Sustainability Analysis Using FORSEE and Continuous Forest Inventory Information to Compare Volume Estimation Methods for the Valencia Coast Redwood Tract in Santa Cruz County, California[1]

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Abstract

The 1,295 ha (3,200 ac) Swanton Pacific Ranch (Swanton) and the associated Valencia Tract in Santa Cruz County have been managed by California Polytechnic State University, San Luis Obispo (Cal Poly) since 1987. Swanton's Valencia Tract is a 239 ha (591 ac) property located north of Watsonville, California. Cal Poly forest managers have conducted two harvest entries since acquiring ownership of the Valencia tract utilizing a modified BDq individual tree selection approach. A 10-year continuous forest re-inventory (CFI) was completed for the Valencia coast redwood tract to update and enhance the growth and yield analysis needed for the Non-Industrial Timber Management Plan (NTMP) sustainability analysis.

The California Growth and Yield Modeling Cooperative - Forest and Stand Evaluation Environment (FORSEE) program and 10-year CFI data were utilized to perform a sustainability analysis comparing trees per acre, basal area per acre, quadratic mean diameter, and gross volume per acre. Several tree volume estimation methods were evaluated for differences in yield reporting.

It was determined that: 1) by 2012 actual stand volume growth had completely recovered from harvest and exceeded the pre-harvest 2001 gross volume by 9.7 percent (i.e., average stand growth of 1,266 board feet per acre per year, or 3.0 percent growth rate per year); 2) the Spaulding equation appears to be a solid medial choice for Valencia Tract sustainable yield analysis; 3) sustainable uneven-age stand management resulted from setting residual stand basal area (b), maximum diameter (d) and trees per acre by diameter prescription targets (q) while leaving a few trees greater than the established maximum diameter (i.e., a modified BDq approach); 4) the project model underestimated basal area per acre growth, overestimated change in quadratic mean diameter (QMD), overestimated diameter growth of smaller trees (< 30.5 cm (12 inches) diameter at breast height (DBH; 1.37 m)); underestimated diameter growth of larger trees (> 33 cm (13 inches) DBH), underestimated height growth of larger trees (> 53.3 cm (21 inches (DBH), underestimated volume (16.3 percent lower than actual CFI volume figures). It is postulated that this difference in FORSEE model projection is either a result of the way the CFI data was processed in FORSEE, regional differences, or inherent projection inaccuracies not fully understood by FORSEE users.

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Introduction

Forest management at California Polytechnic State University, San Luis Obispo (Cal Poly)'s Swanton Pacific Ranch (Swanton) and School Forest began in 1986 when owner Mr. Al Smith requested the university's assistance with management of his agricultural and forested properties. Mr. Smith bequeathed those properties to Cal Poly in 1993. Mr. Smith's long-term vision focused on Swanton Pacific Ranch and the Valencia Tract being a sustainably managed working ranch and forest with many interdisciplinary Learn by Doing activities involving students, staff, and faculty.

Swanton Pacific Ranch is located in the southern sub-district of the Coast District (Cal Fire 2016). Very strict forest practice rules were developed for this district due to citizen concerns about the extensive clearcut logging that occurred in the early 1900s to help rebuild San Francisco after the 1906 earthquake. These current, sub-district California Forest Practice Rules specify tree removal limits by diameter class, maximum permitted opening size, and Watercourse and Lake Protection Zone requirements. Sustainable management of the working forested areas of the Valencia Tract are guided by a 2001 Non-Industrial Timber Management Plan (NTMP) and a 2013 NTMP amendment (Cal Poly and Big Creek 2001, 2013). Uneven-aged forest management was implemented utilizing a modified BDq approach (Guldin 1991; Piirto et al. 1996, 2007, 2009, 2012).

The application of ecosystem management principles requires understanding of past and present conditions as desired future conditions are defined and adaptive forest management occurs (Manley et al. 1995, Piirto and Rogers 2002). Given these considerations, how effective is the current growth and yield model at estimating volume and predicting future growth at the Valencia Tract? The objectives of this observational sustainability study were to:

1. Standardize the formats of the 2001 pre-harvest, 2002 post-harvest and 2012 forest inventory data sets and conduct individual tree record quality control to validate consistency and growth of measurements.
2. Upload the data into Forest and Stand Evaluation Environment (FORSEE) databases for inventory analysis and comparison utilizing various available or project developed volume equations.
3. Grow the post-harvest 2002 dataset to 2012 and compare the results to the actual 2012 CFI inventory measurement.
4. Identify a suitable volume estimation method for future growth and yield sustainability analysis.

Methods

Project Area

The area delineated for this study was the 239 ha (591 ac) Valencia Tract of Swanton Pacific Ranch. Two management units were established largely due to topographic differences and logging systems planning needs. Inventory data acquisition was completed in 2001, 2002, and 2012. Five forest vegetation types and non-commercial landslide areas were identified within the Tract (table 1) (Cal Poly and Big Creek 2001, 2013) accounting for 228 manageable ha (563 manageable ac) out of the total 239 ha (591 ac); specific areas were excluded from management accounting for the difference.

Table 1—Valencia Tract – units, vegetation types, acres and CFI plots

Unit	Vegetation type	Total acres	Acres in analysis	Number of lots
1	Redwood	210	210	39
1	Douglas-fir	3	3	1
1	Hardwood	26	26	1
1	Brush	19	0	0
1	Landslide	1	0	0
Unit 1 subtotal	**Subtotal**	**259**	**239**	**41**
2	Redwood	259	259	32
2	Douglas-fir	0	0	0
2	Hardwood	42	42	6
2	Brush	23	23	3
2	Landslide	8	0	0
Unit 2 subtotal	**Subtotal**	**332**	**324**	**41**
Grand total		**591**	**563**	**82**

A total of 82 CFI inventory plots were measured throughout the 228 ha (563 ac) project area. The project area, vegetation types, and inventory plot locations are illustrated in fig. 1.

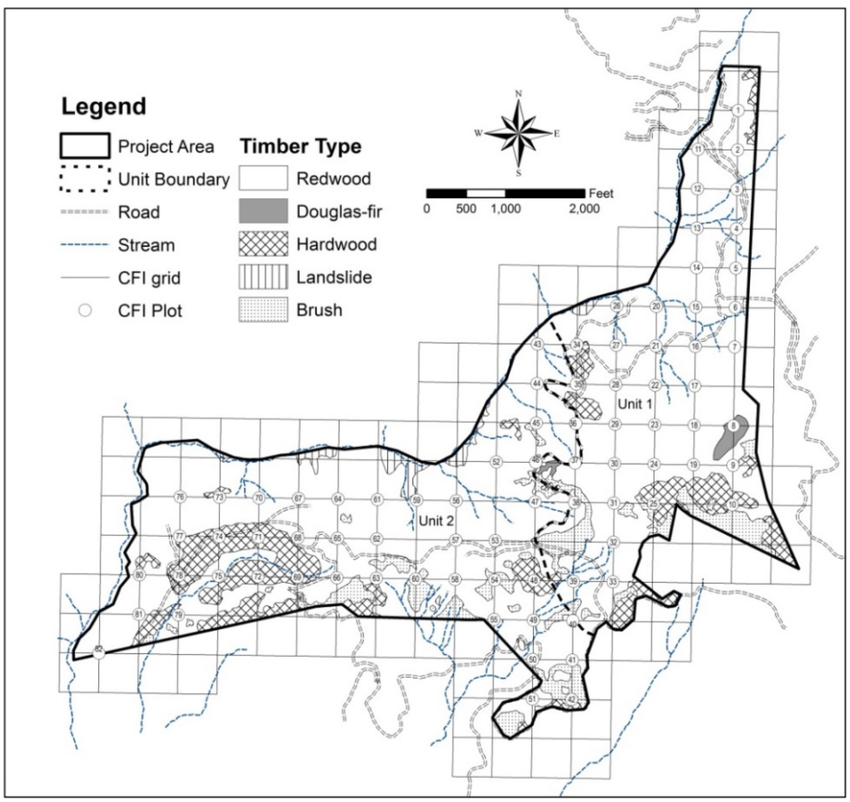

Figure 1—Swanton Pacific Ranch Valencia Tract vegetation types and CFI plots.

Continuous Forest Inventory Design, Measurement, Data Formats and Quality Control

The forest resources of the Valencia Tract were first inventoried in 2001 to support development of the Valencia NTMP (Cal Poly and Big Creek 2001). A 152.4 m (500 ft) uniform grid system was established in relation to a baseline and benchmark at the intersection of Bean Hill Road/Fern Flat Road/and Rusk Grade. Eighty-two circular 0.08 ha (0.2 ac) plots, radius 16.1 m (52.7 ft), were installed in 2001 using a systematic approach at the intersecting points of the grid to develop a

Continuous Forest Inventory (CFI) system. A few sample locations throughout the systematic grid were not measured due to accessibility constraints and other factors. The CFI plots were re-measured in 2002 and 2012. A timber harvest occurred in the project area in 2002, and a post-harvest assessment was conducted at the CFI sample locations to record which trees had been removed and/or damaged because of the harvest. A complete CFI re-measurement was conducted in 2012, 10 years after harvesting.

All inventory data were collected on paper field forms then converted into one spreadsheet template with consistent species designations, data fields, notations, and formats. Initial data set validation was conducted by Cal Poly forest managers (Steve Auten, 2012, personal communication). Inventory data inconsistencies were verified and corrected with original field notes where possible, and 2012 data inconsistencies were field verified in 2014 (Ben Han, 2014, personal communication). Additional data validation and comparison of data set measurements were conducted by Cal Poly forest managers and Environmental Resource Solutions, Inc. during data review and upload. Data field names required minor modifications to be compatible with FORSEE's naming conventions. Tree, stand, and site data went through an integrated auditing process during import into Microsoft Access and uploaded to the FORSEE software. There were some unresolved data inconsistencies.

Use and Development of Volume Estimators

Four different conifer volume estimation sources that included nine different conifer volume equations and one hardwood source that included numerous hardwood species volume equations were used for inventory compilation and volume comparison (table 2). This effort was primarily focused on analyzing various redwood volume equations to determine the differences and the perceived most accurate estimator. The various tree volume equation sources utilized were:

1. Wensel and Krumland (1983): Source 1 is the Bulletin 1907 volume equation and Bulletin 1907 taper equation as this source contains both equation types (Scribner rule) for coastal conifers. The volume equation coefficients utilized for this study are contained in the Bulletin 1907 Appendix table 1A, by species, total height to a 6-inch top diameter inside bark (dib). The Bulletin 1907 volume estimations are postulated by California mensurationists to overestimate tree volumes in the range of 10 to15 percent due to log scaling rounding protocols (Dr. Bruce Krumland, personal communication). The Bulletin 1907 taper equation coefficients utilized are contained in table 8 of that publication, by species to a 0-inch top.
2. Lennette A. and M. Lennette (1997): Source 2 is the Lennette local volume equations. These equations were developed from a sample of 70 sampled redwoods from the Valencia Tract. During recent timber harvests, Cal Poly forest managers found that these equations tend to underestimate volume by approximately 20 percent.
3. Lindquist and Palley (1963): Source 3 is the Bulletin 796 Spaulding table. Historically, Cal Poly forest managers have used this volume table to represent the redwood board foot volume Spaulding Rule to an 8-inch top inside bark. The Bulletin 796 table depicts the results of a weighted multiple regression equation; however, the equation form is not consistent with the volume model forms utilized in FORSEE. Dr. Bruce Krumland[9] converted the Bulletin 796 Table 28 Total Height Volume Table for Young Growth Redwood board foot for an 8-inch top Spaulding rule to a Wensel-Olsen model form[10] for integration with FORSEE. Dr. Krumland utilized the Statsoft Corp. Statistica, version 7 software package to develop a weighted non-linear regression model. The weighting data included 689 redwood trees from the Valencia Tract, ranging between 30.5 to 139.7 cm (12 to 55 inches) DBH that did not have visible indicators of height defects. The resulting R^2 for the model was 0.99998 and the regression standard error was 9.2 board feet.

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[9] Mensurationist, author and programmer of the CRYPTOS Growth and Yield Model, and developer of the FORSEE software.

[10] The Wensel/Olsen model (1995): V=a*(DBH^b)*(HT^c)*(d^DBH).

4. Han, Ben[11]: Source 4 refers to two equations developed by Ben Han. These equations were based on fall and buck data from 104 trees collected from the Valencia Tract.
5. Pillsbury and Kirkley (1984): Source 5 is the Pillsbury PNW-414 hardwood equations. Species specific wood volume equations from table 3 in the PNW-414 publication were used for all hardwoods in the inventory.

Table 2—Volume equation sources used for each dataset compilation[a]

Report name	Redwood volume source	Douglas-fir volume source	Hardwood volume source	Conifer top dib
Bulletin 1907 Equation	1 volume equation	1 volume equation	5	6
Bulletin 1907 Taper	1 taper equation	1 taper equation	5	6
Lennette Local Equation	2	2	5	6
Bulletin 796 Spaulding	3	1 volume equation	5	8
Han Masters 6	4	1 volume equation	5	6
Han Masters 7	4	1 volume equation	5	6

[a]Volume equations available upon request.

Data Compilation and Analysis

Inventory data were compiled and analyzed using the **FOR**est and **S**tand **E**valuation **E**nvironment (FORSEE) computer program (CAGYM 2012). The CRYPTOS growth model option within FORSEE was used to model forest growth, as this model is appropriate for the coast redwood forest type (Krumland and Eng 2005, Wensel et al. 1987, Wensel and Olsen 1995). All measured site trees within the project area were utilized to establish the initial site index value for the project area. The FORSEE calculated coast redwood site index (base age 50) was 89, which is considered an acceptable estimate for this area. This average site index estimate falls into a Redwood Site Class III.

The initial 2001 inventory data was compiled to provide a baseline assessment of forest stocking. To simulate the 2002 harvest, 2001 data was grown 1 year before harvested trees were removed from the inventory, identified as the Status Code 2 field in the database, indicating the tree had been removed as a result of harvest. Harvested trees were then removed from the tree database and the inventory was recompiled and grown an additional 10 years to reflect modeled conditions as of 2012. The grown stand was saved and recompiled before reporting the modeled 2012 data statistics. The CFI re-measurement in 2012 represents the most recent inventory of forest conditions for the tract.

FORSEE compilation assumptions were:

1. No ingrowth was added to the grown 2002 data.
2. Stand BR_2 did not exist in the 2001 data, but did exist in the 2012 data for plots 42, 54, and 60. These plots were moved to the BR_2 stand in the 2001 data.
3. No site trees for stand BR_1 were taken during the inventory process. To compensate for this, site trees from stand HW_1 were duplicated. The HW_1 stand was picked because both stands exhibited a similar under-performing conifer component.
4. All volume models were set up for a 6-inch top dib, except the coast redwood Spaulding equation that was run to an 8-inch top dib due to the basis of the original volume table.
5. Only trees 12 inch DBH and greater were compiled for volume.

All inventory data sets were compiled to report forest metrics and statistics at the unit vegetation type level.

[11] Han, W.B. Comparing volume equations for young-growth redwood in Santa Cruz County. Master's thesis in progress. California Polytechnic State University, San Luis Obispo, CA.

Results

The summarized information for the 2001 pre-harvest data, 2002 post-harvest data, 2002 post-harvest data grown to 2012, and 2012 data CFI inventories are shown in tables 3 to 6, and figs. 2 through 12. The data summarizes the FORSEE modeled and measured changes of 82 CFI inventory plots over 563 timbered acres of the Valencia Tract. There may be minor summation issues due to programmatic and table display rounding. Reported values are for the total project area within the Valencia Tract for all vegetation types and units included in the analysis.

The data shows an uneven-aged forest with a reverse J-shaped diameter distribution. The current 2012 actual stand data (table 6, figs. 7 and 8) indicates the forest stocking contains approximately 304 trees per acre (TPA) of all species, has a total quadratic mean diameter (QMD) of 13.34 inches, a total basal area per acre of 295 ft^2, a conifer basal area per acre of 207 ft^2, and a conifer gross volume (Spaulding Rule) per acre of 39,367 board feet. The 2012 CFI- re-measurement data was evaluated using coast redwood gross volume equations to produce per acre estimates ranging from 29,427 board feet (Source 2) to 38,073 board feet (Source 1), which represented a 29 percent swing in stand volume. The ability of Cal Poly Forest Managers to predict growth and yield for the Swanton Pacific School Forest and the associated Valencia Tract depends on identifying a suitable volume estimation source.

The results from each dataset (2001 pre-harvest, 2002 post-harvest, 2002 grown to 2012, and 2012 actual stand re-measurement) and volume source (table 1) compilation are presented in tables 3 through 6. Stand forest metrics (TPA, QMD, BA/Ac, CO2e/Ac) are reported by species.

Table 3—Swanton Pacific Ranch Valencia Tract – FORSEE 2001 pre-harvest yield summary

Forest stocking metrics				
Species group	**TPA**	**QMD**	**BA/ac**	**CO2e/ac**
All Conifers	147.23	16.1	208.09	343.93
Redwood	131.92	16.43	194.15	320.28
Douglas-fir	15.31	12.92	13.94	23.47
Hardwoods	176.87	9.56	88.25	140.25
Totals	**324.1**	**12.95**	**296.35**	**484.37**

Gross volume per acre estimation source						
Species group	**Bulletin 1907 equation**	**Bulletin 1907 taper**	**Lennette local equation**	**Bulletin 796 Spaulding**	**Han Masters 6**	**Han Masters 7**
All conifers	38,330	36,697	30,713	36,065	33,026	33,514
Redwood	35,188	33,576	27,836	32,858	29,884	30,372
Douglas-fir	3,142	3,121	2,877	3,207	3,142	3,142
Hardwoods	2,358	2,358	2,358	2,358	2,358	2,358
Totals	**40,688**	**39,055**	**33,071**	**38,423**	**35,384**	**35,872**

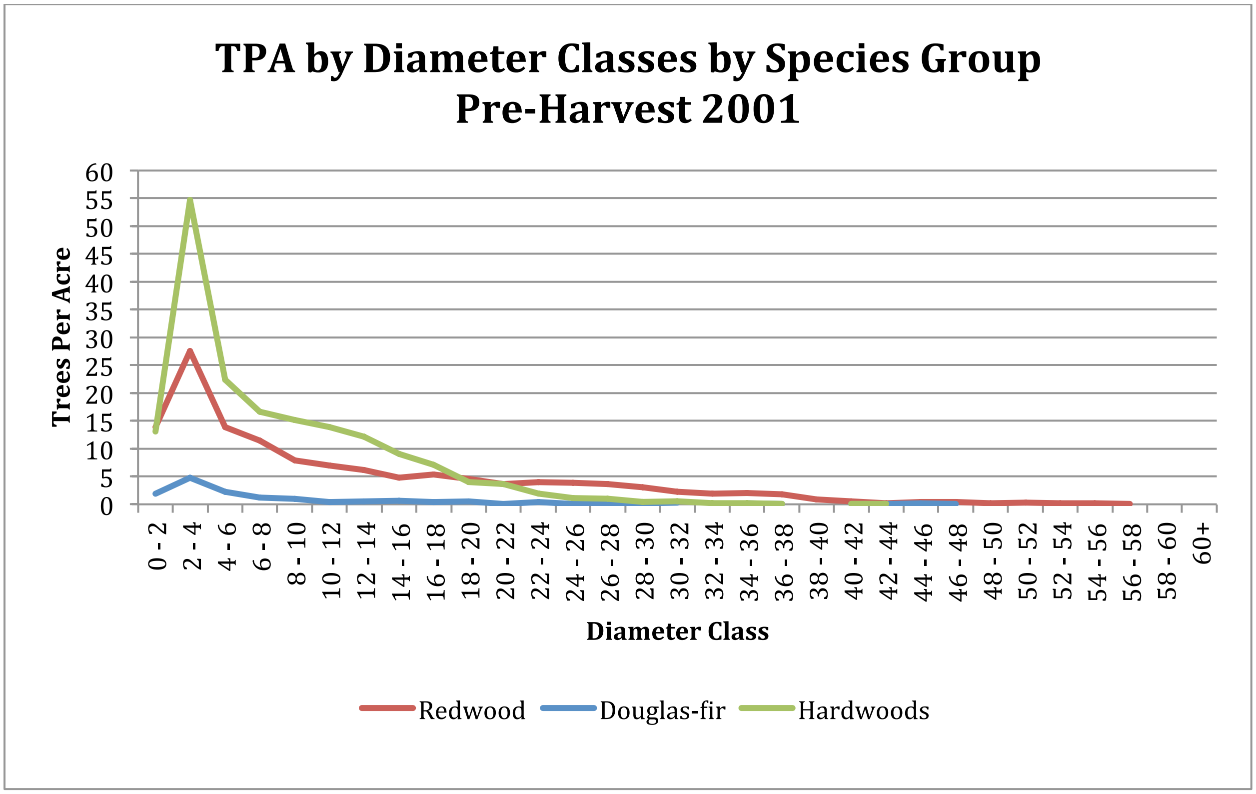

Figure 2—Swanton Pacific Ranch Valencia Tract – FORSEE 2001 pre-harvest summary. Trees per acre by diameter class and species group.

Table 4—Swanton Pacific Ranch Valencia Tract – FORSEE 2002 post-harvest yield summary

Forest stocking metrics				
Species group	**TPA**	**QMD**	**BA/ac**	**CO2e/ac**
All conifers	120.16	15.73	162.25	264.92
Redwood	108.22	15.90	149.17	242.73
Douglas-fir	11.94	14.17	13.07	22.37
Hardwoods	138.15	10.26	79.38	126.87
Totals	**258.31**	**13.10**	**241.63**	**391.97**

Gross Volume per Acre Estimation Source						
Species group	**Bulletin 1907 equation**	**Bulletin 1907 taper**	**Lennette local equation**	**Bulletin 796 Spaulding**	**Han Masters 6**	**Han Masters 7**
All conifers	29,053	27,893	22,890	27,343	25,093	25,515
Redwood	26,033	24,907	20,187	24,285	22,073	22,494
Douglas-fir	3,021	2,986	2,704	3,058	3,021	3,021
Hardwoods	2,135	2,135	2,135	2,135	2,135	2,135
Totals	**31,189**	**30,028**	**25,026**	**29,478**	**27,229**	**27,650**

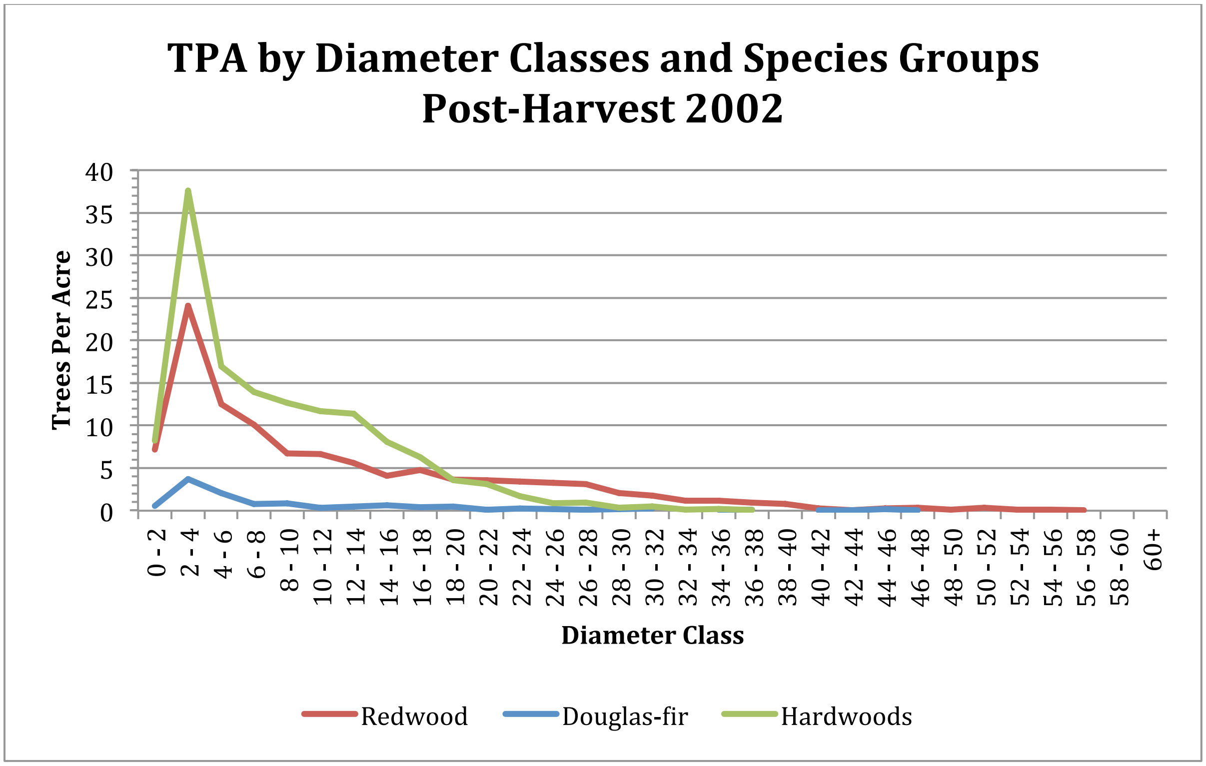

Figure 3—Swanton Pacific Ranch Valencia Tract – FORSEE 2002 post-harvest summary. Trees per acre by diameter class and species group.

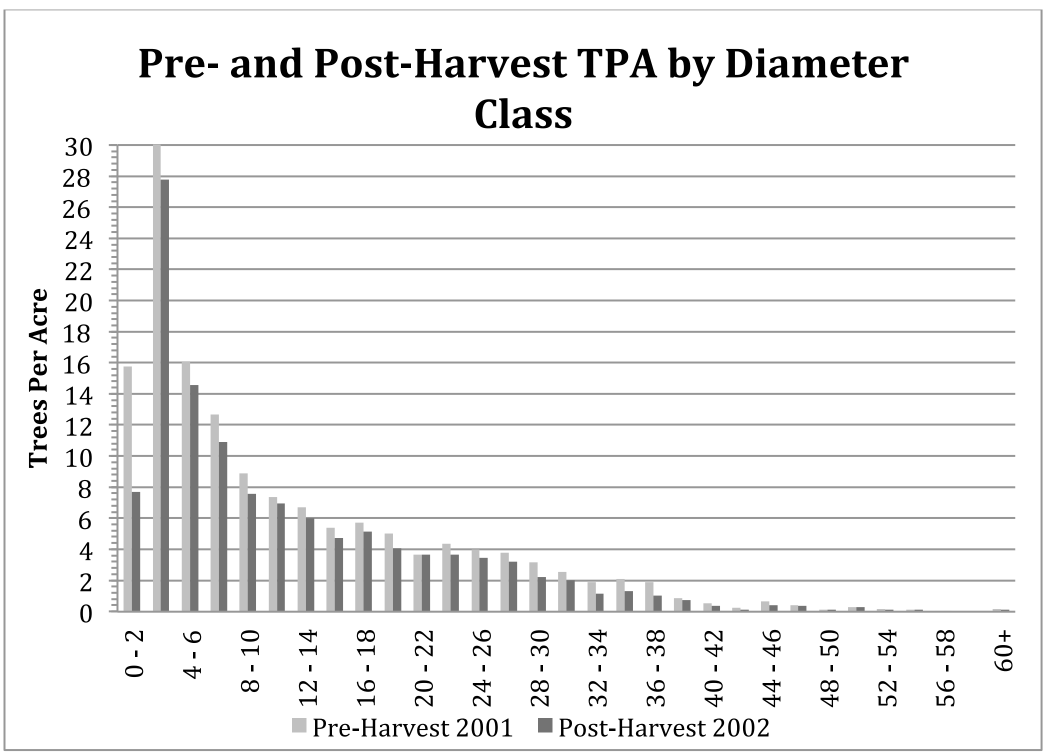

Figure 4—Swanton Pacific Ranch Valencia Tract – FORSEE 2002 post-harvest actual stand data summary. Comparison of 2001 pre-harvest and 2002 post-harvest diameter distribution.

The Valencia Tract was harvested in 2001 and 2002. Actual log scale records indicate a harvest volume of 4,106,000 for the entire Valencia Tract (467 harvested acres). The project data set indicate a harvest volume of 4,165,000 (Taper equation) and 4,330,000 (Spaulding) which is within 1.4 percent and 7.9 percent respectively of the actual volume harvested.

Table 5—Swanton Pacific Ranch Valencia Tract – FORSEE 2002 grown to 2012 yield summary

Forest stocking metrics				
Species group	**TPA**	**QMD**	**BA/ac**	**CO2e/ac**
All conifers	121.06	16.97	190.11	312.03
Redwood	108.97	17.10	173.75	283.62
Douglas-fir	12.09	15.75	16.37	28.23
Hardwoods	138.55	11.08	92.77	151.25
Totals	**259.61**	**14.13**	**282.88**	**463.10**

Gross volume per acre estimation source						
Species group	**Bulletin 1907 equation**	**Bulletin 1907 taper**	**Lennette local equation**	**Bulletin 796 Spaulding**	**Han Masters 6**	**Han Masters 7**
All conifers	34,913	33,402	26,495	32,712	30,119	30,588
Redwood	31,034	29,658	23,301	28,817	26,240	26,710
Douglas-fir	3,878	3,744	3,194	3,895	3,878	3,878
Hardwoods	2,538	2,538	2,538	2,538	2,538	2,538
Totals	**37,451**	**35,940**	**29,033**	**35,251**	**32,657**	**33,127**

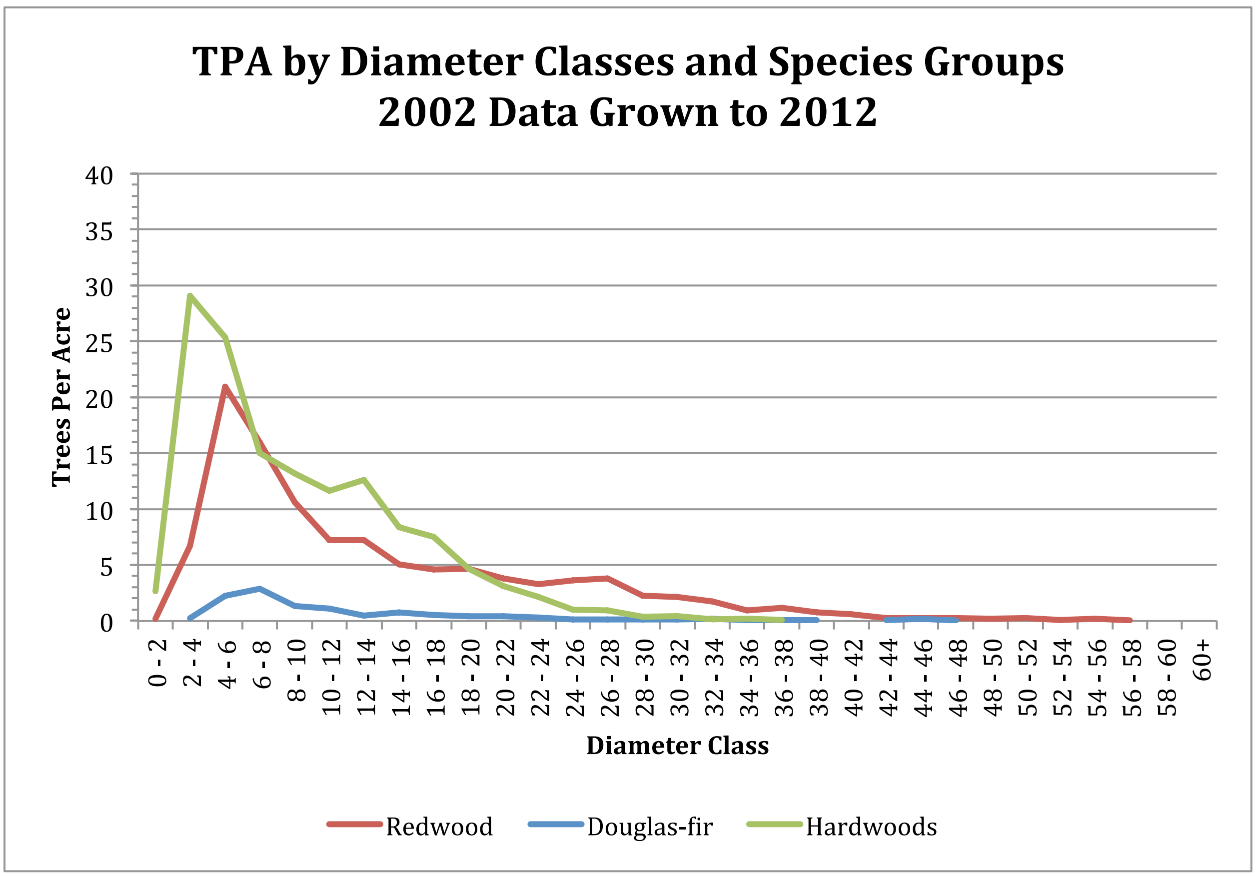

Figure 5—Swanton Pacific Ranch Valencia Tract – FORSEE 2002 grown to 2012. Post-harvest summary. Trees per acre by diameter class and species group.

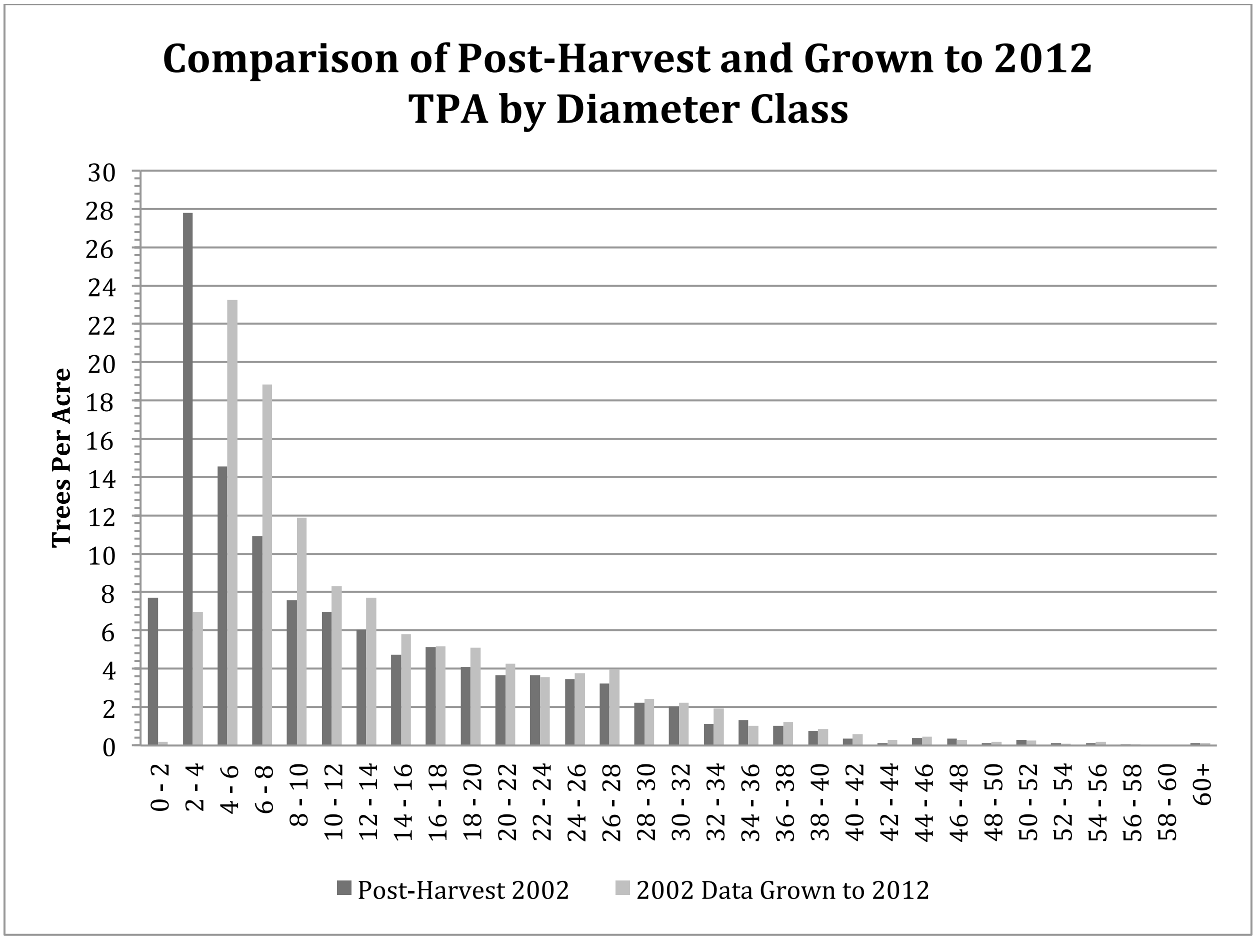

Figure 6—Swanton Pacific Ranch Valencia Tract – FORSEE 2002 grown to 2012. Post-harvest summary comparison of 2002 post-harvest and 2002 grown to 2012 diameter distribution.

Table 6—Swanton Pacific Ranch Valencia Tract – FORSEE 2012 actual stand yield summary

	Forest stocking metrics			
Species group	**TPA**	**QMD**	**BA/ac**	**CO2e/ac**
All conifers	155.11	15.64	206.88	354.93
Redwood	142.99	15.64	190.73	326.15
Douglas-fir	12.12	15.63	16.16	28.78
Hardwoods	148.6	10.42	88.04	150.52
Totals	**303.71**	**13.34**	**294.92**	**505.27**

	Gross volume per acre estimation source					
Species group	**Bulletin 1907 equation**	**Bulletin 1907 taper**	**Lennette local equation**	**Bulletin 796 Spaulding**	**Han Masters 6**	**Han Masters 7**
All conifers	42,227	39,784	32,994	39,367	36,361	36,527
Redwood	38,073	35,739	29,427	35,191	32,207	32,374
Douglas-fir	4,154	4,045	3,567	4,176	4,154	4,154
Hardwoods	2,773	2,773	2,773	2,773	2,773	2,773
Totals	**45,000**	**42,557**	**35,767**	**42,140**	**39,134**	**39,301**

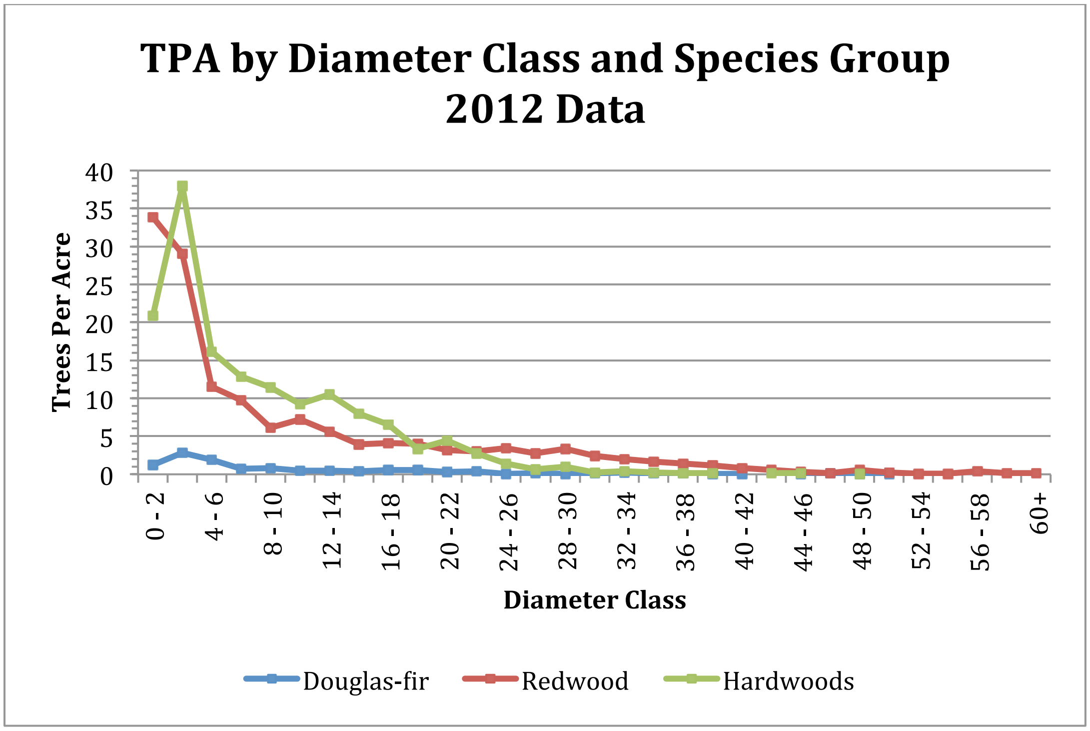

Figure 7—Swanton Pacific Ranch Valencia Tract – FORSEE 2012 actual stand summary. Trees per acre by diameter class and species group.

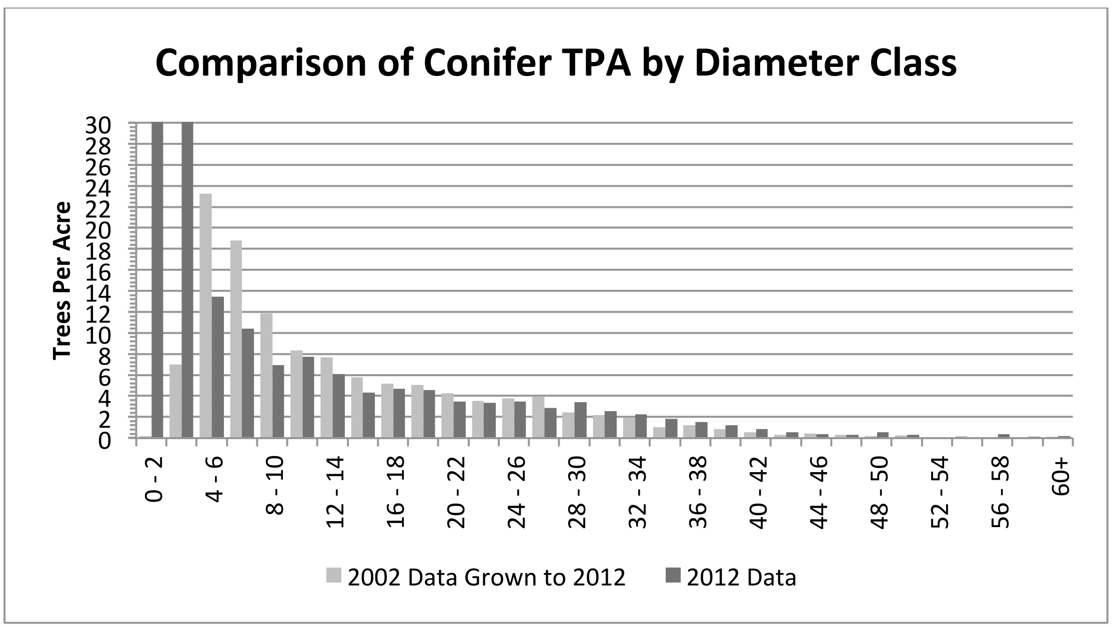

Figure 8—Swanton Pacific Ranch Valencia Tract – FORSEE 2012 CFI Summary. Comparison of 2002 grown to 2012 and 2012 CFI data.

The comparison of the volume equations (based on the 2012 CFI actual stand dataset) are listed from highest to lowest computed redwood volume in table 7.

Table 7—Redwood volume computation ranked from highest to lowest volume per acre based on 2012 CFI dataset

Equation name	Source	Redwood gross volume per acre
Bulletin 1907 equation	1	38,073
Bulletin 1907 taper	1	35,739
Spaulding rule	3	35,191
Masters 7	4	32,374
Masters 6	4	32,207
Lennette local	2	29,427

As previously indicated, the Bulletin 1907 equation is postulated to over-estimate volume by 10 to 15 percent. Likewise, Cal Poly forest managers have experienced that the Lennette Local equation under-estimates volumes by up to 20 percent. Therefore, it seems prudent to identify a reliable volume estimation source between these two extremes. Many California mensurationists are choosing the Bulletin 1907 Taper equation as the best publicly available source. The site specific Han fell and buck volume equations (see footnote 11) is 9 percent less than the Bulletin 1907 Taper estimates, and indicates lower redwood volumes per acre. This project has converted the Lindquist and Palley Bulletin 796 Spaulding Rule table to a form compatible with FORSEE and provides a slightly more conservative estimate of volume due to the 8-inch top diameter, a manufacturing specification that has been common for California mills purchasing coast redwood sawlogs.

The 11-year interval measurement (2001 pre-harvest data and 2012 measured data) indicates that the Valencia Tract was harvested in 2002 at a per acre conifer volume rate of approximately 24 percent (8,712 board feet per acre). By 2012, the Spaulding equation indicates the stand volume growth had completely recovered after harvest and exceeded the pre-harvest 2001 gross volume condition by 9.7 percent (average stand growth of 1,266 board feet per acre per year, or 3.0 percent growth rate per year). The robust growth rate may be attributable, in part, to maintaining large trees in the stand structure.

FORSEE estimates of overall volume grown to 2012 were under-estimated by 16.3 percent compared to 2012 actual measured data (fig. 9). It is postulated that this difference in FORSEE model projection is either a result of the way the CFI data was processed in FORSEE, regional differences, or inherent projection inaccuracies not fully understood by FORSEE users.

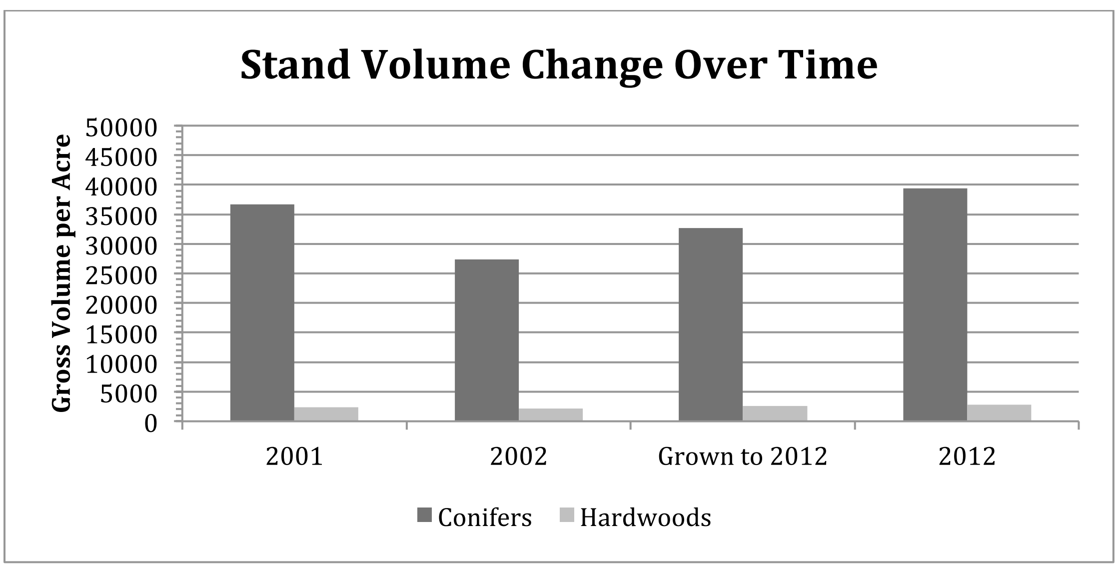

Figure 9—Stand board foot volume change over time.

The measured increase in conifer basal area from 2002 to 2012 was 44.63 square feet per acre, whereas the FORSEE model predicted an increase of 27.86, which represents an 8 percent underestimation in conifer basal area growth based on how the CFI data was processed in the FORSEE model, primarily attributed to not including ingrowth. The 2012 actual stand data indicates the stand has regrown all basal area in the last decade (2001 conifer basal area was 208 per acre; 2012 conifer basal area is 207 per acre).

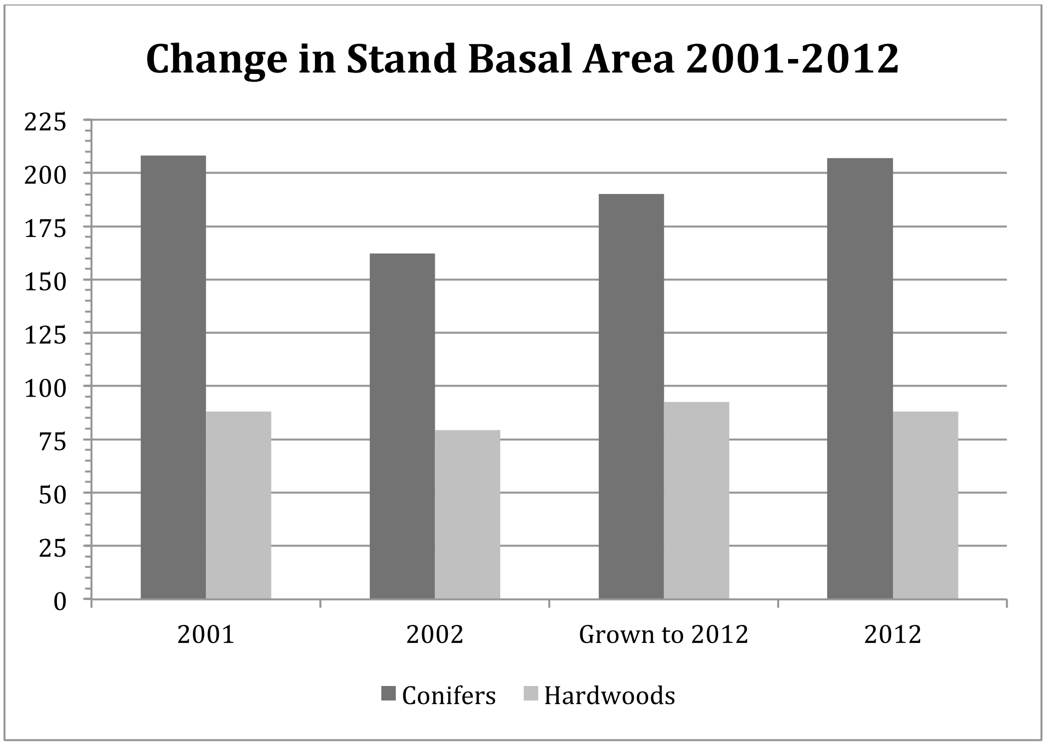

Figure 10—Change in stand basal area 2001-2012.

The FORSEE model predicted a 7.9 percent increase in conifer quadratic mean diameter (QMD); however, there was actually a 0.9 percent decrease per the 2012 data measurement. This is consistent with expectations when not including ingrowth to the FORSEE model.

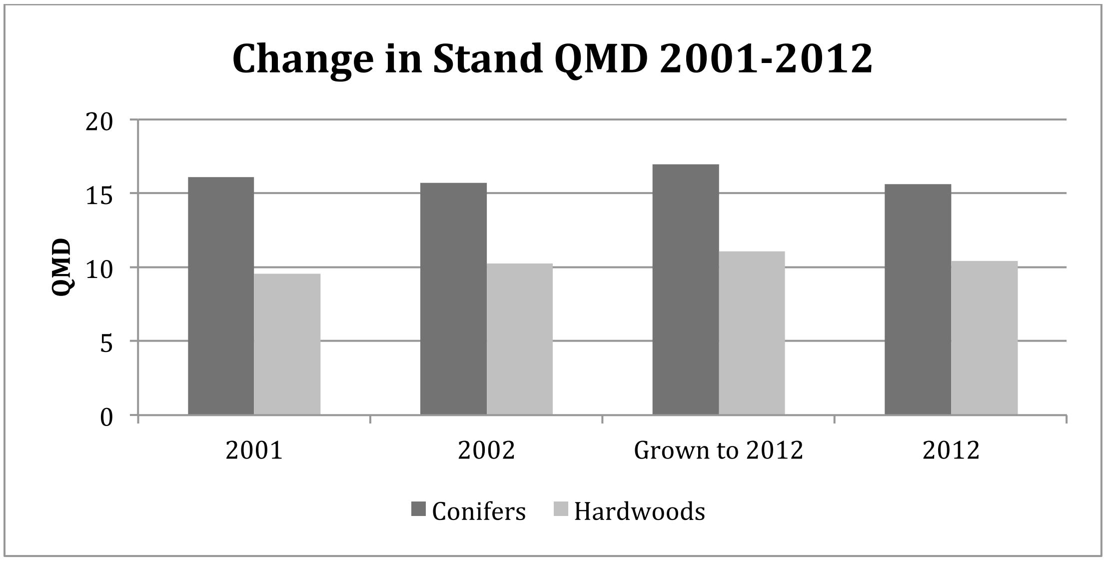

Figure 11—Change in stand QMD 2001-2012.

The FORSEE model predicted very little change in numbers of TPA. This was expected because no ingrowth was added to this growth regime. In comparison to the 2012 data, we may expect more TPA due to sprouting and new seedlings. The 2012 data indicates approximately 34 additional conifer TPA, generally consistent with expectations.

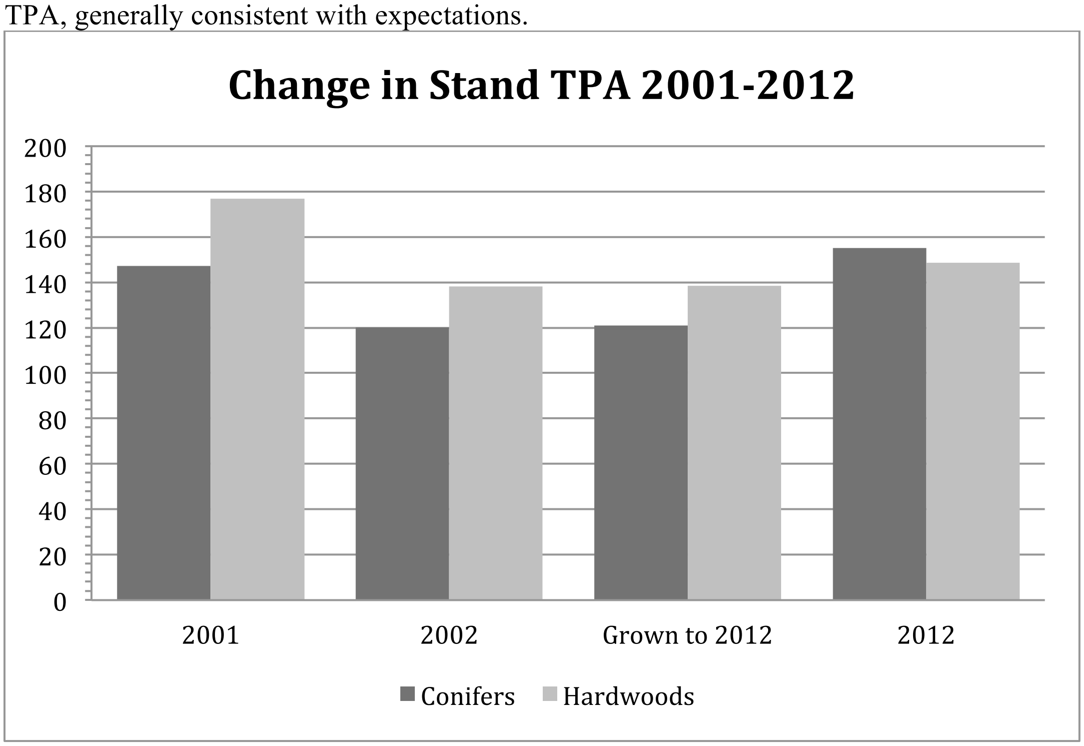

Figure 12—Change in stand TPA 2001-2012.

A detailed examination of the tree growth data revealed that the FORSEE growth model underestimated diameter growth on trees > 33 cm (13 inches) DBH, and underestimated height growth on trees > 53.3 cm (21 inches) DBH; FORSEE growth estimates below these DBH and height values were moderately overestimated. Underestimating growth on the larger trees would underestimate volume, which is consistent with the reported results; overestimating growth on smaller trees would likely have a small impact on volume in the short term, especially considering that trees less than 30.5 cm (12 inches) were not included in the volume reporting totals.

Discussion

We have completed the project objectives, learned lessons, and gained valuable insight into processes that are used to guide future forest management. In developing this comparative study, Cal Poly forest managers needed to review and provide quality control for continuity of inventory data, and while this provided some difficulty, this process will help guide future data collection quality control efforts and record keeping.

Second, Cal Poly forest managers had previously utilized a static local volume table for redwood that was based on Bulletin 796. This project allowed the development of a standardized volume equation utilizing the board foot Spaulding Rule. This fitted equation is compatible with FORSEE and can also be used in other spreadsheet programs that will allow reliable volume estimations for growth and yield updates, timber sale harvest volumes, etc.

Third, the accuracy of the FORSEE growth model for use in the southern sub-district was compared to measured data at a 10-year interval. While growth rates can be adjusted in FORSEE, and the calculated stands site index is a factor in FORSEE growth, the results from the default model settings indicate that for the Valencia Tract, the FORSEE growth model underestimated basal area per acre growth, overestimated the change in QMD, overestimated the growth potential of smaller trees < 30.5 cm (12 inches) DBH, and underestimated the growth potential of larger trees > 33 cm (13 inches) DBH within this forest. This study validates what many forest managers in California have speculated, that updated, regionally specific, growth models are necessary to provide accurate estimates for forest managers to conduct responsible forest planning and for public agencies charged with enforcing long-term sustained yield plans.

Lastly, Cal Poly managers have evaluated six different redwood volume estimation methods and shown that the medial published source (Spaulding Rule) appears reliable for growth and yield reporting for its Santa Cruz County forest tracts. The use of Spaulding Rule volumes is consistent with Cal Poly's historic reliance on this source and its perceived accuracy during previous timber harvest cutouts. Having this equation for direct inventory compilation in FORSEE will be a valuable asset during future management planning and harvesting projects.

Conclusion and Management Implications

The Valencia Tract FORSEE growth results for the Spaulding model (gross volume per acre) were approximately 16.3 percent low for the 2002 to 2012 10-year measurement interval. Based on these results, it is recommended that either a growth adjustment be applied, adjustments to site index, or development of updated, regionally specific growth models be undertaken. Growth adjustments can be difficult to calibrate and defend; updated growth models would aid in the accuracy of estimating and reporting volume growth trends for long-term sustained yield plans and other biomass estimation projects.

Successful use of CFI data and FORSEE growth and yield analysis is dependent upon several factors in addition to landowners' objectives. The collected data is most useful when identified and formatted correctly for use in the analysis. Identification of data needs to include property name, unit and/or stand designator, month and year of data collection. Data format should be consistent with inventory compiler input fields and utilize consistent and repeatable identification codes for status, damage, defect, and other attributes. If working on large properties where data collection effort spans more than one season, a geographic information system is useful to maintain historic records and effectively plan inventory effort to maximize forest management options.

Summarizing, it was determined in this Valencia Tract coast redwood sustainability analysis that: 1) consistency and validation of CFI data is paramount for reliable comparisons; 2) this analysis underestimated basal area per acre growth, overestimated change in QMD), overestimated diameter growth of smaller trees (< 30.5 cm (12 inches) DBH), underestimated diameter growth of larger trees (> 33 cm (13 inches) DBH), underestimated height growth of larger trees (> 53.3 cm (21 inches) DBH), underestimated volume (16.3 percent lower than actual CFI volume figures); 3) by 2012 stand volume growth had completely recovered and exceeded the pre-harvest 2001 gross volume by 9.7 percent (i.e., average stand growth of 1,266 board feet per acre per year, or 3.0 percent growth rate per year); 4) the Spaulding rule appears to be a medial choice for Valencia Tract sustainable yield analysis; 5) sustainable stand management resulted from setting residual stand basal area (b), maximum diameter (d) and trees per acre by diameter targets (q) while leaving a few trees greater than the established maximum diameter. FORSEE is a useful inventory, growth, and yield model that can become better with local calibration and proper use by trained professionals.

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