Calforests
California Forestry Association

1215 K Street, Suite 1830
Sacramento, CA 95814
916.444.6592

April 10, 2017

Mary D. Nichols, Chair
California Air Resources Board
1001 "I" Street
Sacramento, CA 95814
RE: "Proposed 2030 Target Scoping Plan"

Dear Chair Nichols and Board Members:

Thank you for the opportunity to comment on the 2030 Target Scooping Plan. The California Forestry Association represents landowners who own over 4 million acres of timberlands in the State. Our comments focus on the Natural Resource Working Lands sections in the main report and Appendix G.

We strongly support the statement at page 19 regarding forests and natural resource lands:

"These lands support clean air, wildlife and pollinator habitat, and rural economies, and are critical components of California's water infrastructure. Keeping these lands and waters intact and at high levels of ecological function (including resilient carbon sequestration) is necessary for the well-being and security of Californians in 2030, 2050, and beyond. Forests, rangelands, farms, wetlands, riparian areas, deserts, coastal areas, and the ocean store substantial carbon in biomass and soils. Natural and working lands are a key sector in the State's climate change strategy. Substantially storing carbon in trees, other vegetation, soils, and aquatic sediment is the most effective way to remove carbon dioxide from the atmosphere. "

We also strongly support the statement beginning at page 108:

"Policy in this sector must balance carbon sequestration with other co-benefits. California's climate objective for natural and working lands is to maintain them as a carbon sink (i.e., net zero or even negative GHG emissions) and minimize the net GHG and black carbon emissions associated with management, biomass utilization, and wildfire events. "

California's timberlands are currently a carbon sink. While wildfires and unprecedented tree mortality are sources of carbon releases, the most recent field data collected by the US Forest Service indicates there both public and private timberlands have net increase in tree volume. The US Forest Service "Forest

Inventory and Analysis (FIA)" program has installed over 5,500 permanent sample plots across California that are re-measured at regular intervals to track changes in forest conditions. The national forest timberlands (over a ten year period) and both corporate and non-corporate (over a 20 year period) all had positive net changes in tree volume and biomass.

We believe the greatest opportunity for maintaining California's timberlands as a carbon sink (with all of the added co-benefits) is to:

> I) Conduct active management to improve forest heath and increase resilience to insects, disease and wildfire;
> 2) Maintain cost-effective regulatory programs to encourage continued timberland management;
> 3) Develop incentive programs to support ongoing timberland ownership;
> 4) Support programs that maintain current and create opportunities for new manufacturing infrastructure;
> 5) Support biomass-based energy (current and new).

We have major concerns over the graphs in Appendix G at pages 20 and 21. Both of these graphs show a substantial drop in forest "landscape carbon" (page 20) and "wood carbon" (page 21) starting in 2017. The cause of this substantial drop associated with forest carbon below the baseline is not well explained in the document, and can be easily taken out of context. The graph does not explain the total life cycle involved with forest carbon, and could be construed by uninformed individuals that forest harvesting results in a loss of forest carbon as a result. Although we know that is not the case, in order to provide context to what occurs on the forested landscape we would suggest that studies from the University of California (Stewart and Sharma, 2015 and Stewart and Nakamura, 2012, both attached) be included or incorporated to give broader context and an accurate description of the forest carbon life cycle.

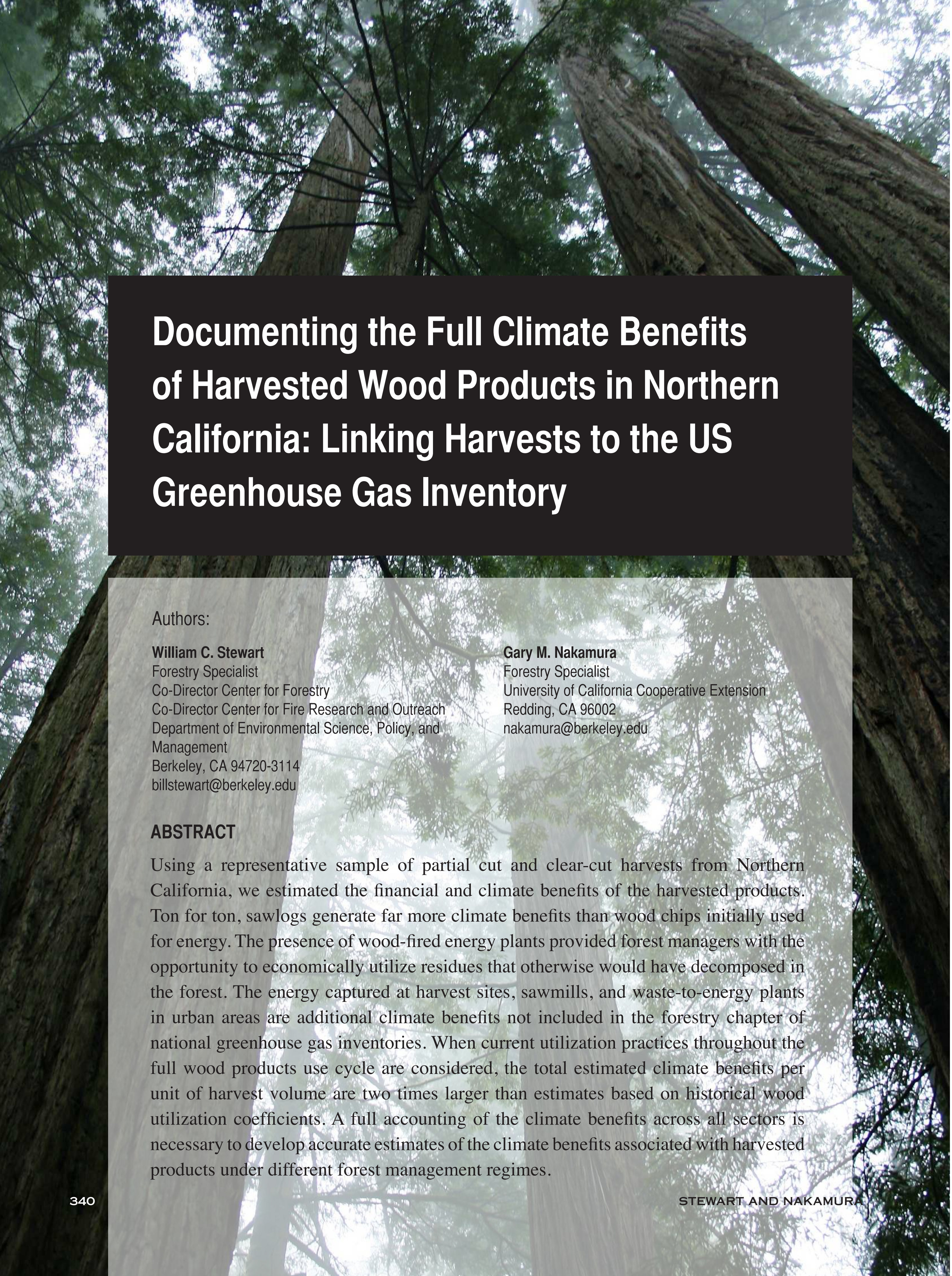
Our landowners must comply with the California Forest Practice Act and Rules. This comprehensive system mandates Long Term Sustained Yield (LTSY) and Maximum Sustained Production (MSP) in addition to consideration of all environmental benefits. This means that all major timberland owners (>50,000 acres) are required under the Forest Practice Rules to demonstrate how they will maximize sustained yield and balance harvest and growth over a 100 planning horizon. Reviewing the documentation submitted to CAL FIRE demonstrates increasing net timber inventories (growth minus timber harvest) for the planning horizon.

Thank you for the opportunity to review and comment on the Proposed 2030 Target Scoping Plan.

Sincerely,

George Gentry

George D. Gentry
Vice President-Regulatory Affairs
California Forestry Association
1215 K St., Suite 1830
Sacramento, CA 95814
916-208-2425
georgeg@calforests.org



Documenting the Full Climate Benefits of Harvested Wood Products in Northern California: Linking Harvests to the US Greenhouse Gas Inventory

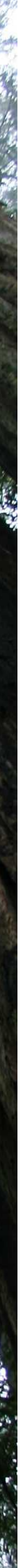
Authors:

William C. Stewart
Forestry Specialist
Co-Director Center for Forestry
Co-Director Center for Fire Research and Outreach
Department of Environmental Science, Policy, and Management
Berkeley, CA 94720-3114
billstewart@berkeley.edu

Gary M. Nakamura
Forestry Specialist
University of California Cooperative Extension
Redding, CA 96002
nakamura@berkeley.edu

ABSTRACT

Using a representative sample of partial cut and clear-cut harvests from Northern California, we estimated the financial and climate benefits of the harvested products. Ton for ton, sawlogs generate far more climate benefits than wood chips initially used for energy. The presence of wood-fired energy plants provided forest managers with the opportunity to economically utilize residues that otherwise would have decomposed in the forest. The energy captured at harvest sites, sawmills, and waste-to-energy plants in urban areas are additional climate benefits not included in the forestry chapter of national greenhouse gas inventories. When current utilization practices throughout the full wood products use cycle are considered, the total estimated climate benefits per unit of harvest volume are two times larger than estimates based on historical wood utilization coefficients. A full accounting of the climate benefits across all sectors is necessary to develop accurate estimates of the climate benefits associated with harvested products under different forest management regimes.



INTRODUCTION

The potential to increase climate benefits through changes in the management of existing forests is a topic of increasing interest but limited certainty (Nabuurs et al. 2007). A positive net climate benefit balance from managed temperate forests was proposed and initially demonstrated with modeled forest simulations by Schlamadinger and Marland (1996) and supported by other modeled forest examples (Perez-Garcia et al. 2005, Eriksson et al. 2007, Hennigar et al. 2008). Numerous policy analyses support the benefits of continued sustainable management of temperate forests (Nabuurs et al. 2007, Canadell and Raupach 2008, Malmsheimer et al. 2011) based on modeled forest stands, harvesting assumptions, and consumer use patterns. While most European studies based on project level data generally concur with these conclusions (Gustavsson and Sathre 2011, Gustavsson et al. 2011, Makela et al. 2011, Richardson 2011, Werhahn-Mees et al. 2011, Kilpeläinen et al. 2012), a number of US-based authors have suggested that greater climate benefits in temperate forests could be achieved by reducing harvest levels below sustainable harvest levels (Harmon et al. 1996, Gutrich and Howarth 2007, Nunery and Keeton 2010, Gunn et al. 2011, Hudiburg et al. 2011).

The goal of this study was to use project-level data from a region that exemplifies best practices in terms of efficient utilization of harvested products to test whether the divergence in outcomes is primarily related to assumptions regarding the allocation of harvested biomass into long-lived products, paper products, energy, and uncollected waste. Because many of the studies in the United States used similar forest growth models but still came to conflicting conclusions, this article focuses solely on the harvested products. We analyzed the utilization of wood biomass from 28 recent harvest operations conducted by five different forest owners over 6,870 hectares in Northern California. The operations included a mix of partial cut and clear-cut harvests in a region with both sawmills and wood-fired energy plants but no pulp mills or wood-based panel plants. We estimated the financial benefits using regional product prices and costs. We estimated climate benefits with utilization efficiencies at the harvest, mill, consumer, and postconsumer stages from both historically based estimates (Smith et al. 2006) as well as more recent estimates (Skog 2008, Smith et al. 2009, Keegan et al. 2010b, US Environmental Protection Agency 2012).

METHODS

To develop a representative sample of harvested products, we collected project data from private forest landowners in the northern interior region of California where there are five large sawmills and five wood-fired energy plants. High wholesale energy prices and long-standing state policies supporting wood-fired energy plants have been important in supporting wood-fired energy plants that purchase logging residues for fuel. More than half of the timberland in the region is publicly owned, but nearly all the harvest volume currently comes from private lands (California State Board of Equalization 2010). Private landowners use both partial cuts and clear-cuts to produce sawlogs for sawmills as well as chips for wood-fired energy plants. Based on Forest Inventory and Analysis (FIA) data for California harvests between 2001 and 2005, 49 percent of harvest area was partial cuts and 51 percent was clear-cuts (Christensen et al. 2008, Smith et al. 2009).

All of the harvests in our sample were conducted under the sustainable forest practice regulations of the California Forest Practice Rules (California Department of Forestry and Fire Protection 2009), and all the forest landowners were certified under the Sustainable Forestry Initiative or the Forest Stewardship Council systems. High-value sawlogs are the dominant consideration of California forest managers (Keegan et al. 2010a). Because the harvests were undertaken by profit-making entities, it was assumed that collecting forest chips for energy was done because it had a positive cash flow, was a silvicultural investment for future timber harvests, or was a less expensive option for disposing of harvest residues.

The lack of pulp mills and major wood-based product facilities in California means that the only economically viable use of low-value forest biomass wood chips collected at the harvest site is to generate thermal energy for use inside the plant or electricity that is sold into the regional grid. A network of wood-fired power plants was constructed in the 1980s in response to the Public Utilities Regulatory Policies Act (PURPA 1978; Hirsh 1999). California currently has 23 biomass-fueled energy plants, with about half of them located in forested regions (Mayhead and Tittmann 2012). While reducing wildfire risks through fuel treatments and biomass utilization has been proposed for many fire-prone forests in California and other dry forests (Becker et al. 2009) and has been demonstrated to be cost-effective in this region (Fried et al. 2003, Daugherty and Fried 2007, Barbour et al. 2008), the area actually treated to reduce fire risk has been small compared with the area of silvicultural treatments undertaken for other objectives on private forest lands.

Sampling of study sites

We interviewed the five major private forest landowners in the region who provided us project-level operational data on recent projects. To develop a representative view of the regional climate benefits, we applied the average per hectare values for partial cut and clear-cut harvests to the ratio of those treatments in the region as measured in the most recent FIA survey. The study involved 28 timber harvest projects that applied a mix of partial cuts and clear-cuts on 6,870 hectares of private land in Northern California between 2000 and 2008. The sites were located between 40°15′36″N and 41°53′24″N latitude and 120°39′0″W and 122°39′0″W longitude. Elevations ranged from 581 to 2,216 m in a region with a Mediterranean climate, a long summer dry season, and significant fire risk. The forest types are mainly dry mixed conifer forests dominated by ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), white fir (*Abies concolor* (Gord. & Glend) Lindl.), incense-cedar (*Calocedrus decurrens* (Torr.) Florin), and California black oak (*Quercus kelloggii* Newb.). The region also has high risks of large-scale, damaging crown fires (California Department of Forestry and Fire Protection 2008, Christensen et al. 2008).

Analysis of biomass utilization

Information was provided by the operators on the silvicultural methods, the harvest method (machine whole tree harvest or manual felling and bucking), the weights of harvested and uncollected material, the moisture contents of the products, and the distance to the sawmill and biomass facilities. The mass of logging residue left on site was extrapolated from operator estimates of the number and size of slash piles, the amount of scattered biomass left on the sites, and volume-to-weight conversions from Hardy (1996). The five different operators provided similar estimates of logging residues per unit of area, but the lack of recorded measurements increased the chance that we underestimated the volume of logging residues left on site for eventual pile burning.

Based on 2006 California sawmill inventory results in Smith et al. (2009) and Keegan et al. (2010b), 75 percent of the delivered sawlogs ended up as wood products, 24 percent was used for energy, and 0.9 percent was uncollected waste. These more recent studies document a much more efficient process than the assumed 20 percent uncollected waste in Harmon et al. (1996) or the assumed 16 percent uncollected waste in Smith et al. (2006).

Financial analysis

To account for variable market prices of sawlogs and woody biomass delivered to power plants, we applied the decadal average market prices and industry-wide estimates of harvesting cost to all the operations. Over 95 percent of area of partial cuts and clear-cuts in our sample were harvested with mechanical whole tree harvesting methods in which the tops and branches came to the landing as part of the tree, were separated from the sawlogs, and then chipped and loaded into chip vans. The net revenue for sawlogs and chips accounted for the costs to bring the trees to the landing as well as the transport cost by log trucks to the sawmills and chip vans to the power plants. We could not include the significant costs associated with planning, permits, and the regulatory approval process because we were not able to reconstruct these costs.

Analysis of the carbon balances and climate impacts

The postharvest forests should continue to accumulate carbon at or above current rates because private forest owners are required to meet postharvest stocking requirements and are inclined to implement improved technologies to achieve higher value growth of their forest stands. Clear-cut harvest areas are replanted to meet state forest practice laws and will not be harvested for decades. Partial cut harvest areas will typically be harvested periodically every 10 to 20 years. The harvested woody biomass goes into products, energy, or uncollected waste. Sawlogs will be delivered to sawmills where dimensional lumber is the main product and chips are a secondary product. The products are sold and used for a variety of products with varying carbon retention half-lives. Based on the average initial allocation of products over the past 30 years in which half of all timber products go into single family houses and half goes into multifamily buildings and other uses (McKeever and Howard 2011) and the estimated half-life of different types of wood products (Skog 2008), we calculated a 52-year half-life for wood products manufactured in California. This is considerably longer than the retention estimate in Smith et al. (2006) that is mathematically equivalent to a 25-year half-life for wood products manufactured in California. The Smith et al. (2006) tables are embedded in the now suspended Department of Energy's 1605b guidelines (US Department of Energy 2012) that are still used in many voluntary greenhouse gas accounting systems, all of the recent US Forest Service carbon calculators (US Department of Agriculture Forest Service–Northern Research Station 2012), as well as in the current forest offset protocols accepted by the California Air Resources Board (2011) for evaluating forest offset projects.

Woody biomass is currently the second largest source of renewable energy in the United States, with the majority of the energy being used within sawmills and pulp mills and a minor share to generate electricity for sale to the grid (US Environmental Protection Agency 2011). Using more wood residues for energy is often promoted as part of larger renewable energy programs (European Union 2009, United Nations Economic Commission for Europe/Food and Agriculture Organization 2009). We followed the Intergovernmental Panel on Climate Change assumption (Sims et al. 2007, US Environmental Protection Agency 2012) that the use of terrestrial carbon, as opposed to geologic carbon, for energy is carbon neutral. This assumption is mathematically similar to assuming that the wood-based energy replaces coal-based energy (Rannik et al. 2002; Wahlund et al. 2002, 2004; Wolf et al. 2006; Ranta et al. 2007; Sims et al. 2007; Cherubini et al. 2009; Ferreira et al. 2009; Soliño et al. 2009; Walker et al. 2009; US Environmental Protection Agency 2012).

While it does not explicitly show up in national greenhouse gas inventories, there is considerable evidence that using wood rather than steel or cement in buildings reduces the total amount of energy used to produce building products as well as to heat and cool the buildings. Policy analyses of national forest sector models from around the world have produced a wide range of estimates of the energy benefits of using wood in buildings (Lippke et al. 2004, Perez-Garcia et al. 2005, Gustavsson and Sathre 2006, Gerilla et al. 2007, Sathre and Gustavsson 2007, Woodbury et al. 2007, Upton et al. 2008, Sathre and O'Connor 2010). A meta-analysis by Sathre and O'Connor (2010) of 21 international studies concluded that each ton of carbon in wood building products avoided an additional 1.1 tons of carbon emissions that would have occurred through producing more fossil fuel–intensive materials such as steel and cement.

Little is known about the current efficiency of postconsumer collection of wood residues or what the efficiency will be when future consumers throw products away. California's increasingly strict regulations to improve the recycling and utilization of waste products (California Air Resources Board 2008) would suggest that the Smith et al. (2006) estimate that only 65 percent of postconsumer wood waste will be sent to engineered landfills or waste-to-energy plants is low. For our analysis, we assume that improved regulations and technology will result in 90 percent of future post-consumer wood going to engineered landfills or wood-fired energy plants.

RESULTS AND DISCUSSION

Biomass utilization: harvest and removals

The 28 harvest operations over 6,870 hectares produced 221,555 metric tons of carbon (MgC) in sawlogs and forest biomass chips. Table 1 depicts the individual projects that ranged in size from 31 to 788 hectares and often included different types of silviculture within a single harvest plan. According to the California's Forest Practice Rules (California Department of Forestry and Fire Protection 2009), partial cut or commercial thinning operations do not require replanting if they are maintained in fully stocked condition. Clear-cut harvests involve the removal of all trees except residual live and dead trees retained for habitat and aesthetics and require replanting and maintenance of 740 trees per ha.

Nearly half of the harvested output came from projects that included both commercial thin subunits and clear-cut harvest subunits. In addition, the sample harvests were not necessarily representative of the harvest pattern across the re-

Table 1. Harvest area and volumes from 28 harvests.

No.	Year	Total area (ha)	Partial cut (ha)	Clear-cut (ha)	Total harvest (MgC/ha)	Logs (MgC/ha)	Chips (MgC/ha)	Uncollected logging residue (MgC/ha)	Distance to energy plant (km)
1	1997	648	648	0	12.4	0.0	10.2	2.2	121
2	1997	132	132	0	16.3	0.0	14.1	2.2	121
3	2001	31	31	0	38.8	29.1	8.7	1.0	40
4	2001	623	623	0	11.0	3.4	7.5	0.1	48
5	2002	788	788	0	26.5	5.4	21.0	0.1	40
6	2004	247	247	0	31.4	22.8	8.4	0.1	48
7	2004	438	438	0	27.9	8.9	18.8	0.1	48
8	1996	501	501	0	19.9	7.6	12.2	0.1	97
9	1998	95	95	0	39.8	19.7	19.2	0.9	24
10	1999	116	93	23	40.7	30.9	8.2	1.5	37
11	2000	221	146	75	31.4	21.0	4.0	6.4	113
12	2000	123	95	29	20.8	12.1	5.5	3.2	129
13	2003	221	221	0	26.5	22.9	2.2	1.4	161
14	2004	558	447	112	26.7	14.4	10.0	2.2	113
15	2004	323	270	53	23.3	9.6	11.5	2.2	113
16	2000	255	83	173	49.2	33.4	14.9	0.9	97
17	2003	349	21	328	45.9	33.7	11.1	1.0	145
18	2006	39	0	39	81.2	56.0	22.9	2.2	97
19	1999	382	195	187	38.2	29.0	7.0	2.2	145
20	2002	197	0	197	76.1	64.3	9.6	2.2	97
21	2004	160	0	160	113.5	98.2	13.1	2.2	97
22	2004	61	43	18	33.8	26.4	0.0	7.4	73
23	2004	61	0	61	43.7	37.9	0.0	5.8	73
24	2004	66	0	66	89.8	87.6	0.0	2.2	89
25	2004	36	0	36	41.8	39.5	0.0	2.2	89
26	2003	36	0	36	84.6	82.3	0.0	2.2	145
27	2003	92	0	92	58.2	56.0	0.0	2.2	145
28	2005	72	0	72	77.2	74.9	0.0	2.2	81

Table 2. Harvest site allocation of harvested biomass per hectare for Northern California (*n* = 28).

Silviculture	Mean MgC/ha (SE)			
	Sawlogs	Forest chips for energy	Uncollected logging residue	Total harvested
Partial cut	5.3 (1.6)	13.3 (1.2)	0.9 (1.9)	19.5 (1.9)
Clear-cut harvest	52.2 (4.7)	7.9 (3.3)	2.5 (0.7)	62.6 (5.5)

Table 3. Post sawmill and energy plant allocation of harvested biomass for Northern California (*n* = 28).

	Wood products	Sawmill energy	Sawmill waste	Forest chips for energy	Uncollect–ed logging residue	Total harvested
Partial cut (PC) (MgC/ha)	3.9	1.3	0.1	13.3	0.9	19.5
Clear-cut harvest (CC) (MgC/ha)	39.3	12.5	0.5	7.9	2.5	62.6
Avg. California harvest (½ PC, ½ CC) based on Forest Inventory and Analysis surveys (MgC/ha)	21.6	6.9	0.3	10.6	1.7	41.1
% of total	52	17	1	26	4	100

gion. To develop unique per hectare estimates for the partial harvests (mainly commercial thins) and clear-cut harvests, we used an ordinary least squares model (Cottrell and Lucchetti 2009) to develop area-based harvested biomass coefficients for partial and clear-cut harvests. The harvest volumes in Table 2 show the mass of wood removed as sawlogs, forest chips that are transported in chip vans to wood-fired energy plants, and uncollected logging residues.

At the sawmill, the sawlog biomass was partitioned into timber, clean chips to be used for higher value products or energy, hog fuel chips usable only for energy, and uncollected waste. At the wood-fired energy plants, all the biomass delivered in chip vans was used to generate energy. Without wood-fired energy plants willing to buy forest chips, all of the biomass would have been left as logging residues and unmerchantable ladder fuel trees. The after harvest and processing allocation of biomass from partial cuts, clear-cuts, and the regional average are shown in Table 3.

The field and sawmill processing results concur with other studies on the West Coast (Harmon et al. 1996, Hudiburg et al. 2011) that estimated only half the harvested biomass ends up in solid lumber products. Sawmill operators typically keep detailed accounts of the chips, shavings, and sawdust that can be used to generate energy or sold to other users. The absence of pulp mills and wood-based panel plants resulted in most of the collected biomass that did not go into lumber products being used for energy rather than being left in the forest or at the sawmill as uncollected waste. In other regions of the North America, much of the non-sawlog volume often goes to pulp mills and wood-based panel plants.

Financial analysis of harvest product revenues

The net value of the delivered harvested products is the best estimate of financial benefits to the forest owner. Forest landowners will not deliver large volumes of wood for generating carbon neutral energy if the benefits are not greater than the costs. We used the reported stumpage values for the three major timber species as well as average logging costs (California State Board of Equalization

Figure 1. Distance versus chip value at the landing. Value ($MgC) of chips at the landing = 4.93 - 0.30 - distance (kilometers). $n = 15$, $r^2 = 0.69$, ANOVA Prob > F = <0.0001.

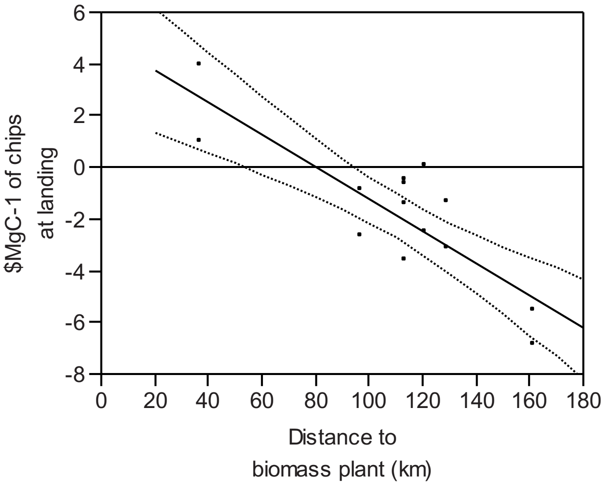
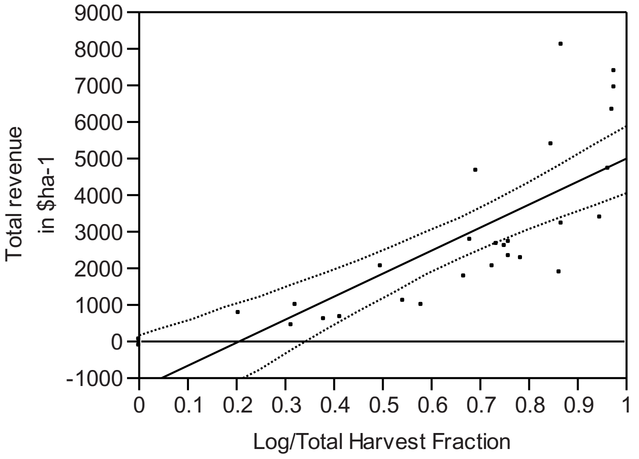


Figure 2. Log/harvest fraction versus net revenue per hectare. Dollars of net revenue per hectare harvested = 1,277 + 6,267 (sawlog/total harvest). $n = 28$, $r^2 = 0.60$, ANOVA Prob > F = <0.0010.



1998–2008) to estimate the gross value of sawlogs at the landing. After subtracting an average sawlog harvest and transport costs to sawmills (Hartsough 2003), we estimated the net value of delivered sawlogs to be US$76/MgC. With whole tree harvests, the branches, tops, and noncommercial trees are already brought to the landing, so no logging costs were apportioned to the forest chips. We estimated the net value of the forest chips collected at the harvest by subtracting the transport costs from the delivered prices for bone dry tons of chips as reported by the operators.

The haul distance from the landing to biomass plants had a significant effect on the net value of biomass chips at the landing. When collection and transportation costs are subtracted from the reported delivered prices of US$24/MgC ± US$3/MgC for wood chips over the period 2000 to 2008, the net revenue per ton was negligible. We used the reported prices and transport costs from the 15 projects with the same forester to develop a standardized price and cost per kilometer schedule. The net value of the chips at landings of varying distances from energy plants was then applied to all the projects. Figure 1 shows the value of the chips at the landing based on 15 deliveries with comparable data on revenues and costs.

The net value of wood chips at the landing across the projects varied considerably because of market prices and site-specific conditions. Although the estimated value of chips at the landing was less than zero where the distance to the biomass plant was greater than 80 km, chips were shipped more than 80 km at 13 of the 21 sites where both sawlogs and chips were removed. While some biomass utilization models assume that chips will not be hauled if the value is negative, biomass harvesting was apparently a less expensive logging residue treatment than the operational and permitting costs associated with burning logging residues at the harvest site. Logging residue disposal to reduce fire risk is a legal requirement of state forest practice rules and costs are significant. When deciding to undertake costly collection and removal of chips from harvest operations, operators mentioned the advantages of reduced risk from escaped control burns or future wildfires. Biomass harvests can also be considered silvicultural investments to reduce fire and insect risks and improve the quality and growth of the remaining trees. The low and often negative value of chips at the landing required operators to include some sawlogs in nearly every harvest to avoid a negative cash flow for individual operations. Figure 2 illustrates the relationship of the sawlog fraction of total harvests to the estimated net revenue per acre for the 28 projects.

Based on the harvested amounts of sawlogs and biomass chips, these commercial operations in Northern California included at least 20 percent sawlogs in the total removals and appeared to strive to at least break even on each harvest op-

Table 4. Historic and current best practices woody biomass utilization coefficients.

Utilization step	Pre-2008 USFS wood utilization coefficients[a]			Post-2008 USFS wood utilization coefficients[b]		
	Product	Energy	Waste	Product	Energy	Waste
1. At the harvest site	0.60	0.00	0.40	0.70	0.26	0.04
2. At the sawmill and energy plant	0.67	0.17	0.16	0.75	0.24	0.01
3. After the product's initial lifetime[c]	0.43	0.22	0.35	0.65	0.25	0.10

[a] Source: Smith et al. 2006. USFS = USDA Forest Service.

[b] Sources: California Air Resources Board (2008), Skog (2008), Smith et al. (2009), Keegan et al. (2010b), US Environmental Protection Agency (2012).

[c] Engineered landfill deposition is considered to the be the "product."

Table 5. Estimated climate benefits in tons of CO_2 equivalent (tCO_2 eq) of harvested products from a 100-tCO_2 eq representative harvest in Northern California.[a]

Forest product–related climate benefits	Pre-2008 USFS wood utilization coefficients	Post-2008 USFS wood utilization coefficients
Long-term carbon storage in products	15	27
Long-term carbon storage in landfills	11	7
Energy from logging residues	0	26
Energy from sawmill residues	17	23
Energy from postconsumer residues	7	11
Energy benefits from product substitution	16	30
Total	66	123

[a] 1 MgC = 3.667 tCO_2 eq. USFS = USDA Forest Service.

eration. Because of the long haul distances in this region, biomass harvesting revenues alone would not cover operational costs at current prices for the majority of the forested lands.

Climate benefits

The interest in developing more accurate estimates of how long wood products remain in use in developed countries has led to significant improvements in the empirical basis for the estimates. While some policy models use historical data with low conversion efficiencies to estimate current and future utilization (Harmon et al. 1996, Smith et al. 2006), more recent work has documented high and continually improving conversion efficiencies from harvest to postconsumer collection (Barlaz 2006, Skog 2008, Smith et al. 2009, Keegan et al. 2010b). In addition to log–to–wood product utilization improvements of 20 percent over the past 30 years for West Coast sawmills (Keegan et al. 2010b), large gains in utilization of all bark, chips, shavings, and sawdust have also been documented (Smith et al. 2009). Table 4 compares the estimated allocation of woody biomass at three steps for older and more recent forest product utilization coefficients. The products from each step are moved onto the next step where there is another allocation of the product into new products, energy, and waste.

Table 5 compares climate benefits under two sets of published utilization coefficients. Emissions and climate benefits for forest projects are commonly measured in tons of CO_2 equivalent (tCO_2 eq) over a 100-year period. The first column of values summarizes the climate benefits based on the product allocations in Smith et al. (2006) that are also used in most current voluntary forest carbon standards. The last column summarizes the climate benefits based on representative deliveries to Northern California sawmills and energy plants, current estimates of plant efficiencies (Skog 2008, Smith et al. 2009, Keegan et al. 2010b, McKeever and Howard 2011), an estimate of improved postconsumer disposition of woody biomass in California when it is eventually transferred from the consumer to the waste management sector (US Environmental Protection Agency 2012), and the estimated energy benefits of using more wood and less steel and cement in building (Sathre and O'Connor 2010).

The use of current and empirically documented coefficients on sawmill and consumer sector wood utilization efficiencies nearly doubled the full cycle estimate of climate benefits (123 vs. 66 tCO_2 eq from a harvest of 100 tCO_2 eq of forest biomass) compared with the widely used Smith et al. (2006) coefficients. The majority of the additional climate benefits are related to direct and indirect energy substitution benefits that are tracked in the energy chapter rather than the forestry chapter in national and international greenhouse gas emission inventories (US Environmental Protection Agency 2012). Carbon accounting methodologies such as Compliance Offset Protocol: US Forest Projects (California Air Resources Board 2011) that ignore all the foregone energy benefits of offset projects will significantly underestimate the climate benefits of the "no project" baseline harvest and therefore overestimate the number of offset credits that could be claimed by forest management projects based on a reduction in sustainable harvests.

The scientific consensus that increasing concentrations of greenhouse gases in the atmosphere are harmful has focused attention on estimating the current and potential climate benefits related to temperate forests. Various modeling based policy assessments have come to conflicting conclusions regarding forest harvesting and the net level of climate benefits related to managed forests of North America (Harmon et al. 1996, Lippke et al. 2004, Eriksson et al. 2007, Hennigar et al. 2008, Upton et al. 2008, Hudiburg et al. 2011). Our analysis of a representative set of harvests in Northern California in a region with competitive markets for both sawlogs and forest chips suggests that most of these differences arise directly from the assumptions regarding product utilization efficiencies and treatment of the energy produced from woody residues at the harvest, processing, and postconsumer stages. In particular, the projection of poorly documented historical estimates of wood utilization into the future rather than using current best practices as an estimate of standard practices in upcoming decades (Ince et al. 2011) implies a much more wasteful system of wood product utilization than what recent surveys have documented.

Estimating the total climate benefits of harvested wood products requires using four different chapters of the US greenhouse gases inventory (US Environmental Protection Agency 2012). The long-term carbon storage in wood products and landfills tracked in the Land Use, Land-Use Change, and Forestry chapter in the inventory constituted only 27 percent of the total climate benefits attributable to forest products in our study. The energy benefits of wood collected at the harvest, the sawmill, and after products were discarded by consumers are tracked in the Energy chapter and represented 48 percent of climate benefits related to the harvests. The substitution benefits of using wood rather than energy- and emission-intensive building materials represent another 24 percent of the climate benefits based on considering the avoided emissions of reduced production of steel, cement, and other energy-intensive products in the Industrial Processes chapter, as well as in reduced building energy use tracked in the Energy chapter. The emissions from paper production and waste paper utilization are tracked in the Waste chapter but were not covered in our study.

In California, sawlogs dominated the revenue to forest landowners because the current financial value of wood residues used for energy is low. Sawlogs also dominated total climate benefits due to the efficient use of sawmill residues and wood's long residency times and energy-saving properties when used in buildings. Forest owners in our study collected little if any revenue from forest chips sold to energy plants. Higher prices for carbon neutral energy would promote the collection of more logging residues and fuel reduction project residues.

CONCLUSIONS

Ton for ton, sawlogs generate far more climate benefits than wood chips initially used for energy. The presence of wood-fired energy plants provided forest managers with the opportunity to economically utilize residues that otherwise would have decomposed in the forest. The existence of a competitive forest biomass market of sawmills and wood-fired energy plants in Northern California significantly increased the climate benefits associated with the harvested wood products from these forests but had limited impact on the financial benefits to forest landowners. The collected logging residues were a major reason for our calculated total climate benefits being nearly double those based on commonly used accounting systems such as Smith et al. (2006) and nearly four times as great as forest project protocols (California Air Resources Board 2011) that ignore all energy benefits from the utilization of woody residues. The combination of high collection costs and relatively low prices for woody residues collected at the landing, sawmill, and postconsumer locations created a situation in which the private sector only collected and delivered woody residues to wood-fired energy plants if they were a by-product of other positive revenue operations. Greater financial recognition of the climate benefits not accounted for in the Land Use, Land-Use Change, and Forestry chapter of national greenhouse gas inventories could substantially increase the recognized climate benefits of an ecologically and economically sustainable forest sector.

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Carbon calculator tracks the climate benefits of managed private forests

by William C. Stewart *and* Benktesh D. Sharma

As part of California's strategy to reduce greenhouse gas emissions, private forest landowners are now required to address carbon sequestration as a management goal when submitting timber harvest plans. Using public data on forests and forest products, we developed a calculator that tracks the carbon sequestration benefits related to live trees, wood used for bioenergy and wood going into products. The calculator is adapted for different forest types, forest management techniques and time frames. Based on current best practices used in California, we estimate that harvested and regenerated forests will provide approximately 30% more total carbon sequestration benefits than forests left to grow for an equal time. More than half of the total benefits relate to harvested wood substituting for fossil fuels and fossil fuel–intensive materials such as cement and steel. With relatively efficient management practices, harvesting a ton of wood provides more sequestration benefits than leaving that ton growing in the forest.

It is well documented that very limited progress has been made at the global level to reduce greenhouse gas emissions and that geoengineering technologies will be insufficient to reverse the trend of rising emissions (Nordhaus 2013). However, there is progress at the state level. As it implements the California Global Warming Solutions Act of 2006 (AB 32), California is taking the lead in this country in promoting innovative approaches to emission reductions and mitigation measures. One potentially cost-effective mitigation measure is the maintenance and enhancement of carbon sequestration in forests and forest products (Joyce et al. 2014; Smith et al. 2009).

How to compare the climate benefits of joint use and no-harvest forest management approaches is being debated. Some researchers suggest that the "joint use of carbon sequestration and the provision of forest-derived products (e.g., timber and biomass for energy) will optimize the contribution of forestry in climate mitigation" (Canadell and Raupach 2008). Researchers who ignore the climate benefits related to forest products often conclude that a no-harvest approach is preferable.

There is no consistent approach for counting carbon sequestration benefits of forests and forest products in global, federal and state inventory systems. At the global level, benefits are covered in three different sections of national greenhouse gas inventories: agriculture, forests and other land uses (AFOLU); energy systems; and buildings (IPCC 2006). At the federal level, greenhouse gas inventories, emissions and net sequestration are tracked for forests, wood products in use and wood products deposited in landfills. Emissions from wood used for bioenergy are not included in national emission totals since they reduce the need to burn fossil fuels (US EPA 2014). Sequestration benefits of using wood for bioenergy depend on fossil fuel displacement and how the bioenergy utilization is integrated with overall forest management (Malmsheimer et al. 2011; Smyth et al. 2014). At the state level, California's 2014 Climate Change Scoping Plan mentions the positive benefits of using more wood products in construction and more wood chips to generate energy, but the accounting framework and recommended policies focus only on increasing carbon inventories in the forest (California Air Resources Board 2014).

UC researchers have developed a tool that helps users understand how forest management options will affect carbon sequestration. *Above,* managed stands of mixed-conifer forest in the Sierra Nevada.

Online: http://californiaagriculture.ucanr.edu/landingpage.cfm?article=ca.v069n01p21&fulltext=yes

doi: 10.3733/ca.v069n01p21

The increase in carbon stands over time in a let-grow forest, *above*, is based on the observed rate of live tree carbon by stand age.

Foresters who submit timber harvest plans in California face the challenge of demonstrating compliance with California's numerous climate-oriented laws even though different carbon accounting systems can produce conflicting results and the relevant laws are complex in their aims. In 2010, AB 1504 revised the intent of the Z'Berg Nejedly Forest Practices Act regulating nonfederal forest lands to ensure both of these goals: "(a) Where feasible, the productivity of timberlands is restored, enhanced, and maintained. (b) The goal of maximum sustained production of high-quality timber products is achieved while giving consideration to values relating to sequestration of carbon dioxide, recreation, watershed, wildlife, range and forage, fisheries, regional economic vitality, employment, and aesthetic enjoyment" (California Code of Regulations 2010). In addition, the state's forests are diverse; they vary considerably in terms of dominant tree species, ownership and productivity (table 1).

Developing a calculator

To help forest landowners describe how a managed forest meets the goals of the Forest Practices Act, we developed a carbon calculator to document the climate benefits of a forest and any harvested forest products. To be relevant for both submitters and regulators, the calculator covers a range of forest types, forest management options and products. We used current publicly available information and presented the carbon calculation in a disaggregated format so that submitters, regulators and other interested parties can see how it is achieved.

To project forest carbon inventories over long time periods with significant but unknown probabilities of disturbance losses, we used the Carbon Online Estimator (COLE) growth model (Van Deusen and Heath 2014). This free Web-based tool allows users to create and download reports summarizing carbon sequestration in U.S. Forest Service forest inventory and analysis (FIA) plots.

We used tree growth data from nearly 2,000 FIA plots on private and federal lands to generate reports for California's four major timberland types — mixed conifers, ponderosa pine, Douglas fir and redwood. We then used Von Bertalanffy growth equations (Van Deusen and Heath 2014) for each forest type to model live tree carbon. The trajectory of a let-grow forest — one that is not harvested but left to grow — is based on the observed rate of live tree carbon by stand age. It illustrates a slowing growth rate of net aboveground carbon sequestration as the forest ages.

To estimate the sequestration benefits associated with harvested products, we used the most current state and regional information on where harvested wood goes (Morgan et al. 2012) and how products are used (McKeever and Howard 2011; Sathre and O'Connor 2010; Skog 2008; Smith et al. 2009). Stewart and Nakamura (2012) used these same sources and estimated that the sequestration benefits of harvested wood were two times (when wood used for bioenergy is

TABLE 1. Area of timberland, number of FIA plots and average site productivity for four California major forest types

	Mixed conifers	Ponderosa pine	Douglas fir	Redwood
Area (acres)	6,359,900	1,946,700	942,600	592,200
All FIA plots (no.)	1,374	263	187	118
Private FIA plots (no.)	351	112	101	95
Average productivity (cubic feet/acre/year)	103	77	115	180

Robert York

considered) to four times (when bioenergy use is not considered) larger than those estimated by models such as the greenhouse gas emission calculator developed by the California Department of Forestry and Fire Protection (Cal Fire 2010) that use the older estimates from Smith et al. (2006).

All forest carbon that is cut at harvest was accounted for as logging slash left, logging slash used for energy, mill residues used for energy, wood products and mill waste. The regenerated forest was then modeled with the Von Bertalanffy growth coefficients based on relevant private forest plots, where competing vegetation is controlled. The emissions related to fossil fuel energy used in the harvest operations were estimated as 3% of the total energy value of the harvest based on Wihersaari (2005) and subtracted to generate a net carbon sequestration value for the harvest operations.

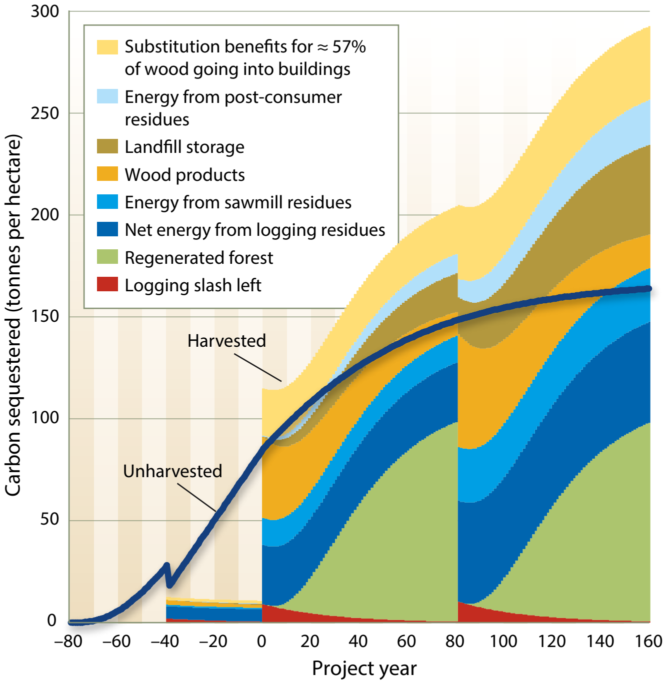


Fig. 1. Cumulative sequestration benefits over time from 1 hectare of a mixed-conifer forest under two scenarios: unharvested (or let-grow), and even-aged harvest and regeneration with 75% of slash (logging residues) used for energy at a harvest at year 0. The life cycle includes the 80 years since the forest started from seedlings as well as two cycles of harvesting and replanting.

We used the best practices assumption of 75% slash utilization for delivery to wood-fired energy plants with the remainder left to slowly decompose on site. This is lower than the sample of projects in Northern California documented by Stewart and Nakamura (2012) but higher than the 66% used by Ince et al. (2011). We provided variants with 0% and 25% slash utilization since recent closures of some wood-fired energy plants due to insufficient payments for the wholesale electricity warrant modeling lower collection rate estimates.

Our modeling tracked wood products through sawmills and energy plants, drawing on published allocation of products and conversion efficiencies (Christensen et al. 2008; Morgan et al. 2012). Our 45-year half-life for wood products produced in California was based on the weighted combination of a 60-year half-life for lumber products (McKeever and Howard 2011; Skog 2008) and a 15-year half-life for other products that is proportional to the allocation in California (Morgan et al. 2012). According to McKeever and Howard (2011), 57% of California's lumber products go into buildings, where the wood is estimated to provide additional carbon sequestration benefits and energy savings by displacing fossil fuel alternatives (Sathre and O'Connor 2010). The estimated allocation of postconsumer wood residues between landfills, energy and uncollected waste was based on estimates by Stewart and Nakamura (2012) of current best practices in California; undoubtedly these could

Above, a forest stand at Blodgett Forest Research Station treated with uneven aged, 75% slash utilization forest management.

improve with better technologies and financial incentives.

To conform with the units used in COLE reports (Van Deusen and Heath 2014), we used a single hectare (2.47 acres) as the unit of analysis. We modeled different actions on an 80-year-old forest that had been treated with a light commercial thin 40 years earlier. The regenerating forest as well as the products were then tracked for 40 years, 80 years (approximately the half-life of wood used in single family homes (Skog 2008)) and 160 years to illustrate how the length of the analysis affected the climate benefit comparisons.

As noted earlier, uncertainty remains on how to account for future rates of forest growth as well as climate benefits that accrue outside of the forest sector related to using wood products and bioenergy rather than fossil fuel–intensive products such as cement, steel, coal and natural gas (Smyth et al. 2014). We cannot accurately predict how future forest growth rates will compare to the historic rates used in the calculator. We also did not include any probability of stand-terminating disturbances such as wildfires or insect outbreaks that would reduce long-term carbon sequestration. Different building rating systems such as LEED and Green Globe use various methods to estimate the carbon footprint of using wood rather than concrete in buildings. Depending on the location of a forest project, the ability to sell the slash for bioenergy in the future may be limited if the goals of California's 2012 Bioenergy Action Plan are not achieved.

Using the calculator

In 2013, we expanded the carbon sequestration model submitted with our 2011 timber harvest plan for the mixed-conifer forests at the UC Blodgett Forest Research Station (University of California 2014) to cover more forest types and more management options. The current tool and a user guide are posted on UC's Forest Research and Outreach website (UCCE 2014). The user's first step is to choose a forest type that best matches the area in the user's proposed timber harvest plan. After choosing the relevant forest type, users can review worksheets with detailed forest growth and product life cycle information based on published literature to choose the relevant factors to match their plan. If desired, the user can alter any of the input coefficients to customize the output.

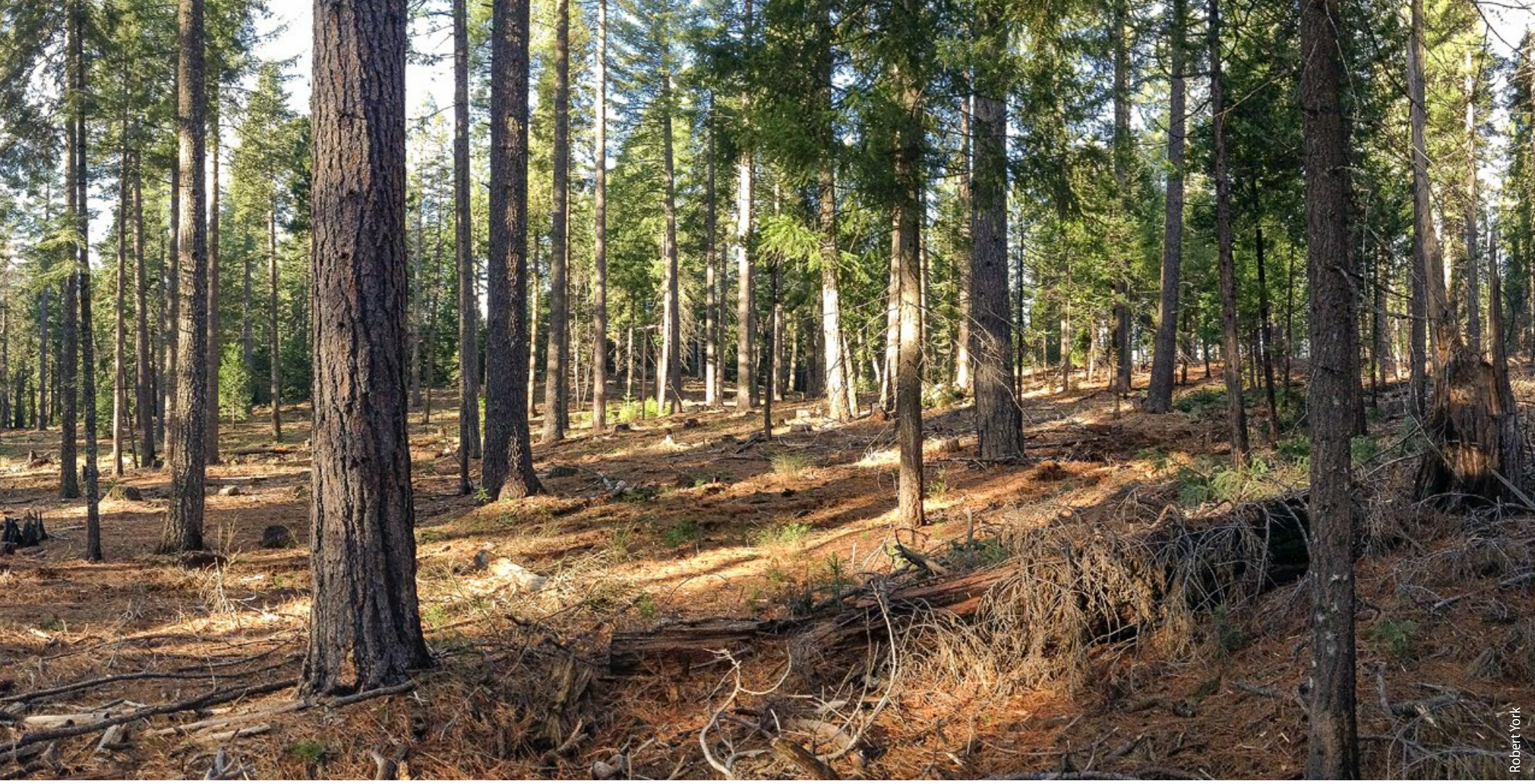
The next step is to choose the forest management option that best matches the user's situation. A let-grow alternative is included with each option to provide a harvest/no-harvest comparison. Tables and figures in the upper left section of each management option worksheet summarize the input coefficients as well as the results.

Users can estimate the total sequestration for their timber harvest plan by multiplying the area of the most relevant harvest type by the relevant coefficients. Carbon quantities should be multiplied by 3.67 to provide measurements in standardized tons of carbon dioxide used in emission-based accounting systems.

A review of a forest project example demonstrates the results a forester can gain by using the calculator to estimate the net climate benefits associated with a timber harvest plan. Figure 1 shows the

TABLE 2. Components of the cumulative life cycle carbon sequestration benefits, averaged over 160 years, of mixed-conifer forest under two management scenarios

Scenario (in both, trees start as new seedlings)	Live trees	Wood products	Bioenergy	Landfill storage	Building product substitution	Total benefits
	tonnes of carbon per hectare					
Let-grow	77	0	0	0	0	77
Harvested and regenerated	43	12	26	6	12	99



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carbon sequestration in a mixed-conifer forest under two scenarios: unharvested (or let-grow) and an even-aged harvest and regeneration option with 75% of slash (logging residues) used for energy. The solid blue line models the predicted rate of carbon sequestration in live trees for the unharvested forest based on the COLE forest growth model. The stacked columns show the carbon sequestration of the harvested forest — the regenerated forest (also modeled with the COLE forest growth model) plus the sequestration benefits associated with the harvested products.

Table 2 compares the cumulative carbon sequestration benefits of the two scenarios for 160 years starting from new tree seedlings. The harvested scenario includes a commercial thin at 40 years, a final harvest at 80 years, and regeneration of the forest for 80 more years. The harvested forest has lower average sequestration benefits in the live trees but greater overall sequestration benefits when the harvested products are considered.

Table 3 summarizes our best practices estimate of annual carbon sequestration rates for four forest types, five management options and three time periods. The more productive redwood and Douglas fir forests sequester considerably more carbon than the mixed-conifer and ponderosa pine forests. Efficient utilization of harvested products increases overall sequestration benefits across all forest types and time periods.

More benefits in joint use

Managed (harvested and regenerated) forests provide more carbon sequestration benefits than let-grow forests when the benefits of the harvested products are accounted for. Table 4 summarizes the relative carbon sequestration benefits of let-grow forests and managed forests weighted by the total area of private

TABLE 3. Cumulative life cycle carbon sequestration benefits, averaged over 120, 160 and 240 years, for four forest types and five management options

Management, logging residue utilization	Mixed conifers			Ponderosa pine			Douglas fir			Redwood		
	Time frames (years)											
	120	160	240	120	160	240	120	160	240	120	160	240
	tonnes of carbon per hectare											
Let-grow	56	77	104	51	60	69	125	154	187	156	213	288
Even aged, 0%	63	87	126	66	85	114	153	203	278	166	226	322
Even aged, 25%	65	91	134	69	89	121	159	213	295	173	237	342
Even aged, 75%	70	99	149	74	98	135	171	233	329	185	260	383
Uneven aged, 75%	70	103	166	71	95	142	167	233	362	194	283	458

TABLE 4. Ratio of sequestration benefits of managed (harvested and regenerated) forests compared to let-grow forests for 40, 80 and 160 years after initial harvest of a mature forest stand

Management, logging residue utilization	Years after harvest		
	40	80	160
Let-grow baseline	1.00	1.00	1.00
Even aged, 0%	1.15	1.18	1.28
Even aged, 25%	1.19	1.24	1.36
Even aged, 75%	1.28	1.35	1.51
Uneven aged, 75%	1.28	1.40	1.70
Four-treatment average	1.23	1.29	1.46

forests in California. If all carbon sequestration benefits are counted, we project that California's private forests that are harvested and regrown for another 80 years will provide approximately 30% more total carbon sequestration benefits than forests left to grow for 80 years. The relative advantage of the managed forest over the let-grow forest is slightly less for shorter timeframes and slightly greater for longer timeframes. Expanded residue utilization for bioenergy increases total sequestration benefits compared with leaving slash to decompose in the forest. The increased benefits resulting from uneven-aged management systems compared with even-aged management are smaller than the increased benefits related to more slash utilization.

> ***Harvested and regenerated forests provide more carbon sequestration benefits than let-grow forests when the benefits of the harvested products are accounted for.***

The carbon calculator helps users understand how forest management options will affect carbon sequestration. It can be used anywhere in the United States where relevant FIA plot data is available. And its assumptions, inputs and coefficients can be changed to match the analytical needs of regulators and submitters. The carbon sequestration categories we presented here match up well with the U.S. Greenhouse Gas Inventory (US EPA 2014) in terms of tracking carbon in live trees, forest products and landfills, and bioenergy. Under the relatively efficient management practices currently used by private forest owners in California and depending on what percentage of logging residues are used for bioenergy, calculations show that a ton of harvested wood provides slightly more or significantly more sequestration benefits than leaving that ton in the forest.

The calculator's simple and transparent format can improve the regulatory review process for forest landowner's compliance with legislation designed to reduce California's greenhouse gas emissions. It is also a useful tool for assessing forest management options in private and federal forests.

W.C. Stewart is UC Cooperative Extension Forestry Specialist in the Department of Environmental Science, Policy and Management at UC Berkeley; B.D. Sharma is Postdoctoral Scholar in the Department of Environmental Science, Policy and Management at UC Berkeley.

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