Mapping American black bear habitat shifts in Washington state following wildfires

by

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ABSTRACT

Mapping American black bear habitat shifts in Washington state following wildfires

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After decades of fire suppression, wildfires in the Pacific Northwest have increased in size and quantity in recent years. Little is known about how these fires may be impacting black bear (*Ursus americanus*) habitat. My research examined wildfire-related land change and its impact on plausible black bear habitat in Washington state from 2010 and 2020. Using GAP program habitat maps, LANDFIRE disturbance data, and MTBS wildfire severity data, I created a series of maps in ArcGIS Pro to identify where wildfire-related habitat change may be occurring and its potential impact on habitat concentration areas (HCAs). I found that all fires impacted black bear habitat in the short-term by reducing cover and food resources, but that location and size of the fires determined how severe these impacts were. Fires that fell completely within the HCAs generally had enough surrounding habitat that their impact was minimal. Fires that fell outside of the HCAs, but along travel corridors, likely had more impact since suitable habitat along the corridors is sparce. While this study can provide insight into how bears may be affected by habitat change due to wildfires, additional studies will be needed to understand these impacts. Future studies should include telemetry data from populations most at risk for exposure to fire, habitat assessments following those fires, and physical observations of these populations.

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Acknowledgements

Growing up in the Rust Belt, I never imagined that I would end up here, on the opposite side of the country, studying wildlife that I had not seen until I was 22. My love for forests began with running and eventually carried me to an internship at the Great Smoky Mountains National Park, where I saw burned land and bears for the first time. I was curious about where the bears went after the fire and how they survived, but I didn’t give it much thought. Now I’m here, knowing a lot more about black bears and fire than I did then. I want to thank everyone who has helped guide me here; though there are too many people to name, I appreciate everyone’s role in my life that has led me here. Most importantly I thank my partner Vanessa for bringing me balance, encouraging me to take breaks, get outside, and do what I genuinely want—I could not have done this without you.

“*Last but not least, I wanna thank me”* – Snoop Dogg

Introduction

American black bears (*Ursus americanus*) have been extensively studied in Washington State. They have a broad distribution throughout Washington (Hummel et al., 1991; Johnson & Cassidy, 1997), are associated with forested habitats (WDFW, n.d.), and display wide-ranging space-use patterns (WDFW, n.d.). Studies on the eastside of the Cascades found that important habitats included riparian forest, deciduous forest, and montane-high elevation forest. Dry non-forest habitats such as shrub steppe were ranked as low use by bears (Lyons et al., 2003; Gaines et al., 2005).

However, researchers in Washington State have not adequately studied black bear habitat in relation to fire and vegetation changes. Within the past decade, there have been 19 fires in Washington larger than 200 km^2, the size of the average female black bear home range (Koehler & Pierce, 2003). In this thesis research, I wanted to understand black bear habitat in dynamic fire-shaped environments. How have wildfires changed the landscape in Washington State and have these changes been significant enough to impact American black bear habitat? I answered these questions by assessing land change in relation to fire and comparing habitat concentration areas (HCA) for black bears from 2010 to 2020.

I used a combination of habitat models to assess the plausible habitat of the American black bear in Washington State. Based on the parameters set by Washington Wildlife Habitat Connectivity Working Group (Working Group), I assessed habitat change since their last published map (2010). To do this, I updated the GAP Program habitat maps following methods outlined by McKerrow et al. (2014). Once the land cover layers were updated, I completed a habitat analysis following steps outlined by Working Group (2010). I then compared these changes to fire severity data from a select number of fires within the last ten years (MTBS).

Based on recent wildfire data, I predicted that wildfires have created a shift in black bear habitat by transitioning forested areas to grass or shrub-land and removing cover and potential food sources. However, this was not the case as land cover change showed areas of ecological succession near areas of burned habitat, meaning areas that were previously classified as grassland transitioned to shrubland, and areas that were previously classified as shrubland transitioned to forest. This suggests that while fire may have removed cover in one area, other areas were developing more cover or potential food sources.

The consequences of wildfire on black bear habitat can be beneficial, depending on severity, frequency, and size. Fires that reduce food resources, cover, and potential den sites may negatively impact black bears within the first year following the fire (Bogener, 2003; Daubenmire, 1968; French & French, 1996; Hamilton, 1981). Specifically, severe fires that remove large amounts of snags, coarse woody debris, and vegetative cover are most likely to negatively impact black bears (Bull et al., 1997; Davis, 1996; Hall, 1976; Jonkel & Cowan, 1971). However, in areas where vegetation growth favors fire, fire exclusion may have adverse effects on foraging (Unsworth et al., 1989). For example, certain shrubs, like blueberry and blackberry produce the most fruit several years after a fire (Landers, 1987). In the absence of fire, these shrublands may be shaded out by developing forests, diminishing a food source. In fact, a study by Potter and Kessell (1985) found that black bears showed the lowest preference for foraging in unburned communities and the highest preference for foraging in communities burned 10 years prior. Fires that create a mosaic of burned and unburned areas are most beneficial (Allen, 1987; Bendell, 1974; Cunningham et al., 2003; Kelleyhouse, 1979).

Literature Review

Introduction

Wildfires in the Pacific Northwest have grown in size and quantity in recent years (Halofsky, 2020). To better understand wildfires and their impact on black bear habitat, I reviewed literature on fire regimes in Washington and how land change is mapped. This research shows that fire regimes in Washington range from infrequent high-intensity fires to frequent low-severity fires. Changes from these fires are mapped using LANDFIRE disturbance data and comparing satellite imagery from before the fire. I then reviewed literature on black bear habitats, their responses to disturbance, their behaviors, and tracking. Black bear habitat preferences have been found to vary geographically, but their response to disturbance is generally the same. Black bears tend to prefer areas with a mosaic of land cover from shrublands to forests, depending on the season and food sources. They tend to avoid developed or populated areas, but will venture out if their food is scarce. They are usually tracked using a combination of GPS collars and on the ground observations.

Fire

Regimes in Washington

Fire regimes are characterized by the intensity of a fire and the frequency of burn. They are typically described by a combination of forest types and the known or hypothesized effects of fires in them. Fire severity is the effect that fire has on an ecosystem, including anything of value: vegetation, soils, streams, timber, wildlife habitat, and human communities (Tappeiner II et al., 2015). It is commonly correlated with intensity; however, not every intense and stand-replacing crown fire is severe, nor is every low-intensity surface fire harmless to an ecosystem. Severity is rooted in the intersection of plant and ecosystem adaptations of fire: the intensity of a particular fire and the resistance and resilience of plants, soils, and other parts of the ecosystem to that fire (Kilgore, 1981).

Agee (1993) classified several forest types with respect to fire frequency, intensity, and perceived intensity. However, there are important aspects of a fire regime that cannot be documented by mean fire return interval alone (Agee, 1993; Baker and Ehle, 2001). Actual fire occurrence and severity could vary throughout forests that are in the same severity classification. This can happen when applied to areas of large forest types and areas that vary in topography and microclimate, species composition and stand structure, total amount and arrangement of fuels, and probabilities of ignition or spread.

An infrequent high-severity fire regime creates major shifts in the structure, composition, and function of a forest. These forests have generally productive stands, with a high accumulation of fuels, and where seasonally dry weather promotes sufficiently low fuel moisture. Fires spread rapidly during the hottest and driest parts of the season and burn large areas with patch sizes ranging from 10-10,000 acres. Historically, major fires occurred at least every 100 years. Washington has several examples of infrequent high-severity fire regimes such as Douglas fir/western hemlock forests, lodgepole pine forests, and true fir forests. Douglas fir/western hemlock forests and coastal redwood forests in the western slopes of the Cascades and Olympic Mountains of Oregon and Washington fall into this regime. Between stand-replacing events, surface fire occurred sporadically associated with drier microsites and indigenous burning practices (Peter and Harrington, 2014). Lodgepole pine forests in the Cascades regenerate quickly after stand-replacing fires and form dense stands that susceptible to severe fires after 60 years. The quantity of dead wood generated by self-thinning, insect mortality, and understory growth of trees and shrubs make this forest type susceptible to fire.

True fir forests occurring at subalpine elevations with a persistent snowpack and short growing season generally regenerate slowly after a fire (greater than 400 years). Fire may occur during extended years of drought, possibly associated with subtle changes in climate (Tappeiner II et al., 2015).

Fires in the mixed-frequency and severity fire regime generally cause ongoing temporal and spatial shifts in the character of a forest. This creates more variability than is found in either high- or low-severity regimes. Mixed fire regimes have regular fire within parts of the landscape, with mean fire return intervals (MFRI) of less than 20 years (Sensenig et al., 2013), but less frequent fires in other parts of the forests, ranging from 25-100 years, depending on the season and weather conditions. Mixed severity fires reduce stand density on average but leave patches of trees unburned as well. Biomass is accumulated relatively quickly between fires. Plant communities in topographic positions with higher probabilities of burning tend to burn most frequently, creating an ecological memory in the landscape (Tappeiner II et al., 2015). Dry Douglas fir forest in the eastern Cascades, west-central Cascades and Sound Trough have a fire return interval of 70-100 years. The forest structure is often patchy, with regeneration occurring in openings caused by fires, often with a hardwood component.

Frequent low-severity fire regimes, also known as understory regimes, have historically occurred on drier sites, with short return intervals ranging from 5-25 years. Drier sites have lower productivity with a high chance for ignition and little time for major fuel accumulation between fires. Fire seasons are generally long and widespread with periodic fuel accumulation to bark beetles or other insects. Forest types in this regime include ponderosa pine forests, mixed-conifer forests on the east side of the Cascades, and oak woodland forests along the fringes of valleys in western Washington. Sites with annual fire seasons that are dominated by ponderosa pine, with grass and shrub understories, normally have return intervals of 5-15 years. Mixed-conifer forests on the east sides of the Cascades are composed of ponderosa pine, sugar pine, Douglas fir, incense cedar, and white fir. Oak woodland forests had low-intensity fires that burned through an understory dominated by grasses. These fires were typically initiated by Native Americans for food and wildlife habitat, which could account for the short return interval of <25 years. With fire exclusion policies, Douglas fir trees have often invaded these sites, overtopping, and killing oak trees (Tappeiner II et al., 2015).

Mapping

McKerrow et al. (2014) used land cover and disturbances to update the National Gap Analysis Program's Species Habitat Map. They relied on deductive modeling of habitat attributes using these products to create models of habitat availability. They tested the integration of the Multi-Resolution Landscape Characterization Consortium's National Land Cover Database 2011 and LANDFIRE's Disturbance Products to update the species models. The update approach was tested in three geographic areas. NLCD products were used to identify areas where the cover type mapped in 2011 was different from what was in the 2001 land cover map. Satellite imagery from Google Earth and ArcGIS basemaps were used as reference imagery to label areas identified as "changed" to the appropriate class. Areas that were mapped as water or urban in the updated NLCD map were accepted without further validation and recoded to the corresponding GAP class. LANDFIRE's Disturbance products were used to identify changes that are the result of recent disturbance to inform the reassignment of areas to their updated thematic label. Areas that were changed in the 2011 NLCD map but having no record of disturbance were reclassified using the nearest neighbor function. Once land cover was updated, they ran a habitat species model for three species created by GAP. To compare how land change may have impacted habitat they ran the model for the 2001 NLCD map and the updated land cover map they created. This analysis showed that the three species were impacted by land cover change from recent disturbances (McKerrow et al., 2014).

American black bear

Habitat and Disturbance

Habitat diversity is important as bears require a mosaic of vegetation. Preference is given to mesic over xeric sites and forest over open areas (Unsworth et al., 1989). Habitat use is dictated by seasonal food production (Amstrup & Beecham, 1976; Hatler, 1972). Meadows are generally preferred for foraging on grass and forbs during spring (Gill & Beck, 1990). Riparian habitat, avalanche chutes, and early-successional habitat created by logging or fire are preferred in the summer (Fuller & DeStefano, 2003; Hamer, 1995). Mature forest containing hard mast is preferred during fall (Elowe & Dodge, 1989; Litvaitis, 2001).

Habitat modification has a greater effect on American black bears than direct mortality from wildfires (Yellowstone National Park, 1991). Fires that create patches of burned and unburned areas are most beneficial (Allen, 1987; Bendell, 1974; Cunningham et al., 2003; Kelleyhouse, 1979). Fires that reduce food resources, cover, and potential den sites may negatively impact black bears in the short-term (Bogener, 2003; Daubenmire, 1968; French & French, 1996; Hamilton, 1981). A severe fire that removes large amounts of snags, coarse woody debris, and vegetative cover would most likely negatively affect American black bears (Bull et al., 1997; Davis, 1996; Hall, 1976; Jonkel & Cowan, 1971). However, fire exclusion may have adverse impacts on foraging in areas where vegetation growth favors fire (Unsworth et al., 1989). Huckleberries and blueberries are more productive on recently burned sites compared to unburned sites. Logging treatments that include severe soil scarification or slash burns may also reduce berry yields. In areas where timber harvesting favors berry production, lack of cover in early postfire years may limit its use.

Potter and Kessell (1985) modeled potential feeding and reproductive habitat utilization for large mammals in any homogenous forest community. They examined wildlife use of an unburned habitat and habitats at 0, 10, and 25 postfire years. American black bear showed the lowest preference for foraging in unburned communities and the highest preference for foraging in the postfire year 10 community.

Wildfires, prescribed burns, and thinning treatments can cause significant changes to habitat conditions such as increasing fragmentation (Mitchell & Powell 2003), and reducing cover (White et al., 2001; Tredick et al. 2016). Forage availability varies with precipitation patterns and rate of vegetation maturation, which results in seasonal shifts in forage consumption (Pelchat and Ruff, 1986; Auger et al., 2005). Post-disturbance recovery of vegetation can vary by burn severity, plant species, and climatic conditions (Bartel et al., 2016). These disturbances have the potential to create unfavorable environmental conditions, at least short-term, as they reduce forage availability, horizontal cover, and basal area, which could result in area avoidance by bears until adequate vegetation recovery has occurred (Mitchell et al., 2005; Baruch-Mordo et al., 2014).

A study by Cunningham and Ballard (2004) found that the largest impact of wildfire was lack of recruitment of cubs in the yearling age class over a period of 4 years after a fire in central Arizona. It was suggested that continued poor recruitment could result in a population decline if vegetation regeneration is prolonged. They suggested an altered hunting strategy, which could be useful in managing populations in Washington. The most supported models suggested that black bears were more likely to select bed sites with a combination of low horizontal visibility and high basal area. Black bears were found to use all disturbed sites to varying degrees, although 48% of bed sites were in undisturbed habitat (Bard & Cain 2020). Site selection was most strongly related to decreased visibility due to obstruction from boulders, vegetation cover, and downed logs (Bard & Cain, 2020).

The impacts of roads on black bears are determined by location, road structure, amount of traffic, and timing of road use. In the northern Cascade Range of Washington, roads consistently had a negative impact on habitat used by female American black bears (Gaines et al., 2005). Roads may not be problematic if they are gated to reduce vehicular traffic and maintained as linear wildlife openings (Gaines et al., 2005; Frederick & Meslow, 1977; Lyons et al., 2003).

Den types vary geographically; however, den sites located in dead- and live-tree cavities are preferred across the American Black Bear's range (Bull et al., 1996, 1997). Denning periods depend on the length of winter but typically occur October-May. In the northeastern Cascade Range of Washington, females entered dens approximately 1 week earlier in the fall and left dens 1 week later in the spring than males (Gaines, 2003). Pregnant females will den longer (up to 247 days in one bear in Alaska) (Schwartz et al., 1987).

Black bears are common throughout Washington except for the non-forested areas of the Columbia basin. Black bears live in a diverse array of forested habitats in the state, from coastal rainforests to the dry woodlands of the Cascades’ eastern slopes. In general, black bears are strongly associated with forest cover, but they do occasionally use relatively open country, such as clearcuts and the fringes of other open habitat (WDFW, nd).

Home Ranges

Home range size, distribution within home ranges, and density of black bears are determined by sex, habitat quality, population density, distribution of food, breeding season, and topography (Amstrup & Beecham, 1976; Archmabault et al., 1990; Elowe & Dodge, 1989). Adult males have the largest home range followed by adult females, yearling males, and yearling females (Powell et al., 1997). Size and distribution is the greatest in the summer, during breeding season, for adult males and largest for adult females and cubs from September until October during high food abundance. All bears reduce their range size in late Fall through Spring during denning (Powell et al., 1997).

Females that are related usually have overlapping home ranges (Amstrup & Beecham; Horner & Powell, 1990; Jonkel & Cowan, 1971). Subadult males and females may be allowed to stay on their mothers' home ranges for their first year of independence before dispersing (Kolenosky et al., 1987). When female yearlings separate from their mothers at 16-17 months of age, they live alone within their native home range. Mothers may shift their territories away from their daughters, possibly to avoid overcrowding (Rogers, 1987).

Tracking and Modeling

In New Mexico, Bard and Cain (2020) used a combination of GPS location data and a use/available study design. By using a combination of GPS tracking with on the ground observations, they were able to identify den and bed sites and gather their attributes. GPS collars to track wildlife is common practice, but the rate in which data is collected varies by the objective of the study. To conserve battery, it is best practice to use GPS collars with motion sensors so that they are only collecting data when there is activity.

Tracking efforts in Yosemite have involved ground-based telemetry techniques to collect locations on radio-collared bears (Matthews et al., 2006). Telemetry locations were collected from two or more locations using the loudest signal to determine azimuths (Springer, 1979) using a handheld receiver. The location error was then determined using the location error method (Zimmerman & Powell 1995). To measure location error, the distance between the actual location and estimated location were measured. Ground-based telemetry efforts were restricted to the Valley because of limited road availability. To generate home range estimates of radio-collared bears in areas outside of the Valley, aerial telemetry was used (Matthews et al., 2006). Location data was collected during 24-hour monitoring events for 30 seconds in 15-minute intervals. During monitoring, motion sensors were used to monitor pulse rate to determine bear activity (Ayres et al. 1986). Movements were then quantified by measuring distance traveled between two locations collected in 1-hour intervals during the monitoring event. Matthews et al. (2006) found that adult male bears were significantly more active during nocturnal and diurnal periods, whereas adult female, subadult male, and subadult female showed no significant difference in diurnal and nocturnal activity. Adult females were shown to be more active during nocturnal periods when they were located only in natural areas. Diurnal patterns of bears could be explained by foraging behavior (Bacon & Burghardt, 1976; Lariviere et al., 1994). Bears rely on visual cues for foraging, making daylight more efficient. Bears who have been found foraging in developed areas may display nocturnal behavior to avoid human harassment (Ayres et al. 1986; Lariviere et al. 1994; Pelton 2000). Human activity and use of developed areas in

Yosemite Valley by bears result in behavioral differences between bears near humans and bears in areas with less human impact (Matthews et al., 2006).

Washington Wildlife Habitat Connectivity Working Group (2010) created a state analysis for certain focal species, one being the American black bear. For their analysis, they consulted habitat and wildlife specialists to inform on important habitat attributes for each species. Studies by Cushman et al. (2006, 2008) were used to identify important attributes for black bears. Attributes that were considered were: distance from roads, human population, habitat type, elevation, and slope. Habitat attributes were then weighted for each species based on their importance and used to determine landscape-resistance. This helped inform on where black bears would most likely not be found, which was determined to be the inverse of ideal habitat. Cushman et al. (2006) used genetic distance metrics to test landscape-resistance. They used elevation, slope, roads, and land cover to develop their hypotheses. The models most supported by genetic distance data showed strong relationships with forest cover and mid-elevations, with variable support for different levels of road factors and no relationship with slope (Cushman et al., 2006). The best supported model had high road resistance, which was then used to identify corridors. In 2008, Cushman et al. used the model to identify potential corridors for American black bears between forested portions of the Canadian border down to the northern boundary of Yellowstone National Park. They identified three categories of potential barriers along the movement corridors: gaps in federal ownership that contain freeways and major highways; areas within federal ownership where major highways cross the corridor; and areas where major corridors parallel highways (Cushman et al., 2008).

Studies of American black bears in Washington have focused on habitat preference related to human activities and habitat modeling (Cushman et al., 2006, 2008). These studies helped inform important habitat attributes that were used to create a map of predicted habitat concentration areas (HCAs) for black bears (Working Group, 2010). To understand black bear habitat in dynamic fire-shaped environments I asked: How have wildfires changed the landscape in Washington State and have these changes been significant enough to impact American black bear habitat? I answered these questions by assessing land change in relation to fire and comparing habitat concentration areas (HCAs) for black bears from 2010 to 2020.

Methods

The following methods were adapted from Working Group's 2010 Statewide Analysis. To ensure the exact methods were followed I had intended to use the model (Gnarly Landscape Utilities, 2010) that was created as a product of their analysis in lieu of individual calculations in ArcGIS Pro. However, due to updates in software and the need for updated code, I chose to follow the steps outlined below.

Three national datasets were used to update land cover to 2021. The Ecological Systems map (GAP, 2011) was the primary base layer and was updated with Fuel Disturbance data (Landfire, 2020) to make reclassifying disturbed areas possible. Current Land Cover (NLCD, 2019) was used for comparison of forest harvest and regeneration areas. Additional base layers used for the analysis include elevation (National Elevation Dataset, n.d.), slope, roads (TIGER, 2000), and housing density (U.S. Census, 2000) all of which were maintained from WWHWG's 2010 analysis. Although roads and housing density may have significantly impacted habitat concentration areas for black bears, land use layers should have reflected at least some of that change by reclassifying areas as urban or developed. Previous analysis included forest structure data, such as canopy cover and height, but was excluded from this analysis due to incongruencies experienced in the 2010 analysis.

Once data was obtained and imported into ArcGIS Pro v2.9.2 it was projected onto a World Topographic Map using NAD 1983 (2011) State Plane Washington South FIPS 4602 (meters). GAP (2011) was reclassified to the Working Group classifications listed in Appendix A. It was then combined with Fuel Disturbance (LANDFIRE, 2020) and filtered to target areas in which disturbance occurred. Forest areas identified as disturbed were recoded into the appropriate ecosystem classification based on the time and severity of the disturbance (Appendix

B). Areas that were not designated as forested habitat or shrub initially were not recoded according to disturbance. Large or severely disturbed areas were compared to NLCD (2019) to designate the appropriate ecosystem classification. The updated land use layer was converted from 30m cells to 100m cells to match the other base layers.

Each base layer was reclassified according to resistance values provided by Working Group (Appendix C). The resistance layers were combined, and resistance was calculated by summing their resistance values and adding one to account for Euclidian Distance. Suitable habitat was identified as areas with a resistance value of ≤ 6, a home range radius of 2.6 km, a moving window threshold of 0.5, and a minimum patch size of 200 km^2.

To better understand how specific fires may have shaped black bear habitat, I looked at wildfire severity data and compared it to vegetation change. I focused on fires that have occurred within the past 10 years and fell within or near the habitat concentration areas. By looking at specific fires, I was able to see what vegetation change was a result of natural processes and what vegetation change was a result of human error in mapping.

Results and Discussion

State Level Patterns

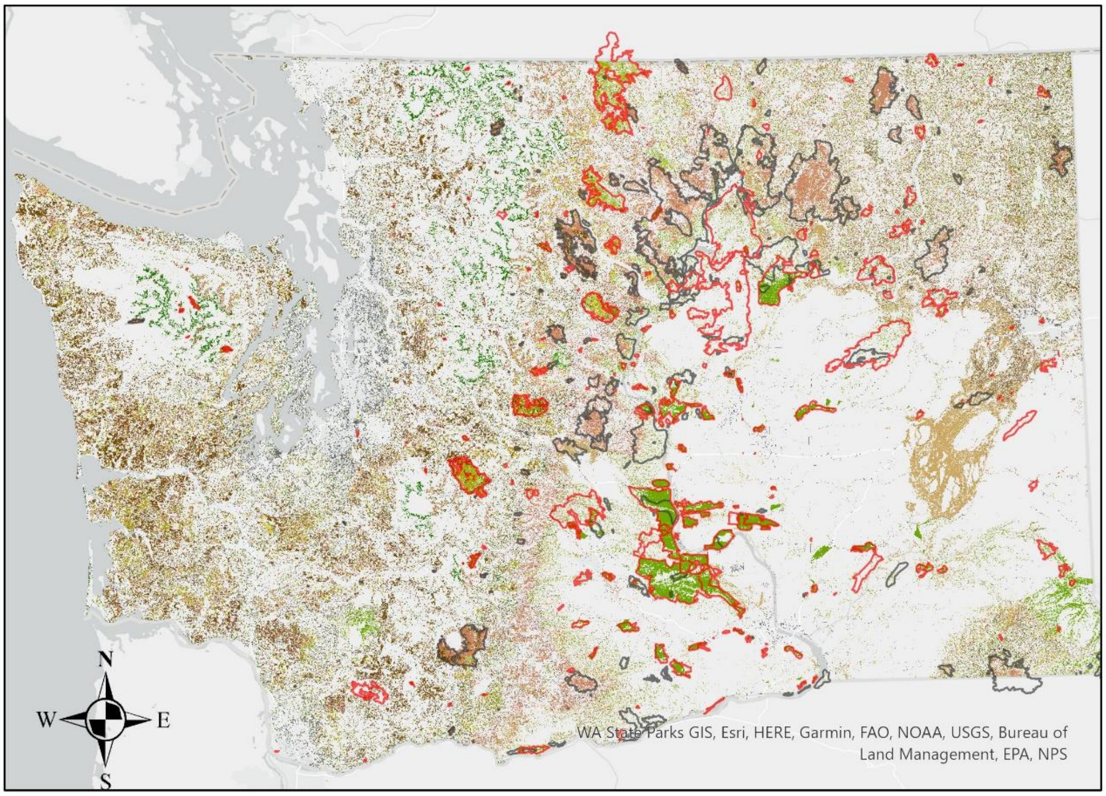
Large wildfires are becoming increasingly common in the western United States. High intensity wildfires can impact habitat by changing vegetation growth, allowing for invasive vegetation establishment, removing tree coverage used for denning, and damaging food resources for black bears (Halofsky et al., 2020). How have wildfires changed the landscape in Washington State? Have these changes been significant enough to impact American black bear habitat? While the largest of these fires fell outside the ideal habitat area for black bears, a few fell completely or partially within these areas (Map 1). To determine if these fires have impacted black bear habitat, I compared land classifications from 2001 to 2020 (Appendix A). Areas that were previously classified as wet or dry forest and then reclassified to either shrub- or grass-dominated would have the most impact on black bears by removing cover used for denning sites. Likewise, areas that transitioned from grass- or shrub-dominated to wet or dry forest could provide more habitat for bears by providing cover and food sources.

The largest fires within the past 10 years fell on the east side of the Cascades between or partially within HCAs. These include the Lime Belt, Tunk Block, North Star, and the Carlton Complex fires. Nearly all the remaining fires fell within the HCAs along the Cascades. These include the Diamond Creek, Jolly Mountain, Norse Peak, and Buck Creek fires. Hayes Two fell completely within the HCA in the Olympic Peninsula.

To understand wide-scale landscape changes in Washington State, I compared land change from GAP v.2.2 to GAP v3.0 (Map 1). The largest change, covering 56634.3 km^2, was from wet forest to dry forest. Grass-dominated to shrub-dominated was the next largest change, accounting for 44577.9 km^2. Areas classified as wet forest include mesic forests and mixed hardwood-conifer forest (Appendix A). American black bears prefer mesic or xeric sites (Unsworth, 1989). Changes from wet to dry forest could be significant because of loss of cover for denning and loss of food resources. Changes from grass- to shrub-dominated show evidence of succession, which may provide more habitat for black bears in the future.

Major landscape changes such as fires may not worsen black bear habitat. Fires that contain a mosaic of burned and unburned areas are preferred (Allen, 1987; Bendell, 1974; Cunningham et al., 2003; Kelleyhouse, 1979). A closer look at fires in or near HCAs within the past 10 years shows that fires had a significant short-term impact on black bears, but may have been beneficial in the long-term.

Map 1: Land change with fire perimeters 2001-2020



Scale: 1:3,100,000

0 25 50 100 Kilometers

Legend

- Dry Forest->Grass-dominated
- Dry Forest->Shrub-dominated
- Dry Forest->Sparsley Vegetated
- Dry Forest->Urban/Developed
- Dry Forest->Wet Forest
- Grass-dominated->Dry Forest
- Grass-dominated->Shrub-dominated
- Grass-dominated->Sparsley Vegetated
- Grass-dominated->Urban/Developed
- Grass-dominated->Wet Forest
- Shrub-dominated->Dry Forest
- Shrub-dominated->Grass-dominated
- Shrub-dominated->Sparsley Vegetated
- Shrub-dominated->Urban/Developed
- Shrub-dominated->Wet Forest
- Sparsely Vegetated->Dry Forest
- Sparsely Vegetated->Grass-dominated
- Sparsely Vegetated->Shrub-dominated
- Sparsely Vegetated->Urban/Developed
- Sparsely Vegetated->Wet Forest
- Wet Forest->Dry Forest
- Wet Forest->Grass-dominated
- Wet Forest->Shrub-dominated
- Wet Forest->Sparsley Vegetated
- Wet Forest->Urban/Developed

Year of Fire

- 2012-2015
- 2016-2020

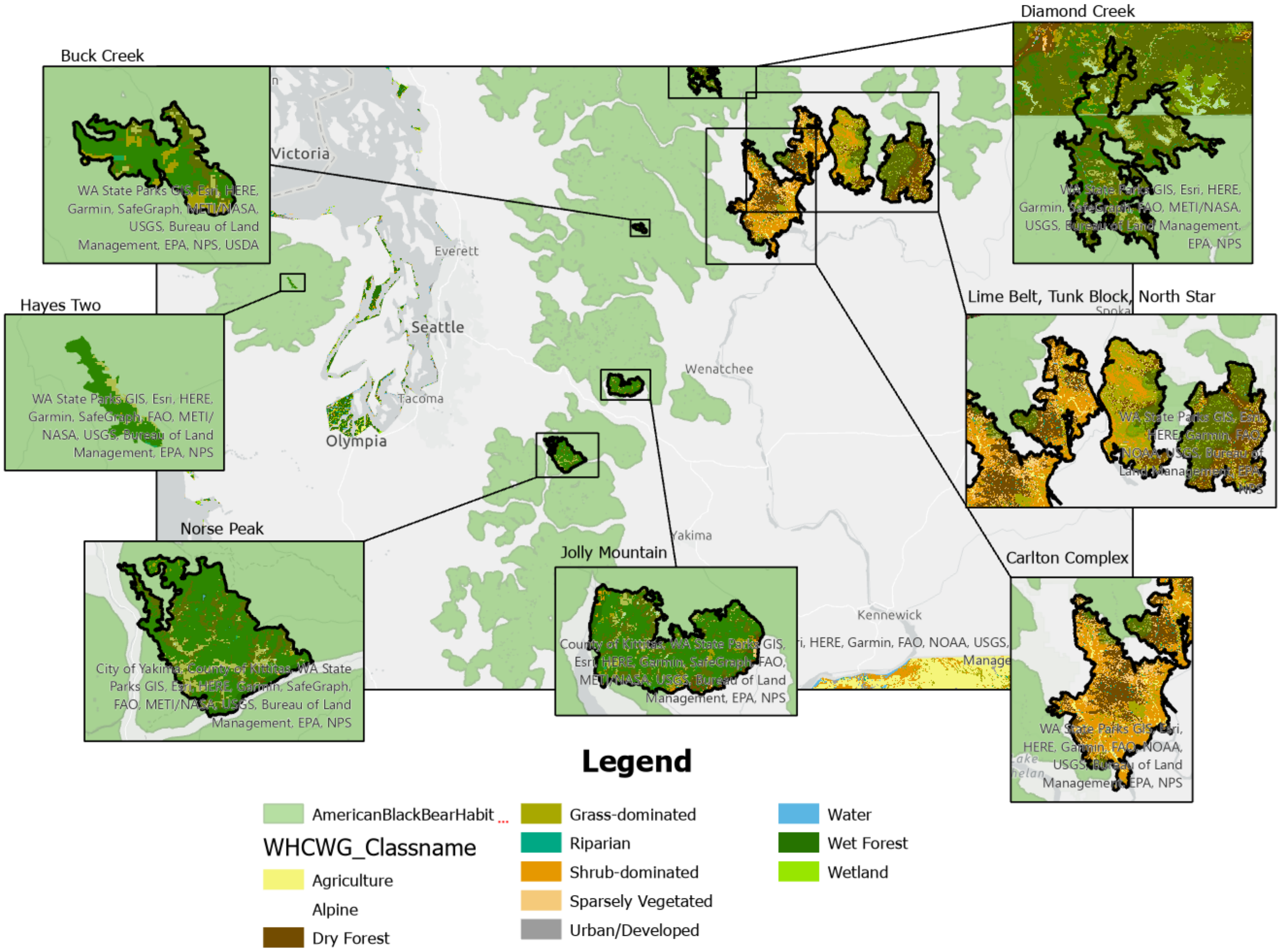
This map shows the differences between reclassified GAP v2.2(2001) and GAP v3.0(2011) updated with LANDFIRE disturbance data. Differences may not be indicative of on-the-ground changes. Fire perimeters are shown for fires larger than 100 acres as recorded by Northwest Coordination Center (2020).

My study builds upon and updates previous analysis on habitat concentration areas for black bears in Washington state. In 2010, Washington Wildlife Habitat Connectivity Group (Working Group) conducted a statewide analysis of focal species habitat concentration areas, landscape resistance, and habitat connectivity. Their model modified existing habitat connectivity models (Singleton et al., 2002; Cushman et al., 2006) with local research on resource selection (Koehler & Pierce, 2003; Lyons et al., 2003; Gaines et al., 2005). Since its publication in 2010 there have been 19 fires larger than 200 km^2 (Landfire, 2020). This analysis used the same parameters as Working Group with updated vegetation and wildfire data to determine if and how wildfire may have impacted black bear habitat concentration areas (HCAs).

Land cover change was visible when comparing the GAP/LANDFIRE National Terrestrial Ecosystems data [Previously GAP's National Land Cover Dataset] from v2.2 (2001) to v3.0 (2011). Landsat imagery used for the GAP v2.2 analysis layer was collected from 1999-2001, while the GAP v3.0 was updated with NLCD data and compared to satellite imagery to verify changes (Homer et al., 2015). Comparison of GAP v2.2 and the updated GAP v3.0 layers showed over 290,161 km^2 of land cover change to and from grass-dominated, shrub-dominated, and forest classification layers (Map 1). Appendix A shows the differences in classifications from GAP v2.2 to v3.0 and the approximate area that changed.

To understand the potential role of fire in these landscape changes, I added a layer showing outlines of fires larger than 200 km^2 from 2010-2021 (Map 1). I found that most of these fires occurred on the east side of the Cascades, just outside of black bear habitat concentration area (HCA). The fires that did occur within the HCA were generally small or low severity. To see how fire has changed land classifications I compared land change within fire perimeters to their fire severity maps. I focused on fires that fell within or bordered the HCA that have occurred within the last 10 years (Maps 3 to 11). In the following section, I provide a map and overview of the key aspects of each fire, the dominant habitat type preceding the fire, major vegetation changes within the last decade in which the fire occurred, and the likely short- and long-term implications for black bear habitat. Short-term changes were defined as anything that was impacted for less than a year. Long-term changes were defined as anything that was impacted longer than a year.

Map 2: Vegetation types within fire perimeters 2010-2020

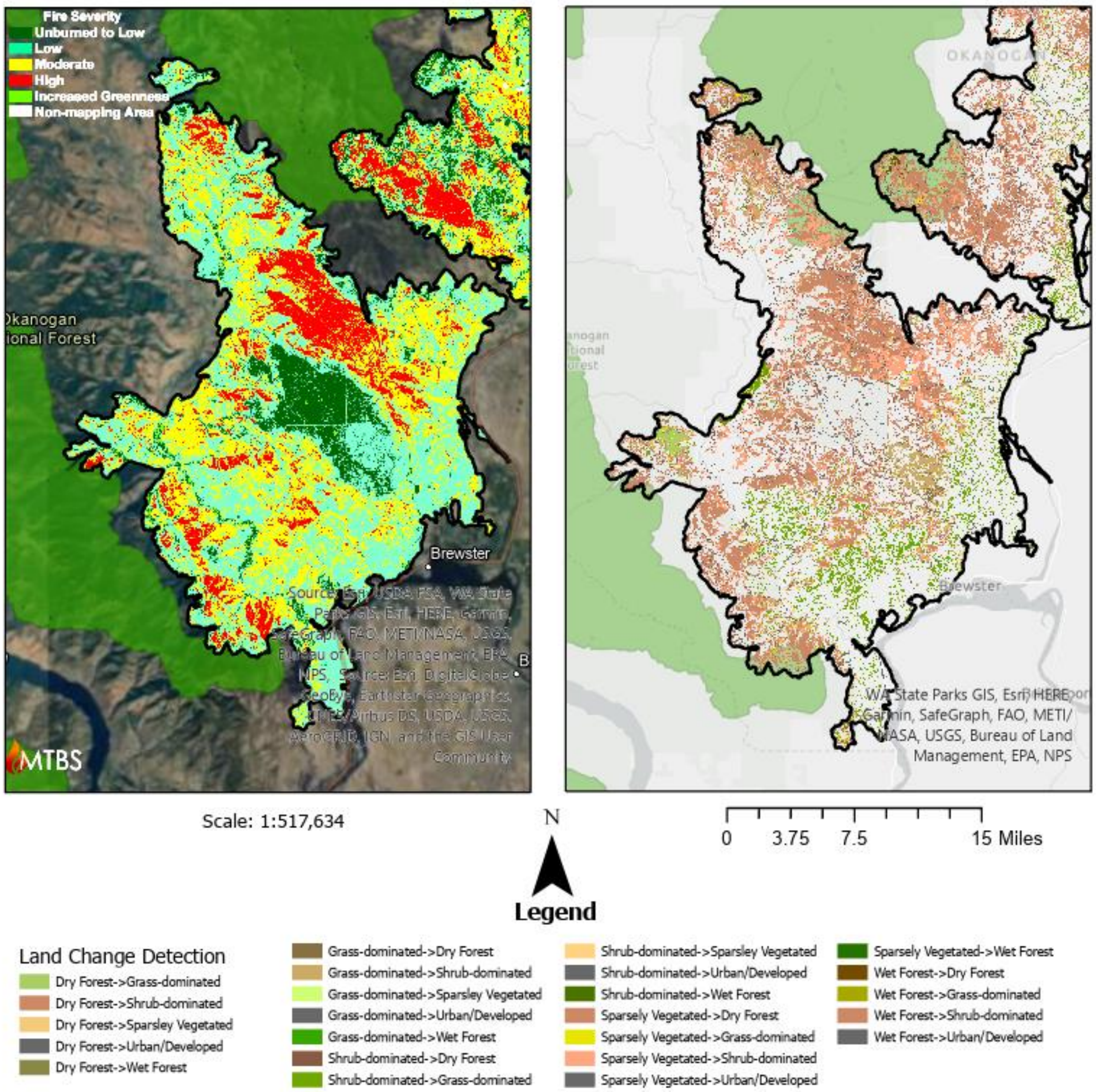


This map shows the vegetation type prior to each fire, as classified by Working Group. West of the Cascades vegetation was classified as wet forest, wetland, and grass dominated. East of the Cascades, where the largest fires occurred, vegetation was classified as dry forest, grass-dominated, and shrub-dominated with patches of agriculture. These fires bordered habitat concentration areas but did not fall directly within.

Individual Fires / Case Studies

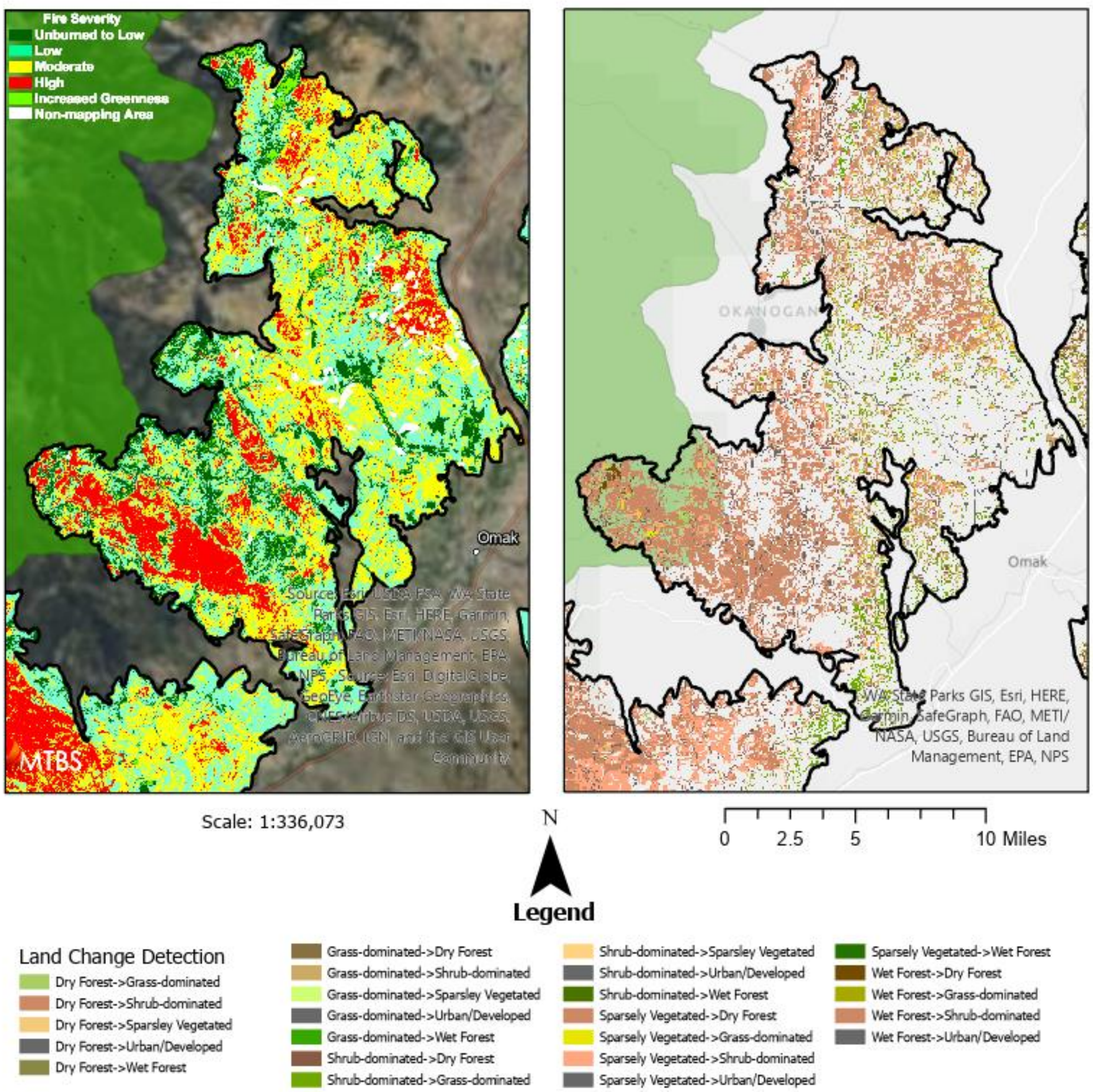
The Carlton Complex (Map 4) burned from July 14, 2014 to August 24, 2014. It included Stokes, Gold Hikes, French Creek, and Cougar Flat fires—all of which started as the result of lightning strikes. It burned 256,108 acres and destroyed nearly 300 homes. The primary fuels were timber (grass and understory) and dry forests such as ponderosa pine and Douglas-fir. The high severity area in the northeast portion of the fire transitioned from dry forest to shrub-dominated and from sparsely vegetated to shrub-dominated. On the westernmost portion of the fire vegetation transitioned from dry forest to grass-dominated. The fire spread rapidly due to strong winds and heavy fuels (Prichard et al., 2020). It did not pose a significant risk to black bear habitat because of its location, which was outside two HCAs and not a predicted travel corridor.

Map 3: Carlton Complex, 2015



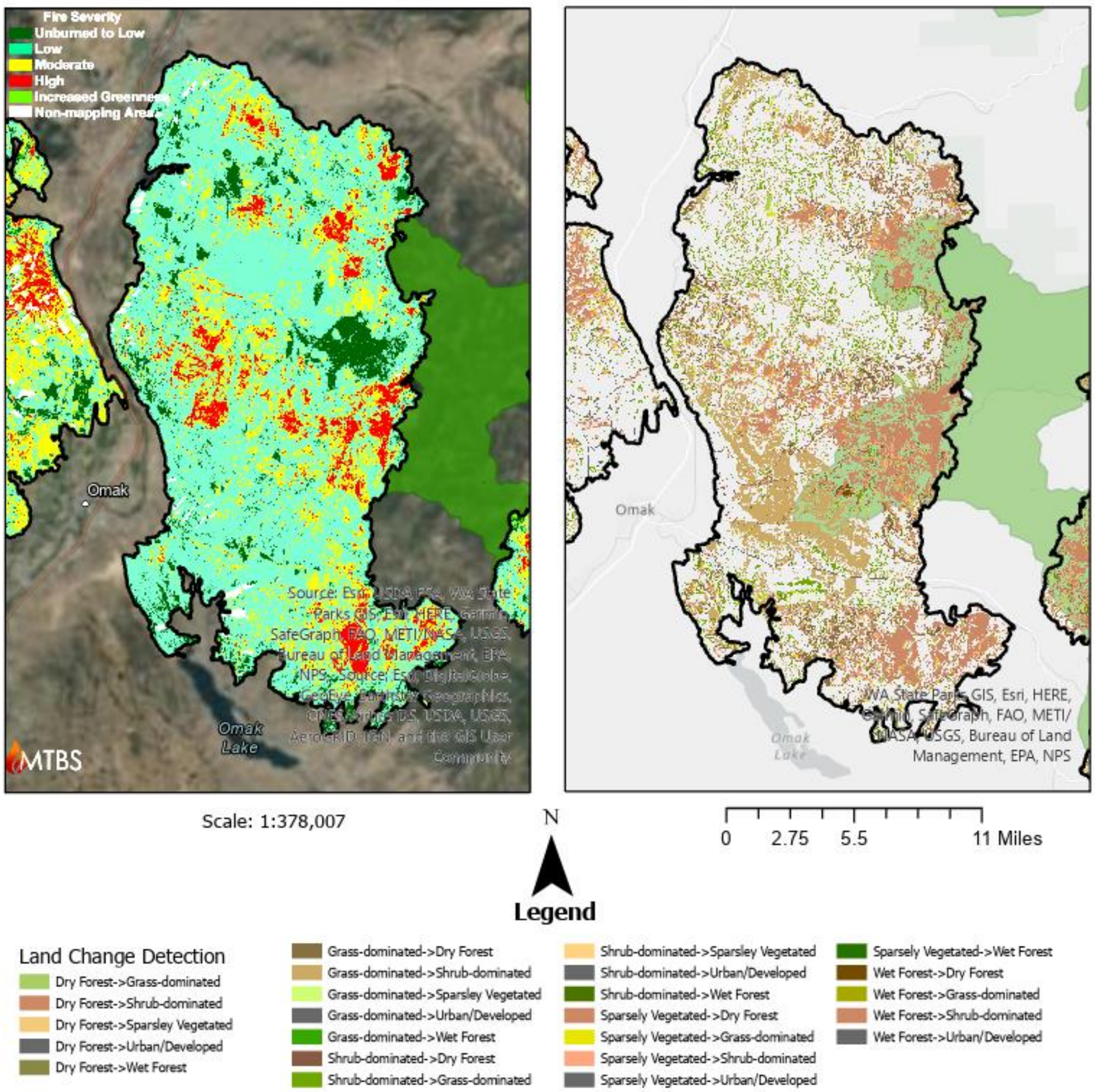
Both the Lime Belt (Map 4) and Tunk Block (Map 5) fires were a part of the Okanogan Complex which covered Omak, Tonasket, and Okanogan. Lime Belt burned from August 14, 2015 to September 30, 2015 and covered 133,428 acres. It burned mostly at low-moderate severity. The westernmost portion of the fire showed the highest burn severity and fell within the HCA. Tunk Block burned from August 13, 2015 to October 15, 2015 and covered 213,138 acres. It burned at low severity with some high severity areas (Inciweb, Tunk Block Fire, 2015). Both fires were ignited by an unknown source. The vegetation burned consisted of shrub-steppe, ponderosa pine, and Douglas-fir, which are fire adapted and dependent (BAER, Lime Belt Fire, 2015). While short-term there may have been impact on black bear habitat due to the highest severity burn occurring within the HCA (habitat concentration area), long term vegetation growth would be improved. Both fires fall within possible linkage zones as determined by Working Group (2010). This fire may have changed where the linkage zone was drawn. Areas that had severe burns may have been impacted short-term because of lack of cover and food resources. However, long term vegetation growth would be improved because of the fire dependency of this habitat type, which thrives with more frequent burns (Agee, 1993).

Map 4: Lime Belt Fire, 2015



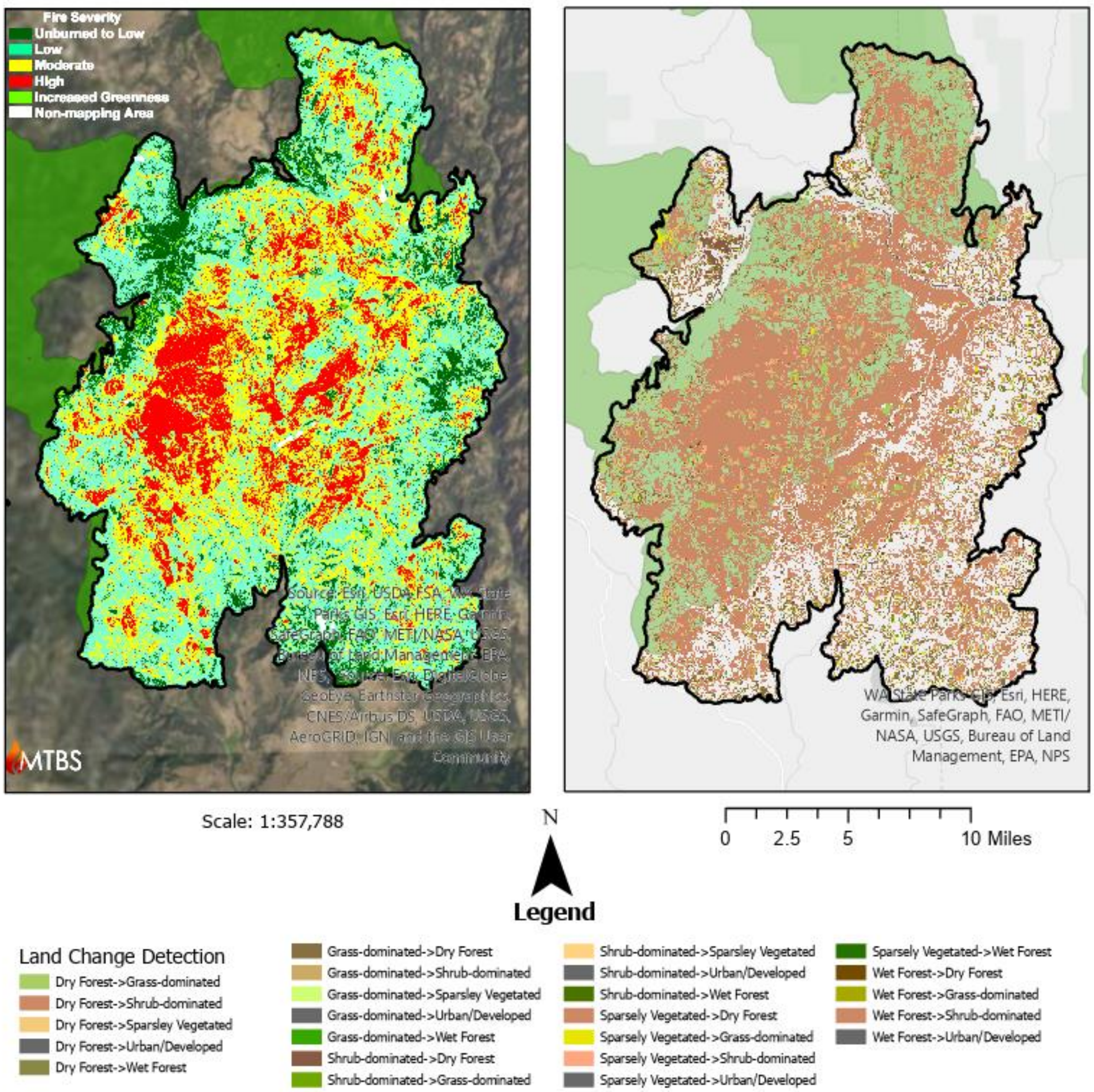
Orange indicates vegetation change from sparsely vegetated to shrub dominated. Dark brown indicates change from shrub-dominated to dry forest. Yellow indicates change from sparsely vegetated to shrub-dominated. Beige indicates change from dry forest to shrub-dominated. Bright green indicates change from shrub-dominated to grass-dominated.

Map 5: Tunk Block Fire, 2015



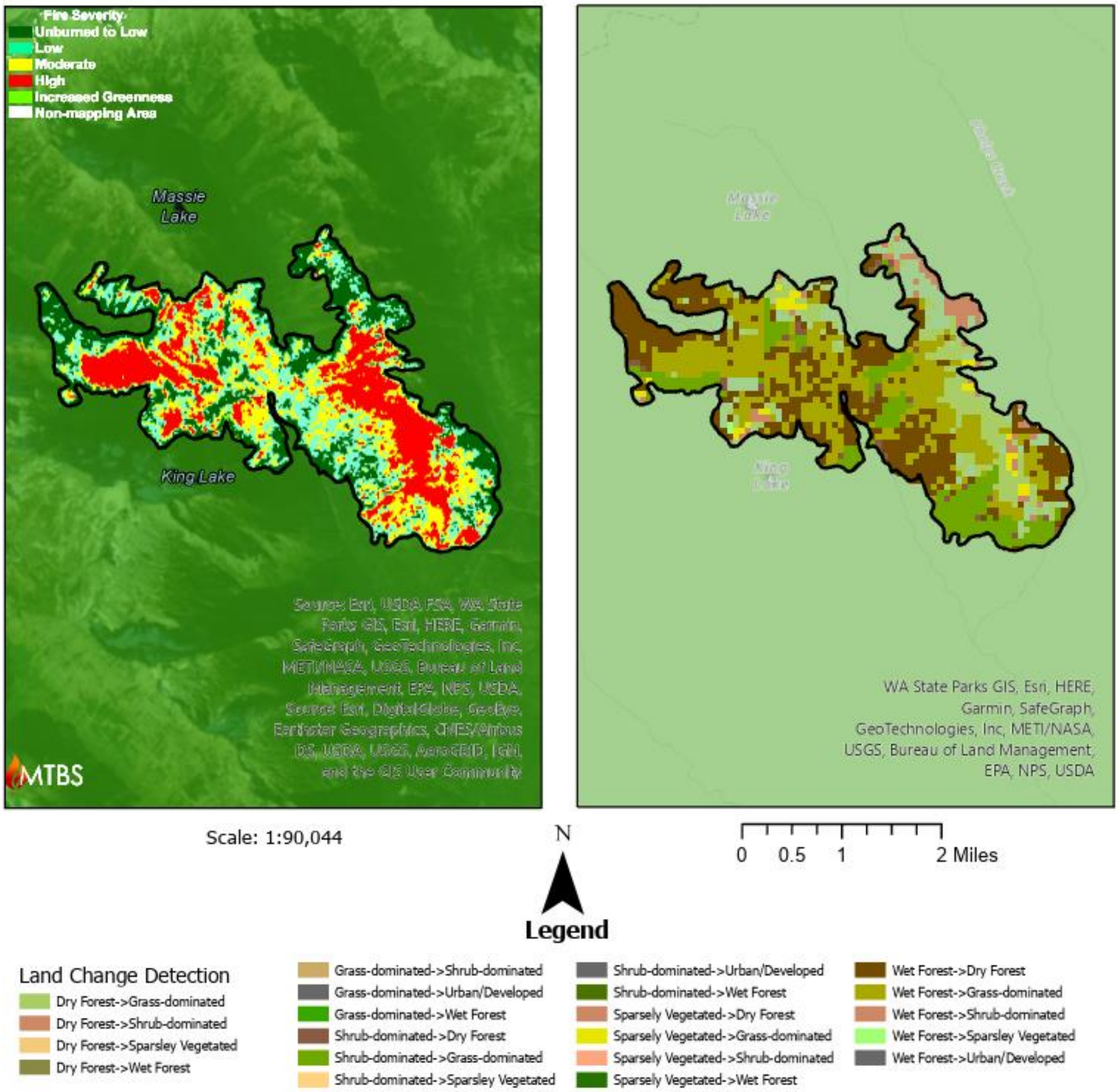
North Star fire (Map 6) burned 217,619 acres from August 13, 2015 to September 28, 2015 and was human-caused. It burned forested areas on the Colville Reservation at moderate to high severity. The vegetation that burned at high severity was classified as dry-forest such as ponderosa pine and Douglas-fir (Inciweb, North Star Fire, 2015). A majority of the land transitioned from dry forest to shrub-dominated. A small portion in the northwest portion of the fire, shown in dark brown, transitioned from shrub-dominated to dry forest. A significant portion of the fire fell within the HCA and likely had short-term impacts on black bears. Areas with low to moderate severity burning may have provided enough cover for black bears to forage once new vegetation grew. The portion of the North Star fire that fell within the HCA was classified as high severity. This portion of the fire would impact habitat preference because of loss of coverage and food resources.

Map 6: North Star Fire, 2015



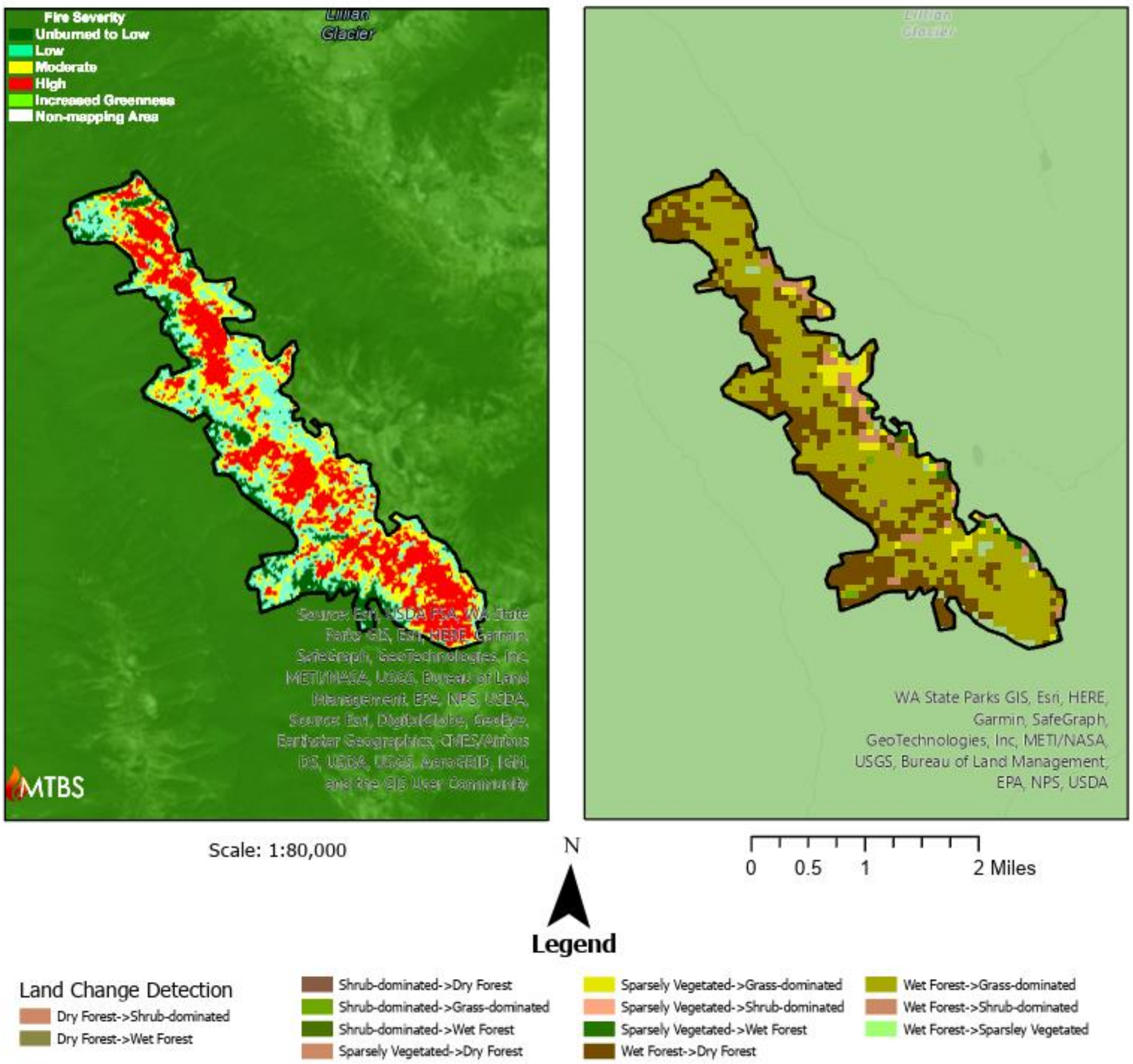
Buck Creek fire (Map 7) burned from July 22, 2016 to August 30, 2016. It covered around 3,500 acres in the old growth areas of Glacier Peak Wilderness. It burned at moderate to high severity and was ignited by lightning. The area burned was primarily spruce, western hemlock, and ponderosa pine. The areas that burned at high severity transitioned from wet forest to grass-dominated, while areas that burned at low severity transitioned from wet forest to dry forest. While it fell completely within the HCA, its impact to black bears would be minimal because of its location and size; it was located completely within the HCA and was smaller than the average female home range, leaving the bears ample options for navigation.

Map 7: Buck Creek Fire, 2016



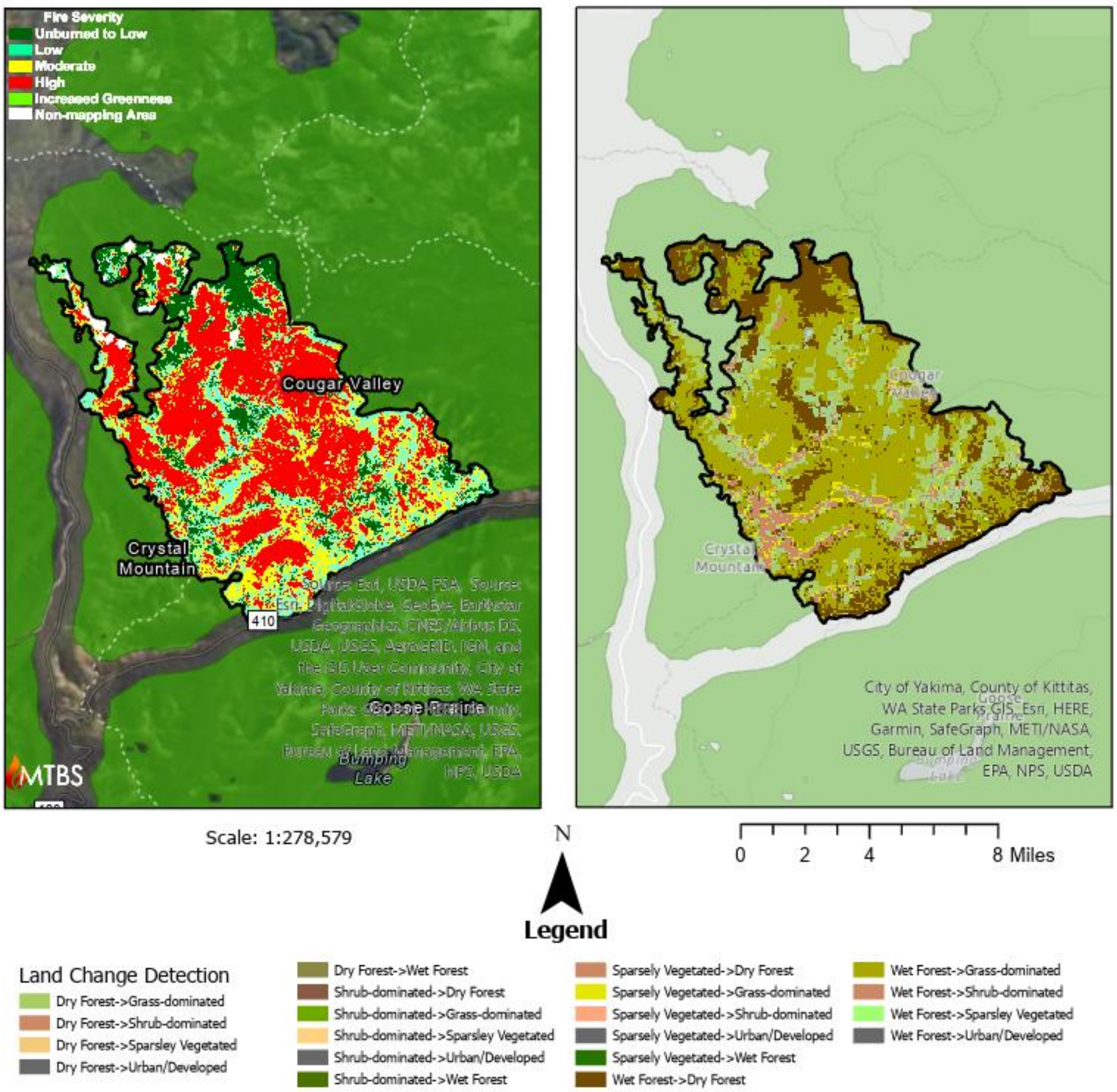
Hayes Two fire (Map 8) burned from July 21, 2016 to August 28, 2016 and covered around 3,000 acres. It was ignited by a lightning strike in Olympic National Park 20 miles south of Port Angeles. The fire burned at high severity along a ridge line, consuming rotten and dead trees (Inciweb, Hayes Two, 2016). Most of the land, and all of which burned at high severity, transitioned from wet forest to grass dominated. Areas that burned at low severity transitioned from wet forest to dry forest. Because this was a small fire fell completely within the HCA, its impact to black bears would be minimal. Hayes Two burned rotten and dead trees, which provided enough fuel to classify this fire as high severity, due to crown burning. Like Buck Creek fire, it also fell completely within the HCA. Due to it being surrounded by suitable habitat, it likely had minimal impact on black bears.

Map 8: Hayes Two Fire, 2016



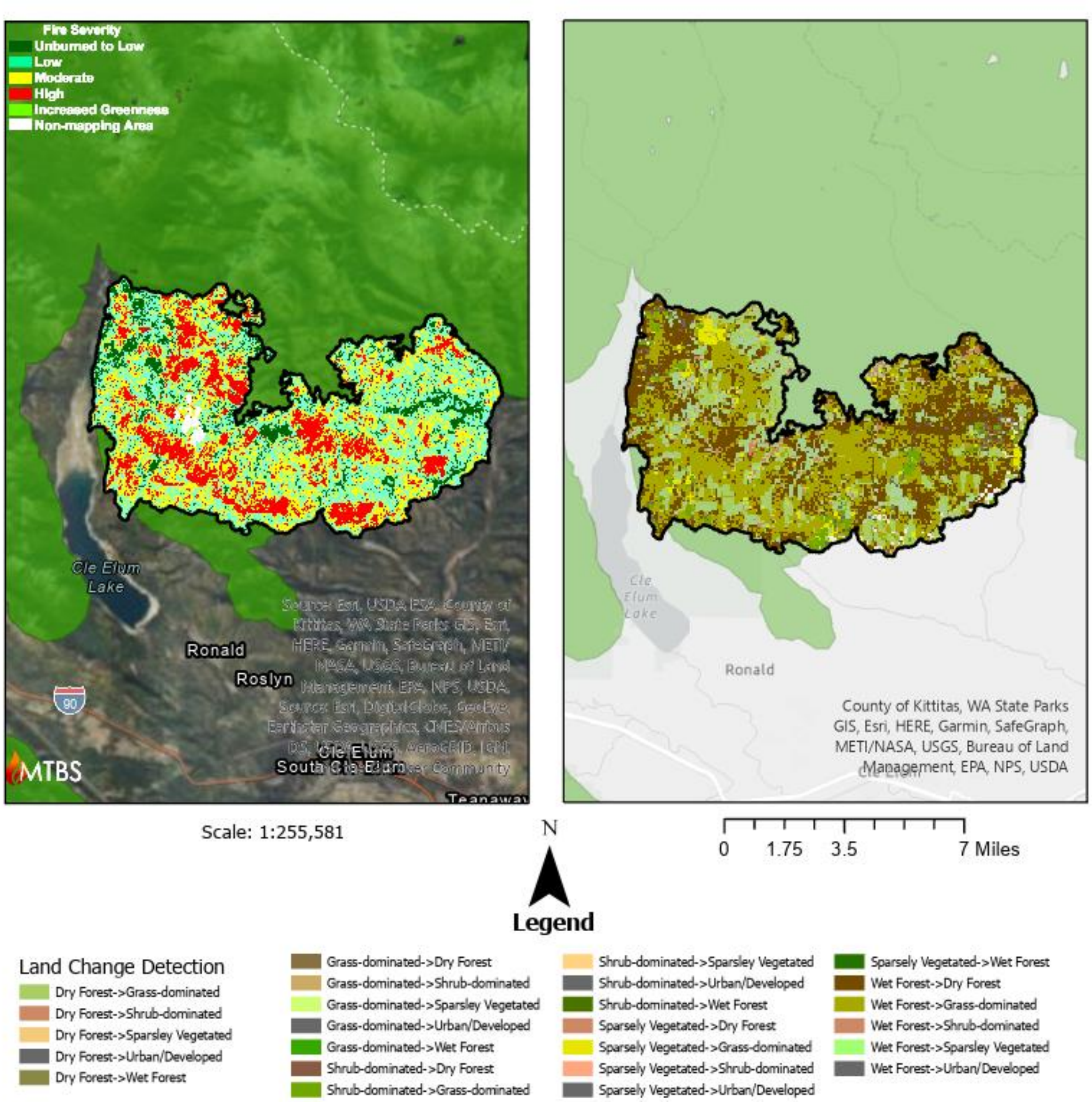
Norse Peak fire (Map 9) burned from August 11, 2017 to November 1, 2017 in Mt. Baker-Snoqualmie National Forest and Okanogan-Wenatchee National Forest. It was started by lightning strike and burned 55,290 acres, with the highest severity in the wilderness interior. The vegetation burned consisted of dry-forest types such as Douglas-fir, grand fir, mountain hemlock, pacific fir, subalpine fir, and western hemlock. It burned around a portion of the Pacific Crest Trail between Crystal Mountain and Cougar Valley, which has high foot traffic. Due to the severity and location of the fire, there is a high risk of introduction or spread of invasive plant species. Bare soil exposure also provides prime habitat for weed establishment, since the weeds cannot be shaded out by native vegetation (USDA Forest Service, 2017). It likely had a significant short-term impact on black bear habitat due to its location and severity, which likely removed denning habitat for bears by removing downed trees that bears typically take shelter in (Bull et al., 1997).

Map 9: Norse Peak Fire, 2017



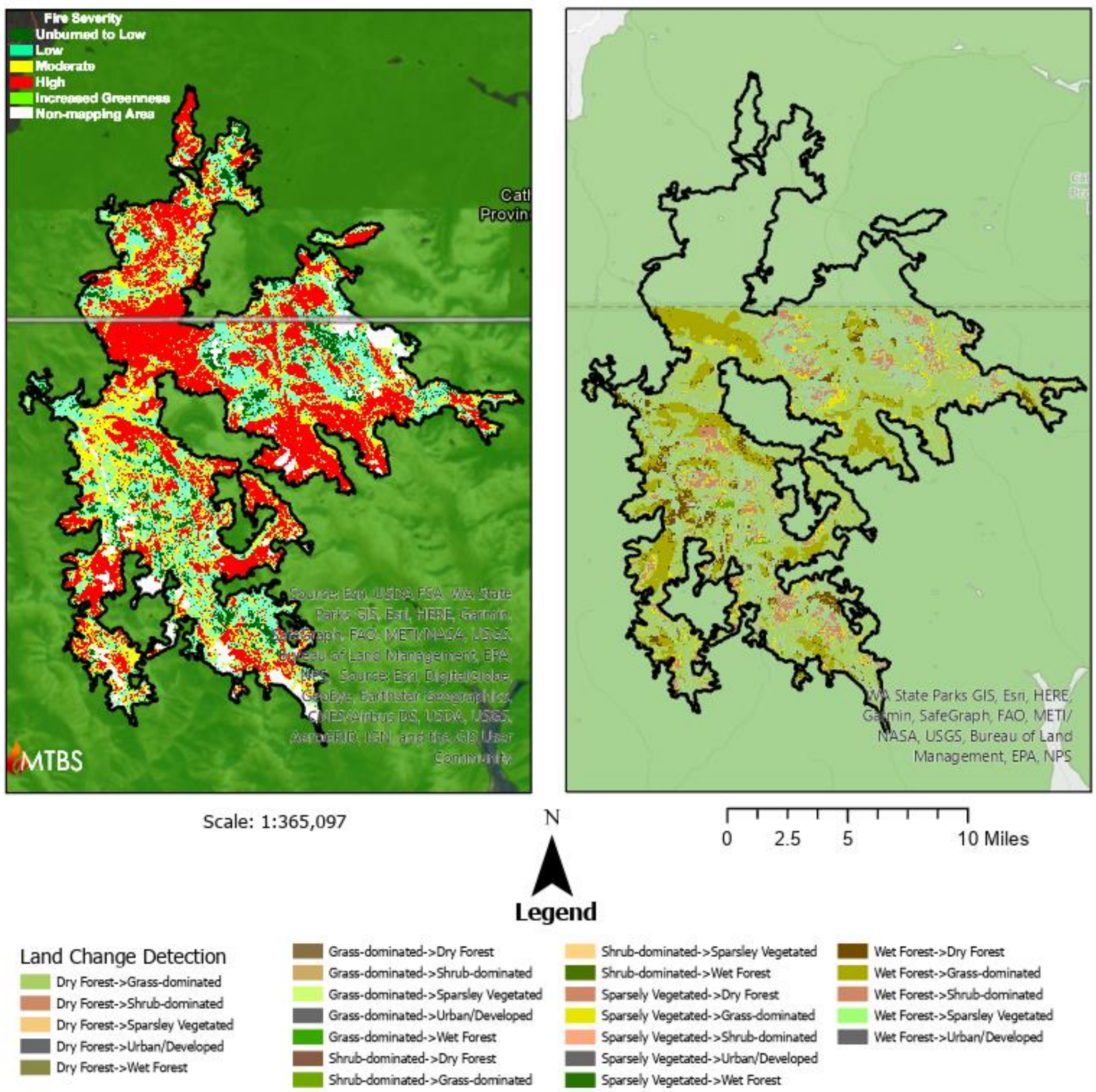
Jolly Mountain fire (Map 10) burned from August 11, 2017 to November 2, 2017 in Wenatchee National Forest. It was started by lightning and covered over 36,000 acres. It burned a combination of whitebark pine, subalpine fir, huckleberry, Douglas fir, bitter cherry, and beaked hazelnut. It burned at moderate to high severity (BAER, Jolly Mountain Fire, 2017). Vegetation change was a mix of wet forest to dry forest and wet forest to grass-dominated. The loss of food sources such as huckleberry and beaked hazelnut likely impacted black bears. However, since the fire fell on the outer edge of the HCA, the impact may have been minimal.

Map 10: Jolly Mountain Fire, 2017



Diamond Creek fire (Map 11) burned from July 23, 2017 to mid-September in Pasayten Wilderness. It started due to an improperly extinguished campfire. It covered 128,272 acres, most of which burned severely. The vegetation burned consisted of mountain larch, whitebark pine, subalpine fir, Englemann spruce, lodgepole pine, Alaskan yellow cedar, silver fir, and mountain hemlock (BAER, Diamond Creek Fire,2017). Areas that burned at high severity were reclassified from dry forest to dry forest. The fire fell completely within the HCA and likely impacted black bear habitat by damaging possible denning sites and removing food resources.

Map 11: Diamond Creek Fire, 2017



Short-term habitat-related fire effects were classified as effects that persisted less than a year. This includes reduction of food resources, cover, and potential den sites (Bogener, 2003; Daubenmire, 1968; French & French, 1996; Hamilton, 1981). Availability of forage may decrease in the short-term, but may begin to increase one year following a fire. As production of early-seral vegetation increases, more food and cover become available (Cunningham et al., 2006). As the canopy closes in later stages of succession, availability of some foods may decrease; however, cover and potential den sites increase (Kellyhouse, 1979; Keyser and Ford, 2006).

Long-term effects were classified as effects that persisted longer than a year. These include forest regeneration, invasive species, and loss of food resources. Potter and Kessell (1985) found that black bears showed the lowest preference for foraging in unburned communities and the highest preference for foraging in the postfire year 10 community. This could be because American black bears require a mosaic of successional stages for foraging, cover, and denning, so fires that create patches of burned and unburned habitat are most beneficial (Bendell, 1974; Cunningham et al, 2003; Kellyhouse, 1979; Kovalchick and Clausnitzer, 2004).

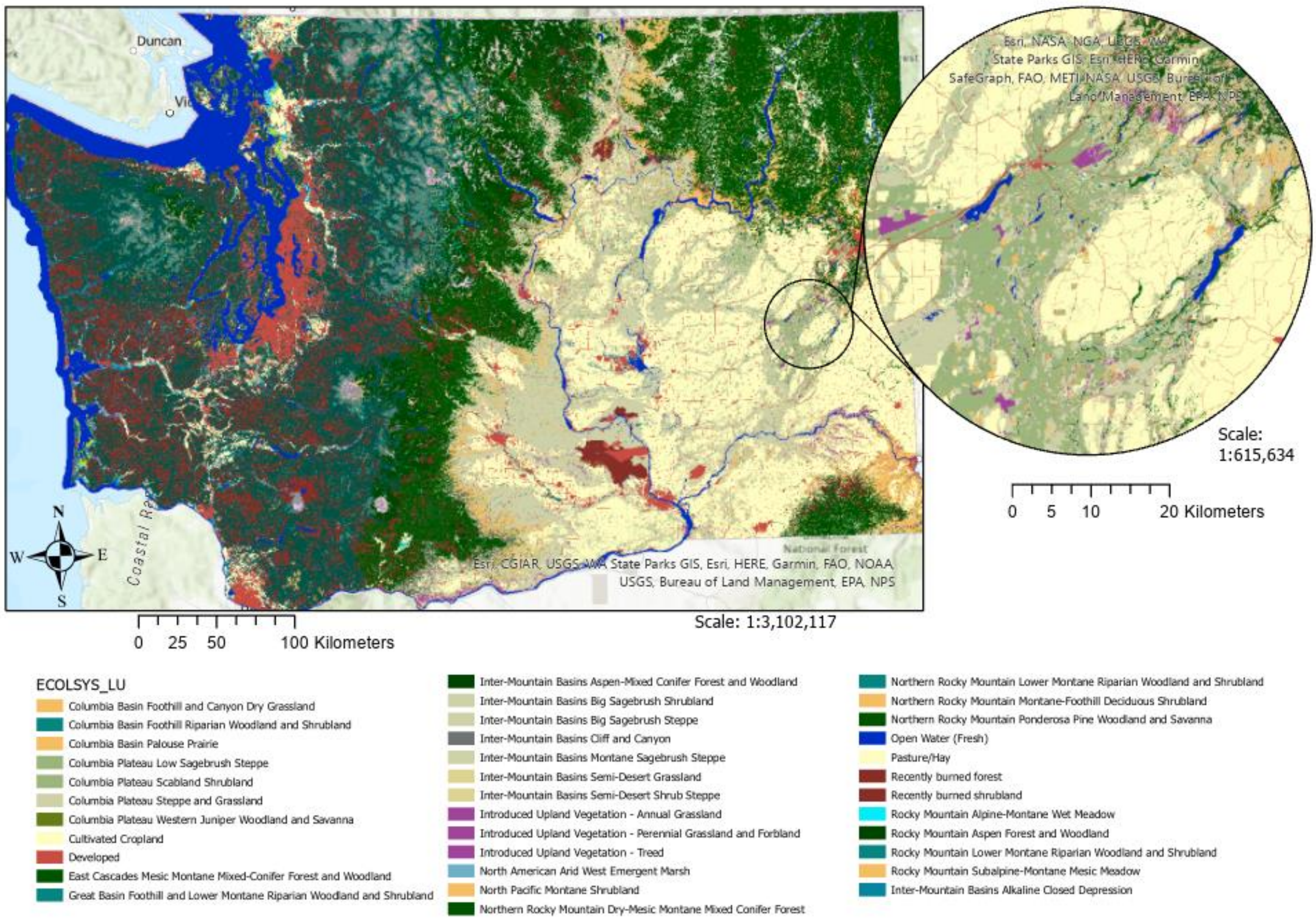
Although these fires varied in size, intensity, and location they all impacted black bear habitat short-term by either removing food resources or damaging denning sites. The fires that occurred outside of the HCA may have impacted areas that were important transportation corridors for black bears. For instance, the Tunk Block and North Star fires fell between two HCAs that were previously found to be potential travel corridors by Working Group (2010). These corridors connect the HCAs from the Cascade Range to eastern Washington. Fires with high intensity had the most impact on habitat due to their locations within the HCA and their loss of tree cover. Nearly all these fires had high tree cover and fuel loading which allowed the flames to creep into tree crowns and reduce cover at least short-term.

Not all fires shown in Map 1 were used to update GAP v3.0 because they lacked intensity information that was used to reclassify vegetation. However, most of these fires fall outside of the habitat concentration area because they were previously classified as non-ideal habitat for black bears. Fires that occurred along the center of the Cascades would have had the biggest impact on black bear habitat. These fires showed changes from wet forest to grass-dominated, suggesting a loss of cover but increase in spring forbs that bears may forage on.

Changes in classifications were likely due to more than disturbance, such as changes in satellite imagery, mapping methods, and human error. The goal of the GAP v3.0 update was to "generate a detailed land cover product representing the 2011 timeframe. Differences between the 2011 GAP maps do not always represent on-the-ground changes in vegetation communities" (USGS, Gap Analysis Program, 2011). Some of the differences may be the product of corrections to misclassifications in the original 2001 map. An area that contained the same vegetation in 2001 and 2011 but was incorrectly mapped in 2001 would show up as changed. The concepts of the Ecological Systems used to define the map legend are variable with a range of physiognomic and phenological conditions possible in a single system. There are cases where Ecological System land cover class may have remained "unchanged", but the general land cover class had changed between 2001 and 2011. For example, some areas correctly mapped as shrub in the NLCD Layer (based on the NLCD definition) are best mapped as the Northern Rocky Mountain Ponderosa Pine Woodland and Savanna ecological system in the GAP map and therefore the 2001 Woodland and Savanna label would be retained (USGS, 2011). The most notable example of this is visible in Map 12, in an area south of Spokane. In the 2001 Statewide

Analysis it was classified as grassland (Working Group, 2010). However, in GAP v3.0 it was classified as Columbia Plateau Scabland Shrubland, Intermountain Basins Big Sagebrush Steppe, and Northern Rocky Mountain Montane-foothill Deciduous Shrubland- all of which were reclassified to shrub-dominated in the 2001 analysis. This area was classified as herbaceous according to NLCD in 2019, suggesting that the land cover had not actually changed, but there is a difference in classification definitions between NLCD and GAP. While using NLCD to assess land change would leave less room for error, it only contains 16 land cover classes not suitable for habitat assessment.

Map 12: South Spokane GAP Classification



Conclusion

In 2010 HCAs covered 53,071 km^2 of the project area (Working Group). By using updated GAP Analysis (2020) vegetation data along with disturbance data (LANDFIRE, 2020), I was able to recalculate HCAs following the same methods used by Working Group. I found that HCAs cover roughly 45,063 km^2 of the assessment area, suggesting a loss of 8,008 km^2 in suitable habitat.

However, because land change detected from GAP v2.2 to v3.0 contained mostly undisturbed areas, this could be a result of reclassification and not an indicator of on-the-ground change. To further understand how much of the change was due to human error or remapping efforts a comparison of satellite imagery and land cover layers should be done. To improve habitat assessment more detailed vegetation data should be used in conjunction with disturbance data. Visually comparing NLCD classifications to GAP classifications proved helpful in identifying possible land change, but the differences in classifications are enough that they may skew habitat assessments for more specialized species. As such, GAP's habitat maps would best suit such analyses.

While this study can provide insight into how bears may be affected by change in habitat due to wildfires, additional studies will be needed to assess how they may be affected. Future studies should include telemetry data from populations most at risk for exposure to fire, habitat assessments following those fires, and physical observations of these populations. Telemetry data would allow for a more accurate representation of where black bears reside in Washington, as well as any changes in habitat preference following wildfires. Habitat assessments following fires would give a more comprehensive view of the vegetation present post-burn and how long vegetation recovery takes. If a fire occurred in an area and that area still had black bear visitation, physical observation could provide insight into how the changed habitat is being utilized. In combination telemetry data, habitat assessments, and physical observations would give a clearer picture as to what is actually happening following a fire. This could change our understanding of where habitat concentration areas are and where the linkage zones pass through. This would allow for wildlife management following wildfires, especially near residential areas.

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Appendices

Appendix A: Gap Reclassification

WHCWG	WHCWG Classification	Value	GAP Ecosystem Classifications (2011)
1	Agriculture	556	Cultivated Cropland
		557	Pasture/Hay
2	Urban/Developed	580	Quarries, Mines, Gravel Pits and Oil Wells
		581	Developed, Open Space
		582	Developed, Low Intensity
		583	Developed, Medium Intensity
		584	Developed, High Intensity
3	Water	510	North Pacific Maritime Eelgrass Bed
		552	Unconsolidated Shore
		578	Open Water (Brackish/Salt)
		579	Open Water (Fresh)
4	Sparsely Vegetated	380	North Pacific Coastal Cliff and Bluff
		381	North Pacific Maritime Coastal Sand Dune and Strand
		434	Columbia Plateau Vernal Pool
		456	Inter-Mountain Basins Alkaline Closed Depression

		458	Inter-Mountain Basins Playa
		529	Rocky Mountain Cliff, Canyon and Massive Bedrock
		531	North Pacific Montane Massive Bedrock, Cliff and Talus
		532	North Pacific Serpentine Barren
		533	North Pacific Active Volcanic Rock and Cinder Land
		543	Columbia Plateau Ash and Tuff Badland
		545	Inter-Mountain Basins Active and Stabilized Dune
		546	Inter-Mountain Basins Cliff and Canyon
		565	Disturbed, Non-specific
5	Alpine	308	North Pacific Alpine and Subalpine Dry Grassland
		502	Rocky Mountain Alpine Fell-Field
		506	North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-field and Meadow
		507	Rocky Mountain Alpine Tundra/Fell-field/Dwarf-shrub Map Unit
		549	Rocky Mountain Alpine Bedrock and Scree
		551	North Pacific Alpine and Subalpine Bedrock and Scree
		554	North American Alpine Ice Field

6	Riparian	265	Columbia Basin Foothill Riparian Woodland and Shrubland
		266	Great Basin Foothill and Lower Montane Riparian Woodland and Shrubland
		269	Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland
		270	Rocky Mountain Lower Montane Riparian Woodland and Shrubland
		272	Rocky Mountain Subalpine-Montane Riparian Woodland
		274	North Pacific Lowland Riparian Forest and Shrubland
		275	North Pacific Montane Riparian Woodland and Shrubland
		439	Rocky Mountain Subalpine-Montane Riparian Shrubland
		562	Introduced Riparian and Wetland Vegetation
7	Wetland	268	Northern Rocky Mountain Conifer Swamp
		273	North Pacific Hardwood-Conifer Swamp
		276	North Pacific Shrub Swamp
		397	North Pacific Bog and Fen
		398	Rocky Mountain Subalpine-Montane Fen
		431	North Pacific Intertidal Freshwater Wetland

		432	Temperate Pacific Freshwater Emergent Marsh
		433	Temperate Pacific Freshwater Mudflat
		438	Rocky Mountain Alpine-Montane Wet Meadow
		440	Temperate Pacific Montane Wet Meadow
		443	North American Arid West Emergent Marsh
		455	Temperate Pacific Tidal Salt and Brackish Marsh
		508	Temperate Pacific Intertidal Mudflat
		513	Temperate Pacific Freshwater Aquatic Bed
8	Grass-dominated	306	Columbia Basin Foothill and Canyon Dry Grassland
		307	Columbia Basin Palouse Prairie
		309	North Pacific Montane Grassland
		311	Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland
		314	Northern Rocky Mountain Subalpine-Upper Montane Grassland
		319	North Pacific Herbaceous Bald and Bluff
		321	Willamette Valley Upland Prairie and Savanna
		323	Rocky Mountain Subalpine-Montane Mesic Meadow

		441	Willamette Valley Wet Prairie
		487	Columbia Plateau Steppe and Grassland
		497	Inter-Mountain Basins Semi-Desert Grassland
		558	Introduced Upland Vegetation - Annual Grassland
		559	Introduced Upland Vegetation - Perennial Grassland and Forbland
		567	Harvested Forest - Grass/Forb Regeneration
		571	Recently burned grassland
		573	Recently burned forest
9	Shrub-dominated	182	Columbia Plateau Western Juniper Woodland and Savanna
		184	Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland
		310	North Pacific Montane Shrubland
		312	Northern Rocky Mountain Montane-Foothill Deciduous Shrubland
		313	Northern Rocky Mountain Subalpine Deciduous Shrubland
		320	North Pacific Hypermaritime Shrub and Herbaceous Headland
		430	North Pacific Avalanche Chute Shrubland

		457	Inter-Mountain Basins Greasewood Flat
		484	Inter-Mountain Basins Mat Saltbush Shrubland
		485	Inter-Mountain Basins Mixed Salt Desert Scrub
		489	Inter-Mountain Basins Big Sagebrush Shrubland
		490	Inter-Mountain Basins Big Sagebrush Steppe
		491	Inter-Mountain Basins Montane Sagebrush Steppe
		493	Columbia Plateau Low Sagebrush Steppe
		494	Columbia Plateau Scabland Shrubland
		498	Inter-Mountain Basins Semi-Desert Shrub Steppe
		561	Introduced Upland Vegetation - Shrub
		568	Harvested Forest-Shrub Regeneration
		572	Recently burned shrubland
10	Dry Forest	54	East Cascades Oak-Ponderosa Pine Forest and Woodland
		57	North Pacific Dry Douglas-fir-(Madrone) Forest and Woodland
		58	North Pacific Oak Woodland
		137	Middle Rocky Mountain Montane Douglas-fir Forest and Woodland

		138	Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest
		141	Northern Rocky Mountain Ponderosa Pine Woodland and Savanna
		142	Northern Rocky Mountain Western Larch Savanna
		145	Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland
		147	Northern Rocky Mountain Subalpine Woodland and Parkland
		148	Rocky Mountain Aspen Forest and Woodland
		149	Rocky Mountain Lodgepole Pine Forest
		150	Rocky Mountain Poor-Site Lodgepole Pine Forest
		151	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland
		174	North Pacific Wooded Volcanic Flowage
		563	Introduced Upland Vegetation - Treed
		569	Harvested Forest - Northwestern Conifer Regeneration
		136	East Cascades Mesic Montane Mixed-Conifer Forest and Woodland
11	Wet Forest	140	Northern Rocky Mountain Mesic Montane Mixed Conifer Forest
		152	Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland

		166	North Pacific Broadleaf Landslide Forest and Shrubland
		167	North Pacific Dry-Mesic Silver Fir-Western Hemlock-Douglas-fir Forest
		168	North Pacific Hypermaritime Sitka Spruce Forest
		169	North Pacific Hypermaritime Western Red-cedar-Western Hemlock Forest
		170	North Pacific Lowland Mixed Hardwood-Conifer Forest and Woodland
		171	North Pacific Maritime Dry-Mesic Douglas-fir-Western Hemlock Forest
		172	North Pacific Maritime Mesic-Wet Douglas-fir-Western Hemlock Forest
		173	North Pacific Mesic Western Hemlock-Silver Fir Forest
		177	North Pacific Maritime Mesic Subalpine Parkland
		178	North Pacific Mountain Hemlock Forest
		260	East Gulf Coastal Plain Near-Coast Pine Flatwoods - Open Understory Modifier

Appendix B: LANDFIRE Disturbance Reclassification

Time Since Disturbance	Disturbance Severity	From Habitat Type	To Habitat Type
2-5 Years	High	Wet Forest	Grass-dominated
		Dry Forest	Grass-dominated
		Shrub-dominated	Grass-dominated
	Medium	Wet Forest	Grass-dominated
		Dry Forest	Grass-dominated
		Shrub-dominated	Grass-dominated
	Low	Wet Forest	Dry Forest
		Dry Forest	Dry Forest
		Shrub-dominated	Grass-dominated
6-10 Years	High	Wet Forest	Shrub-dominated
		Dry Forest	Shrub-dominated
		Shrub-dominated	Shrub-dominated
	Medium	Wet Forest	Shrub-dominated
		Dry Forest	Shrub-dominated
		Shrub-dominated	Shrub-dominated
	Low	Wet Forest	Dry Forest
		Dry Forest	Dry Forest
		Shrub-dominated	Shrub-dominated

Areas classified as disturbed by LANDFIRE Fuel Disturbance (2020) were reclassified according to the above table, which updated the 2011 GAP layer.

Appendix C: Resistance Values

Spatial data layers and included factors	*Resistance value*
land cover/land-use	
agriculture	100
urban/developed	200
water	100
sparsely vegetated	1
alpine	0
riparian	0
wetland	0
grass-dominated	1
shrub-dominated	1
dry forest	1
wet forest	0
Elevation (meters)	
0-250	5
>250-500	5
>500-750	4
>750-1000	3
>1000-1500	2
>1500-2000	1
>2000-2500	0
>2500-3300	1
>3300	100

slope (degrees)	
0-20	0
>20-40	1
>40	3
Housing density (acres per dwelling unit)	
>80	0
>40 <80	10
>20 <40	10
>10 <20	10
<10	100
Road type and distance (meters)*	
freeway >500-1000 buffer	10
freeway > 0-500 buffer	50
freeway centerline	1000
major highway > 500-100 buffer	5
major highway > 0-500 buffer	10
major highway centerline	100
secondary highway > 500-1000 buffer	4
secondary highway > 0-500 buffer	8
secondary highway centerline	50
local road > 500-1000 buffer	1
local road > 0-500 buffer	2
local road centerline	3

Appendix D: Land Classification Change 2001-2021

Classvalue	Name	From	To	Area (km^2)
122	No Change	Same	Same	1182580
121	Wet Forest->Dry Forest	Wet Forest	Dry Forest	56634.3
89	Grass-dominated->Shrub-dominated	Grass-dominated	Shrub-dominated	44577.9
99	Shrub-dominated->Grass-dominated	Shrub-dominated	Grass-dominated	42627.1
50	Sparsely Vegetated->Dry Forest	Sparsely Vegetated	Dry Forest	40077.6
19	Agriculture->Shrub-dominated	Agriculture	Shrub-dominated	31411
100	Shrub-dominated->Dry Forest	Shrub-dominated	Dry Forest	25435.5
120	Wet Forest->Shrub-dominated	Wet Forest	Shrub-dominated	22153.9
110	Dry Forest->Shrub-dominated	Dry Forest	Shrub-dominated	21234.6
113	Wet Forest->Urban/Developed	Wet Forest	Urban/Developed	20491.2
90	Grass-dominated->Dry Forest	Grass-dominated	Dry Forest	20191.8
119	Wet Forest->Grass-dominated	Wet Forest	Grass-dominated	18077.8
51	Sparsely Vegetated->Wet Forest	Sparsely Vegetated	Wet Forest	18016.8
12	Agriculture->Urban/Developed	Agriculture	Urban/Developed	17294.7
111	Dry Forest->Wet Forest	Dry Forest	Wet Forest	15511.4
109	Dry Forest->Grass-dominated	Dry Forest	Grass-dominated	12489
49	Sparsely Vegetated->Shrub-dominated	Sparsely Vegetated	Shrub-dominated	11798.7
18	Agriculture->Grass-dominated	Agriculture	Grass-dominated	11788.3
101	Shrub-dominated->Wet Forest	Shrub-dominated	Wet Forest	8752.5
48	Sparsely Vegetated->Grass-dominated	Sparsely Vegetated	Grass-dominated	8425.9
93	Shrub-dominated->Urban/Developed	Shrub-dominated	Urban/Developed	8111.4
83	Grass-dominated->Urban/Developed	Grass-dominated	Urban/Developed	6709.2
117	Wet Forest->Riparian	Wet Forest	Riparian	6500.4
82	Grass-dominated->Agriculture	Grass-dominated	Agriculture	6074

45	Sparsely Vegetated->Alpine	Sparsely Vegetated	Alpine	4448.5
92	Shrub-dominated->Agriculture	Shrub-dominated	Agriculture	4404.7
103	Dry Forest->Urban/Developed	Dry Forest	Urban/Developed	4191.4
43	Sparsely Vegetated->Urban/Developed	Sparsely Vegetated	Urban/Developed	3891.1
71	Riparian->Wet Forest	Riparian	Wet Forest	3142.9
107	Dry Forest->Riparian	Dry Forest	Riparian	2893.9
118	Wet Forest->Wetland	Wet Forest	Wetland	2686
91	Grass-dominated->Wet Forest	Grass-dominated	Wet Forest	2476
70	Riparian->Dry Forest	Riparian	Dry Forest	2129.1
97	Shrub-dominated->Riparian	Shrub-dominated	Riparian	2098.1
63	Riparian->Urban/Developed	Riparian	Urban/Developed	2058.9
20	Agriculture->Dry Forest	Agriculture	Dry Forest	1735.3
21	Agriculture->Wet Forest	Agriculture	Wet Forest	1727.9
42	Sparsely Vegetated->Agriculture	Sparsely Vegetated	Agriculture	1625.3
16	Agriculture->Riparian	Agriculture	Riparian	1539.3
73	Wetland->Urban/Developed	Wetland	Urban/Developed	1528.6
72	Wetland->Agriculture	Wetland	Agriculture	1490.1
22	Urban/Developed->Agriculture	Urban/Developed	Agriculture	1466.8
81	Wetland->Wet Forest	Wetland	Wet Forest	1382.6
69	Riparian->Shrub-dominated	Riparian	Shrub-dominated	1307.1
112	Wet Forest->Agriculture	Wet Forest	Agriculture	1239.9
114	Wet Forest->Water	Wet Forest	Water	1203.3
62	Riparian->Agriculture	Riparian	Agriculture	1189.9
87	Grass-dominated->Riparian	Grass-dominated	Riparian	1125.9
94	Shrub-dominated->Water	Shrub-dominated	Water	961.3
29	Urban/Developed->Shrub-dominated	Urban/Developed	Shrub-dominated	950.8
31	Urban/Developed->Wet Forest	Urban/Developed	Wet Forest	915.5
98	Shrub-dominated->Wetland	Shrub-dominated	Wetland	859.8
44	Sparsely Vegetated->Water	Sparsely Vegetated	Water	842.2
67	Riparian->Wetland	Riparian	Wetland	792.3
64	Riparian->Water	Riparian	Water	785.9
33	Water->Urban/Developed	Water	Urban/Developed	778.9
77	Wetland->Riparian	Wetland	Riparian	769.6
84	Grass-dominated->Water	Grass-dominated	Water	766.6

30	Urban/Developed->Dry Forest	Urban/Developed	Dry Forest	723.3
46	Sparsely Vegetated->Riparian	Sparsely Vegetated	Riparian	676.1
55	Alpine->Sparsely Vegetated	Alpine	Sparsely Vegetated	669.9
95	Shrub-dominated->Sparsely Vegetated	Shrub-dominated	Sparsely Vegetated	647.9
61	Alpine->Wet Forest	Alpine	Wet Forest	638.9
68	Riparian->Grass-dominated	Riparian	Grass-dominated	627.6
80	Wetland->Dry Forest	Wetland	Dry Forest	621.3
28	Urban/Developed->Grass-dominated	Urban/Developed	Grass-dominated	600.3
17	Agriculture->Wetland	Agriculture	Wetland	589.7
41	Water->Wet Forest	Water	Wet Forest	564.8
78	Wetland->Grass-dominated	Wetland	Grass-dominated	556.9
88	Grass-dominated->Wetland	Grass-dominated	Wetland	511
74	Wetland->Water	Wetland	Water	495.3
39	Water->Shrub-dominated	Water	Shrub-dominated	485.9
13	Agriculture->Water	Agriculture	Water	482.6
60	Alpine->Dry Forest	Alpine	Dry Forest	463.4
40	Water->Dry Forest	Water	Dry Forest	437.7
115	Wet Forest->Sparsely Vegetated	Wet Forest	Sparsely Vegetated	411
79	Wetland->Shrub-dominated	Wetland	Shrub-dominated	393.2
85	Grass-dominated->Sparsely Vegetated	Grass-dominated	Sparsely Vegetated	385.7
106	Dry Forest->Alpine	Dry Forest	Alpine	383
36	Water->Riparian	Water	Riparian	366.5
47	Sparsely Vegetated->Wetland	Sparsely Vegetated	Wetland	348.3
23	Urban/Developed->Water	Urban/Developed	Water	320.3
102	Dry Forest->Agriculture	Dry Forest	Agriculture	320.1
108	Dry Forest->Wetland	Dry Forest	Wetland	281.4
32	Water->Agriculture	Water	Agriculture	271.4
38	Water->Grass-dominated	Water	Grass-dominated	249.8
116	Wet Forest->Alpine	Wet Forest	Alpine	246
37	Water->Wetland	Water	Wetland	236.4
105	Dry Forest->Sparsely Vegetated	Dry Forest	Sparsely Vegetated	221
104	Dry Forest->Water	Dry Forest	Water	210.5
26	Urban/Developed->Riparian	Urban/Developed	Riparian	168.3
27	Urban/Developed->Wetland	Urban/Developed	Wetland	133.2
14	Agriculture->Sparsely Vegetated	Agriculture	Sparsely Vegetated	95.4

59	Alpine->Shrub-dominated	Alpine	Shrub-dominated	84.1
96	Shrub-dominated->Alpine	Shrub-dominated	Alpine	74.8
86	Grass-dominated->Alpine	Grass-dominated	Alpine	59.5
34	Water->Sparsely Vegetated	Water	Sparsely Vegetated	53.9
65	Riparian->Sparsely Vegetated	Riparian	Sparsely Vegetated	40.1
58	Alpine->Grass-dominated	Alpine	Grass-dominated	33.6
54	Alpine->Water	Alpine	Water	28.7
75	Wetland->Sparsely Vegetated	Wetland	Sparsely Vegetated	19.5
24	Urban/Developed->Sparsely Vegetated	Urban/Developed	Sparsely Vegetated	18.6
35	Water->Alpine	Water	Alpine	8.1
53	Alpine->Urban/Developed	Alpine	Urban/Developed	7
15	Agriculture->Alpine	Agriculture	Alpine	6.1
66	Riparian->Alpine	Riparian	Alpine	5.3
56	Alpine->Riparian	Alpine	Riparian	4.1
57	Alpine->Wetland	Alpine	Wetland	4
76	Wetland->Alpine	Wetland	Alpine	2.6
52	Alpine->Agriculture	Alpine	Agriculture	0.8
25	Urban/Developed->Alpine	Urban/Developed	Alpine	0.8

Red rows highlight changes that could be due to disturbance, such as fire. Orange rows highlight areas that could be re-establishing post-disturbance. Gray rows highlight classes that have been reclassified as developed. Rows below the bold black line are changes that are smaller than the average American black bear home range (200 km^2). It is important to note that all changes may not be reflective of on-the ground change, but reclassifications or improvements in satellite imagery.

Appendix E: Data Sources

Land Cover/ Land-Use and Forest Structure

Theme: **Gap Analysis Program National Terrestrial Ecosystems**

Source: Gap Analysis Project, USGS

Format: raster

Cell size: 30 meters

Publication date: 2011

Landsat acquisition period: ~2001

Online linkages: https://www.usgs.gov/programs/gap-analysis-project/science/land-cover-vision

Theme: **NLCD Land Cover**

Source: Multi-Resolution Land Characteristics (MRLC) Consortium

Format: raster

Cell size: 30 meters

Publication date: 2019

Online linkages: https://s3-us-west-2.amazonaws.com/mrlc/nlcd_2019_land_cover_l48_20210604.zip

Theme: **Existing Vegetation Type (EVT)**

Source: LANDFIRE (Landscape Fire and Resource Management Planning Tools Project)

Format: raster

Cell size: 30 meters

Publication date: 2016

Online linkages: https://landfire.gov/bulk/downloadfile.php?FNAME=US_200_mosaic-LF2016_EVT_200_CONUS.zip&TYPE=landfire

Theme: **National Vegetation Classification (NVC)**

Source: LANDFIRE (Landscape Fire and Resource Management Planning Tools Project)

Format: raster

Cell size: 30 meters

Publication date: 2016 REMAP

Acres per Dwelling Unit (Housing Density)

Theme: **Housing Density 2010**

Source: Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO

Format: raster

Cell size: 100 meters

Publication date: 2011

Elevation

Theme: **National Elevation Dataset (NED)**

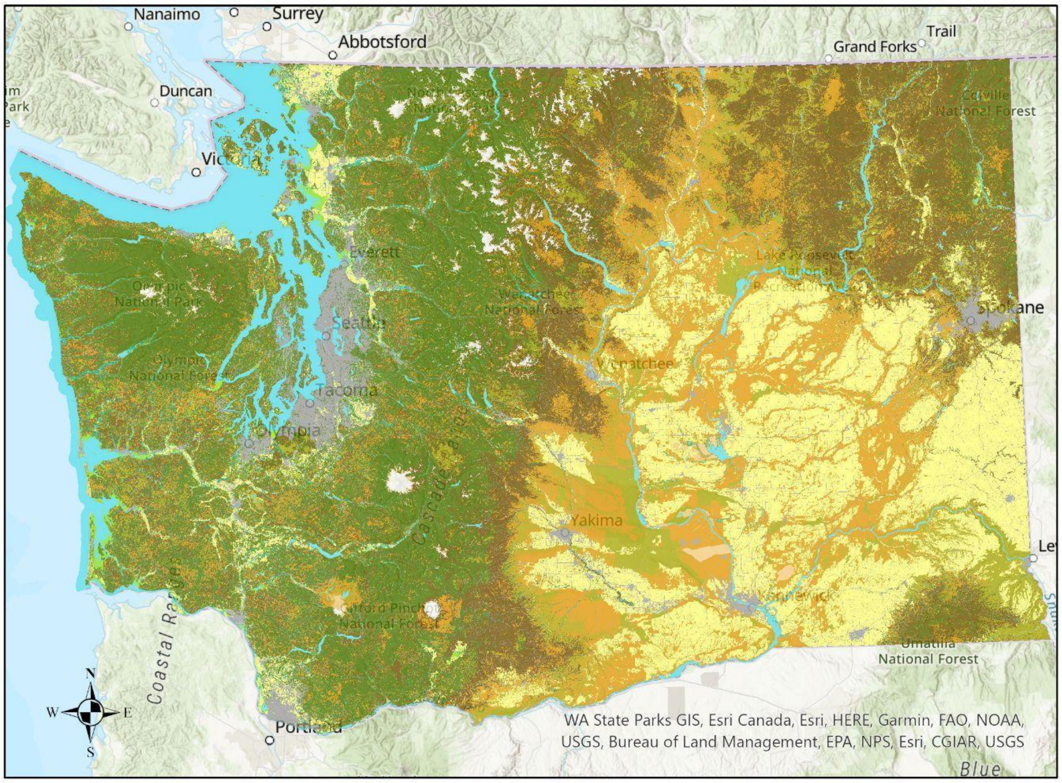
Source: US Geological Survey

Format: raster, elevation unit meters

Cell size: 30 meters

Appendix F: Base Maps

2020 GAP Ecosystem Update



Legend

WHCWG_Classname

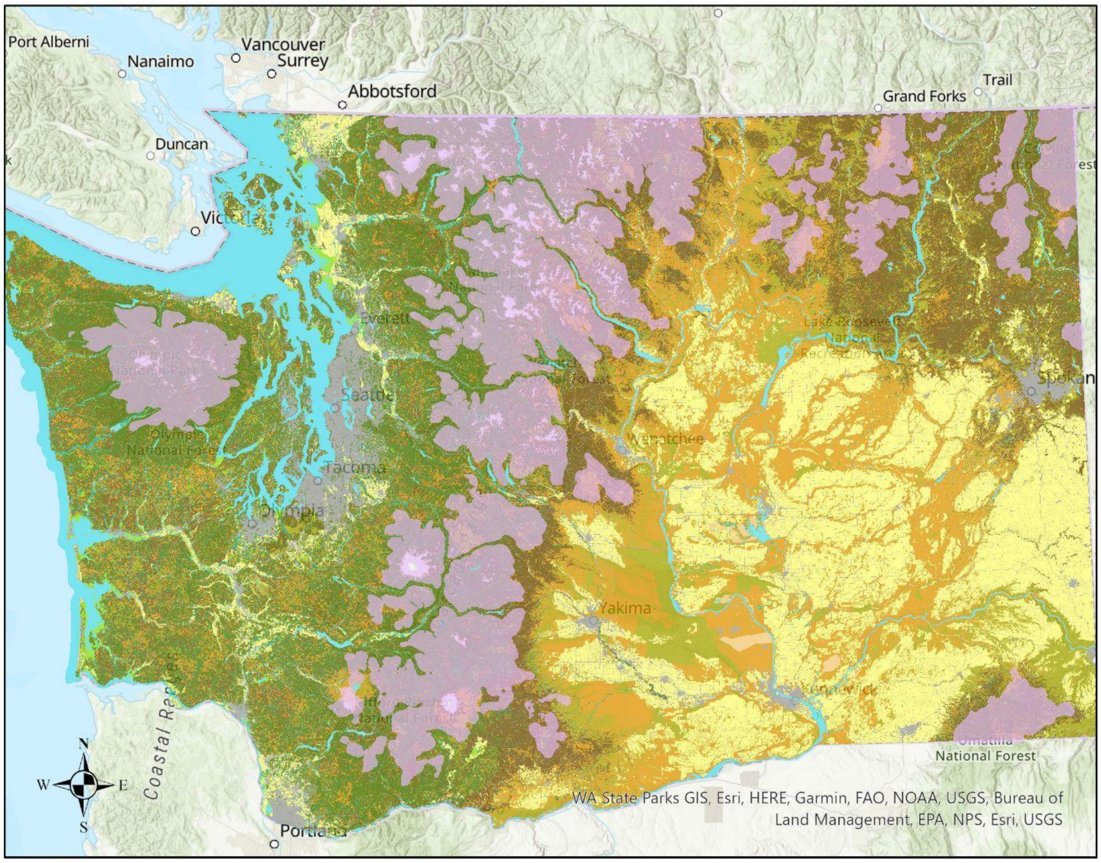
- Agriculture
- Alpine
- Dry Forest
- Grass-dominated
- Riparian
- Shrub-dominated
- Sparsley Vegetated
- Urban/Developed
- Water
- Wet Forest
- Wetland

Scale: 1:3,313,364

0 25 50 100 Kilometers

This map shows GAP (2011) vegetation and land cover updated with fuel disturbance data (Landfire, 2020). See table 1 for reclassification rules.

American Black Bear Habitat Concentration



Legend Scale: 1:3,068,273

0 25 50 100 Kilometers

Value

Habitat Concentration Area

WHCWG_Classname

- Agriculture
- Alpine
- Dry Forest
- Grass-dominated
- Riparian
- Shrub-dominated
- Sparsley Vegetated
- Urban/Developed
- Water
- Wet Forest
- Wetland

This map shows updated Habitat Concentration Areas for the American black bear.