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Denning Ecology of Black Bears on Intensively Logged Prince of Wales Island, Southeast Alaska

Boyd Porter, David P. Gregovich, and Stephen W. Bethune

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Alaska Department of Fish and Game Division of Wildlife Conservation

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Denning Ecology of Black Bears on Intensively Logged Prince of Wales Island, Southeast Alaska

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Cover Photo: Black bear denning in a log. ©2012 ADF&G. Photo by Stephen W. Bethune.

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Abstract

Information on the denning behavior of black bears in intensively logged areas of Southeast Alaska is lacking but important in assessing the potential effects of timber harvest on bears and their populations. We identified 91 den locations via a combination of field visits and GPS-collar location clusters during 2009–2014 and collected information on the den microsite (e.g., tree species, tree dimensions, and bedding materials) and macrosite (i.e., GIS-derived landscape) characteristics. We built resource selection functions contrasting the landscape attributes of den sites versus random locations. We also obtained information on denning chronology, including den entrance and emergence dates and the duration of 'walking hibernation,' a post-denning period of reduced movement rates. Dens were associated with living or dead woody structures in all but one case and were split between multiple coniferous tree species, most commonly western hemlock (44%) and Sitka spruce (26%). The mean size of woody structures used as dens was 1.38 m diameter at breast height, and most bears denned under the stem of the woody structure (76%) rather than inside the trunk (24%). Most dens were associated with standing or cut trees (47% and 45%, respectively), not naturally down trees (8%). Overall, bears were up to 11.70 times more likely to select den sites in commercial forest classes (whether old-growth or previously logged stands) than in areas without such forest. Bears selected for second-growth timber as strongly as old-growth forest, as large stumps suitable for denning are common in second growth and persist for an unknown period post-logging. We found bears in our study area used den sites associated with large trees also targeted by the logging industry. Extensive large-scale commercial logging during the past 70 years has reduced the recruitment of such large trees. Although den structures can persist for some time post-logging, their production is likely to be further reduced by planned U.S. Forest Service logging. Balanced forest management should account for the denning requirements of black bears and their use of large living and dead trees as dens.

Key words: black bear, *Ursus americanus,* denning, hibernation, logging, Prince of Wales Island, Southeast Alaska

Introduction

Black bears are a recreational and economic resource in Alaska, providing the public with hunting and viewing opportunities and income via visiting nonresident hunters and guided hunts. Statewide, there has been a mean annual harvest of 1,650 black bears 2012–2019 (the period of current hunting regulations). Due to seasonally abundant food resources, including salmon and berries, black bears can reach high densities in the coastal temperate rainforest of Southeast Alaska (Peacock et al. 2011). For example, Prince of Wales Island within Game Management Unit 2 supported a mean annual harvest of about 140 bears in the same period (Alaska Department of Fish and Game, unpublished data).

Much of the forested land in Southeast Alaska is managed for timber harvest. Industrial-scale logging on POW and other areas commenced in the 1950s, and by 2004, 32% of all available commercial old-growth forest on POW had been harvested (Albert and Schoen 2013). Logging continues on POW; the U.S. Forest Service (USFS) has proposed harvesting up to another 9,417 ha of old-growth and 7,837 ha of second-growth timber over the next 15 years (USFS 2019a). This planned harvest of additional old-growth forest in an already intensively harvested landscape will further alter black bear habitat and may affect abundance.

Dens fulfill a critical life function for black bears and understanding the denning ecology of black bears is important in evaluating the potential effects of land management actions (Pelton 1985, Hillman and Yow 1986, Weaver and Pelton 1994, Linnell et al. 2000). Black bear survival appears to be promoted by use of dens that afford adequate protection from predators and weather extremes (Johnson and Pelton 1981). This may be the case particularly in northern regions where food availability is limited for long periods in the winter, den residence is prolonged (Lindzey and Meslow 1976), and energetic stores must last longer. Although the denning period can be abbreviated in southern latitudes (Leopold 1959), it is protracted to 7 months or more in the north (Smith et al. 1994), allowing bears to survive long periods of low food availability. Females are particularly vulnerable to excessive energy expenditure in dens, as they incur the additional cost of lactation to feed newly born cubs. The cubs and adult bears are also protected from predation by adequate dens (Alt 1984, Paquet and Carbyn 1986, Davis and Harestad 1996).

Denning ecology of black bears in Southcentral and Interior Alaska has been studied (Miller et al. 1982, Schwartz et al. 1987), but little is known of black bear denning ecology in the coastal temperate rainforest of Southeast Alaska, especially with regard to the potential effects of intensive timber management. Although black bears den in caves or excavate dens in some parts of their range, there is evidence that trees (either living or dead) are heavily used as dens in the forests of western North America (Noble et al. 1990, Davis 1996, Davis et al. 2012). Climatic conditions in coastal temperate rainforests such as in Southeast Alaska are substantially wetter than other areas within the geographic range of black bears (Davis et al. 2012), and potentially constrain the types of structures that are suitable for denning. A. Crupi (ADF&G wildlife research biologist, unpublished data) found 54% of brown bear dens near Yakutat, Southeast Alaska, were in or under living or dead trees. Additionally, shallow soils in the region may limit the ability of bears to excavate dens. Large diameter living or dead woody structures (e.g., standing trees, logs, cavities, root wads, and stumps) may be the only features suitable for keeping bears warm and dry during wet, temperate winters (Davis 1996). Trees suitable for den sites can become scarce due to development and logging (Hamilton and Marchinton 1980), and this may especially be the case in areas experiencing intensive timber harvest of old-growth trees, such as POW.

The goals of our study were to characterize the landscape features associated with den sites and attributes of structures used for denning by black bears in Southeast Alaska, where only a few dens have been previously described (Erickson 1982), and to evaluate the likely effects of past and current old-growth timber management on the current availability and future recruitment of suitable denning structures.

More specific objectives were to 1) assess factors that influence den site selection at a macro scale using resource selection functions (RSFs, Boyce et al. 2002, Manly et al. 2002), 2) describe microscale den characteristics, and 3) describe denning phenology and chronology. The results from this study can assist managers in balancing competing timber and wildlife interests by providing information on the habitats which promote the presence of dens used by black bears.

Study Area

The study area (Fig. 1) is located on northcentral POW, a large (6,670 km^2) island which has a temperate maritime climate characterized by cool summer (<18° C) and mild winter temperatures (>0° C). POW is the fourth largest island in the United States and the largest in the myriad islands that comprise the Alexander Archipelago. Annual mean precipitation is approximately 2.5 m, often falling as snow November–March, particularly at higher elevations; annual mean snowfall is 0.57 m (Western Regional Climate Center 2018).

Conifer forests are prevalent on POW, which are interspersed with fens (on relatively flat slopes with poorly drained soils), shrubs (particularly on steep slopes that experience recurring landslides and/or avalanches), and, at higher elevations, alpine tundra. The conifer forests are dominated by Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), Alaska yellow cedar (*Chamaecyparis nootkatensis*), and western red cedar (*Thuja plicata*). The plant understory community is a mix of species, including blueberry (*Vaccinium* spp), salal (*Gaultheria shallon*), devil's club (*Oplopanax horridus*), salmonberry (*Rubus spectabilis*), and others (Alaback et al. 2013). The island also supports resident populations of Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) and wolves (*Canis lupus*).

Industrial scale logging on POW began in the 1950s (Albert and Schoen 2013) and has continued to the present. Prior to logging, virtually all forests in Southeast Alaska were old growth due to limited large-scale disturbances. Land cover in the study area consisted of 58% commercially valuable forest with the remainder non-commercial forest, wetlands, shrubs, and alpine vegetation. Clearcut logging has converted 36% of the commercially valuable forest to younger successional stages (USFS 2019c; Fig. 1) and human access for hunting and other purposes has been greatly improved by construction of thousands of kilometers of logging roads. Commercial forest lands within the study area are now a mosaic of stand ages, including recent clearcuts (<30 years old) with a dense shrub understory and open but developing tree canopy, older clearcuts (≥30 years old) with a dense, even-aged tree canopy and little understory, and old-growth forest

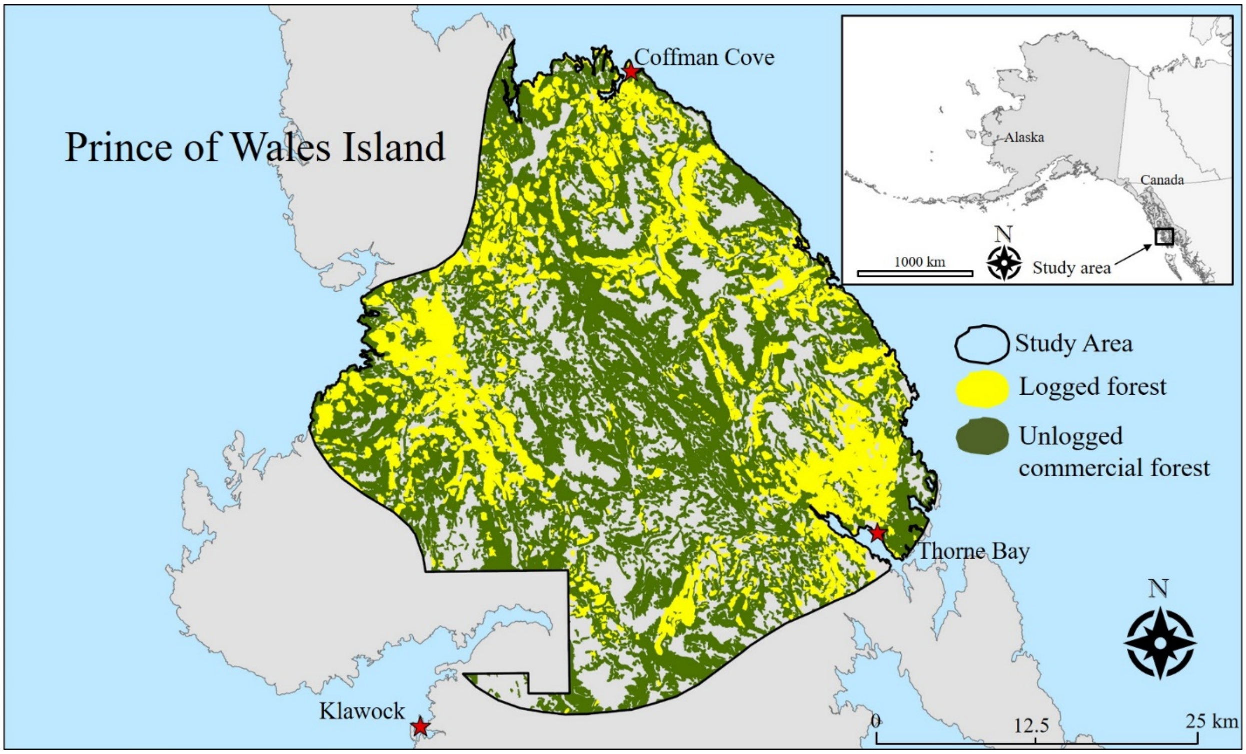

Figure 1. Black bear denning study area on Prince of Wales Island, Alaska, defined by the 95% kernel density polygon of all locations of GPS-collared bears (*n* = 47) collared 2009–2014 and clipped (southwest portion) to exclude lands where landscape covariate data were missing.

with canopy gaps and complex stand structure (Alaback et al. 2013). Ninety six percent of the land in the study area is within the Tongass National Forest and managed by the USFS, and the remaining 3.7% is managed by the State of Alaska (Division of Forestry) or private owners.

Methods

Capture

We captured bears periodically during May–October each year 2009–2012. We used bucket snares consisting of a single spring activated Aldrich foot snare inside a 5-gallon plastic bucket (M-15 model, Snare Shop, Lidderdale, Iowa, USA) affixed to trees at a height of approximately 2 m intended to capture bears by a front paw. Due to the high density of Sitka black-tailed deer in the study area this bucket snare system was selected over other models because it cannot be triggered by deer. We deployed motion-triggered trail cameras (Moultrie 990i, Calera Alabama, USA) at each site to observe bear visits and bear behavior at the traps. We also installed very high frequency (VHF) transmitters (Telonics, Inc., Mesa, Arizona, USA) at all active trap sites to alert us when a trap was tripped. All active trap sites were visually inspected at least once per day to ensure we did not have a trap transmitter failure. The use of VHF trap transmitters allowed the remote monitoring of many traps from the road over a large area during the capture periods. This reduced human presence at the trap sites and bear restraint time after a bear was captured. For efficiency, bait sites not visited by bears within a few days were abandoned, which confined trapping efforts to sites with regular bear visitation, thereby greatly increasing capture success.

Also, a subset of bears were recaptured inside winter dens to change collars and assess reproduction. Den sites were visited between February and March if collar adjustments or replacement were required. Immobilized bears were not removed from dens during winter handling to minimize disturbance, and dens were sealed with vegetation once the visit was complete.

We immobilized bears with Telazol® (Telazol®, Fort Dodge, Iowa, USA) (3–5mg/lb; Taylor 2000) using Telinject darts (3 cc capacity, 1.5–4 cm needle length). We used a hand-held jab stick or CO_2 powered telinject pistols (Telinject USA, Inc. Agua Dulce, California) set at low air pressure, and Telinject darts for den captures. We fitted bears with Telonics Global Positioning System (GPS, model TGW-3600, 3700, or 3790) or Telonics VHF collars. GPS collars were set to attempt GPS fixes every 30 minutes except in winter (1 November–31 March) when fixes were attempted every 24 hours. Each GPS data fix produced a data string which included: location, air temperature, and animal movement associated with activity. During animal handling, all bears were carefully examined and monitored following standard veterinary procedures. Biological samples and morphological data were collected from each bear, including the following: a premolar tooth for cementum aging (Willey 1974), blood and tissue samples, body weight, body length and girth, and skull size. Live-trapping and radiocollaring protocols were approved by the Alaska Department of Fish and Game, Division of Wildlife Conservation Institutional Animal Care and Use Committee (IACUC, ACUC Assurance No. 09-17).

DENNING CHRONOLOGY

Chronology information for a subset of dens (males: $n = 19$, females: $n = 30$) was used because not all bears had GPS collars allowing detailed monitoring of den entrance and emergence, and because some dens were used in the middle of winter but not during the entrance or emergence period. We inspected temperature and activity readings from each GPS collar, and an increase in temperature and simultaneous decrease in activity was assumed to indicate the beginning of residence in the den. When temperature readings rose to >20° C with a concurrent reduction in activity sensor readings, we assumed a bear had denned. Conversely, in spring, activity increase and temperature decrease indicated emergence from the den. Although GPS locations were at times only sporadically available during winter (due to a decreased interval 24-hour fix rate after 1 December and poor GPS reception inside dens), we were able to corroborate den timing for some bears by noting when the spatial position of GPS locations stabilized upon den entrance and resumed activity on emergence.

Prior to denning in the fall black bears may start to transition into the physiological state of hibernation. They may also enter a similar phase after the denning period when they transition out of the state of hibernation while still in close proximity to their dens in spring (Nelson et al. 1973, Nelson et al. 1975, Nelson et al. 1983). This transitional state of physiology before entering and after exiting winter dens has been described as “walking hibernation” (Nelson et al. 1983). Preliminary data exploration revealed a period in the spring in which some bears exited the den yet were restricted in their movements. We defined this as the period between emergence from the den and the last day in which a bear’s location displaced a total distance of <300 m in a

24-hour time span. We considered this period to exist if upon den emergence a bear spent >4 days with <300 m total displacement in each day.

Additionally, we noted instances of potential reuse of winter dens during the non-denning season (1 May–31 October), as defined by consecutive (≥2) GPS locations within 25 m of dens used during a previous winter—either by the same bear or another individual. To ensure adequate sample sizes, we pooled female bears that had cubs entering the den with her and females with cubs exiting the den with her as ‘females with cubs.’

DEN CHARACTERISTICS

We located a total of 91 dens, 50 using aerial telemetry and subsequent searches on the ground, and 41 dens using the cluster of GPS locations collected at den sites. At the dens located by aerial telemetry we collected latitude and longitude coordinates with a handheld GPS unit (Garmin 60csx, Garmin, Olathe, Kansas, USA). If the den was associated with large woody debris, we noted the species of tree and whether it was alive or dead. Additionally, we measured the diameter of the den structure (living tree, logged stump, or fallen log) at breast height (DBH, 1.37 m above the roots of the structure), When dens were located in second growth, we used a timber-related database (USFS 2019c) to determine the year in which the logging occurred. We also noted plant materials used as bedding inside the den, when feasible (some dens were not accessible for close inspection as they were situated deep inside a standing snag or down log).

DEN SITE SELECTION

Dens were retained for den selection analysis only if they had been used for >7 days. Dens used multiple times by an individual bear were included in models only once. Den site selection was analyzed via pooled RSF models (Manly et al. 2002), in which landscape covariate values (Table 1) at den site locations were contrasted with those of randomly generated available points within the study area using the equation

$$w_x = \exp\left(\beta_1 x_1 + \beta_2 x_2 + \cdots \ldots \beta_n x_n\right) \qquad \text{Equation 1}$$

where *w(x)* is the relative probability of an animal using a resource unit (i.e., one of the 30-m pixels within the study area). To delineate the study area, we first constructed a polygon using the 95% kernel density estimate (kde) function of R package adehabitatHR, Calenge 2006; R statistical environment version 3.3.0; R Development Core Team 2017) based on all locations obtained from GPS-collared bears (n = 47 bears) in the period 2009–2014. We then clipped this polygon to the marine shoreline and to the boundary of private lands where covariate data were not available (Fig. 1).

We attributed all den locations and available points (generated at a density of 60/km^2; 101,820 total points) with landscape covariates (Tables 2 and 3) having some precedent of use in prior literature on bear den site selection (Gaines 2003, Pigeon et al. 2014). Covariates took the form of geographic information system (GIS) rasters, and included elevation, slope, topographic position index (TPI), density of open roads (those roads suitable for travel by high-clearance vehicles), and solar radiation, all of which were calculated at 30-m resolution. For elevation and slope, both linear and quadratic terms were included, which allowed minimum or maximum relative probability of use at intermediate values of these factors. TPI is a relative measure of landscape position describing whether a given pixel is situated above (positive values) or below (negative values) surrounding pixels. Open road density (km/km^2) was calculated within a 200-m radius. Additionally, solar radiation ($WattH/m^2$) was calculated for a single day, 1 April, to characterize the time at which bears leave their dens and young vegetation is becoming available as a food source.

For each continuous covariate, we calculated the mean and range, and we scaled predictors by subtracting the mean and dividing by the standard deviation (Menard 2004). We processed all landscape covariate data using either ArcGIS (Version 10.5.1, ESRI 2016) or the R packages sp (Pebesma and Bivand 2005) and raster (Hijmans 2017).

We also included categorical landcover classes in the pool of covariates (Table 2). These classes were derived from the cover type database created by the U.S. Forest Service, Tongass National Forest (USFS 2019c), and were related to forest management: 1) young clearcuts (≤30 years), 2) old clearcuts (>30 years), 3) forest stands that have been thinned in preparation for future commercial use, and 4) uncut, productive old-growth forest. All other non-commercial forest and other vegetation types were grouped together and used as the reference category (Hosmer and Lemeshow 2000).

A pool of 16 ecologically plausible candidate models consisting of combinations of 15 covariates (Table 3) were created using Akaike's Information Criterion (AIC) to rank the performance of each of the 16 models on subsets of the bear den data: 1) males, 2) females with cubs, and 3) females without cubs. To ensure adequate sample sizes, we pooled female bears that had cubs entering the den with her and females with cubs exiting the den with her as ‘females with cubs.’ Because of our particular interest in bear selection of the logging-related land cover classes, all candidate models contained these covariates. The model with the lowest AIC score was considered the top model for each data subset, and we summarized the coefficients (β) of each factor for these models. To ease interpretation, for each land cover class we calculated the probability of selection (RPS) ($\exp(\beta)$; Lele et al. 2013) relative to the reference category (all lands without commercial forest).

We used k-fold cross-validation to determine how well models distinguished between used and available locations (Boyce et al. 2002). We performed 100 cross-validation trials and calculated the mean and standard deviation of Spearman’s rank correlation across these trials.

To summarize den selection across reproductive status (males, females with cubs, and females without cubs), we also built a model for all dens via mixed effects models with intercepts and random slopes included for reproductive status (Gillies et al. 2006). As with the individual RSF models, we chose the top pooled model across 16 candidate models. The main purpose of the pooled model was to create an overall model that could be used to predict important denning habitat summarized across reproductive classes. We used Equation 1 to calculate an RSF map illustrating the relative probability of den selection across the study area and using the mixed-effects model. To highlight areas most important for denning, we reclassified this RSF map into binary form, with the top 20% quantile of values delineating the most valuable denning habitat within the study area (Johnson et al. 2006).

Table 1. Mean and range of terrain covariates included in final black bear den resource selection functions (RSFs), Prince of Wales Island, Alaska, 2009–2014.

Model factor	Males (*n = 38*)	Females without cubs (*n = 24*)	Females with cubs (*n = 29*)	Total (*n = 91*)	Available points (*n = 101,820*)
Elevation (m)	299.18 (34.52–646.28)	244.14 (49.6–434.82)	177.24 (23.22–570.65)	245.21 (23.22–646.28)	225.49 (1.1–1157.51)
Slope (◦)	25.29 (3.54–43.6)	24.23 (3.51–56.01)	14.29 (1.77–39.49)	21.46 (1.77–56.01)	12.80 (0.00–62.92)
Topographic position index	0.55 (-7.95–9.33)	3.96 (-5.86–26.59)	-0.14 (-8.73–6.33)	1.24 (-8.73–26.59)	0.02 (-27.00–33.25)
Open road density, 200–m radius	0.38 (0.00–4.25)	0.58 (0.00–4.66)	0.81 (0–4.66)	0.57 (0.00–4.66)	0.44 (0.00–9.07)
Solar radiation (KW/m^2)	4,066.49 (2,741.1–5,031.25)	3,753.76 (1,523.4–4,757.76)	4,168.14 (3,156.24–4,870.07)	4,015.85 (1,523.4–5,031.25)	4,271.83 (1,016.39–5,475.69)

Table 2. Proportion of black bear dens and available points within forestry-related land cover classes used in resource selection functions (RSFs), Prince of Wales Island, Alaska, 2009–2014.

Model factor	Males	Females without cubs	Females with cubs	Total	Available points
Young clearcut (≤30 years)	0.11	0.00	0.07	0.07	0.03
Old clearcut (≥30 years)	0.14	0.21	0.31	0.21	0.09
Thinned stands	0.19	0.17	0.14	0.17	0.06
Productive old growth	0.41	0.46	0.31	0.39	0.25
Other vegetation types (reference category)	0.16	0.17	0.17	0.17	0.57

Table 3. Candidate models for black bear den resource selection function (RSF) analysis, Prince of Wales Island, Alaska, years 2009–2014. 'X' indicates inclusion of factor in each candidate model. Model 8 was the top model (via AIC score) for males and females with cubs. Model 6 was the top model for females without cubs.

	Model															
Factor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Elevation	X	X	X	X	X	X	–	–	X	X	X	X	X	X	–	–
Elevation^2	X	X	X	X	X	X	–	–	X	X	X	X	X	X	–	–
Slope	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Slope^2	X	–	X	–	X	–	X	–	X	–	X	–	X	–	X	–
Open roads, density 200–m radius (km/km^2)	X	X	X	X	–	–	–	–	X	X	X	X	–	–	–	–
Solar Radiation (KW/m^2)	X	X	–	–	–	–	–	–	X	X	–	–	–	–	–	–
Topographic position index (9–pixel neighborhood)	X	X	X	X	X	X	X	–	X	X	X	X	X	X	X	–
Old clearcuts (>30 years)	X	X	X	X	X	X	X	X	–	–	–	–	–	–	–	–
Young clearcuts (≤30 years)	X	X	X	X	X	X	X	X	–	–	–	–	–	–	–	–
Thinned stands	X	X	X	X	X	X	X	X	–	–	–	–	–	–	–	–
Productive old growth	X	X	X	X	X	X	X	X	–	–	–	–	–	–	–	–

Results

Capture

A total of 59 bears (32 males and 27 females) were fitted with either GPS (22 males and 25 females) or VHF (10 males and 2 females) collars, which were deployed in the period 2009–2012. We monitored bears and collected data for 5 years during 2009–2014, and bears wore collars for a mean of 426 (range = 30–1,167) days. Fifteen radiocollared bears died during the study: 11 male and 1 female bears were legally killed by hunters, 1 male died as result of hunter wounding loss, and 2 males died of unknown causes.

Denning Chronology

We collected den chronology information for a subset of bears (males: n = 19, females: n = 30) (Fig. 2) because not all bears had GPS collars that allowed detailed monitoring of den entrance and emergence, and because some dens were used in the middle of winter but not during the entrance or emergence period. Median den entrance dates were 10 November for males, 15 November for females without cubs, and 1 November for females with cubs. Median den emergence dates were 5 April for males, 13 April, for females without cubs, and 12 April for females with cubs (Fig. 2). Using these median entrance and emergence dates we found all bear groups spent similar time (days) inside winter dens: males (115), females without cubs (128), females with cubs (131).

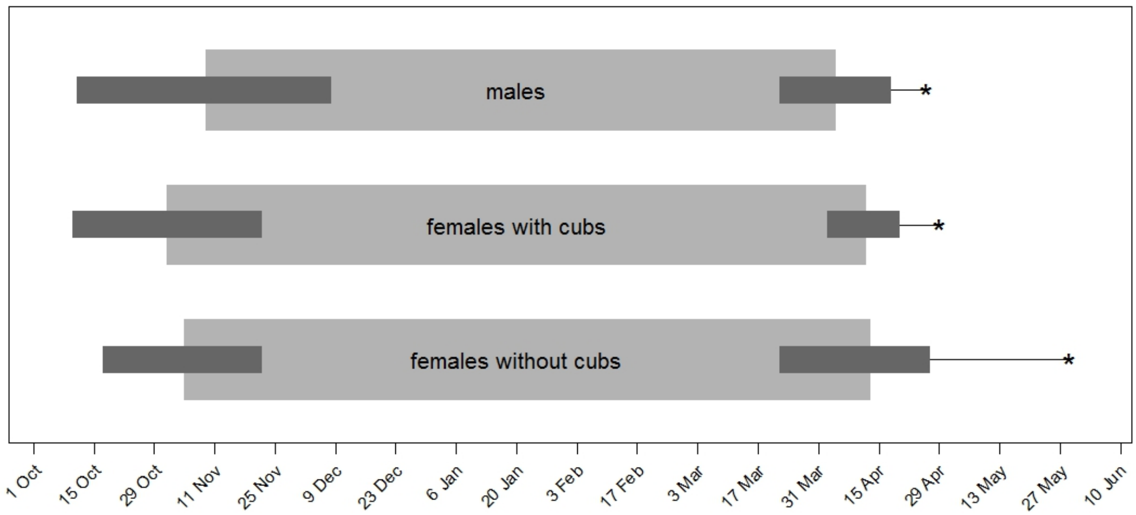

Figure 2. Denning phenology of radiocollared black bears on Prince of Wales Island, Alaska, 2009–2014. The thick grey bar is bounded by the median dates of entrance and emergence from dens, the dark bars by earliest and latest entrance and emergence, and the asterisk the latest date of 'walking hibernation' (<300 m displacement/day).

The period of 'walking hibernation' in the spring (as defined by at least 4 days of <300 m net movement in each day) was displayed by 64% (n = 7) of male bears, 86% (n = 12) of females without cubs, and 70% (n = 7) of females with cubs. The mean length (days) of this period for each group was: male = 6.0; females without cubs = 13.6, and females with cubs = 6.3.

Individual female bears (n = 10) visited winter dens (or the area within 25 m of the den) in the non-denning (1 May–31 October) season a total of 15 times, and male bears (n = 2) visited winter dens a total of 3 times. Two females and one male also visited dens in summer that were subsequently used by a different bear during the following winter. The longest stay at (or near) a den during one of these revisits was 8.5 hours. Due to GPS location error, it is not clear whether bears actually entered the winter dens or stayed very near them (within 25 m). In 3 cases, bears moved to a new den partway through the winter, while in 3 other cases we displaced bears when visiting dens.

Den Characteristics

Dens we visited in the field were associated with living or dead trees in all but one case and were split between multiple coniferous tree species, most commonly western hemlock (47%) and Sitka spruce (26%, Table 4). Dens were most commonly found in ground cavities among roots under the boles of trees, snags, or stumps (78%) as opposed to inside the trunk (22%, see Appendix A for depiction of den structures). Most were associated with standing or cut trees (47% and 45%, respectively) as opposed to naturally down trees (8%). The mean DBH of woody structures used by bears in the study area was 1.38 m (range = 0.76–2.13 m) and varied little between sexes. All but 2 dens were in woody structures > 1.0 m diameter, with 75% of dens (37) in structures > 1.25 m and 3 dens in structures > 2.0 m diameter (Fig. 3). Bedding materials (branches, moss, bark chips) were found in all dens investigated. The most common bedding materials were branches from western hemlock (60%) and *Vaccinium* spp. (35%). Cupressaceae spp. (either Alaska.

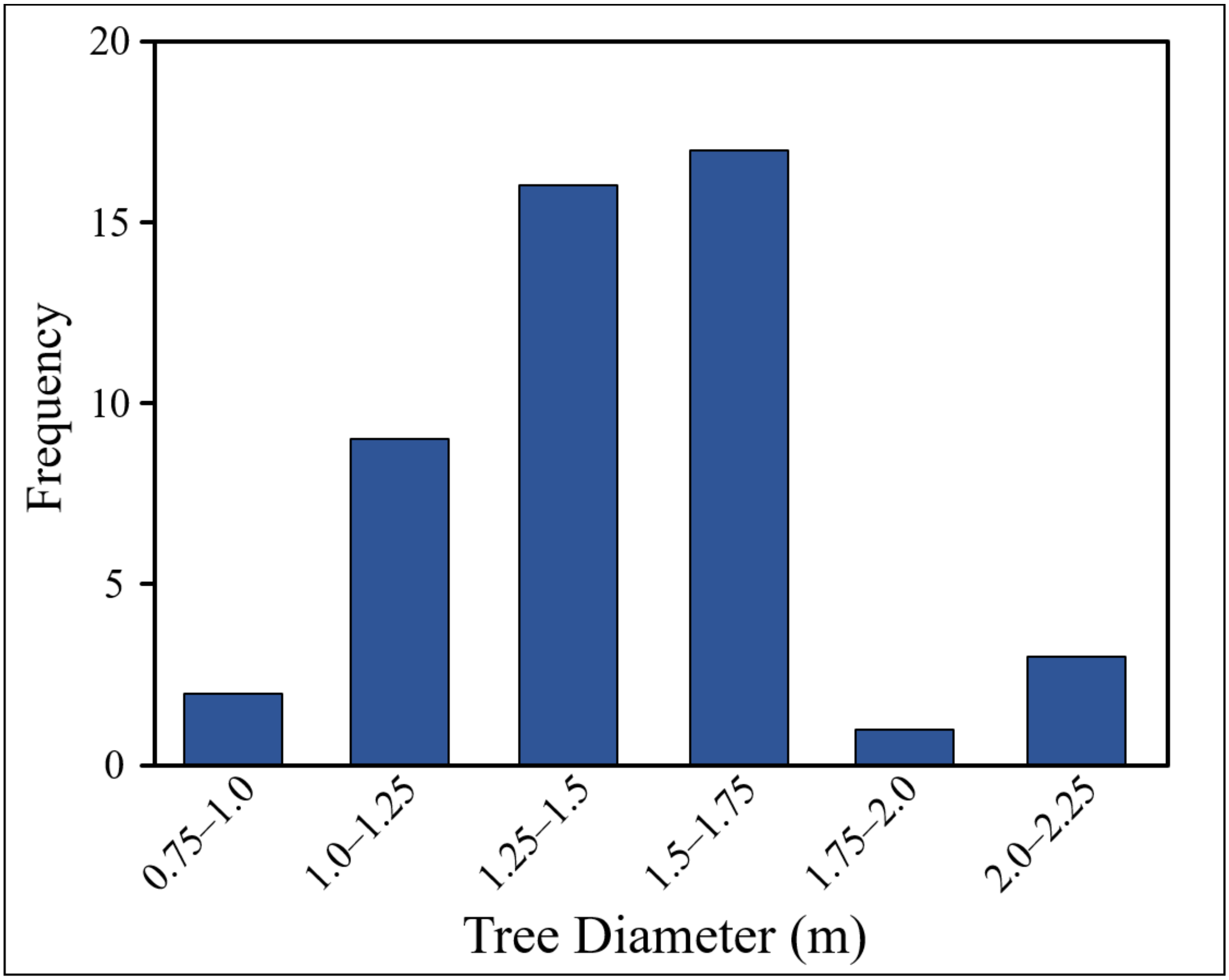

Figure 3. Histogram of the diameter at breast height (DBH) of trees and woody structures used as dens by black bears on Prince of Wales Island, Alaska 2009–2014.

yellow cedar or western red cedar), Sitka spruce, salmonberry, and mosses were also represented in smaller proportions of dens (Table 4). Broken branches and shrubs near dens suggested at least some of the bedding materials were gathered nearby. Some nest materials appeared to be dry and several years old from previous use, while many dens included newly added green materials. Wood shavings or chips found in several dens were likely from both natural deterioration or from bears scratching the surrounding woody structure from within the den, and the chips were formed into a bowl shape on the den floor

.

Table 4. Black bear den characteristics observed during field visits to radiocollared bear dens (n = 50) on Prince of Wales Island, Alaska, 2009–2014. Values (when units not stated) represent proportion of class in each category. Species was delineated to taxon when possible.

Parameter	Male	Females without cubs	Females with cubs	Total
n	18	10	22	50
Den structure				
Alaska yellow cedar	0.06	0.10	0.00	0.04
Western red cedar	0.06	0.10	0.00	0.04
Unknown cedar	0.06	0.20	0.18	0.14
Sitka spruce	0.28	0.30	0.23	0.26
Western hemlock	0.56	0.20	0.47	0.44
Unknown (decayed) species	0.00	0.10	0.09	0.06
Not associated with woody structure	0.00	0.00	0.05	0.02
Woody structure status[a]				
Standing	0.44	0.50	0.48	0.47
Down	0.12	0.10	0.04	0.08
Cut	0.44	0.40	0.48	0.45
Situation within woody structure[a]				
Inside trunk	0.22	0.40	0.19	0.24
Within or under roots	0.78	0.60	0.81	0.76
Diameter at breast height of woody structure (m)[a], mean (min–max)	1.44 (1.22–2.03)	1.40 (0.76–2.13)	1.33 (0.92–1.52)	1.38 (0.76–2.13)
Den bedding materials[b]				
Cupressaceae spp.	0.00	0.10	0.05	0.04
Sitka spruce	0.06	0.00	0.00	0.02
Western hemlock	0.61	0.50	0.65	0.60
Blueberry	0.39	0.30	0.35	0.35
Salmonberry	0.06	0.10	0.00	0.04
Bryophyta spp.	0.11	0.10	0.10	0.10
Wood chips	0.17	0.10	0.04	0.10
Unknown	0.17	0.40	0.20	0.22

[a] Calculated across all dens associated with woody structures.

[b] More than one bedding material possible at a den site, so proportions do not sum to 1.

DEN SITE SELECTION

Den site selection models were built with dens used for more than 7 days (males: n = 38, females without cubs: n = 24, females with cubs: n = 29). Top models consisted of a set of continuous and categorical variables (Tables 3 and 4 respectively). Of the 16 candidate models (Table 1), 2 models ranked as the top model for data subsets. One of the two top models (model 8) consisted of slope and the 4 forestry-related land cover classes and ranked as the top model for males and for females with cubs (Table 5). The other top model (model 6) consisted of elevation, elevation^2, slope, topographic position index, and the 4 landcover classes (ranked as top model for females without cubs).

Bears of all status selected for (i.e., positive coefficients) classes of cut or uncut commercial forest over non-commercial forest lands. The coefficients for all forest classes were usually informative (i.e., CI not overlapping zero) for reproductive subsets, except for young clearcuts in the model for females with cubs and old growth for females without cubs. The relative probability of selection of commercial forest landcover classes (in relation to all other lands) ranged from 2.53 (CI = 0.83–9.49) for productive old growth by females without cubs to 11.13 (CI = 3.86–36.30) for old clearcuts by females with cubs (Table 6). No dens of females without cubs were found in young clearcuts making a coefficient and relative probability of selection for this class inestimable.

The relative probability of selection for productive old growth forest was the lowest for land cover classes in the models for all models (Table 6). The relative probability of selection of thinned stands was highest of all land cover classes in all models except second highest in the model for females with cubs.

The linear slope factor was always positive, showing selection for greater slopes, and was informative (CI not overlapping 0) except in the females with cubs model. Linear and quadratic terms for elevation were included for females without cubs but the linear term was uninformative (CIs overlapped zero). Topographic position index was included in the top model for females without cubs and had a positive, informative coefficient (Table 6). Cross validation indicated the male model (Spearman's rank correlation 0.71, Table 5) predicted den sites better than the models for females without cubs (0.60) and females with cubs (0.52) (Fig. 4).

The top 20th percentile of RSF values from the overall, mixed-effects model indicated important denning habitat across all lands not in private ownership on POW (Fig.4). The high cross-validation score (0.90) of this model indicates utility in predicting relative probability of selection across POW (Johnson et al. 2006). We did not predict RSF models to private lands as timber-related covariates were not available in these areas.

Table 5. Coefficients (β) of top den site selection models for black bears, Prince of Wales Island, Alaska, 2009–2014.

	RSF models for each reproductive status											
	Males			Females without cubs			Females with cubs			Mixed-effects model		
Factor	β	LCL[a]	UCL[b]	β	LCL	UCL	β	LCL	UCL	β	LCL	UCL
Elevation	–[c]	–	–	-0.06[d]	-0.94	0.86	–	–	–	0.13[d]	-0.44	0.70
Elevation^2	–	–	–	-0.86	-1.90	-0.08	–	–	–	-0.31[d]	-0.64	0.03
Slope (degrees)	0.94	0.66	1.22	0.82	0.39	1.25	0.05	-0.37	0.42	0.56	0.13	0.98
Topographic Position Index	–	–	–	0.71	0.38	1.02	–	–	–	0.27[d]	-0.08	0.63
Old clearcuts (≤30 yrs)	1.53	0.28	2.73	1.58	0.21	3.01	2.41	1.35	3.60	2.21	1.42	2.99
Young clearcuts (>30 yrs)	2.17	0.81	3.43	NA[e]	NA	NA	1.92	-0.03	3.46	1.90	0.88	2.91
Thinned stands	2.32	1.22	3.46	1.88	0.40	3.37	2.03	0.64	3.37	2.46	1.63	3.28
Productive old growth	1.25	0.34	2.29	0.93	-0.19	2.25	1.37	0.29	2.56	1.47	0.76	2.18
Number of dens	38			24			29			91		
Cross–validation, mean Spearman's rank correlation (SD)	0.71(0.06)			0.60(0.15)			0.52(0.16)			0.93(0.01)		

[a] LCL = lower confidence interval.
[b] UCL = upper confidence interval.
[c] A dash indicates factor was not included in the model.
[d] Uninformative parameter (per Leroux 2019).
[e] NA indicates the coefficient was not estimated as no dens existed in the landcover class.

Table 6. Relative probability of selection (RPS) of forestry–related land cover classes selected by black bears on Prince of Wales Island, Alaska, 2009–2014.

	Males			Females without cubs			Females with cubs			All status		
	RPS	LCL[a]	UCL[b]	RPS	LCL	UCL	RPS	LCL	UCL	RPS	LCL	UCL
Old clearcuts (≤30 yrs)	4.62	1.32	15.33	4.85	1.23	20.29	11.13	3.86	36.60	9.12	4.14	19.89
Young clearcuts (>30 yrs)	8.76	2.25	30.88	NA[c]	NA	NA	6.82[d]	0.97	31.82	6.69	2.41	18.36
Thinned stands	10.18	3.39	31.82	6.55	1.49	29.08	7.61	1.90	29.08	11.70	5.10	26.58
Productive old growth	3.49	1.40	9.87	2.53[d]	0.83	9.49	3.94	1.34	12.94	4.35	2.14	8.85

[a] LCL = lower confidence interval.
[b] UCL = upper confidence interval.
[c] NA indicates the coefficient was not estimated as no dens existed in the landcover class.
[d] Based on uninformative parameter (per Leroux 2019).

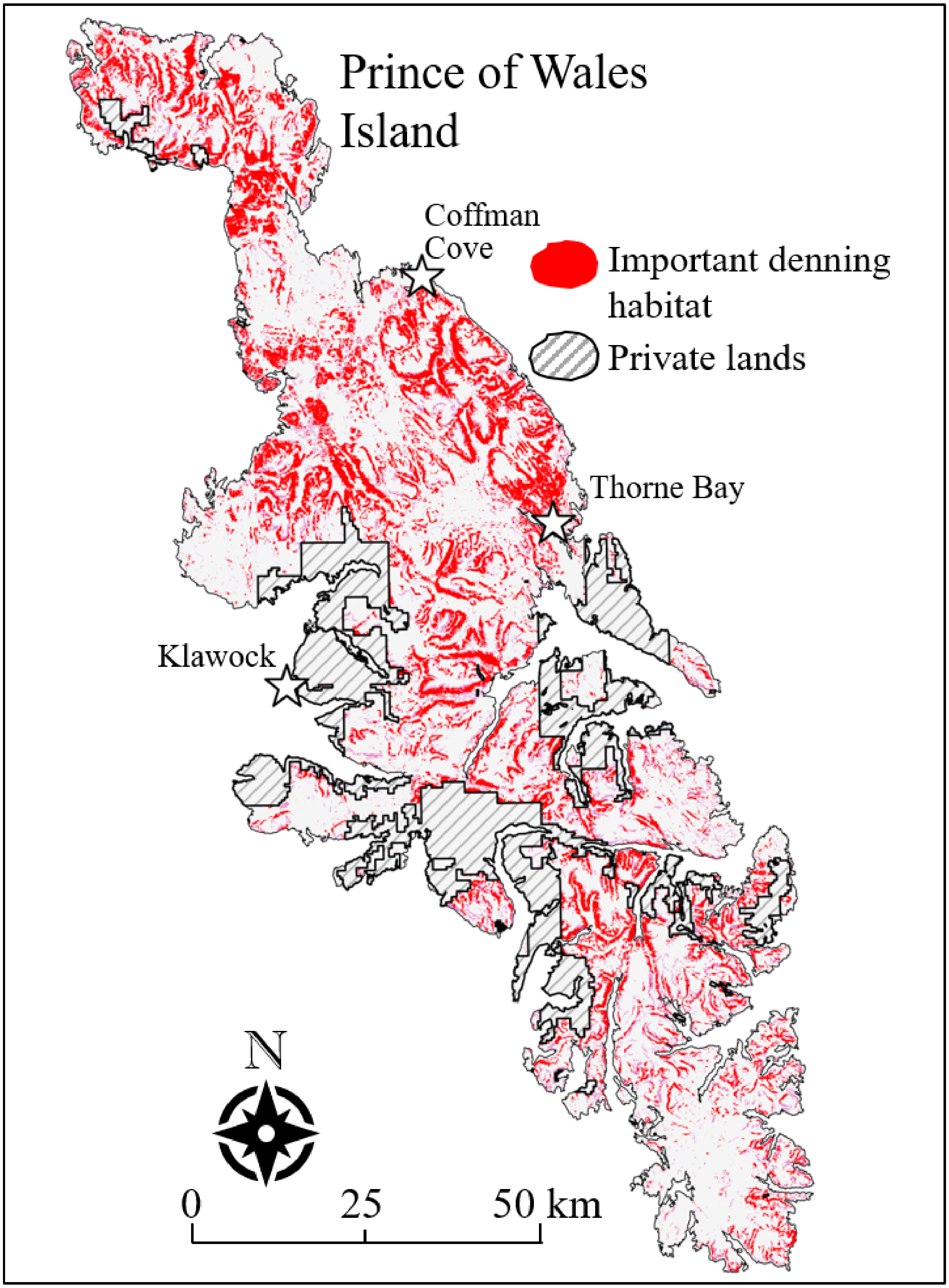

Figure 4. Important denning areas for GPS-collared black bears on Prince of Wales Island, Alaska, years 2009–2014, defined by the intersection of the top 40th percentile of resource selection function (RSF) values from models of males, females without cubs, and females with cubs.

Discussion and Conclusions

Denning Chronology

Female bears in this study tended to enter dens earlier and emerge from dens later than males. Den entrance timing has been linked to fall food supplies (Tietje and Ruff 1980, Schooley et al. 1994), and body fat (Servheen and Klaver 1983). Allen (2001) found that black bears in southwest British Columbia, a coastal temperate region similar to POW, entered dens in mid-October and emerged in mid-May. Schwartz et al. (1987) evaluated black bear den chronology in Alaska and found bears on the Kenai Peninsula entered dens 18 October on average and emerged 19 April. In the Susitna River Basin, they found the mean date of entrance was 9 October and emergence 6 May. In Prince William Sound mean emergence was 30 April (mean entrance was not obtained). In the Northeastern Cascades of Washington, Gaines (2003) found males and females entered dens in late October and emerged in early May. Male bears in Arizona entered dens later and emerged earlier than black bears in Alaska (mean entrance = 24 November and emergence = 20 March) while female bears in Arizona were similar to our findings for female bears on POW (entrance = 10 November and emergence = 4 April, LeCount 1983). There is a 97-day span between the earliest and latest den emergence date observed in the studies listed above, much of the variability related to climate, with bears at higher latitudes, similar to that of the present study, spending longer in dens. This highlights the potential importance of dens to black bears in extreme environments such as exist on POW.

Bears remaining near dens in spring after emergence (walking hibernation), as we observed in this study, may allow them to make a slow transition to normal physiological activity and food intake levels. However, there may also be a behavioral component. Females with first-year cubs may use this extended time near the den to allow cubs to become fully mobile, able to travel, and to climb trees to avoid predators before moving away from the safety and familiarity of the den. This period may also allow recently emerged bears time to assess the early vegetation green-up and amount of food available (Beck 1991) since snowpack, temperature, and the timing of succulent plant emergence vary annually. Lab work with denning black bears in captivity showed they did not resume normal intake of food for 10–14 days after leaving dens although food was provided (Nelson et al. 1983). Lindzey and Meslow (1976) found this post-denning lethargy common in recently emerged bears and especially pronounced for females with offspring. This physiological transition phase from fasting and low activity to normal movement and feeding may have several advantages for bears (Nelson et al. 1973).

During this study female black bears were more likely to visit dens (or come in close proximity) during the non-denning season than males. Of 15 documented visits to dens during the non-denning period 12 were by females. More frequent den visits by female bears during the off-season may suggest den characteristics are more important to females for energy conservation, security, birthing, and cub survival. Additionally, these winter dens may also serve as important temporary beds at other times of year to avoid periods of adverse weather and/or predation risk.

DEN CHARACTERISTICS

All but one den in this study was associated with woody structures, and the trees, logs and stumps used by bears tended to be very large. Shallow soil profiles paired with the extreme precipitation that tends to saturate soils on most of POW may deter bears from excavating dens in soil. On Mitkof Island in Southeast Alaska, Erickson (1982) found similar use of woody structures for 13 dens, and no excavated dens. Studies on the ecologically similar northwest coast of North America also found extensive use of old-growth derived woody structures (Erickson 1982, Noble et al. 1990, Bull et al. 2000, Callas 2002, Davis et al 2012). Davis et al. 2012 also observed preference for large wood structures (mean DBH 1.43 m) in coastal forests of British Columbia, as did Bull et al. (2000) in northwestern Oregon (mean DBH = 1.11 m).

To emphasize how uncommon the large diameter trees used for dens in this study are on POW, post-hoc we analyzed extensive USFS forest plot data (described in Caouette and DeGayner 2008) from forest classed as commercially productive (>46.6 m^3/ha; USFS 2008). We excluded trees < 20 cm DBH to avoid underestimating the percentage of large trees, as most trees in these stands are < 20 cm. For each of the diameter bins used in the histogram in Figure 3, we calculated the estimated percentage of trees that fall into each size bin (Fig. 3) used as dens by bears on POW (Table 7).

Table 7. Number of bear dens within diameter classes of trees, and the percentage of all available trees within each class, on Prince of Wales Island, Alaska, 2009–2014.

Tree Diameter range (m)	Number of dens	Percentage of available trees
0.75–1.00	2	20.39
1.01–1.25	9	5.16
1.26–1.50	16	1.12
1.51–1.75	17	0.22
1.76–2.00	1	0.07
2.01–2.25	3	0.02

In some geographies, wood structures are not as heavily utilized for dens. For instance, in other areas of Alaska, Schwartz et al. (1987) found bears use a lower percentage of woody structures as dens, including the Susitna River Basin (44%), Prince William Sound (33%), and the Kenai Peninsula (4%). Studies further south have found less use of woody structures for dens and more common use of partially or totally excavated sites. Beecham et al. (1983) found 20% of dens in Idaho were in hollow tree trunks, 8% were in hollow logs or rock cavities, and the remainder were excavated. Pederson et al. (2008) found most black bears in Utah excavated ground dens and only a few used tree dens. In Arizona there was no use of tree structures and all dens were found under rocks, with 76% of them excavated and the remainder in natural cavities (LeCount 1983). It appears, though, that in landscapes where large trees exist they are utilized as dens by bears.

Our research found all dens included some type of bedding materials, including branches of Sitka spruce, western hemlock, Alaska yellow cedar, western red cedar, blueberry, salmonberry, and mosses (Table 4). Our study identified wood and bark chips used as bedding in several dens with no other materials present. This has not been previously reported in black bear dens. We also found many dens with multiple layers of nesting materials accumulated through time, suggesting a long history of den use. Bedding materials are used in a high proportion of black bear dens across the range of the species (Jonkel and Cowan 1971, Lindzey and Meslow 1976, Johnson and Pelton 1981, Erickson 1982, Beecham et al. 1983, LeCount 1983, Schwartz et al. 1987, Noble et al. 1990, Davis 1996, Bull et al. 2000, Callas 2002). Nesting materials provide a thermoregulatory advantage during the cold damp winter period when bears are nestled on the ground and must conserve critical fat reserves. Bedding material has many air pockets which may trap body heat and form a microclimate around the bear that helps to retain heat and maintain temperature (Craighead and Craighead 1972).

Den Site Selection

According to our den selection models all subsets of bears strongly selected commercial forest lands over non-commercial forest and unforested lands for denning. Within commercial forest lands selection coefficients were more strongly positive for stands clearcut ≥30 years ago than for remaining old-growth forest. We believe this difference results from historic timber harvest patterns where stands with the largest trees have been disproportionately targeted for harvest (Albert and Schoen 2013). One consequence of this pattern is that older clearcuts appear to supply many stumps of the size used for denning by black bears.

In old-growth forests on POW, bears used live standing trees, fallen logs, and stumps for dens. As long as these stands remain in their natural condition, recruitment of large-diameter woody structures suitable for denning will continue. However, in the extensive stands of logged forest classes (young and old clearcuts and thinned stands) where the only structures used as dens in this study were the stumps of cut trees, the future availability of large-diameter woody structures suitable for denning is uncertain. Davis et al. (2012) documented a 50% reduction in suitable dens located in second-growth stands in coastal British Columbia over a 15-year period. A future harvest cycle of 100–150 years for most second-growth timber is anticipated on POW, making it unlikely that trees of the diameter and age used as dens by bears in this study (likely >300 years, Nowacki and Kramer 1998) will again develop.

We anticipated that TPI, which measures the degree to which a given location is situated above or below the surrounding area, would play a greater role den site selection, with bears avoiding gullies or swales where water could collect. However, except for females without cubs, that was not the case. It may be that TPI needs to be measured at a finer scale to produce a quantifiable effect. Linear terms for elevation were not important in RSF models, so although females with cubs tended to select elevations right around the mean (225.49 m), as evidenced by the small linear and positive quadratic coefficient for elevation, there was no trend seen towards lower or higher elevation dens. The area of high-elevation, treeless alpine in the study area is limited relative to other areas of Southeast Alaska. It could be that black bears inhabiting areas with more alpine would show selection for relatively low, forested terrains. Bears in this study tended to den on steeper slopes (though the coefficient for females with cubs was small and uninformative). Steeper slopes promote drainage and grow larger trees relative to shallow slopes that often consist of forested wetlands and muskegs with poor tree growth.

Management Implications

In some parts of POW, the legacy of timber harvest has resulted in large and nearly continuous landscapes of logged forest with relatively little commercially valuable old-growth forest remaining (see Fig. 1). The largest land manager, the U.S. Forest Service, plans to continue logging old growth but over the next 15 years transition to harvesting mostly second growth (USFS 2019b). The State of Alaska land parcels on POW are 'intended for very active timber production' (Alaska Department of Natural Resources 2016) and private land managers also continue logging as tree growth and market conditions allow. The large-diameter woody structures used as dens by bears in this study likely required more than 300 years to develop (Nowacki and Kramer 1998) but planned timber harvest rotation times are much shorter. As existing denning structures in harvested landscapes decay and no new denning structures similar to those used as dens in this study are recruited, the number and distribution of suitable dens available to bears may decline. Dens play an important role in survival and reproduction of black bears. A paucity of suitable dens in logged landscapes could lead to a decline in bear abundance. As habitat available to bears continues to change wildlife managers will need to carefully monitor hunter effort and harvest metrics to ensure harvests remain sustainable.

In logged landscapes where retaining harvestable populations of black bears is a priority, our findings suggest land managers need to consider retaining and recruiting numerous and well-distributed denning structures similar to those identified in this study. Doing that will require retaining and ensuring future recruitment of windfirm stands of very large trees, the same types of stands that usually have the highest commercial value. On commercial timber lands in the Tongass National Forest the existing Old Growth Reserve (OGR) system designates large, medium, and small reserves with requirements for size, spacing, and habitat composition. Large and medium OGRs are generally fixed in the Forest Plan, but small OGRs can be moved and modified at the project level. We suggest that the denning habitat RSF derived for this study (Fig. 3) and descriptions of denning structures can be used to locate small OGRs that could be included at the project level to retain suitable denning structures.

Finally, bear dens are often cryptic, but occasionally they are known or discovered prior to timber harvest. Our findings on den entry and emergence dates provide guidance to managers who wish to avoid disturbing known or potentially occupied dens. In our POW study area bears rarely entered dens prior to mid-October and usually emerged from dens by the first week of May.

♦ ♦ ♦

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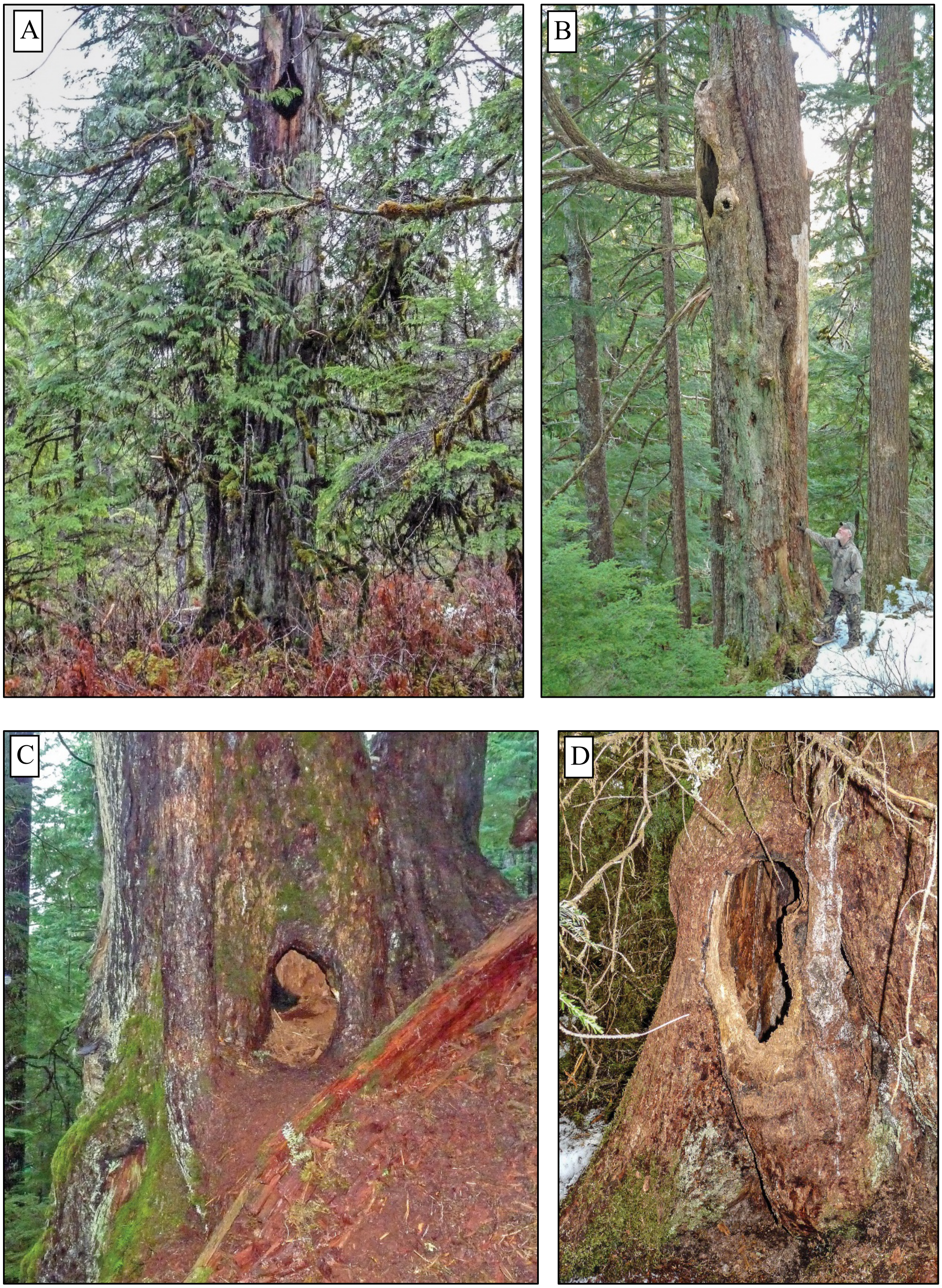
Appendix A. Black bear den situations within trees and stumps on Prince of Wales Island, 2009–2013: A) Alaska yellow cedar tree, B) western hemlock tree, C) within the roots of a live Sitka spruce, and D) logged Sitka spruce stump.



Appendix B. Bedding materials used by black bears to line dens on Prince of Wales Island 2009–2013: A) moss and Alaska yellow cedar branches, B) dead Alaska yellow cedar branches, C) Alaska yellow cedar and western hemlock branches, and D) woody debris.