Bear M740 remained along the upper Alsek River until 15 August (occasion 3), when he returned to the forelands through the same pass, and began pursuing salmon along the Italio River. The GPS collar data recorded this bear within close proximity to several detectors and his DNA was successfully identified in both the third and fourth occasions.

Table 2. Summary of brown bears GPS radiocollared in Yakutat, Alaska during the study period 15 July 2013–30 August 2013. Capture method includes free-range darting (FR), helicopter (H), and foot snare (FS).

BearID	Sex	Age	Capture date	Capture method	Date start	Date stop	# Locations	Bear status	Female reproductive status during	DNA detected?
735	F	3	8/5/2011	H	8/5/2011	8/30/2015	2050		No cubs	No
740	M	6	10/10/2012	FR	10/10/2012	8/24/2013	1544			Yes
741	F	13	10/11/2012	FR	10/11/2012	9/30/2013	1		2 1-yr cubs	Yes
811	F	18	7/14/2012	H	7/14/2012	2/4/2014	1817	DEAD: 2/4/14	No cubs	No
816	M	9	7/29/2013	H	7/29/2013	10/15/2013	1464	DEAD: 10/15/13		No
825	F	12	7/29/2012	H	7/29/2012	12/8/2013	2739		3 1-yr cubs	Yes
826	F	10	8/2/2011	H	8/2/2011	8/19/2013	1423		No cubs	Yes
827	F	4	8/2/2011	H	8/2/2011	8/22/2013	1		No cubs	No
829	F	16	8/3/2011	H	8/3/2011	8/19/2013	1707		No cubs	Yes
834	F	5	7/14/2012	H	7/14/2012	9/1/2014	2455	DEAD: 9/1/14	1 1-yr cub	No
835	M	5	7/14/2012	H	7/14/2012	6/25/2014	1580			No
837	M	8	7/28/2012	H	7/28/2012	5/13/2014	1680			No
838	M	10	7/28/2012	H	7/28/2012	4/17/2014	1697			Yes
840	F	15	7/5/2013	H	7/5/2013	7/9/2014	2212		2 2-yr cubs	No
841	F	7	7/6/2013	H	7/6/2013	10/22/2014	2172		1 0-yr cub	Yes
842	F	3	7/10/2013	H	7/10/2013	5/21/2014	2186		No cubs; sub-adult	Yes
846	M	10	7/12/2013	H	7/12/2013	10/7/2013	2191			Yes
847	M	8	7/29/2013	H	7/29/2013	5/9/2014	1246	DEAD: 5/9/14		Yes
848	F	9	7/30/2013	H	7/30/2013	7/31/2013	22		2 1-yr cubs	No
849	M	4	7/31/2013	H	7/31/2013	8/28/2013	1206			No
850	M	4	7/31/2013	H	7/31/2013	5/15/2014	1421	DEAD: 9/16/14		Yes
851	M	8	8/3/2013	H	8/3/2013	8/11/2013	306			Yes
853	M	3	8/9/2013	H	8/9/2013	5/10/2014	418	DEAD: 5/10/14		No
854	M	4	8/10/2013	H	8/10/2013	2/20/2015	952			Yes
855	F	12	8/19/2013	FS	8/19/2013	8/10/2014	338	DEAD: 10/8/15	No cubs	No
856	M	3	8/22/2013	FS	8/22/2013	9/19/2014	219			Yes
857	F	9	8/24/2013	FS	8/24/2013	12/16/2014	203		No cubs	Yes
858	M	6	8/27/2013	FS	8/27/2013	10/3/2015	44			Yes

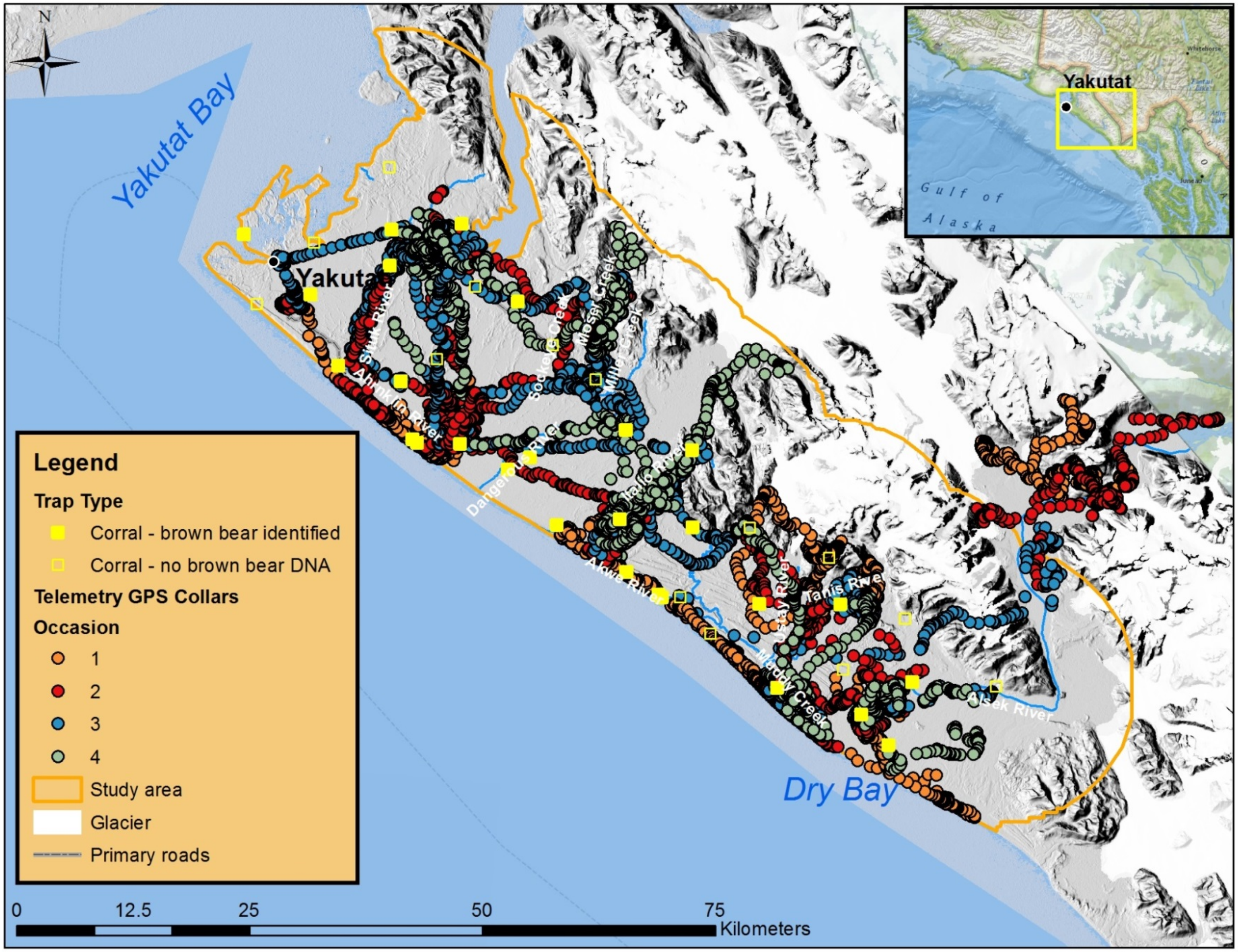

Figure 9. Brown bear GPS locations during 4 sampling occasions and hair sampling corral locations for the brown bear density estimate in the Yakutat Forelands, 15 July–30 August 2013.

Table 3. Mean daily movement rates (± SD) of GPS collared brown bears 15 July–30 August 2013 in Yakutat, Alaska.

	Occasion			
	1	2	3	4
No. brown bears	16	20	20	21
Mean daily distance traveled (m)	6834.2 ± 3255.8	6801.2 ± 3501.2	7515.8 ± 3745.7	6281.2 ± 3241.3
Male daily distance traveled (m)	5747.8 ± 3287.8	6512.3 ± 3705.1	7131.9 ± 3966.1	5841.6 ± 3418.5
Female daily distance traveled (m)	7491.3 ± 3063.8	7125.4 ± 3247.3	7990.9 ± 3124.2	6910.6 ± 3271.5

Table 4. Home range sizes of brown bear cohorts in Yakutat, Alaska, during the study period (15 July–30 August 2013), using a 95% fixed kernel density estimator (KDE).

Cohort	No. radio collars	Mean no. locations ± SE	95% KDE ± SE (km^2)
Adult female no cubs	6	1,586.8 ± 272.5	146.2 ± 56.7
Adult female w/ cubs	4	2,394.5 ± 130.8	141.2 ± 59.4
Adult male	7	1,628.9 ± 109.8	227.4 ± 81.9
Subadult male	4	999.3 ± 216.2	184.8 ± 67.5
Mean female	10	1,909.9 ± 210.8	144.2 ± 39.3
Mean male	11	1,399.9 ± 137.4	211.9 ± 55.7

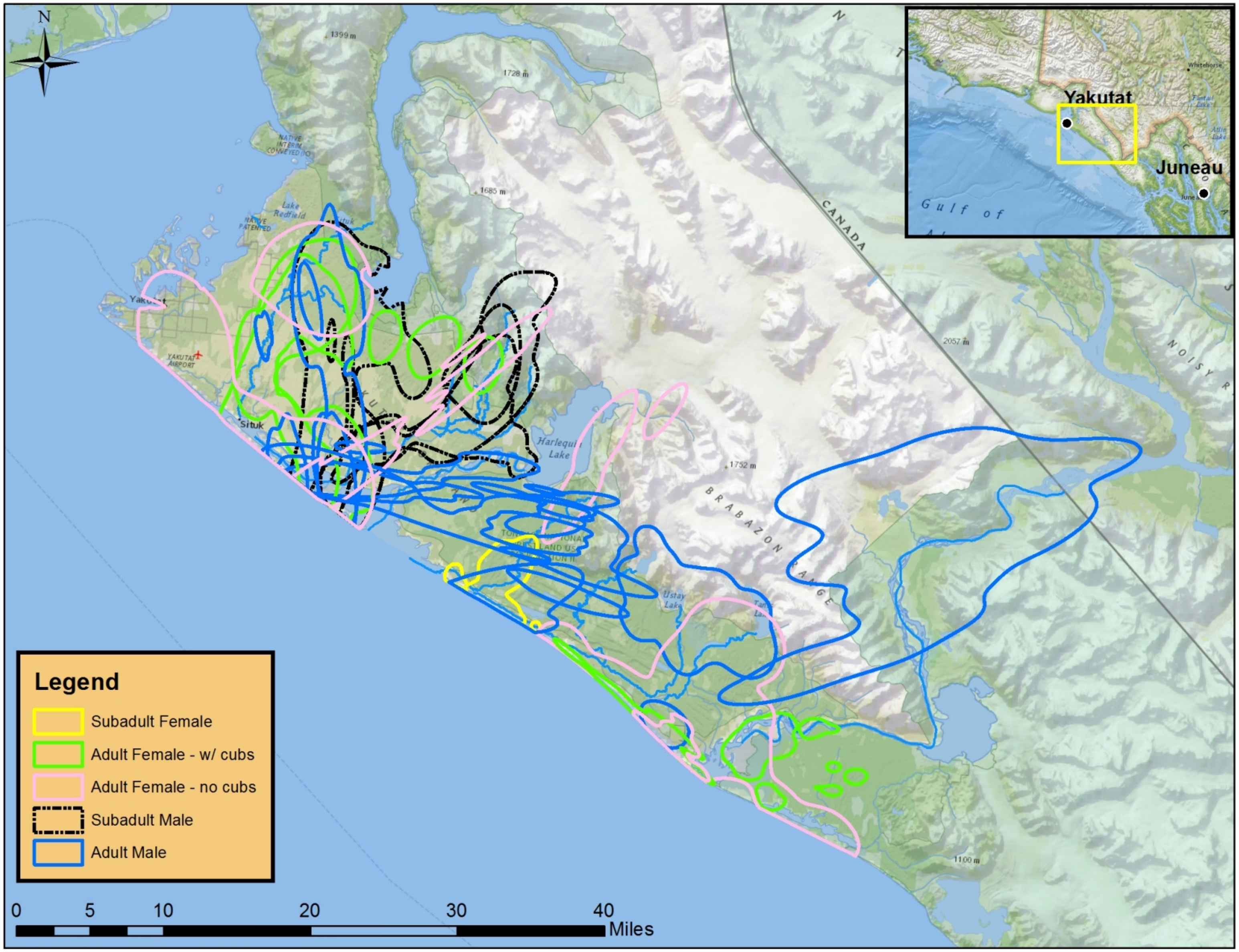

Figure 10. Late summer brown bear home ranges (15 July–30 August 2013), 95% fixed kernel density estimates, Yakutat, Alaska.

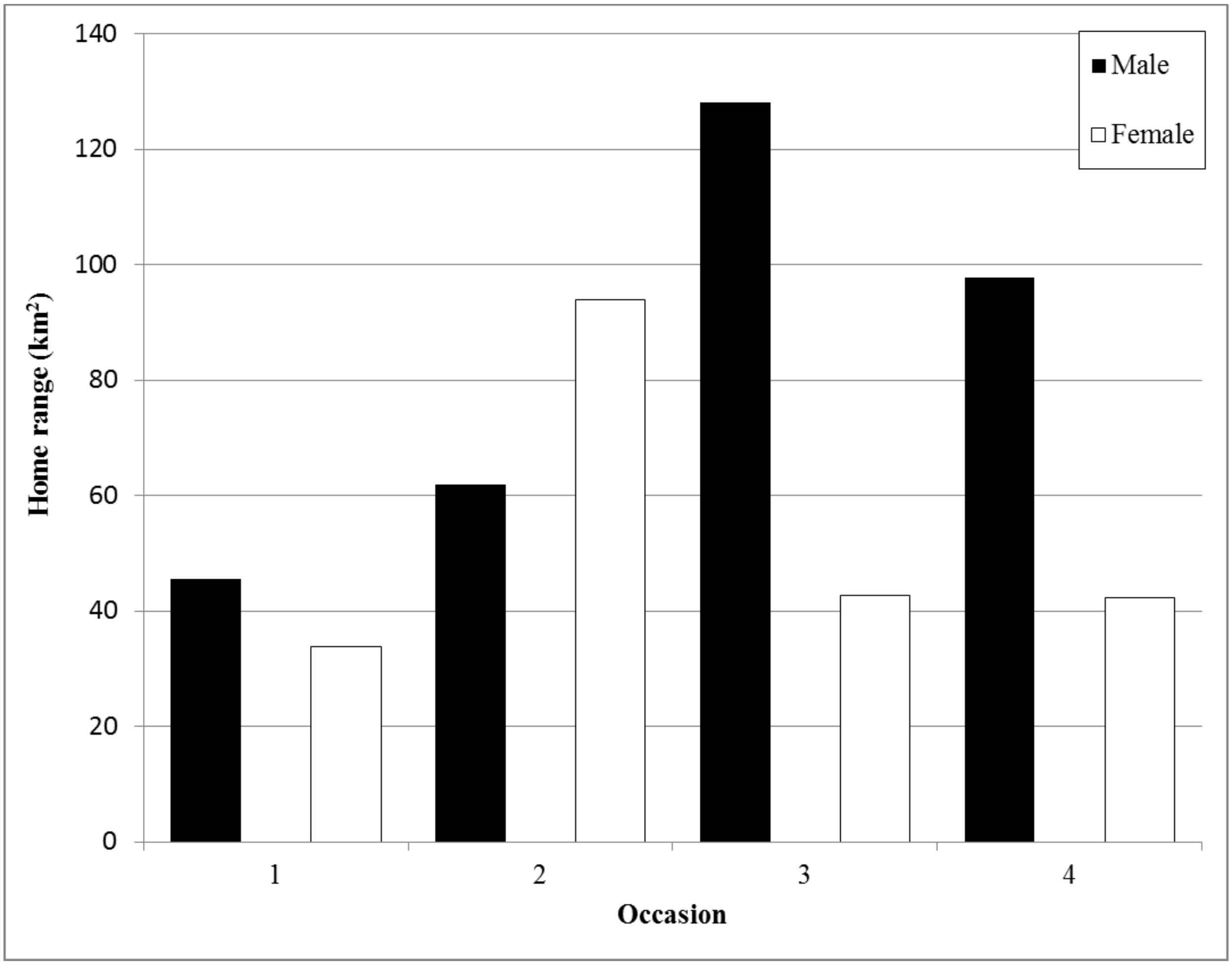

Figure 11. Mean home range size of male and female brown bears on the Yakutat forelands during 4 sampling occasions in late summer, 15 July–30 August, 2013.

NONINVASIVE DNA-BASED POPULATION ESTIMATION

Genetic Sampling

Between 15 July and 30 August 2013, we used 3 different types of hair traps to collect brown bear hair for DNA identification. We deployed 41 barbed-wire corrals, 518 hair snares, and affixed barbed wire to 6 natural scent marking rub trees. Detectors were distributed throughout the study area with corrals systematically spaced within the grids at a mean distance of 5,011.9 m between each corral. Rub trees were located 844.5 m apart and snares were spaced at 137.1 m intervals. We monitored detectors during four 9-day sampling occasions but weather and flight logistics altered our ability to check traps at exact intervals. The mean duration between trap checks varied by trap type with corrals checked at 9.0 ± 0.11 day intervals, snares checked every 9.48 ± 0.04 days, and rub trees checked at 9.54 ± 0.04 days. Therefore, we included day of trap check as a covariate in the density model to account for variation in trapping effort.

We collected 849 hair samples from the hair traps with 569 samples (67%) collected by hair snares, 269 hair samples (32%) detected at corrals, and 11 samples (1%) deposited at scent marking rub trees. Hair snares realized a 60% detection rate as 312 of 518 snares collected hair samples. Hair samples were collected at 36 of the corrals (88%) and 5 of the rub trees (83%). The number of hairs collected in each sample varied with 343 samples containing more than 10 hairs, 283 included 3–9 hairs, and 223 samples contained fewer than 3 hairs.

Within 5 miles of the village of Yakutat we monitored 155 detectors and collected 108 hair samples. Bears were regularly attracted to the unsecured and burning trash at the Yakutat landfill and we collected 45 hair samples from 21 snares deployed on trails leading to the landfill. During occasion 1 we collected 10 samples, 11 during occasion 2, 8 in occasion 3, and 16 samples were collected during the final occasion, indicating regular presence at the landfill.

Genetic Analysis

We submitted 849 hair samples for DNA extraction and the laboratory discarded 224 samples considered having a low probability of extraction or to be from non-bear species, such as wolf or moose. Extractions were performed on 625 samples (74%) and complete extractions were successful on 418 samples, yielding a 67% amplification rate. Brown bears were identified in 389 of the samples belonging to 152 unique individuals, with 1–10 detections per individual. The sex ratio of the hair samples collected was 215 females (55%) and 174 males, similar to the proportion of unique individuals identified; 85 females (56%) and 67 males. The remaining 29 hair samples were determined to be black bear (14F:15M), and were snagged from 22 unique individuals (10F:12M). The number of unique individuals identified varied by occasion with the greatest number of black bears detected in the first and fourth sampling occasion (Table 5).

Genotyping success of both brown and black bears from each detector type varied with 44% (4/9) amplification success at rub trees, 67% (283/425) of hair snare samples amplified, and 69% (131/191) from corrals. Successfully genotyped brown bear samples were collected from 195 hair snares (37%), 28 corrals (68%), and 2 scent marking rub trees (33%, Table 6). We collected 107 brown bear samples at the corrals and for the density estimate limited detections to those that were unique to the individual, occasion, and trap, totaling 60 samples. This included 49 unique individuals detected at the corrals and accounted for the recapture of 11 individuals (5F:6M). We collected 4 successfully genotyped rub tree samples and identified 2 unique males with one recapture each. We successfully genotyped 278 hair snare samples, in which we identified 127 unique individuals (72F:55M) and detected 151 recaptures. Twenty four individual bears were detected by multiple trap types and 2 bears were detected by all 3 trap types. The majority of bears (88) were recaptured 2–10 times, while 64 unique bears (40F:24M) were only detected a single time. The mean maximum distance traveled between traps for each individual was 5,629.6 m, and the mean distance between consecutive capture locations was 2,761.4 m.

Table 5. Total number of male and female black bears identified from DNA samples in the Yakutat study area during each sampling occasion, 15 July–30 August 2013.

Sex	Occasion			
	1	2	3	4
Male	5	1	1	8
Female	9	2	1	2
Unique individuals	10	3	2	8

Table 6. Number of unique brown bears and total number of samples successfully genotyped at each detector type.

Detector type	Unique males	Unique females	Total detectors	Detectors visited	Detector success	Brown bear samples
Corral	24	25	41	36	28	107
Hair snare	55	72	518	312	195	278
Rub tree	2	0	6	5	2	4

Near the village of Yakutat, we identified 45 brown bear samples within 5 miles of town representing 20 unique individuals (11F:9M) (Fig. 12). Five of the animals identified were bears previously marked with a radiocollar. In this area brown bears were detected at 33 hair snares and 2 corrals. From the samples collected at the Yakutat landfill, 23 were successfully genotyped and we identified a minimum of 10 individual bears (6M:4F) that visited the landfill, including 1 bear (M704) previously marked with a radiocollar.

Brown bears were identified during each occasion with varying detection rates. Table 7 details the detection rates of individuals detected at all detector types during the 4 occasions. More than 60 bears were identified in each of the first 3 occasions and the number of new unique animals decreased throughout the sampling period. The greatest number of unique individuals detected at corrals occurred during occasion 2, while a similar number of bears were detected during the other occasions (Table 8). Detections of bears at hair snares declined during the study with the greatest number of individuals detected during the first occasion, reflecting a shift in bear use of seasonal resources. Rub tree detections were few with 2 individuals detected during both the second and third occasions. Detections of brown bears within 5 miles of Yakutat remained fairly constant during the study with 9 individuals identified during occasion 1, 6 in occasion 2, 10 in occasion 3, and 7 individuals detected in occasion 4.

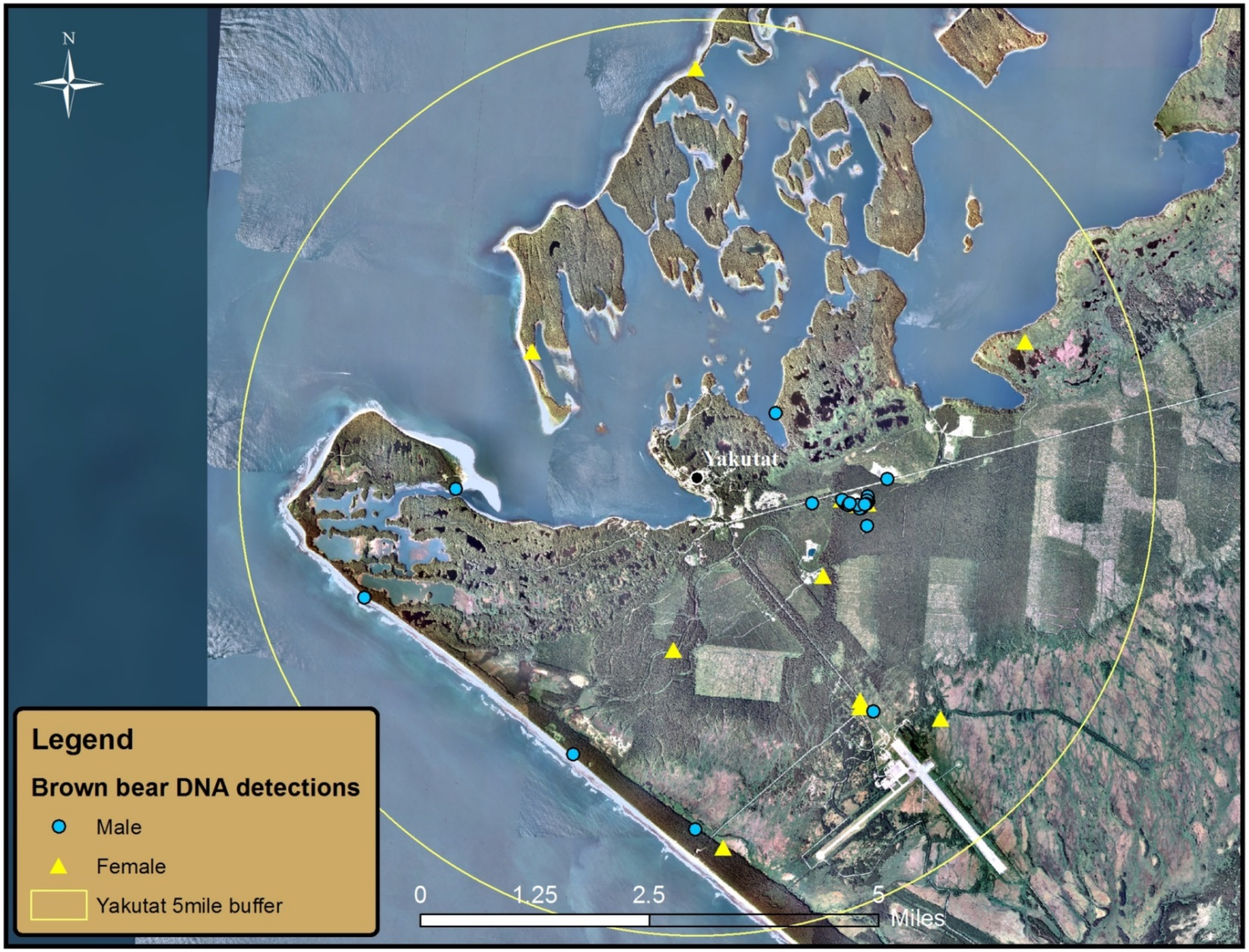

Figure 12. DNA detections of male and female brown bears (15 July–30 August 2013) near the village of Yakutat, Alaska.

Table 7. Noninvasive DNA-based detection rates from capture histories collected from 15 July–30 August 2013, in Yakutat, Alaska.

	Occasion				Total	Mean ± SD
	1	2	3	4		
Animals detected	62	61	63	49	235	58.8 ± 6.6
Unique animals detected	62	41	34	15	152	38.0 ± 19.4
Repeat detection frequency	95	37	14	6	152	38.0 ± 40.2
Cumulative detections	62	103	137	152	152	
Total detections	100	91	85	62	338	84.5 ± 16.2
Detectors visited	93	83	80	57	313	78.3 ± 15.2
Mean occasion length (days)	9.8	9.2	9.2	9.5		9.45 ± 0.04

Table 8. Total number of brown bears identified from DNA samples in the Yakutat study area during each sampling occasion, 15 July–30 August 2013, by detector type.

	Occasion			
Detector type	1	2	3	4
Corral	24	38	23	22
Hair snare	89	70	72	47
Rub tree	0	2	2	0

Trap Encounters

We mapped bear locations during each sampling occasion to visualize the general pattern of bear movement relative to the location of detectors (Fig. 9). GPS location data within 250 m of detectors showed 24 radiocollared bears encountered corrals and 23 bears in proximity to hair snares. Brown bear distribution shifted over the duration of the study. During the first sampling occasion many bears were concentrated near the shoreline and were observed foraging on herbaceous vegetation and coastal strawberries. Brown bears were also attracted to concentrations of forage fishes near the mouth of the Ahrnklin River and stranded fish along the beach. Telemetered bears were located within 100 m of 4 corrals during the first occasion, 6 corrals in occasion 2, 5 corrals during occasion 3, and 3 corrals in occasion 4. The detection rates of GPS collared bears during each occasion were similar to the frequency of bears identified at corrals by DNA. Salmon were abundant in anadromous streams by occasion 4 and bears gathered along these rivers to maximize lipid intake.

Prior to the beginning of the DNA sampling period, 47 of the 79 marked brown bears were known to be alive and 18 were known to have died. Through DNA sampling we detected 31 of the 47 (66%) known alive marked bears during the survey. We monitored 28 brown bears with GPS radio collars during the population estimate and our DNA sampling methods successfully detected 16 (57%) of these animals at the hair traps. We identified half of the instrumented females (7 of 14), including 1 sub-adult female, 3 of 7 adult single females, 1 female with cubs of the year, 2 of 4 females with yearlings, and 1 female with 2 year old cubs was not detected. We detected DNA from 9 of 14 (64%) radiocollared males, with similar proportions of sub-adult (3/5) and adult (6/9) males being detected. The proportion of collared individuals detected, 50% of females and 64% of males, was similar to the proportion of the estimated population sampled (58%, 152/260).

Population Density and Abundance Estimates

We used capture history data from 152 unique individual brown bears, identified from 338 samples collected at 565 hair sampling traps, to estimate brown bear density and abundance in the study area near Yakutat, Alaska. Using SECR models that incorporated telemetry data, we estimated the density of the population as 98.8 ± 8.2 bears/1,000 km^2, 95% CI [84.1–116.2], and a density coefficient of variation (CV_D) of 0.08. Table 9 summarizes model selection results based on AIC_c for the top models including telemetry data. The top supported telemetry model accounted for all of the weight of evidence and both the baseline detection probability parameter (g_0) and the spatial range parameter (σ) included 4 covariates: day of year; site specific trap behavior; trap type; and sex. Three covariates significantly influenced the g_0 parameter: day of year, trap type, and sex (Table 10). The coefficient for day of year was negative, suggesting that g_0 decreased over time. Trap type and sex were also significant factors on the σ parameter. In the top model sex effects were added to both g_0 and σ parameters while a similar model without sex effects (Table 11) found σ was influenced by a behavioral effect and day of year, indicating that the variation in the movement range parameter was accounted for by sex in the final model.

Across all of the top ranking models we found that density and precision were very similar in magnitude. Some models with less support included an interaction between behavior and sex, or σ parameter simply including trap type. The density estimate of the model with an interaction between behavior and sex was higher but variance and precision slightly decreased and the model had less support in terms of AIC_c, showing that sex effects were important. The null model (the model without any covariates on g_0 or σ) and other competing models that included only individual covariates such as behavior, trap type, or sex were not supported, reflecting that multiple effects best explained the density of brown bears in this study area.

We generated 2 estimates of population size ($\hat{N}$) for the highest ranked telemetry model, the realized $\hat{N}$ and the expected $\hat{N}$. The realized $\hat{N}$ combines the number of bears detected in the study area plus a model-based estimate of the number of bears that were not detected within the study area. The realized population estimate was 241.6 ± 14.2 bears, 95% CI [218.4–274.8]. When spatial process variance is included across a homogeneous density surface we estimated expected $\hat{N}$ as the volume under the density surface. The expected $\hat{N}$ was 260.1 ± 21.5 bears,

Table 9. Model selection results for the spatially-explicit capture–recapture (SECR) hybrid mixture models incorporating GPS telemetry data for brown bear population density and abundance estimates in 2013 within a study area near Yakutat, Alaska, USA. Density values are presented ± SE (95% CI).

Model	Model parameter specifications[a]	AIC_c	ΔAIC_c	AIC_{cwt}	Density (bears/1,000 km^2)	CV_D	Expected $\hat{N}$
1	g_0~cdoy+bk+trapType+sex, σ~cdoy+bk+trapType+sex	4171.1	0	1.0	98.8 ± 8.2 (84.1, 116.2)	0.083	260.1 ± 21.5 (221.2, 305.7)
2	g_0~cdoy+bk×sex+trapType σ~ cdoy+bk×sex+trapType	4196.4	25.3	0.0	102.0 ± 8.6 (86.5, 120.3)	0.084	268.4 ± 22.6 (227.5, 316.5)
3	g_0~cdoy+bk+trapType, σ~cdoy+bk+trapType	4242.4	71.3	0.0	96.0 ± 7.8 (81.8, 112.6)	0.081	252.6 ± 20.6 (215.4, 296.2)
4	g_0~cdoy+bk+trapType, σ~trapType	4292.8	121.7	0.0	95.9 ± 7.8 (81.7, 112.6)	0.082	252.4 ± 20.7 (215.1, 296.2)

[a] An explanation of the symbols used for g_0 and σ: cdoy = Julian day centered and standardized to mean occasion check date; bk = animal × site behavioral response, site-specific step change; trapType = detector type including corrals, rub trees, or hair snares, sex = male or female.

Table 10. Brown bear population density and abundance model parameters including sex and GPS telemetry data in spatially-explicit capture–recapture (SECR) hybrid mixture model within a study area near Yakutat, Alaska, USA.

Model parameter	β	β SE	95% CI	CV
g_0	-4.104	0.220	(-4.534, -3.673)	0.054
g_0.cdoy	-0.248	0.101	(-0.446, -0.050)	0.407
g_0.bkTRUE	-0.006	0.290	(-0.573, 0.561)	48.333
g_0.trapType-rubtree	0.091	0.910	(-1.692, 1.874)	10.000
g_0.trapType-snare	-2.470	0.211	(-2.883, -2.057)	0.085
g_0.h2M	-0.915	0.179	(-1.266, -0.565)	0.196
σ	7.833	0.097	(7.692, 8.073)	0.012
σ.cdoy	0.090	0.047	(-0.002, 0.182)	0.522
σ.bkTRUE	3.572	5.136	(-6.495, 13.638)	1.438
σ.trapType-rubtree	-0.325	0.273	(-0.860, 0.210)	0.840
σ.trapType-snare	0.568	0.098	(0.377, 0.759)	0.173
σ.h2M	0.698	0.081	(0.539, 0.857)	0.116
Sex ratio	-0.553	0.181	(-0.908, -0.199)	0.327
Density	98.814	8.166	(84.060, 116.157)	0.083
Expected $\hat{N}$	260.078	21.494	(221.246, 305.725)	0.083
Realized $\hat{N}$	241.612	14.210	(218.371, 274.788)	0.059

Table 11. Brown bear population density and abundance model parameters without sex parameter (model 3) and including GPS telemetry data in spatially-explicit capture–recapture (SECR) hybrid mixture model within a study area near Yakutat, Alaska, USA.

Model parameter	β	β SE	95% CI	CV
g_0	-5.209	0.189	(-5.579, -4.838)	0.036
g_0.cdoy	-0.448	0.099	(-0.643, -0.253)	0.222
g_0.bkTRUE	0.349	0.297	(-0.233, 0.931)	0.851
g_0.trapType-rubtree	-1.203	0.777	(-2.727, 0.320)	0.646
g_0.trapType-snare	-1.852	0.216	(-2.277, -1.428)	0.117
σ	8.540	0.087	(8.369, 8.710)	0.010
σ.cdoy	0.187	0.045	(0.098, 0.276)	0.243
σ.bkTRUE	1.432	0.447	(0.556, 2.308)	0.312
σ.trapType-rubtree	-0.026	0.265	(-0.545, 0.493)	10.322
σ.trapType-snare	0.267	0.104	(0.064, 0.470)	0.388
Sex ratio	-0.369	0.174	(-0.709, -0.028)	0.471
Density	95.977	7.815	(81.841, 112.554)	0.081
Expected $\hat{N}$	252.611	20.569	(215.406, 296.242)	0.081
Realized $\hat{N}$	262.194	13.056	(239.753, 291.282)	0.050

95% CI [221.2–305.7](Table 9). Based on the model from the top telemetry model, we estimated the sex composition of the population as 165 female bears, 95% CI [122–218] and 95 male bears, 95% CI [73–151].

We predicted the population size for all of GMU 5A using the expected $\hat{N}$ for the study area combined with the expected density of the remaining available bear habitat in GMU 5A (1,133 km^2)(Fig. 13) for a total of 353.8 ± 29.2 bears, 95% CI [300.9–415.8](Table 12). We estimated the sex composition of the entire population in GMU 5A as 225 female bears, 95% CI [165–296] and 129 male bears, 95% CI [99–205].

In comparing top models with and without telemetry data, we found the range of density and abundance estimates to be fairly similar, though telemetry models realized greater predictive precision (Table 13). Non-telemetry models resulted in slightly higher estimates of density and abundance though at the cost of lower precision. Parameter estimates from the top non-telemetry model showed that day of year, site-specific behavior, trap type and sex influenced g_0 while both trap type and sex contributed to σ (Table 14). The addition of telemetry space-use data in the model showed that both male and female σ substantially increased, indicating that both sexes ranged further than was detected with non-telemetry models. We found that telemetry models improved our precision of baseline detection probability and male bear g_0 was significantly lower than females at all trap types. In both telemetry and non-telemetry models, the baseline detection probability for hair snares was significantly lower than for both corrals and rubtrees (Fig. 14).

Detection probability for hair snares was based on individual animals, at each trap, on each day, and we expected a lower g_0 for snare detectors due to: their passive nature, which was not designed to attract animals to the detector; their small detection radius; and the limited surface area of the detector (e.g., 3 hair collection barbs on snares vs. 40 m of barbed wire at corrals). The addition of telemetry data decreased the probability of detection at distances closer to the corral and rubtree trap types, though extended detection probability farther from both male and female activity centers. In both telemetry and non-telemetry models, female and male g_0 for hair snares decreased similarly as distance between the trap and bear's activity center increased. As expected from home range analyses, male σ was greater than that for females and detection probability was lower for all trap types in both models (Tables 15 and 16).

To evaluate the effect of hair snares, we modeled density and abundance using only encounter history data from traditionally-used detectors: corrals and rub trees. Overall, this comparison resulted in fewer captures and recaptures (60 captures, 49 unique) when hair snare capture histories were eliminated. We also only detected 1/3 of the unique individuals, and detected a higher proportion of male bears using traditional detectors, showing hair snares proved to be a

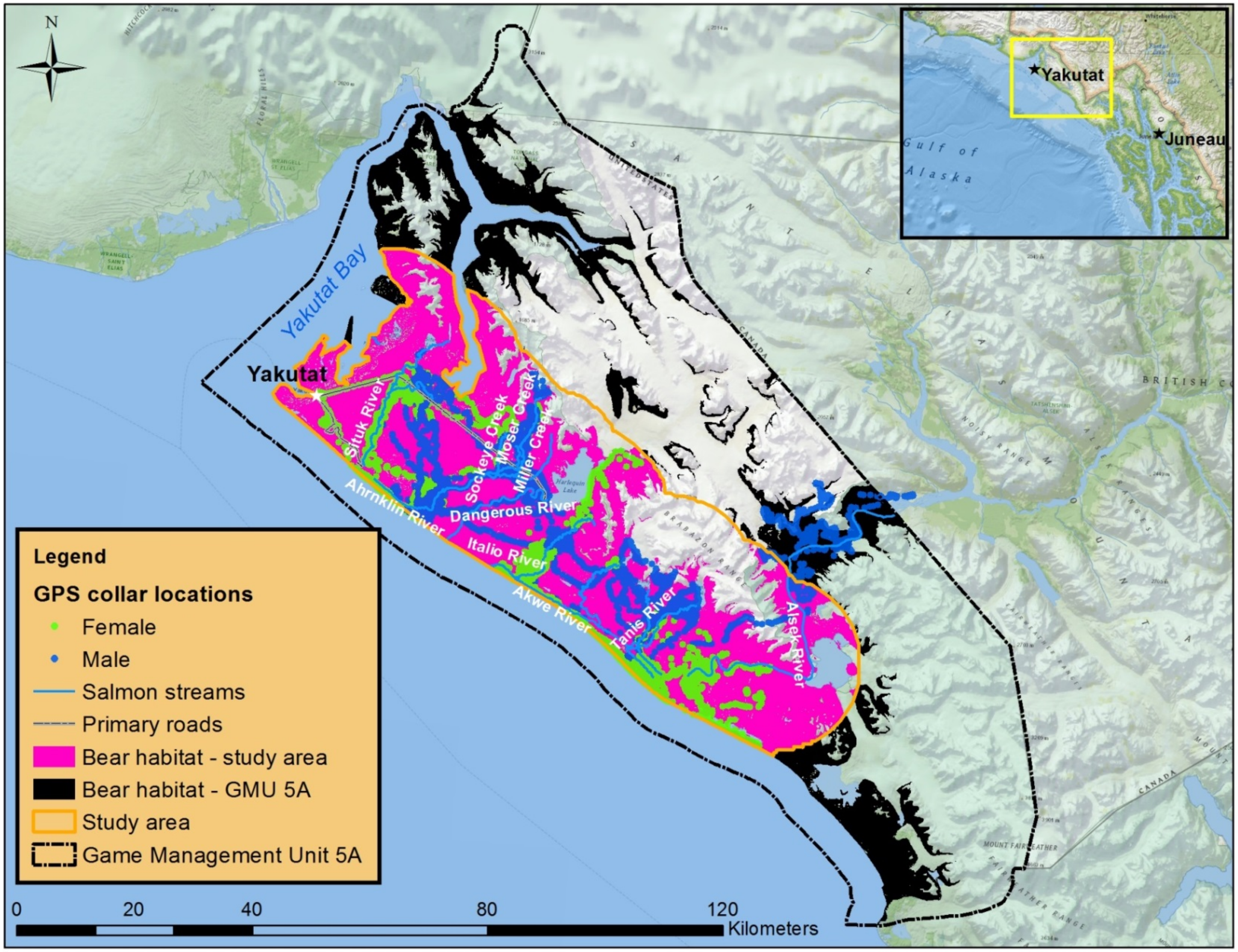

Figure 13. Brown bear habitat and GPS collar locations in the study area and remainder of GMU 5A near Yakutat, Alaska.

Table 12. The top models of predicted brown bear population estimates in 2013 from the most parsimonious models including telemetry data for the Yakutat forelands and Game Management Unit (GMU) 5A. Values are presented ± SE (95% CI).

Model	Model parameter specifications[a]	Expected $\hat{N}$	
		Yakutat Forelands	GMU 5A
1	g0~cdoy+bk+ trapType+sex, σ~cdoy+bk+trapType+sex	260.1 ± 21.5 (221.2, 305.7)	353.8 ± 29.2 (300.9, 415.8)
2	g_0~cdoy+bk×sex+trapType, σ~ cdoy+bk×sex+trapType	268.4 ± 22.6 (227.5, 316.5)	365.0 ± 30.8 (309.5, 430.5)
3	g0~cdoy+bk+ trapType, σ~cdoy+bk+trapType	252.6 ± 20.6 (215.4, 296.2)	343.6 ± 28.0 (293.0, 402.9)
4	g0~cdoy+bk+ trapType,σ~ trapType	252.4 ± 20.7 (215.1, 296.2)	343.3 ± 28.1 (292.5, 402.9)

[a] An explanation of the symbols used for g_0 and σ: cdoy = Julian day centered and standardized to mean occasion check date; bk = animal × site behavioral response, site-specific step change; trapType = detector type including corrals, rub trees, or hair snares; sex = male or female.

Table 13. Model selection results for the non-telemetry spatially-explicit capture–recapture (SECR) hybrid mixture models for brown bear population density and abundance estimates in 2013 within a study area near Yakutat, Alaska, USA. Density values are presented ± SE (95% CI).

Model	Model parameter specifications[a]	AIC_c	ΔAIC_c	AIC_{cwt}	Density (bears/1,000 km^2)	CV_D	Expected $\hat{N}$
1	g_0~cdoy+bk×trapType +sex σ~ trapType+sex	3936.7	0	1.000	103.2 ± 9.4 (86.3, 123.3)	0.091	271.6 ± 24.7 (227.3, 324.5)
2	g_0~cdoy+bk×trapType, σ~ trapType	3970.9	34.2	0	100.8 ± 9.2 (84.3, 120.4)	0.091	238.2 ± 17.8 (209.7, 280.7)
3	g_0~cdoy+bk+trapType, σ~ trapType	3975.2	38.5	0	104.8 ± 9.8 (87.4, 125.7)	0.093	243.4 ± 19.6 (212.4, 290.5)
4	g_0~1 σ~1	4199.6	262.9	0	105.7 ± 9.2 (89.1, 125.4)	0.087	278.2 ± 24.3 (234.5, 330.1)

[a] An explanation of the symbols used for g_0 and σ: cdoy = Julian day centered and standardized to mean occasion check date; bk = animal × site behavioral response, site-specific step change; trapType = detector type including corrals, rub trees, or hair snares.

Table 14. Brown bear population density and abundance non-telemetry model parameters from the top spatially-explicit capture–recapture (SECR) hybrid mixture model within a study area near Yakutat, Alaska, USA.

	β	*β SE*	95% CI	CV
g_0	-2.243	0.223	(-2.680, -1.807)	0.099
g_0.cdoy	-0.346	0.079	(-0.501, -0.191)	0.228
g_0.bkTRUE	-1.684	0.431	(-2.529, -0.838)	0.256
g_0.trapType-rubtree	-0.304	0.805	(-1.881, 1.273)	2.648
g_0.trapType-snare	-4.354	0.236	(-4.817, -3.891)	0.054
g_0.h2M	-0.742	0.176	(-1.087, -0.396)	0.237
g_0.bkTRUE:trapType-rubtree	-0.728	3.841	(-8.256, 6.800)	5.276
g_0.bkTRUE:trapType-snare	2.436	0.580	(1.298, 3.573)	0.238
σ	7.089	0.084	(6.924, 7.255)	0.012
σ.trapType-rubtree	-0.567	0.279	(-1.113, -0.020)	0.492
σ.trapType-snare	1.410	0.089	(1.236, 1.583)	0.063
σ.h2M	0.469	0.081	(0.310, 0.627)	0.173
Sex ratio	-0.495	0.171	(-0.830, -0.159)	0.345
Density	103.175	9.395	(86.343, 123.289)	0.091
Expected $\hat{N}$	271.557	24.728	(227.254, 324.497)	0.091
Realized $\hat{N}$	227.802	18.436	(199.382, 273.266)	0.081

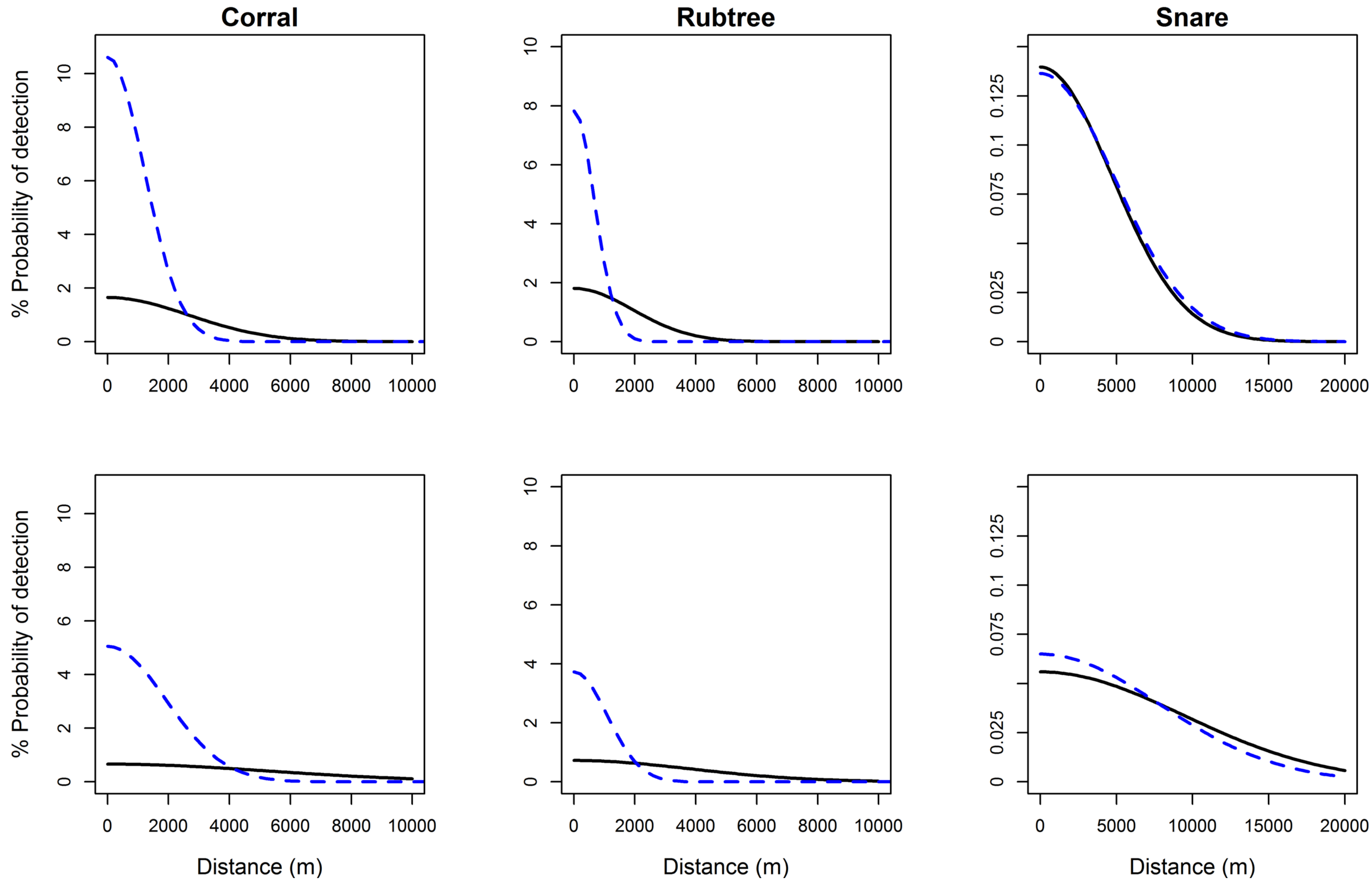

Figure 14. Half-normal detection function for naïve female (top row) and male (bottom row) brown bears for the three trap types (corrals, rubtrees, and snares). Y-axis shows the baseline percent probability of detection (100 × g_0) and x-axis is the distance in meters between the trap and the bear's center of activity (home range center). Dashed lines represent the top non-telemetry model and solid lines reflect the top ranked telemetry model.

Table 15. Parameter estimates from top-ranked SECR model including telemetry data.

Naïve Females	$g_0 \pm$ SE (95% CI)	$\sigma \pm$ SE (95% CI)
Corral	0.0230 ± 0.0054 (0.0146, 0.0361)	2351.9 ± 221.8 (1955.7, 2828.3)
Rubtree	0.0252 ± 0.0290 (0.0041, 0.1527)	1699.4 ± 480.4 (986.9, 2926.4)
Snare	0.0019 ± 0.0003 (0.0014, 0.0027)	4150.1 ± 322.3 (3565.0, 4831.3)
Naïve Males		
Corral	0.0092 ± 0.0019 (0.0061, 0.0138)	4726.3 ± 413.3 (3983.2, 5608.0)
Rubtree	0.0101 ± 0.0110 (0.0018, 0.0570)	3415.1 ± 893.3 (2062.7, 5654.3)
Snare	0.0008 ± 0.0001(0.0005, 0.0011)	8339.9 ± 802.2 (6909.9, 10065.9)

Table 16. Parameter estimates from top-ranked non-telemetry SECR model.

Naïve Females	$g_0 \pm$ SE (95% CI)	$\sigma \pm$ SE (95% CI)
Corral	0.1681 ± 0.0425 (0.1032, 0.2737)	1198.9 ± 101.3 (1016.2, 1414.6)
Rubtree	0.1240 ± 0.1171 (0.0259, 0.5930)	680.2 ± 195.0 (392.1, 1179.9)
Snare	0.0022 ± 0.0003 (0.0016, 0.0029)	4909.0 ± 287.7 (4376.8, 5505.9)
Naïve Males		
Corral	0.0801 ± 0.0197 (0.0498, 0.1286)	1915.9 ± 142.0 (1657.4, 2214.9)
Rubtree	0.0591 ± 0.0538 (0.0129, 0.2710)	1086.9 ± 301.3 (637.7, 1852.6)
Snare	0.0010 ± 0.0002 (0.0008, 0.0014)	7844.5 ± 573.0 (6799.4, 9050.3)

less biased detector of females. If we had only deployed traditional detectors, density, precision, and abundance would all have substantially decreased totaling 41.2 ± 5.3 bears/1,000 km^2, 95% CI [31–52], CV_D =0.13, and expected $\hat{N}$ of 124.0 ± 9.4 bears, 95% CI [108.3–145.6].

Apparent Harvest Rate

During regulatory year (RY) 2012 (1 July 2012–30 June 2013), 27 brown bears died (16 males and 11 females), and were sealed in GMU 5A by ADF&G. Hunter harvest accounted for 19 of the bears killed with nonresident guided hunters taking 6 male and 3 female bears and resident hunters harvesting 6 male and 4 female brown bears. In RY 2012 the number of bears sealed (27) and the proportion of female bears harvested (37%) were similar to long term averages in GMU 5A (1991–2014 mean bear mortality 26.3, proportion females 32.4%, mortality source: DLP 10%, Illegal 1%, Natural/Unknown 3%, Guided 62%, Resident 24%).

Apparent harvest rate for GMU 5A was determined from the number of animals harvested in RY 2012 and the number of bears available after the fall 2012 and spring 2013 hunting seasons. The apparent harvest rate in 2013 was calculated as 19 harvested bears divided by the total population estimate of 354 bears in GMU 5A, yielding an estimated harvest rate of 5.4%, 95% CI [3.3–8.3]. Total mortality rate in RY 2012 for GMU 5A was 7.6%, 95% CI [5.1–10.9].

Discussion

Population Estimate Using Noninvasive DNA-based Methods

Through this study, we produced precise estimates of brown bear population size and density using multiple detector types and auxiliary telemetry data. Using SECR methods, we were able to provide the first reliable estimate of brown bear density along the northern SEAK mainland coast (98.8 bears/1,000 km^2). Brown bear density in this region was similar to bear densities found along the central mainland coast of SEAK (Flynn 2012, 103 bears/1,000 km^2 bear habitat) and southcentral Alaska coastal populations near Katmai and Lake Clark National Parks (Olson and Putera 2007, 150 bears/1,000 km^2), substantially greater than interior bear densities (Miller et al. 1997, 10–29 bears/1,000 km^2), and significantly less than SEAK island populations (Miller et al. 1997, 399 bears/1,000 km^2). The lower brown bear densities found along the SEAK mainland coast could be explained by differences in sampling techniques, decreased habitat quality, larger home range size, reproductive ages, smaller litter sizes, shorter life spans, higher harvest rates, or decreased survival. Regardless of the mechanism that regulates lower population densities, it is important to recognize the differences in management priorities and population demographics when devising harvest strategies (Van Daele 2007).

The top model combined telemetry data with detection data and contained a site-specific behavior term (bk), day of year, and trap type in the baseline detection probability (g_0) and range parameters (σ). Day of year was an important covariate on g_0, as it accounted for asynchronous trap checks, and the negative coefficient suggests that detection decreased over time, possibly due to the seasonal shift in animal distribution. The trap type covariate contributed to both g_0 and σ resulting in decreased detection rates and increased detection range for specific trap types.

We extended the SECR model by incorporating telemetry data, which improved the model parameter estimates associated with movement and increased the precision of the density estimate. The results of this study confirm that the addition of telemetry data to the density model can improve the model parameters (Ivan et al. 2013, Sollmann et al. 2013). We found that incorporating telemetry data increased the precision of detection probability and substantially increased the female range parameter, σ. Telemetry data, in the form of high resolution GPS locations, offered independent information on a small portion of the population (10%) that otherwise may not have been detected through noninvasive sampling, as evidenced by the DNA detection rate of 57% of the telemetry equipped bears. We also found that while density decreased from 103.2 to 98.8 bears per 1,000 km^2 between non-telemetry and telemetry models, abundance precision increased. While there are several benefits of incorporating telemetry data in both baseline detection probability and range parameter estimates, it also improves our understanding of animal movement behavior and confirms that the animals collared were representative of the population encountering the detector array. For both male and female brown bears σ was significantly different for all 3 trap type detectors and was highest for snares, but the difference was greater for the top model that included telemetry. We recommend that future bear density studies consider marking animals with GPS radiocollars, and incorporating those telemetry data in a unified SECR modeling framework (Fig. 15).

Figure 15. Photograph of a 3-year-old female brown bear equipped with a GPS radiocollar and biologist Anthony Crupi. GPS telemetry data from 28 bears greatly improved parameter estimates of the SECR model used to estimate the density and abundance of the population near Yakutat, Alaska.

Similar to many conventional mark–recapture estimates, SECR models need to meet assumptions such as population closure, correct identification of individuals, retention of marks on animals, animal home ranges with an activity center, detection probability as a function of the distance between that activity center and the trap, and spatially accurate trap locations. Another important assumption of non-spatial mark–recapture models is that all individuals have an equal probability of detection (Otis et al. 1978); however, previous studies to estimate bear density have investigated heterogeneous detection probabilities (Boulanger et al. 2004b), and have shown a bias against detecting females with cubs of the year (Miller et al. 1987, Ballard et al.

1990, Miller and Sellers 1992). Our DNA sampling methods successfully detected female bears, as evidenced by the number and proportion of collared females identified, as well as the unbiased detection of females with single-catch hair snares compared to those detected at corrals and rub trees. Other studies have indicated varying sex-specific capture probabilities with detection biased towards males (Obbard et al. 2010, Morton et al. 2016). Potential explanations for this bias may be a behavioral response to trap investigation with females being more wary, or males may simply be exposed to more corrals as a function of their larger home range size (Boulanger et al. 2004b). We did not detect females at rub tree detectors, as female capture probability at rub trees has been shown to be low unless sampling extends into the autumn (Boulanger et al. 2008, Kendall et al. 2008, 2009). Increased sampling of females in the fall is not necessarily a shift in behavioral strategy as much as increased occurrence in the area sampled (Clapham et al. 2012). SECR models can explicitly account for heterogeneous detection probabilities among individuals that may be due to, for example, sex- or age-based behavioral differences among individuals, or due to the spatial distribution of animals in relation to the hair traps.

Reliable population density estimates are dependent upon both geographic and demographic population closure. Conventional mark–recapture studies assume geographic closure when estimating population size, and density is derived for an effective trapping area that is somewhat arbitrarily defined through various ad hoc approaches. To deal with population closure and edge effects of animals associated with home range boundaries extending beyond the study area, methods have been developed to incorporate the proportion of time telemetered animals spend in the study area (Ivan et al. 2013). In this study, brown bears tend to occupy stable home ranges in late summer, and the majority of the study area is geographically closed as evidenced from our GPS telemetry dataset (Crupi, unpublished data) and regional population structure analysis (Flynn et al. 2012), suggesting that the ocean, mountains, and glaciers surrounding GMU 5A limit the immigration/emigration of brown bears to or from the area. Although 1 animal's late summer foray briefly extended beyond the border of the study area, he returned to the trapping grid and foraged near his activity center. To meet the assumption of demographic closure we conducted the study during a short 6 week period in late summer, prior to the onset of the harvest season. In late summer, bears generally have high survival, and in 2013 no mortalities were reported during the study period.

BEAR DENSITY ESTIMATES USING MULTIPLE DETECTOR TYPES

The inclusion of multiple simultaneous sampling techniques has recently been suggested to improve model parameter estimates (Boulanger et al. 2008, Kendall et al. 2008, Gervasi et al. 2012, Sawaya et al. 2012). The use of hair snares in combination with corrals and rub trees proved to be a very important addition to the design of this study. First, single catch devices take 1 sample, eliminating the potential for mixed samples from multiple individuals and the need for samples to be screened and discarded. Second, hair snares limit trap avoidance behaviors and sex biases as these traps were set along bear trails that led to natural attractants (i.e., spawning salmon and coastal strawberries), and likely go undetected as the bear transits the trail. Third, we compared our top model to a model just using capture histories from corrals and rub trees and found that we detected 2.5 times as many individuals and a greater proportion of females by incorporating hair snares as sampling detectors. Simply deploying traditional corrals and rub tree sampling devices would have resulted in fewer captures and recaptures, decreased the estimated density and abundance by more than half, and reduced precision. Lastly, genotyping success of hair samples collected at hair snares was similar to corrals (67% vs. 69%) providing further evidence for the inclusion of hair snare detectors to benefit traditional study designs.

To improve rub tree detection rates, we could have increased the number of rub trees sampled, though despite the several kilometers of hair snare line that we monitored each day, we did not encounter additional scent marking rub trees. There were likely other available rub trees to sample, although a substantial amount of time would have been required to conduct trail transects to find an adequate number of trees to sample and the time to check highly-dispersed sampling stations would likely hamper efficiency. Seasonal differences in rubbing rates for male and female bears have shown that females are more likely to be detected in the fall season than in the spring, and in some cases this is a result of seasonal presence rather than a distinct communication strategy (Kendall et al. 2016, Kendall et al. 2009, Clapham et al. 2012). As well, rub trees have been shown to have lower capture probabilities than corrals (Boulanger et al. 2008).

It has been reported that female bears, particularly females with offspring may be more reluctant to investigate corrals than males (Ebert et al. 2010). The use of hair snares tends to be a more passive approach to sample collection than corrals as they encounter the snare while traversing a trail. It is possible that the animals see or smell the snares, but photos and videos from remote cameras indicate that bears approaching hair snares only pause briefly before continuing through the hair snare and leaving a sample. However, hair snares may have limited utility in study areas with minimal bear trails and dispersed food sources, as well as in habitats that do not have suitable vegetation on which to set these types of detectors. Other examples of passive detections of bears for density estimation have been through fecal sampling (Wasser et al. 2004) or through swab sampling of bear saliva from captured salmon carcasses (Wheat et al. 2016). Wasser et al. (2004) detected a larger portion of the population through fecal sampling than hair sampling, as baited hair corrals only identified 46% of the individuals identified by scats, a slightly higher proportion of individuals than identified by corrals (32%) in this study. Wheat et al. (2016) found swab sampling of saliva to have higher genotyping success (55%) than scat samples (34%). As sampling biases may influence the detection of various age and sex cohorts, it will be beneficial to minimize obvious sampling biases and employ multiple sampling strategies to detect a broader spectrum of individuals.

Understanding detectability is important to making sound sampling design decisions, including when, where, and how to sample. Our evaluation of detector types and optimal trap spacing will assist the department and other researchers in designing future study plans that maximize parameter estimate precision and ultimately minimize associated costs. Sun et al. (2014) found that parameter precision and accuracy were improved by increasing the number of traps per cluster, which improved detection rates. They also recommended spacing traps relative to the spatial scale parameter at a distance $\leq 2\sigma$. Sollmann et al. (2012) also advised spacing traps less than 2σ. Sun et al. (2014) also suggested that 2 traps be placed within an individual's home range while the often-cited Otis et al. (1978) recommended setting 4 traps per home range. In this study, most grid cells had multiple detectors and while our trap spacing varied by detector type, the mean trap spacing between all detector types (285 m) was less than twice σ (5,301.5 m), resulting in precise detection probabilities. After investigating the 21 GPS collared bears' movements and home ranges occupied during the study period, we calculated a mean of 60.7 ± 8.5 hair sampling traps per home range. Each animal had the opportunity to encounter corrals within its home range with a mean of 3.9 ± 0.6 corrals per home range. Hair snares accounted for the majority of hair traps, averaging 56.3 ± 8.0 snares within each home range. The number of detectors present within each home range clearly exceeds the recommended minimum number of traps, yet when we estimate the density with just the capture history data from corrals, which were adequately spaced (5,011.9 m vs. recommended 5,301.5 m), we were unable to adequately estimate the density and abundance.

Brown Bear Population Abundance, Harvest, and Management

In 1993, Miller reported a population of 522 ± 130.5 brown bears in GMU 5A and we estimated abundance at 354 ± 29.2 bears. The current population estimate appears to suggest a decline in the bear population in GMU 5A, however, we caution that this interpretation is unjustified. Miller acknowledged that density was not directly estimated in GMU 5A, instead an informed guess was interpolated and extrapolated from density estimates generated for other regions in the state and bounded by 25% to establish the minimum and maximum estimate. Density in GMU 5A was considered high (>175 bears/1,000 km^2) while all other brown bear populations along the mainland coast of SEAK were considered intermediate density. At the time, the population status was reported to be steady to declining. Miller identified the need for bear population estimates to be refined when additional information became available. Given the uncertainty in the method used to produce the previous estimate, it is difficult to conclude that a lower estimate in 2013 equates to a reduction in population size. Since the population trajectory is unknown, it is impossible to attribute any change in abundance to a particular cause, such as overharvest, unreported human-caused mortality, reduced survival, declining reproductive rates, limited recruitment, habitat fragmentation, or apparent changes in climate, habitat, or food resources. Brown bear density in GMU 5A and other coastal mainland habitats in SEAK with similar landscape and population characteristics should be considered intermediate (40–175 bears/1,000 km^2) density populations.

Effective brown bear management relies on accurate estimates of abundance. Brown bear population abundance, demographic parameters, and limitations on population growth have been reported for other areas (Miller 1990b, Schwartz et al. 2006, Harris et al. 2011, Proctor et al. 2010) and these factors should be considered in SEAK. It is important to recognize that even the best attempt from ADF&G to maintain a 4% harvest guideline level could result in significant declines if the estimated population size is inaccurate. For example, the current harvest guideline level of an estimated 522 bears has been 21 bears/year, but given a population size of 354 brown bears, the harvest guideline level should consider being revised to 14 bears/year. Brown bear mortality in GMU 5A represents 12% of the total mortality in the SEAK region (GMUs 1–5). For the period 1990–2014, the 25-year mean annual mortality level in GMU 5A was 26.3 bears, ranging from 19–37 bears, with an average of 8.5 females (32%), a mortality level that could significantly exceed the sustainable harvest guideline and result in a downward population trajectory (Appendix C). Since the inception of this research project (RY 2009–2014), 139 brown bears have been sealed in GMU 5A, averaging 23.2 bears/year with 8 females (34.5%).

We effectively sampled 68% (2,447 km^2) of the usable bear habitat in GMU 5A and predicted the population size by applying the estimated density for the core study area to the remaining bear habitat in the subunit (1,133 km^2). The majority of the habitat surrounding the core study area is federally managed by the National Park Service (NPS) as Park and Preserve lands and USFS Wilderness designated lands extending into Russell Fiord. A portion of the NPS Preserve lands near Dry Bay are accessed by resident hunters and non-resident guided brown bear hunters. Although habitat value, brown bear density, and harvest effort in these surrounding areas may be different than the core study area, we applied the same density estimate to the remaining habitat. Given the large extent of the study area, variation in these factors would likely have little effect on the population estimate. We acknowledge there will be some variation in density for the remaining habitat area, however, the study area provides a representative sample of habitats of varying density and we believe this to be the most sound approach to estimating the population of the entire subunit. Considering the GPS radio collar telemetry data combined with evidence from the genetic population structure analysis (Flynn et al. 2012, Paetkau pers. comm.), immigration or emigration into or out of the study area is unlikely, and population augmentation through immigration should not be considered a feasible solution if faced with an overharvested population.

Another important consideration in harvest management is the proportion of the population that is considered available for harvest. Miller (1993) estimated population size for bears ≥ 2 years old and his discussion pertaining to sustainable harvest rates (Miller et al. 1987, Miller 1988, Miller 1993, Miller and Nelson 1993), was calculated for the harvestable portion of the population. In SEAK the management goal has been to maintain a standard harvest rate of 4% of the entire population (Unit 4 Brown Bear Management Team 2000).

The department collects information on the age, sex, and skull size of brown bears harvested in Alaska at sealing and this information is an important component of harvest management. Biennial management reports summarize these data and other harvest statistics for each GMU (Harper and McCarthy 2013). However, a decrease in mean harvest age or an increase in the proportion of female bears harvested is interpreted in the context of other factors and often does not lead to unequivocal interpretation nor management action.

Harvest Rates

In the absence of precise population modeling parameters, Miller (1993) discussed the importance of managing with conservative harvest guidelines and acknowledged that overharvest can result from an overestimation of the population size or an underestimation of the harvest rate. Miller cautioned managers to be concerned about the potential for overharvest when apparent harvest rates exceed 5%. In RY 2012 both the apparent harvest rate (5.2%) and total mortality rate (7.6%) exceeded this recommendation. Between RY 2009–2014, brown bear hunting harvest in GMU 5A ranged from 14–23 brown bears with a mean of 16.7 bears harvested per year. If we were to presume a stable population structure over this period, which is not necessarily a valid assumption, apparent harvest rates during this period based on our population estimate varied between 4.0–6.5%, with a mean harvest rate of 4.7%. Total mortality, including non-hunting mortality, ranged from 5.7% to 7.6% of the total population, with a mean of 6.5%. Historically, spring brown bear harvests in GMU 5A are male biased accounting for 79% of the harvest, whereas fall bear hunts realize an increase in the number and proportion of females (39%) harvested. The seasonal timing of harvest is important as female vulnerability increases in the fall and pregnant females are at higher risk of harvest because they are not associated with dependent cubs.

Managers of harvested brown bear populations are faced with setting conservative harvest guidelines in the presence of uncertain population parameters. This study advances our understanding of population density and abundance and some demographic parameters of reproduction and survival that will be useful in modeling population trends under various harvest scenarios. The results of extensive population modeling efforts consistently show that female survival is crucial to population conservation due to slow reproductive rates and low intrinsic growth rates (Bunnell and Tait 1981, Eberhardt 1990, Kovach et al. 2006). Due to these factors brown bear populations are known to be slow to recover from human-caused declines, so it is prudent to ensure that harvest rates and harvest guideline levels maintain sustainable population sizes (Miller 1990b). Compared to almost any other big game animal hunted in North America, brown bears are recognized as one of the most sensitive to human-caused mortality (Bunnell and Tait 1981, Weaver et al. 1996). Harris (1986) simulated the effects of various harvest rates on sustained yields using population demographic data for southern interior grizzly populations and found populations chronically declined at harvest rates exceeding 6.5%. Sustainable yields were less sensitive to male harvest rates and were maintained when female harvest rates did not exceed 3%. In light of these considerations, the department should consider estimating a sustainable level of mortality for the Unit 5A population and then determine the annual allowable harvest, including a maximum level of female mortality.

FUTURE DIRECTIONS

Department sealing records indicate that over the past several decades, there has been a steady increase in the number of brown bears harvested throughout Alaska. The interpretation of brown bear harvest data requires a solid understanding of brown bear population dynamics. In the absence of complete population demographic data, simulations can be used to understand the impacts of various management decisions and harvest strategies, and to establish sustainable harvest guidelines.

Modeling Population Dynamics

Modeling population dynamics is a useful method to assess risks associated with population declines and identify parameters necessary for population recovery and growth (Beissinger and McCullough 2002). Shortcomings with indices used to monitor population trends such as sex-age-kill models have been evident (Millspaugh et al. 2009), though there remains a need for robust, harvest management tools. With the recent development of statistical population reconstruction models (Gove et al. 2002) and integrated population models (Fieberg et al. 2010) abundance can be estimated at broad spatial scales and population changes can be monitored over time. It would be valuable to assess the application of these approaches to both brown and black bear harvest strategies using age-at-harvest data that has been collected in SEAK for decades. These data have been successfully integrated with auxiliary data such as survival, abundance, telemetry data, harvest level, and hunting effort to estimate harvest rates and population trends (Fieberg et al. 2010, Clawson et al. 2013) and in the future we should test the applicability to SEAK populations. These models can also serve as a framework to identify which demographic parameters are most important to monitor. We suggest monitoring population density and abundance at regular intervals in various game management subunits throughout SEAK, so managers can assess the effects of management actions on harvest guideline levels. In areas with conservation concerns and/or a lack of biological data on which to inform management decisions, we suggest the department begin monitoring population demographics with studies that estimate the survival, natality rate, and recruitment levels. It will be important to learn what information can best be combined with harvest data to provide us the most insight into the demography of the population (Beston and Mace 2012).

Establish Harvest Guideline Levels

As we move forward with an understanding of brown bear population size and density in GMU 5A, it will be important to determine sustainable harvest rates, especially for female brown bears. Although not previously discussed in this report, we have collected data on several population parameters identified as necessary to modeling sustainable harvest rates, including Kaplan—Meier survival rates, female birth rate (female cubs/adult female/yr), age at first reproduction, mean litter size, breeding interval, and maximum age. It will also be important to identify relative vulnerability of various age and sex cohorts to hunting. Our initial approach to establishing a sustainable harvest guideline will incorporate the population parameters we measured in the field to simulate various harvest scenarios using the stochastic model RISKMAN (McLoughlin et al. 2003). By incorporating actual survival and reproduction parameters and variances the population projections resulting from management policies will more accurately reflect the estimated population dynamics.

Throughout SEAK, it will be important to establish sustainable harvest guideline levels for each management unit and adopt the practice of identifying a maximum female harvest guideline, such as 2% of the female population, 1/3 of the harvest, or 1.5% of the population >2 years old, rather than using current harvest ratio objectives of 3 males:2 females (Harper and McCarthy 2013, i.e., Unit 4, Unit 16). Given the current abundance estimate, we recommend that additional efforts be made to coordinate with the USFS to identify appropriate harvest levels (both recreation and subsistence) to ensure the sustained yield of the brown bear harvestable surplus without leading to population declines. Developing harvest strategies for brown bear populations in SEAK is an important management priority, acknowledging that a universal approach needs to consider variation in population demographics, harvest patterns, and management objectives.

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Appendices

Appendix A: Definition of predictor variables used in detection models (modified from Efford 2015, secr 2.9 overview).

Predictor	Description	Notes
b	Learned behavioral response	Global response. Animals become attracted to (trap happy) or repelled by (trap shy) detectors after the first detection (step change) throughout the entire study area. Response persists throughout duration of study.
B	Transient behavioral response	Global response. Response depends on detection at each preceding occasion (Markovian response).
bk	Animal × site response	Similar to “b”, except rather than a global step change, the behavioral response is specific to each detector or site.
Bk	Animal × site response	Similar to “B”, except rather than a global transient change, the behavioral response is specific to each detector or site.
cdoy	Site-specific time coefficient	Julian day corresponding to the midpoint of each detector’s sampling occasion.
k	Site learned response	The effectiveness of the detector/site changes once any animal caught. This change persists for the remainder of the study period.
K	Site transient response	The effectiveness of the detector/site changes once any animal caught. This change depends on each preceding occasion.
trapType	Type of trap	Specific type of trap used in the detection, corral, rub tree, or single catch hair snare.

Appendix B: Project 04.43 timetable.

1 July 2009–27 August 2013: Captured and GPS radiocollared brown bears to identify prioritized brown bear habitats for sampling and incorporate telemetry data in spatial analyses and SECR models.

1 July–15 July 2013: Preparations for field sampling.

15 July–30 August 2013: Conducted four 9 day sampling occasions using a 8 $km^2 \times 8$ km^2 grid based design with scent-baited hair trap corrals, scent marking rub trees, and single catch hair snares. Processed hair samples and stored dried in a cardboard box with silica gel desiccant until samples were shipped for analysis.

September–November 2013: Cataloged hair samples and entered sample information into database. Obtained USFWS CITES permits 3-177 and 3-201A for sample export to British Columbia for DNA genotyping.

December 2013: Exported samples to Wildlife Genetics International for DNA genotyping.

December 2014: WGI delivered preliminary DNA genotyping results.

January 2015: Capture history data compiled and initial models developed for SECR analysis.

June–January 2015: Recovered GPS collars, compiled data, and incorporated auxillary telemetry data into SECR models.

February 2016: Received extended genotyping data from WGI.

February–December 2016: Modeled population density and abundance using SECR and drafted final report.

January 2017: Published final report on Yakutat population density and abundance estimate.

Appendix C. Brown bear mortality in GMU 5A, Southeast Alaska, regulatory years 1990–2014.