

METHODS TO DEVELOP THE FORESTLAND DATABASE FOR THE CALIFORNIA BIOPOWER IMPACTS PROJECT

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1 INTRODUCTION

Two Tasks for the California Biopower Impacts Project are supported by the methodologies and datasets described in this document. First, an estimate of forest conditions and residual timber harvest biomass for a wide range of treatments was developed for Task 5: California Residual Biomass-To-Energy Carbon Accounting Tool (CARBCAT). All treatments were simulated at all locations and a transportation analysis was also developed to over 100 facilities. It is intended for the user of CARBCAT to select treatments and locations that result in a useful analysis.

The primary inputs for characterizing forest conditions across California included the 2012 Gradient Nearest Neighbor dataset and disturbance layers for timber harvest, fire, and mortality events. Forest conditions were updated to 2018 by simulating disturbances and growth in annual time steps in the Forest Vegetation Simulator. A set of silvicultural treatments was implemented on the updated forest conditions to bracket potential management intensities ranging from no action to thinning to clearcut. For each treatment, residual standing and harvested tree biomass was calculated for stem, branches, foliage, and bark categories. Rasters summarizing these results were provided for each treatment.

Inputs for the transportation analysis included potential facility locations and a road network layer. ArcGIS Network Analyst was used to calculate travel times and distances to each facility from locations in California. Results were converted into rasters that align with the treatment summary rasters.

Second, a harvested parcels dataset was developed for Task 4: Residual Biomass-To-Energy Life Cycle Emissions Accounting Framework. Parcels were harvested to match historical harvest levels. Treatments were selected by county and owner to reflect typical forest management as identified in timber harvest plans and activities datasets.

Inputs for the parcel analysis included parcel data for each county in California and streams, waterbodies, and wetlands layers. Buffers were calculated for each water feature to identify riparian and upland management zones. A large intersect analysis was then conducted on the parcel, updated forest condition, and management zone layers. The resulting layer identified owner, forest condition, and management zone for each location in California. Appropriate treatments were identified for each owner class, and treatments were restricted to upland zones with appropriate forest conditions. Residual standing and harvested tree biomass are provided for each harvested parcel.

This analysis builds on two related projects. The big data approach used in this analysis was first developed for the Washington Forest Biomass Supply Assessment project. Much of the parcel, ownership, water, and forest data used in this study was developed for the Waste to Wisdom project, which expanded the scope the Washington Forest Biomass Supply Assessment to include Oregon and California. These projects are described first.

2 RELATED PROJECTS

2.1 WASHINGTON FOREST BIOMASS SUPPLY ASSESSMENT

The Washington Forest Biomass Supply Assessment integrated tax parcel, water, and forest condition datasets to estimate residual timber harvest biomass in Washington state (Perez-Garcia et al., 2012).

The project was funded by the Washington State Department of Natural Resources. The project developed a high-resolution spatially explicit database to identify owner, forest class, and management zone. Owner surveys were conducted to inform modeling of harvest techniques and biomass recovery. Silvicultural treatments were modeled, and harvests were simulated on parcels to match historical harvest levels for counties and owner classes. Most of the methods developed for the Washington Forest Biomass Supply Assessment remain applicable for this project.

2.2 WASTE TO WISDOM

The Waste to Wisdom project investigated the conversion of forest residues into biofuels and other products through new collection techniques and localized processing facilities. It was funded by the U.S. Department of Energy Biomass Research and Development Initiative program. For this project, a new spatially explicit database was developed for Washington, Oregon, and California using the methods established previously (Oneill et al., 2017). The database supported supply chain optimization using mobile processing units, demand curve estimation of locally produced biomass products, local air quality assessments of biomass burning, and a life-cycle assessment of biomass recovery. The tax parcel, ownership, water, and forest condition datasets obtained for the Waste to Wisdom project form the starting point for this analysis.

2.3 COMPARISON TO RELATED PROJECTS

Methodologies between this project and related projects differ in a few ways. First, the Washington Forest Biomass Supply Assessment and Waste to Wisdom projects only provided summarized results at the parcel level. This project provides treatment summaries at the 30 meter raster cell resolution for the CARBCAT tool and parcel summaries for the Residual Biomass-To-Energy Life Cycle Emissions Accounting Framework. Second, previous projects used ownership, management zone, and forest conditions to restrict treatment results to a set that was representative of typical management activities. This project summarized the full range of treatments for all owners at all locations in California. Third, each project differed in how the Forest Vegetation Simulator (FVS) was incorporated. The Washington Forest Biomass Supply Assessment used FVS to update forest conditions to a common year by simulating timber harvests to match tabular data by county and owner class, then simulated treatments 30 years into the future. The Waste to Wisdom project did not use FVS to update forest conditions or simulate future treatments. This project used FVS to update forest conditions using spatially explicit timber harvest, fire, and tree mortality disturbance layers, but did not simulate growth or treatments into the future. Treatments implemented on the updated forest conditions are reasonably representative for a 10 year time period, after which addition growth should be accounted for. Fourth, the previous projects used recovery and economic factors to determine the amount of residual harvest biomass left scattered in the woods, piled at the landing, and delivered to processing facilities. This project does not make use of these factors but does provide the ownership, slope, and transportation data necessary to allow them to be applied.

3 FORESTLAND DATABASE

The Forestland Database was developed by intersecting spatial layers for tax parcels, forest condition, and riparian management zone. This intersection divides California into approximately 112 million

segments, with a maximum segment size of 900 square meters. To process the large dataset, custom scripts were written with the ArcPy package for Python (ESRI, 2016; Python Software Foundation). ArcGIS version 10.5 and Python version 2.7 were used for this analysis. A description of the input layers and processing steps are provided next. Prior to the intersection analysis, the forest condition dataset (GNN) was updated with recent timber harvests and disturbance events. This process is described in the following section.

3.1 PARCELS AND OWNERSHIP

A tax parcel layer was obtained for California as part of the Waste to Wisdom project. Tribal and publicly owned parcels were identified using the Protected Areas Database of the United States (PADUS) layer (US Geological Survey 2012). Private industrial parcels were identified using a layer provided by the California Department of Forestry and Fire Protection (2015). Other parcels were assumed to be private non-industrial. All parcels were classified as either private non-industrial, private industrial, California Department of Forestry and Fire Protection, state other, tribal, Forest Service, Bureau of Land Management, or federal other. Permanently unmanaged parcels were also identified using the PADUS layer.

3.2 FOREST CONDITION (GNN)

The Gradient Nearest Neighbor (GNN) dataset is produced by the Landscape Ecology, Modeling, Mapping & Analysis research group, a partnership of the USDA Forest Service, Pacific Northwest Research Station and the Department of Forest Ecosystems and Society, Oregon State University. GNN is a spatially explicit forest inventory covering Washington, Oregon, and California. It is developed by imputing inventory plots from Landsat imagery, topographic attributes, climate and other environmental variables as predictor variables (Ohmann and Gregory, 2002). GNN data is distributed as a raster of forest class identification number (FCID) that corresponds to an inventory plot, and a database of tree, snag, and coarse woody debris records suitable for simulation and analysis with the Forest Vegetation Simulator. The GNN raster was converted into polygons during the intersection process for the Forestland Database.

3.3 WATERBODIES, WATERCOURSES, AND WETLANDS

Watercourses and waterbodies spatial layers were obtained from the California Department of Fish and Wildlife (2015). The National Wetlands Inventory was used to locate wetlands (US Fish and Wildlife Service, 2016). Water features were buffered by 150 feet to delineate riparian management zones.

3.4 SLOPE

During the intersection process, the average slope was calculated for each segment. A 1 arc second (approximately 30 meter) digital elevation model was obtained from the 3D Elevation Program (US Geological Survey, 3D Elevation Program, 2017). A slope raster was created using the ArcGIS Spatial Analyst Slope tool, and the Zonal Stats tool was used to calculate average slope for each polygon.

4 Updating GNN Forest Inventory

The most recent GNN imputation maps are based on Landsat imagery from 2012. Forest disturbance events and growth occurring after 2012 are not accounted for. To address this, timber harvests and natural disturbances were simulated in the Forest Vegetation Simulator (FVS) growth model from 2012 through 2017 (Dixon, 2002). Fires were simulated with the Fire and Fuels Extension for FVS (Rebain, 2010). FVS variants covering California are listed in Table 1.

Table 1. FVS variants covering California and used in this analysis.

Code	FVS Variant	Description
1	CA	Inland California and Southern Cascades
2	CR	Central Rockies
3	NC	Klamath Mountains
4	SO	South Central Oregon and Northeast California
5	WS	Western Sierra Nevada

Spatial datasets were identified for timber harvest, fire, and tree mortality. These layers were overlaid on the original GNN raster, along with the FVS variant layer, and the unique combination of growth and disturbances to be simulated with each forest class was determined. The types of each disturbance are described below. Simulating growth and disturbances in FVS is then described in the following section.

4.1 TIMBER HARVEST

Timber harvest plans for private industrial and non-industrial owners are available from the California Department of Forestry and Fire Protection (California Department of Forestry and Fire Protection Timber Harvest Plans 2018). These plans include sale boundaries, year completed, and the silvicultural treatment applied. Silvicultural treatments were classified into reforestation, salvage, pre-commercial thin, commercial thin, shelterwood thin, seed tree thin, overstory removal, clearcut, and uneven-aged management. These treatments are described in the California Forest Practices Rules and Act (California Department of Forestry and Fire Protection 2018). Each treatment category has a range of allowable harvest amounts. The most common harvest parameters from past timber harvest plans were used as the quantitative definition for each category, shown in Table 2.

Forest Service silvicultural activities are provided in a number of spatial datasets covering reforestation, timber stand improvement, fuel treatment reduction, and timber harvests (2018). For this analysis, treatments were first classified into the nine classes listed in Table 2. Where multiple treatments occurred, the most intensive treatment was assigned.

No significant amount of timber harvest activity occurred in other ownerships during the analysis period. For reference, Table 3 lists the reported acres by owner, treatment type, and year. Caution is required when interpreting the table. First, the Forest Service commonly reports the same activity in multiple datasets (i.e. a thin appears in both the Hazardous Fuels Reduction and Timber Harvest datasets). This double counting is accounted for in the GNN updating process but not in Table 3. Second, the regeneration category for private industrial and non-industrial owners in Table 3 likely reports only

those acres of regeneration not associated with another silvicultural treatment. Regardless, for this analysis, regeneration was simulated in FVS following all shelterwood, seed tree, and clearcut treatments.

Table 2. Silvicultural treatments used to update GNN.

Code	Treatment	Description
1	Regeneration	Plant 435 trees per acre
2	Salvage	Remove all dead trees and plant 435 trees per acre
3	Pre-commercial thin	Thin from below to 300 trees per acre and remove all dead trees and hardwoods
4	Commercial thin	Thin from below to 100 sq ft of basal area and remove all dead trees
5	Shelterwood thin	Thin proportionally to 30 sq ft of basal area above 18 inches and 45 sq ft of basal area below 18 inches and plant 435 trees per acre
6	Seed tree thin	Thin from below, minimum DBH of 4 inches, to 30 sq ft of basal area and plant 435 trees per acre
7	Overstory removal	Remove all trees greater than 18 inches and thin from below to 100 sq ft of basal area
8	Clearcut	Remove all trees (0 trees per acre) and plant 435 trees per acre
9	Uneven-aged management	Thin proportionally to 100 sq ft of basal area and plant 435 trees per acre

Table 3. Silviculture treatment acres by owner, type, and year.

Private Industry						
	2012	2013	2014	2015	2016	2017
Reforestation	1,279	1,688	563	863	272	94
Salvage	13,984	1,464	4,920	3,308	4,287	516
Pre-commercial thin	-	-	53	-	-	114
Commercial thin	10,115	7,972	4,375	4,737	2,013	291
Shelterwood thin	150	-	142	-	71	-
Seed tree thin	526	490	503	361	39	68
Overstory removal	25,059	21,672	10,551	13,160	4,497	1,779
Clearcut	90,302	96,257	52,789	77,737	56,853	14,084
Uneven-aged management	6,449	9,209	7,478	8,023	1,233	469
Private Non-Industrial						
	2012	2013	2014	2015	2016	2017
Reforestation	402	-	98	-	91	-
Salvage	60	-	-	-	-	344
Pre-commercial thin	-	-	-	-	-	-
Commercial thin	28	-	-	94	-	78
Shelterwood thin	-	-	-	-	-	-
Seed tree thin	-	-	-	-	-	-
Overstory removal	-	-	-	-	-	-
Clearcut	7,226	1,544	3,612	2,655	5,556	2,161
Uneven-aged management	-	-	229	-	794	-
Forest Service						
	2012	2013	2014	2015	2016	2017
Reforestation	7,288	6,739	5,711	13,652	12,039	13,739
Salvage	1,680	230	294	299	1,542	104
Pre-commercial thin	39,132	35,769	32,012	37,134	24,680	24,523
Commercial thin	50,300	49,125	60,329	46,833	62,437	54,943
Shelterwood thin	-	-	-	-	-	-
Seed tree thin	36	601	5,223	424	2,351	74
Overstory removal	131	-	13	-	-	-
Clearcut	784	430	2,342	5,808	8,172	2,802
Uneven-aged management	-	-	-	-	-	-

4.2 FIRE

Fire datasets for years 2012 through 2015 were available from the Monitoring Trends in Burn Severity (MTBS) program (US Geological Survey and USDA Forest Service Geospatial Technology and Applications

Center, 2017). This interagency program maps fire perimeters and burn severity at 30 meter resolution using Landsat data (Eidenshink et al., 2007). Burns are classified into low, moderate, and high severity. Low severity burns may kill 50% of sapling-size trees and up to 25% of intermediate and overstory trees. High severity burns kill greater than 75% of overstory trees. The moderate class is described as transitional in magnitude between the other classes.

MTBS data was not available for 2016 and 2017. For Forest Service land in 2016, fire severity was determined using the Rapid Assessment of Vegetation Condition after Wildfire (RAVG) dataset (USDA Forest Service Geospatial Technology and Applications Center, 2017). The RAVG dataset estimates the percentage of basal area loss following wildfire. This data was classified into low, moderate, and high severity classes matching those from the MTBS data: less than 25% mortality, 25-75% mortality, and greater than 75% mortality for low, moderate, and high severity, respectively.

For non-Forest Service land in 2016 and all ownerships in 2017, only fire perimeter data was available. Datasets were downloaded from the USGS Geospatial Multi-Agency Coordination website (<https://www.geomac.gov/>). Within these fire perimeters, high severity fires were assumed. Table 4 reports the acres of low, moderate, high, and unknown fire severity by year.

Table 4. Wildfire acres by fire severity class and year.

Fire Severity Class	2012	2013	2014	2015	2016	2017
Low	361,638	195,370	170,808	293,163	50,569	0
Moderate	195,753	173,882	162,486	216,646	42,980	0
High	96,622	109,834	158,816	156,421	215,541	0
Unknown	0	0	0	0	129,692	1,090,673

Quantitative definitions for fire severity classes are provided in Table 5. Wind speed, moisture, and temperature are model variables used by FFE to adjust fire behavior. The values listed in Table 5 correspond to the default low, moderate, and high severity fire conditions as described in the FFE documentation. A limited examination of simulation results was conducted to determine that output mortality reflected input classification ranges.

Table 5. Parameters to simulate fire in FFE by fire severity class.

Code	Severity Class	Wind Speed	Moisture	Temperature
1	Low	6	3	60
2	Moderate	6	2	70
3	High	20	1	80

4.3 TREE MORTALITY

Tree mortality spatial datasets were obtained from the California Tree Mortality Task Force (<http://www.fire.ca.gov/treetaskforce/>). Annual mortality polygons with estimated severity have been developed from aerial surveys conducted by the USDA Pacific Southwest Region Forest Health

Protection staff. For this analysis, annual mortality was summed from 2012 to 2017 except where a silvicultural treatment, moderate severity fire, or high severity fire occurred. At those locations, mortality was summed only for years later than the disturbance. This assumes dead trees were removed or knocked over during a silvicultural treatment or consumed by the fire. Mortality was then classified into low, moderate, and high severity classes based on threshold values in Table 6. Because the mortality was estimated from an airplane, it is assumed the surveys were of overstory trees. Therefore dead TPA simulation targets are for trees greater than 4 inches DBH.

Table 6. Tree mortality class and dead tree simulation target definitions.

Code	Severity Class	Dead Trees Per Acre	FVS Target Dead TPA
1	Low	10 - 30	20
2	Moderate	30 - 80	50
3	High	>= 80	110

4.4 TREATMENT ORDER

It was possible for more than one disturbance to occur at a single location during the update years. For tree mortality, this was accounted for as described in the Tree Mortality section above and in the FVS modeling. After summing tree mortality over the years, it was assumed to represent 2018 conditions. Between silvicultural treatment and fire, order was determined from the datasets, with options including silviculture before fire, fire before silviculture, or both treatments occurring during the same year. In the last case, order was determined by FVS internal program execution, with silvicultural treatments simulated before fire.

Because FVS always simulates silvicultural treatments before fire within a growth cycle, two growth cycles were used to update GNN from 2012 to 2018. If both silviculture and fire occurred during a simulation, and not during the same year, the first disturbance was simulated in 2012, then the inventory was grown to 2015. The second disturbance was then simulated in 2015, and the inventory was grown to 2018. If both occurred in the same year or only one occurred, the disturbances were simulated in 2015. Tree mortality was always simulated in 2018. Table 7 lists the treatment order possibilities.

Table 7. Treatment order definitions.

Code	Description
1	Silviculture and fire occur in the same year
2	Silviculture occurs before fire
3	Fire occurs before silviculture

4.5 EXAMPLE GNN UPDATE TABLE

Table 8 provides an example intermediate result from the update process described above. Tables 1, 2, 5, 6, and 7 can be referenced to translate the codes. The FCID column provides the initial GNN forest class identification number in 2012. For FCID 69907 (row 1), the Inland California and Southern Cascades

variant was used to simulate a moderate severity fire in 2012, followed by a pre-commercial thin in 2015. After growing the inventory to 2018, additional mortality was simulated if necessary to equal 50 dead trees per acre greater than 4 inches DBH. Finally, a new FCID was created for the unique combination of FCID, growth, and disturbance. The update process resulted in 226,203 unique forest classes in 2018.

Table 8. Example intermediate result from the GNN update process.

FCID	FVS Variant	Silviculture	Fire	Tree Mortality	Treatment Order	New FCID
69907	1	3	2	2	3	351732796
102192	1	7	1	1	3	484613032
106385	1	3	3	1	2	520992807
139505	1	7	1	1	3	579903032
77884	1	7	2	1	3	376523048

4.6 FOREST VEGETATION SIMULATOR

Simulations were performed with FVS for each set of values in the update table (part of which is presented in Table 8). Default growth model values (location, habitat code, slope, aspect, elevation, site index, maximum stand density index) were used for each variant. Standing and cut tree list tables were parsed from the main FVS output files providing tree species, DBH, height, board foot and cubic foot volumes, and trees per acre expansion factor. The Detailed Snag Report, Down Woody Debris Cover Report, Down Woody Debris Volume Report, and All Fuels Report were obtained from FFE. Field descriptions and units are available for each report in the FFE documentation or the User Guide to the Database Extension (Crookston et al., 2003).

4.7 UPDATED GNN RASTER

A new raster was created that provides the updated GNN forest class (FCID) at each location in California in 2018. The FCID provides the relationship to the simulated tree, snag, and coarse woody debris data from FVS. The GNN update process resulted in an identical data structure to the original GNN dataset.

5 SIMULATING TREATMENTS

5.1 TREATMENT DESCRIPTIONS

Fourteen treatments were simulated on each 2018 GNN FCID. Treatments were simulated on all FCID's, including those which would not be feasible for economic or operational reasons. For each treatment, a harvested (or cut) and residual standing tree list was created. The harvested tree list represents those trees that would be removed during the treatment. The residual tree list represents those trees that would be left standing following the treatment.

First, no action and clearcut treatments were simulated for each FCID. No action removed no trees and clearcut removed 100% of the trees. Next, three sets of treatments were simulated, each removing 20, 40, 60, and 80% of the basal area. To achieve these targets, trees were removed solely on the basis of DBH without preference for species. The first set removed trees from below by DBH. This removed the smallest trees (by DBH) first until the basal area removal target was achieved. The second set of treatments removed trees proportionally by DBH. This removed an equal proportion of each tree in the tree list across the range of DBH's in the stand until the basal area removal target was achieved, again with no preference for species. The last set of treatments removed trees from above by DBH. This removed the largest trees (by DBH) first until the basal area target was achieved.

5.2 SNAGS AND DOWNED WOODY DEBRIS

Snags and downed woody debris were summarized separately from live trees. A table was created reporting snag density (snags per acre), basal area, quadratic mean diameter, and biomass, and downed woody debris biomass. Biomass is reported in pounds per acre. Snag size, number, cubic foot volume, and decay class (hard or soft) was calculated by FVS FFE. Snag biomass was then calculated by multiplying volume by wood specific gravity (Forest Products Laboratory, 2010). Snags in the soft decay had biomass reduced by a factor of .5 to account for decay. FFE reports downed woody debris biomass directly. For each of the 14 treatments described, snags could be included or excluded in the silvicultural prescription using this table.

5.3 TREATMENT SUMMARIES

Summary tables were produced for each treatment. An identical set of fields were reported for both residual standing and cut trees. It is possible to calculate pre-treatment conditions by summing residual standing and cut fields. All values are reported on a per acre basis. For each FCID, standard stand structure variables including trees per acre, basal area (square feet per acre), and quadratic mean diameter (inches) were reported. Volume fields included cubic foot and board foot volumes to a six-inch top in trees less than nine inches DBH and in trees greater than nine-inch DBH; and cubic foot volume between a six- and four-inch stem diameter.

Biomass was reported in pounds per acre for stem, bark, branch, foliage, stump, and root components. Stem biomass fields include biomass to a six-inch top in trees less than nine-inches DBH and in trees greater than nine-inches DBH, and biomass between a six- and four-inch stem diameter. Stump biomass was reported separately assuming a one-foot tall stump. Bark biomass was reported for categories that correspond to the stem and stump categories. Branch biomass includes stem biomass from the top of a tree above a four-inch stem diameter. Discussions on the volume and biomass fields are provided in the next section. All summary table fields are described in Table 9.

Table 9. Treatment raster field descriptions.

Field	Description
Value	GNN FCID 2018 version.
Age	Pre treatment stand age.
TPA	Post treatment residual trees per acre.
BA	Post treatment residual basal area (square feet per acre).
QMD	Post treatment residual quadratic mean diameter (inches).
CV6LT9	Post treatment residual cubic foot volume per acre to a 6 inch top in trees with DBH less than 9 inches.
CV6GE9	Post treatment residual cubic foot volume per acre to a 6 inch top in trees with DBH greater than or equal to 9 inches.
CV4To6	Post treatment residual cubic foot volume per acre between 4 to 6 inches stem diameter.
BF6LT9	Post treatment residual board foot volume to a 6 inch top in trees with DBH less than 9 inches.
BF6GE9	Post treatment residual board foot volume to a 6 inch top in trees with DBH greater than or equal to 9 inches.
Stem6BLT9	Post treatment residual stem biomass (pounds per acre) to a 6 inch top in trees with a DBH less than 9 inches.
Stem6BGE9	Post treatment residual stem biomass (pounds per acre) to a 6 inch top in trees with a DBH greater than or equal to 9 inches.
Stem4To6B	Post treatment residual stem biomass (pounds per acre) between 4 to 6 inches stem diameter.
BarkStem6BLT9	Post treatment residual bark biomass (pounds per acre) to a 6 inch top in trees with a DBH less than 9 inches.
BarkStem6BGE9	Post treatment residual bark biomass (pounds per acre) to a 6 inch top in trees with a DBH greater than or equal to 9 inches.
BarkStem4To6B	Post treatment residual bark biomass (pounds per acre) between 4 to 6 inches stem diameter.
BranchB	Post treatment residual branch biomass (pounds per acre).
FoliageB	Post treatment residual foliage biomass (pounds per acre).
StumpB	Post treatment residual stump biomass (pounds per acre).
BarkStumpB	Post treatment residual stump bark biomass (pounds per acre).
RootB	Post treatment residual root biomass (pounds per acre).
CutTPA	Harvested trees per acre.
CutBA	Harvested basal area (square feet per acre).
CutQMD	Harvested quadratic mean diameter (inches).
CutCV6LT9	Harvested cubic foot volume per acre to a 6 inch top in trees with DBH less than 9 inches.
CutCV6GE9	Harvested cubic foot volume per acre to a 6 inch top in trees with DBH greater than or equal to 9 inches.
CutCV4To6	Harvested cubic foot volume per acre between 4 to 6 inches stem diameter.
CutBF6LT9	Harvested board foot volume to a 6 inch top in trees with DBH less than 9 inches.
CutBF6GE9	Harvested board foot volume to a 6 inch top in trees with DBH greater than or equal to 9 inches.

CutStem6BLT9	Harvested stem biomass (pounds per acre) to a 6 inch top in trees with a DBH less than 9 inches.
CutStem6BGE9	Harvested stem biomass (pounds per acre) to a 6 inch top in trees with a DBH greater than or equal to 9 inches.
CutStem4To6B	Harvested stem biomass (pounds per acre) between 4 to 6 inches stem diameter.
CutBarkStem6BLT9	Harvested bark biomass (pounds per acre) to a 6 inch top in trees with a DBH less than 9 inches.
CutBarkStem6BGE9	Harvested bark biomass (pounds per acre) to a 6 inch top in trees with a DBH greater than or equal to 9 inches.
CutBarkStem4To6B	Harvested bark biomass (pounds per acre) between 4 to 6 inches stem diameter.
CutBranchB	Harvested branch biomass (pounds per acre).
CutFoliageB	Harvested foliage biomass (pounds per acre).
CutStumpB	Harvested stump biomass (pounds per acre).
CutBarkStumpB	Harvested stump bark biomass (pounds per acre).
CutRootB	Harvested root biomass (pounds per acre).

5.4 TREATMENT RASTERS

Summary tables for treatments and snags were joined to the updated GNN raster to create 14 rasters that represent the post-harvest biomass for each treatment described above. Fields are described in Table 9. These provide biomass and harvest volume data for each treatment at all locations in California.

6 CALCULATING TREE BIOMASS

6.1 TREE COMPONENT BIOMASS

Tree component biomass was calculated using the component ratio method (Heath et al., 2009). First, biomass in the merchantable stem was calculated from tree volume estimates and wood specific gravity (Forest Products Laboratory, 2010). Merchantable volume from FVS was used for this analysis.

Next, merchantable stem biomass was calculated again using national biomass estimators (Jenkins et al., 2003). This approach uses allometric equations to predict tree component biomass from DBH and species. The ratio of merchantable stem biomass using the two approaches was calculated. Finally, tree component biomass for bark, live branches, dead branches, foliage, and roots was calculated using the national biomass estimators and scaled using the calculated ratio.

Jenkins defined the merchantable stem by a one-foot stump and minimum top diameter of four inches. Biomass in the stem top was included with the live branches and stump biomass was disregarded. In FVS, merchantability was defined as a one-foot tall stump and six-inch minimum top diameter. To be consistent between two merchantable stem biomass estimates described above, biomass representing the stem between four- and six-inches was added to the FVS estimate. First, cubic foot volume including top and stump (CVTS) was obtained from FVS. CVTS is a standard tree metric

measuring woody stem volume from the ground (root collar) to the tip of the bole. Subtracting the merchantable volume from the total volume leaves the volume in the stump and the top (above a six-inch diameter) of the tree. Stump volume was calculated as the frustum of a cone, with the top of the stump five percent larger than the DBH and the bottom of the stump 10% larger than the DBH. The stump volume was subtracted away leaving only the top volume. The top of the stem above a six-inch diameter was assumed to be a cone. The volume between a six- and four-inch top was therefore assumed to be 56% of the remaining top volume. Stem biomass calculated using CVTS and wood specific gravity was allocated proportionally by volume among the stem sections. Bark biomass calculated using the component ratio method was also divided among the stem sections in the same way.

6.2 RESIDUAL HARVEST BIOMASS

Residual harvested biomass is the biomass from harvested trees that is not part of a merchantable log. This amount can be calculated from the component biomass estimates but requires assumptions that are not made in this analysis. The Washington Forest Biomass Supply Assessment and Waste to Wisdom projects assumed residual harvested biomass included biomass from live branches, dead branches, foliage, and a proportion of the stem due to breakage and defect (10% was assumed in each project). These studies also included stem biomass from small non-merchantable trees.

For this study, stem biomass and volume were broken out into several categories to support multiple economic assumptions. Mill infrastructure (including proximity to a mill and log size specifications for a mill) and market conditions (e.g. log prices) determine in part whether small logs are merchantable or should be counted as residual harvested biomass. Small logs come from trees with small DBH's and from the top log of larger trees. This study used a nine-inch DBH to identify potentially non-merchantable trees. For trees smaller than nine inches, both stem biomass and board feet were reported. Trees larger than nine inches were always assumed to have a merchantable stem. Similarly, stem biomass was broken out for the stem between six- and four-inches in diameter. Board foot volume was not reported for this material; however, it might be considered merchantable as part of a pulp or chip-and-saw log.

In the previous studies, residual harvested biomass was further categorized into "scattered throughout the harvest unit" and "piled at the roadside and landing." This was calculated using owner survey information about harvest systems (ground or cable based). Recovery factors representing the proportion of residual harvested biomass that reaches the roadside is listed in Table 10. A slope break of 30% was used to delineate ground and cable harvest systems in the previous studies. For the Washington Forest Biomass Supply Assessment, these factors were reported by region in Washington, incorporating different equipment and techniques. The regional factors were averaged and applied as rough estimates for the Waste to Wisdom project. These averages may or may not be useful in California.

Table 10. Recovery factors by harvest system and owner type used in the Waste to Wisdom project.

	Ground	Cable
Private	.94	.78
Federal	.62	.56

7 TRANSPORTATION

A transportation analysis was conducted to 163 locations in California representing potential biomass processing facilities. A layer with existing, historical, or proposed power plant and wood processing facilities was developed in part from mill locations collected by Prestemon et al. (2005) and Spelter et al. (2009). The ArcGIS Network Analyst Service Area tool was used with a road network layer from ESRI Business Analyst to calculate miles and minutes from each location in California to each facility. Results were accumulated in five mile or minute intervals. Maximum values of either 240 miles or minutes were allowed, with the limiting factor being 240 minutes for the vast majority of locations. Each service layer was converted into time and distance rasters, totaling 326 transportation rasters.

Because the Business Analyst road network does not include all forest roads, a distance to road raster was created using the ArcGIS Spatial Analyst Euclidean Distance tool. The distance to roads was report in meters. This straight-line distance could be multiplied by a factor representing road travel time or distance and added to the transportation rasters to estimate total travel.

8 FOREST CLASS CLUSTER ANALYSIS

A clustering analysis was performed to identify groupings within the 2018 pre-harvest forest classes. A representative forest class was selected for each group. The clustering analysis was completed to allow project partners to work with a smaller dataset for subsequent analyses.

First, a dominant species class was determined for each forest class. FCID's with greater than 80% basal area in a single species were classified by that species (i.e. "DF" for Douglas fir). Stands with less than 80% were classified as mixed (prepended with an "M"), followed by the species with the majority or plurality of basal area, followed by other species with at least 20% basal area in descending order (i.e. "MDF" for mixed Douglas fir with minor species, "MDFBO" for mixed Douglas fir with a significant black oak component (> 20% by basal area)). All species groups that made up at least 1% of forest area in California were identified. The remaining species groups were generalized by first keeping the majority/plurality species but lumping minor species into hardwoods or softwoods (i.e. "MDFOS" for mixed Douglas fir with other softwoods or "MDFOH" for mixed Douglas fir with other hardwoods). Finally, species groups that still didn't make up at least 1% of forest area were further generalized into "MOSOH" (mixed other softwoods with other hardwoods) or "MOHOS" (mixed other hardwoods with other softwoods).

Next, within each dominant species class, k-means clustering was used to group FCID's with similar structural attributes (R Core Team, 2017). Centering and scaling was used to normalize trees per acre, quadratic mean diameter, stand height, snag tons per acre, and downed woody debris tons per acre. Elbow plots of within groups sums-of-squares were produced using 1 to 15 clusters. The optimal number of clusters was identified as the breakpoint that results in a segmented linear model that minimizes the variance amongst all possible segmented models. This decision criteria approximates an analyst manually implementing the "elbow method" to identify the optimal number of clusters, whereby adding addition clusters improves the variation explained by only a small amount (Thorndike 1953).

Finally, for each species-structure group, a representative forest class was identified. This was the forest class with the minimum Euclidean distance from the mean values in normalized space. A total of 177 groups and representative stands were identified. Raster and tabular datasets were developed to link the representative forest class to the 2018 forest class. Tree, snag, and downed woody debris data was provided for each representative stand as a Microsoft Access database.

9 SIMULATING HARVESTS TO MATCH HISTORICAL LEVELS

Historical timber harvest data was obtained from the University of Montana Bureau of Business and Economic Research, which provided annual harvested board foot volume by county and owner. Average board foot volume was calculated for each county and owner for years 2012 to 2016 and multiplied by 10 to simulate harvesting over a decade. To characterize silvicultural methods across California, private timber harvest plans and Forest Service activities were intersected with counties and the acres for clear-cuts and thins were summed. Thins were assumed to produce half the volume of clear-cuts. New harvest targets by activity were then calculated by apportioning the county and owner targets by the activity acres and thinning weight.

A thin treatment was identified for each FCID from the simulated treatments and using the basal area requirements in the California Forest Practice Rules. Thins were always assumed to be from below by DBH. Conditions for residual basal area target (125, 100, 75, and 50 square feet per acre) and minimum harvested volume (4000, 3000, 2000, and 1000 board feet per acre) were then considered in pairs. For each FCID, the treatment that removed at least the minimum volume and retained the basal area target was identified. If no treatment satisfied the condition, the next pair of values was considered. If no treatment satisfied the conditions the FCID was not eligible to be treated. Clear-cuts removed 100% of the trees and were required to remove at least 5000 board feet per acre of volume.

After identifying treatments, the parcels were prioritized for thins by calculating the average harvested volume per acre from the parcel. Only forested segments that were in a managed zone with ages between 20 and 150 years old. Age data came from the GNN dataset. Riparian forests and permanently unmanaged forest segments were removed from the analysis. Parcels were then selected for harvest until the thin target was achieved for each county and owner. Next, parcels not harvested with thins were prioritized to be clear-cut in the same way.

A file geodatabase of harvested parcel data was provided. The geodatabase includes the harvested parcel points and tables with distance to road, miles and minutes to each facility, and harvested segments. The harvested segments table identifies the FCID, representative FCID, treatment applied, slope, and acres for each segment. Finally, the treatment summary fields for both residual standing and cut trees were provided. The harvested volume, biomass, and transportation data (and linkage to the representative FCID for other analyses) should support a life-cycle assessment.

10 DATA SOURCES

10.1 PARCELS AND OWNERSHIP

1. Parcels: Waste to Wisdom project acquisition
2. Major Public Ownership: <https://gapanalysis.usgs.gov/padus/>

10.2 FOREST CLASS

1. GNN: <https://lemma.forestry.oregonstate.edu>

10.3 WATERCOURSES, WATERBODIES, AND WETLANDS

1. Watercourses and waterbodies: <https://www.wildlife.ca.gov/Data/GIS/Clearinghouse>
2. National Wetlands Inventory: <https://www.fws.gov/wetlands/data/Mapper.html>

10.4 TIMBER HARVEST ACTIVITY

1. Forest Service Activity: <https://data.fs.usda.gov/geodata/edw/datasets.php>
2. California Private Timber Harvest Plans:
http://www.fire.ca.gov/resource_mgt/resource_mgt_forestpractice_thpstatus

10.5 FIRE

1. MTBS: <https://www.mtbs.gov/>
2. RAVG: <https://www.fs.fed.us/postfirevegcondition>
3. Perimeters: <https://www.geomac.gov/>

10.6 TREE MORTALITY

1. Tree Mortality: <http://egis.fire.ca.gov/treemortalityviewer/>

10.7 TRANSPORTATION

1. Facility locations (in part): <https://www.srs.fs.usda.gov/econ/data/mills/>
2. Transportation: ESRI Business Analyst (2016)

10.8 HISTORICAL TIMBER HARVEST DATA

1. http://www.bber.umn.edu/FIR/H_harvest.asp

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