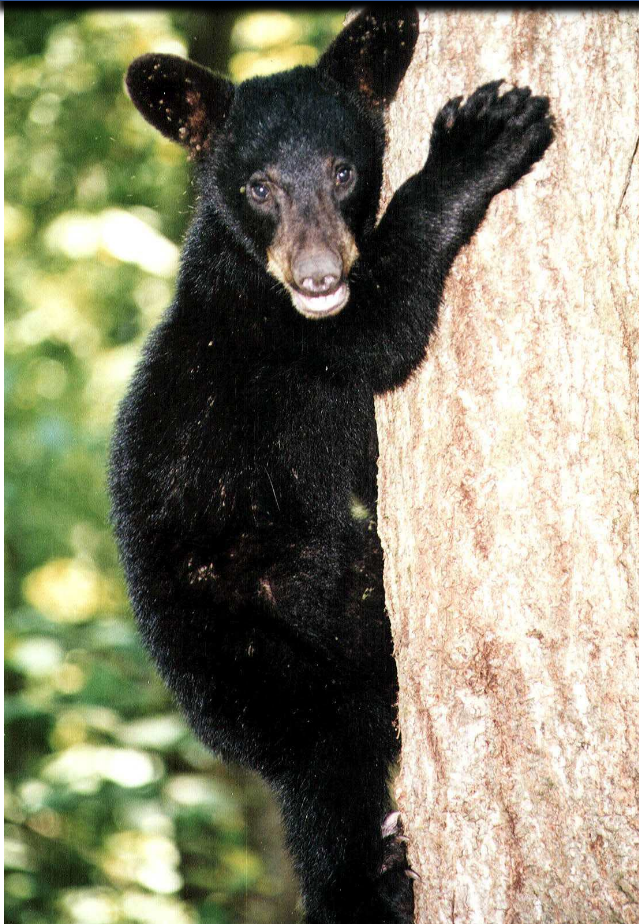
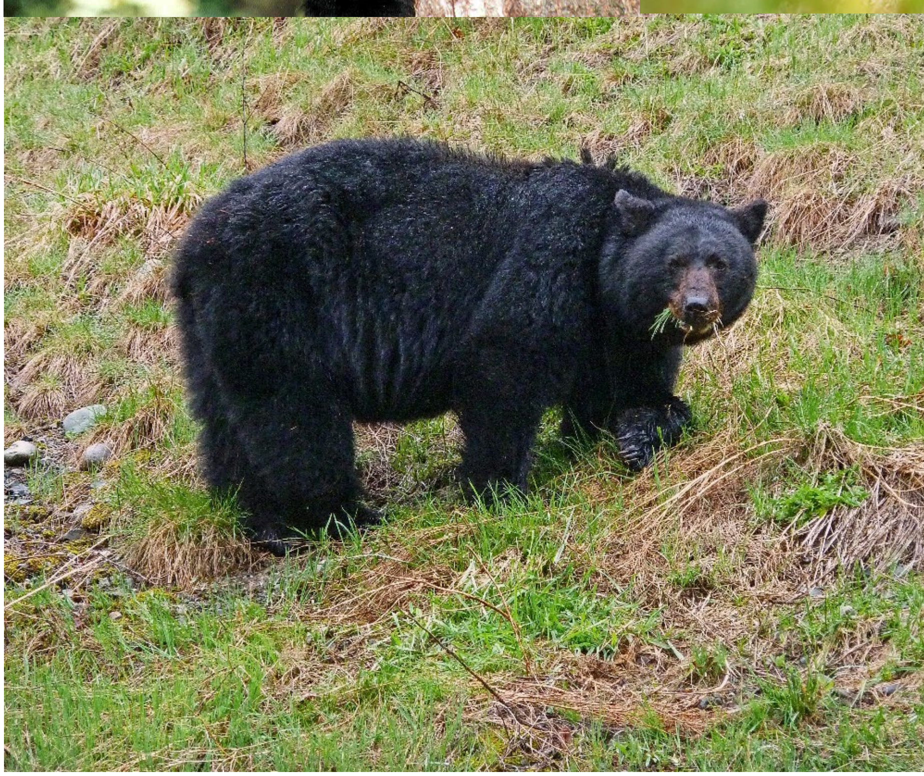
STATEWIDE BLACK BEAR DENSITY MONITORING IN WASHINGTON:
A CROSS-REGION AND INTERAGENCY TEAM APPROACH

May 2023





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This Program Receives Federal Aid in Wildlife Restoration Funds
Project W-96-R

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DEDICATION: THIS REPORT IS DEDICATED TO DAVID VOLSEN AND DEVON COMSTOCK, TWO GENUINELY KIND AND COMPASSIONATE FRIENDS. THEIR OUTSTANDING PROFESSIONALISM, LEADERSHIP, DEDICATION TO THE RESOURCE, AND KNOWLEDGE AS WILDLIFE BIOLOGISTS WILL BE GREATLY MISSED BY ALL.

BACKGROUND

Black bear density estimates are necessary to assess population management objectives and understand the relationship between abundance, habitat characteristics, and harvest at varying scales. In Washington, statewide black bear abundance estimates are predicated on derivations made in the 1970's and the 1990's and hypothesized to be a function of habitat quality based on variations in precipitation and vegetation. To evaluate current black bear density and landscape relationships in Washington, WDFW conducted a 4-year capture-recapture study (2013-2016) in 2 areas of the North Cascade Mountains using 2 detection methods, non-invasive hair collection/DNA analysis and physical capture using global positioning system (GPS) radiocollars (Welfelt et al. 2019). Within Game Management Units (GMUs) 245, 454, and 460, GPS telemetry locations were integrated with spatial capture-recapture (SCR) data to create a SCR-resource selection model to estimate density as a function of spatial covariates and test the hypothesis that density is higher in areas with greater vegetative food resources. During this phase of the project (4 of 10 years total), 118 bears were captured and collared 132 times and 7,863 hair samples were collected at hair traps where 537 individual bears were identified from 1,237 detections via DNA. The most-supported model in the western North Cascades depicted a negative relationship between black bear density and an index of human development; average bear density was estimated to be 20.1 bears/100 km^2, but density varied from 13.5/100 km^2 to 27.8 bears/100 km^2 depending on degree of human development. The model best supported by the data in the eastern North Cascades resulted in an average density estimate of 19.2 bears/100 km^2, ranging from 7.1/100 km^2 to 33.6 bears/100 km^2; density was positively correlated with primary productivity. The hypothesis that greater precipitation and associated vegetative production in western Washington supports greater bear density compared to eastern Washington was not supported by our data. In western Washington, empirically derived average total density estimates (including cubs) were nearly 50% lower than managers expected prior to our research. In eastern Washington, average black bear density was predominantly as expected, but localized areas of high primary productivity supported greater than anticipated bear densities. These stark differences illustrate the need to understand the processes that affect population numbers and that updated, more formal monitoring is necessary. In 2019 we developed a rigorous density monitoring protocol using non-invasive hair-collection/DNA analysis to estimate black bear population densities on a large scale. Using average capture probability and movement information from the North Cascades density analysis (Welfelt et al. 2019), we performed simulations to establish an optimized sampling design that would result in the least amount of staff time, materials, and expense to the agency. The resulting strategy was to select 2-3 project areas annually throughout WDFW's 17 Districts where bears occur to establish density estimates. As more surveys are conducted, additional capture results will further inform the model, therefore making density estimates more robust. As of 2023, monitoring has been completed in 13 study areas (Figure 1) and similar research is being conducted in 2 additional areas in summer 2023 for a total of 15 study areas, resulting in 22 GMUs where black bear density has been completed or is underway.

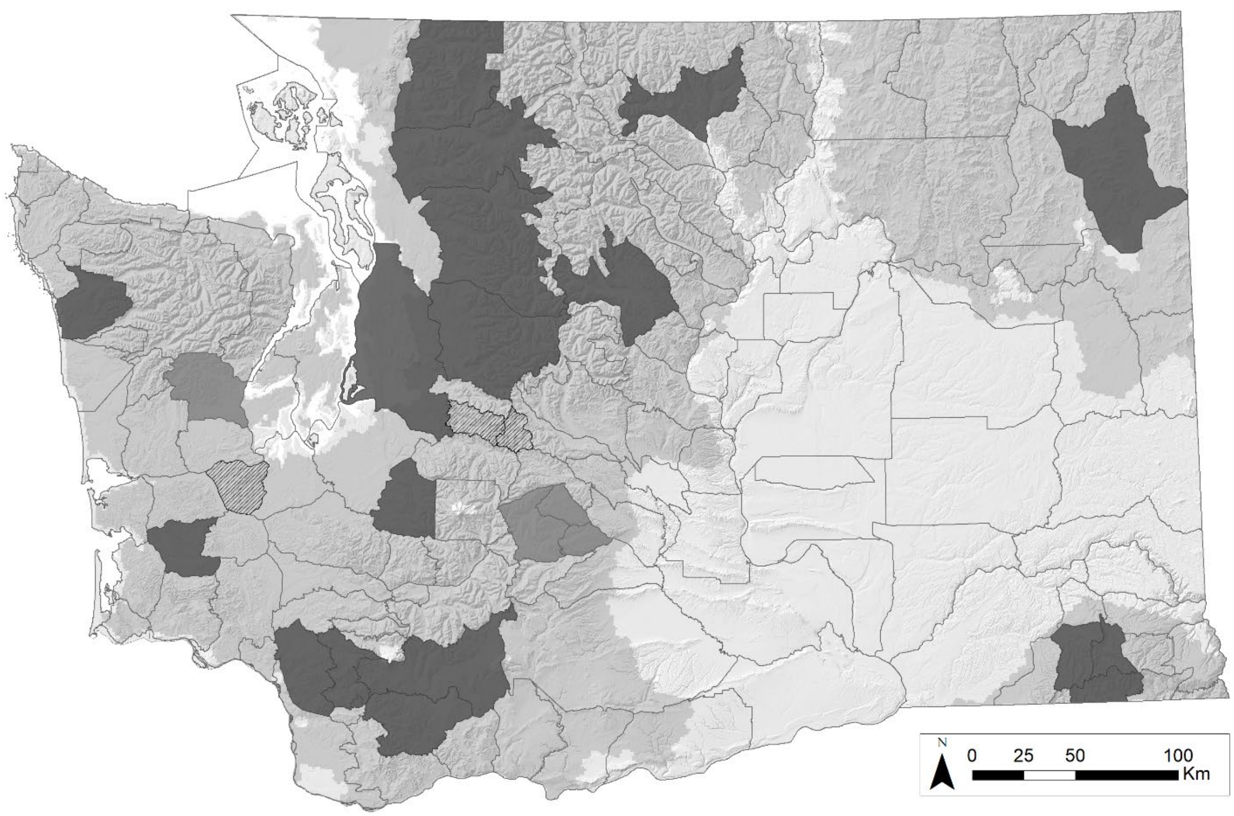

Figure 1. State of Washington with black bear habitat (gray) and Game Management Units (GMUs) shown. Highlighted GMUs (117, 162, 166, 169, 218, 245, 418, 437, 448, 454, 460, 550, 556, 560, 572, 615, 654, and 672) show where black bear density research was completed by WDFW and Tribal co-managers and lighter highlighted GMUs (352/356/360 and 636) where research is underway. Additional density research areas (GMUs 466, 485 (Muckleshoot Tribe), and 663 (WDFW) are also shown and depicted with hashmarks. Washington Department of Fish and Wildlife, 2023.

2013-2016 STUDY AREAS – Districts 7 and 12

The western North Cascades study area in District 12, GMUs 454 and 460, was 488 km^2 and located 20 km east of the city of Seattle in the western foothills of the Cascade Mountains, with elevation ranging from 40 m to 1,265 m. A maritime climate is characteristic of the District 12 study area with an annual average precipitation of 250 cm, falling mostly as rain, and average maximum temperature in July of 22 °C and an average minimum temperature in January of 0 °C (National Climatic Data Center; www.ncdc.noaa.gov; accessed 22 Aug 2017). Lower elevations were dominated by Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*), and higher elevations supported mountain hemlock (*T. mertensiana*) and Pacific silver fir (*Abies amabilis*) forests. Common natural vegetative food items for black bears included skunk cabbage (*Lysichiton americanum*), salmonberry (*Rubus spectabilis*), thimbleberry (*R. parviflorus*), Himalayan blackberry *(R. discolor*), huckleberry (*Vaccinium spp*.), and salal (*Gaultheria shallon*). Common wildlife includes Columbian black-tailed deer (*Odocoileus hemionus columbianus*), Roosevelt elk (*Cervus elaphus roosevelti*), cougar (*Puma concolor*), bobcat (*Lynx rufus*), and coyote (*Canis latrans*), with isolated populations of mountain goat (*Oreamnos americanus*). The District 12 study area primarily consisted of managed corporate timber farms (59%) and Washington Department of Natural Resources (DNR) land (29%) and contained a mosaic of clear-cuts and even-aged stands of varying succession. Access on the corporate timberland section was restricted to timber harvest operations but also included recreational activities for ≤1,000 permittees. Supplemental bear feed was used by corporate timber companies in the area from March through mid-June with the expectation of reducing tree damage associated with cambium feeding by bears (Ziegltrum 2004), but the complete distribution and volume of feed was unknown because it was proprietary information. On the public DNR lands, human recreational use was much greater, although private vehicle access was not allowed. The study area also included a small portion of the Mt. Baker-Snoqualmie National Forest (6%) managed by the United States Forest Service (USFS) with lower road density, but unlimited public access, and a restricted public watershed operated by the city of Seattle (6%). Interstate-90, urban development, and wildland-urban interface bisected the District 12 study area and surrounded much of the western boundary.

The eastern North Cascades study area in District 7 was 484 km^2 and located on the east slopes of the Cascade Mountains in GMU 245, north of State Highway 2 in the area surrounding Lake Wenatchee, with elevation ranging from 365 m to 1,823 m. Because the District 7 study area spanned from the Cascade Mountains and into the rain shadow of eastern Washington, precipitation and land cover type was variable. Precipitation at higher elevations on the western side of the study area averaged 205 cm annually, falling primarily as snow, with average maximum and minimum temperatures in July of 19 °C and in January of −8 °C, respectively (National Climate Data Center). Dominant tree species included lodgepole pine (*Pinus contorta*), subalpine fir (*A. lasiocarpa*), and mountain hemlock. At lower elevations on the eastern side of the study area, average precipitation was 61 cm, mostly falling as snow, with maximum average temperatures in July of 31 °C and minimum average of −7 °C in January (National Climate Data Center). Dominant tree species here include ponderosa pine (*P. ponderosa*) and Douglas fir on drier slopes and western redcedar (*Thuja plicata*) and western hemlock in moist areas. Natural vegetative food items largely comprised of thimbleberry, huckleberry, serviceberry (*Amelanchier alnifolia*), western mountain ash (*Sorbus scopulina*), and blue elderberry (*Sambucus caerulea*). Common wildlife throughout include mule deer (*O. hemionus*), cougar, and coyote, with occasional moose (*Alces alces*), wolf (*C. lupus*), and wolverine (*Gulo gulo*). The District 7 study area was primarily managed as the Okanogan-Wenatchee National Forest by USFS, with managed corporate timber inholdings (<10%). Human development comprised of rural housing and fruit orchards along study area boundaries, with the town of Plain (<2,000 year-round inhabitants) being centrally located. Public access was unrestricted throughout District 7's study area, but lower levels of residential and urban development surrounded the area and less intensive forest management practices occurred than in District 12.

2019 STUDY AREAS – Districts 1 and 17

The District 1 site was characterized by mountainous terrain in the southern portion of the Selkirk Range, with elevations ranging from 500 m to 2,200 m. Eastern portions were within the North-Central Rocky Mountain Forest terrestrial ecoregion, and western portions within the Okanagan Dry Forest ecoregion (Olson et al. 2001). We chose to sample within GMU 117 because it was representative of much of the habitat available in District 1 and the northern portion of District 2. In addition, black bear harvest in GMU 117 typically fell in the middle of what is observed throughout the District (GMUs 101-121). Forests were dominated by mixed conifers, with common species including western hemlock, western red cedar, Douglas fir, western larch (Larix occidentalis), Englemann spruce (*Picea engelmannii*), ponderosa pine, lodgepole pine, western white pine (*P. monticola*), subalpine fir, and grand fir (Franklin and Dyrness 1988). Common deciduous species included Rocky Mountain maple (*Acer glabrum*), serviceberry, oceanspray (*Holodiscus discolor*), mallowleaf ninebark (*Physocarpus malvaceus*), Scouler's willow (*Salix scouleriana*), fool's huckleberry (*Menziesia ferruginea*), huckleberry, snowberry (*Symphoricarpos spp.*), and tobacco brush (*Ceanothus velutinus*; Johnson and O'Neil 2001). Wildlife in addition to black bear included wolves, mountain lions, white-tailed deer (*O. virginianus*), elk, and moose. Most lands were publicly owned (USFWS, USFS, DNR), although large timber companies also owned sizable tracts (Green et al. 2015). Generally, public land was comprised of older forests with thick canopy cover, whereas privately owned lands consisted of younger forest stands, early seral stage plant communities, and less canopy cover. Daily summer temperatures varied from an average maximum of 22.05 °C to an average minimum of 7.00 °C (June–July; NOAA 2020). Annual precipitation averaged 47.7 cm (NOAA 2020).

District 17 site was in the Willapa Hills of southwestern Washington in Grays Harbor county, entirely within the boundaries of GMU 672, northwest of the town of Pe Ell. This area is moderately mountainous with elevations ranging from 130 m to 735 m. The site falls within the Western Hemlock Forest Zone and forest habitats are typical of the heavily managed industrial forests found throughout western Washington. Douglas Fir is currently the dominant tree species and timber harvests are typically less than 200 acres in size where most trees within any individual stand occur as a single age class. Single species dominated stands of western hemlock and alder (*Alnus rubra*) are present but less common. Alder, bigleaf maple (*Acer macrophylum*), and western red cedar are common to riparian areas. Understory plant species include a variety of grasses, forbs, ferns, and shrubs. Dominant shrubs and ferns include salmonberry, devil's club, huckleberry, sword fern (*Polystichum munitum*), salal, Oregon oxalis (*Oxalis oregano*), lady-fern (*Athyrium filix-femina*), and violets (*Viola spp*.). Most of the area was privately owned by corporate industrial timber companies with the remainder being publicly owned and managed by DNR. Decades of forest management practices have resulted in a high-density road system. Annual Precipitation measured 136 cm per year and daily summer temperatures varied from an average maximum of 20.67 °C to an average minimum of 9.44 °C (June–July; NOAA 2020).

2020 STUDY AREAS- Districts 10 and 11

The District 10 site was in the Toutle Range of southwestern Washington in Cowlitz County, within the boundaries of GMUs 550 and 556, west of Mt St Helens and east of the town of Castle Rock. This area is mountainous with elevations ranging from 244 m to 1005 m. The site fell within the Western Hemlock Forest Zone and forest habitats are typical of the heavily managed industrial forests found throughout western Washington. Douglas Fir was currently the dominant tree species and timber harvests are typically less than 200 acres in size, where most trees within any individual stand occur as a single age class. Pacific silver fir and Noble fir (*A. procera*) dominated stands were present in the eastern, higher elevation portion of the study area. Alder, bigleaf maple, and western red cedar are sometimes found in riparian areas along with Douglas fir, the dominant tree species. Understory plant species include a variety of grasses, forbs, ferns, and shrubs. Dominant shrubs and ferns include salmonberry, devil's club, huckleberry, vine maple (*A. circinatum*), Oregon grape (*Mahonia aquifolium*), sword fern, bracken fern (*Pteridium aquilinum*), Oregon oxalis, and violets. Approximately 75% of the study area was privately owned by Weyerhaeuser, a corporate industrial timber company, with the remaining 25% being publicly owned and managed by DNR. Access policies differed among the two landowners in the District 10 study area. In the portion owned by Weyerhaeuser, access is only allowed to permit holders who paid an annual fee to recreate on these lands while the DNR managed portion was open to free, unlimited public recreation, including motorized access. Decades of forest management practices have resulted in a high-density road system. Annual precipitation measured 180 cm per year and daily summer temperatures varied from an average maximum of 24 °C to an average minimum of 10.5 °C (June–July; NOAA 2021).

The District 11 site was characterized by low elevation industrial managed timberlands in the west-central Cascade Range, with elevations ranging from 1400 m to 3400 m. The entire study area is situated within the West Cascades ecoregion (Olson et al. 2001). GMU 654 (Mashel Unit) was chosen because: 1) it supported the only spring bear hunt within the district; 2) had a variety of ownership including federal, state and private; 3) was an area with a history of feeding and removing bears to minimize timber damage; 4) it bordered our largest state national park (Mount Rainier) which acted as a boundary between managed and natural habitats, and 5) was representative of much of the habitat available in the eastern half of the district within which bear management was focused. Black bear harvest in GMU 654 included damage removals, spring special permit season harvest, and general fall season harvest. Forests in the study area were dominated by mixed conifers, with common species including western hemlock, western red cedar, Douglas fir, Pacific silver fir and noble fir (NatureServe 2021). Common deciduous species included black cottonwood (*Populus trichocarpa*), bigleaf maple, red alder, (*Alnus rubra*), and Oregon ash (*Fraxinus latifolia*; NatureServe 2021). Wildlife in addition to black bear included mountain lions, bobcat, coyote, black-tailed deer, elk, and to a lesser degree, wolves. Approximately 2/3 of the study area was privately owned commercial timberland with the remainder state forestland managed by DNR. Generally, timber harvest on the state public land is less aggressive and promotes more habitat diversity than found on the neighboring private commercial forests. Daily temperatures varied from 16 °C in May to 21 °C in July within the study area (NOAA 2020). Annual precipitation averaged 203 cm (US Climate Data 2021).

2021 STUDY AREAS – Districts 3, 6, and 14 & Stillaguamish/Sauk-Suiattle Tribes

In District 3, the Blue Mountains of Washington are in the southeast corner of the state, bordering Oregon and Idaho and part of the Columbia Plateau that was formed by fissure lava flows from the Miocene and early Pliocene periods (Franklin and Dryness 1988). Uplifts occurring during the late Pliocene caused the Blue Mountains to rise above the Columbia Plateau. Erosion over millions of years created the major drainages of the Blue Mountains: Asotin Creek, Grande Ronde River, Mill Creek, Touchet River, Tucannon River, and the Wenaha River. Elevations range from 366 m to 1859 m. Summers are normally dry and hot, whereas winters are relatively mild. The 30-year average minimum and maximum temperatures at Dayton, 1971-2000, were near -4 °C and 32 °C, and occurred about January 1 and August 1, respectively (Western Regional Climate Center, wrcc@dri.edu., accessed 02 June 2011). Average annual precipitation at Dayton was 48 cm for the period 1931 to 2005, with 46% (22 cm) falling December through March. Precipitation decreases across the herd area from west to east, creating a drier climate along the eastern front of the Blue Mountains. The vegetative communities of the Blue Mountains are a mixture of forests and open bunchgrass communities. The lowlands are typically characterized by agricultural fields with intermixed rangeland. Kuchler (1964) describes the following forest types for the Blue Mountains of Washington: western spruce (*Picea spp*.)-fir (*Abies spp.)* forest, ponderosa pine forest, grand fir forest, and Douglas fir forest. Higher elevations are characterized by heavy conifer forests on north slopes and in canyons, whereas south slopes are open, with scattered conifers and shrubs. As elevation decreases, steppe habitat becomes more prominent, and south slopes are more open, with bunchgrass and low shrubs comprising the dominant vegetation. Riparian zones are dominated by deciduous trees and shrubs. The hair collection sites were located on USFS and WDFW lands in the Tucannon, Touchet, and Wenaha watersheds (GMUs 162, 166, and 169). Elevations for the sampling sites ranged from 853 to 1768 m.

The District 6 survey took place on USFS land on the east slope of the North Cascade Mountains north of the towns of Winthrop and Mazama in the Methow River Watershed. Elevations ranged between 850-1610 m. The climate is characterized by hot, dry summers and cold, wet winters with much of the annual precipitation (roughly 50-115 cm) falling as snow. Forest types vary from the dry Douglas fir and ponderosa pine zone at the lowest elevations to the moist Engleman spruce and subalpine fir zone at the highest elevations. Stand conditions are a mosaic of mature forest, second growth forest, natural clearings, and fire scars of various ages. The understory is characterized by a varied mix of forbs, shrubs and grasses including several important bear foods such as serviceberry, chokecherry (*Prunus virginiana*), thimbleberry, huckleberry, elderberry (*Sambucus spp*.), currant (*Ribes spp*.), and western mountain ash. Wildlife commonly within the study area includes cougar, wolf, lynx (*Lynx canadensis*), coyote, bobcat, mule deer, white-tailed deer, and moose.

The District 14 study area was entirely within Game Management Unit 418. Grid cells were placed north and south of State Route 542 (Mt. Baker Highway), largely between the towns of Deming and Glacier, WA. The study area was a mix of public and private land ownership, with all corrals located on WA DNR, USFS, or Sierra Pacific Industry lands. Elevations within grid cells vary from approximately 213 m to more than 1,200 m. Two forest zones comprise the study area: western hemlock and Pacific silver fir. The western hemlock zone, the most important timber production zone in the study area, generally reaches its upper limit at 600 meters (1,980 feet) elevation. The predominant tree species in this zone are Douglas fir, western hemlock, and, on moist sites, western red cedar. Hardwood species, such as red alder and bigleaf maple, occur mainly as pioneers on recently disturbed sites or in streamside habitats. The Pacific silver fir zone extends from about 600 to 1,300 m (1,980–4,290 feet). It is characterized by wetter and colder weather than the lower western hemlock zone, as it receives more winter snowfall and has a shorter growing season. Common understory plants are often herbaceous, including huckleberry and mock azalea (*Menziesia spp*.). In the study area, mean annual precipitation measured 248 cm and mean daily summer temperatures in June and July were 14.4 °C and 17.2 °C, respectively (NOAA 2000–2021).

The Stillaguamish/Sauk-Suiattle site was located on the west slopes of the north Cascade Range within the lowland and highland forest ecoregions of north Snohomish and south Skagit counties. The project area contained portions of the North Fork Stillaguamish and Sauk River valleys and was bisected by State Route 530 between Oso and Darrington, WA. The elevation range was 76 m to 1,219 m and included the south face of Mount Higgins and flanks of Whitehorse Mountain. Climate was maritime with annual precipitation ranging from 120 cm to 300 cm and an annual temperature range of -4 ºC to 27 ºC (National Climate Data Center). Forest zones in this region were dominated by western hemlock, Douglas fir and western red cedar. Common deciduous species include red alder, black cottonwood, and bigleaf maple.

Understory species primarily consisted of salmonberry, vining maple (*Acer circinatum*), and red huckleberry (*Vaccinium parvifolium*). In addition to black bear, common wildlife included cougar, Columbian black-tailed deer, bobcat, and coyote. The site occurred in both GMUs 437 and 448 with wide-ranging public access and extensive state and federal road networks throughout. Land ownership consisted of approximately 43% USFS, 33% DNR, 18% private rural residential/noncommercial agriculture, 6% private timber and 1% tribal properties. Federal lands were primarily second growth forests with < 10% considered late successional reserve. State lands consisted of low to moderate managed forests with typically a 40-year rotation, while private timber harvest intensity was high with shorter rotations. Private rural residential lands consisted of single-family homes and hobby farms, primarily concentrated on major road systems and river corridors. Tribally owned properties were primarily low elevation stewardship lands for floodplain restoration and contained enhanced riparian corridors, open-water wetlands, and wildlife meadows.

2022 STUDY AREAS - Districts 9, 15 & Stillaguamish/Sauk-Suiattle Tribes

The District 16 study area was in the western Olympic Peninsula in Jefferson County, entirely within the boundaries of GMU 615. The Clearwater River is the major watershed within the area. Grid cells were located between the Hoh River to the north and the Queets River to the south. Olympic National Park, which includes the Olympic Mountain Range is located to the east and the Quinault Indian Reservation is located to the south of the site. The study area is within the temperate rainforest zone of the Pacific Coastal Ecoregion (Naiman et al, 2000). Elevations varied within the corral locations from 132m to 263m. The climate is strongly influenced by the Pacific Ocean, and the area receives heavy precipitation ranging from 203cm to 355cm per year with the majority falling as rain during the winter. The study area is comprised of two climax vegetation zones as described in Franklin and Dyrness 1973. The low elevation forest (0-150m) within the Sitka spruce (*Picea sitchensis*) vegetation zone contained some hair corrals but most of the corrals were located within the western hemlock (Tsuga heterophylla) zone. Douglas fir is a seral component in both these zones while red alder (Alnus rubra) is common in riparian zones and recently disturbed areas at lower elevations. Common understory plants include a variety of grasses, forbs, ferns, and shrubs. Dominant shrubs and ferns include salmonberry, various huckleberry species (*Vaccinium spp*.), devil's club, red elderberry, salal, and sword fern. Most of the study area is publicly owned and managed by the Department of Natural Resources (DNR) but some parcels in the western portion of the area are privately owned by corporate industrial timber companies. The state forest land is actively managed under a dual mandate from the state legislature to produce revenue for various trusts (e.g. schools, counties, universities) in perpetuity while also sustaining ecosystem values. There is a high-density road system within the study area due to the long history of forest management practices. All hair corrals were located on DNR land that was accessible from ungated roads. This study area was partially selected in the district because DNR granted access, but also to help determine the black bear density in a district GMU that typically has a high harvest rate for bears. The site is also representative of less aggressive timber management practices than most private commercial forests and can possibly be compared to other large DNR ownerships on the Olympic Peninsula.

The District 9 study area included lands within the Gifford Pinchot National Forest in the South Cascades of southwest Washington within GMUs 560 (Lewis River) and 572 (Siouxon), west of Mt. Adams. This area is mountainous with elevations ranging from 400m to 1500m. Annual precipitation averages 223 cm per year and daily summer temperatures varied from an average maximum of 26 °C to an average minimum of 9 °C (NOAA 2023). The study area included the Western Cascades Montane Highlands and Cascade Crest Montane Forest Level IV Ecoregions. These ecoregions are characterized by a deep annual snowpack, volcanic buttes and cones, glaciated lakes, and forests dominated by Pacific silver fir, mountain hemlock, western hemlock, noble fir, grand fir, and Douglas fir. Hardwoods such as alder occurred in the lower elevations and riparian areas. Understory plants included a variety of grasses, forbs, and shrubs, notably vine maple, huckleberry, Oregon grape and salal. Several large huckleberry fields in the vicinity have been historically maintained using fire, by local Native American Tribes. The Gifford Pinchot National Forest, along with other adjacent National Forests, is managed under the Northwest Forest Plan and timber harvest has been very limited since the 1994 inception of the Plan. We chose this study area because we believe it to be representative of National Forest lands in the South Cascades. In April 2022 a storm deposited large amounts of snow at all elevations of the study area making access challenging for our work as well as limiting early summer food resources for black bears.

The Stillaguamish site was located on the west slopes of the north Cascade Range within the lowland and highland forest ecoregions of north Snohomish and south Skagit counties. The project area contained portions of the North Fork Stillaguamish, Lake Cavanaugh and Pilchuck creek watersheds of Snohomish and Skagit county Washington. The elevation range was 25 m to 823 m and included Fraley and Stimson Mountains. Climate was maritime with annual precipitation ranging from 120 cm to 300 cm and an annual temperature range of -4 ºC to 27 ºC (National Climate Data Center). Forest zones in this region were dominated by western hemlock, Douglas fir and western red cedar. Common deciduous species included red alder, black cottonwood, and bigleaf maple. Understory species primarily consisted of salmonberry, vining maple, and red huckleberry. In addition to black bear, common wildlife included cougar, Columbian black-tailed deer, bobcat, and coyote. The site occurred in GMU 437 with wide-ranging public access and extensive road networks throughout. These roads were used extensively by recreationalists for hiking, mountain biking and e-biking. The site also encompassed Walker Valley Off Road Vehicle Park. Walker Valley ORV Park is approximately 13 km2 and contains 42 miles of ORV trails. Land ownership consisted of approximately 69% DNR and the remaining 31% being largely held in private timber. Rural residential and tribally owned properties made up a small portion of the study site. State lands consisted of moderate or heavily managed forests with typically a 40-year rotation, while private timber harvest intensity was high with shorter rotations. Private rural residential lands consisted of single-family homes and hobby farms, primarily concentrated on major road systems and around Lake Cavanaugh.

METHODS

Capture-Recapture Field Methods

As the source of capture-recapture sampling, we constructed one non-invasive hair collection enclosure within each 9 km^2 grid cell resulting in 36 cells and an average study area size of 324 km^2. Enclosures consisted of 2 strands of barbed wire at 35 cm and 65 cm above the ground stretched around 3-6 trees, with scent lure placed in the center (Figure 2; modified version of Woods et al. 1999). We attracted bears into the enclosure with an olfactory lure using 3 L of a 2:1 mixture of aged cattle blood and fish oil poured on top of a pile of forest debris (Kendall et al. 2009). In 2021 fruit-scented liquid attractants were used in sampling occasions 3 and 4 in GMUs 437/448. While food baits at hair enclosures can cause a behavioral response, this olfactory lure provided no food reward to bears. We refreshed the lure and collected hair samples from the barbed wire at the end of each 10-day occasion. When samples were collected, we recorded strand, barb location, number of hairs, and presence of roots for each sample and placed the sample in paper coin envelopes. After each sample was collected, we placed tweezers and barbs under a flame for several seconds to reduce DNA contamination (Waits and Paetkau 2005). To minimize DNA degradation of the samples, we stored hair samples at room temperature and in color-indicating silica desiccant.

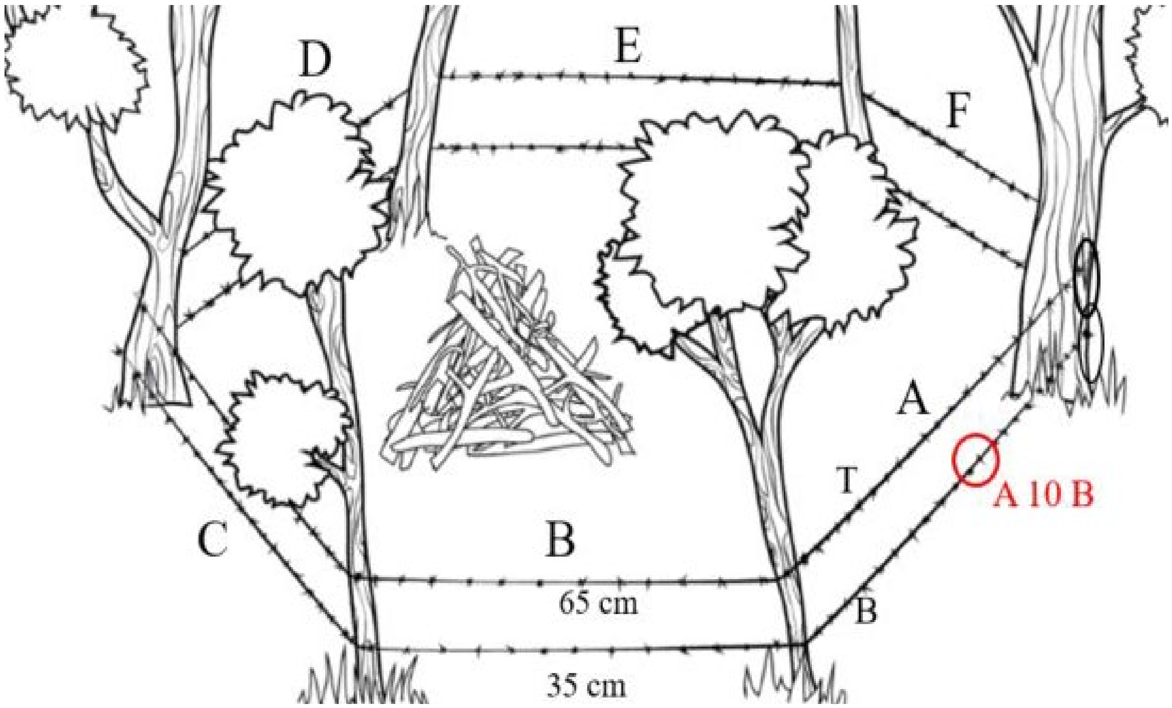

Figure 2. Visual representation of a typical barbed-wire hair enclosure used to capture hair samples for DNA collection. Red text shows how each strand and barb was identified (side A, barb 10, bottom strand), Washington Department of Fish and Wildlife.

The capture-recapture sampling timeframe occurred on each study area between May through the end July, with specific dates depending on snowmelt, access, and avoidance of mortalities which may violate assumptions of demographic closure. Dates did not extend more than 1-2 days past the end of July to avoid the fall general hunting season, August 1 – November 15, which occurred in all study areas. To avoid mortality of detected bears, hair trap enclosures were not deployed and baited until spring permit hunting seasons closed, where applicable. Timber damage removals (District 10, 11, and 17) did not have a specific timeline; therefore, DNA samples were collected from each of those kills by regional staff, and those individuals that were killed were censored from further analyses.

DNA Analysis

To retain DNA from as many individuals as possible but minimize multiple samples from the same individual at a single hair trap, we subsampled by incorporating sample quality (hair roots present and number of hairs), hair color, and adjacency to other samples. For every series of 3 adjacent barbs with hair samples of the same color, we submitted only the best quality sample for DNA analysis assuming they were from the same individual. For hair traps with a larger number of samples we repeated this process for a longer series, such as the best 3 of 9 continuous samples (Proctor et al. 2010, Kendall et al. 2016). This process was aided by cameras placed at the sites. Wildlife Genetics International (WGI) in Nelson, BC extracted and genotyped DNA within 2-3 months of collection (Roon et al. 2003). The lab included up to 10 guard hair roots or 30 whole underfurs per sample for DNA extraction and used negative controls in each extraction and polymerase chain reaction (PCR) to monitor for contamination. Microsatellite loci were generated for each study area, drawing on genotypes of black bears in the Cabinet-Yaak ecosystem for the samples in GMU 117 and from the South Cascades and Olympics for samples in GMU 672 in 2019, which were then used for GMUs 550/556 and GMU 654 in 2020 and GMUs 218 and 418 in 2021. Genotypes for bears in GMUs 162/166/169 were generated from bears in the Cabinet-Yaak ecosystem, the Boise Idaho regions, and the Washington Cascades. Genotypes for bears were generated using 8 microsatellite loci: GMU 117 used G1D, G10H, G10J, G10X, MU59, CPH9, MSUT2 and the ZFX/ZFY sex marker, GMUs 218, 418, 550/556, 654, and 672 used G1A, G1D, G10B, G10J, G10L, G10P, MU59, and ZFX/ZFY, GMUs 162/166/169 used G10H, G10P, G10J, G10B, G10L, G10M, G1A and ZFX/ZFY, and GMUs 437/448 used G10B, G10J, G10L, MU59, G10P, G1A and G1D, plus ZFX/ZFY. The lab performed genotype matching for individual identification and considered 2 genotypes a match if their genotypes were identical or if they contained mismatches at the 1-3 loci and were consistent with allelic dropout. For more detailed information on the DNA analysis, see attachment from WGI.

Density Estimation

We created spatially referenced binomial capture-recapture histories for individual bears detected at hair traps consisting of 4 sampling occasions each year. We estimated density in each study area separately using the R package oSCR (Sutherland et al. 2018). This SCR density model estimates parameters for the baseline detection probability at an individual's activity center (p0), a spatial scaling parameter (σ) describing how detection probability decreases as a function of distance from the individual's activity center to a detector, and density (D), the number of activity centers within a given area, which can be described as a function of habitat covariates.

We created SCR models using the halfnormal detection function and developed a set of a priori models for each study area to test for variation in detection (p0 and σ). We included general categorical factors of sampling occasion (t), and sex, to detect p0 heterogeneity: $\text{logit}(p0) = \alpha 0 + \alpha t + \alpha \text{male}$. Treating capture probability for each sampling occasion independently allowed us to directly test for changes in detection probability due to time, such as changes to natural food availability and seasonal molting (Wegan et al. 2012). Because female bears have smaller home ranges than males (Koehler and Pierce 2003), all models included sex specific spatial scale parameter: $\log(\sigma) = \delta 0 + \delta male$. We did not incorporate a behavioral response for p0 or other sources of individual heterogeneity for p0 or σ due to data sparsity and a lack of individual covariates, though these effects may be present. We did not test for variations in density due to habitat features between or within each study area at this time but will further assess as more data is collected.

We created a state-space for each study area, represented by a grid of potential activity center locations for individuals with a non-zero probability of being detected on the study area. We buffered detector locations by 10 km, $> 3\sigma$ recommended to produce unbiased results (Borchers and Efford 2008), and set the grid spacing at 1000 m, or $< 0.5\sigma$, to balance space use relative to movements with computational efficiency (Royle et al. 2014).

To evaluate the best model in terms of complexity and fit to the data, model selection was completed using an information theoretic approach to rank models with Akaike's Information Criterion (AIC; Burnham and Anderson 2002). We considered candidate models to be competing models if they were within $\Delta AIC < 2$ of the top ranked model and interpreted coefficients to be significant if included in top ranking models and 95% confidence intervals did not overlap 0.

RESULTS

Capture-Recapture Field Methods

During June through July 2019, we collected 1,625 hair samples: 1,260 at 36 hair traps in GMU 117 and 365 at 36 hair traps in GMU 672. After sub-sampling, we submitted 1,034 samples for DNA analysis, 736 from GMU 117 and 298 from GMU 672. From 848 samples that produced a consistent consensus genotype (91% success rate of analyzed samples), we recorded 212 detections of 103 (53F:50M) individual bears in GMU 117 and 59 detections of 28 (12F:16M) bears in GMU 672. In GMU 117 up to 9 individual bears were detected at a single site (these include females with cubs), and individual bears were detected between 1 and 8 times throughout the study area. In GMU 672 up to 4 individual bears were detected at a single site (also including females with cubs) and individual bears were detected between 1 and 5 times throughout the study area.

During June-August 2020 we collected 1,349 hair samples: 181 at 36 hair traps in GMU 550/556 and 1,168 at 36 hair traps in GMU 654. After sub-sampling, we submitted 605 samples for DNA analysis, 107 from GMU 550/556 and 498 from GMU 654. From 502 samples that produced a consistent consensus genotype (84% success rate of analyzed samples), we recorded 16 detections of 14 (6F:8M) individual bears in GMU 550/556 and 158 detections of 74 (40F:34M) bears in GMU 654. In GMU 550/556 up to 3 individual bears were detected at a single site and individual bears were detected 1 or 2 times throughout the study area. In GMU 654 up to 7 individual bears were detected at a single site (including females with cubs) and individual bears were detected between 1 and 8 times throughout the study area. Matching DNA of timber damage removals and bears detected via capture-recapture methods, resulted in 1 bear being removed from the density analysis in District 10 and 3 in District 11.

During May-July 2021, WDFW-led efforts collected 3,521 samples in: 779 at 36 hair traps in GMUs 162/166/169, 1,419 at 36 hair traps in GMU 218, and 1,323 at 36 hair traps in GMU 418. After sub-sampling, we submitted 2,207 samples for DNA analysis: 659 from GMUs 162/166/169, 778 from GMU 218, and 770 from GMU 418. The Stillaguamish tribe additionally submitted 462 samples for DNA analysis from 36 hair traps in GMUs 437/ 448. The genetics lab was able to produce a consistent genotype for 2,097 combined samples, equivalent to a 79% genotyping success rate. From the identified samples WDFW recorded 156 detections of 98 (43F:55M) individual bears in GMUs 162/166/169, 309 detections of 100 (35F:65M) bears in GMU 218, and 209 detections of 92 (52F:40M) bears in GMU 418, and the Stillaguamish tribe recorded 169 detections of 96 (46F:50M) individual black bears in GMUs 437/448. The number of individual bears that were identified at a single hair trap were 10 in GMUs 162/166/169, 12 in GMU 218, 9 in GMU 418, and 8 in GMUs 437/448. Individual bears were detected up to 4 times in GMUs 162/166/169, 12 times in GMU 218, 13 times in GMU 418, and 4 times in GMUs 437/448.

Wildfires occurred in GMUs 162/166/169 and the surrounding areas during sampling and staff were not able to collect samples and replenish lure at all sites for sampling occasions 2-4, due to both road closures and direct fire activity (Figure 3). Staff were able to recover many samples and use remote cameras to identify which sampling occasion hair was deposited. Though it is well documented that bears will move within (Zeller et al. 2019) or outside (Noyce and Garshelis 2010) their home range to adjust to seasonally available foods, and the potential impact this can have on capture-recapture estimates (McCall et al. 2013, Stetz et al. 2018), the consequence of wildfire is less clear. Fire and fire related activities, such as increased vehicle traffic, road building, and back burning may cause a barrier to detections between previously connected areas that alter the scale and direction of movements. This in turn may affect the delineation of the state-space in the analysis. With few redetections overall, it was a challenge to quantify impacts on the sampling. However, DNA results of hair samples documented that >50% of the bears detected in sampling occasion 4 had never been detected in prior occasions and spatial redetections seldom occurred in sessions 3 and 4. Although the extent of the change cannot be completely determined from the detection data, the assumption that the fire did not impact bear movements or detection probability was unlikely to be met. The conservative approach we took to retain unbiased data was to exclude inaccessible areas in sessions 2 and 3, and censor all sampling from session 4, as the fire rapidly grew during this time. This resulted in a 1 site reduction in effort in sampling session 2, a 17-site reduction in session 3, and a complete 36-site reduction in session 4 which reduced the detection data to 134 detections of 86 individuals.

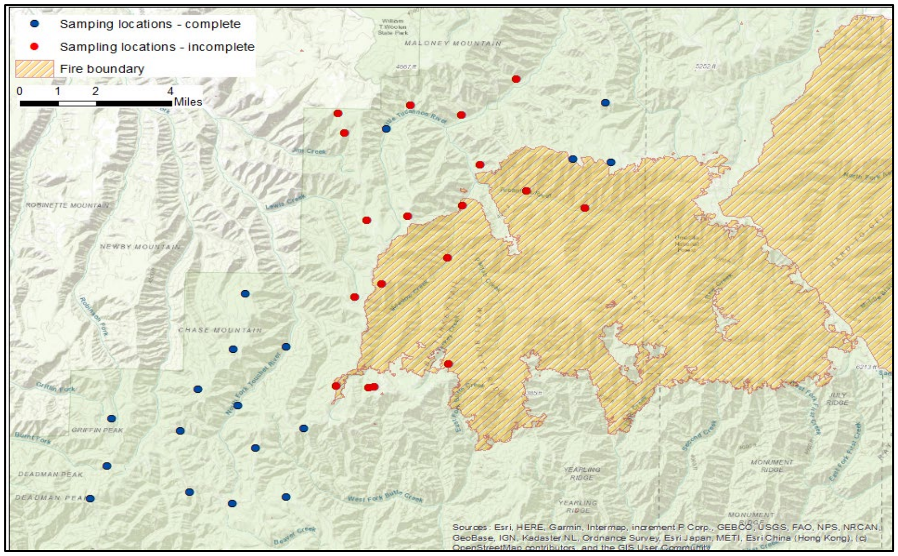

Figure 3. Green Ridge fire boundary and sampling locations within GMUs 162, 166, and 169 in 2021. Completely and incompletely sampled areas over the 4 occasions are shown.

During May-July 2022, WDFW-led efforts collected 3,277 samples: 2,263 at 36 hair traps in GMUs 560/572, and 1,014 at 36 hair traps in GMU 615. In GMUs 560/572, 3 hair traps could not be deployed in the first sampling occasion due to deep snow, but all hair traps were in use for the remaining occasions. After sub- sampling, we submitted 1,635 samples for DNA analysis: 1,036 from GMUs 560/572, and 599 from GMU 615. The Stillaguamish tribe additionally submitted 279 samples for DNA analysis from 36 hair traps in GMU 437. The genetics lab was able to produce a consistent genotype for 1,544 combined samples (all 3 study areas), equivalent to an 81% genotyping success rate. From the identified samples

WDFW recorded 303 detections of 103 (48F:55M) individual bears in GMUs 560/572, 166 detections of 92 (38F:54M) bears in GMU 615, and the Stillaguamish tribe recorded 110 detections of 55 (26F:29M) individual black bears in GMU 437. The number of individual bears that were identified at a single hair trap were 12 in GMU 560/572, 10 in GMU 615, and 5 in GMU 437. Individual bears were detected up to 12 times in GMU 560/572, 6 times in GMU 615, and 6 times in GMU 437.

Density Estimation

The top SCR detection model in GMUs 117, 218, and 418, included the effects of sex on capture probability, with females having a higher average baseline capture probability (p0) than males (Table 1). In GMUs 437, 550/556, 560/572, 654, and 672, sampling occasion and sex both affected capture probability, and again females had a higher average capture probability than males (Table 1). In GMUs 437/448 and 615 there was no sex effect on capture probability, but sampling occasion had an effect, whereas in GMUs 162/166/169 there was no sex or sampling occasion effect in the top ranked model. Due to a low number of detections in GMUs 550/556, the density analysis in this study area was modelled along with GMUs 654 and 672 which allowed us to use data collected in those areas to help inform model parameters, while estimating the density in GMUs 550/556 separately. In all GMUs, except 437/448, males moved larger distances than females, contributing to their lower baseline capture probability, while overall detections of both sexes were similar.

Estimated total density was highest in the farthest western and eastern parts of Washington. On the western edge, density in GMU 615 was estimated at 31.2 bears/100 km^2 (95% CI: 17.4-44.0; Table 2) and in eastern Washington GMU 117 was estimated at 31.1 bears/100 km2 (95% CI: 25.0-38.6; Table 2) and in GMUs 162/166/169 was estimated at 34.8 bears/100 km2 (95% CI: 26.2-46.3; Table 2). Conversely, we identified the lowest black bear densities in southwest Washington, GMUs 550/556 and 672, with 7.6 bears/100 km2 (95% CI: 3.7-15.3; Table 2) in GMUs 550/556 and 7.7 bears/100 km2 (95% CI: 5.0-11.9; Table 2) in GMU 672. Due to data sparsity, we were unable to estimate sex specific density in GMUs 550/556. Density in all other study areas was estimated between the upper and lower ends of the spectrum (Table 2). By comparing DNA from non-invasive methods to captured bears of known sex and age in previous work, we confirmed that two-strand hair traps detect both sexes and all age classes. Since cubs of the year typically comprise approximately 20% of the population (WDFW unpublished data, Beck

1991 [ID], Lindzey et al. 1986 [WA], Beecham 1980 [ID]), estimates from this project can be adjusted to determine harvest rates on independent-aged bears (Table 3 and 4).

Table 1. Model selection results from spatial capture-recapture density analysis of black bears in Washington, 2019-2022. Factors to estimate detection probability include sampling occasion (t) and sex. Models are evaluated in terms of Akaike's Information Criteria (AIC) and ranked compared to the model with the lowest AIC.

Year	GMUs	Detection Model	AIC
2019	117	sex	1129.724
		sex + t	1132.901
		constant	1178.962
		t	1180.961
	672	sex + t	432.153
		sex	434.354
		t	434.515
		constant	436.650
2020	654	sex + t	963.952
		sex	967.342
		t	971.763
		constant	974.624
	550/556	sex + t	1536.958
		sex	1547.953
		t	1552.835
		constant	1563.256
2021	218	sex	1743.801
		constant	1744.834
		sex + t	1749.548
		t	1750.713
	418	sex	1178.819
		sex + t	1183.719
		constant	1192.306
		t	1197.480
	162/166/169	constant	683.952
		sex	685.779
		t	686.027
		sex + t	687.837
	437/448	t	994.257
		sex + t	995.930
		constant	1006.706
		sex	1008.449
2022	437	sex + t	679.662
		t	684.580
		sex	718.830
		constant	724.243
	560/572	sex + t	1681.375
		sex	1684.525
		t	1688.964
		constant	1691.789
	615	t	969.444
		sex + t	971.307
		constant	980.808
		sex	982.557

Table 2. Total and sex-specific spatial capture-recapture density (D) estimates (black bears/100 km^2), and 95% confidence intervals (CI), in Washington, 2019-2022.

GMUs	D_{total}	D_{Female}	D_{Male}	95% CI
117	31.1	18	13.1	25.0 - 38.6
162/166/169	34.8	16.3	18.5	26.2 - 46.3
218	21.6	9.7	11.9	17.6 - 26.7
418	28.3	19.6	8.7	22.3 - 35.8
437	16.4	10.2	6.2	9.1 - 23.5
437/448	25.7	12.3	13.4	20.3 - 32.6
550/556	7.6	-	-	3.7 - 15.3
560/572	22.5	13.4	9.1	16.0 - 29.0
615	31.2	19.4	11.8	17.4 - 44.0
654	16.9	12.6	4.3	12.7 - 22.6
672	7.7	4.4	3.3	5.0 - 11.9

Table 3. Black bear habitat, density of bears > 1 year old, and estimated harvest rates from black bear surveys in Game Management Units (GMU) in Washington, 2013-2022, Washington Department of Fish and Wildlife.

Study Area GMU	Bear Habitat (km^2)	> 1 Year Old Density /100km^2*	Abundance >1 Year Old	2020-22 Average Annual Harvest†	2020-22 Avg. Harvest Rate
117	2450	24.9	610	81 (15S:66F)	13%
162/166/169	1306	27.8	363	53 (11S:42F)	15%
218	1173	17.3	203	22	11%
245	1504	15.4	231	32	14%
418	2139	22.6	483	85 (6S:79F)	18%[1]
437	2287	13.1	300	32	11%[1]
437/448	5197	20.6	1071	91	8%[1]
454	1091	15.0	163	21	13%
460	2401	20.3	487	31	6%
550/556	1468	6.1	89	10	11%[1]
560/572	2884	18.0	519	45	9%
615	811	25.0	203	19	9%
654	842	13.5	114	23	20%[1]
672	662	6.2	41	15	37%[1]

* Total density adjusted by 20% to remove cubs of the year
† Tribal harvests not included. Spring (S) special permit (2020 & 2021) and fall general season (F) hunts included where appropriate.
[1] Bears are taken annually for timber damage so the combined mortality rate may be higher.

Table 4. Annual black bear monitoring results by Game Management Unit (GMU) using barbed wire hair enclosures and DNA analysis on 324 km^2 study areas (each with 36 9 km^2 cells), in Washington, 2013-2022.

GMU	# Samples Collected[b]	# Subsampled for Lab Analysis[b]	Total # Detections[b]	# Individuals Identified	Male	Female
162/166/169	779	659	156	98	55	43
117	1,260	736	212	103	50	53
218	1,419	778	309	100	65	35
245[a]	1,113	387	164	117	56	62
418	1,323	770	209	92	40	52
437	279	279	110	55	29	26
437/448	613	462	169	96	50	46
454/460[a]	852	335	145	93	49	44
550/556	181	107	16	14	8	6
560/572	2,263	1,036	303	103	55	48
615	1,014	599	166	92	54	38
654	1,168	498	158	74	34	40
672	298	292	59	28	16	12
Totals	**12562**	**6938**	**2176**	**1065**	**561**	**505**

[a]Used annual average from the 4-year study (Welfelt et al. 2019) for comparison purposes.
[b]Including cubs

DISCUSSION

As observed in the current study, it is not uncommon for black bear densities to vary widely throughout their range, within jurisdictions, and within jurisdictional regions. Other research also using capture-recapture techniques reported varying densities within jurisdictions in the western United States including New Mexico with 16.5–25.7 bears/100 km^2 (Gould et al. 2018), California with 18–38 bears/100 km^2 (Fusaro et al. 2017), and Montana with 11.4 bears/100 km^2 in one study area where black bears were sympatric with grizzly bears (*Ursus arctos*; Stetz et al. 2014). A large range of densities, 3.8 – 74.3 bears/100 km^2, was reported for varying habitats in Utah; however, the authors suggest that the estimates at the upper end were likely inflated due to inadequate sampling (Schmidt et al. 2022). Density estimates reported in Washington all fell near the range of densities observed in the North Cascades Project (Welfelt et al. 2019), where density variation occurred in the eastern North Cascades (GMU 245) ranging from 7.1 bears/100 km^2 in areas of the lowest primary productivity to 33.6 bears/100km^2 in areas with the highest primary productivity. Similar projects in the western North Cascades reported an average density of 17.5 bears/100 km^2 in GMUs 466 and 485 (McDaniel and Middleton 2014), and 12–14 bears/100 km^2 in GMU

663 (Beausoleil et al. 2012), with cubs excluded in each of these estimates. Together, estimates from independent studies throughout western Washington indicate that similar processes that affect density may be occurring throughout western Washington, with the potential for additional human impacts on population in southwest Washington.

Capture probability was higher in 2019-2021 study areas compared to those observed in the North Cascades study. Much of this can be attributed to the simulation study that resulted in a modified sampling design (3 km^2 grids vs 4 km^2), whereby spatial recaptures are more likely. This contributed to the increased levels of precision in the estimates and suggests improved results with the current sampling design. Further improvements may occur by maintaining a contiguous compact sampling area and minimizing highway or improved road crossings or other deterrents to movement (Figure 4), especially for females. Contiguous areas facilitate multiple recaptures, thus the number and distribution of animals detected, and animals not detected, can be estimated with higher confidence.

The loss of data collection that occurred due to wildfires in the Blue Mountains in 2021 (~25% fewer detection opportunities) and very few bear detections observed in GMUs 550/556 in 2020 highlighted the potential for incomplete surveys and/or data sparsity that can occur with current collection methods. Such factors can greatly increase confidence intervals (Table 2) and the ability to draw inference from density estimates. Taking completed survey efforts, upcoming data needs, and new analysis techniques into account, survey methods are likely to be updated in the future.

To estimate abundance and harvest rate of black bears > 1 year old, we reduced density estimates by 20%, which represents the percentage of cubs in the estimate, and extrapolated those to the larger study area GMUs (Table 3). Hunters are urged not to harvest cubs of the year or female bears with cubs, and WDFW tooth age data suggests cubs represent < 1% of the harvest. These harvest rate estimates for black bears are the first presented in Washington and can be used as a tool to gain inference on current and future management strategies. What will be more difficult to ascertain without a mandatory reporting system or improved tooth submission rates (currently ~25%) for the fall general season hunt is determining age distribution and age class of the population, as subadult male dispersal from other areas can sustain a density even when the intrinsic growth rate is below 1.0 (Beecham 1980, Wielgus and Bunnell 1994).

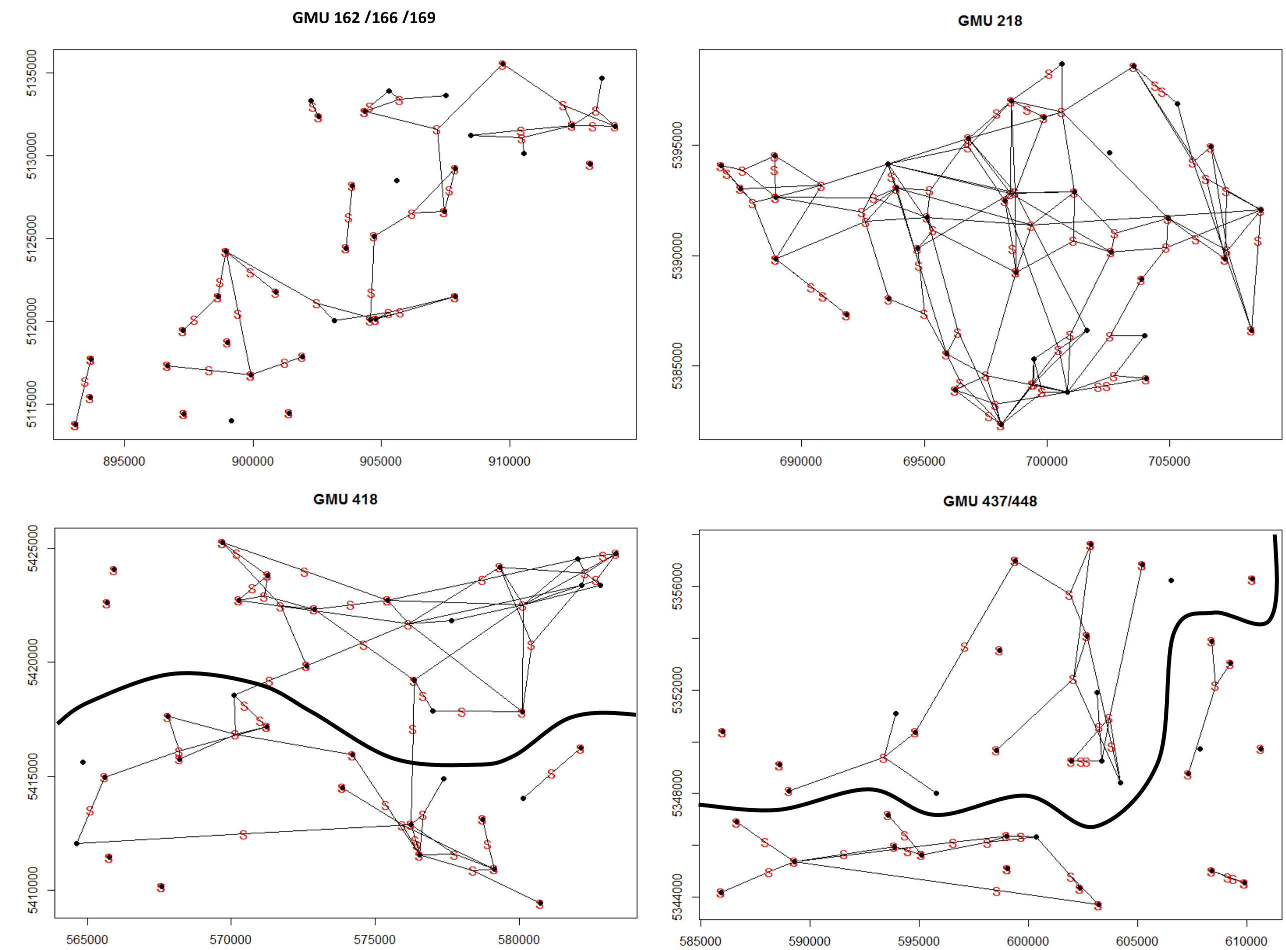

Figure 4. Array of sampling sites (black dots) with mean detection location (red with black spokes) for 2021 study areas. Thick black lines in GMUs 418 and 437/448 indicate state highways 542 and 530, respectively, which few bears crossed. The results in GMU 218 represent an ideal scenario with recaptures at multiple sites. Coordinates are shown as WGS 84 UTM.

Though density may not be uniform throughout each GMU, the areas sampled include representative habitat types of the larger GMU; therefore, the harvest rate estimates reported may be considered a reliable gauge. It is important to note that while hunter harvest is the primary source of mortality in Washington's black bear populations, other human-caused mortality such as timber damage removals, conflict related mortality, and vehicle collisions can be additive and contribute to higher overall mortality rates.

Our findings underscore the importance that black bear density is not uniform and management risk and/or lost opportunity may be increased if an average density is applied at too large a scale due to spatial and temporal variability of natural food resources, land management practices, management objectives,

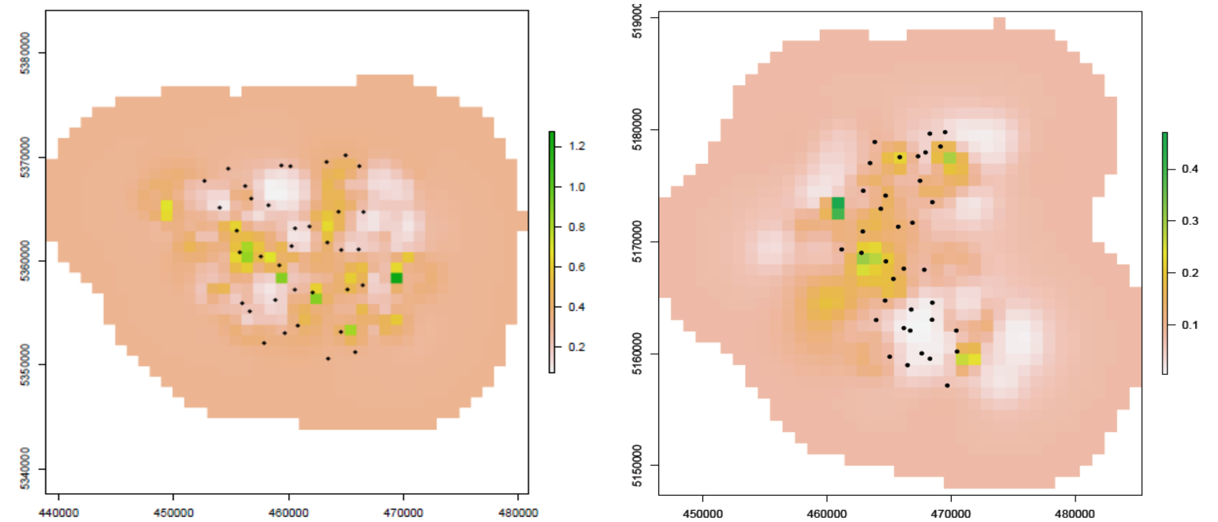

Figure 5. Visualization of realized bear density (bears/km^2) from detected and undetected individuals in GMU's 117 (left) and 672 (right) from DNA research conducted in 2019. The dots represent the detectors and the scale for each varies. Washington Department of Fish and Wildlife, 2021.

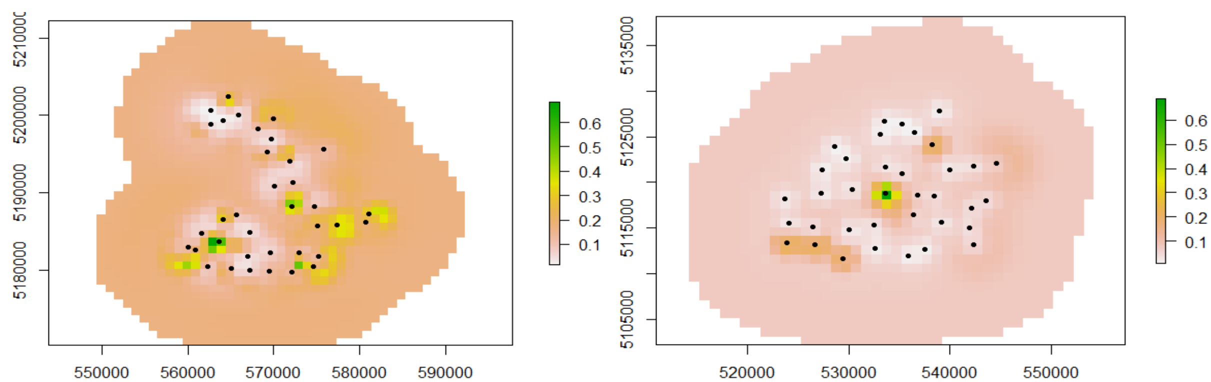

Figure 6. Visualization of realized bear density (bears/km^2) from detected and undetected individuals in GMU's 654 (left) and 550/556 (right) from DNA research conducted in 2020. The dots represent the detectors and the scale for each varies. Washington Department of Fish and Wildlife, 2021

and human populations. As seen here (Table 2; Figures 5-8) and in the North Cascades project (Welfelt et al. 2019) variations in density can occur both within and between GMUs, thus extrapolations without taking those variations into account can be inappropriate. For example, in the North Cascades (Welfelt et al. 2019), variations in density were correlated with different habitat and human factors in different areas, so we did not want to assume the same factors are affecting density similarly in all areas in Washington. There may be several interacting factors impacting density statewide that only a thorough evaluation will reveal. Therefore, the long-term value and goal of these density monitoring projects is a statewide habitat-

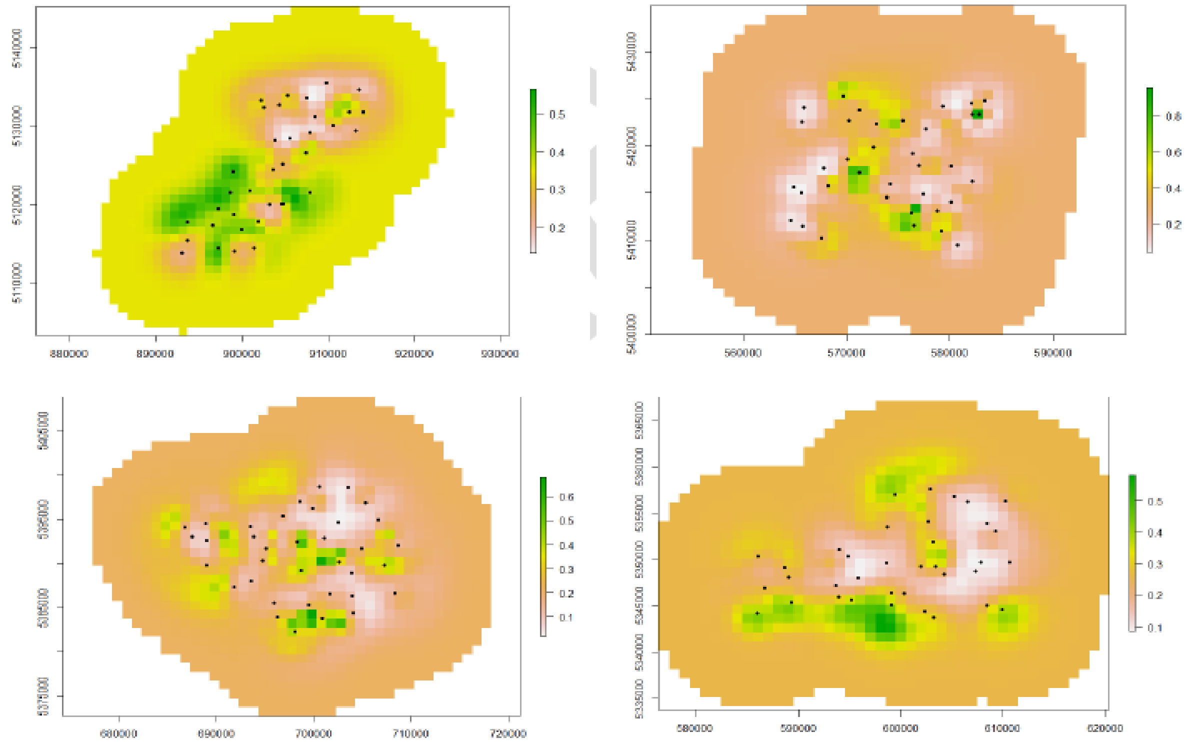

Figure 7. Visualization of realized black bear density (bears/100 km^2) from detected and undetected individuals in GMUs 162/166 (top left), 218 (top right), 418 (lower left), and 437/448 (lower right) from DNA monitoring in 2021. The dots represent the detectors and the scale for each varies. Washington Department of Fish and Wildlife, 2022)

based model of density with the flexibility to take multiple factors into account and adjust as habitat or management changes occur over time. As monitoring density at a statewide scale annually may be infeasible, a habitat-based model would be a more appropriate way to infer density in unsampled areas. Given that sampling has occurred in medium to high quality bear habitat and harvest levels, and in areas that private timber companies have been known to feed bears with the expectation that it will reduce timber damage, sampling locations need to be broadened to include lower harvest and less productive areas including alpine habitats and more arid landscapes where bears are known to occur. As time progresses and sampling gaps are filled, thus further informing density in additional habitat and land management types, we will likely have an even more representative model which can then be expanded to incorporate forest age and productivity over time, harvest and mortality patterns, and development. Such a model can also form the building blocks of an overarching assessment of black bear population size, trend, and the effects of management actions by integrating additional data such as age at harvest, research data from GPS collared bears, hunter effort, and harvest distribution.

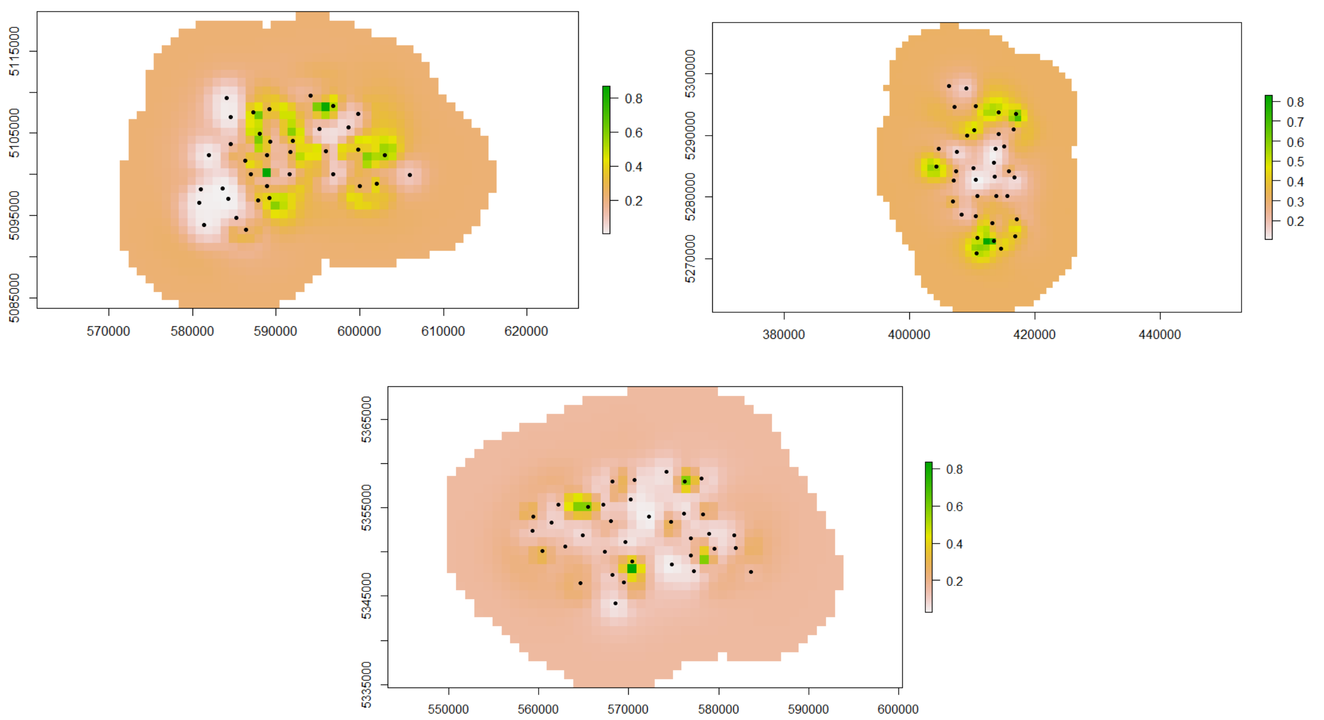

Figure 8. Visualization of realized black bear density (bears/100 km^2) from detected and undetected individuals in GMUs 437 (top left), 560/572 (top right), and 615 (bottom) from DNA monitoring in 2022. The dots represent the detectors and the scale for each varies. Washington Department of Fish and Wildlife, 2023).

MANAGEMENT IMPLICATIONS

These results provide a standing density estimate within each of the districts for the 40-day sampling period; although this is a short timeframe, these densities can be instructive in a variety of ways. Most importantly, we demonstrate the density variation that occurs not only within the jurisdiction of Washington, but also within each region and within each district. This updates information from the previous black bear management plan (WDFW 1997) where densities were presumed to be more uniform on each side of the Cascade Mountains. Our results also suggest that black bear distribution throughout the state is much different than previously forecasted (WDFW 1997), and statewide abundance is likely smaller than previously predicted using population reconstruction and harvest data. Finally, the estimated density in study areas within the North Cascades (GMUs 218, 418, 437/448) are consistent with those derived from more rigorous density estimation work conducted nearby (GMUs 245, 454/460) from 2013-2016 (Welfelt et al. 2019) giving us confidence that the simulation work we conducted prior to sampling was adequate and produced unbiased results.

In the next phase of this work, we plan to incorporate all data into a habitat-based model using Bayesian inference, identifying which co-variates best explain variations observed, and if the best-fitting model(s) can reliably be used to predict densities in both sampled and unsampled areas. For that step, Game Division staff will work with agency biometricians and research scientists to allow the model to have the flexibility to take multiple factors into account and adjust as habitat or management changes occur through time. Upcoming surveys will focus on filling in habitat gaps and may transition into a larger scale but less intensive survey design that multiple districts could collaborate on simultaneously. As more nuanced models with more data are developed, it's likely the density within and around the study areas will be updated. The final step for black bear monitoring will be to detect change in local and statewide populations. For that, we may need additional data such as revisiting previously sampled areas, information on age of harvested bears, and sex-age specific survival and reproduction data from GPS collared individuals, but that step requires considerable planning and discussion before it can be implemented.

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