Huckleberry Monitoring
in the Gifford Pinchot National Forest

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INTRODUCTION

Big huckleberry (*Vaccinium membranaceum*) can be found in many coniferous forests of the western United States. It is commonly found in the Pacific Silver Fir and Mountain Hemlock Vegetation Zones as well as forest areas dominated by subalpine fir, Douglas-fir, and western hemlock (Brockway et al. 1985, Friesen 2016). Populations of big huckleberry are generally found between 3,000 and 5,400 feet in elevation (Yang et al. 2008).

Big huckleberry spreads through seeds, root crowns, and rhizomes (adventitious buds), with reproduction through seed being the least common and rhizomatous spread being the dominant and quickest form of expansion (Stark 1989, Ingersol and Wilson 1990). Winter, spring, and summer weather impacts annual fruiting, with regard to the timing of fruit production, timing of ripening, and amount of fruit (Shaffer 1971, Minore and Dubrasich 1978, Martin 1979). Similar to most fruiting species, fruit production is heavily influenced by solar radiation whereas plant growth and lateral expansion is less sensitive to smaller variations in sun exposure and can advance in environments likely too shaded for heavy fruiting (Dahlgreen 1984). Since flowers develop in early spring, snow depth and the timing of snowmelt impact huckleberries in a number of ways, such as delays in flowering in areas where snow persists into spring and boosts in growth from consistent moisture availability during times of snow melt (Minore 1972, Minore and Dubrasich 1978, Martin 1979).

Twelve species of huckleberry are found throughout the Gifford Pinchot National Forest (GPNF), but the most culturally and ecologically significant is big huckleberry (hereafter referred to as “huckleberry”). The units within our project area have extensive histories of providing optimal habitat to productive huckleberry plants that served as a sustainable food source for Native Americans, local communities, and various wildlife species. For centuries, the forest stands within Sawtooth and Polepatch endured recurring stand-replacing fires, both natural and anthropogenic, allowing for huckleberry to dominate the landscape (French 1999, Hudec and Harris 2012). Native Americans of the region (including Cowlitz Indian Tribe and Yakima Nation) would travel to and temporarily settle in upland areas during harvest time (around August) to pick big huckleberry (Filloon 1952). Intentional fires were set by Native Americans to maintain the huckleberry fields (Boyd 1999). Huckleberry plants can persist in low severity fires because the foliage has low flammability. Conversely, higher severity fires can kill huckleberry plants, yet they can also sometimes promote new rhizomatous shoots from parts of the plants left living underground (Dahlgreen 1984). Plants are only consumed by fire when sufficient fuels are present to dry and preheat stems and foliage (Miller 1977). By the 1910s, Native American land was ceded and the Forest Service became proponents of fire suppression thus halting the maintenance of huckleberry fields by fire, causing conifers to encroach onto the open fields (Fisher 1997, Mack 2003). Forest succession and encroachment are thought to be main causes for decline in huckleberry fruit production and huckleberry plants today (Minore 1972, Minore et al. 1979, Minore 1984). Declines in huckleberry are largely from anecdotal observations, but forest inventory data and historical photos (aerial and other) support this view.

Due to a growing interest in restoring historic huckleberry picking sites and increasing the overall amount of fruiting huckleberry, there have been a number of huckleberry restoration efforts carried out in the region over the last few decades, including several in the GPNF. In addition to the units in our study area, forest thinning for huckleberry enhancement was implemented in the Lodgeberry Thinning Project, two miles north of Mount Adams Wilderness, and in the Mowich Huckleberry Enhancement Project, in the south part of the GPNF and in the Western Hemlock Zone. There was little to no monitoring work recorded for these efforts so their impacts have yet to be quantified. In general, very little research has been carried out to measure the effectiveness of different silvicultural approaches or to determine optimal locations or site characteristics for restoration.

In coordination with Cowlitz Indian Tribe and other local stakeholders and in compliance with the cultural foods obligations of the Treaty of 1855, the U.S. Forest Service undertook a huckleberry management effort involving analyses and restoration activities. The goal was to "develop a multi-year, self-sustaining huckleberry habitat restoration program on the Gifford Pinchot National Forest that will lead to increased huckleberry production and improvement to local forest community economies." As a part of the Forest Service's Huckleberry Management Strategy, select forest units within Sawtooth and Polepatch were thinned with the goal of providing huckleberry with optimal habitat for fruit production and lateral expansion of huckleberry plants. These stands were selected using a number of factors including existing and nearby huckleberry cover, plant associations, accessibility from roads, and knowledge from local community members (Hudec and Harris 2012). Based on these criteria, forest management prescriptions were created. These prescriptions included distinct variations of tree removal to decrease canopy cover and, in certain cases, prescribed fire.

For our study, we selected units within Sawtooth and Polepatch for on-the-ground surveys to evaluate the effectiveness of different silvicultural treatments in enhancing production and growth of big huckleberry. A second objective was to engage stakeholders and community volunteers in monitoring activities. The overarching monitoring question we aimed to answer was: To what extent did vegetation management impact huckleberry cover, fruit production, and ecosystem characteristics within the plot and unit? Our goal was to aid ecologically similar areas throughout the Pacific Northwest in being able to adopt effective and data-supported huckleberry restoration strategies.

METHODS

Study area and site selection

The 2,021-acre study area includes two separate project sites, Sawtooth and Polepatch, on the Gifford Pinchot National Forest in the state Washington. The Sawtooth units are just north of Indian Heaven Wilderness and include the historic Sawtooth Berry Fields, an area regarded as one of the most productive huckleberry sites in the Pacific Northwest (Minore 1972, Fisher 1997). The Sawtooth Berry Fields are in the Pacific Silver Fir and Mountain Hemlock Vegetation Zones where huckleberry is a common understory plant (Brockway et al. 1985). Polepatch is located approximately twelve miles northeast of Mount St. Helens and is comprised of Polepatch-North (Veta) and Polepatch-South (Pinto). Although not as renowned as the Sawtooth Berry Fields, many areas in Polepatch also served as traditional huckleberry fields. The Polepatch units lie within the Pacific Silver Fir Zone (Hudec and Harris 2012).

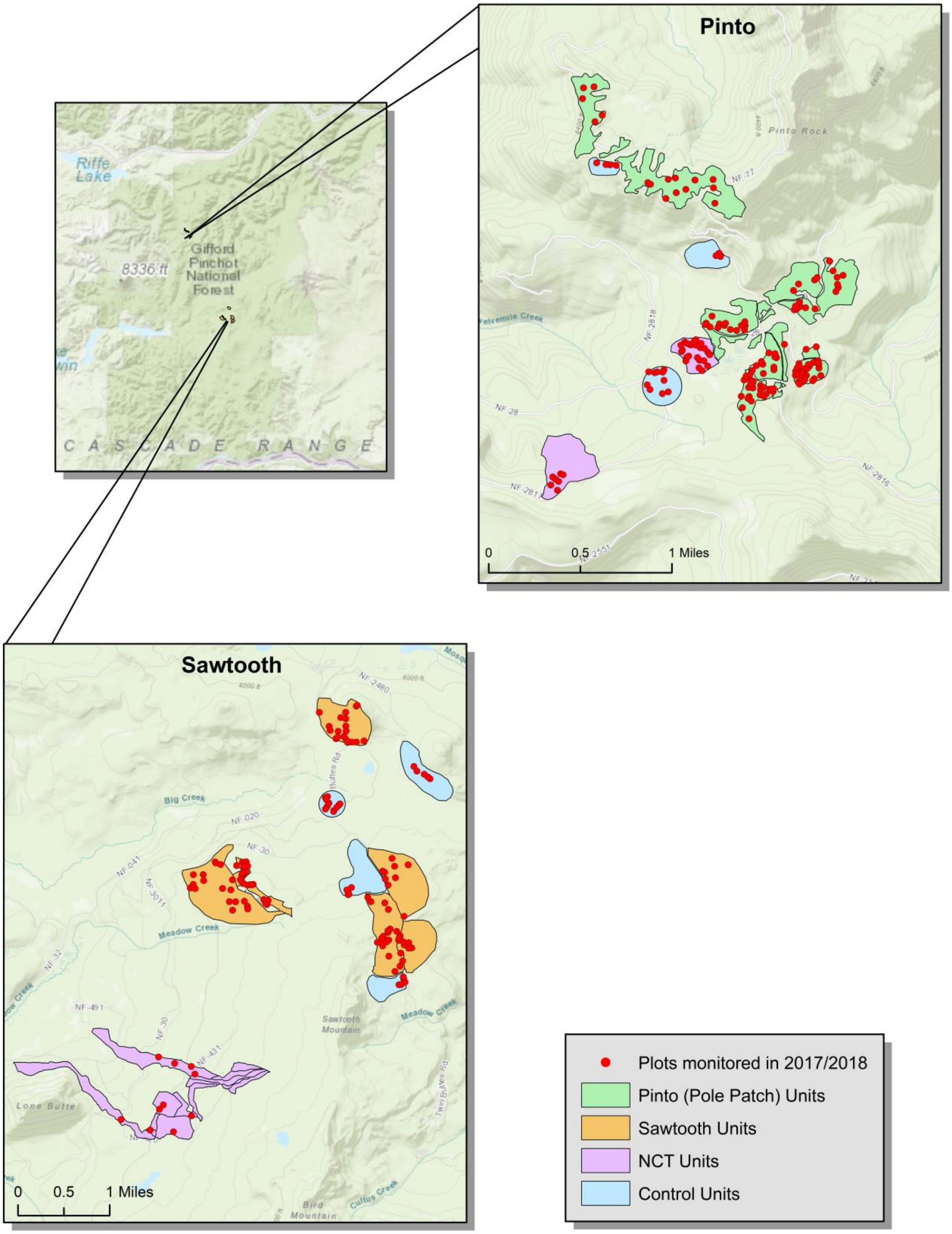


Figure 1: Map of the two survey areas, Pinto (Pole Patch) and Sawtooth. The red dots are the plots that were monitored in 2017 and 2018. The two years were combined for the analysis.

Five units within Polepatch (Pinto 6, 7, 8, 9, and 11) and six units within Sawtooth (Sawtooth 3, 8, 9, 10A, 11A, and 12) were assigned prescriptions by the U.S. Forest Service based on site characteristics, to promote the growth of huckleberries (Figure 1). Each prescription had recommendations that included a method for cutting and extracting trees, target residual canopy cover, and a fuel treatment (only Sawtooth 12 had been burned prior to this study). Methods for extracting trees were with the use of ground-based machinery (GBM) or hand tools (HT). Ground-based machinery involves the mechanical extraction of trees with a feller buncher and skidder whereas the use of hand tools involves the manual extraction of trees with tools such as chainsaws, axes, and hand saws.

Treatment units were thinned between 2010 and 2016. In addition to surveying plots in these project areas, we also surveyed three additional units (Pinto 543, 556, and Sawtooth 102) that had been treated with hand tools under a non-commercial thinning prescription intended to promote huckleberry growth as well as tree growth. Pinto 7, 8, 9 and Sawtooth 8, 9, 10A, 11A were surveyed in 2017. In 2018, we revisited all of the units surveyed in 2017 to increase our sample size and additionally surveyed Pinto 6, Pinto 11, and Sawtooth 12. To establish controls, we surveyed plots located in similar forest areas near huckleberry treatment units that had not been recently thinned for huckleberry restoration. In total, we visited 309 survey plots in 2017 and 2018 combined. At all survey sites, we monitored huckleberry and ecological characteristics in 100m^2 plots and captured fine-scale observations of huckleberry growth in 2m^2 subplots.

Survey protocol

Plot establishment

Using a map with randomly selected points as a guide, we established 100 m^2 plots within all survey units. We also established three 2m^2 square subplots within the larger plot for finer scale observations of huckleberry phenology, with one at the center of the 100 m^2 plot, one 1.4 m north from the edge of the center plot, and one 1.4 m south from the other edge of the center subplot (Figure 2).

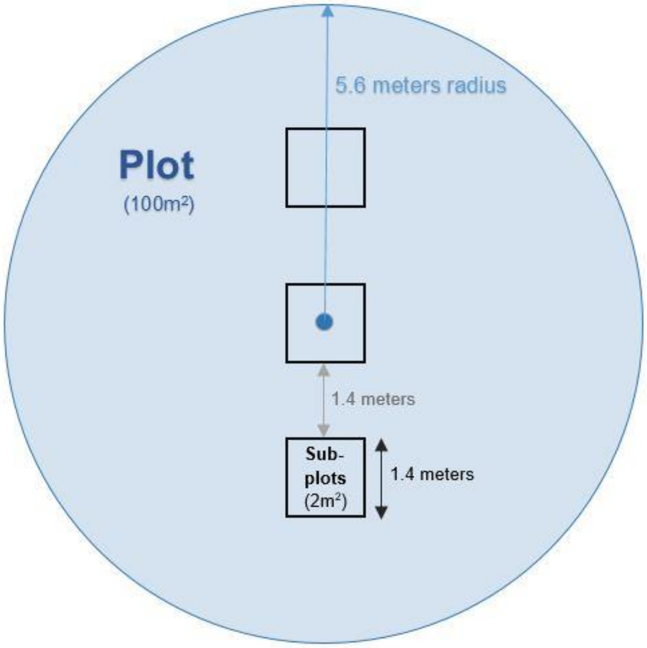


Figure 2. Plot design for huckleberry monitoring.

The following observations and measurements were recorded at each 100m^2 plot: percent canopy cover, huckleberry percent cover, and beargrass percent cover. Percent canopy cover was measured with a GRS densitometer. We recorded and averaged five densitometer readings per plot. Canopy measurements were taken while facing north and standing at the center and the north, south, west, and east boundary of the plot. We chose this method because the densitometer is known to be quick, accurate, and repeatable amongst multiple users (Stumpf 1993, Paletto and Tosi 2009). Huckleberry and beargrass percent cover were recorded as visual estimates of the plant as seen from above, and we allowed for overlaps of the percent covers to occur (i.e. total percent of both huckleberry and beargrass could surpass 100%). At the subplot level, we estimated fruit production and plant height and gave each a categorical rank (Table 1). Fruit production categories (derived from Anzinger 2002) were based on average fruits per stem. We defined a stem as the newest shoot growth that was bearing fruit (i.e. a raceme). We collected qualitative information on soil disturbance, biodiversity, canopy structure, tree count, and huckleberry shrub spatial distribution, but we did not use this data for analysis. Following monitoring, we derived additional plot-level variables, including aspect, elevation, and solar radiation using a 10m x 10m digital elevation model in ArcMap (Version 10.4, ESRI). We calculated solar radiation as the amount of radiant energy for a given location. This data was extracted at the plot level and was an average of daily intervals of solar radiation from April to August of the year the plots were monitored. The variables that were included in the calculation were influenced by aspect, slope, zenith, azimuth, diffuse radiation, and transmission (for more information see Fu and Rich 2002). Solar radiation levels do not take canopy cover into account.

Table 1. Categories for assessing huckleberry fruit production (Anzinger 2002).

Category	Fruiting Classifications
0	No huckleberry plants in plot
1	Huckleberry plants in plot, no fruit
2	Low (< 5 fruits/stem on all stems in plot.)
3	Medium (<5 fruits/stem on most stems in plot, between 5-10 fruits on others.)
4[a]	Medium-high (< 10 fruits on most stems in plot, between 10-15 fruits on others.)
5[b]	High (< 15 fruits on most stems in plot, between 15-20 fruits on others.)
6[b]	Extra high (>20 fruits on most stems in plot.)

[a] Only one subplot fit this category, and it was changed to category 3 for analysis.
[b] These categories were not observed in 2017/2018.

Category	Height Classifications
1	Average height less than 0.1 m (4 in.)
2	Between 0.1 m and 0.5 m (4 in. – 1.6 ft.)
3	Between 0.5 m and 1 m (1.6 – 3.2 ft.)
4	Greater than 1 m (3.2 ft.)

Analysis

Canopy Cover

We calculated mean percent canopy cover of all plots within the unit to estimate an overall canopy cover. We compared mean measured canopy cover to the prescribed canopy cover for each of the treatment units (Figure 3).

Huckleberry cover

Because canopy cover and treatment method are two variables of the management prescription, we first tested whether these factors were related to the percentage of huckleberry cover within plots. All analyses were performed in R (Version 2.15.1). To test these relationships and allow for a curvilinear effect of canopy cover, we used a multifactor linear model with logHC as the dependent variable and CanCov, $\text{CanCov}^{2,}$ and treatment (Method) as independent variables. This allowed us to test whether huckleberry cover varied among areas with different treatment methods (GBM, HT, None) while controlling for differences in canopy cover.

Next, we used an Akaike Information Criterion (AIC) framework to compare a set of multifactor linear models that each contained all three prescription variables (CanCov, CanCov^2, Method), hereafter referred to as the "base model." Nine models were compared and shown in Table 5: the base model (model 1), four models that each contained the base model plus one additional independent variable (Zone, Elev, Bear, Rad, models 2–5), three models that each included the base model plus two additional variables that were both significant in the previous step (models 6-8), and one model that contained the base model plus all three variables that were identified as significant in previous steps (model 9). For each of these models, we calculated Akaike's Information Criterion (AIC), identified the lowest AIC value within the model set, and calculated ΔAIC value for each model (Burnham and Anderson, 1998). In addition to identifying the best model of the set, we were interested in whether independent variables showed consistent relationships with huckleberry cover when analyzed in different combinations with other variables.

To explore whether huckleberry cover changed over time in the years following treatment, we removed all control plots from the data set and tested a set of linear models that included Time as an additional variable along with CanCov and CanCov^2. We tested data for all treatment plots combined and also tested the data separated by Method and Zone.

Fruit Production

Fruit vs. no fruit

We collected fruit production data at all three subplots within each plot. We conducted a chi-squared analysis to test whether huckleberry plants within areas with different treatment methods produced fruit in different proportions, including post-hoc comparisons between each pair of treatments types.

Next, we used a generalized linear model with a binomial response variable (fruit or no fruit) to model the factors that might influence whether or not huckleberry plants produced fruit. First, we included only the prescription variables: CanCov, CanCov^2, and Method. After identifying which prescription variables showed a relationship with fruit production, we tested additional models with the following independent variables: Height, Rad, Bear, Zone, Day. Similar to the model comparison for huckleberry cover, we used an AIC framework to compare models that contained various combinations of variables found to be significant in preliminary steps (Table 6).

To explore whether the proportion of huckleberry plants producing fruit increased over time in the years following treatment, we removed all control plots from the data set and tested a set of linear models that included Time as an additional variable along with Method.

Low fruit vs. high fruit

For analysis of fruit production level, we combined categories 3 and 4 (there was only 1 subplot in the category 4), hereafter referred to as High production. We conducted a chi-squared analysis to test whether huckleberry plants within areas with different types of treatment methods produced fruit at different levels, including post-hoc comparisons between each pair of treatments types. Due to the very small number of plants producing High fruit levels, we did not conduct multifactor modeling for this response variable.

Table 2: Variables collected at each plot, variable notation used in the text, and range of values for that variable documented during the study.

Continuous variables	Notation	Values observed	Notes
Huckleberry percent cover	HC	0–90	Estimated in the field.
Huckleberry percent cover: log(HC+1)	logHC	0–1.95	HC data was transformed to meet the assumption of independently distributed residuals in linear models.
Canopy percent cover	CanCov	0–100	Measured in the field.
Canopy percent cover squared	$CanCov^2$	0–10000	CanCov was squared to allow for modeling a curvilinear relationship using a linear model.
Beargrass percent cover	Bear	0–90	Estimated in the field.
Elevation (m)	Elev	1138.58–1417.31	Elevation was derived for each plot from a 10m DEM in ArcMap
Solar radiation (WH/km2)	Rad	140.27–181.95	Incoming solar radiation was derived for each plot at as an average of months April–August of survey year.
Years since treatment	Time	1–8	For GMB and HT sites only.

Categorical Variables	Notation	Values observed	Notes
Fruit production	Prod	No fruit, low fruit, medium, medium-high	Explanation of fruit production categories found in Table 1.
Plant height	Height	< 0.1 m, 0.1–0.5 m, 0.5–1 m, > 1m	Explanation of fruit production categories found in Table 1.
Method of timber harvest	Method	Ground based machinery (GBM), hand tools (HT), no treatment (None)	
Zone	Zone	Sawtooth, Pinto	

RESULTS

We collected data from 260 plots in 14 treatment units and from 49 plots in corresponding control areas. The range of values measured for each variable are included in Table 2. Of the 309 plots, 281 (91%) contained huckleberry plants.

We collected data on fruit production and plant height at 927 subplots, but due to various recording mistakes we were able to use only 918 subplots for analysis. Of those subplots, 618 (67%) contained huckleberry plants and 208 (34%) contained fruit producing plants (Table 3).

Table 3. Number of subplots that contained no huckleberry plants, huckleberry plants but no fruit, and fruiting huckleberry plants, by zone.

Huckleberry status	Pinto	Sawtooth	Total
No plants	232	68	300
Plants, without fruit	183	227	410
Plants with fruit	73	135	208
All subplots			918

Canopy Cover

Mean measured canopy cover in the treatment units ranged from 19% to 40%. In nine of the eleven treatment units, the canopy cover measured at our survey plots fell inside the prescribed treatment range or was within 3%. The greatest difference between measured canopy cover and prescribed canopy cover was at Pinto 7 and 9, where the measured canopy cover was 10% and 12% respectively, higher than the prescribed treatment target. Mean measured canopy cover for the Pinto and Sawtooth control areas were 77% and 43% respectively. Mean measured canopy fore Pinto and Sawtooth treated units were 31% and 27% for respectively.

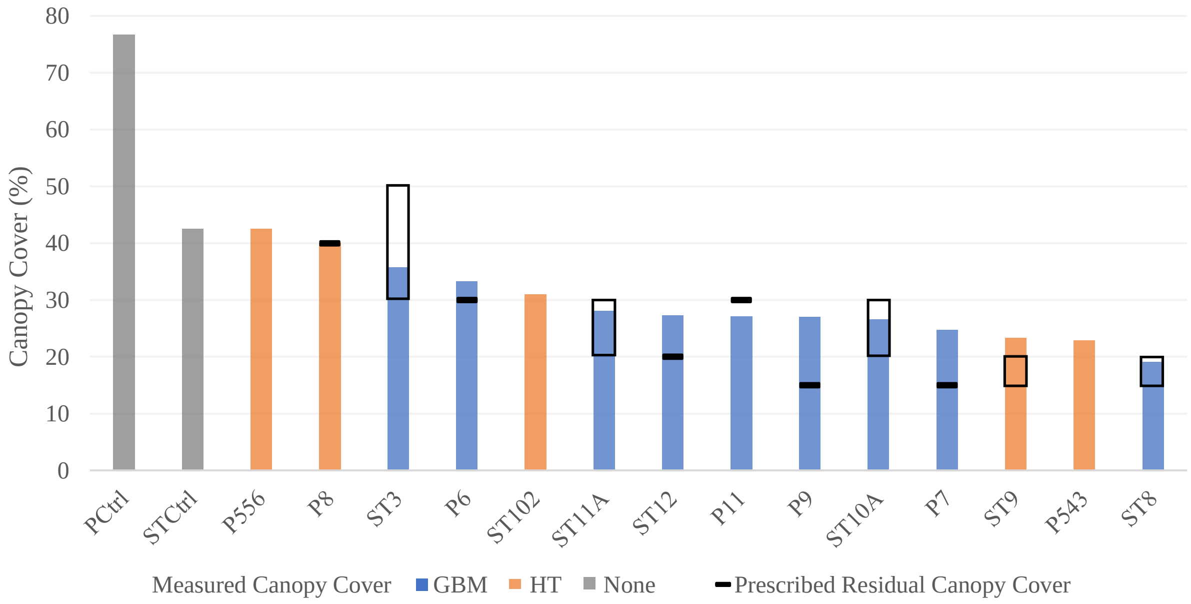


Figure 3. Mean percent canopy cover measured in 2017 and 2018 for each surveyed unit. The dash represents a specific target and the open box represents a range for prescribed canopy cover for each treatment unit. (P: Pinto; ST: Sawtooth). P556, P543, and ST102 did not have a prescribed residual canopy cover.

Huckleberry Cover

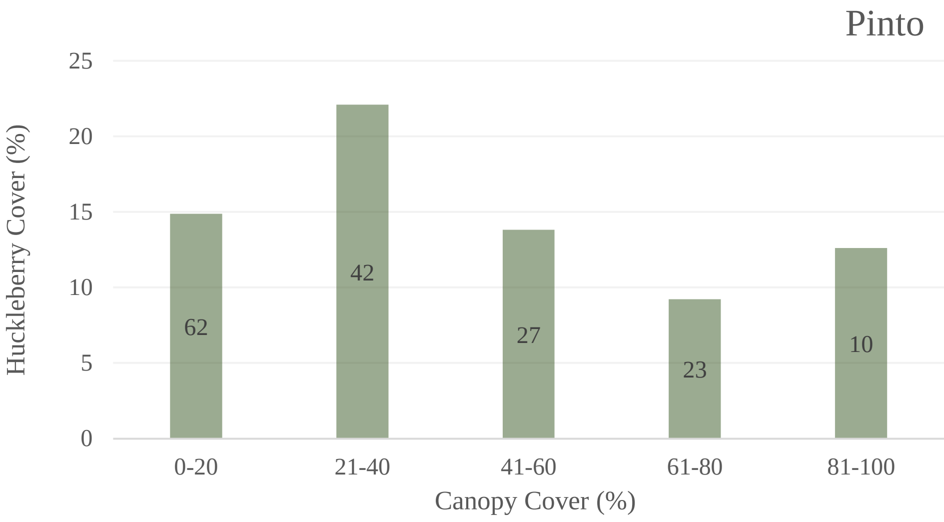
At the unit level, mean huckleberry cover ranged from 8% to 56% (Table 4). The highest huckleberry cover measured at the plot level was 90%.

Table 4. Number of plots surveyed, mean huckleberry cover, and range of huckleberry cover for each unit surveyed in 2017 and 2018.

Unit	n	Zone	Harvest Method	Mean HC (%)	Range (%)
PCtrl	17	Pinto	None	7.47	0–35
P9	28	Pinto	GBM	7.57	0–40
ST11A	20	Sawtooth	GBM	12.8	0–85
P8	16	Pinto	GBM	13.69	0–60
P7	35	Pinto	GBM	17.26	0–80
PNCT556	24	Pinto	HT	17.29	0–75
P6	16	Pinto	GBM	18.5	1–87
P11	21	Pinto	GBM	21.38	0–75
ST3	20	Sawtooth	GBM	22.5	0–60
STNCT	10	Sawtooth	HT	22.6	3–60
ST8	12	Sawtooth	HT	22.83	2–60
STCtrl	32	Sawtooth	None	25.16	1–90
ST12	18	Sawtooth	HT	26.78	1–85
ST10A	14	Sawtooth	GBM	27.5	0–60
PNCT543	7	Pinto	HT	34.14	0–60
ST9	19	Sawtooth	HT	56.42	7–85

Prescription variables

CanCov (t=2.037, df=296, p=0.043), $CanCov^2$ (t=-2.772, df=296, p=0.006), and Method (see below) were all found to be significant predictors of logHC (statistical values are from the model with the lowest AIC value, model 6). The beta estimates for the canopy cover variables support a curvilinear relationship between canopy and huckleberry cover. Canopy cover values between 21% and 40% supported the highest percentage of huckleberry cover in both Sawtooth and Pinto (Figure 4).



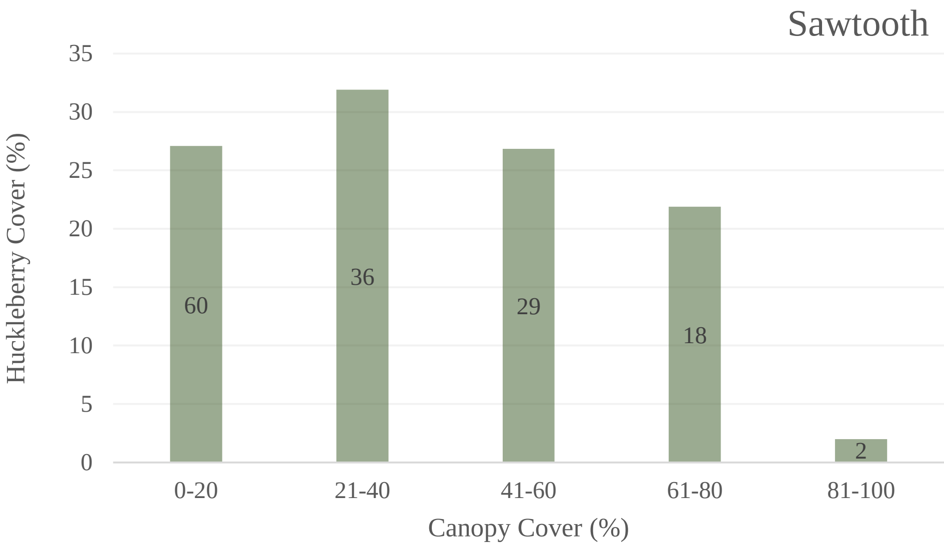


Figure 4. Relationship between canopy and huckleberry cover. Numbers indicate number of plots per canopy cover bin.

Additionally, controlling for differences in canopy cover, we found that treatment method had a significant relationship with huckleberry cover. Specifically, we found that the use of hand tools had a positive relationship with huckleberry cover compared to the use of ground-based machinery (t=3.844, df=296, p<0.001, values from model 6). While plots treated with hand tools had similar canopy cover to those treated with ground-based machinery, huckleberry cover was higher at the hand tool sites (Figure 4).

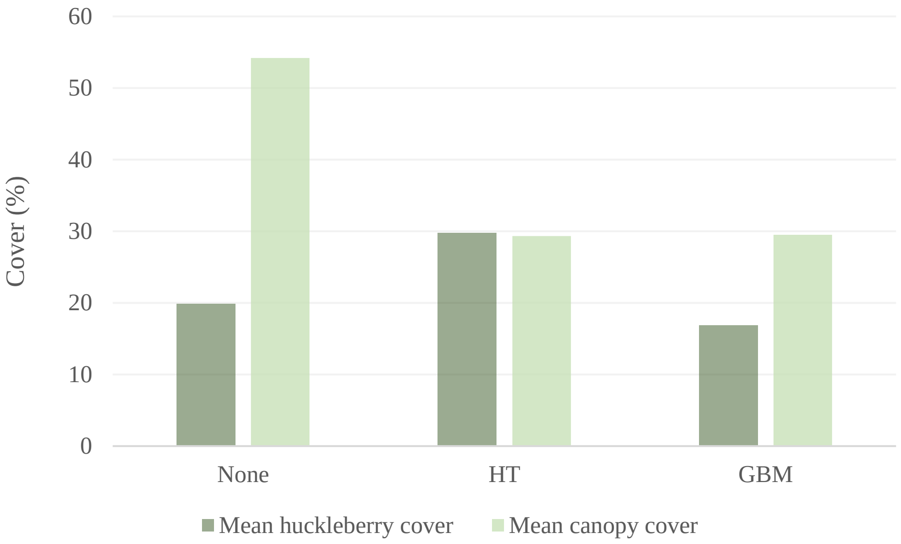


Figure 5: Mean huckleberry cover and canopy cover of plots within the different treatment methods. GBM: ground-based machinery, HT: hand tools, and None: no treatment.

Non-prescription variables

When single non-prescription site characteristics were added to the base model, Bear, Elev, and Zone were identified as having significant relationships with logHC. Thus, these three variables were included in the suite of models compared using AIC (Table 5). Rad was not a significant factor.

The model that included Zone and Elev had the lowest AIC value (Table 5), but ΔAIC values for the full model and the model including Elev and Bear were less than one and should be interpreted as equally compelling. The three prescription variables showed the same significant relationships identified above indicating a curvilinear relationship between canopy cover and huckleberry cover and a positive impact of hand tools compared to ground-based machinery. The relationship between logHC and Elev was significant and positive in all models where Elev was included. The variable Zone was significant in three of the four models in which it was included, with huckleberry cover being significantly higher in the Sawtooth Zone. The variable Bear was significant and positive in two of the four models in which it was included.

We did not find statistical support for the hypothesis that huckleberry cover increased over time following treatment.

Fruit Production

Fruit vs. no fruit

We surveyed 618 subplots that contained huckleberry plants. Of those, 208 produced fruit (34%). Separated by treatment method, the proportions are as follows: GBM: 25%, HT: 42%, and None: 44%. Our chi-squared analysis indicated that the proportions of plants producing fruit were significantly different than expected by chance (χ^2=20.4, df =2, p<0.001). A post-hoc test showed significant differences between GBM and HT (χ^2=14.5, df=1, p<0.001) and GBM and None (χ^2=11.5, df = 1, p<0.001). Fruiting proportions were similar between HT and None.

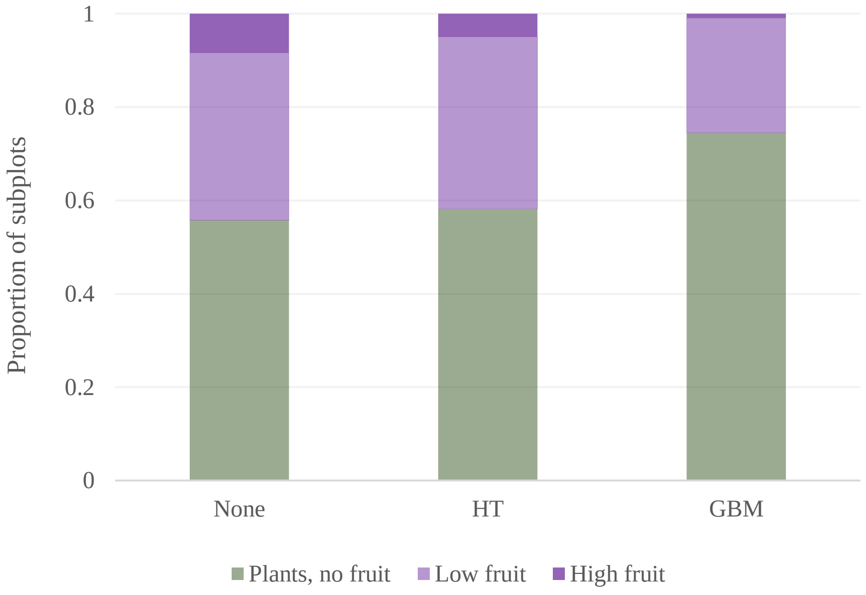


Figure 6. Proportions of subplots in each treatment method that contained huckleberry plants at different fruiting levels, including no fruit.

In additional to Method, the model with the lowest AIC value identified significant relationships between fruiting and the following variables: Elev (z=5.05, df=617, p<0.001), Height (z=9.39, df=617, p<0.001), Rad (z=2.26, df=617, p=0.024), and Day (z=-4.221, df=617, p<0.001). The significant relationships identified for these non-prescription variables (positive relationships with Elev, Height, and Rad, and a negative relationship with Day) were consistent across the set of models tested. Fruit production was consistently found to be significantly higher at None sites than GBM sites. In the model with the lowest AIC value, no significant difference was found between fruit production at HT sites and GBM sites – but eleven of the sixteen competing models found significantly higher fruit production at HT sites. CanCov, CanCov^2, Zone, Bear, and Year were not significantly related to fruit production.

Low fruit vs. high fruit

Of the 208 subplots that produced fruit, 90% produced at levels classified as Low production. The proportions of subplots that produced Low fruit in each treatment type were as follows: GBM - 96% HT – 88%, None – 81%. A chi-squared analysis indicated that a significantly higher proportion of plants produce High fruit levels in None plots compared to GBM plots (χ^2=6.34, df =1, p<0.012. The intermediate fruit production levels in HT sites were not significantly different than those in either of the other two treatment classes (Figure 6).

Table 5. Models included in the comparison set exploring independent variables related to huckleberry cover. Each was analyzed as a linear model with logHC as the response variable. Table includes model number, variables included, AIC, Δ AIC, and significant ($p<0.05$) relationships identified. Model with lowest AIC is bolded.

Model	**AIC**	**Δ AIC**	**CanCov**	**CanCov^2**	**Method**[a]	**Zone**	**Elev**	**Bear**	**Rad**
1. Base	508.00	13.39	+	–	HT +				
2. Base + Zone	497.15	2.54	+	–	HT +	ST +			
3. Base + Elev	497.78	3.17	+	–	HT +		+		
4. Base + Bear	502.30	7.70	+	–	HT +			+	
5. Base + Rad	510.11	15.50	+	–	HT +				NS
6. Base + Zone + Elev	**494.61**	**0**	**+**	**–**	**HT +**	**ST +**	**+**		
7. Base + Zone + Bear	497.56	2.96	+	–	HT +	ST +		NS	
8. Base + Elev + Bear	495.27	0.66	+	–	HT +		+	+	
9. Base + Zone + Elev + Bear	495.00	0.40	+	–	HT +	NS	+	NS	

[a] Relationship is in comparison to ground-based machinery. No significant differences were found between None (no treatment) and either harvest method.

Table 6. Models included in the comparison set of generalized linear models (binomial distribution) with fruiting (yes or no) as the response variable. Table includes model number, variables included, AIC, Δ AIC, and significant ($p<0.05$) relationship identified. Model with lowest AIC is bolded.

			Method[a]					
Model	**AIC**	**Δ AIC**	**HT**	**None**	**Elev**	**Height**	**Rad**	**Day**
1. Method	775.14	157.34	+	+				
2. Method + Elev	746.11	128.31	+	+	+			
3. Method + Height	672.67	54.87	+	+		+		
4. Method + Rad	767.46	149.66	+	+			+	
5. Method + Day	762.98	145.18	+	+				–
6. Method + Elev + Height	641.15	23.35	NS	+		+		
7. Method + Elev + Rad	742.31	124.51	+	+	+		+	
8. Method + Elev + Day	738.5	120.7	+	+	+			–
9. Method + Height + Rad	664.07	46.27	+	+		+	+	
10. Method + Height + Day	647.61	29.81	NS	+		+		–
11. Method + Rad + Day	758.63	140.83	+	+			+	–
12. Method + Elev + Height + Rad	758.62	140.82	NS	+	+	+	+	
13. Method + Elev + Height + Day	621.03	3.23	NS	+	+	+		–
14. Method + Elev + Rad + Day	736.65	118.85	+	+	+		NS	–
15. Method + Height + Rad + Day	642.67	24.87	+	+		+	+	–
16. Method + Elev + Height + Rad + Day	**617.8**	**0**	**NS**	**+**	**+**	**+**	**+**	–

[a] Relationship is in comparison to ground-based machinery. No significant differences were found between HT (hand tools) and None (no treatment).

DISCUSSION

Huckleberry cover and fruiting characteristics within the Gifford Pinchot National Forest are influenced by a broad range of factors including canopy cover, restoration treatment methods, elevation, and solar radiation. The relationships that we identified are not unexpected given the general knowledge about the natural history of huckleberry in the region. With a few exceptions, our results offer additional support to previous research.

Canopy Cover

We measured canopy cover to assess whether prescribed target canopy values were achieved and to serve as an explanatory variable for varying levels of huckleberry cover and fruit production. The measured values of canopy cover in units were mostly similar to the prescribed target canopy covers. Only two units had a measured canopy cover that was more than 10% different from the target residual canopy cover. Discrepancies in canopy cover could be the result of forest management or survey inaccuracies.

The controls units had higher average canopy cover than the treatment units, which is not surprising, as they had not recently been thinned. However, some of our control units had low canopy cover values. This was particularly the case for control units established in Sawtooth, which lie next to the treated Sawtooth units. These areas had sparse canopies that reflected their historic conditions.

Prescription variables

Canopy Cover

We found consistent, significant relationships between huckleberry cover (HC) and both canopy cover variables (CanCov, CanCov2), supporting the presences of a curvilinear relationship. Huckleberry cover was highest at intermediate values of canopy cover, peaking in the range of 21% to 40%. Huckleberry is known to be most abundant, both in cover and fruit production, in early seral stages of forest succession (Martin 1979). As forest succession continues and the canopy fills in, the light, moisture, temperature and nutrients below change (Brockway et al. 1985). Huckleberry plants often persist under a closed canopy, but an increase in light in more open canopies may help stimulate the plants to grow more vigorously and increase fruit yields (Douglas 1970, Minore 1972). However, too much sun exposure can burn the leaves, hindering the process of photosynthesis (Stark and Baker 1992). Over-exposure can also potentially affect the shallow rhizomes especially on south facing slopes (Higgin et al. 2004). Both previous research and our results support the idea that an intermediate amount of canopy is optimal to allow sunlight while protecting the plants from overexposure. A report by Friesen (2016) summarized a selection of research trials and concluded that leaving a residual canopy cover of 30–50% may benefit huckleberry plants.

However, we did not find a relationship (either linear or curvilinear) between canopy cover and fruit production. Minore and Dubrasich (1978) found similar results in their study of huckleberry in the region. Other studies suggest that growth patterns might be more impacted by snowpack depth and duration, drought, and precipitation at the time of flowering and fruiting than by canopy densities (Minore 1972, Minore and Dubrasich 1978, Martin 1979). Much of the success of fruiting depends on the meteorological conditions prior to early spring as opposed to the levels of canopy cover.

Time since treatment

We did not find statistical support for the hypothesis that huckleberry cover or fruit production increased over time following treatment. It is very likely that our most of our surveyed plots have not had sufficient time to begin to expand laterally or to recover from disturbances caused by treatment. Time is needed for plants to respond to the change in environmental conditions post-treatment. All of the treatment units we surveyed were thinned from 2010 to 2016, meaning those units ranged in time since treatment from one to eight years based on when we surveyed in 2017 or 2018. The time required for recovery depends on the severity and nature of the disturbance. Some plants will need to recover from damage to stems and/or rhizomes that occurred during treatment. Alaback and Tappeiner (1991) found that following clear-cutting, huckleberry sprouted largely from rhizomes and took 3–7 years to exert dominance over the understory herb layer. For newly established seedlings, they found it could take longer than 3–7 years to attain similar structural dominance. Friesen (2016) found that post-disturbance, huckleberry plants will sprout vigorously, but fruit production could be delayed by 3–10 years. Martin (1979) suggests fruit productivity will not be highest until 50 years after disturbance.

Treatment type

After controlling for canopy cover, huckleberry cover was significantly lower within units that had been treated with ground-based machinery compared to sites treated with hand-tools. Both measures of fruit production (proportion of plants producing fruit and proportion of fruit-producing plots with high fruit levels) were lower within units that had been treated with ground-based machinery compared to those within units treated with hand tools or left untreated. We did not quantify the particular effects of disturbance that occurred during treatment but we can make inferences as to why fruiting levels might be lower in plots where ground-based machinery was used. The use of skidders, loaders, tractors, and other heavy machinery near the existing huckleberry plants increases the chance of physical damage to the stems and leaves as well as the roots and rhizomes. Soil compaction, displacement, and scarification from heavy machinery can lower soil productivity. Compaction can affect the pore spaces within the topsoil which in turn reduces the amount of available moisture and nutrients, slows root elongation, and inhibits the diffusion of gases (Topik 1989). The potential for soil displacement at both Sawtooth and Pinto is already high because the topsoil consists of low density materials—volcanic ash and high organic matter (Brockway et al. 1985). Scarification to the soil could damage or destroy rhizomes because huckleberry rhizomes are particularly shallow (Minore 1975). Conversely, under certain circumstances, lower severity disturbances to the plants and soil can stimulate the growth of new stems or shoots new stems (Minore et al. 1979, Minore 1984). Manual removal of trees using hand tools could reduce the potential for damage to the huckleberry plants and soil.

Other variables

In addition to treatment method and canopy cover, there was a great deal of variability throughout our study area in terms of elevation, aspect, solar radiation, forest type, presence of beargrass, plant height, and zone.

Both huckleberry percent cover and fruit production increased at higher elevations. In the Pacific Northwest, huckleberry has a historic range of 3,000 and 5,400 feet (Yang et al. 2008). Minore et al. (1979) found the most productive huckleberry plants at sites between 3,937 and 5,905 feet. All of our plots were within the historic range (since that is where the restoration treatments occurred), but the higher huckleberry cover values found at higher elevations could indicate that conditions are more favorable in the upper parts of the elevation range. Elevation can impact the microclimate, therefore creating more favorable conditions for the huckleberry plants, such as more precipitation, deeper snowpack, and longer snowpack durations, some of which can protect plants from early spring frosts (Minore and Dubrasich 1978, Martin 1979, Dahlgreen 1984).

Solar radiation did not show an effect on huckleberry percent cover but it was positively associated with fruit production. Higher solar radiation values typically corresponded with south and southwestern aspects, while lower values corresponded to northern facing aspects. Martin (1979) found fruit production to be higher at higher elevations and attributed that to more available solar radiation. Southern aspects are typically drier than northern aspects, and huckleberry have shown to be more productive on northern aspects (Martin 1979, Dahlgreen 1984). However, with enough canopy to provide light shade and porous soils (like volcanic ash) to retain adequate moisture, huckleberry plants can be highly productive on southern aspects (Barney 1999).

Taller plants produced fruit more often than shorter plants. Anzinger (2002) found a positive correlation between plant height and fruit production. Based on results from Stark and Baker (1992), Anzinger suggested the association between height and fruit may have something to do with soil fertility. This is contrary to a finding by Martin (1979) that showed no correlation between plant height and fruit production. She attributed the lack of correlation to fruiting being more influenced by meteorological patterns, than solar radiation.

We found beargrass cover to be correlated with huckleberry cover in some models, but only in models that did not include Zone (treatment area) as an additional variable. Beargrass cover was much greater in the Sawtooth zone. This apparent relationship may actually be due to beargrass serving as a surrogate for different treatment areas, as there are negligible amounts of beargrass in Pinto. Anecdotally, we observed high percent cover for both huckleberry and beargrass in close proximity in Sawtooth, which may contrast other work suggesting they are competitors (Minore et al 1979, Higgins et. al 2004).

Huckleberry percent cover was significantly higher in the Sawtooth units but fruit production and fruiting level were not significantly different between the two zones. The difference in huckleberry cover could be partially attributable to historic conditions. Pinto and Sawtooth have similar fire histories—both sites were naturally revegetated after fires in the early 1900s. The most recent fire in Sawtooth occurred in 1904 (thought to be attributed to huckleberry management by Native American) in an area that had previously burned 7–24 years earlier (Mack 2003). Polepatch experienced its last major fire in 1918 which created a mosaic of patchy forested areas and small meadows (Hudec and Harris 2012). Forest succession and an era of fire suppression eventually allowed for conifers and other shade tolerant species to encroach the once dominant huckleberry fields that were traditionally used in both Sawtooth and Polepatch.

Differences in past treatment histories could provide some explanation for current variation in huckleberry percent cover when comparing sites. Sawtooth units 8, 9, 10, and 12 had previously received huckleberry enhancement treatments at various times between the 1960s and 2012 (USFS 2009). The recent treatment in Sawtooth could contribute to the higher levels of huckleberry cover because more of Sawtooth is within the early seral stage. Polepatch has far less treatments For the units we monitored in Pinto, unit 6 had trees strip planted in the 1920s (Hudec and Harris 2012) which may have an impact on current huckleberry distributions.

The current forest stands in both zones are comprised of similar overstory and understory species. Pinto units 7, 8, 9, and 11 are in the Pacific silver fir/Alaska huckleberry association and Pinto unit 6 is in the Pacific silver fir/big huckleberry/queen's cup bead lily association. All of the Sawtooth units were within the Pacific silver fir/big huckleberry/beargrass association. Analysis of LEMMA data (Ohmann and Gregory 2002) shows that, in addition to Pacific silver fir, other dominant tree species at both zones include Douglas-fir, subalpine fir, and western hemlock.

Citizen Science

Public involvement in science and restoration projects can help ensure buy-in and support from the community, which can advance future efforts and expand the potential audience. From the outset of the project and throughout, citizen science was an integral part of the huckleberry monitoring effort. By working with volunteers, we were able to collect significantly more data and keep project costs low. While there are many benefits to using citizen science in a project of this type, there are also negative aspects to consider. Data quality and consistency can suffer, as people join the effort with different levels of expertise or experience and for different amounts of time. For instance, we were forced to discard data for entire plots where a field was left blank or where the input of qualitative observations were suspect. Expecting this and hoping to keep these occurrences to a minimum, we tended toward simplicity in survey design and clarity in the survey forms. Despite a loss of some data points, we recommend utilizing citizen science for future huckleberry monitoring efforts and other similar projects.

Conclusion

With the decline in huckleberry productivity, there is an obvious need to better understand the best way to manage for huckleberry. We hope this work will help in our understating of the impacts of huckleberry restoration and in identifying effective treatment approaches. Our investigation was by no means exhaustive, and although we found significant associations related to the explanatory variables we observed, our results were quite variable and suggest a need for further study. Future efforts, focusing on a variety of potential facets of huckleberry restoration, could help bring clarity to many important aspects we were not able to explore. These include: a dedicated examination of burning impacts versus similarly treated areas that did not undergo burning; deeper investigation into the impacts of soil type and aspect on growth and fruit production; an experimental design exploring different non-commercial thinning treatments; the collection of data to better understand soil disturbance; and a survey of units that have yet to be treated to collect baseline data to better understand change over time.

Our data set from the field surveys of 2017 and 2018 can serve as baseline data for future studies. This can help address and mitigate some of the issues we encountered when designing this study as there were pre-treatment and pre-project unknowns that likely affected our analysis in ways that are difficult to quantify. For instance, prescriptions for some of the units in our study were assigned based on pre-treatment canopy. Sawtooth units 8 and 9 were thinned with hand tools because they had a sparse canopy (USFS 2009), which could have allowed for a higher density of huckleberry plants pre-treatment compared to other units. Without baseline data on huckleberry cover at each site, we cannot be certain how much of the variation in huckleberry cover could be attributed to pre-treatment huckleberry levels.

Management Implications

Our research points to possible steps that can be taken to maximize huckleberry growth and fruit production while minimizing the amount of disturbance. Minore et al. (1979) recommend frilling and girdling to remove overstory cover as a way to improve huckleberry growth and fruiting while keeping disturbance to a minimum. These methods both involve cutting a strip of bark/cambium around the full circumference of the tree as a way to kill the tree without requiring the use of heavy machinery. Anzinger (2002) proposes the idea of implementing thinning treatments that more closely mimic the impacts of low-severity fire or using prescribed burning in combination with logging or instead of logging to reduce ground disturbance. Operating under the presumption that treatment with hand tools can promote huckleberry growth while decreasing disturbance, we can suppose that a variety of commercial and non-commercial prescriptions could be employed using this type of method. If a certain unit or project requires logging with ground-based machinery or does not lend itself to treatment using hand tools, there are likely steps that can be taken to minimize disturbance and maximize huckleberry growth. These include designing the placement of skid trails and landing areas in a way that mimics fire behavior or by identifying and prescribing zones in the treatment area where machines are not allowed to go due to high abundance of huckleberry before treatment. Collecting more data on the potential impacts to the plants and soil is also a goal for future surveys. Our data suggest plots with ground-based machinery are not producing as much fruit as hand tool or control plots. For now, we can only speculate that it has something to do with damage caused by the heavy machinery. The effects of activity slash (tree branches, tops and trunks which are scattered or piled) are also of interest. Slash mats are designed to protect against soil disturbance, but could be hindering new plant growth.

The use of fire is a common way to bring the landscape back to a condition that is likely favorable to huckleberry growth and fruiting. Low- to moderate-severity fires can benefit overall huckleberry production by killing off old, unproductive stems, stimulating shoot growth from rhizomes, and lessening competitors. Prescribed burning was (and, in some cases, still remains) a prescription component for many of the units in Sawtooth and Pinto, but it was not implemented in most units. There can often be a small, and sometimes non-existent, window of time when burning is allowed and fuels are dry enough to burn, specifically in forest types where huckleberry grows. This, as well as other factors, likely contributed to burn plans not being implemented. Considering these realities when planning treatments will be an important step in future restoration projects. Moreover, there may be cases where managers are able to contract certain pieces of long-term projects to help mitigate these limiting factors.

Future Steps

For future survey efforts, we will be shifting methodologies to adapt to new information and lessons learned through this work. In addition to collecting categorical measures of fruit production per stem, we will be collecting information on overall fruit production per plant using a binning and visual estimate approach. Moreover, we recommend adjusting the categories to account for the fact that we rarely used the top three categories (see Table 1). Also, the nature of the categories and the fact that we did not collect information on a plant per plant basis, created gaps in information that would have been best to avoid. For instance, plants that had one stem with an average of 5–10 fruits would be categorized the same as a plant with numerous stems with an average of 5–10 fruits. We believe the categories we used and our definition of stem ended up making fruit production levels seem lower than they were in reality. Nonetheless, the categories still provided a relative comparison of fruiting and can serve as a starting point and baseline measure for future efforts. Before this study, the U.S. Forest Service captured photopoints at many of the different treatment locations. And, during our study, we continued this and captured around 100 photopoints throughout the study area. We intend for the photopoints to serve as a starting point for future studies and to help researchers be able to tell the story of huckleberry restoration through pictures as well as statistical analysis.

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