

Estimating Populations of Whitebark Pine in Mount Rainier National Park, Washington, Using Aerial Photography

Abstract

Whitebark pine abundance is declining in western North America due to white pine blister rust, fire exclusion, and mountain pine beetle. In this study, natural color aerial photograph (23 x 23 cm) negatives, scales between 1:2,000 and 1:6,000) were used to estimate whitebark pine abundance in Mount Rainier National Park. Ground truth field plots were similar to counts from aerial photographs (80.2% accuracy). Correlation analysis between subpopulation area and abundance was used to supplement incomplete aerial coverage and determine the final whitebark pine abundance in the Park. Whitebark pine density, and vegetation cover type, influenced counts from the aerial photographs. Highly clustered whitebark pine sites demonstrated 7% greater accuracy when compared to sites that exhibited little clustering. Count accuracy was 4-5% more accurate on whitebark pine dominant habitats compared to subalpine fir dominant and subalpine parkland habitat. The total number of living adult whitebark pine within park boundaries was ~22,000, with 3,160 adult trees found in the Sunrise region. Aerial photography holds promise as a way to inventory and monitor whitebark pine.

Introduction

Whitebark pine (*Pinus albicaulis* Engelm.) extends from the Sierra Nevada mountains north through the Cascade Mountains and west through the Rocky Mountains in the Intermountain West, United States and southern Canada (Arno and Hoff 1990, McCaughey and Schmidt 2001). In the Cascade Mountains, Washington, whitebark pine typically exists in isolated pockets 1700-2200 m elevation (Rocheft 1995), often as the dominant species on drier, high-elevation sites (Bedwell and Childs, 1943, Franklin and Dymess 1988, Arno and Hoff 1990). On more mesic sites, whitebark pine exists in mixed stands with subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) and Engelmann spruce (*Picea engelmannii* Parry), and is often out-competed by these more shade tolerant species (Arno and Hoff 1990). Mount Rainier National Park, Washington, contains 67 subpopulations of whitebark pine in five community types (Rocheft 1995) with the majority of trees located in the Sunrise area and eastward under drier climatic conditions (Figure 1). Whitebark pine communities were originally classified in 1935 from mountaintop surveys, and subsequent field surveys verified whitebark pine habitats (Rocheft 1995, and DelPrato 1999).

Whitebark pine populations are declining across North America (Arno 1986, Kendall and Arno 1990, Keane and Arno 1993, Kendall and Keane 2001) as a result of fire exclusion, insect outbreaks, and various fungal blights and rusts (Arno and Hoff 1990, Hoff and Hagle 1990, Keane and Arno 1993, Keane et al. 1994). White pine blister rust (*Cronartium ribicola* Fischer) is the most severe threat to whitebark pine in the Pacific Northwest (Rocheft 1995, DelPrato 1999). Blister rust is an exotic fungus that was introduced to British Columbia in 1910 (Hoff and Hagle 1990). The fungus spread rapidly to the Rocky Mountains. For example, Idaho cankers were dated as early as 1923 (Hoff and Hagle 1990), and throughout the Cascade Mountains between 1937 and 1939 (Bedwell and Childs 1943). In Mount Rainier National Park, 55% blister rust infection was recorded by 1951 (Gynn and Chapman 1951), increasing to 73% (of whitebark pine sample plots) by 1994 (Rocheft 1995). The future of the species within the park is in question (DelPrato 1999).

Aerial photography has been used to examine forest health (see Ciesla 2000 for recent review) including to estimate insect damage (Wear et al. 1966, Klein et al. 1978, Hostetler and Young 1979, Klein et al. 1980, Harris et al. 1983, Knepeck and Ahern 1989), successional status (Turner et al. 1996, Mast et al. 1997), foliar nutrient levels (Lyons and Buckner 1981), tree mortality (DeMars et al. 1982, Hamilton 1984), seedling abundance

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(Smith et al. 1986), and species distribution (Needham and Smith 1987). Aerial photographs of 1:20,000 (or 1:24,000) scale are sufficiently detailed to document vegetation cover and major differences in vegetation types (Turner et al. 1996, Mast et al. 1997). Larger-scale photographs are required to observe more detailed features such as tree abundance and foliar damage (Hamilton 1984, Needham and Smith 1987, Warner and Fry 1990). An assessment of mountain pine beetle-related mortality in British Columbia incorporated 70 mm aerial photographs at 1:6,000 scale. On average, 62% and 72% accuracy were determined in comparing ground with aerial photographic estimates (Harris et al. 1983). Mapping pine mortality from southern pine beetle with aerial photographs between 1:4,000 and 1:8,000 scale was 70% accurate and an acceptable form of risk assessment in Umstead State Park, North Carolina (DeMars et al. 1982). Most whitebark pine sites in the Cascade Mountains of Washington have relatively open canopies allowing the potential identification of individuals from aerial photographs.

In this study, aerial photographs were used to document whitebark pine populations in Mount Rainier National Park. Whitebark pine has experienced between 21% and 90% mortality in Mount Rainier due to white pine blister rust infection over the last 50 yr (DelPrato 1999). Previous field sampling documented changes due to blister rust in whitebark pine demography on a subpopulation basis (Rocheftort 1995, DelPrato 1999). We use aerial photographs to estimate whitebark pine populations in Mount Rainier National Park. Data from this study were used to initialize subpopulations of a spatially explicit metapopulation model to conduct a risk assessment of whitebark pine in Mount Rainier National Park (Cottone 2001).

Methods

Normal color aerial photographs (23 x 23 cm negatives) were taken in the summer of 1984 to document impacts of elk (*Cervus elaphus* Erxleben) in subalpine habitats in Mount Rainier National Park (Ripple et al. 1986). The scale ranged from 1:1,538 to 1:6,253 (mean=1:3,150). Large-scale (1:2,500) photographs were used to estimate population abundance in most cases, with lower scale photographs (1:6,000) used for orientation and habitat delineation. Full aerial coverage was

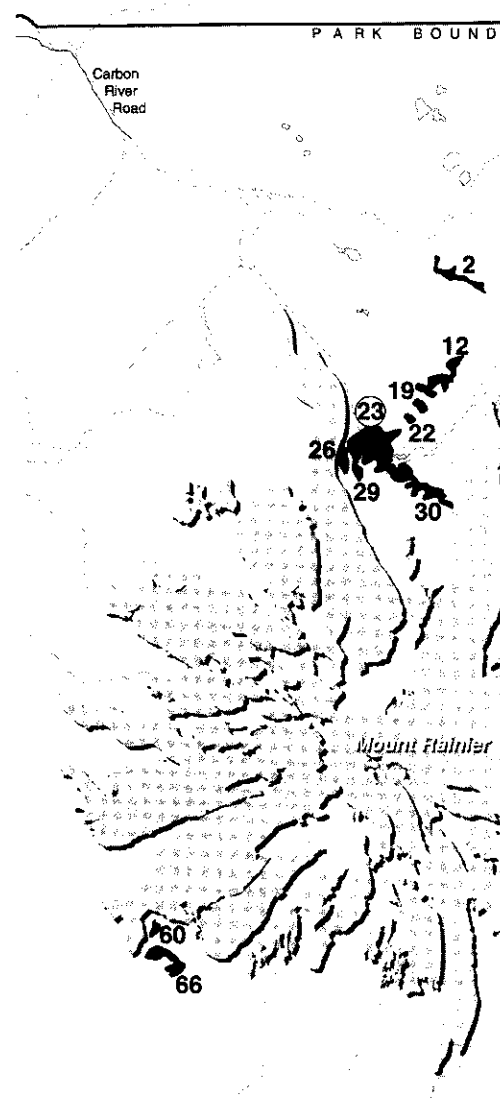


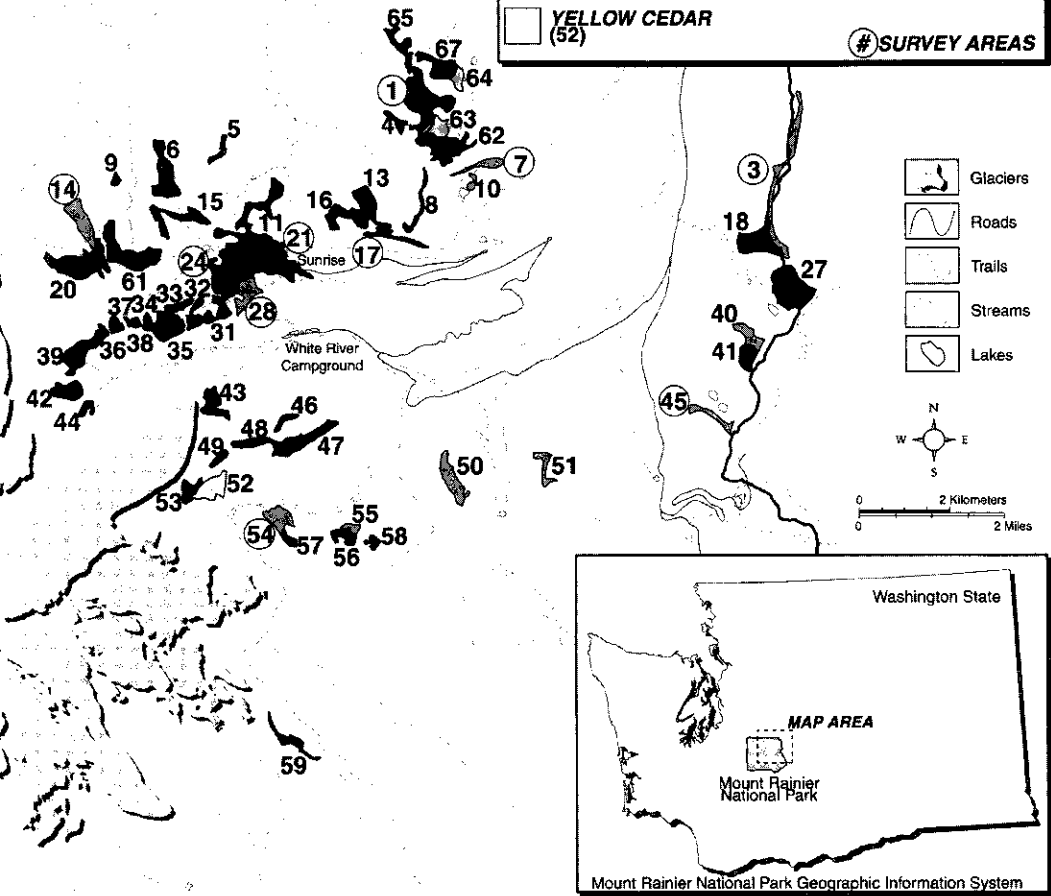
Figure 1. The distribution of

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Whitebark Pine Areas

- SUBALPINE FIR**
(13, 18, 21, 23, 27, 31, 35, 41, 43, 47, 49, 53, 59, 62, 65)
- SUBALPINE PARKLAND**
(1, 2, 4, 5, 6, 8, 9, 11, 12, 15, 16, 17, 19, 20, 22, 24, 26, 29, 30, 32, 33, 34, 36, 37, 38, 39, 42, 44, 46, 48, 56, 57, 58, 60, 61, 66, 67)
- WHITEBARK PINE DOMINANT**
(3, 7, 10, 14, 28, 40, 45, 50, 51, 54, 55)
- HEMLOCK DOMINANT**
(63, 64)
- YELLOW CEDAR**
(52)

SURVEY AREAS



whitebark pine in Mount Rainier National Park, including dominant vegetation type for each site.

not available, so whitebark pine were counted on 41 of 67 subpopulations (Figure 1). Systematic counts of whitebark pine were conducted in 2000 by first organizing all aerial photographs pertaining to a particular subpopulation, then drawing the border of the subpopulation directly on overlying transparent acetate sheets. Monoscopic analysis of photographs was possible because whitebark pine were readily identified on high quality, large scale photographs. The largest scale photo with the greatest contrast between subalpine fir and whitebark pine leaf color was chosen for counting where aerial photographs overlapped. In some cases, several photographs were incorporated to count trees in one subpopulation. Also, overlapping photos were used to interpret problem regions of high density because variation in shadow was a key factor in counting error.

Within each aerial photograph, 5 cm x 5 cm regions (~1 ha) were counted. This region was then compared to other photographs of the same area if they existed, and any discrepancies were resolved. Whitebark pine has been observed within the Park within five broadly classified habitat domains: 1) subalpine parkland (defined as mixed subalpine forest and meadow habitat below treeline), 2) subalpine fir dominant, 3) whitebark pine dominant, 4) mountain hemlock (*Tsuga mertensiana* [Bong.] Carr.) dominant, and 5) yellow cedar (*Chamaecyparis nootkatensis* [D. Don] Spach) dominant (Figure 1). Subalpine fir was the dominant tree species on most sites. Of the 67 subpopulations, 37 were subalpine parkland, 16 were subalpine fir dominant, and 11 sites were classified as whitebark pine dominant. Within the park, most of these subalpine parkland regions are also dominated by subalpine fir, differing with subalpine fir dominant habitats typically by overall tree density. Accurate estimates of whitebark pine depend on the ability to distinguish subalpine fir from whitebark pine individuals. The spire-shaped shadow cast by a subalpine fir was easy to distinguish from the rounder, broad shadow cast by whitebark pine.

Whitebark pine counts from aerial photographs were verified in the field. Field plots were established on 23 different subpopulations (67 total plots) to compare with aerial photograph counts. Whitebark pine is often found on steep inaccessible slopes, many of which are only accessible by helicopter, and therefore plots were not determined randomly. As a result, a larger number of

field plots were established on subalpine fir dominant and subalpine parkland sites that are near trails. Plots were located near distinguishing landscape features (trails and rock formations) for reference on photos, and plot size varied according to the location of these features. Plots ranged from 0.02 ha to 1 ha in size with an average plot size of 0.2 ha. A range finder (Bushnell Yardage Pro 500, 1 m accuracy), transect tape (to verify range finder measurements), and compass were used to establish plots. Adult whitebark pine in each photograph were tallied, and checked by physically walking through the plot or using binoculars when terrain was difficult to traverse. Sample plots were walked on all but three of the 23 subpopulations, which accounted for 15% of the ground truth plots in total. One factor ANOVA or two-tailed independent *t*-tests (assuming unequal variance) were used to compare differences in count accuracy between aerial photographs and field counts for differences in whitebark pine density, field plot size, photographic scale, and habitat type (Zar 1999). The significance level was chosen at 5%.

Only living whitebark pine reproductive adults were counted in the aerial photographs. Species of dead trees were difficult to identify from aerial photographs because loss of foliage alters crown shadows. Similarly, non-reproductive adults, saplings, and seedlings were not counted because shadows were difficult to discern. Based on previous field observations of cone production (DelPrato 1999), non-reproductive adults were defined as trees with a diameter at breast height < 10 cm but height > 2 m. Any living adult of bole width > 10 cm was included in the ground tallies. On some treeline sites with particularly steep terrain, whitebark pine grows in a shrub-like krummholz form (Clausen 1965). In this case, adults were distinguished from saplings in the field based on number of annual whorls. Although krummholz adults are similar in size to saplings, they often grow in low densities on steep ledges, making them conspicuous in the aerial photographs. In this case, abundance could be estimated without shadow cast. The area of each site was determined from topographic layers in the Mount Rainier National Park GIS database (Darin Swinney, Geographer/GIS Specialist, Mount Rainier National Park, Longmire, Washington, personal communication). The photographic coverage was overlain on top of a topographic map of whitebark pine sites.

On sites lacking aerial coverage, the total number of whitebark pine was estimated from final counts on sites with coverage and total site area. Whitebark pine subpopulation counts are highly correlated with site area ($r=0.88$, Figure 2). The number of whitebark pine was interpolated from the size of the site in hectares on those sites with only partial aerial coverage or no aerial coverage. We explored the possibility that different relationships existed among vegetation types (e.g., subalpine parkland vegetation was represented by a different correlation from subalpine fir dominant vegetation). However the population-area relationships were not improved by sorting sites into habitat type. The outcome from the correlation analysis (using all data points) was therefore used to predict the number of whitebark pine on sites with no aerial coverage. On the sites with partial aerial coverage, whitebark pine was counted, and the remaining area outside the photograph, was determined from topographic data layers in the Mount Rainier National Park GIS database.

The percent area outside of the photograph was multiplied by the total number of trees counted and the result was added to the original aerial counts of the partially covered site. This method allowed for partial coverage of a site to be directly influenced by total coverage, rather than relying upon interpolation from correlation.

Results

There are ~22,000 living adult whitebark pine in Mount Rainier National Park. The largest cluster of whitebark pine was in the Sunrise area (3160 total: Site 21 = 2,055, Site 24 = 425, and Site 28 = 680). Most of the whitebark pine are located within subalpine fir dominated habitat and subalpine parkland (Table 1). Whitebark pine dominant habitat typically has lower tree density. Of the 21,764 adults counted, 10,412 reside in subalpine parkland 7,840 in subalpine fir dominant habitat, and 2,813 in whitebark pine dominant habitat. Most accessible whitebark pine dominant

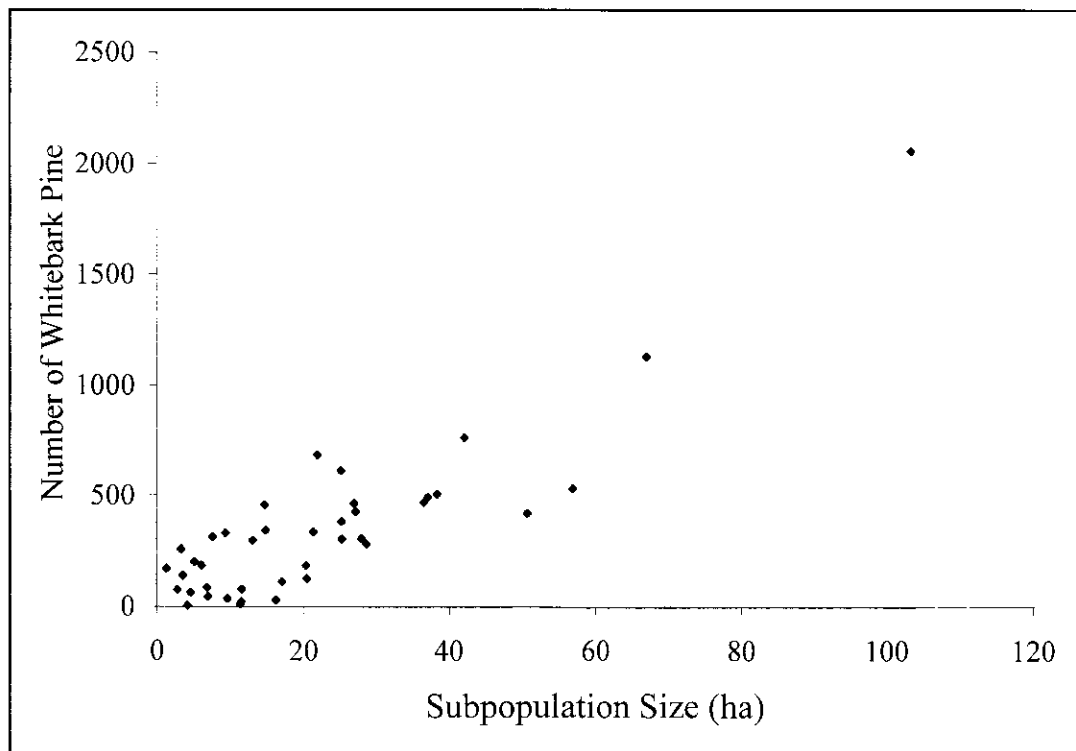


Figure 2. Correlation between whitebark pine abundance and subpopulation size derived from 37 of 67 subpopulations with aerial coverage. This correlation was used to determine abundance on subpopulations without aerial coverage.

TABLE 1. Whitebark pine suitable habitat within Mount Rainier National Park including dominant vegetation type, polygon size, and aerial coverage. Aerial coverage was used to determine number of adults on the site, and accuracy was verified using ground plots.

Polygon no.	Habitat type	Area (ha)	Coverage	Adults	# Ground plots	% Accuracy
63	Hemlock dominant	13.30	None	193		
64	Hemlock dominant	8.82	None	126		
13	Subalpine fir dominant	23.49	None	346		
18	Subalpine fir dominant	37.71	None	559		
21	Subalpine fir dominant	103.22	Full	2055	13	81.2
23	Subalpine fir dominant	66.97	Partial	1127		
25	Subalpine fir dominant	9.75	Full	35	1	53.8
27	Subalpine fir dominant	57.58	None	858		
31	Subalpine fir dominant	26.90	Full	461	4	85.9
35	Subalpine fir dominant	27.99	Full	305		
41	Subalpine fir dominant	16.29	Partial	27		
43	Subalpine fir dominant	20.51	Partial	125		
47	Subalpine fir dominant	34.52	None	512		
49	Subalpine fir dominant	5.55	None	76		
53	Subalpine fir dominant	13.12	Partial	296		
59	Subalpine fir dominant	15.19	None	221		
62	Subalpine fir dominant	43.74	None	650		
65	Subalpine fir dominant	12.94	None	187		
1	Subalpine parkland	66.91	None	998		
2	Subalpine parkland	14.75	Full	454		
4	Subalpine parkland	7.45	None	105		
5	Subalpine parkland	7.04	Full	44		
6	Subalpine parkland	38.26	Full	504	2	79.4
8	Subalpine parkland	11.50	Partial	11		
9	Subalpine parkland	3.55	Full	139		
11	Subalpine parkland	42.03	Full	761	3	79.6
12	Subalpine parkland	25.08	Full	610		
15	Subalpine parkland	25.30	Full	302	4	81.8
16	Subalpine parkland	24.29	None	358		
17	Subalpine parkland	17.10	Partial	110	2	88.8
19	Subalpine parkland	5.21	Full	198		
20	Subalpine parkland	56.86	Partial	530	2	64.7
22	Subalpine parkland	2.84	Full	74		
24	Subalpine parkland	27.08	Full	425	2	73.0
26	Subalpine parkland	9.49	Partial	328		
29	Subalpine parkland	6.17	Full	184		
30	Subalpine parkland	36.47	Full	466		
32	Subalpine parkland	4.67	Full	63	2	85.1
33	Subalpine parkland	14.89	Full	340	3	74.3
34	Subalpine parkland	3.64	Full	137	1	77.1
36	Subalpine parkland	7.67	Full	312	4	87.2
37	Subalpine parkland	1.36	Full	169	2	83.5
38	Subalpine parkland	3.36	Full	256	4	76.4
39	Subalpine parkland	36.97	Full	490	4	81.8
42	Subalpine parkland	20.45	Full	183	2	63.4
44	Subalpine parkland	6.94	Full	83	1	100
46	Subalpine parkland	6.46	None	90		
48	Subalpine parkland	12.35	None	179		
56	Subalpine parkland	12.21	None	176		
57	Subalpine parkland	6.12	None	85		

Continued, next page

TABLE 1, continued.

Polygon no.	Habitat type	Area (ha)	Coverage	Adults	# Ground plots	% Accuracy
58	Subalpine parkland	5.41	None	74		
60	Subalpine parkland	4.30	None	58		
61	Subalpine parkland	50.64	Full	419	3	71.7
66	Subalpine parkland	21.36	Partial	334		
67	Subalpine parkland	24.66	None	363		
3	Whitebark pine dominant	39.11	None	580		
7	Whitebark pine dominant	11.65	Partial	21		
10	Whitebark pine dominant	4.23	Full	4	1	75.0
14	Whitebark pine dominant	28.64	Partial	280	3	85.2
28	Whitebark pine dominant	21.89	Partial	680	3	85.0
40	Whitebark pine dominant	15.91	None	232		
45	Whitebark pine dominant	11.67	Partial	76	1	88.5
50	Whitebark pine dominant	27.13	None	400		
51	Whitebark pine dominant	11.33	None	163		
54	Whitebark pine dominant	20.61	None	303		
55	Whitebark pine dominant	5.39	None	74		
52	Yellowcedar dominant	25.20	Partial	380		
Total		1431.19		21764 ¹	67	80.2 ²

¹21,764 accounts for the total number of live mature adults, excluding seedlings and saplings that were not consistently visible on aerial photographs.

²The total average accuracy of all ground plots calculated separately was 80.2%.

habitat (four of six sites), however, was reclassified as subalpine fir dominant in 1998 (DelPrato 1999), suggesting there may be a recent decrease in the amount of whitebark pine dominant habitat in the park.

Whitebark pine grow as both solitary individuals and in clusters of two to five individuals (Tomback 1982, Arno and Hoff 1990), so that aerial counts would be expected to underestimate whitebark pine abundance. In fact, 87% of the ground truth plots yielded a higher ground tally of whitebark pine than those determined through aerial photography. This occurs because successful whitebark pine establishment depends on Clark's nutcracker (Hutchins and Lanner 1982) which caches on average three to four seeds at a time (Tomback 1978). However, aerial photograph counts were similar to ground counts, 80.2% average accuracy. We found no significant difference in aerial photograph and field count accuracy when comparing whitebark pine density ($>$ or ≤ 1 whitebark pine/0.01 ha), field plot size ($>$ or ≤ 0.1 ha plots) photographic scale of aerial photographs (comparing 1:6,000, 1:3,000 and 1:2,000), or among habitat types (subalpine fir dominant, subalpine parkland, and whitebark pine dominant).

Discussion

Aerial photography is an excellent tool for rapid assessment of whitebark pine abundance at the 1:6,000 scale, providing managers with a means of quickly estimating whitebark pine populations, including spatial orientation, to determine regions to concentrate field surveys. Whitebark pine grows on steep slopes that retain snowpack through most of the summer, making many sites inaccessible. The total abundance in the Park across 67 sites, which total 1431 ha, was estimated relatively quickly in comparison to a complete field survey. The majority of the time was spent in the field constructing ground truth plots as opposed to counting trees in the aerial photographs. We believe that the techniques we describe will apply well to other locations (e.g., throughout the Intermountain West), because whitebark pine is typically found in open sites, where we experienced nominally higher accuracy. This technique also holds potential as a long-term monitoring tool.

The level of acceptable count accuracy is specific to the goals of the study, but when viewing infected trees in pest studies, levels as low as 62% have been determined sufficient (DeMars et al.

1982, Harris et al. 1983, Needham and Smith 1987, Warner and Fry 1990). We believe that the 80% accuracy of whitebark pine tallies from aerial photographs, when compared with ground counts, is sufficient to estimate the population of whitebark pine within Mount Rainier National Park. For our purposes, it is reassuring that 87% of the aerial counts underestimated actual abundance (determined from ground truth plots), because estimates from this paper are being used to initialize whitebark pine populations in a spatially explicit metapopulation model (Cottone 2001). In risk assessment, we believe it is better to overestimate extinction probabilities so that more definitive action will be taken hastily to ensure the viability of the species in the future.

Several obstacles were encountered when counting whitebark pine from aerial photographs. Stand density was higher on subalpine fir dominant sites, causing difficulty in determining the number of whitebark pine on photographs because some trees were below canopy level. However count accuracy was indistinguishable between subalpine fir dominant sites and more open subalpine parkland sites. Gains in accuracy by counting a more vacant stand are offset by the larger plot size we constructed on more open sites, because large plot size demonstrates marginally lower accuracy (vegetation plots < 0.1 ha are 5% more accurate than plots > 0.1 ha, but the estimates are not significantly different). Lower canopy visibility (whitebark pine being partially excluded from the canopy by taller subalpine fir) also explains why 87% of the 67 subpopulations ground checked displayed larger ground abundance counts than aerial counts. All photograph scales were relatively large, and therefore small changes in scale between 1:6,000 and 1:2,000 did not affect accuracy.

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Whitebark pine were counted from photos without the assistance of a stereoscope reducing our overall accuracy and ability to document mortality. The 80% accuracy among ground and aerial photograph counts suggests that non-stereo 1:6,000 scale photographs are sufficient to distinguish whitebark pine from subalpine fir. It should also be noted that our field counts occurred in the summer of 2000, 16 years after the aerial photographs were originally taken. A portion of our error in reconciling ground counts with the aerial photo counts is likely attributable to this time lag. We believe that our 2000 counts are similar to the counts from 1984 photos, because whitebark pine is a long-lived, slow-growing species and therefore differences in the number of adult trees during the intervening 16 yr were minimal. Color aerial photographs at 1:2,000 scales were not adequate when counting seedlings, saplings, and non-reproductive adults, however stereoscopic viewing may allow smaller individuals to be distinguished. The photographs yielded an estimate for living adults, but estimate mortality poorly since it was impossible to distinguish the species of dead trees. Although living adults were counted, the resolution was also too weak to discern various stages of fungal infection.

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