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Estimation Procedures for the Combined 1990s Periodic Forest Inventories of California, Oregon, and Washington

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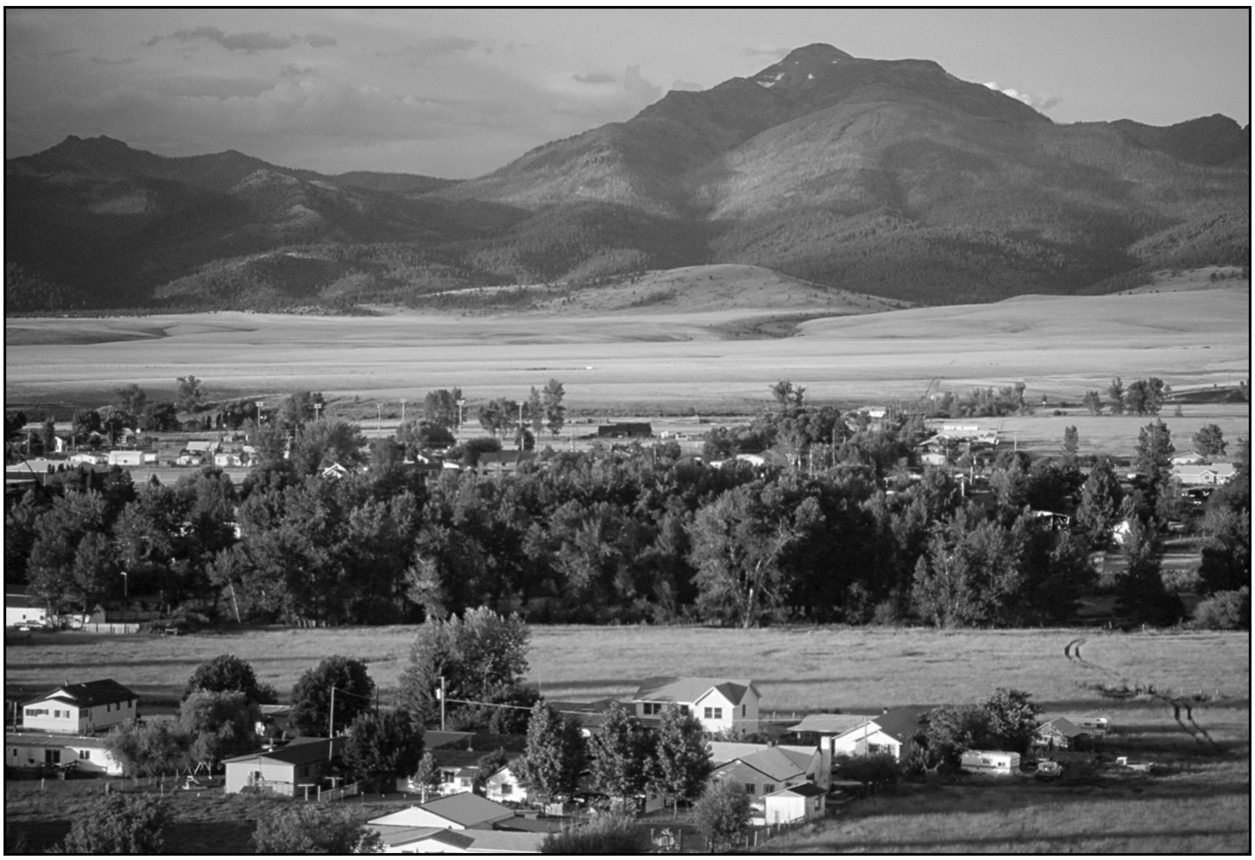

Errata: the equation 13 on page 15 and equation 14 on page 16 have been corrected (7/8/04).

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Abstract

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During the 1990s, forest inventories for California, Oregon, and Washington were conducted by different agencies using different methods. The Pacific Northwest Research Station Forest Inventory and Analysis program recently integrated these inventories into a single database. This document briefly describes potential statistical methods for estimating population totals, means, and associated sampling errors for these inventories. Differences in estimates using past methods for periodic inventories compared to estimates from proposed methods for a new annual inventory system were generally minor. This document is intended to be a resource for researchers using the 1990s forest inventory data for these states; examples are included to illustrate issues.

Keywords: Forest inventory, double sampling for stratification, west coast forests.

Contents

Introduction

Since 1928, assessment and monitoring of the Nation's forest ecosystems have been provided by the Forest Inventory and Analysis (FIA) program, part of the research branch of the Forest Service. In recent years, the program has been transitioning from a system of periodic inventories to an annualized system (Gillespie 1999). As one of the five regional FIA programs undergoing this transition, the Pacific Northwest Forest Inventory and Analysis (PNW-FIA) program now measures 10 percent of plots each year and plans to complete a full set of plot measurements for Oregon, California, and Washington in 2010, 2011, and 2012, respectively. In this annual system, a full set of remeasured plots is planned to be completed for these three states in 2020, 2021, and 2022.

The "integrated database" (IDB) produced by PNW-FIA combines recent (1990s) periodic inventories for Oregon, California, and Washington (Waddell and Hiserote 2003). Until sufficient annual data are available, it is expected that this database will be a primary resource for forest inventory information in these three states.

This document provides a brief overview of the sampling procedures for four of the periodic inventories in the integrated database. For each inventory, it describes methods for providing estimates of population means, population totals, and associated sampling errors. Where different methods were considered for use with the integrated database, these are described and discussed. A much more detailed discussion of FIA estimation procedures for the annual inventory is presented in Bechtold and Patterson (in press). This document is only intended to provide a supplementary description for the 1990s periodic inventories of California, Oregon, and Washington.

The four inventories described in this document are:

- The 1991-94 FIA inventory of California, unreserved timberland and unproductive forest land outside national forests.
- The 1991-94 FIA special woodland inventory of California, outside national forest.
- The 1995-2000 Pacific Southwest Region inventory of California, national forests lands.
- The 1993-97 Pacific Northwest Region inventory of Oregon and Washington, national forest land.

The IDB (Waddell and Hiserote 2003) also contains inventories of Bureau of Land Management forest lands and periodic FIA inventories of Oregon and Washington. Because the periodic FIA inventories of Oregon and Washington are extremely similar to those of California, they are not described here.

The 1991-94 FIA Inventory of Unreserved Forest Land in California Outside National Forests

Sampling Design

The initial population was considered to be land area as defined by the USDC Bureau of the Census. The Bureau provided land area estimates by county. The population was further limited to be land (1) outside national forest boundaries and (2) unreserved from timber production. As examples, this excluded land such as national parks or land managed for municipal water reservoirs.

Estimates are typically only provided for areas:

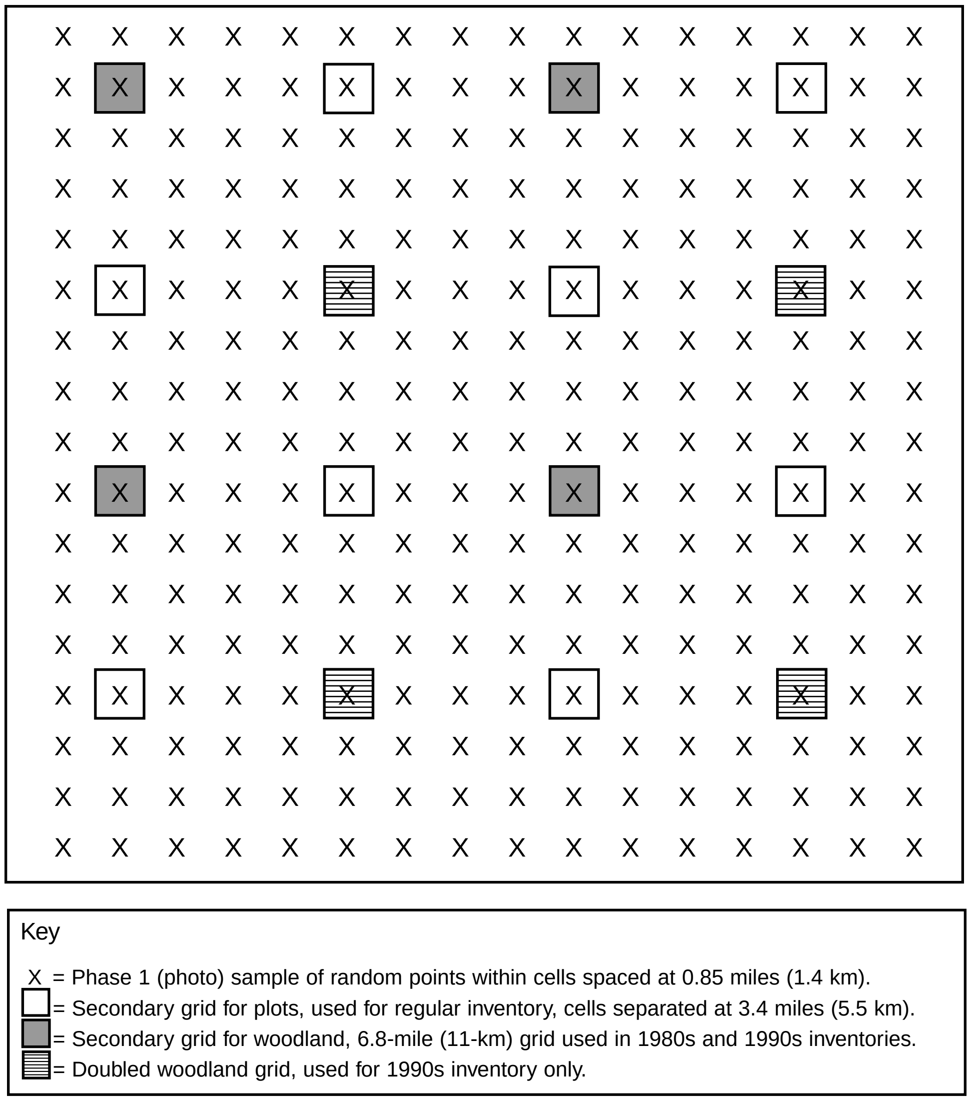
- That were forest land, which is defined as land that is at least 10 percent stocked (or capable of being 10 percent stocked) with trees. In practice, some hardwood species do not have stocking rules, so this was translated as at least 10 percent canopy cover. Forest land had to be at least 1 acre in size and 115 feet wide.
- That were devoted to forest uses. Examples of nonforest uses include urban parks, tree farms, and golf courses.

The sampling procedure was double sampling for stratification similar to that described by Cochran (1977). The phase 1 sampling units were photointerpreted 6.2-ac (2.5-ha) circular plots, each randomly located within a 0.85-mile square grid cell (fig. 1). Interpreters classified each plot into one of a number of classes that can be used for stratification. Typically these classes are combined with county and broad ownership classes to create more detailed strata. Current recommendations by the national FIA program are that a minimum of four plots be present in each stratum.

The phase 2 (field) sampling of plots consisted of those plots from the phase 1 sample (air photos) that fell in a 3.4-mile grid, resulting in approximately one phase 2 plot per 7,400 acres. Although the sampled population is all land excluding census water, in practice, the typical attributes of interest occur on forest land. An additional photointerpretation process was used for plots on the phase 2 sampling grid to determine whether or not they had any forest. Completely nonforest plots (for example, in water, urban, or rocky areas) were not visited. When there was some doubt as to whether a phase 2 plot was forest, it was visited by a field crew.

Ownership for plots was determined through county records or other ancillary information, and permission for access was obtained before field visits. Field plots were a 5-point cluster of subplots within a larger 6.2-acre plot (fig. 2). Each subplot was bounded by a circle with a 56-foot fixed radius, within which large trees were sampled by variable-radius sampling and smaller trees sampled on smaller fixed-radius plots. Subplots were mapped by “condition class,” or differences in broad forest type, stand size, stocking density, or cutting history. Many of the values shown in FIA reports—for example, land area by forest type—are calculated by using the proportion of plot area in a particular condition class.

Historically, FIA periodic inventories measured trees within timberland condition classes (land capable of producing at least 20 cubic feet per acre per year of timber volume at culmination of mean annual increment). Measurement of trees in lower site forest land, such as juniper or oak woodlands, has differed for inventories done at



For 1990s inventory, woodland plots spaced at $(3.4^2 + 3.4^2)^{0.5}$ = 4.8 miles (1.4 km).

Phase 1 (photointerpreted) plots: 462 ac/plot (187 ha/plot).
Secondary sample plots, regular inventory: 7,398 ac/plot (2994 ha/plot).
Secondary sample plots, 1980s woodland inventory: 29,594 ac/plot (11 976 ha/plot).
Secondary sample plots, 1990s woodland inventory: 14,795 ac/plot (5987 ha/plot).

Figure 1—Example of phase 1 and phase 2 samples for special hardwood and regular periodic 1991-94 FIA inventories of California, unreserved nonfederal lands.

different times or for different regions. For example, in California for the 1991-94 inventory, oak woodland condition classes were mapped for all plots, but trees in these woodland condition classes were only measured as part of a special “hardwood woodland” inventory on half of the field plots. Thus the regular inventory can be used to develop an estimate of woodland area, but cannot be used to estimate volume or other woodland attributes calculated from tree measurements.

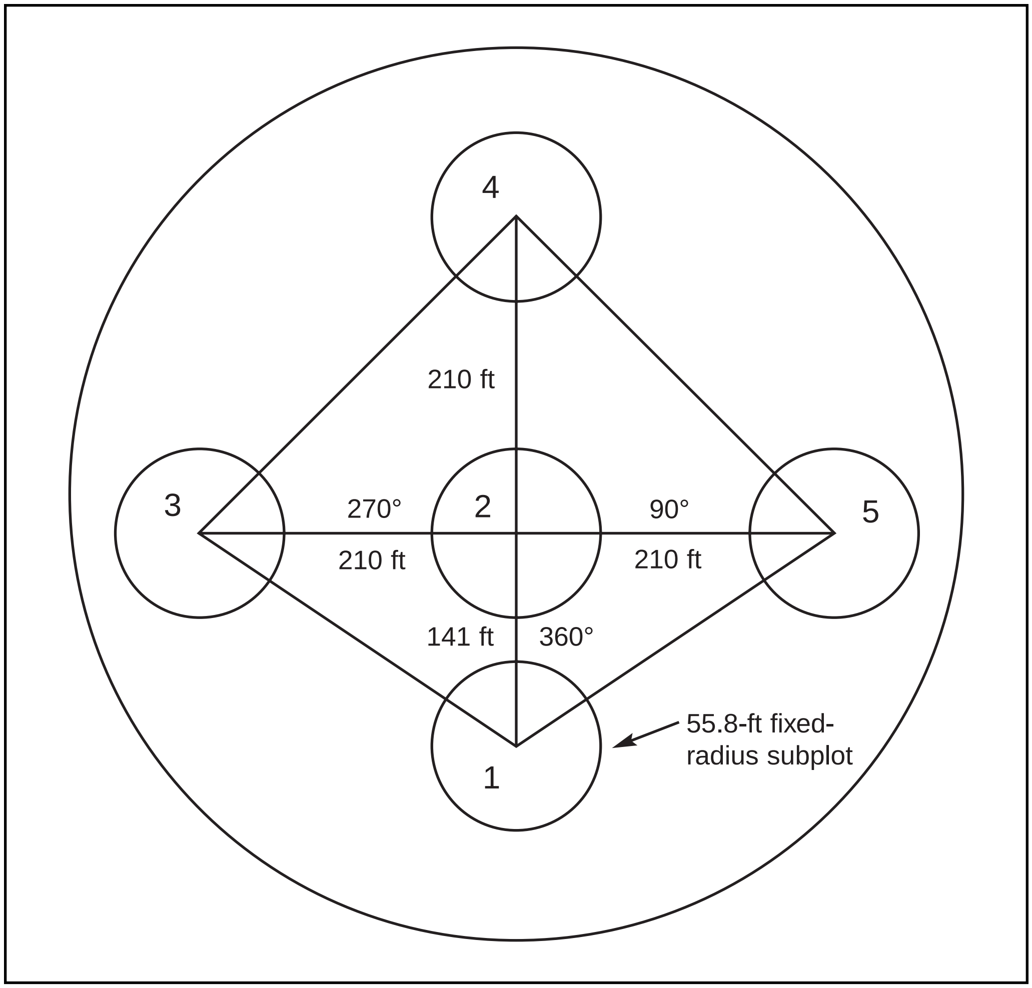


Figure 2—The FIA 1991-94 design for California consisted of a cluster of five subplots within a larger 6.2-acre plot used for the sampling unit.

Results of the California 1990s inventories were presented in a series of "Timber Resource Statistics" bulletins for different resource areas in California, such as for the northern interior region (Waddell and Bassett 1997). Details such as volume equations, site index equations, and calculations of growth and mortality, can be found in the techniques documentation developed at that time. For more information on field measurements, photointerpretation, or calculated variables, respectively, refer to the field manual (USDA FS 1992), the photointerpretation manual (USDA FS 1993), or the techniques documentation (Waddell 1991).

Estimation

Two methods of calculating estimates and sampling error for this inventory are discussed. These are the PNW-FIA method for periodic inventories (Bednar 2000) and the national FIA method, which will be used for the annual inventory (Bechtold and Patterson, in press). The PNW-FIA periodic inventory method was most recently implemented for the eastern and western Oregon inventories (Azuma et al. 2002a, 2002b) and is coded as a SAS (SAS Institute 1985) program; the 1988-91 Washington inventories and the 1991-94 California inventories also used double sampling for stratification and the same equations as presented here, but compilation was done with a national software program that is no longer used.

PNW-FIA periodic method—The sampling unit was defined as the 6.2-acre area used in the phase 2 sample of air-photo plots, shown as the outer circle in figure 2. Variables used in the calculations:

A_T = Total area in the population in acres

a = Sampling unit (plot) area

∂_{hi} = Area of plot i in stratum h that is accessible and in the population

$\O_{hic}$ = Area of plot i in stratum h that is in condition c

N = Number of sampling units in the population; calculated as A_T/a

n' = Number of phase 1 (photo) plots sampled

n = Number of phase 2 (field) plots sampled

H = Number of strata

h = Stratum index, $h = 1 \ldots H$

n'_h = Number of phase 1 (photo) plots classified as stratum h ($h = 1 \ldots H$, H = total number of strata)

n_h = Number of field plots with phase 1 assignments to stratum h

w_h = Weight for stratum h, that is, the proportion of the population that is in stratum h; calculated as n'_h/n'

N_h = Number of sampling units in stratum h in the population; calculated as Nw_h

W_h = Weight for stratum h when the area in the stratum is assumed to be known; typically derived from remote sensing data

i = Plot index, $i = 1 \ldots n_h$

Attributes of interest such as forest-type area, volume, or number of trees can be expressed as individual plot values. More detailed descriptions of how plot-level attributes are calculated can be found in the documents cited above. Let

P_{hi} = area of interest for plot i in stratum h (for example, plot area in a Douglas-fir forest type).

Average plot value within a stratum is then estimated as:

$$\hat{\bar{P}}_h = \frac{1}{n_h} \sum_i P_{hi} \quad , \tag{1}$$

with estimated variance:

$$\mathrm{var}(\hat{\bar{P}}_h) = S_h^2 / n_h = \sum_i \frac{\left[P_{hi} - \hat{\bar{P}}_h\right]^2}{n_h(n_h - 1)} = \frac{\sum_i P_{hi}^2 - \frac{\left[\sum_i P_{hi}\right]^2}{n_h}}{n_h(n_h - 1)} \quad . \tag{2}$$

Total within a stratum is estimated as:

$$\hat{P}_h = \frac{N_h}{n_h} \sum_i P_{hi} = N_h \hat{\bar{P}}_h \quad . \tag{3}$$

Average across the population is estimated as a weighted average of the individual stratum means:

$$\hat{\bar{P}} = \sum_h w_h \hat{\bar{P}}_h \quad . \tag{4}$$

Total across the population is then estimated as:

$$\hat{P} = N \hat{\bar{P}} \quad . \tag{5}$$

Variance of the average is estimated by using Cochran (1977) eq. 12.24:

$$\mathrm{var}(\hat{\bar{P}}) = \sum_h w_h \left[\frac{\sum_i \left[P_{hi} - \hat{\bar{P}}_h\right]^2}{n_h - 1}\right]\left[\frac{n'_h}{n' n_h} - \frac{1}{N}\right] + \frac{N - n'}{n'(N-1)} \sum_h w_h \left[\hat{\bar{P}}_h - \hat{\bar{P}}\right]^2 \quad , \tag{6}$$

and variance of the total is estimated as

$$\mathrm{var}(\hat{P}) = N^2\, \mathrm{var}(\hat{\bar{P}}) \quad . \tag{7}$$

National FIA method for the annual inventory—In response to the 1998 farm bill, the FIA program developed a national estimation procedure that will be used to compile annual inventory data (Bechtold and Patterson, in press). Slight differences exist from the estimation procedures described above. These differences are:

1. Definition of the sampling unit. One alternative that was considered during the development of the annual inventory was to view the sampling unit as the cluster of the subplots rather than the encompassing circle used in photointerpretation. This redefinition may be in part a consequence of increasing use of remote sensing data for stratification in place of aerial photography. For the California FIA inventory, this means that the plot area (*a*) would be 1.12 acres (the total area for the five subplots) instead of the 6.2-acre photo plot area (fig. 2). Variables such as N and N_h would change accordingly.

Table 1—Sampling error for different sampling units and variance equations

	Original PNW-FIA; sampling unit is bounding circle, no finite population correction			Sampling unit is summed subplots, no finite population correction	Sampling unit is summed subplots, with finite population correction
	Timberland	Samp. error	Samp. error	Samp. error	Samp. error
Eastern Oregon	- - - - - - - - *Acres* - - - - - - - -		- - - - - - - - - - - - - - - - *Percent* - - - - - - - - - - - - - -		
BLM	144,014	24,076	16.72	16.73	16.69
County-municipal	4,028	4,030	100.04	100.07	99.99
Forest industry	1,603,747	75,625	4.72	4.72	4.71
Other private	1,097,920	71,399	6.50	6.51	6.50
State	88,389	24,132	27.30	27.31	27.28
All	2,938,097	77,058	2.62	2.63	2.62
Western Oregon					
County-municipal	104,588	28,439	27.19	27.20	27.12
Forest industry	4,177,446	88,041	2.11	2.11	2.10
Other federal	6,655	5,445	81.81	81.84	81.71
Other private	1,881,766	80,285	4.27	4.27	4.26
State	739,171	51,794	7.01	7.01	6.99
All	6,909,625	77,285	1.12	1.12	1.12

It was expected that this difference would result in a small increase for estimated sampling error. The effect of this change in sampling unit area was calculated for the western Oregon inventory with the result that estimated sampling error increased by less than one-tenth of one percent for typical estimates (table 1).

A second alternative considered for the annual inventory sampling unit is the center point for the central subplot. At the time this document was written, this alternative, with the added dimension of time, appeared to be the most likely to be adopted as the national paradigm. With point sampling, the size of a population is no longer finite. However, because the standard error method used by PNW-FIA (equation [6]) for past periodic inventories did not include a finite population correction, the standard error calculation in the national method is actually the same as what has been used by PNW-FIA in the past.

For a finite population, Cochran (1977) replaces equation 12.24 with the unbiased version, equation 12.32. Using our notation, equation (6) above is changed to:

$$\mathrm{var}(\hat{P}) = \frac{1}{N}\left\{(N-1)\sum_h w_h \left[\frac{\sum_i \left[P_{hi} - \hat{P}_h\right]^2}{n_h\,(n_h - 1)}\right]\left[\frac{n'_h - 1}{n' - 1} - \frac{n_h - 1}{N - 1}\right] + \frac{N - n'}{n' - 1}\sum_h w_h \left[\hat{P}_h - \hat{P}\right]^2\right\} \qquad (6')$$

Because 1/*N* and 1/*n*' are usually very close to zero, it is expected that there will be little difference between (6) and (6'). This was tested for the inventory of western Oregon; decreases for typical estimates of standard errors were on the order of one-tenth of one percent (table 1). Because the finite population correction factor has no noticeable effect, equations (6) and (6') appear to be equivalent for estimating standard errors for the FIA inventories in the integrated database.

2. Slight differences in presentation exist between the most recent draft of the national estimation document (Bechtold and Patterson, in press) and the notation used here. Equations in that document are presented with the variable of interest (*P*) representing proportion of the plot in the area of interest, and population area (*A*) replacing population number (*N*) in equations, as appropriate.

3. The national design explicitly describes a method to adjust for:

- Plots that are partially out of the population because of: (1) international boundary, (2) ownership boundary that defines a different population (for example, national forest boundaries in the California FIA 1991-94 inventory), or (3) census water.
- Whole or partial plots that were not measured (that is, access denied, data lost, or hazardous).

This method adjusts estimates by a factor representing the average percentage of mapped plot area within the stratum:

$$\bar{\pi}_h = \frac{\sum_i \partial_{hi}}{n_h a}$$

where the numerator is the total summed plot area in the stratum that was accessible and in the population, and the denominator is the area of a plot times the number of plots.

Equations (1) and (2) are changed to:

$$\hat{\bar{P}}_h = \frac{1}{\bar{\pi}_h n_h} \sum_i P_{hi} \qquad (1')$$

with estimated variance:

$$\mathrm{var}(\hat{\bar{P}}_h) = \frac{1}{\bar{\pi}_h^2} \frac{S_h^2}{n_h} = \sum_i \frac{\left[P_{hi} - \hat{\bar{P}}_h\right]^2}{\bar{\pi}_h^2 n_h (n_h - 1)} = \frac{\sum_i P_{hi}^2 - \frac{\left[\sum_i P_{hi}\right]^2}{n_h}}{\bar{\pi}_h^2 n_h (n_h - 1)} \quad . \qquad (2')$$

This adjustment method is different from the PNW-FIA periodic inventory method. Discussions with current and former PNW-FIA personnel suggest a variety of practices were used to deal with unmeasured field samples. These practices might result in some differences between (1) and (1') and between (2) and (2').

For example, in some cases for PNW inventories, denied-access or hazardous plots were simply replaced with new randomly chosen plots. In other cases, the unit made the same assumption as the national FIA method: denied-access, missing, or inaccessible plots had the mean of measured plots. In these cases, for whole plots that were denied-access plots, hazardous plots, or out of the population, the plots were simply removed from the sample; this practice would result in the same estimates for $\overline{P_h}$ as the national FIA method. In other cases, for denied-access or hazardous plots, attributes were modeled forward from previous inventories; this would contribute to bias, although the magnitude is unknown.

With the exception of census water, it is usually not possible to identify portions of plots outside of population boundaries (state boundaries, national forest boundaries, country boundaries). When it was possible to identify out-of-population status, plots in the PNW-FIA periodic inventories were not installed if the center of the central subplot was out of the population. It appears that plots partially out of the population (usually census water) were treated as whole plots in variance estimates; this would result in smaller PNW-FIA estimates of var ($\overline{P_h}$) compared to the national method. For plots partially out of the population, the PNW-FIA method of calculating expansion acres (next section) may result in some differences for estimates of means and totals compared to the national method.

Expansion Acres Vs. Number of Sampling Units

For convenience in calculation, users of FIA data often prefer to work with “expansion acres.” Expansion acres for a plot in the periodic California 1991-94 inventory were calculated as:

$$Xacres_{hi} = \frac{\left[\frac{n'_h}{n'} A_T\right]}{n_h} \quad . \tag{8}$$

Each plot in the stratum was assigned this value. When plot attributes such as volume are put on a per-acre basis (v_{hi}), the estimated population total for volume can be written as:

$$\hat{P} = \sum_{h,i} Xacres_{hi} v_{hi} \quad . \tag{9}$$

The simplicity of this formula is the reason expansion acres are used for calculation, although the practice sometimes leads to the misunderstanding that the plot "represents" that number of acres. In the integrated database, expansion acres are attached to condition classes within a plot, rather than to the plot. Condition class expansion acres for accessible plots in the population are calculated as:

$$Xacres_{hic} = \varnothing_{hic} \frac{\left[\frac{n'_h}{n'} A_T\right]}{n_h} \quad , \tag{10}$$

where φ_{hic} is the proportion of plot i in stratum h in the condition class of interest (c). In the integrated database, these values appear in the column ACRES in the condition class table, COND. For the California 1991-94 inventory, a second set of expansion factors appears in the column ACRES_VOL. These different expansion factors are used with plots that had additional measurements taken on oak woodlands, as described in the next section.

For the California inventory, plots that were partially out of the population (in census water or in a national forest), or partially inaccessible or to which access was denied, had adjustments to the remaining condition class area estimates. In these cases,

$$Xacres_{hic} = \frac{\varnothing_{hic}}{\partial_{hi}} \frac{\left[\frac{n'_h}{n'} A_T\right]}{n_h} \quad , \tag{11}$$

where φ_{hic} is the area of plot i in stratum h in condition class c that is accessible and in the population and ∂_{hi} is the total area of plot i in stratum h that is accessible and in the population. Whole plots that were out of the population, or plots that were entirely inaccessible, not replaced, and not modeled from a previous measurement, were dropped from the calculation of expansion acres. This description of the calculation of expansion acres is based on discussion with FIA personnel who were involved with periodic inventory development.

Users need to be aware that expansion acres for PNW-FIA inventories in the integrated database are specific to a particular phase 1 stratification. Providing estimates for different geographic units would be best accomplished with new stratification.

The 1991-94 FIA Inventory of Oak Woodland

In the regular California FIA inventory, trees were only measured within timberland and low-site timberland condition classes, although oak woodland and other hardwood conditions were mapped for area. For half of all the phase 2 sample plots, referred to hereafter as "oak woodland plots," trees within these oak woodland and hardwood condition classes were also measured. These oak woodland plots are, on average, spaced at 4.8 miles apart; this spacing was the result of using a 6.8-mile (11-kilometer) grid in the 1980s, which was then doubled in intensity for the 1990s, resulting in approximately one field plot per 14,800 acres. The relation of phase 1 and phase 2 sampling units for the regular inventory and for the oak woodland plots is shown in figure 1.

Because oak woodland volume measurements were made on a subset of the plots, a different set of expansion factors, called “ACRES_VOL”, is used in the integrated database for volume (or tree attribute) estimation.

It was judged that area expansion factors for oak woodland would be best estimated by starting with the estimate of oak woodland area made from the full set of plots. In addition, because there were fewer plots with oak woodland tree measurements, a less detailed stratification needed to be used. Thus expansion acres were calculated by using a two-step process for each reporting unit. Reporting units are subsections of a state and can function as a subpopulation of known area A_t.

1. Total oak woodland area (OW_{h*}) for each generalized stratum $h*$ (broad ownership category) was estimated by using the standard PNW-FIA technique (equation 5), the full set of strata used for standard inventory reporting, and all the phase 2 sample plots.

2. Expansion acres for oak woodland plots in each more general stratum ($h*$) were calculated by using:

$$Xacres_{h*} = \frac{OW_{h*}}{n*_{h*}} \frac{n*}{\sum_{i=1}^{n*} ow_i} \tag{12}$$

where OW_{h*} = estimated oak woodland area for stratum $h*$,

$n*$ = number of oak woodland plots in reporting unit (with usual adjustment for out-of-population plots or unreplaced access-denied plots),

$n*_{h*}$ = number of oak woodland plots in the stratum $h*$, and

ow_i = portion of oak woodland plot i in oak woodland condition class.

Expansion acres for condition class within a plot were then calculated as:

$$Xacres_{h*ic} = \O_{h*ic}\ Xacres_{h*}$$

where $\O_{h*ic}$ is the proportion of plot i in stratum $h*$ in condition class c.

Estimates of means and totals are made in the usual fashion by summing the product of expansion acres and the attribute of interest (such as volume per acre).

An example of the PNW-FIA calculation of expansion acres for the regular inventory and the woodland inventory is shown in table 2. The number of phase 1 and phase 2 sampling units corresponds to the example shown in figure 1, with an assumption that the starting land area A_t = 135,000 acres. The example includes plots mapped for three conditions (timberland, woodland, and nonforest), a partially out-of-inventory plot, an access-denied plot, and an unvisited nonforest plot, to illustrate how these unusual cases were handled in the inventory.

The phase 1 sample was used to estimate the area in each stratum. Expansion acres for each plot ($Xacres_{hi}$) were calculated by dividing these estimated stratum areas by the number of field plots in that stratum as shown in equation (8). Oak woodland area

Table 2—California 1991-94 FIA inventory, example of expansion acre calculations for phase 2 plots shown in Figure 1

Plot	Grid	Stratum	Field visit	Condition: Timberland	Condition: Woodland	Condition: Nonforest	Out of pop. or access denied	Timberland condition in population	Timberland plot expansion	Woodland condition in population	Woodland plot expansion
				- - - - - *Proportion of whole plot area*			- - - - -	*Percent*	*Acres*	*Percent*	*Acres*
1	Woodland	A	yes	0.50			0.50	100	10,000	0.0	17,598
2	Standard	A	yes	1.00				100	10,000	0.0	
3	Woodland	A	yes	.60	0.40			60	10,000	40.0	17,598
4	Standard	A	yes	.40	.60			40	10,000	60.0	
5	Woodland	A	yes	.40	.40	0.20		40	10,000	40.0	17,598
6	Standard	A	yes	.40	.40	.20		40	10,000	40.0	
7	Woodland	A	yes		1.00			0	10,000	100.0	17,598
8	Standard	A	no				1.00		NA		
9	Woodland	A	no			1.00		0	10,000	0.0	17,598
10	Standard	A	yes		.38	.63		0	10,000	37.5	
11	Woodland	B	yes	.50	.25	.25		50	7,500	25.0	17,598
12	Standard	B	yes	1.00				100	7,500	0.0	
13	Woodland	B	yes	1.00				100	7,500	0.0	17,598
14	Standard	B	yes	1.00				100	7,500	0.0	
15	Woodland	B	yes	.50	.50			50	7,500	50.0	17,598
16	Standard	B	yes		1.00			0	7,500	100.0	

Total phase 1 (photo) plots = 336. Of these, suppose 36 are out of population (reserved, national forest, census water, or out of state).
Of phase 1 (photo) plots in population, suppose 200 are in stratum A and 100 are in stratum B, and population land area = 135,000 acres.

Applying equation 8:
Stratum A in-population area estimated as (200/300) * 135,000 = 90,000 acres.
Stratum B in-population area estimated as (100/300) * 135,000 = 45,000 acres.
Plot expansion acres: for stratum A plots = 90,000/(10 - 1) = 10,000; for stratum B plots = 45,000/6 = 7,500

Summing equation 11 over all plots to estimate total area in each condition:
Estimated timberland area: for stratum A = 90,000 * (3.8/9) = 38,000 acres; for stratum B = 45,000 * (4/6) = 30,000 acres; $\sum$ = 68,000 acres.
Estimated woodland area: for stratum A = 90,000 * (3.175/9) = 31,750 acres; for stratum B = 45,000 * (1.75/6) = 13,125 acres; $\sum$ = 44,875 acres.

Using equation 12 to calculate plot expansion factors for oak woodland:
The sum of woodland conditions on the woodland grid ($=\sum ow_i$), is the equivalent of 2.55 plots.
For this example, we combine strata A and B so that $n^*_{h^*} = n^*$.
Thus using equation 12, woodland volume expansion acres for plots on the woodland grid = (31,750 + 13,125) / 2.55 = 17,598 acres.

for each stratum (OW_h) was estimated by using equation (11) and summing over all plots in that stratum. Equation 12 was used to apportion estimated oak woodland area (OW_h) to each plot on the woodland grid, resulting in a set of oak woodland plot expansion factors.

Variance of estimates from oak woodland can be calculated in the usual manner, by using either the national FIA method or PNW-FIA method with the sample size set as the number of plots on the oak woodland grid (n^* and $n^*_{h^*}$). This method should provide a conservative (overestimate) of true variance because woodland area was actually calculated with the full set of field plots.

To produce variances and standard errors over the combined inventories, the method proposed is to treat the woodland and regular California inventories as entirely separate inventories and to use stratified estimation to estimate variance. As with separate estimates for woodland, sample size in a woodland stratum would be set as the number of plots on the woodland grid (n^* and $n^*_{h^*}$). This should provide a conservative (overestimate) of true variance, because:

- It uses a conservative estimate of sample size for oak woodland area.
- Covariance between oak woodland and regular inventory measurements would be ignored.

The 1995-2000 Inventory of National Forest Land in California

Prior to 2001, inventory of national forests in California was the responsibility of the Pacific Southwest Region (Region 5) of the National Forest System (NFS). The inventory procedures are documented in USDA FS (2000b). This document only addresses those aspects of the inventory related to general sample design and estimation procedures.

The 1995-2000 NFS inventory used stratified estimation. Strata weights came from classified area maps of vegetation type developed from Landsat remote-sensing ancillary data. Sampling intensities differed by stratum and include sampling from a 0.395-mile grid (100 acres), 0.425-mile grid, 0.85-mile grid, 1.7-mile grid, and 2.4-mile grid (as documented in http://www.fs.fed.us/r5/rsl/projects/inventory/intensified.shtml). Subplots within the same plot could be assigned to different vegetation types (strata). In some cases, this would result in a plot crossing a boundary of different sampling intensities; in these cases, subplots that were not on the sampling grid for that vegetation type were put in a special stratum to be dropped before estimation. These dropped subplots have not been included in the integrated database.

Like the PNW-FIA design, a cluster of five subplots was used for field-visited plots. However, several differences occur:

1. Each subplot was assigned to only one condition, compared to condition-class mapping used by PNW-FIA. The Region 5 inventory could be considered a mapped design, although mapped only to the subplot level.

2. Where multiple conditions occurred on a plot and at least two subplots were in a condition, additional subplots were added to have four subplots in the condition. Subplots were added on 6 percent of plots in the integrated database. This practice was dropped on some forests in later years.

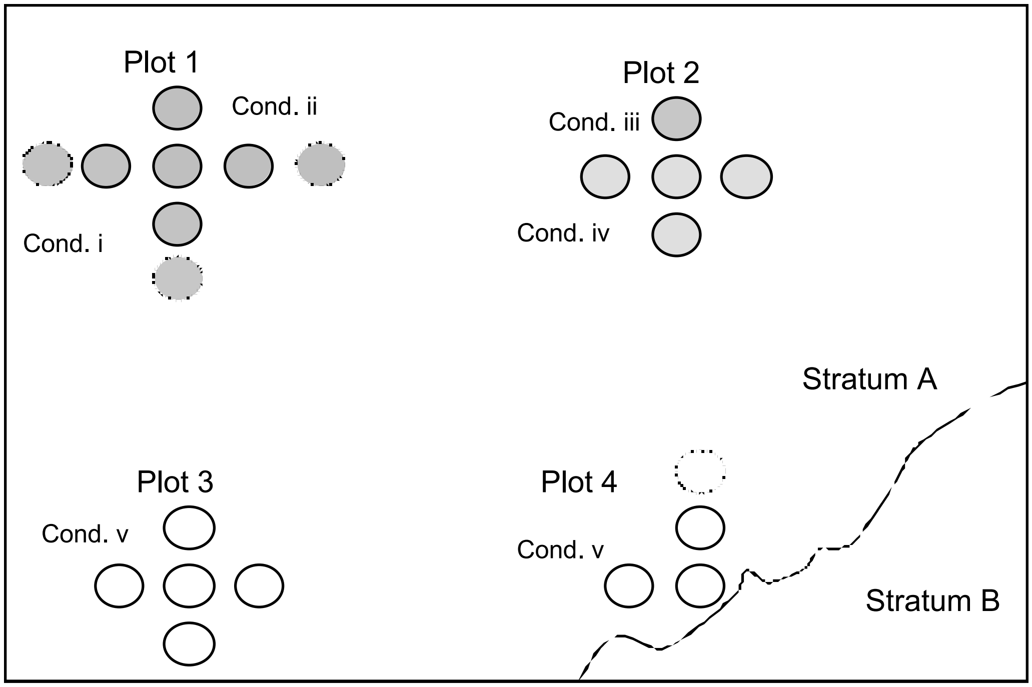


Figure 3—Variations for plot configurations in the California (Region 5) national forest inventory.

Figure 3 shows some examples of the scheme. Plot 1 shows additional subplots added to make four in a single condition. Plot 2 shows an example of a plot that had only one subplot in a separate condition: in this case, subplots were not added. Plot 4 shows a plot crossing a strata boundary, with two subplots dropped and one added to make four in the condition. The majority of plots would have been plots such as plot 3, without split conditions; stratification was made based on cover type, and conditions were usually uniform within a contiguous cover type.

From discussions with Region 5 personnel, I concluded that the method used for the 2000 Resources Planning Act assessment treated the sampling unit as the combination of condition class and plot. This method assigns equal weight to each condition class on a plot, regardless of the number of subplots where that condition occurred. A different method that would more closely conform to sampling units as defined by FIA is proposed for use with the integrated database. This would treat the original five subplot configuration as the sampling unit, ignoring added subplots. For the example in figure 3, the difference for the two methods is shown in table 3, assuming 10,000 acres in stratum A. Because multiple conditions were relatively uncommon, occurring on 12 percent of plots in the database, relative differences will not be as extreme as in this example. The methods will differ, however, whenever multiple conditions occur on at least one plot in a stratum.

Condition classes are very frequently used in calculating and reporting inventory results. Sliver conditions (conditions falling on portions of a plot) pose a continual challenge for FIA, both in calculating classified attributes (for example, stand size class, old-growth classification, or “stocked” or “nonstocked” condition) and in increased variation for real-valued attributes. The practice of adding subplots can be

Table 3—Example of difference in estimation methods for Region 5 inventory

	Region 5 method used for 2000 RPA assessment	PNW-FIA method, used for Region 5 in the integrated database
Condition 1 acres	1,667	1,111
Condition 2 acres	1,667	1,667
Condition 3 acres	1,667	556
Condition 4 acres	1,667	2,222
Condition 5 acres	3,333	4,444
Total acres	10,000	10,000
n_h	6	4
$\overline{\pi}_h n_h$		3.6

Note: n_h = number of plots sampled in stratum h.
$\overline{\pi}_h n_h$ = number of plots sampled in stratum h, adjusted for subplots which fell out of the stratum or out of the population.

beneficial in providing a consistently sized unit within a condition for calculating these classified variables. Including the added subplots in inventory compilation, however, will result in unequal probability for selection where multiple conditions occur. For this reason, the PNW-FIA program will not use the added subplots; sampling unit area with the PNW-FIA method would be the sum of the subplot areas, or 1.25 acres (= 5 x 1/4-acre subplot). In addition, conditions within a plot will be weighted by their occurrence, rather than the equal weighting method used for the 2000 RPA assessment. These changes were made to the PNW-FIA integrated database version 1.3. Estimates of forest area did change, although in most cases the amount of change was fairly minor. For example, estimated total national forest timberland in California (12.6 million acres) decreased by 0.2 percent, and oak woodland (1.5 million acres) decreased by 0.74 percent. Some less common forest types showed larger shifts; for example, whitebark pine (*Pinus albicaulis* Engelm.) forest, with an estimated 63,600 acres, had a 22 percent decrease with the new method. In general, area estimates for common forest types changed by only 1 or 2 percent, well within typical sampling errors.

Estimation methods are somewhat different from those discussed for the FIA inventory of private lands because of the use of remote-sensing data instead of interpreted air-photo plots for phase 1. The essential difference is that stratum areas (A_h) are treated as known rather than estimated. The necessary adjustment for estimates of population means requires replacing $w_h = n'_h / n'$ with $W_h = A_h / A_t$ in equation (5). In other words, the stratum weight is determined by the proportion of remote-sensing area within a stratum instead of by the proportion of air-photo plots within a stratum.

If we assume that the sample design uses stratified random sampling, then variance of the mean would be estimated by using Cochran (1977), eq. 5.6:

$$\mathrm{var}(\hat{P}) = \sum_h W_h^2 \left[1 - \frac{n_h}{N_h}\right] \left[\frac{\sum_i \left[P_{hi} - \hat{P}_h\right]^2}{n_h\,(n_h - 1)}\right] . \qquad (13)$$

The estimated variance of the population total can be expressed as:

$$\mathrm{var}(\hat{P}) = \sum_h N_h (N_h - n_h) \left[\frac{\sum_i \left[P_{hi} - \hat{P}_h \right]^2}{n_h (n_h - 1)} \right] . \tag{14}$$

The 1993-97 Inventory of National Forest Land in Oregon and Washington

This inventory is known as the current vegetation survey (CVS). Measurements from 1993 through 1997 are referred to as occasion 1. Like the periodic PNW-FIA and California national forest inventories, plots were selected from a regularly spaced grid. Within wilderness areas, plots were installed on a 3.4-mile grid. All other national forest lands had plots installed on a 1.7-mile grid. With the exception of very large trees, most tree measurements were taken on five subplots within a larger 2.47-acre circular plot.

This paper only discusses possible estimation methods for the inventory. Field procedures are described in USDA FS (2000a). A description of the plot design and a comparison to other methods are available in Max and others (1996). For this inventory, the sampling unit is considered to be the 2.47-acre circle encompassing the five subplots. The sampling unit is not defined to be the sum of the subplot areas, as is used by the PNW-FIA program, because large trees (>32 inches or >48 inches diameter) were measured on the full 2.47 acres (1 ha).

Unlike the other inventories discussed here, plots were not mapped by condition class in the field. However, condition classes were calculated by FIA in the development of the integrated database. For more information on condition class calculation or development of expansion acres, see Waddell and Hiserote (2003).

The only prestratification used in this inventory was wilderness or nonwilderness and national forest. There are two possible estimation methods being considered for this inventory, either bootstrapping or classical. Bootstrapping has not been used by PNW-FIA for standard reports for the states discussed in this paper, although the Alaska office recently tested it for southeast Alaska (van Hees 2002). In that comparison, standard error estimates for an unstratified systematic sample were similar between a ratio-of-means approach and bootstrapping. However, processing time with the Visual Basic implementation prevented adoption of bootstrapping as the standard technique. The Pacific Northwest Region (Region 6) has developed a Visual Basic program that uses bootstrapping for estimation with the CVS inventory. The software program's bootstrapping estimator is intended as an aid for forest planners, researchers, and other users of inventory data. Both the Pacific Northwest Region and PNW-FIA intend to apply the classic estimation methods described here and in the national FIA document (Bechtold and Patterson, in press) to the CVS inventory for regional reports.

Without stratification, a classical estimator for either (a) wilderness areas or (b) nonwilderness areas (but not both) is

$$\hat{P} = \frac{1}{n} \sum_i P_i \tag{15}$$

with estimated variance:

$$\mathrm{var}(\hat{\bar{P}}) = S^2 / n = \sum_i \frac{\left[P_i - \hat{\bar{P}}\right]^2}{n(n-1)} = \frac{\sum_i P_i^2 - \frac{\left[\sum_i P_i\right]^2}{n}}{n(n-1)} \quad . \tag{16}$$

If post-stratification using complete areal coverage (remote sensing) were used, then estimates of the population mean would be:

$$\hat{\bar{P}} = \sum_h W_h \hat{\bar{P}}_h \tag{17}$$

and as discussed in Bechtold and Patterson (in press), Cochran (1977) equation 5A.42 provides an estimate of variance:

$$\mathrm{var}(\hat{\bar{P}}) = \frac{1}{n}\left\{\left[1 - \frac{n}{N}\right]\sum_h W_h \left[\frac{\sum_i \left[P_{hi} - \hat{\bar{P}}_h\right]^2}{n_h - 1}\right] + \frac{1}{n}\sum_h (1 - W_h)\ \frac{\sum_h \left[P_{hi} - \hat{\bar{P}}_h\right]^2}{n_h - 1}\right\} . \tag{18}$$

Estimates of a population total and the variance of that total can use equations (5) and (7), respectively. Estimation of population totals including land from both wilderness and nonwilderness is simply the sum of the totals, and its variance is the sum of their variances. Users of the IDB need to be careful not to average unweighted plot values across wilderness and nonwilderness (for Region 6) or across vegetation type (for Region 5) because sampling intensity differed in these two inventories. Instead, users should either use the condition-class expansion factors or, equivalently, the equations in this document.

Providing Regional Estimates Across Populations

The FIA California inventory outside national forests, the California national forest (Region 5) inventory, and the Oregon and Washington national forest (Region 6) inventory can be treated as separate inventories of different subpopulations, in effect using stratified estimation. Thus providing estimates over combined inventories could be done as simple sums of individual estimates:

$$P_{total} = P_{FIA} + P_{Region\ 5} + P_{Region\ 6} \ . \tag{19}$$

The variance of the sum of independent random variables is the sum of the variance of those variables. Therefore, estimated variance of the population total can be calculated as the sum of the individual estimated variances:

$$\mathrm{var}(P_{total}) = \mathrm{var}(P_{FIA}) + \mathrm{var}(P_{Region\ 5}) + \mathrm{var}(P_{Region\ 6}) \ . \tag{20}$$

Estimated averages for the population can be calculated as:

$$\overline{P}_{total} = P_{total} \,/\, (A_{t\,(FIA)} + A_{t\,(Region\ 5)} + A_{t\,(Region\ 6)}) = P_{total} \,/\, A_{total} \quad , \tag{21}$$

with estimated variance:

$$\text{var}(\overline{P}_{total}) = \frac{1}{A^2_{total}} \text{var}(\overline{P}_{total}) \qquad . \tag{22}$$

The FIA Oregon and Washington periodic inventories outside national forests can be included in the same manner. Users should note that this technique adds estimates of population **totals** and variances of population **totals** rather than means.

Conclusion

Assessment and monitoring of forests in California, Oregon, and Washington are currently in a transition period. An integrated database recently produced by the Pacific Northwest Research Station (Waddell and Hiserote 2003) combines a collection of periodic inventories that will be a primary inventory resource until annual data are available; current expectations are that 50 percent of annual plot data will be collected by 2005 for Oregon, 2006 for California, and 2007 for Washington. The recommended estimation procedures described in this document will be used by the Pacific Northwest Forest Inventory and Analysis program for assessment with the integrated database until annual inventory data can be used. The procedures described here are not necessarily the methods that will be used by other agencies or by individual researchers.

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches	2.54	Centimeters
Feet	.3048	Meters
Miles	1.609	Kilometers
Acres	.405	Hectares
Cubic feet	.0283	Cubic meters
Cubic feet per acre	.06997	Cubic meters per hectare

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