ESTIMATION OF BLACK BEAR POPULATION SIZE ON KUIU ISLAND, ALASKA USING TETRACYCLINE BIOMARKING SUPPLEMENTED WITH GENETIC METHODS

INTRODUCTION

Bears (*Ursus* spp.) in Southeast Alaska (Figure 1) are valued for hunting and viewing, and also for their role in the ecosystem, as they mediate transportation of marine nutrients to the terrestrial ecosystem through predation on spawning salmon (Schwartz and Franzmann 1991, Willson *et al.* 1998). The high density populations of brown bears (*U. arctos*) have been well studied (Hilderbrand *et al.* 1996, Miller *et al.* 1997, Paetkau *et al.* 1998a, Gende and Willson 2001, Ben-David *et al.* 2004), and their harvest is conservatively managed at a level of 4% of the size of each population (Whitman 2001). There have been no population-level studies of American black bears (*U. americanus*) in Southeast Alaska. Yet, black bears in the region are of interest to wildlife managers and biologists, as they also occur at very high densities, may also function in nutrient transport, and their hunting and viewing has been increasingly important to local economies. Two studies that have occurred on black bears in Southeast Alaska have focused on viewing (Chi 1999) and denning (Erickson *et al.*1982).

Black bear harvest has increased most dramatically on Kuiu Island (Figure 2, 134°10' W, 56° 45' N), due to large trophies and reporting of high densities by the popular hunting press; harvest has increased 46% on Kuiu Island in the Alexander Archipelago of Southeast Alaska during the 1990’s (Figure 3). Hunting has increased to the extent that local wildlife managers have begun to question whether current hunting levels are sustainable, and a harvest cap of 120 bears per year was established for Kuiu Island in 2000 through regulatory action. Sustainably managing bear populations can only be done successfully with adequate information on population size and trend.

Brown bear population size in Alaska has been estimated using Capture-Mark-Resight (CMR, Miller *et al.* 1997), in which animals are physically captured, marked with a radio-collar and then resighted. CMR studies on Admiralty Island in the Alexander Archipelago have produced density estimates of 0.26 ± 0.03 adult bears/km^2 (mean ± SE, Miller *et al.* 1997). Brown bears are known to use non-forested alpine areas, where individuals can be resighted. This prerequisite for CMR does not occur for black bears in the temperate rainforest of Southeast Alaska, as black bears do not readily use the small amount of alpine habitat that is available on the Archipelago's black bear islands (*e.g.,* Kuiu, Kupreanof, Mitkof and Prince of Wales).

My objective was to estimate the density and adult survival rate of black bears on Kuiu Island using tetracycline biomarking (Garshelis and Visser 1997), a method in which bears are remotely marked with tetracycline-laced baits, and which does not require resighting individuals. Garshelis and Visser (1997) first used tetracycline biomarking successfully to estimate the size of very large populations (15,000 – 25,000 animals) across expansive areas in Michigan and Minnesota (43,000 – 83,000 km^2).

METHODS

I used tetracycline biomarking to estimate the size of the black bear population on northern Kuiu Island (673 km^2) in 2000 and 2002. I altered methods described by Garshelis and Visser (1997) slightly to accommodate a smaller sample size and the higher density of bears. Baits were laced with the antibiotic tetracycline and distributed; when a bait was taken by a bear, the tetracycline was incorporated in the newly-forming bone tissue (Johnson 1964). As the recovery sample, hunters provided bear bones that were examined under an ultraviolet microscope for the fluorescent biomark.

Since bears were marked remotely, the number of bears marked was likely higher in comparison to methods in which bears must be captured. Disadvantages of the tetracycline method include the fact that bears could be recaptured only once (*i.e.,* recovered), bears did not have individual marks, and the population had to be hunted to supply the recapture sample. In addition, little is known about the marked animals (*e.g.,* sex, age, reproductive history). I augmented the tetracycline method with genetic information regarding sex identity, from a sample of the animals that took baits, which aided in an investigation of possible biases in the population estimate.

Field methods

I used tetracycline-laced baits to mark individual black bears on Kuiu Island, north of the Bay of Pillars and Port Camden isthmus (Figure 4), in 2000 and 2002. The isthmus is a 1.5 km wide land bridge that connects northern and southern Kuiu Island. I chose this study area due to its insular nature, which maximized geographic closure, and because logging roads facilitated bait distribution.

In late June 2000, I distributed tetracycline baits on northern Kuiu Island over the course of four days. I distributed baits (n = 188) at 1.6-km intervals along the coast and road system and left them out for an eight day period (Figure 5a). In 2002, I made methodological changes to decrease a possible bias resulting from the manner in which I distributed baits in 2000, and to increase precision in the population estimate. I divided northern Kuiu Island into 1.6 km^2 grid cells, and systematically placed baits as close to the centers of these cells as possible (Figure 5b). I did not place baits in cells that were entirely composed of rock or ice, or where helicopter access was dangerous. To increase precision, I distributed 29% more baits (n = 263) than in 2000, over the course of five days. Crews first revisited baits eight days after I distributed the initial baits. However, because of initial low visitation, possibly associated with cooler weather, I left out baits for an additional one to five weeks, depending on how quickly the bait was taken.

Baits consisted of nine, 500 mg tetracycline capsules embedded in 0.5 kg of suet and bacon. This dose of tetracycline is sufficient to mark bears up to 225 kg (20 mg/kg, Taylor and Lee 1994, Garshelis and Visser 1997). Only approximate weights are known for the Kuiu Island black bears, since few non-urban black bears have been weighed in Southeast Alaska. I assumed the maximum weight of an adult male black bear to be approximately 215 kg and the average weight of independent black bears to be approximately 115 kg (R. Lowell, L. Beier, pers. comm.). Therefore, the dosage of the tetracycline baits used on Kuiu Island was sufficient to mark the bears.

I used scent flags soaked in a fish-shrimp soup to attract bears to the baits. I enclosed baits in wood-panel boxes (30 cm x 10 cm x 10 cm in 2000 and 22.5 cm x 10 cm x 10 cm in 2002), and attached them at a height of 2 m on trees. I chose to use a box and the box height to diminish the possibility of non-target species accessing the bait. If a non-target animal took the bait, the presence of the box would cause the animal to leave enough sign to reveal its identity. I hung a barbed-wire strand around each box to collect a hair sample of the individual taking the bait (Figure 6). I used hair samples to genetically determine sex and individual identity of a proportion of bears that took baits.

Crews inspected the immediate vicinity of the bait station for uneaten tetracycline capsules. If more than half of the capsules remained, I considered the bait not taken, as the dosage ingested would be less than that required (20 mg/kg) to mark an average-sized bear (115 kg). I assumed that all bears marked with tetracycline were independent subadults or adults, because I considered the likelihood that a sow would share a small, 0.5-kg bolus of meat with a cub-of-the-year to be low. I assumed the number of baits taken by bears to be the number of tetracycline marks then in the population. The number of marks in the population does not equal the number of marked bears, as bears could take multiple baits. Therefore, I calculated the number of marked bears by reducing the number of marks in the population by a rate of double-marking.

Bone and tooth examination

All hunters that killed a black bear in Southeast Alaska were required to register the bear by Alaska Department of Fish and Game (ADF&G) officials. I requested that hunters submit toe bone (metatarsal) samples from their harvested bears from the fall of 2000 through the spring of 2003 from the entirety of Kuiu Island. I requested bone samples, as tetracycline is incorporated more readily in the bone than in teeth, due to the rate of deposition of new material (Garshelis and Visser 1997). When hunters did not provide a toe bone, I used a premolar tooth for analysis. I also collected samples from bears harvested from Kupreanof Island from spring 2002 to spring 2003 to further address the assumption of geographic closure. I only requested bone samples from western Kupreanof Island, but I obtained biomark data from bears harvested from the remaining areas of Kupreanof by screening the teeth submitted for age analysis.

I analyzed bones and teeth for biomarks at the Minnesota Department of Natural Resources (1201 East Highway 2, Grand Rapids, MN 55754) and Matson's Laboratory LLC (P.O. Box 308, Milltown, MT 59851). I cut cross sections of the bone, approximately 100 +/- 20 microns in width (Matson and Kerr 1998), and longitudinal sections of tooth samples using a double-bladed diamond saw. I examined the sections for tetracycline fluorescence (Figure 7) under an ultraviolet microscope (40-100x; Leitz Laborlux S, Bartels and Stout, Inc.). Because marked bears harvested in the fall of 2002 and spring of 2003 could have been marked either in 2000 or 2002, Matson's Laboratory LLC prepared half of the tooth for age analysis (by counting cementum annuli), and the other half for tetracycline analysis. The lab examined concurrently the tetracycline and age preparations to determine the year of marking (Matson and Kerr 1998), and also aged all marked and unmarked harvested bears from the study area.

Genetic laboratory methods

I genetically examined hair samples collected from the barbed wire associated with bait boxes to: 1) determine the sex of the animal that took the bait to address a potential bias due to unequal capture and recapture probabilities of the sexes; and 2) determine the genetic identities of the animals that took baits to assess the rate of double-marking.

I extracted DNA from 130 hair samples, which represented 65% of the baits taken in 2002. I extracted DNA from the follicles of the hairs using the QIAGEN DNeasy 96-well plate extraction kit. To determine sex of the genetic sample, I amplified the DNA extract using polymerase chain reaction (PCR) at a sex-specific locus on the ameliogenin gene (Poole *et al.* 2001), using the primers SE47 (with fluorescent label VIC) and SE48 (Table 1); primer sequences are published in Ennis and Gallagher (Ennis and Gallagher 1994). If the sample was male, I observed two fragments, a 187 base pair (bp) fragment and a 239 bp fragment. Only the 239 bp fragment was present in females.

I used a suite of seven microsatellite loci (Paetkau and Strobeck 1994, Paetkau *et al.* 1995, Paetkau *et al.* 1998a) for individual identification of the hair samples that I collected from baits in 2002 (Table 1). I ran all PCR's on a Peltier Thermal Cycler 225 or 200 (MJ Research) in 15 µl volumes (Table 2). The concentration of the DNA extract was generally < 1 ng/µl, and therefore I was not able to quantify the concentration of the extract using standard fluorometry. Instead, I used 5 µl of DNA template in each PCR. I started all PCR's with a one-minute hot start at 95°C, followed by a cycling sequence: the DNA was denatured for 30 seconds at 95°C, primers were bound to the template at the primer-specific annealing temperature for 30 seconds, and fragments were built at 72°C for 30 seconds. I repeated this sequence for 30 to 45 cycles, dependent upon the efficiency of the reaction. I followed the cycling sequence with a 72°C extension for ten minutes.

I variously diluted PCR products with deionized water based on the efficiency of the reaction (no dilution to 1:200). I ethanol-precipitated PCR products to remove non-bounded primers, and combined the precipitated PCR product with either a formamide-LIZ or -ROX (ABI) ladder (total volume, 20 µl), which were used to calibrate fragment size estimation. I fluorescently labeled the forward primer in all PCR's (OPERON and ABI), allowing for size estimation of the fragments using capillary electrophoresis on an ABI 3700 or 3730 automated sequencer at the Nevada Genomics Center at the University of Nevada, Reno.

To determine the probability of identity (see below) for the northern Kuiu Island population, I also extracted DNA from 117 representative tissue samples of known northern Kuiu Island individual bears, and amplified the extract at seven microsatellite loci.

Analysis

Estimation of number of marked bears

In most mark-recapture studies the number of marks in the population is known; in this study I estimated this value. To avoid an overestimate of the number of marked animals, I reduced the number of baits taken by bears by an estimate of the rate of double-marking. I used two methods to assess the rate of double-marking.

Bone method

Empirical evidence from known marking events suggested that multiple tetracycline marks could be detected in individual bears if baits were taken at least 24 hours apart (Garshelis & Visser 1997). I divided the total number of marks (including double marks) detected in the harvest, by the total number of marked bears (a double marked bear is one marked bear) in the harvest to estimate the number of marks/marked bear (double-marking estimate). I divided the number of baits taken by this double-marking estimate to calculate the number of individual bears marked in the population (Garshelis and Visser 1997).

Hair method

Because bears may ingest multiple baits in less than 24 hours, I also estimated the rate of double-marking by comparing individual genetic fingerprints of the hair samples that were associated with bait boxes in 2002. I compiled genotype data at each microsatellite locus to produce a multilocus genotype (*i.e.,* genetic fingerprint) for each successfully amplified hair sample (n = 103). I wrote the program IDENTITY in Visual Basic 6.0 to sort and compare each genetic fingerprint (Appendix I). IDENTITY compared the genotypes at each locus for each pair of samples sequentially, and tallied the number of matched and mismatched locus-genotypes between a pair of samples. If two samples matched at at least five genotypes (see discussion on *probability of identity* below), and had no mismatches, I considered the samples to represent a single individual. IDENTITY compared all pairs of genetic fingerprints in this way. I used this program to ultimately identify the number of unique genetic individuals within the set of hair samples.

To ensure that genetic individuals were equivalent to real individuals, I calculated the probability that two individuals had the same genetic identity, *i.e.,* the probability of identity (PI), for the northern Kuiu Island black bear population (Taberlet and Luikart

1999, Waits *et al.* 2001). A low PI (< 0.01) was required to assume that one genetic individual represents one real individual (Mills *et al.* 2000). I calculated unbiased PI using equations for small sample size (Paetkau *et al.* 1998b, Valiere 2002). I discounted the number of baits taken by bears, by the number of baits taken per genetic individual. This resulted in the number of marked bears in the population.

I assumed that the estimation of double-marking using hair samples was more accurate and precise than the method using detection of double-marks in the bones. The hair method included bears that took multiple baits within a 24 hour period, and was based on a larger sample size (*n* = 103 hair samples *vs.* 30 bones). Therefore, I derived the population and survival estimates from the estimated number of marked bears using the hair-sample method.

Estimation of the number of recovered bears

I increased the number of marked harvested bears (recoveries) slightly due to consideration of the decreased uptake of tetracycline in teeth, with respect to bone. The number of marks recovered in teeth was divided by 0.9 (Garshelis and Visser 1997), to obtain the estimated number of marks in teeth.

Density estimate

I used the Lincoln-Petersen model corrected for small sample size (Chapman 1965) to estimate population size:

$$\hat{N} = \frac{(M+1)(C+1)}{(R+1)} - 1$$

where *M* was the number of animals marked, *C* was the number of animals harvested, and *R* was the number of harvested animals with marks (recovered). I used the tetracycline mark data from 2000 and 2002 for northern Kuiu Island in separate Lincoln-Petersen models. I used bears killed in the harvest regulatory year 2000 (fall 2000 and spring 2001) as the recovery sample for the 2000 marks, and bears killed in regulatory year 2002 as the recovery sample for the 2002 marks. Thus, these two models used only the recoveries from the first year post marking.

The Lincoln-Petersen model assumes geographic closure, an assumption that was most likely not supported, thus the population estimates from these models should be considered as super-population estimates (Kendall 1999).

I also ran additional Lincoln-Petersen models by reducing the number of marked bears available for recovery by an estimate of annual immigration of unmarked individuals to Kuiu Island. I calculated the annual immigration rate for each data set (2000 and 2002) separately, from data regarding the *emigration* of marks; I assumed that immigration and emigration were equal. I calculated the ratio of the number of marked bears harvested on southern Kuiu and Kupreanof islands to the total number of bears marked bears harvested in the years post marking. Thus for the 2000 data set, I divided this figure by three, to calculate an estimate of an annual emigration rate. In this assessment of emigration of marked individuals, I did not include the differential probability of marked bears being available outside the study area.

I calculated density estimates by dividing the population estimate by island area, 673 km^2. This area was the entirety of Kuiu Island, north of the Bay of Pillars and Port Camden isthmus, including higher elevation rock. I considered all of the area bear habitat for this analysis, as there was little concrete information on black bear habitat use in Southeast Alaska (but see Erickson *et al.* 1982). The density estimates, based on the area of northern Kuiu Island, are likely biased high due to this closure violation.

Survival estimate

I used a Brownie recovery model with the mark and recovery data of 2000 and 2002 tetracycline marks (Brownie and Pollock 1985) to estimate the survival *(S)* and recovery *(f)* rates of independent black bears marked on Kuiu Island (Appendix II). I used data from all bears recovered from 2000 to 2002 in this analysis. In this study, the age and sex of all marked individuals was unknown, and therefore I assumed recovery and survival rates to be independent of these parameters. This assumption was likely to be violated. For example, if capture and recovery samples were skewed in the same direction, for example toward older males, the survival estimate would have been biased toward the survival rate for older males. I assumed that the mark did not affect survival rate, and the survival of marked animals were independent of one another. I also made the basic assumptions of mark-recapture that are also inherent in the Brownie recovery model such as equal catchability (*i.e.,* the sample was representative of the target population) and no mark loss within the time period of the study.

To estimate survival, two encounter occasions were required after marking (Brownie *et al.* 1985). Marked bears that survived the first interval may or may not have been sampled in the second encounter occasion, as recovery probability was less than one. Therefore, to estimate both survival and recovery rates, a third encounter occasion was needed. Data from animals recovered in this third session, but not in the second, were used to estimate survival. Therefore, with these tetracycline data, I estimated a survival rate for the interval from the fall of 2000 to the fall of 2001. I used only data from the capture of 2000 marks to estimate survival, as there have not been enough encounter occasions of 2002 marks to estimate survival during later intervals. However, I included data from the recovery of 2002 marks in this model to estimate recovery rate with higher precision. A more precise estimate of recovery rate would result in a more precise estimate of survival, as recovery rate is used in the estimation of survival (Brownie *et al.* 1985), whether or not I used recovery of 2002 marks *per se* to estimate survival.

Recovery rate in the Brownie model was equivalent to $Kc\lambda$, where K was the probability that an animal was shot, c was the probability that an animal was retrieved and λ was the probability that a harvested bear was registered (Brownie *et al.* 1985). I assumed that $\lambda = 1$, as there was an incentive to register the bear, since skull size could not be officially recorded without registration through ADF&G. Therefore $f = Kc(1)$, where Kc represented the reported harvest. The probability that an animal died from natural causes was $(1 - S) - f$. In the case presented here, 'natural' causes included: 1) mortality not associated with hunting; 2) bears shot and not retrieved, hereafter referred to as "wounding mortality"; and 3) the probability that a mark did not appear in the bone or tooth of a bear that took a bait (see discussion on biases in the data set below). Therefore, $1 - [(1 - S) - f]$ was the estimate of survival of black bears from fall 2000 to fall 2001, without harvest . Note, this is not an estimate of "true" survival, *i.e.*, survival in the absence of hunting, as it is not known whether black bear hunting on Kuiu Island is compensatory or additive.

I ran Brownie recovery models with *f* varying according to year. I examined models: *f*(.)*S*(.); *f*(t)*S*(.); *f*(1_2, 3)*S*(.) and *f*(1,2_3)*S*(.). In the latter two models, I held the recovery rate constant for the first (1_2) and last two intervals (2_3), respectively, allowing it to differ from recovery rate in the remaining interval (3 and 1, respectively). I included these models as the legal harvest differed between the years (Figure 3). I used program MARK (White and Burnham 1999) to generate maximum likelihood estimates of the parameters and variance, and used Akaike's Information Criterion (AIC) corrected for small sample size (Anderson *et al.* 2001) to rank the ability of the different models to explain the data. I used model-averaging to produce the annual survival and recovery rate estimates.

RESULTS

Estimation of the number of marked bears

In 2000, 144 of the 188 distributed baits were taken (76.6%), and 138 were taken by bears. One bait was taken by a red squirrel and I found unconsumed tetracycline capsules at the other five bait stations. In 2002, 73 – 76% of the 263 distributed baits were taken by bears (n = 191 – 201); ten of the taken baits may or may not have resulted in a marked bear. At nine of these ten bait stations, there was no animal sign. It seems likely that a smaller animal would have left sign, as the box would have been more difficult for them to open. I suggest that these nine baits were most likely consumed by bears. At the tenth bait station, I found four tetracycline capsules, thus I considered this bait to be taken by a bear, as fewer than half of the capsules were found. Because the total number of baits taken in 2002 was somewhat ambiguous, I modeled two scenarios, one with 201 and one with 195 baits taken by bears (the latter assuming that ½ of the baits from the ambiguous bait stations were taken by other animals).

The rate of double-marking during the 2000 baiting effort, using the occurrence of double marks that appeared in the recovered bones, was 5%; one sample had two marks out of the 20 marked bears harvested from 2000 to 2002. The estimate of double-marking during the 2002 baiting effort was 10%; one out of ten marked bears harvested had two 2002 marks. This estimate for the 2002 marking was based only on the first year of recaptures after marking. This high percentage of double 2002 marks may be an overestimate due to low sample size, as there was no reason to expect that double-marking should be greater in 2002 than 2000. In 2002, I did not place baits along roads, but systematically near the center of grid cells, which would have likely decreased double-marking. Thus, it is likely that as more bears are recaptured with 2002 marks, this estimate of double-marking will decrease.

Unbiased PI, calculated from the 117 representative northern Kuiu Island tissue samples, was sufficiently low to identify known individuals with only five microsatellite loci (PI = 0.002 – 0.0001 for five loci, depending on the actual five loci used for identification; Figure 8). Therefore, I used samples that successfully amplified at five to seven loci. From the individual identification of hair samples (n = 103) from the taken baits, I estimated that an average of 1.062 baits were taken by each baited bear, a double-marking estimate of 6.2%. Most bears that took multiple baits, took baits adjacent to one another (Figure 9). I used the estimate of double-marking derived from the hair samples, to estimate the number of marked bears. I estimated the number of marked bears in the summer of 2000 to have been 129.4. In the summer of 2002, 188.5 or 182.9 bears had 2002 marks, if 201 or 195 baits were taken, respectively.

I successfully amplified 89 hair samples associated with bait boxes in 2002 at both enough microsatellite loci for individual identification and at the sex identification locus. This sample represented 44% of baits taken. Of these samples, 54% of the identified individuals were male (n = 48) and 46% were female (n = 41).

Estimation of the number of recovered bears

I found 32 marks in 503 bone and tooth samples from Kuiu and western Kupreanof islands. Two samples had double marks from the same marking year; one sample had a mark from both 2000 and 2002. I found 27 marks from bears harvested on northern Kuiu Island, and five marks from bears harvested outside of the study area on southern Kuiu Island (n = 2) and Kupreanof Island (n = 3; Table 3). Of 10 known marked northern Kuiu bears (based on examination of bone samples), I found eight marks in corresponding teeth, a detection rate for teeth of 80%. This detection rate for teeth was similar to what Garshelis & Visser (1997) found empirically (90%) from 207 samples. Using this 90% detection rate (due to higher sample size), I increased the number of recovered bears in the Lincoln-Petersen models using 2000 marks from 9 to 9.1, because one mark was found in a tooth sample (1/0.9 detection rate = 0.1 additional bears marked).

Imprecise kill locations for bears harvested in 2000 (n = 2) and 2002 (n = 3) were recorded for bears killed in Port Camden and Bay of Pillars (Figure 4). These five bears were unmarked. Whether these bears were taken from the north or south side of these bays would determine whether they were taken from the study area (northern Kuiu Island) or from outside the study area on southern Kuiu Island. I assumed that half of these numbers (1 bear in 2000 and 1.5 in 2002) were taken from northern Kuiu Island, and used these harvest numbers for population estimation.

Density

I estimated the population size for northern Kuiu Island using the 2000 marks to have been 1019 bears with a coefficient of variation (CV) of 0.31, using recovery data from regulatory year 2000 (fall 2000 and spring 2001, Table 5). Based upon this population estimate, I estimated the density to have been 1.51 bears/km^2. Population point estimates using the 2002 marks and recovery data, were 983 (1.46 bears/km^2) and 1013 (1.51 bears/km^2), derived from both the low (195) and high (201) estimates of total baits taken by bears, respectively, with CV's of 0.31 (Table 4). Using marked bears recovered outside of the study area, I calculated the rate of emigration of marks of 6.6% for the 2000 marks and 10% for the 2002 marks. If I use this mark emigration rate to reduce the number of marked bears available as a surrogate for immigration of unmarked individuals, density point estimates range from 1.31 to 1.51 bears/km^2.

Survival

Of 129 bears marked in 2000, 21 were recovered from 2000 through 2002, while ten of the 189 bears marked in 2002 were recovered in 2002 (Table 5). The best Brownie model (AICc weight = 0.36) held recovery rates constant (Table 6). The model-averaged estimate of annual survival from fall 2000 to fall 2001 was 0.67 ± 0.18 SE (Table 7), which included mortality due to legal recovery (f(2000) = 0.079 ± 0.02, f(2001) = 0.072 ± 0.02 , f(2002) = 0.060± 0.02). Using a estimate of f (0.068 ± 0.014) from the best model, the estimate of ‘natural’ mortality, $1 - S - f$, was 0.26 ± 0.2 (complied SE), which included mortality due to natural causes and wounding loss. Wounding loss results in the reported harvest to be roughly 70% of actual harvest, based on reports from hunting guides (R. Lowell, pers. comm.). Thus recovery rate with incorporated wounding loss was roughly 9.7% (0.068/0.7) and therefore adult survival from fall 2000 to fall 2001 without incorporating harvested animals was approximately 75%.

DISCUSSION

Density

This study is the first to estimate a population density of black bears in Southeast Alaska. The estimate of 1.51 bears/km^2 (both the 2000 and 2002 estimates) is among the highest published black bear density across the entire distribution of the species. Incorporating immigration of unmarked individuals, which would dilute the proportion of marks available, the point estimates range from 1.31 to 1.51 bears/km^2.

At the southern extent of the coastal rainforest, Lindzey & Meslow (1977b) documented an increase in the density of black bears (determined by a census of known individuals) on Washington’s Long Island (21 km^2) from 1.14 bears/km^2 to 1.57/km^2 from 1973 to 1975. By 1982, the density on this small island had remained at 1.0/km^2 for several years (Lindzey *et al.* 1986). Urban black bears, in relatively small areas, approach the densities found on Kuiu and Long islands. Beckmann and Berger (2003) concluded that the density of black bears (a minimum census density of known bears) in the urban areas of the Lake Tahoe region was 1.2/km^2. This urban black bear density is probably representative of other black bear populations in urban areas or around landfills, where human food serves as an attractant. Higher densities of bears can occur in areas of seasonally high food concentrations, such as on salmon-spawning streams (Miller *et al.* 1997, Chapter 3). In other systems, without a seasonal concentration of food or significant access to human food, Martorello *et al.* (2001) used photographic mark-recapture to estimate relatively high black bear densities of 0.80 bears/km^2 in eastern North Carolina and 0.71 bears/km^2 in the Great Smoky Mountains National Park. Belant *et al.* (2004) estimated black bear density, using genetic tagging, on two of the Apostle Islands in Lake Superior to be 0.6 and 0.5 bears/km^2. Much lower black bear densities occur in the Susitna Valley of interior Alaska, where the density is estimated at 0.065 bears/km^2 (Miller *et al.* 1997), and in the wildland areas around Lake Tahoe where Beckmann and Berger (2003) established a black bear density of 0.032 bears/km^2.

Survival

I estimated the annual survival rate for the adult black bears marked on Kuiu Island to be 0.67 ± 0.18 SE. This estimate probably has a negative bias due to the small data set, as additional encounter occasions can only reveal more survivors, although the marked population likely accurately represents the population (see discussion of biases in the data set below). In addition, this estimate of survival is relatively imprecise, due to the small sample size, and should be interpreted cautiously.

Annual adult survival in non-hunted populations in the southeast of the United States ranges from 0.69 to 1.00 ($\overline{X}$ = 0.89, Freedman *et al.* 2003). The lowest survival estimates for a non-hunted population, 0.69 and 0.77 for females and males, respectively, are reported for black bears in North Carolina (Lombardo 1993), where there was significant mortality due to traffic. Beck (1991) estimated adult survival to be 0.70 and 0.96 for male and female bears, respectively, in a protected area of Colorado, which was surrounded by hunting. Survival increased from 0.58 to 0.98 in the Pisgah bear sanctuary in North Carolina after management actions decreased poaching (Sorensen and Powell 1998); hunting was allowed outside the sanctuary. Martorello (1998) estimated survival of adult females to be 0.90 in a hunted population in North Carolina. In Alberta, adult survival of an unprotected bear population was 0.84, which the authors suggested was comparable to other unprotected populations (Hebblewhite *et al.* 2003).

Despite my concerns regarding the precision and bias of this survival estimate, it is the only estimate of survival for black bears in Southeast Alaska, and I think it is relevant to discuss this fairly low survival estimate. In addition, since population growth rate in black bears is often most sensitive to annual adult survival (Freedman *et al.* 2003, Hebblewhite *et al.* 2003), it is important to speculate on why the survival estimate on Kuiu Island is low. After accounting for legal harvest and estimated wounding loss, the survival of marked bears was approximately 0.75, *i.e.*, 25% of the adult population on north Kuiu died due to natural causes. Wildlife viewers, pilots and hunting guides on northern Kuiu Island have observed wolves (*Canis lupus ligioni*) killing adult bears. I frequently found black bear hair in wolf scat on Kuiu Island (Peacock, unpublished data). The most common prey species of wolves in Southeast Alaska is Sitka blacktail deer

(*Odocoileus hemionus sitkensis*; Person *et al.* 1996), yet deer abundance is very low on Kuiu Island (Kirchhoff 2000). The beaver (*Castor canadensis*) was the only other species whose frequency of occurrence in wolf scat on Prince of Wales Island was greater than 10%. Wolves may also eat salmon, mustelids, small mammals and birds, but not in significant amounts (Person *et al.* 1996). The rate of occurrence of black bear hair in wolf scat, low deer numbers and anecdotal observations of predation events, suggest that annual survival of adult black bears on Kuiu Island may be influenced by wolf predation.

Bias in the data set

The high black bear population and low survival estimates reported in this study requires a rigorous analysis of the possible biases. In addition, in a mark-recapture study where the number of marks is not known but estimated, it is especially important to address the criteria used in estimating the number of marked bears, as an over or underestimate of the animals marked will lead to biases in the demographic estimates.

Negative bias

In 2000, I distributed baits only along the coastline and road system due to accessibility. Because the recovery sample (hunter harvest) was also skewed towards sites with easier access, I expected a negative bias in the 2000 estimate. In 2002, I sought to reduce this potential bias by distributing the baits according to a systematic grid. Therefore, I assumed that hunters, while still inclined towards roads and the coastline, had an equal probability of capturing a marked or unmarked bear. However, I detected no negative bias in the 2000 estimate when compared with the 2002 estimate (both estimates were identical, 1.51 bears/km^2). Thus, bears or hunters may move around more than I had expected. Another possibility is that population size decreased between the two years, and that the first estimate did actually contain a negative bias. However, there is no way to address the possibility of a decreasing population trend with the data from this study alone.

A negative bias due to heterogeneity of behavior of marked and unmarked bears could have resulted if bears that were more likely to take human-distributed baits, were also more susceptible to hunters. Heterogeneity in capture and recapture probability has been detected in other studies of bears (Boulanger and McLellan 2001), and is possibly why most mark-recapture studies produce underestimates of population size (Garshelis and Visser 1997).

Hunters took male bears disproportionately on northern Kuiu Island during the years of this study: 82% and 75% in 2000 and 2002, respectively. In 2002, males took 54% of the baits. The sex ratio in the population was unknown, though probably was biased towards females as males were targeted in the harvest. Therefore, there may be a negative bias due to heterogeneity in capture and recapture between the sexes.

Positive bias

An overestimate of the number of marks in the population would inflate the population estimate. I took precautions to not overestimate the number of marks in the population. An overestimate of the number of marks could result from: 1) taken baits that did not result in a marked bear; 2) an underestimate of double-marking and/or 3) immigration of unmarked individuals.

Baits taken not resulting in marked bears

The first assumption regarding this bias is that if tetracycline is ingested, a mark will be detected. Garshelis and Visser (1997) estimated the probability that a mark appeared in the bone as 1 when a captured bear was fed or injected with tetracycline (n = 36). They estimated that the probability that a mark appears in the tooth, if detected in a bone, as 0.9 (n = 207). I adjusted for probability of detection in teeth, by increasing the number of marks recovered according to this detection probability.

Assuming that marks will be detected if they are ingested, I must next evaluate whether a taken bait results in the ingestion of the bait by a bear. I determined the number of baits taken by bears after taking into account baits taken by other animals (n = 1). I also did not consider taken baits from which more than half of the capsules were found in the vicinity of the bait. The bait was relatively small, and therefore the bait was most likely eaten immediately. Therefore, it was improbable that any uneaten capsules were dispersed outside the immediate vicinity of the bait station. The area near each taken bait for uneaten tetracycline capsules was searched by two to three crew members. In 2002, no animal sign was found at ten bait stations where baits were taken. Although I expected that a smaller animal would leave more sign than a bear, I explored the implications of this ambiguity by running models with the conservative estimate (all ambiguous baits were taken by bears) of the number of baits taken, and a smaller estimate assuming that ½ of the ambiguous bait stations were taken by other animals.

Underestimate of double-marking

I used two methods to estimate double-marking: genetic individual identification of a proportion of the bears that took baits (51%) and the rate of appearance of double marks in the bones. Using the method which assesses the double-marking rate in bone, I estimated a rate of 5 – 10% double-marking from a sample of 30 marked bones. From the genetic identification of 103 baited bears in 2002, I calculated an estimate of 6.2% double-marking. This latter estimate would include bears that took multiple baits within 24 hours. Due to the fact that genetic identity is only a probability of identity, and not an exact identity, any error in this estimate of double-marking due to this factor would tend to lean towards an overestimate of double-marking. A review of the tendency of genetic identification that would lean towards an underestimate of double-marking, due to genetic data quality, is given in Chapter 3. With the similarity in the estimation of double-marking using these two independent methods (three data sets), I suggest that I have not underestimated the extent of double-marking.

Immigration of unmarked individuals

In 2000 and 2002, the estimates of 1019 bears and 1013 bears, respectively, should be considered super-population estimates (Kendall 1999). The super-population estimate includes all bears using the northern Kuiu Island area over the period of the study, if we assume that immigration and emigration were random with respect to the mark. These numbers are biased, if we ask how many animals are on northern Kuiu Island at a particular time (*e.g.*, the time of the 2000 baiting). Therefore, the estimates are only biased if our “frame of reference” (Kendall 1999) is the study area, not the super-population, which Kendall (1999) asserts may be more ecologically relevant.

If I use the northern Kuiu Island study area as my “frame of reference,” the estimates produced by reducing the number of marked bears available will better reflect the number of bears on northern Kuiu Island at a particular time. I detected the first emigration events in spring 2001, when I found marks in two bears harvested on southern Kuiu. By spring 2003, I had found 20% of the recaptured 2000 marks (n = 20) outside of northern Kuiu Island (two on southern Kuiu Island and two on Kupreanof Island). By the first spring after the 2002 marking, I had found 10% (n = 1) of the recovered 2002 marks (n = 10) outside of the study area, on Kupreanof Island. If I assume that emigration of marked bears and immigration of unmarked bears were equal, the population size estimation may be inflated due to the immigration of unmarked individuals from Kuiu Island. Therefore, I included Lincoln-Petersen estimates that incorporate estimates of the rates of immigration of marked individuals, based on empirical data on the rate of emigration of marks. However, genetic data suggest that movement of black bears between Kuiu and Kupreanof Islands was asymmetrical. The number of migrants per generation, incorporating an unknown microsatellite locus mutation rate, was 16.12 (95% CI =15.37 – 16.77) from Kuiu to Kupreanof and 10.69 (95% CI = 9.6 – 11.36) from Kupreanof to Kuiu (Chapter 2). Thus, immigration of unmarked individuals from Kupreanof may have been slightly lower than emigration of marked individuals from Kuiu Island. The next closest population of black bears is on Prince of Wales Island (11 km over salt water from Kuiu Island), however based on genetic information, it is unlikely that unmarked bears immigrated from Prince of Wales (Chapter 2).

This closure assumption was not made for the survival estimate, as the model estimated the survival of all animals marked on Kuiu Island in 2000; where the bears were harvested was irrelevant.

Precision of the data set

The coefficients of variation (0.30 – 0.31) of these black bear population estimates and standard error of the survival estimate (0.67 ± 0.18 SE) are greater than in studies in which bears can be recaptured or resighted multiple times. However, when I regressed standard error of recent North American black bear density estimates against estimated density, the precision associated with the estimate presented in this study is consistent with these other studies (Figure 10). Precision can only be influenced by the success of the baiting effort and the number of animals harvested. Baiting success in this study was high, approximately 70% in both years, in comparison to other tetracycline studies, where 31% of the baits were taken by bears in Michigan and 34% in Minnesota (Garshelis and Visser 1997). It would be difficult to increase baiting success, while keeping the rate of double-marking low, as grid cells (1.6 km^2) were already relatively small. I expected that the precision of the estimate produced by the 2002 baiting effort would be greater than that of the 2000 estimate because 32% more baits were distributed. However, despite 30% more bears marked in 2002 than in 2000, 30% fewer bears were harvested in 2002 and therefore the precision of the estimate was left virtually unchanged by these factors.

Other marking methods can produce higher precision of the survival and population estimates, however these methods were not feasible on Kuiu Island. CMR cannot be used in the temperate rainforest, as black bears cannot be resighted. Genetic tagging, where barbed wire hair snagging sites (fences) are visited multiple times, can result in lower variation, but would be very difficult to implement on the remote Kuiu Island. Due to the density of bears on the island, the density of fences used in a genetic tagging study would have to be very high to obtain a modest recapture probability. Fences would have to be distributed at the density of tetracycline baits, 1 per 1.6 km^2 and be visited multiple times to increase precision. It cost roughly $50,000 (not including labor costs) to visit every square mile of northern Kuiu Island two times in 2002 for this tetracycline study. Visiting these sites multiple times would be financially and logistically prohibitive. However, an estimate using one genetic sample of hair-snagged individuals and the genetic identities of the tissue samples in the harvest (Lincoln-Petersen model) would presumably give the same population estimate with the same variation and with the same field cost, but such an approach would have higher analysis costs than tetracycline analysis ($40 – 60/genetic sample *vs*. $3.15/tetracycline sample).

The high density of black bears on Kuiu Island is perhaps due to the confluence of several important factors: access to spawning salmon, absence of brown bears and a heterogeneous topographical and vegetation matrix. Access to spawning salmon is known to increase brown bear population production (Miller *et al.* 1997, Hilderbrand *et al.* 1999), and this is likely true for black bears as high quality fall foods correlate with higher reproduction (*e.g.*, Rogers 1987). However, in other areas of Alaska where black bears occur with spawning salmon runs, densities are not as high. On the Kenai Peninsula, Miller *et al.* (1997) estimated the densities of black bears in two different areas to be 0.15 and 0.20 bears/km^2. They suggested that the black bears in these study areas do not use salmon due to competitive exclusion by brown bears. Other black-bear-only islands in Southeast Alaska where there are abundant salmon streams may also support high black bear densities (Prince of Wales, Kupreanof and Mitkof islands). However, anecdotal observations from biologists and hunting guides suggest that densities on these islands are not as high as on Kuiu Island.

The mountainous topography of Kuiu Island produces avalanche paths, which maintain swaths of land in early seral stages that provide abundant berries (*Vaccinium* spp. and *Rubus* spp.), which in turn likely influences bear population density. In addition to avalanches maintaining berry production at high levels in some areas, new clear-cuts on northern Kuiu Island also provide high berry abundance. Erickson *et al.* (1982) also noted that black bears on Mitkof Island in Southeast Alaska used early seral stage clear-cuts in greater proportion than their availability. Black bears on Long Island, WA also have strong association with early seral stage clear-cuts (Lindzey and Meslow 1977a, b, Lindzey *et al.* 1986), and the authors have shown that the bear density fluctuates with variation in berry production. Early vegetative seral stages subsequent to clear-cutting enhance berry production, however as succession progresses, these clear-cuts enter a stem-exclusion stage, where berry production is reduced. Lindzey *et al.* (1986) documented a reduction in recruitment and an increase in mortality and dispersal as carrying capacity was reduced when berry production declined. Likewise, the high black bear population density on Kuiu Island estimated in this study may be influenced by the abundance and seral stages of clear-cuts. However, the majority of industrial logging on Kuiu Island occurred in the mid 1980’s resulting in clear-cuts just beginning to approach stem-exclusion stage and reduced berry production, and thus population density may respond accordingly. While to date there are no comprehensive studies on habitat use by black bears in Southeast Alaska, I expect the black bear density is likely to fluctuate in relation to habitat quality, which is influenced by timber management policy.

Devil's club berries (*Oplopanax horridus*), which are associated with moist old-growth forests, were singled out as an important summer and fall food for black bears on the Kenai Peninsula on the central coast of Alaska (Schwartz and Franzmann 1991). Black bears used old-growth forests in proportion to their availability on Mitkof Island in Southeast Alaska (Erickson *et al*. 1982), and 13 out of 13 dens examined were associated with old-growth, decadent trees. These authors concluded that "There can be little doubt… that the assured providing of suitable dens for black bears is a serious concern if the near-elimination of old forests… is a management objective" (Erickson *et al*. 1982). Thus while clear-cuts may produce an ephemeral increase in black bear density, the vegetative matrix, which includes old-growth forest, intact riparian areas of salmon streams and avalanche slopes, likely provides a more consistent, heterogeneous and productive environment resulting in a high black bear density.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Garshelis and Visser (1997) have shown that the tetracycline biomarking method is effective at estimating size of large populations (15,000 – 25,000) in areas of 43,000 km^2 (MI) and 83,000 km^2 (MN). I suggest that this method is also effective in a small (673 km^2), dense population. This study benefited from a relatively high harvest rate, and a well coordinated bear registration effort by ADF&G, ensuring high compliance of hunters providing samples (95 – 100%). If future researchers are considering employing tetracycline biomarking in a small population, the small sample size should be offset by a combination of high rate of sample submission by hunters, harvest and baiting success.

This study has produced point estimates of the density of black bears on Kuiu Island. These estimates are among the highest recorded across the species range, suggesting high productivity of the environment. However, the population estimate generated in this study represents a snapshot in time, yet effective population management requires an understanding of temporal trends in population size. It is unknown whether this high black bear density is an ephemeral effect of the current seral stage of clear-cuts on northern Kuiu Island. Because little is known about black bear habitat use in Southeast Alaska, and consumptive use of the black bears and the forest on Kuiu Island continues, further population and habitat studies should be conducted to inform future management actions.

LITERATURE CITED

Anderson, D. R., W. A. Link, D. H. Johnson and K. P. Burnham. 2001. Suggestions for presenting the results of data analyses. Journal of Wildlife Management 65:373-378.

Beck, T. D. I. 1991. Black bears of west-central Colorado. Technical Publication 39, Colorado Division of Wildlife.

Beckmann, J. P. and J. Berger. 2003. Using black bears to test ideal-free distribution models experimentally. Journal of Mammalogy 84:594-606.

Belant, J. L., J. F. Van Stappen and D. Paetkau. 2004. American black bear population size and genetic diversity at Apostle Islands National Lakeshore. Ursus 15.

Ben-David, M., K. Titus and L. R. Beier. 2004. Consumption of salmon by Alaskan brown bears: a trade-off between nutritional requirements and the risk of infanticide? Oecologia 138:465-474.

Boulanger, J. and B. McLellan. 2001. Closure violation in DNA-based mark-recapture estimation of grizzly bear populations. Canadian Journal of Zoology-Revue Canadienne De Zoologie 79:642-651.

Brownie, C., D. R. Anderson, K. P. Burnham and D. S. Robson. 1985. Statistical inference from band recovery data - a handbook, 2nd edition. United States Department of the Interior; Fish and Wildlife Service, Washington D.C.

Brownie, C. and K. H. Pollock. 1985. Analysis of multiple capture-recapture data using band-recovery methods. Biometrics 41:411-420.

Chapman, D. G. 1965. The estimation of mortality and recruitment from a single-tagging experiment. Biometics 21:529-542.

Chi, D. K. 1999. The effects of salmon availability, social dynamics, and people on black bear (*Ursus americanus*) fishing behavior on an Alaskan salmon stream. Dissertation. Utah State University, Logan.

Ennis, S. and T. F. Gallagher. 1994. A PCR-based sex-determination assay in cattle based on the bovine amelogenin locus. Animal Genetics 25:425-427.

Erickson, A. W., B. M. Hanson and J. J. Brueggeman. 1982. Black bear denning study, Mitkof Island, Alaska. Contract No. FRI-UW-8214, School of Fisheries, College of Ocean and Fishery Sciences, University of Washington, Seattle.

Freedman, A. H., K. M. Portier and M. E. Sunquist. 2003. Life history analysis for black bears (*Ursus americanus*) in a changing demographic landscape. Ecological Modeling 167:47-64.

Garshelis, D. L. and L. G. Visser. 1997. Enumerating megapopulations of wild bears with an ingested biomarker. Journal of Wildlife Management 61:466-480.

Gende, S. M. and M. F. Willson. 2001. Passerine densities in riparian forests of southeast Alaska: Potential effects of anadromous spawning salmon. Condor 103:624-629.

Hebblewhite, M., M. Percy and R. Serrouya. 2003. Black bear (*Ursus americanus*) survival and demography in the Bow Valley of Banff National Park, Alberta. Biological Conservation 112:415-425.

Hilderbrand, G. V., S. D. Farley, C. T. Robbins, T. A. Hanley, K. Titus and C. Servheen. 1996. Use of stable isotopes to determine diets of living and extinct bears. Canadian Journal of Zoology 74:2080-2088.

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

Johnson, R. H. 1964. The tetracyclines: A review of the literature - 1948 through 1963. Journal of oral therapy and pharmacology 1:190-217.

Kendall, W. L. 1999. Robustness of closed capture-recapture methods to violations of the closure assumption. Ecology 80:2517-2525.

Kirchhoff, M. J. 2000. Deer pellet-group surveys in Southeast Alaska. Federal Aid in Wildlife Restoration, Annual Report Alaska Department of Fish and Game, Division of Wildlife Conservation, Douglas.

Lindzey, F. G., K. R. Barber, R. D. Peters and E. C. Meslow. 1986. Responses of a black bear population to a changing environment. Int. Conf. Bear Res. and Manage. 6:57-63.

Lindzey, F. G. and E. C. Meslow. 1977a. Home range and habitat use by black bears in Southwestern Washington. Journal of Wildlife Management 41:413-425.

Lindzey, F. G. and E. C. Meslow. 1977b. Populations characteristics of black bears on an island in Washington. Journal of Wildlife Management 41:408-412.

Lombardo, C. A. 1993. Population ecology of black bears on Camp Lejeune, North Carolina. M.Sc. Thesis. University of Tennessee, Knoxville.

Martorello, D. A. 1998. Ecology of black bears in coastal North Carolina. Master of Science. University of Tennessee, Knoxville.

Martorello, D. A., T. H. Eason and M. R. Pelton. 2001. A sighting technique using cameras to estimate population size of black bears. Wildlife Society Bulletin 29:560-567.

Matson, G. M. and K. D. Kerr. 1998. A method for dating tetracycline biomarkers in black bear cementum. Ursus 10:455-458.

Miller, S. D., G. W. White, R. A. Sellers, H. V. Reynolds, J. W. Schoen, K. Titus, V. G. Barnes, R. B. Smith, R. R. Nelson, W. B. Ballard and C. C. Schwartz. 1997. Brown and black bear density estimation in Alaska using radiotelemetry and replicated mark-resight techniques. Wildlife Monographs 133:55.

Mills, L. S., J. J. Citta, K. P. Lair, M. K. Schwarz and D. A. Tallmon. 2000. Estimating animal abundance using noninvasive DNA sampling: Promise and pitfalls. Ecological Applications 10:283-294.

Paetkau, D., W. Calvert, I. Stirling and C. Strobeck. 1995. Microsatellite analysis of population structure in Canadian polar bears. Molecular Ecology 4:347-354.

Paetkau, D., G. F. Shields and C. Strobeck. 1998a. Gene flow between insular, coastal and interior populations of brown bears in Alaska. Molecular Ecology 7:1283-1292.

Paetkau, D. and C. Strobeck. 1994. Microsatellite analysis of genetic-variation in black bear populations. Molecular Ecology 3:489-495.

Paetkau, D., L. P. Waits, P. L. Clarkson, L. Craighead, E. Vyse, R. Ward and C. Strobeck. 1998b. Variation in genetic diversity across the range of North American brown bears. Conservation Biology 12:418-429.

Person, D. K., M. Kirchhoff, V. Van Ballenberghe, G. C. Iverson and E. Grossman. 1996. The Alexander Archipelago wolf: a conservation assessment. Gen. Tech. Rep. PNW-GTR-384, United States Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

Poole, K. G., G. Mowat and D. A. Fear. 2001. DNA-based population estimate for grizzly bears *Ursus arctos* in northeastern British Columbia, Canada. Wildlife Biology 7:105-115.

Rogers, L. L. 1987. Effects of food supply and kinship on social behavior, movements, and population growth of black bears in northeastern Minnesota. 97:72.

Schwartz, C. C. and A. W. Franzmann. 1991. Interrelationship of black bears to moose and forest succession in the northern coniferous forest. Wildlife Monographs:1-58.

Sorensen, V. A. and R. A. Powell. 1998. Estimating survival rates of black bears. Canadian Journal of Zoology-Revue Canadienne De Zoologie 76:1335-1343.

Taberlet, P. and G. Luikart. 1999. Non-invasive genetic sampling and individual identification. Biological Journal of the Linnean Society 68:41-55.

Taylor, M. and J. Lee. 1994. Tetracycline as a biomarker for polar bears. Wildlife Society Bulletin 22:83-89.

Valiere, N. 2002. GIMLET: a computer program for analysing genetic individual identification data. Molecular Ecology Notes 2:377-379.

Waits, L. P., G. Luikart and P. Taberlet. 2001. Estimating the probability of identity among genotypes in natural populations: cautions and guidelines. Molecular Ecology 10:249-256.

White, G. C. and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46 Supplement:120-138.

Whitman, J. S. 2001. Brown bear management report of survey-inventory activities: Unit 4. Project 4.0, Alaska Department of Fish and Game, Juneau.

Willson, M. F., S. M. Gende and B. H. Marston. 1998. Fishes and the Forest: Expanding perspectives on fish-wildlife interactions. Bioscience 48:455-462.

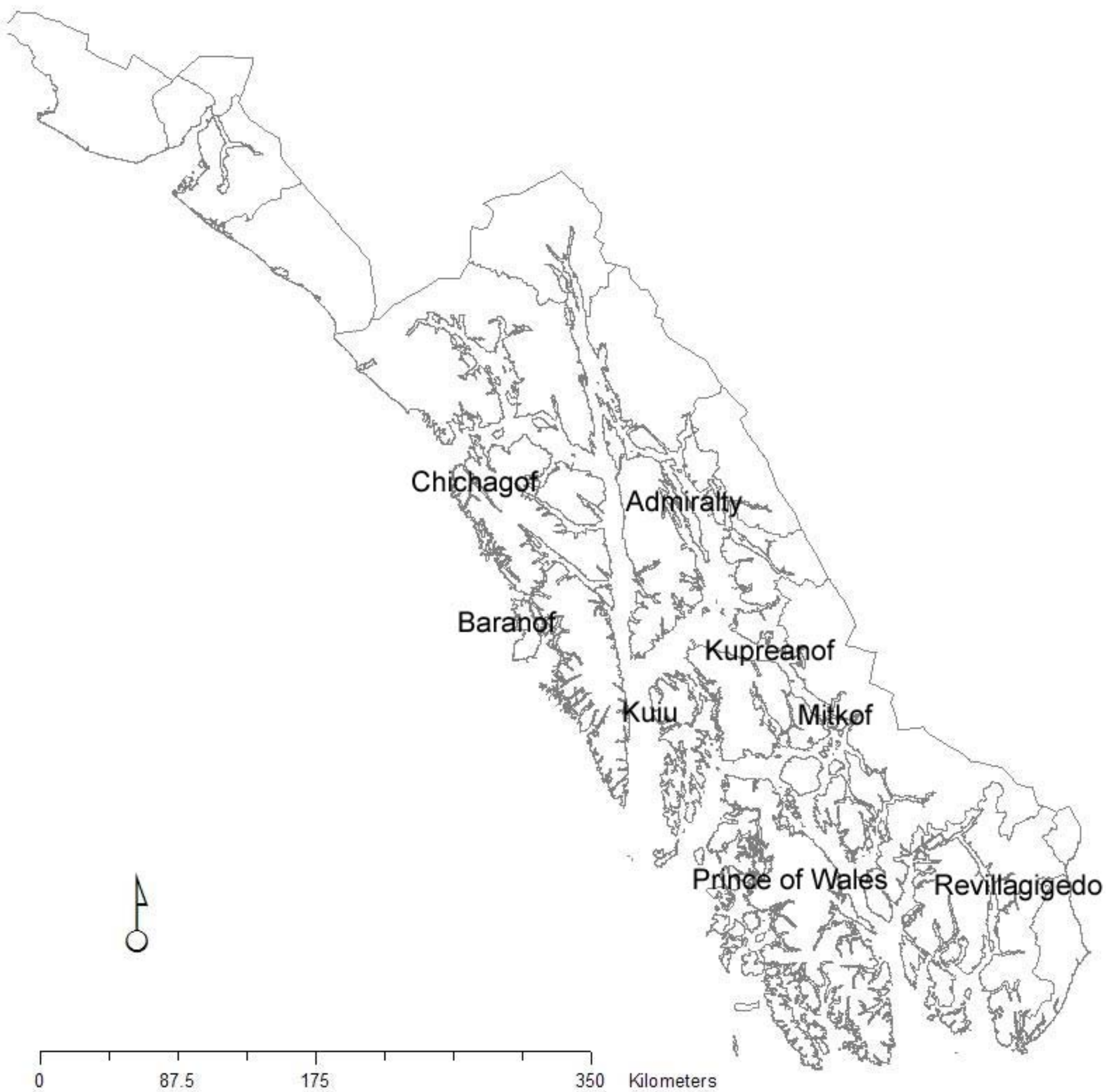


Figure 1. The islands of the Alexander Archipelago of Southeast Alaska.

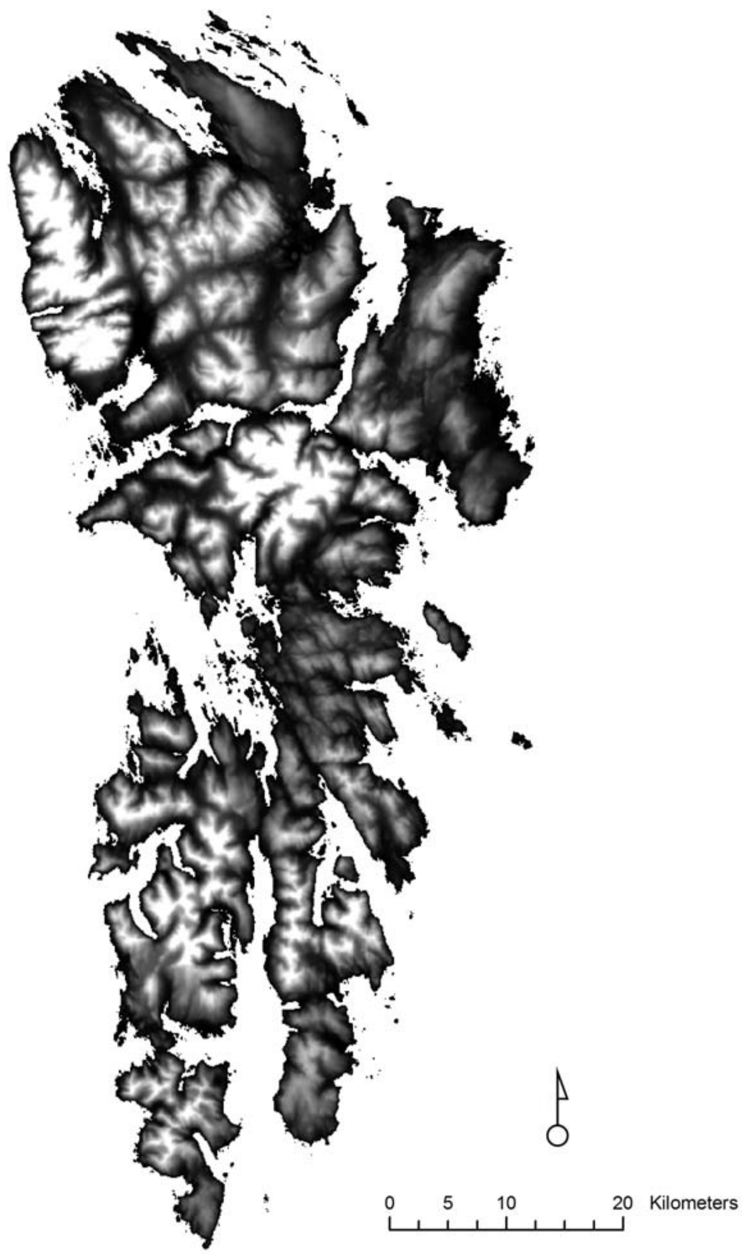


Figure 2. Kuiu Island (1963 km^2) of the Alexander Archipelago, in Southeast Alaska (Digital Elevation Model, provided by USFS).

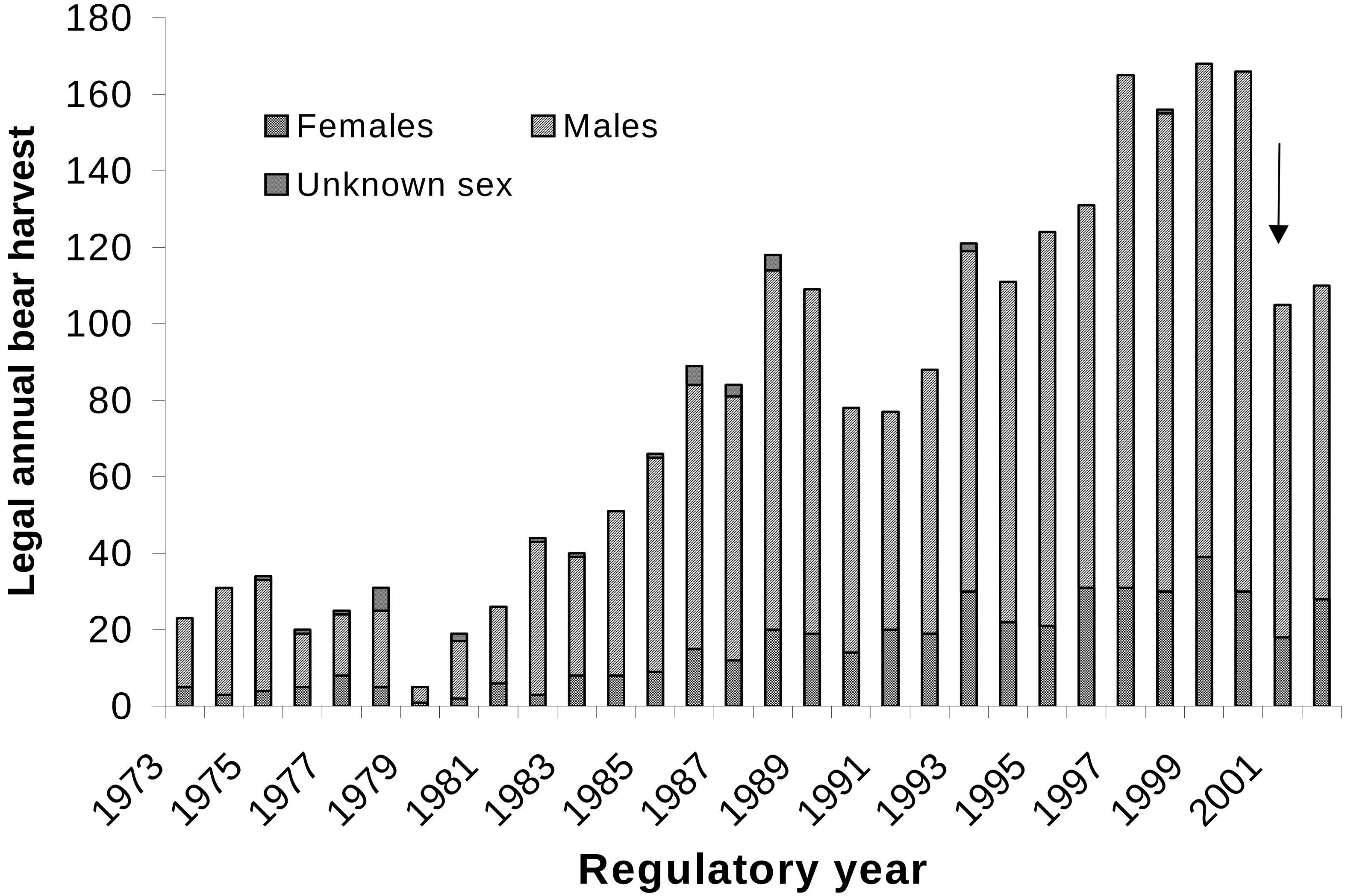


Figure 3. Annual legal black bear harvest on Kuiu Island, Alaska. Data from Alaska Department of Fish and Game. Arrow shows the commencement of the annual harvest cap of 120 bears/regulatory year.

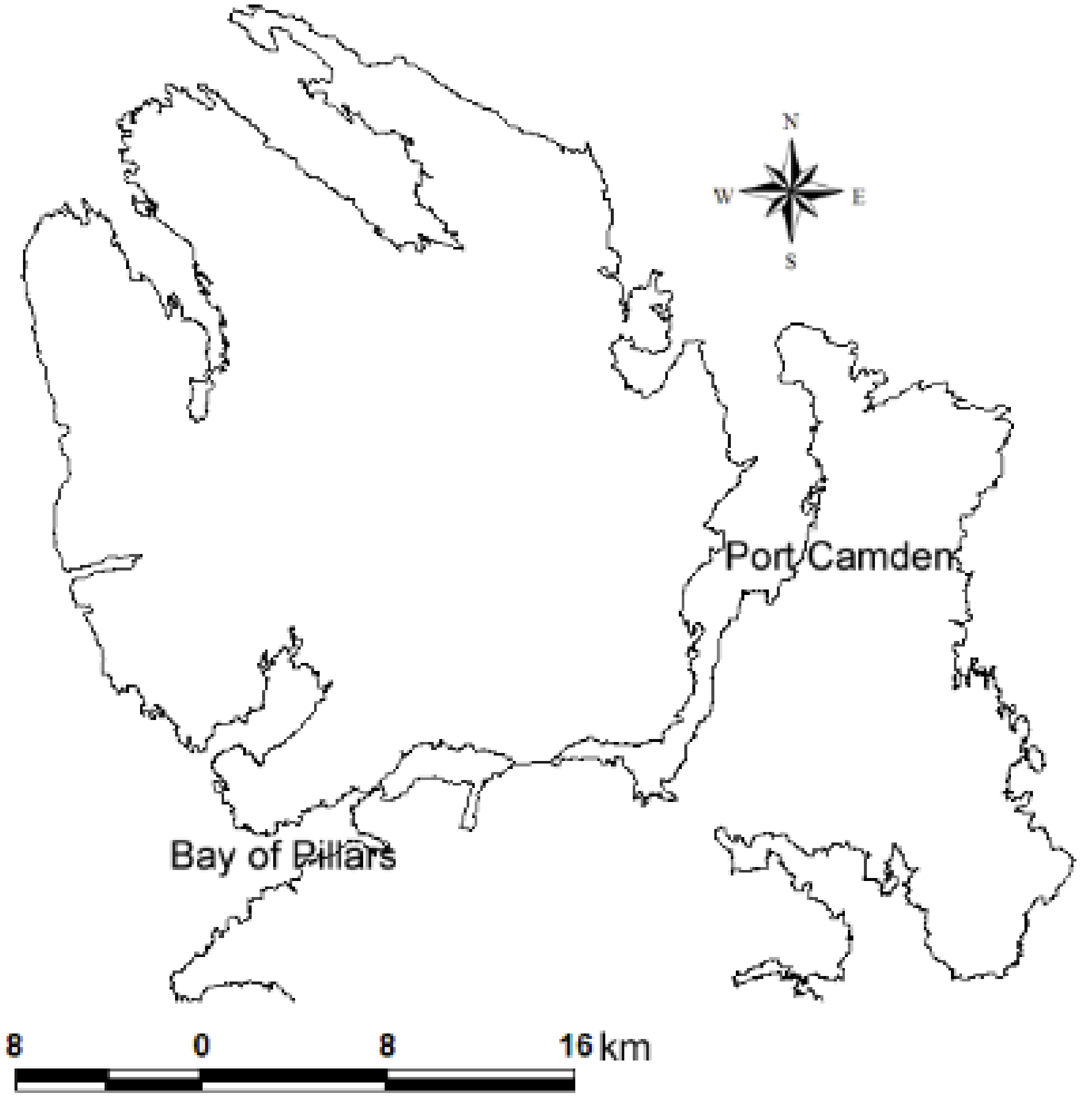
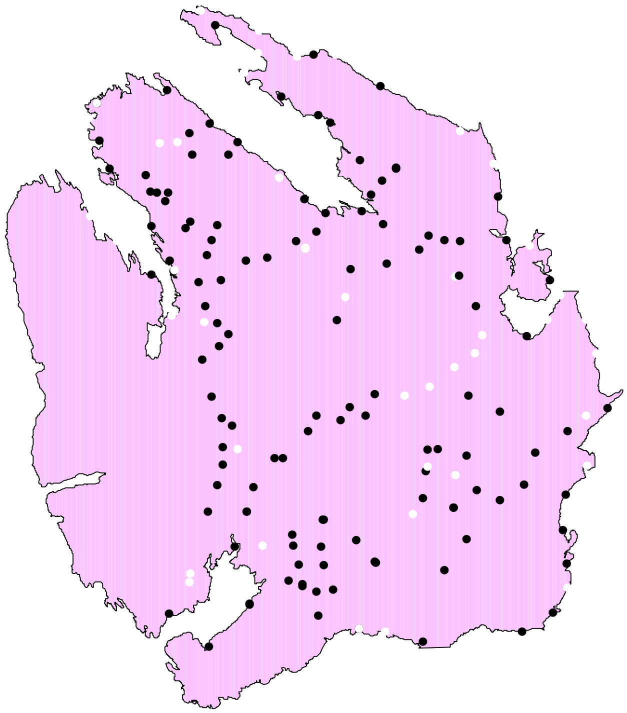
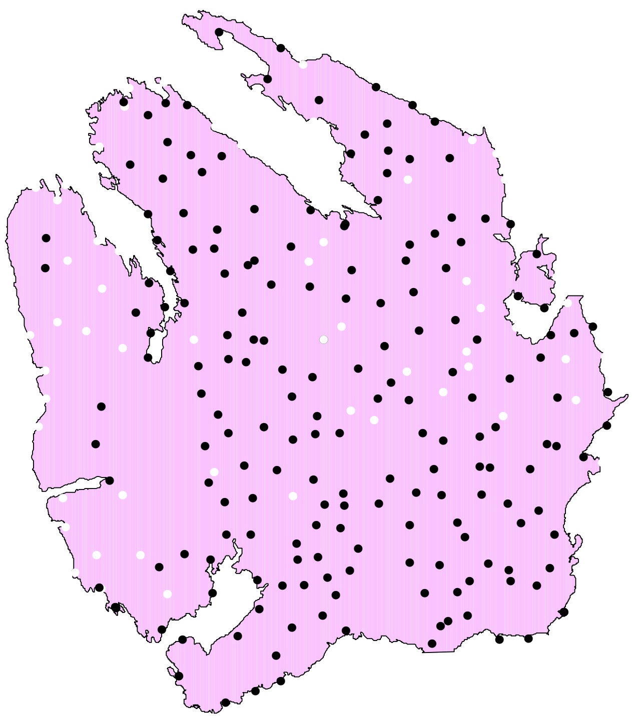


Figure 4. Northern Kuiu Island (673 km^2), Alaska.



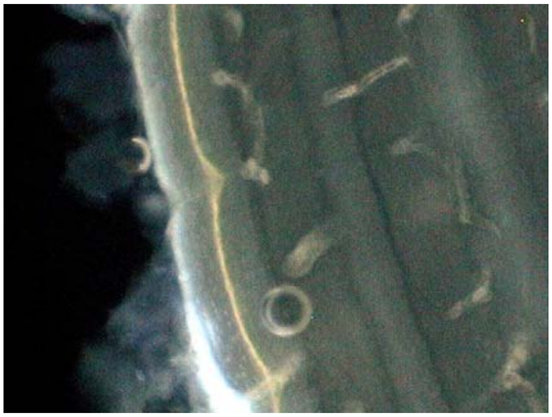
a.



b.

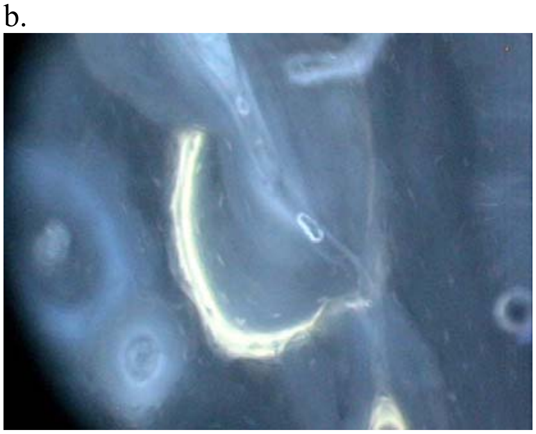
Figure 5. a. Distribution of tetracycline baits in 2000 on northern Kuiu Island. Black dots represent baits taken by bears; white dots represent baits not taken by bears. b. Distribution of tetracycline baits in 2002.

Figure 6. Clockwise from top left: An intact 2000 bait showing barbed wire for hair snaring and scent flag; an intact bait in old-growth hemlock forest; a bear smelling a scent flag with bait in background; remains of taken bait.



a.

b.



c.

Figure 7. a. 40X image of tetracycline mark in Kuiu bear toe bone. b. 40X image of tetracycline marks, partially remodeled in haversian systems of a toe bone. c. 100X image of a double mark in a toe bone. Images provided by D. Garshelis.

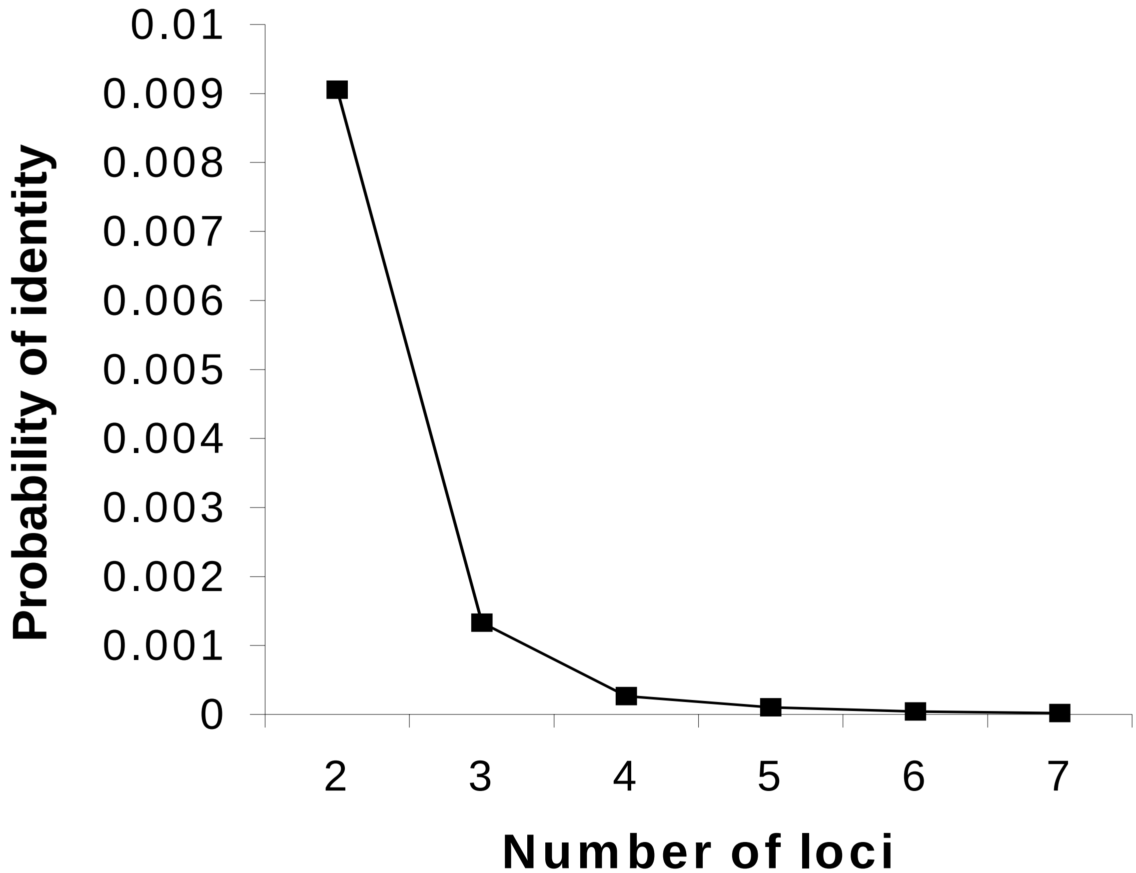


Figure 8. Unbiased probability of identity for northern Kuiu Island black bears, calculated with microsatellite genetic data from 117 tissue samples.

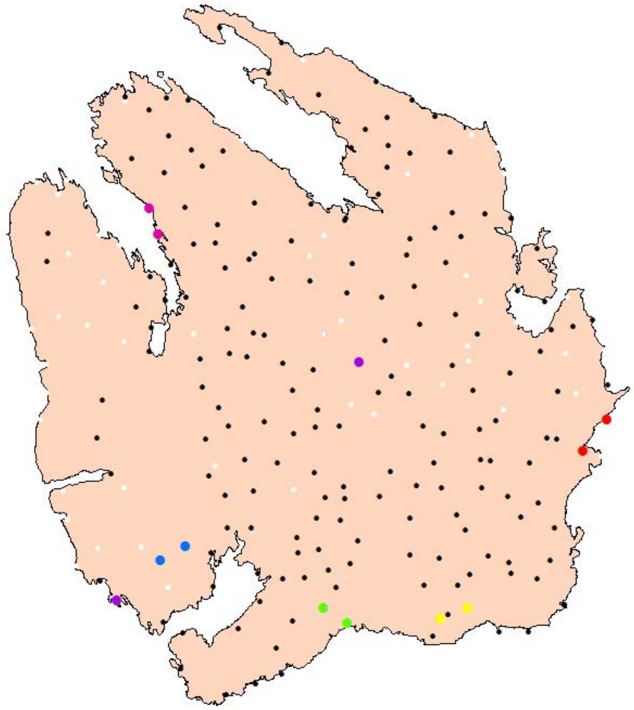


Figure 9. Multiple tetracycline baits taken by the same individual bears in 2002. Each pair of baits with the same color (n = 6) were taken by the same bear. Baits in black were each taken by a single bear, baits in white did not result in a marked bear.

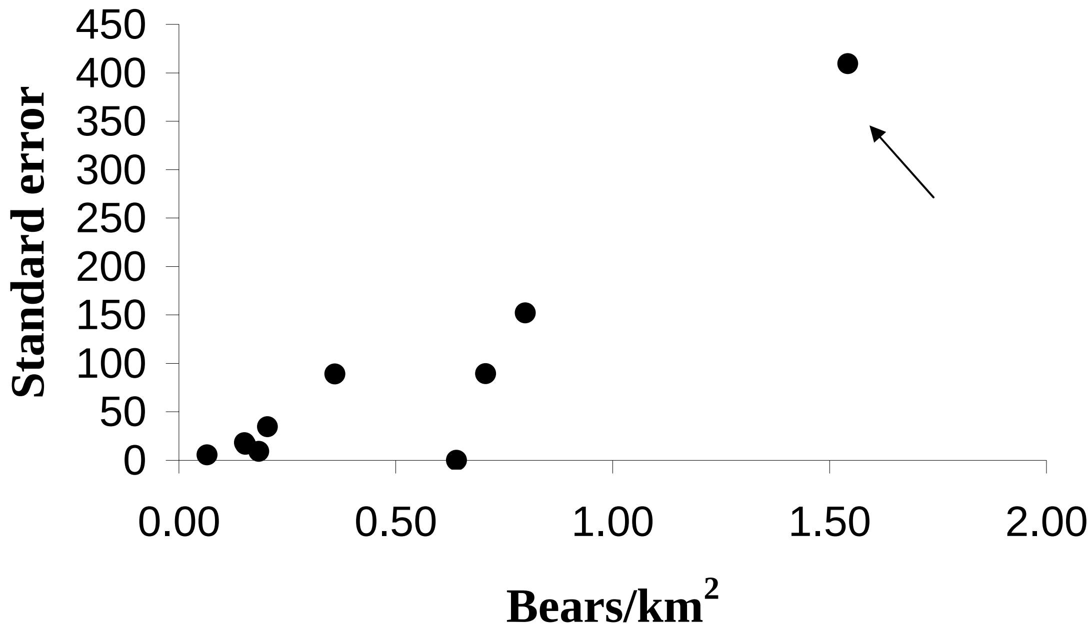


Figure 10. Standard error associated with North American black bear density estimates produced since 1997. Arrow indicates the density and standard error estimated for the Kuiu Island black bears using tetracycline biomarking.

Table 1. Primer pairs used to amplify microsatellite loci (Paetkau and Strobeck 1994, Paetkau *et al.* 1995). Sequences are given in the 5' to 3' direction.

Locus	GenBank accession number	Repeat motif	Forward sequence	Reverse sequence	Dye	Allele range (bp)
O	U22090	$(GT)_n$	CCTTGGCTACCTCAGATGG	GCTTCTAATCCAAAGATGCATAAAGG	5-FAM	164-190
J	U22087	$(GT)_n$	GCTTTTGTGTGTGTTTTTGC	GGATAACCCCTCACACTCC	6-HEX	80-97
L	U22088	$(GT)_n$	GTACTGATTTAATTCACATTTCCC	GAAGATACAGAAACCTACCCATGC	5-FAM	134-172
Ct‡	U22085	$(GT)_n$	AAAGCAGAAGGCCTTGATTTCCTG	**GTTT**GTGGACATAAACACCGAGACAGC	6-HEX	103-123
M	U22089	$(GT)_n$	TTCCCCTCATCGTAGGTTGTA	GATCATGTGTTTCCAAATAAT	NED	209-223
D	U22094	$(GT)_n$	GATCTGTGGGTTTATAGGTTACA	CTACTCTTCCTACTCTTTAAAGAG	NED	180-184
X	U22093	$(GT)_n$	CCCCTGGTAACCACAAATCTCT	GCTTCTTCAGTTATCTGTGAAATCAAAA	PET	141-169

‡ the “t” symbolizes that a tail sequence (GTTT) was added to the 5' end reverse primer in order to decrease the effect of 2-basepair stutter.

Table 2. PCR conditions for microsatellite primer pairs and the sex determining region of the amelogenin gene. Numbers are volume (µl). All reactions were run with 0.6 µl of BSA‡ (20 mg/ml; SIGMA). All reactions are 15 µl total volume, and thus remainder volume not listed here is in dH_20 or DNA template. For PCRs using extracted DNA from hair, 5 µl of DNA template (< 1 ng/ µl) was used. For PCRs using extracted DNA from tissue, 2 µl of template (10 ng/ µl) was used.

Locus	GenBank Accession Number	ABI† $MgCl_2$ (25mM)	ABI† Buffer Cetus II	CLONTECH Titanium *Taq* buffer	DNTPs (10mM)	Betaine (SIGMA)	Primer Mix (10µM)	CLONTECH Titanium *Taq* polymerase	cycles	T_a ††
OJ	U22087 U22090	1.2	1.5	-	0.5	3.0	0.7/0.3	0.2	45	58
L	U22088	1.5	1.0	-	0.5	-	0.5	0.2	30	60
Ct‡‡	U22085	0.9	1.5	-	0.5	-	0.5	0.2	45	62
M	U22089	0.9	1.5	-	0.5	-	0.4	0.2	45	50
X	U22093	-	-	1.5	0.6	-	0.7	0.2	45	58
D	U22094	-	-	1.5	0.5	3.0	0.6	0.3	45	58
SE47/48	-	0.9	1.5	-	0.5	-	0.3	0.2	35	58

†Applied Biosystems, Inc.
‡ Bovine Serum Albumin
††Annealing Temperature, °C
‡‡ the “t” symbolizes that a tail sequence (gttt) was added to the 5' end reverse primer in order to decrease the effect of 2 base pair stutter.

Table 3. Summary of harvested bears that were marked on northern Kuiu Island with tetracycline, and unmarked during three regulatory harvest years (2000 – 2002) from Kuiu and Kupreanof Islands.

	Northern Kuiu		Southern Kuiu		Western Kupreanof	
Year†	# of samples* (% compliance)	# of bears marked	# of samples	# of bears marked	# of samples	# of bears marked
2000	79 (100%)	9 (1 double)	84	2	5	0
2001	57 (100%)	5	48	0	67	1
2002‡ (2000 marks)	54 (95%)	2	54	0	53	1
2002‡ (2002 marks)	54	9 (1 double)	54	0	53	1

† regulatory year. For example, year 2000 includes harvest seasons fall 2000 and spring 2001.
* these include samples from Port Camden and Bay of Pillars, whose precise location is unknown (n = 2, 3 and 3 from 2000, 2001 and 2002, respectively).
‡ One bear harvested in 2002, had a mark from 2000 and a mark from 2002.

Table 4. Lincoln-Petersen population estimates of black bears on Kuiu Island, Alaska using tetracycline biomarking. Estimates are based on bears marked, which is reduced from baits taken by an estimate of 6.2% double-marking. Yearly emigration rate for 2000 was calculated by the number of recoveries of 2000 marks outside northern Kuiu Island divided by total number of recoveries averaged from the three years of data. Emigration for 2002 was calculated by the number of recoveries of 2002 marks outside northern Kuiu Island divided by the total number of 2002 marks recovered. In 2002, the two estimates of baits taken by bears (195 vs. 205) are a liberal and conservative estimate of how many baits with no sign were taken by non-target species.

Year	Baits taken	Emigration	M	C†	R	N est.	SE	95% CI of N	N est./km^2	Lower 95% CL	Upper 95% CL
2000	138	-	129.4	78	9.1	1019	316	538	1.51	0.71	2.3
2000	138	0.066	120.3	78	9.1	948	293	499	1.41	0.67	2.2
2002	195	-	182.9	52.5	9	983	299	510	1.46	0.70	2.2
2002	201	-	188.5	52.5	9	1013	309	526	1.51	0.72	2.3
2002	195	0.100	163.4	52.5	9	879	266	454	1.31	0.63	2.0
2002	201	0.100	168.4	52.5	9	905	275	469	1.34	0.65	2.0

† number of captures includes all captures from northern Kuiu in addition to ½ of imprecise locations (*n* = 2 and 3 for 2000 and 2002, respectively). Imprecise locations are for a few bears from Port Camden and Bay of Pillars, which bisect the study area.

M – number of bears marked; C – number of bears harvested; R – number of bears recaptured. N est. – population point estimate.

Table 5. Mark and recovery data of tetracycline marked black bears used for Brownie survival model.

Year marked	Bears marked	Bears recovered		
		2000	2001	2002
2000	129	11	7	3
2001	0		0	0
2002	189			10

Table 6. Selected Brownie recovery models for black bears marked on northern Kuiu Island in 2000.

Model	AICc	ΔAICc	AICc Weight	Likelihood	# Parameters	Deviance
S(.)*f*(.)	239.93	0.00	0.36	1	2	1.74
S(.)*f*(1, 2_3)	240.23	0.30	0.31	0.86	3	0.01
S(.)*f*(12_3)	240.98	1.04	0.21	0.59	3	0.75
S(.)*f*(t)	242.28	2.35	0.11	0.31	4	0.0

Table 7. Estimates of survival and recovery rate (model averaged) for black bears marked with tetracycline on Kuiu Island in 2000.

Parameter	Estimate ± SE
Survival rate fall 2000 - fall 2001	0.67± 0.18
Recovery rate summer 2000 - fall 2000	0.079 ± 0.02
Recovery rate 2000 - 2001	0.072 ± 0.02
Recovery rate 2001 - 2002	0.060 ± 0.02

Elizabeth Peacock

Digitally signed by Elizabeth
DN: CN = Elizabeth, C = US, O = University of Nevada - Reno, OU = Ecology, Evolution and Conservation Biology
Reason: I am the author of this document
Location: Reno, NV
Date: 2004.12.13 15:20:14 -08'00'