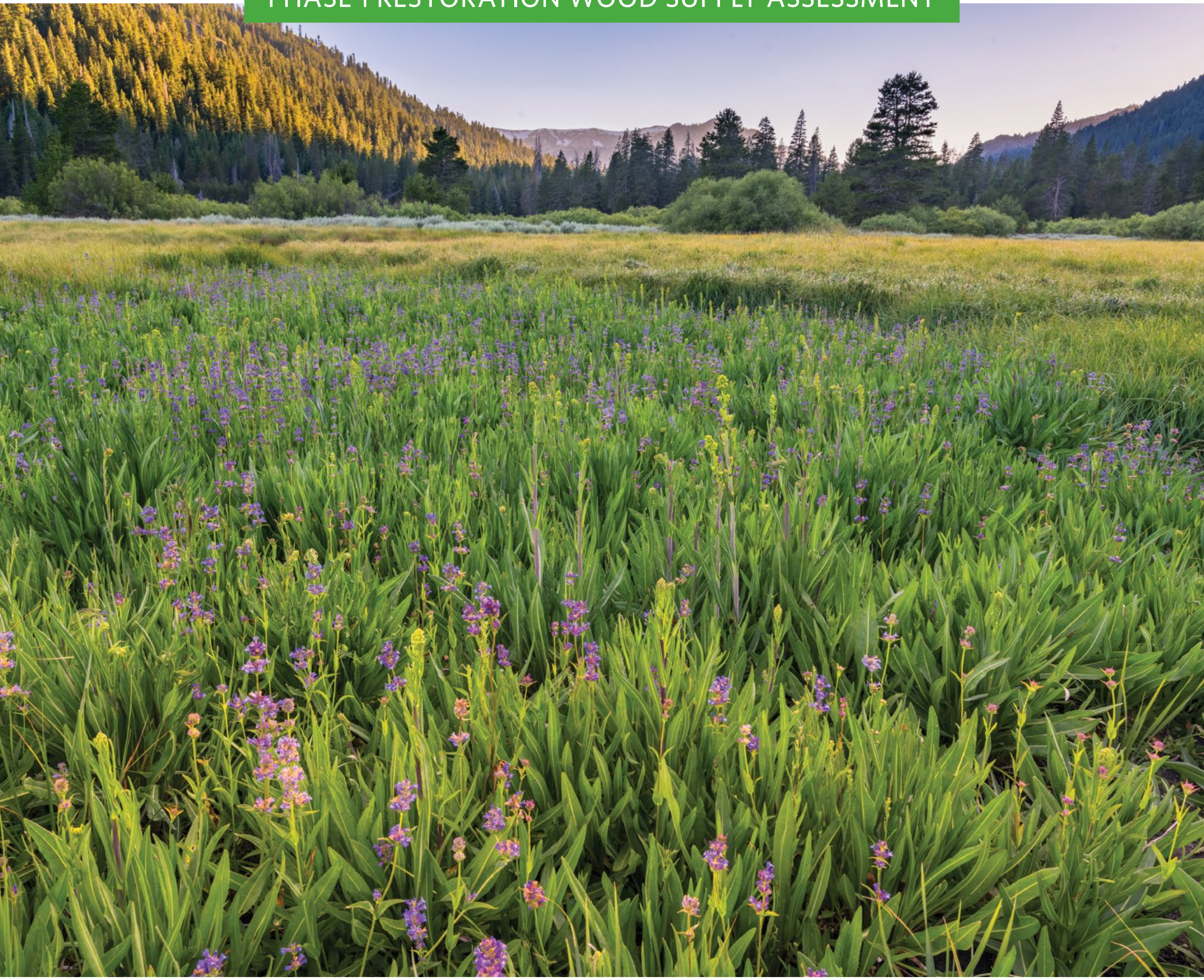
TAHOE-CENTRAL SIERRA INITIATIVE

PHASE 1 RESTORATION WOOD SUPPLY ASSESSMENT



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COVER: Carpenter Valley in spring. © Elizabeth Carmel

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PHASE 1 RESTORATION WOOD SUPPLY ASSESSMENT

100 YEARS AGO

Images from the Wieslander Vegetation Type Mapping Collection are courtesy of the Marian Koshland Bioscience and Natural Resources Library, University of California, Berkeley, www.lib.berkeley.edu/BIOS/vtm/.

TODAY

Dense second growth forest, North Yuba River watershed, Tahoe National Forest. © Allison Thomson

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1.0 EXECUTIVE SUMMARY

The Nature Conservancy (TNC) on behalf of the Tahoe-Central Sierra Initiative (TCSI) contracted with Mason, Bruce and Girard to undertake this timber supply study to assess ecological outcomes and economic viability of forest restoration in the region surrounding Lake Tahoe. Central Sierra Nevada forests have recently experienced extensive drought-related stress and mortality, increasing susceptibility to bark beetles and elevating the risk of catastrophic wildfire. The US Forest Service is the predominant land manager in the area, affording an opportunity to coordinate long-term forest restoration planning using a combination of mechanical thinning, prescribed fire and managed wildfire.

Increasing the pace and scale of forest restoration—including ecological thinning of trees with commercial value—necessitates a strategy for processing the resulting sawtimber and biomass. The TCSI region has no active sawmills or biomass facilities within its 2.4-million-acre boundary; active facilities do exist to the west, north, and south. Those facilities would be able to absorb some of the wood fiber produced during forest restoration but may not be able to accommodate all the volume or do so with a favorable project-level cash flow.

This study anticipates how much timber and biomass may be generated by forest restoration treatments and estimates what fraction can be transported to and processed by existing sawmills and biomass plants. In addition, where biomass from more ambitious restoration scenarios exceeds current capacity, the study identifies locations for electricity generating facilities and estimates the influence of transportation cost on biomass stumpage (defined as delivered price less logging, chipping, and haul costs). Electricity generating facilities were used for the regional economic assessment because associated operating costs and revenues are known. However, the same wood supply findings could, with further analysis, be adapted to test the potential financial performance of alternative processing technologies.

This 20-year, preliminary wood fiber supply assessment recognizes four dimensions to the problem of securing some economic value from the byproducts of forest restoration: (1) measuring the volume of timber and biomass that must be removed, (2) characterizing species composition and size distribution of that material, (3) determining the locations and volume of removable timber and biomass on the landscape and where that material is processed, and (4) assessing the pace and scale of treatment needed to achieve forest restoration goals assuming both existing and expanded regional wood processing capacity. Cost is an important barrier to increasing the pace and scale of forest restoration and long transportation distances of low value material is key driver of high costs. If the net cost of treatments is too high, the restoration work likely will not occur.

Under the set of assumptions imposed for this study, key findings for the Tahoe Central Sierra Initiative Region are as follows.

- A baseline scenario emulating business as usual and reflecting an average of the last five years in terms of timber and biomass harvest finds that the region produces around 80,000 bone dry tons (BDT) of live biomass and 191,000 Mbf sawtimber per year, removed from 410,000 acres over 20 years.
- The baseline sawtimber harvest is consumable at positive stumpage value by several regional sawmills. Only one biomass electricity plant remains operational, however, within reasonable haul distance from the core region (Figure 1). The low market value for biomass and high transportation costs make most biomass too expensive to supply to this location on a break even or net revenue basis.
    - » If consumed by existing electricity generation infrastructure, biomass produced from forest restoration would have a substantially negative value, averaging around -$15/BDT if dispatched to Rocklin.
- Increasing the pace and scale of forest restoration could treat up to and additional (i.e. relative to baseline) 610,000 acres over 20 years,carefully thinning the densest, most fire prone stands of trees on relatively gentle, low slope terrain.
- Restoration byproducts derived from such treatments are projected to quickly overwhelm regional wood processing infrastructure. For example, live biomass production could increase by 1.6 times over baseline, while dead biomass removal could be more than 10 times higher.
    - » Sawtimber harvest would also increase, but existing sawmills may have enough capacity to accommodate this increase, notwithstanding very real financial challenges associated with long haul distances, high costs of handling many small diameter logs, and milling efficiencies.

- To evaluate potential solutions for the current infrastructure bottleneck, we analyzed the potential economic impacts of restarting or establishing new biomass process centers sited closer to the forest, along the main highway corridors on Hwy. 49, Hwy 80, and Hwy 50.
    - » Using a conservative set of assumptions with respect to volume recovery, we estimate that increasing the pace and scale of forest restoration has the potential to produce, on a sustainable basis, an additional 320,000 bone dry tons of biomass per year for 20 years – equivalent to an additional 40 megawatts (MW) of biomass electricity per year.
    - » Accompanying reductions in haul distances and cost are predicted to have a positive effect on biomass stumpage (i.e. the net revenue or reduced project revenue deficit) experienced by the landowner.
    - » Specifically, an optimized fleet of small to mid-sized biomass processing centers in the region (Infrastructure Case C) could offset the average project biomass stumpage deficit from -\$15/BDT to -\$3.35/BDT and result in positive biomass stumpage values for locations closest to the new processing centers.
- Although not explicitly evaluated in this study, blended project level revenues for restoration treatments, accounting for biomass and saw log values, have the potential to be cost neutral or slightly positive, assuming historic log prices stay stable and biomass stumpage deficits can be reduced.

Haul distances within the study region are generally too long to support positive biomass stumpage at a contemporary estimated delivered price of \$40/BDT. Lower market prices for forest biomass, as experienced in 2020, make project economics even more challenging. To make restoration activities economically feasible, biomass prices would need to increase commensurately, or other funding mechanisms would need to be in place to support the added hauling costs. Additional facilities could help accelerate the pace and scale of ecologically-base forest restoration in the TCSI region. Factors influencing construction of new infrastructure include appropriate size and siting, best available pollution control technologies, conservative estimates of long-term sustainable wood fiber supplies, and air quality considerations. From TNC's perspective, public funding or policy that incentivizes wood-processing infrastructure should prioritize removal of small-diameter trees, surface fuels, and ladder fuels (defined further below). Moreover, any tree removal, particularly on federally owned forestlands, should be conducted in a manner consistent with the principles of ecological forestry (e.g., "Wildfires and Forest Resilience: the case for ecological forestry in the Sierra Nevada," "An ecosystem management strategy for Sierran mixed-conifer forests," or an equivalent science-based guidance document).

1.1 Limitations of the Assessment

This 20-year, preliminary wood supply assessment does not account for changes in extant wood volumes caused by future wildfires, drought-induced mortality and other complex forms of forest disturbance. Accounting for these factors is beyond the scope of this study but should be monitored and carefully considered when interpreting the landscape scale finding presented in this report. For example, the United States Forest Service (USFS) has estimated that historically, wildfires would have burned an equivalent of 49,350 acres per year (about 6 percent of the Forest) in the major forest types, based on a mean historic fire return interval of 24 years (North et al. 2012, USFS 2020). Similarly, the maintenance of treatments, be it through subsequent mechanical thinning and/or prescribed fire treatments is not modeled. Areas eligible for treatment are "entered" (i.e. volume removed, or prescribed fire applied) no more than once during the 20-year modeling period.

2.0 REGIONAL BACKGROUND

What is the history of forests in the TCSI region that contributed to their current vulnerability to fire, drought, insects, and disease?

Forests in the Sierra Nevada are at risk from wildfire, drought, pests, and disease. Recent mass tree mortality (2015–2018; Moore et al., 2019) has left around 130 million dead trees across California, with concentrated areas of mortality in the Sierra Nevada. Forests surrounding the 2.4 million-acre TCSI area are of primary concern to TNC and its partners, having already suffered large wildfires (Rim Fire 2013, King Fire 2014, Angora Fire 2007) and containing significant areas of Wildland Urban Interface (WUI) at especially high risk for anthropogenic wildfire ignition. The purpose of TCSI is to assemble a group of private organizations and public agencies with the shared objective of facilitating improved forest management solutions specific to this region.

There is growing consensus among government agencies, rural counties, conservation groups, the timber industry, and others that active forest management—including both prescribed fire and ecological forestry—should be the primary tool to restore California's forests to a structure and composition more closely resembling the historical range of variability (HRV) of forests in the region, which were more resilient than contemporary forests to fires, drought, insects and disease. Regional forests before 300 years ago typically contained relatively few very large trees with an open understory and limited regeneration of small trees (Jeronimo et al., 2019) and were composed of primarily shade-intolerant species except for certain riparian areas or at higher elevations (Safford and Stevens, 2017). This historic forest structure resulted from frequent, but low- to moderate-intensity, naturally occurring wildfires and the burning practices of indigenous tribes (Safford and Stevens, 2017; Jeronimo et al., 2019; Van Wagtendonk et al., 2018). This ecosystem process was disrupted by a near cessation of tribal burning and widespread forest clearing activities in the 1800s and 1900s. The U.S. Forest Service implemented a total wildfire-suppression policy shortly after 1910 (Silcox, 1911), continuing through the late 1970s and 1980s (Pyne, 1994), leading to excessive understory buildup across previously open-structured western forests. Now, forests in the Sierra, and across the western United States, have shifted to a structure and composition more prone to stand-replacing wildfire events, which likely occurred at relatively small scale in historic times (Safford and Stevens, 2017). Long-term fire suppression efforts have allowed cohorts of smaller trees, often shade-tolerant species, to grow among the larger trees, acting as surface and ladder fuels when fire moves through the stands.

Human settlement patterns have also changed, with many communities interspersed within the edges of larger forested landscapes. These WUI areas are disproportionately the origin of ignition events for wildfires due to the concentration of anthropogenic ignition sources. Expansion of the WUI as human population grows, combined with shifts in forest structure and composition rooted in long-standing land management policies, have incrementally brought the region to its current state: with millions of forested acres uniquely vulnerable to multiple threats.

Private timberlands, of which the TCSI region contains 677,000 operable acres, are typically managed on an uneven-aged basis supporting lower stem densities than public lands. Approximately 25 percent of private timberlands across the Sierra Nevada are managed with even-aged methods (Mason, Bruce & Girard and The Beck Group, 2019). Private timberland owners have the incentive to minimize wildfire risk to their investments, and unlike the USFS tend to limit public access. As a result, wildfire is less likely to originate on this ownership class.

Forest managers on public lands have a variety of methods available that could, if resourced appropriately and implemented with the right regional strategy, mitigate the risk of large-scale, high-severity wildfire to the forest and embedded human communities. Management options include prescribed fire (Rx burn), precommercial thinning, commercial thinning, uneven-aged management such as skips and gaps treatments, and even-aged management (14 CCR § 913.1, 933.1, 953.1["clearcutting" defined in subsection (b)]). Even-aged management is atypical on public lands in California. Managed wildfire, or wildfire use for resource benefit, is a rarely utilized but effective tool available to reduce surface and ladder fuels on USFS lands. There are 743,000 acres of forests on operable USFS land in the TCSI study region.

The TCSI is working to gather public support for expanding active forest management with an explicit objective of improving forest resilience. The group's goal with this report is to explore a 20-year strategic plan to restore forest structure using appropriate silvicultural methods and, by doing so, decrease the likelihood of undesirable high-severity wildfire and tree mortality. The TCSI is active on numerous fronts, but this study will focus on forest restoration strategies in the context of sawtimber and biomass production.

2.1 Timber Inventory and Regional Production

What is the forest cover in the TCSI region, and how much timber is currently produced?

2.1.1 Inventory

Forest inventory data were received from SilviaTerra (ST). These data consisted of per-acre tree lists[1] dated to year-end 2018, with a unique tree list for each of 12,649 stands. Stand[2] boundaries were constructed by ST using an unsupervised classification algorithm with an average size target of 120 acres and an achieved stand average size of 50.9 (±0.8) acres. Stand area was constrained on the lower bound to 5 acres; a few stands exceeded 1,000 acres. Tree lists were developed by ST using proprietary methods. The lists contained a minimum tree size of 5-inch diameter at 4.5 feet (diameter at breast height, DBH). Tree height was modeled by ST as a function of tree diameter, introducing a distribution of height values for any given diameter. This modeled tree height was adjusted by ST to reflect species-level ranges derived from regional Forest Inventory and Analysis (FIA) data.

We assessed the dubbed height provided by ST versus tree object height estimates derived from publicly available LiDAR data for a selection of representative stands. Among these stands, top tree height (average height in feet of the 95th percentile) identified by LiDAR was typically within 10 feet of the top tree height reported by SilviaTerra. Approximately 75 percent of the height distributions were monomodal in both datasets, and of those roughly half shared a similar mean height; deviation of mean height was typically less than 20 feet. The LiDAR data identified approximately 25 percent of test stands as having bimodal height distributions. The SilviaTerra height model was exclusively monomodal, so these distributions were less well-aligned. Further description of the inventory and tree-height assessment are in Appendix A, which can be provided upon request. The dataset was transcribed to a format compatible with the Forest Vegetation Simulator (FVS).

Only a few potential inventory sources are available for very large areas that cross multiple ownerships such as the TCSI study region. The two main publicly available candidates are the USFS FIA and the Landscape Ecology, Modeling, Mapping & Analysis (LEMMA) dataset[3]; SilviaTerra canopy basemap and derivatives are the third option, available for a fee.[4] The FIA data are only available at a relatively coarse spatial resolution insufficient for the kind of stand-level analysis undertaken here. The LEMMA data were last updated in 2012, and in such a dynamic system as TCSI these data are obsolete and too difficult to reliably correct for mortality and wildfire. Although unvetted for regional USFS projects, the SilviaTerra data were best suited for the scale of this analysis, and the most contemporary.

2.1.2 Regional Timber Production

Counties within the TCSI region produce an average of 189,000 thousand board feet (MBF) annually.[5] The TCSI study region encompasses all of some counties but only fractions of others, so the sum of harvest volume from each county will not precisely represent the volume harvested from the study region. We calculated the total area of each county and the forested area (national forest and private ownership) within both the county and within the TCSI study region fraction of the county (Table 1). This forested area ratio by owner was applied as a scalar multiplier to the harvest by owner from each county to arrive at an inferred harvest by county within TCSI region only (Table 1). This proportional adjustment resulted in an expected annual average harvest of 191,188 MBF/year, not substantially different from the county total.

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[1] Tree list: Ledger of tree species, count, and size metrics (diameter, height, crown, etc.) that describes forest composition and structure and is used for constructing growth simulations.

[2] Stand: Discrete geographic area, usually contiguous, in which a forest shares a similar structure, composition, age class, and history and which may be effectively managed using a single regime.

[3] https://lemma.forestry.oregonstate.edu/

[4] Value undisclosed to MB&G.

[5] Average of 2014–2018 CA Board of Equalization (BOE) data, aggregated by Bureau of Business and Economic Research (BBER), University of Montana; summary courtesy of The Beck Group.

TABLE 1. County-level harvest inference based on average last five years of timber production, distributed per county by the ratio of total timberland to timberland acres within the TCSI study region, by ownership. The total county-level harvest was adjusted to reflect the amount of timberland within the TCSI fraction of the county forested total acreage. For instance, Placer County had 523,621 acres of timberland in total, and 666,915 acres within the TCSI region—some of the TCSI area was unforested. The total annual timber harvest in Placer County occurs within the TCSI study region, so the California (CA) Board of Equalization (BOE) federal/private proportion was used without modification.

County	State	Acres in TCSI Region			County Timberland Acres			Inferred MMBF Harvest		
		Total	NF	Non-NF	Total	NF	Non-NF	USFS	Private	Total
Alpine	California	16,841	16,095	746	174,725	168,460	6,265	6	-	6
Amador	California	11,069	9,951	1,118	191,017	30,663	160,353	37	33	70
Butte	California	1,177	109	1,068	507,415	160,246	347,169	3	153	156
Carson City	Nevada	13,663	3,846	9,817	16,604	16,604	-	156	-	156
Douglas	Nevada	39,673	17,105	22,567	142,987	79,890	63,097	693	914	1,607
El Dorado	California	669,468	395,504	273,964	763,469	462,393	301,076	21,871	64,327	86,197
Nevada	California	448,414	190,218	258,196	394,344	155,211	239,133	1,389	11,490	12,879
Placer	California	666,915	362,784	304,131	532,621	336,889	195,733	34,527	21,909	56,436
Plumas	California	11,868	8,270	3,598	1,433,876	1,079,303	354,573	296	722	1,017
Sierra	California	385,584	299,678	85,907	531,037	434,080	96,957	5,144	12,661	17,805
Washoe	Nevada	33,879	10,549	23,330	86,624	47,508	39,116	427	945	1,373
Yuba	California	111,626	43,672	67,954	165,151	51,307	113,843	4,284	9,201	13,485
Total:		**2,410,176**	**1,357,780**	**1,052,396**	**4,939,870**	**3,022,555**	**1,917,315**	**68,833**	**122,356**	**191,188**

2.2 Existing Infrastructure

What types and volume of timber processing are currently supported by forest management in the TCSI region?

The Beck Group provided a summary of existing biomass and sawtimber processing capacity surrounding the study region (Figure 1). Within the geographic boundaries of the study region, there are no existing facilities of either type. Several locations fall just outside the region to the west and north or northeast. The only currently operational biomass facility that relies on supplies from forest restoration, as opposed to sawmill residues or other sources, is at Rocklin, to the west of the study area. The Rocklin plant has a contract capacity of 21 megawatts (MW) and consumes 166,000 bone dry tons (BDT) total biomass each year, of which 100,000 BDT/year is likely to derive directly from forest fuels[6]. Until late 2019, another facility at Loyalton had been operating with a contract capacity of 18 MW and a likely total consumption of 142,000 BDT/year, with 83,000 BDT/year from forest fuels. This facility has recently exited bankruptcy proceedings under new ownership but is, as of this writing, not operating and is thus removed from our list of currently operational biomass plants in the core TCSI region.

Biomass facilities elsewhere are too far away to justify hauling low-value material, as we will see in later sections. Sawtimber facilities near the region are mostly owned by Sierra Pacific Industries, including locations at Lincoln, Quincy, Oroville, and Chinese Camp (Figure 1). We distinguish between core and secondary capacity, where core capacity includes only facilities within a likely haul distance of the study area. It is beyond the scope of this report to consider larger-scale material flows, but we acknowledge that timber and biomass produced from TCSI restoration

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[6] One bone dry ton (BDT) is equal to 2,000 pounds (lbs) of wood material at zero percent moisture content. A megawatt is a unit of power equal to one-million watts. For a typical commercial boiler, one BDT produces 10,000 lbs of steam which in turn produces one megawatt hour (MWH) of electricity.

activities would not enter the market in a vacuum. Any timber volume produced here above the business-as-usual level could potentially displace harvests from outside the region, altering delivered log prices by virtue of changing the regional haul cost picture. Conversely, harvests from secondary northern or southern areas could be increased, which may suppress demand by those area mills for material sourced within the TCSI study region. These displacement or demand considerations would apply chiefly to sawtimber, which is of sufficient value to justify hauling longer distances; the lower value of biomass material obviates the question of whether tonnage produced within the TCSI region can have appreciable impacts on secondary market areas. In this study, our economic assessment should be viewed as a relative calculation, not as a formal price forecast.

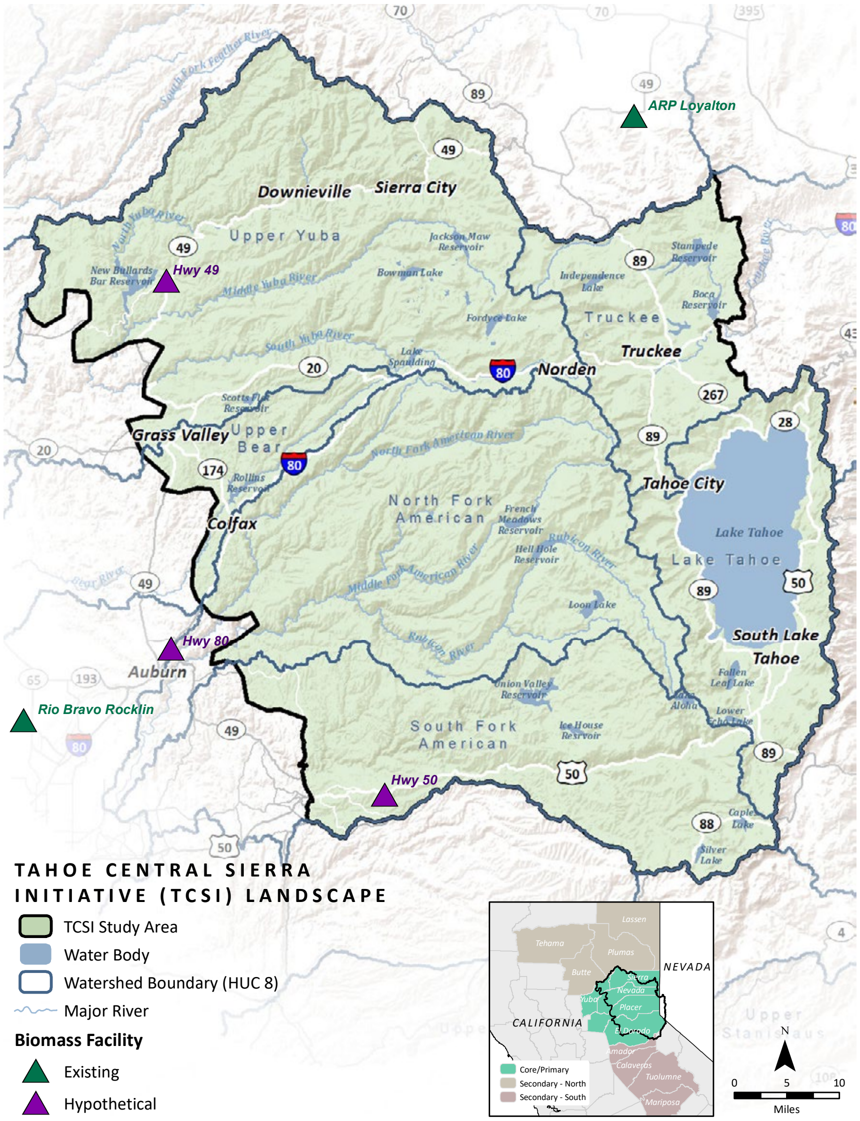

FIGURE 1. Locations of existing timber and biomass processing facilities surrounding the TCSI region. In the inset map, the core supply region is designated in green (right), with secondary regions to the south and north in grey.

3.0 FOREST RESTORATION STRATEGY

3.1 Treatments and Management Zones

Starting from current forest structure and composition, what silvicultural treatments should be prescribed?

The type of silviculture appropriate for restoration treatments depends on the stage of stand development. Young, densely populated stands with small trees could benefit from a pre-commercial thinning (PCT) or from prescribed fire (Rx Burn). Slightly older stands that have some merchantable trees but where densities are still high and pose a risk of wildfire could be treated with a commercial thinning (CT); in practice, the inventory did not permit differentiation between CT and the next treatment. Still older stands, many of which have not received the appropriate early silvicultural interventions, could be restored with a skips-and-gaps (SG) treatment or a regeneration (REG) harvest, the latter applicable only for private lands.

In addition to stage of stand development, forest ownership and/or the forest's administrative designation influences the type and prioritization of silviculture treatments that are implemented. For this analysis, we adopted the management zones being used by the *TCSI Assessment of Current (2018–2020) and Future (2020–2100) Conditions* (Wilson, personal communication; unpublished report, August 2020). The assessment establishes two management zones in the Wildland Urban Interface (WUI). The Defense Zone is a 0.25-mile spatial buffer established from developed areas (Figure 2), which include urban, exurban, and suburban areas with development densities as low as two dwelling units per acre. A wider 1.25-mile Threat Zone buffer was established (Figure 2) using the same development criteria. The General Forest management zone includes both public (USFS) and private forestland that is generally available for management, including mechanical thinning treatments, though specific thinning prescriptions (Table 2, "Rx") are set depending on ownership and other factors like the presence of sensitive environmental resources. Finally, the Wilderness and Roadless management zones preclude the use of mechanical thinning because use of mechanized equipment is prohibited (Wilderness) or technically infeasible (Roadless).

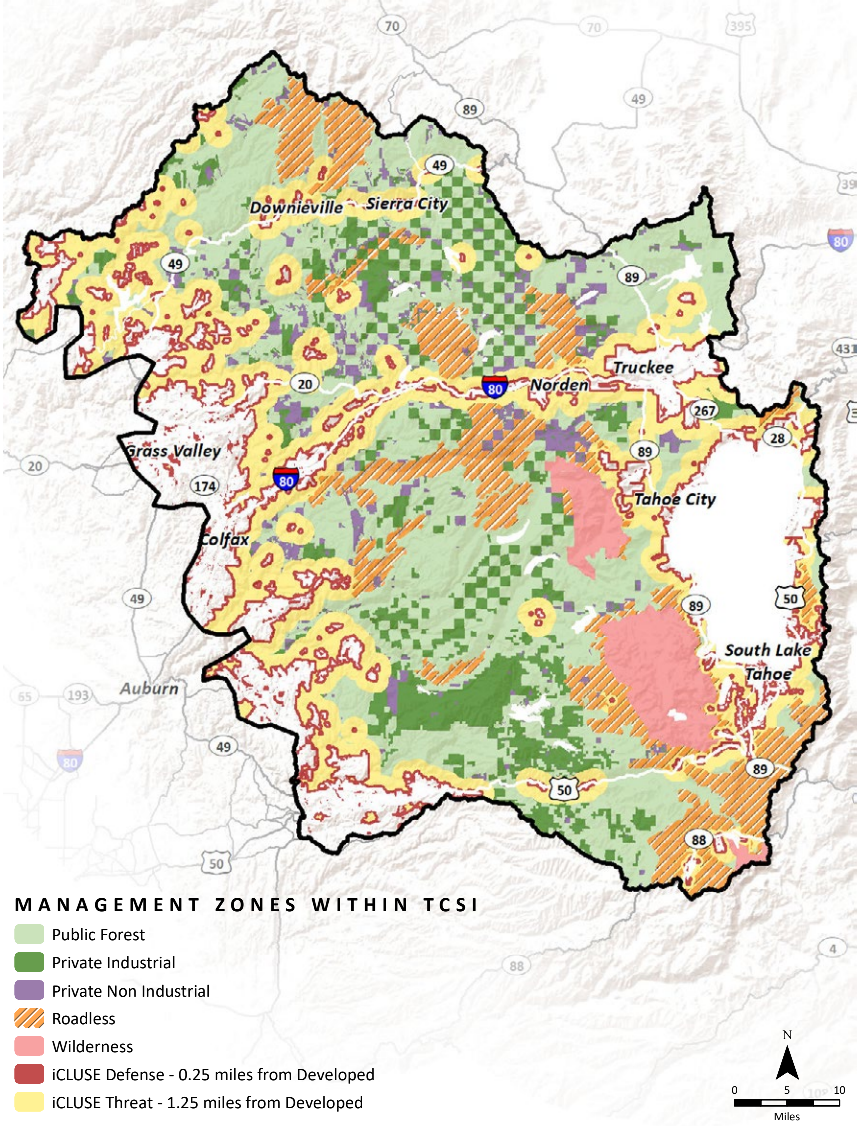

FIGURE 2. Forest management zones for the TCSI region. The iCLUSE Defense and Threat Zones include the Wildland Urban Interface (WUI) surrounding developed areas, including permanent infrastructure (e.g. interstates, highways).

TABLE 2. Eligibility matrix for silvicultural regimes by zone, ownership, operation type, seral stage.

Allocation				Rx			
Zone	**Own**	**Ops**	**Seral stage**	**Rx Burn**	**PCT**	**SG**	**REG**
Defense	USFS	Manual; Mech	Early/Mid/Late	Y	Y	Y	N
	Private†	Manual; Mech	Early/Mid/Late	N	Y	Y	Y
Threat	USFS	Manual; Mech	Early/Mid/Late	Y	Y	Y	N
	Private	Manual; Mech	Early/Mid/Late	Y	Y	Y	Y
General Forest	USFS	Ground-based	Early	Y	Y	N	N
	USFS	Ground-based	Mid	Y	N	Y	N
	USFS	Ground-based	Late	Y	N	Y	N
	USFS	Cable	Early	Y	Y	N	N
	USFS	Cable	Mid	N†	N‡	Y	N
	USFS	Cable	Late	N†	N‡	Y	N
	USFS	NonOperable	Early/Mid/Late	Y	N	N	N
General Forest	Private	Ground-based	Early	Y	Y	N	N
	Private	Ground-based	Mid	Y	N	Y	Y
	Private	Ground-based	Late	Y	N	Y	Y
	Private	Cable	Early	Y	Y	N	N
	Private	Cable	Mid	N	N	Y	Y
	Private	Cable	Late	N	N	Y	Y
	Private	NonOperable	Early	Y	N	N	N
Wilderness	USFS	Off limits	Early/Mid/Late	N	N	N	N

† Includes other non-USFS ownership, limited to a few percent of land base
‡ Indicates a fuels treatment, likely hand-thinning rather than a typical mechanical PCT

The simulation period for the model spans 20 years, from 2019 to 2039. Each harvest operation occurs at the midpoint of a 5-year period; in 2022 for the period from 2019 to 2024; in 2027 for the period from 2025 to 2029, etc. The simulation in FVS is not a harvest scheduling model, so all four potential treatment timings were simulated. The treatment optimization model selects the optimum timing (§3.3). Stands are grown from their 2018 tree lists to 2022, 2027, 2032, and 2037 using FVS, Western Sierras variant.[7] Regimes were applied only on operable acreage (North et al., 2015) as defined by Case C.[8]

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[7] https://www.fs.fed.us/fvs/software/variantkey.shtml

[8] North et al. developed a spatial hierarchy of forest management constraints that generally define operability with mechanized equipment on U.S. Forest Service land. Constraint Levels "0" (Biological), "1" (Legal), and "3" (Administrative) are approximated in this assessment and described elsewhere. Constraint Level "2" (Operational) refers to site-specific constraints on the use of ground-based harvester operations. Level 2, "Case C" reflects the operational guidelines frequently used on U.S. Forest Service lands and includes road-building extensions of up to 2,000 feet to access merchantable timber and mechanized tree removal on 35 percent–50 percent slopes, located within 500 feet of existing roads.

TABLE 3. Criteria for Rx implementation in FVS, Western Sierras variant, combined with limits to geographic and stand structure applicability. Regimes were defined in FVS using Trees Per Acre (TPA) or Basal Area (BA) targets.

Rx	Relevant Stand Information						Dbh limits (LT)	Stand Metric	Values
	Slope	NF	East-West	Seral	Cover	Zone			
Rx Burn	Any	Any	Any	Any	Not Hdwd	No Priv; Def	---	Rx Bn	see refs*
PCT	Any	El Dorado	Any	Early	Not Hdwd	Any	10″	TPA	200
	Any	Tahoe	Any	Early	Pine	Any	10″	TPA	90
	Any	Tahoe	West	Early	MixCon	Any	10″	TPA	150
	Any	El Dorado	Any	Mid, Late	Not Hdwd	Def, Thr	10″	TPA	200
	Any	Tahoe	Any	Mid, Late	Pine	Def, Thr	10″	TPA	90
	Any	Tahoe	West	Mid, Late	MixCon	Def, Thr	10″	TPA	150
Skips/ Gaps†	Low	El Dorado	Any	Mid	Not Hdwd	Any	30″	BA	88
	Mid, Ridge	El Dorado	Any	Mid	Not Hdwd	Any	30″	BA	80
	Low	El Dorado	Any	Late	Not Hdwd	Any	30″	BA	187
	Mid, Ridge	El Dorado	Any	Late	Not Hdwd	Any	30″	BA	170
	Low	Tahoe	West	Any	Pine	Any	30″	BA	99
	Mid, Ridge	Tahoe	West	Any	Pine	Any	30″	BA	90
	Low	Tahoe	East	Late	Pine	Any	30″	BA	87
	Mid, Ridge	Tahoe	East	Late	Pine	Any	30″	BA	79
	Low	Tahoe	West	Any	MixCon	Any	30″	BA	176
	Mid, Ridge	Tahoe	West	Any	MixCon	Any	30″	BA	160
	Low	Tahoe	East	Any	MixCon	Any	30″	BA	155
	Mid, Ridge	Tahoe	East	Any	MixCon	Any	30″	BA	141
Regeneration	Any	Any	Any	Mid, Late	Not Hdwd	Priv. Any	30″	TPA	100%

* https://www.nps.gov/seki/naturescience/upload/tall962b.pdf
* https://www.nps.gov/seki/naturescience/upload/ksm_msla99.pdf
† If Gaps area is 1/4 acre, then 0 BA on that area means compensate * (4/3) on Skips area

Regimes in FVS[9] were implemented within the MBG Tools software. This program is a data-management framework that can interact with an assortment of growth models, including FVS. We adopted this method because FVS cannot merchandise log products within cut trees. For this project, we needed to merchandise trees into products suitable for the region. Whereas a .key file type for FVS may be easily transmitted, the way in which MBG Tools interacts with FVS is sequential, and the .key file is procedurally generated at each growth step in such a way that a single .key is not retained. Further details regarding implementation may be requested.

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[9] Regime instructions provided by T. Walsh and D. Walsh, USFS; TNC working group 8/13/2019.

3.2 Scenarios

What land base should be targeted for restoration treatments, and what broad strategies govern the application of the regimes?

This report defines four potential restoration scenarios, in which each successive scenario incorporates the dynamics of all preceding scenario(s). The scenarios operate on combinations of stands classified by zone, landowner, operability, and forest type (Table 4). Every scenario maintains at its core the continuation of current timber-harvest activities, (the “baseline”), recognizing that restoration objectives must be compatible with existing economic activity.

- Scenario 1, **Baseline**, in which current timber-harvest rates and silvicultural prescriptions continue with no increase in restoration, serves as a baseline. Relevant primarily to General Forest Zone (Private and USFS), with limited areas of non-mechanical treatments in USFS Defense Zone.

- Scenario 2, **Community Protection**, in which restoration is prioritized on areas of USFS ownership designated Defense and Threat, mitigating impacts of wildfire on infrastructure.

- Scenario 3, **Forest Health**, in which restoration treatments expand across approximately 80 percent of the operable General Forest Zone on USFS ownership, at 5 percent allowed deviation from constant yield of sawtimber.

- Scenario 4, **Climate Change Resilience**, in which all operable acres in the General Forest Zone on USFS ownership are treated and prescribed burning is employed to a greater extent on some additional acreage designated non-operable.

Harvest levels in Scenario 1 are calibrated to resemble the five-year average harvest reported by the California State Board of Equalization from 2014 through 2017 (Table 5). Some degree of treatment not requiring mechanized equipment on non-operable acreage is specified in every scenario, corresponding to PCT (Defense, Threat) and Rx Burn (General Forest) on USFS land only. By USFS prescription guidelines, these regimes are suitable only for stands with certain structure (Table 3, references). The ST tree lists, since they exclude trees <5” DBH, are rarely eligible for PCT treatments but may receive some burn treatments. The model was severely constrained in its ability to allocate these treatments, which is inconsistent with current stated USFS management activities. In addition, PCT and Rx Burn treatments do not contribute commercial timber volume or biomass, so their relative absence, though important from silvicultural and ecological perspectives, has no further impact on timber-supply assessments. Regional forest management practices stipulate reduced treatments in northern spotted owl (NSO) habitats and in Riparian Management Zones (RMZs). Since we do not have tree lists or silvicultural regimes specific to NSO habitats or RMZ, we imposed a reduction factor for these land types. For the fraction of acres in every stand designated as habitat, we reduced harvest by 100 percent for NSO, 75 percent for other critical habitats, 50 percent for RMZs, and 100 percent for stand area occupied by roads.

3.3 Optimization

How should active forest management be expanded across the landscape to optimize forest restoration outcomes?

Yields simulated in FVS were organized into a format compatible with the Woodstock harvest scheduling model, a linear programming framework for optimizing outcomes in forest estate planning. We constructed a four-period model with a composite objective function. For Scenario 1, the model was implemented as a goal program, asked to find 191,188 MBF/year of timber harvest across the region (Table 5). For higher-order scenarios, the volume goal program was left in place but augmented by further goals to reach acreage targets (Table 5) and an objective function that sought to minimize terminal stand density index (SDI). An even-flow constraint was applied to sawtimber, which was allowed to fluctuate by 5 percent among periods.

TABLE 4. Acreage of restoration treatments and timber harvest in each scenario, classified by zone and ownership. All treated acres include non-mechanical and mechanical; mechanical treated acres include both business-as-usual and restoration; restoration mechanical excludes the business-as-usual baseline. "Restoration Mechanical" does not include Scenario 1 acres and does not include treatments on private lands.

Scenario	Zone	Owner	All		Mechanical		Restoration, Mech	
			Total Ac	Ac/Year	Total Ac	Ac/Year	Total Ac	Ac/Year
1	Defense	USFS	11,297	565	–	–	–	–
1	General	Priv	215,339	10,767	215,339	10,767	–	–
1	General	USFS	183,554	9,178	183,554	9,178	–	–
		Total:	**410,191**	**20,510**	**398,893**	**19,945**	**–**	**–**
2	Defense	USFS	42,205	2,110	30,907	1,545	30,907	1,545
2	Threat	USFS	177,913	8,896	177,913	8,896	177,913	8,896
2	General	Priv	215,344	10,767	215,344	10,767	–	–
2	General	USFS	262,858	13,143	183,556	9,178	–	–
		Total:	**698,319**	**34,916**	**607,720**	**30,386**	**208,820**	**10,441**
3	Defense	USFS	42,205	2,110	30,907	1,545	30,907	1,545
3	Threat	USFS	177,913	8,896	177,913	8,896	177,913	8,896
3	General	Priv	215,344	10,767	215,344	10,767	–	–
3	General	USFS	480,899	24,045	392,458	19,623	208,902	10,445
		Total:	**916,361**	**45,818**	**816,622**	**40,831**	**417,722**	**20,886**
4	Defense	USFS	42,205	2,110	30,907	1,545	30,907	1,545
4	Threat	USFS	177,913	8,896	177,913	8,896	177,913	8,896
4	General	Priv	215,344	10,767	215,344	10,767	–	–
4	General	USFS	585,586	29,279	397,792	19,890	214,236	10,712
		Total:	**1,021,048**	**51,052**	**821,956**	**41,098**	**423,056**	**21,153**

TABLE 5. Target quantity for each scenario (MBF for Scenario 1, combination of MBF, acres for higher order scenarios), with values for each silvicultural regime by period.

Scenario	Period	Acres Treated by Rx:				Total Acres Tx:		
		Regen.	PCT	Rx Burn	Skips/Gaps	Period	Year	Target
1	1	13,848	3,013	–	85,875	88,888	17,778	MBF
1	2	13,848	2,259	–	85,875	88,135	17,627	MBF
1	3	13,848	3,013	–	85,875	88,888	17,778	MBF
1	4	13,848	3,013	–	85,875	88,888	17,778	MBF
2	1	13,849	19,567	22,658	122,955	165,180	33,036	MBF, acres
2	2	13,849	20,604	22,658	121,918	165,180	33,036	MBF, acres
2	3	13,849	21,411	16,993	121,111	159,515	31,903	MBF, acres
2	4	13,849	21,411	16,993	114,645	153,049	30,610	MBF, acres
3	1	13,849	14,273	25,269	187,545	227,088	45,418	MBF, acres
3	2	13,849	3,228	25,269	187,545	216,042	43,208	MBF, acres
3	3	13,849	2,421	18,952	187,545	208,918	41,784	MBF, acres
3	4	13,849	2,421	18,952	187,545	208,918	41,784	MBF, acres
4	1	13,849	4,375	53,656	232,629	290,660	58,132	MBF, acres
4	2	13,849	3,228	53,656	160,505	217,389	43,478	MBF, acres
4	3	13,849	2,421	40,242	139,649	182,312	36,462	MBF, acres
4	4	13,849	2,421	40,242	232,629	275,292	55,058	MBF, acres

Ecological thinning—French Meadows Project (American River Watershed), Tahoe National Forest. © Brie Anne Coleman, Placer County Water Agency

4.0 RESULTS

The forest restoration model outputs are organized into three sections. First, we review timber and biomass harvest (§4.1) by scenario and five-year period, reporting species and size class for sawtimber and source fraction for biomass. Next, we compare timber and biomass production from scheduled restoration treatments to existing sawtimber and biomass processing capacity by scenario (§4.2). Finally, we present an economic analysis (§4.3) of each scenario under a set of cases representing current processing capacity and several hypothetical expanded-capacity options.

Above: Example of ecological (variable density) thinning at Stanislaus-Tuolumne Experimental Forest near Pinecrest, California. © David Edelson

4.1 Restoration Increases Timber Production

How much additional timber and biomass are produced, beyond the business-as-usual scenario, from increased pace and scale of forest restoration?

Scenario 1 was designed to emulate sawtimber production as measured from the last five years of available data from CA BOE for the study region. This includes 25 percent regeneration harvest and 75 percent skips-gaps on private land and 100 percent skips and gaps for commercial production from USFS ownership. Total production in Scenario 1, fixed across periods, was 191,188 MBF/year (Table 6) This business-as-usual baseline is repeated in Scenarios 2, 3, and 4, with additional harvested volume from forest restoration treatments. Whereas Scenario 1 baseline harvest is constant over time, the model allowed a 5 percent departure from even flow for the restoration scenarios (Table 6).

TABLE 6. Sawtimber harvest from combined business-as-usual (Scenario 1) and forest restoration treatments (Scenarios 2, 3, 4) for each five-year period, with volume classified by species group.

Scenario	Period	MBF/Year Harvested by Species						Total MBF/Year
		DF	IC	PN	PP	RF	WF	
1	1	52,671	10,084	38,742	27,289	33,032	29,371	191,188
1	2	47,193	11,811	37,581	24,534	31,115	38,955	191,189
1	3	37,614	11,503	38,487	26,671	34,248	42,664	191,188
1	4	32,956	12,312	41,246	25,475	34,702	44,498	191,188
2	1	82,909	16,546	41,091	30,777	28,485	44,148	243,956
2	2	47,364	11,923	47,104	27,451	45,874	45,428	225,144
2	3	43,882	10,890	48,154	30,199	40,198	41,937	215,261
2	4	29,688	7,799	49,792	26,903	52,861	35,951	202,993
3	1	87,056	16,456	59,598	36,100	50,627	49,652	299,489
3	2	57,028	13,088	58,540	36,879	44,102	46,680	256,316
3	3	57,714	15,696	68,995	43,442	57,672	62,340	305,859
3	4	51,848	17,734	68,142	43,339	63,368	69,750	314,181
4	1	93,279	17,505	68,936	41,211	56,157	53,404	330,491
4	2	52,932	12,353	51,860	33,620	38,209	43,839	232,812
4	3	48,506	12,631	56,145	36,212	49,022	49,100	251,615
4	4	62,561	21,233	80,980	51,114	72,161	84,741	372,790

In Scenario 2, the focus on restoring more resilient forest structure in Defense and Threat Zones increases annual harvest to 243,956 MBF in the first period, or 52,767 MBF higher than baseline. Over successive periods, this excess production fluctuates and ultimately drops to just 11,804 MBF above BAU. Restoration scenarios are not subject to a flow constraint on sawtimber, so this decline reflects an early emphasis on removing density from heavily over-stocked stands. In later periods, the model allocates treatments to stands that were not as immediately in need of restoration. Sometimes, this strategy does result in higher timber harvests in later periods, as in Scenarios 3 and 4 (Table 6). On average, compared to Scenario 1, Scenario 2 yields 30,650 MBF/year higher; Scenario 3 yields 102,773 MBF/year higher; Scenario 4 yields 105,739 MBF/year higher. These timber volumes do not exceed current regional processing capacity as self-reported by sawmills, although they do approach capacity of mills in the region core.

Harvested sawtimber across all scenarios is approximately 20 percent each Douglas fir (DF), pines not including Ponderosa pine (PN, i.e. all "pines" except Ponderosa pine), red fir (RF), and white fir (WF). Ponderosa pine constitutes around 13 percent of the harvest, and incense cedar (IC) around 5 percent (Table 6). Small variations in tree species volumes across scenarios and rounding artifacts explain the remaining (+/-2 percent) of volume. When classifying timber volume by log size (small end diameter, or SED), most of the volume is found in logs greater than 20" diameter (Table 7). Approximately 45 percent of volume is found in this largest size class, around 15 percent in the 16" to 20" class, 30 percent in the 8" to 16" class, and around 10 percent in the smallest 6" to 8" class. Logs with SED less than 6", often from the tops of trees, are typically too small for sawtimber. For this model, tops were converted to BDT and reported as biomass (Table 8). A complete account of sawtimber volume by scenario, period, diameter class, and species is in Appendix C, which can be provided upon request.

TABLE 7. Sawtimber harvest for each five-year period, with volume classified by log-size class.

Scenario	Period	MBF/Year Harvested by Log SED				Total MBF/ Year
		6″- 8″	8″-16″	16″-20″	≥ 20″	
1	1	18,160	56,031	27,532	89,465	191,188
1	2	19,545	62,361	27,941	81,341	191,189
1	3	18,223	62,563	27,846	82,557	191,188
1	4	17,622	63,401	27,512	82,653	191,188
2	1	33,000	93,497	35,186	82,272	243,956
2	2	25,378	72,349	32,426	94,991	225,144
2	3	20,949	63,769	30,352	100,190	215,261
2	4	13,259	53,195	28,544	107,994	202,993
3	1	32,924	100,122	44,335	122,109	299,489
3	2	25,656	77,324	37,248	116,088	256,316
3	3	28,979	93,965	43,115	139,800	305,859
3	4	29,370	100,158	43,439	141,213	314,181
4	1	35,502	108,001	49,062	137,926	330,491
4	2	23,402	70,909	33,739	104,762	232,812
4	3	23,723	76,290	35,806	115,795	251,615
4	4	34,860	120,022	51,632	166,276	372,790

The biomass produced along with sawtimber is not reliably reported to CA BOE, so it is not possible to set a biomass baseline value for Scenario 1. Biomass estimation in each scenario represents material harvested along with sawtimber production. This could include live biomass from small trees, tops of sawtimber trees, or dead trees (Table 8). In part because of the recent drought-induced tree mortality event, biomass from dead trees constitutes the majority of potentially available material in the study region. Across scenarios, approximately 70 percent of the harvested biomass could derive from dead trees, even accounting for our assumptions that restrict access to dead material after a certain elapsed time and for reductions in handling limitations such as the lack of dead biomass removal during cable logging. The availability of dead biomass changes dramatically over time in all scenarios. Dead trees from the 2015–2018 drought related mortality event are made partially available to the model in the first period but are largely unavailable in subsequent periods. There is a spike in biomass availability in period 1 driven by the dead fraction, ranging from 2.3 to 3.6 times higher than the average biomass production in period 4.

Live biomass production also declines over time (Table 8), but the magnitude of this fluctuation is much smaller. Continued availability of the dead biomass fraction is not guaranteed. The most extensive mortality occurred in 2016 and 2017 (Moore et al., 2019), and much of this material will be impractical to salvage by 2021. As it is unlikely that new biomass facilities would begin accepting material in this timeframe, the rest of this analysis treats dead mass as off limits. Considering only live mass from small trees <10” DBH and from tops, the restoration scenarios do represent an increase in production relative to baseline harvest activity. Compared against a Scenario 1 average yield of 75,606 BDT/year live biomass, Scenario 2 yields 25,456 average additional BDT/year; Scenario 3 yields an additional 47,227 BDT/year; and Scenario 4 yields an additional 47,317 BDT/year.

TABLE 8. Biomass harvest in each scenario derived from forest restoration treatments.

Scenario	Period	BDT/year Biomass Fraction				Total BDT/ Year
		Live	<10″ DBH	Saw Tops	Dead	
1	1	80,659	23,357	57,302	287,926	368,586
1	2	83,227	27,951	55,275	236,170	319,397
1	3	74,397	23,614	50,782	122,901	197,298
1	4	68,141	19,291	48,850	52,811	120,952
2	1	139,016	51,005	88,010	513,336	652,351
2	2	114,534	45,955	68,580	260,150	374,684
2	3	93,361	34,678	58,683	151,936	245,297
2	4	61,336	15,327	46,009	50,369	111,705
3	1	143,254	45,779	97,474	592,213	735,467
3	2	116,641	40,354	76,287	333,693	450,335
3	3	123,793	37,584	86,209	245,371	369,164
3	4	111,642	30,208	81,434	100,898	212,541
4	1	153,148	45,736	107,412	679,852	833,000
4	2	106,201	37,183	69,019	297,025	403,226
4	3	101,528	31,271	70,256	182,023	283,551
4	4	134,817	36,334	98,483	128,582	263,399

4.2 Regional Processing Capacity Exceeded

Can the existing regional timber/biomass-processing industry accommodate/process all of the material produced by expanded forest restoration?

Currently, the only operational biomass-processing facility in the core region is the IHI Rio Bravo BioRAM electricity-generating plant at Rocklin (Table 9). The facility at Loyalton was operational through late 2019 but subsequently filed for Chapter 7 bankruptcy proceedings and recently exited those proceedings under new ownership. Other biomass-fueled electricity-generating plants exist in the secondary areas north and south of the study region, but our understanding (Mason, Bruce & Girard and The Beck Group, 2019) is that biomass is rarely transported to these facilities from within the study region because transport costs are too high. At present, the Rocklin facility constitutes 100 percent of the biomass-processing capacity serving the study area. In this report, we assume that the amount of biomass consumed by Rocklin that is produced within the study area represents the at-capacity usage for this facility. That is, as the single operational biomass facility likely to accept biomass from forest restoration projects undertaken by TCSI, Rocklin is currently accepting material at 100 percent of its practical capacity.

Several sawmills operate in the vicinity of the study region (Table 9), and numerous other mills are also in business in secondary areas beyond the core. Two mills owned by Sierra Pacific Industries (SPI) at Oroville and Chinese Camp are likely to process only cedar from the study region. Other SPI mills at Quincy and Lincoln would process non-cedar sawtimber. The SPI co-generation biomass power facilities at Quincy and Lincoln are fueled by a combination of mill residues and biomass from SPI land holdings outside the study region, so we do not include their capacity for biomass processing. Two very small mills, Apex Lumber and Kubich Lumber, may process some sawtimber.

TABLE 9. Operational processing capacity of biomass and sawtimber facilities surrounding the study region.

Company	City	Abbr.	Facility	Product	Basis	Consumption per Year	
						Likely Actual	Maximum
IHI Rio Bravo	Rocklin	Rckln	Biomass	Biomass	BDT	100,000	184,000
Sierra Pacific Industries	Oroville	SPIOrv	Sawmill	Cedar	MBF	25,700	90,000
Sierra Pacific Industries	Chinese Camp	SPICCp	Sawmill	Cedar	MBF	38,000	95,000
Sierra Pacific Industries	Quincy	SPIQnc	Sawmill	Non-cedar	MBF	122,200	220,000
Sierra Pacific Industries	Lincoln	SPILnc	Sawmill	Non-cedar	MBF	150,000	270,000
Apex Lumber	Oroville	ALOrv	Sawmill	Non-cedar	MBF	700	1,000
Kubich Lumber	Grass Valley	KLGV	Sawmill	Non-cedar	MBF	700	1,000

4.2.1 Biomass Capacity

Scenario 2 biomass yield exceeds Rocklin's processing capacity by a *minimum* of 25,456 BDT/year; Scenario 3 by 47,277 BDT/year; and Scenario 4 by 47,317 BDT/year.

These minimum values assume that only the live biomass fraction is used for fuel from High Hazard Zones (HHZ) within the study area. If salvage of dead material from the mortality event is permitted, then capacity is exceeded to an even greater extent. For example, including dead mass in period 1 of Scenario 2 results in 575,754 BDT/year beyond the Rocklin processing capacity. This period 1 excess for Scenario 3 is 658,861 BDT/year, and for Scenario 4 is 756,394 BDT/year.

The Rocklin facility has a name plate capacity of 21 MW for a likely total consumption of 184,000 BDT operating around 90 percent capacity. This plant participates in the Biomass Renewable Auction Mechanism (BioRAM) program, so its required forest-derived fuel consumption must be 80 percent from HHZ, or 133,000 BDT. It is probable that 20 percent of consumption is from HHZ-derived mill residues, leaving 60 percent direct from forest, or 100,000 BDT annual demand from forest sources. Some fraction of this tonnage is currently sourced from within the TCSI study region, while the remainder would be sourced from elsewhere. To assess whether Rocklin can process the biomass produced from forest restoration, we must assume that the plant is currently operating at practical capacity with (x%) feedstock sourced from the study region and (1-x%) sourced elsewhere. Scenario 1 finds an average of 75,606 BDT live biomass harvested per year, which corresponds to 76% of Rocklin's annual consumption. The balance must be sourced in forests outside the study area. Therefore, any increase in biomass production from within the study region exceeds the processing capacity of the Rocklin plant. Any expansion of biomass source options, such as allowing dead biomass from salvage operations, further exceeds capacity.

Total biomass (live and dead) yields are not sustained over the modeling period, so the extreme capacity overshoot observed in period 1 of the higher-order scenarios would soon give way to more modest excesses ranging from 101,895 BDT/year average in periods 3 and 4 of Scenario 2 to 241,246 BDT/year average in periods 3 and 4 of Scenario 3. In this study we resort to a conservative estimate of biomass availability limited only to the live fraction. In reality, salvage operations are common and dead biomass will be processed. Short-term biomass production from forest restoration activities could exceed existing processing capacity by nearly an order of magnitude and with sustained excesses above a factor of 2.8.

Biomass Capacity Conclusion: Current biomass electricity-generating capacity serving the TCSI study region is insufficient to process material from increasing pace or scale of forest restoration.

4.2.2 Biomass Sustainable Yield

Uneven yield of biomass presents a fundamental challenge to biomass processing and investment in the TCSI region over the next 20 years; investment in biomass infrastructure must be underwritten by a sustainable yield estimate.

Biomass yields in the first period of every scenario dwarf those from later periods (Figure 3). The restoration scheduling model was constructed with a requirement to maintain an even flow of sawtimber (±5 percent) and to seek minimum SDI overall. The model was not required to ensure a sustained biomass yield, however, so one of the best ways to improve stand structure and reduce fire risk (fewer dead trees to serve as wildfire fuel, lowest SDI) was to quickly remove dead biomass from the 2015–2018 mortality event. Standing dead trees are only practically accessible to logging equipment for a few years, so the available pool of dead biomass drops precipitously in period 2 of this model. The dead biomass fraction in periods 2 through 4 is chiefly from the final year of the mortality event or from background levels of tree mortality for the region.

To define a sustainable yield, we skip period 1 and look to Scenarios 3 and 4. Our expectation of a sustainable biomass yield will be the average biomass yield, live and dead combined, from periods 2 through 4 of Scenarios 3 and 4. This precise value is 330,369 BDT/year, but we will adopt 320,000 BDT/year as a more conservative estimate. This biomass yield also translates to an electricity-generating potential of 40 MW.

Long-term sustainable yield of total biomass is defined as 320,000 BDT/year (40 MW), reflecting biomass yields in the later periods of Scenarios 3 and 4. The initial pulse of biomass derived from the 2015–2018 mortality event must not be considered a sustainable level of harvesting, and that material will be largely unavailable after period 1.

4.2.3 Sawtimber Capacity

Current sawmill capacity is sufficient to process most potential sawtimber production under anticipated forest restoration scenarios using facilities only in the regional core operating at present annual consumption rates and not accounting for delivered wood volumes outside the TCSI area.

Cedar: Two SPI mills at Oroville and Chinese Camp are likely to process all of the incense cedar harvested in the study region. Total estimated annual consumption of cedar logs by these two facilities is 63,700 MBF/year. The maximum anticipated annual cedar harvest under increased restoration is an average of 15,931 in Scenario 4, with a periodic maximum of 21,233 in period 4. Even this maximum yield represents only 33 percent of the current consumption. Both cedar mills have a potential combined maximum capacity

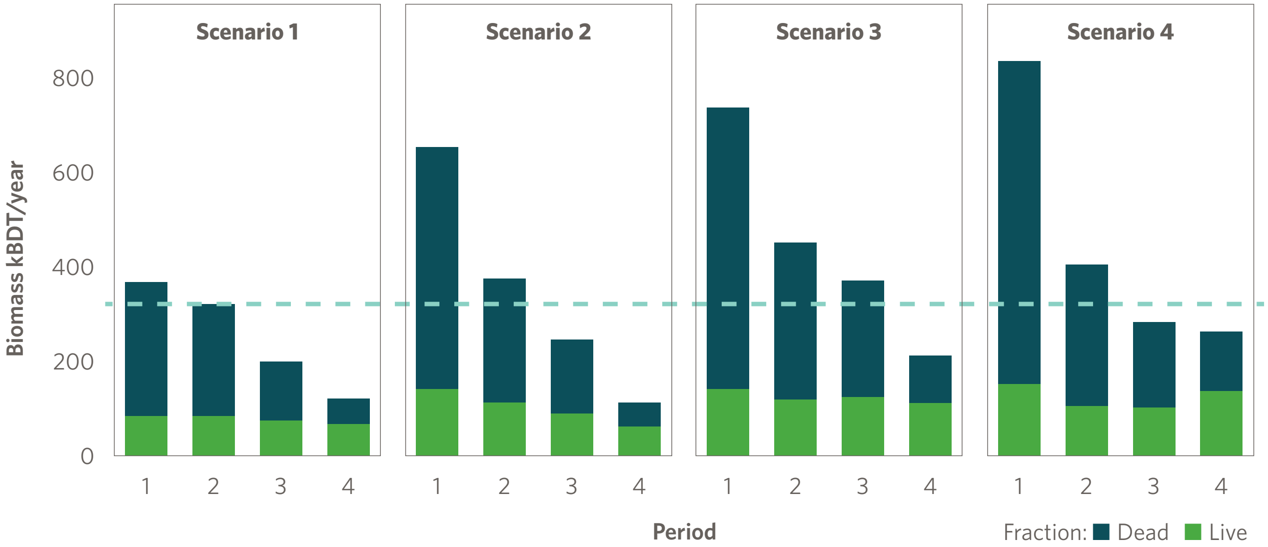

FIGURE 3. High initial biomass yields capture dead material from the recent mortality event. Total production of biomass declines over time, while live biomass yield and background mortality rates remain relatively stable. A reasonable long-term sustainable yield of 320,000 BDT/year (blue dashed line) is expected. Although periods 3 and 4 biomass production may not meet hypothetical facility demand, this production level does not include sawmill residuals or account for alternative higher-yielding silvicultural treatments.

of 185,000 MBF/year, suggesting that consumption could be increased to accommodate cedar resulting from forest restoration activities.

Non-cedar sawtimber: Sawtimber harvested in the study region would be processed primarily at SPI's Quincy and Lincoln mills. Also including small mills in Oroville and Grass Valley, the consumption of sawmills in the regional core is 273,600 MBF/year. We are informed (Anderson, June 2020) that, although these mills are not operating near their absolute maximum capacity, it is uncertain precisely how much additional production could be expected. Although the publicly stated combined maximum consumption for the two SPI mills is 490,000 MBF/year, it is unknown whether this maximum can be realized given the regional constraints on timber production, including demand from area mills, available labor to support logging and hauling logistics, and macroeconomic factors governing demand for wood products.

Baseline harvest activity from recent years, represented by Scenario 1, produces 179,761 MBF/year (non-cedar) from the study region, which is processed almost exclusively by the SPI mills. This volume is 66 percent of the annual consumption. In Scenario 2, forest restoration treatments in the Defense and Threat Zones average 210,049 MBF/year, with a maximum of 227,410 MBF non-cedar harvested in period 1, or 84 percent of capacity. Both Scenarios 3 and 4 on average marginally exceed non-cedar sawmilling capacity, at 102 percent and 103 percent, respectively, but some periods are substantially below 100 percent capacity. In period 4, Scenario 3 harvest is 107 percent of saw capacity, and Scenario 4 harvest is 129 percent of capacity. The market reality in the region is that SPI operates virtually all of the sawmill facilities that could possibly accept timber produced from the TCSI's forest restoration efforts.

Increasing regional pace and scale of forest restoration principally on USFS ownership will produce additional sawtimber directly in competition with SPI. Any increased sawtimber harvest would displace volume currently processed at Quincy and Lincoln. If we view current consumption as congruent with processing capacity, the smallest average sawtimber harvest increase in Scenario 2 represents 30,288 MBF/year beyond current capacity. The largest periodic harvest increase, period 4 in Scenario 4, would be 171,976 MBF/year beyond current capacity. Maximum stated additional capacity (above current consumption) of the two SPI mills is 217,800 MBF/year, or (if accurate) more than enough to accommodate maximum potential restoration sawtimber yield. At the time of this writing, we view regional sawmilling capacity as sufficient to accommodate harvests from forest restoration activities in the study area.

4.3 New Processing Capacity to Support Restoration

How much additional biomass-processing capacity would TCSI need within the study region to accommodate extra production resulting from forest restoration?

In the previous section, we showed that current regional biomass-processing capacity is sufficient for business-as-usual levels of live biomass harvest. This capacity is not sufficient to process all potential biomass, including dead material from business-as-usual harvests, however, nor would it suffice if expanding forest restoration activities led to increasing biomass supply. In this section, we present four **"Cases" (defined further below)** representing possible future processing capacity.

Case A defines current processing capacity serving the study region (Table 9), with a single operational biomass facility at Rocklin and nearly all of the sawtimber-processing capacity operated by SPI at several locations. **The Case A configuration is the foundation for each subsequent case; sawtimber capacity is fixed across all cases.** In all cases, biomass and sawtimber are dispatched to the closest facility; should the capacity of the closest facility to a given stand be exceeded, harvest from that stand is directed to the next closest location, etc.

If the regional biomass-to-electricity facilities burned solely live biomass, this harvest level would constitute only a 23,000 BDT/year increase over the existing demand from the Rocklin facility. We observe that Rocklin must currently absorb at least some of the live biomass being harvested in the study region, but likely not all, so demand from Rocklin should be lower (by some unknown margin) than the approximately 80,000 BDT/year harvested in recent years from the study region. Consequently, at least 43,000 BDT/year of live biomass is likely harvested in the study area that the region does not currently (Case A) have the capacity to process; this corresponds to approximately 5 MW additional electricity-generating capacity, or around one-third of the capacity that would be back online with an operational plant at Loyalton.

The challenge for TCSI is to understand how electricity-generating capacity is distributed across the region and whether the Rocklin and Loyalton locations represent real potential to promote biomass forest restoration. Although these two facilities have the capacity to process all of the live biomass likely to be harvested under the TCSI on a sustained basis during forest restoration, three factors limit their effectiveness:

1. Both are far away from much of the TCSI focal area—high transport costs.

2. They have incentive to source biomass locally—does not support TCSI restoration efforts.

3. Their combined capacity, though sufficient to process the live biomass, cannot accommodate dead biomass that has accumulated after the mortality event, removal of which would be a critical element of forest restoration.

For this report, we seek to define expanded biomass capacity cases that are conservative yet still capture the essential economics of timber transport and forest restoration silviculture. To support such a definition, we proceed with several caveats:

1. Only live biomass produced from each scenario participates in stumpage calculations.

2. Dead biomass would be available in practice, but the 2015–2018 mortality would contribute to an early surplus, while long-term production could not be sustained.

3. If new facilities operate under the BioRAM protocol requiring 80 percent of supply from HHZ, substituting qualifying sawmill residues could reduce consumption of direct-from-forest materials to below 60 percent. Therefore, we shall not require all new capacity to be completely supplied directly from forest restoration sources.

4. Ensuring continued adequate supply of biomass to Rocklin and Loyalton is not an overriding priority; introduction of new facilities may lead to competition.

5. Total new generating capacity should reflect likely long-term sustainable supply, which for a variety of reasons may not precisely mirror harvests in each scenario and period from the timber supply model.

For each ensuing case, we augment Case A with an additional 40 MW of biomass electricity-generating capacity, corresponding to 320,000 BDT/year biomass consumption. This amount of augmented capacity can be interpreted in several ways. First, it is 92 percent of the total (live and dead) average annual biomass production from forest restoration activities under Scenario 2 in our current model and 72 percent of total average annual production in Scenarios 3 and 4. Regarding caveat 5 above, these average long-term supplies are higher than the augmented capacity. Second, if the new facilities operate as BioRAM, consuming 60 percent of their fuel direct from HHZ and 20 percent as qualifying mill residues,[10] demand for biomass direct from forest would be 192,000 BDT/year. Minimum combined live and dead biomass production is 212,541 BDT/year in period 4 of Scenario 3 and 263,399 BDT/year in period 4 of Scenario 4. Annual demand of 192,000 BDT corresponds to 90 percent of the Scenario 3 minimum total production and 73 percent of the Scenario 4 minimum total production. Considering strictly live biomass, Scenarios 3 and 4 average around 120,000 BDT/year, which translates to 65 percent of the direct-from-forest supply needed if 40 MW generating capacity is met with 60 percent direct-from-forest material. Therefore, augmented capacity in each case could be practically met with biomass supply from the forest restoration model as it is configured for this study. It is straightforward to envision pathways toward higher production: where silvicultural regimes extract fractionally more volume, where the objective function of the scheduling model emphasizes production rather than minimized SDI, or where future wildfire events necessitate accelerated salvage operations.

Case B: Here, 40 MW additional electricity-generation capacity and 320,000 BDT/year demand comprise a reopened facility at Loyalton (18 MW) and two new facilities within the study region, each of 11 MW generation capacity and 88,000 BDT/year demand (Figure 1). The new facilities would be located (Figure 4) on Highway 80 near the town of Bowman and on Highway 50 near the town of Camino (Table 10). We selected the Highway 80 location as an average of several possible locations, including Grass Valley, Colfax, and Auburn. This location is not meant to represent practical siting concerns. In contrast, the location on Highway 50 near Camino was at one point the location of a biomass plant. The northern facility, depicted as an orange open diamond, participates in Case C.

A reopened Loyalton facility would generate 18 MW, requiring around 144,000 BDT/year. Practically, the plant would presumably need to operate at 90 percent capacity to avoid conditions that led to its current bankruptcy (Anderson, June 2020). Actual direct-from-forest requirements could be lower; for example, operating at 90 percent capacity and sourcing 75 percent of its biomass direct from forest, the Loyalton facility might consume 107,000 BDT/year. At the time of this writing, TNC and other interested parties were attempting to schedule a meeting with the new owner (Jeff Holland) to gauge the timing and level of future operations.

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[10] This is the current fuel source profile for Rio Bravo Rocklin.

If the new facilities each also operated at 90 percent capacity and sourced 60 percent direct from forest, their consumption would be 50,160 BDT/year each. In our present definition of Case B, we describe stumpage based on the 90 percent/75 percent version for Loyalton and the maximum potential demand for the Highway 80 and Highway 50 facilities.

Case C: In this case, the same 40 MW additional generation capacity is distributed over four new facilities (Figure 4, Table 11). There is no change to the Loyalton location versus case B, but each of the new locations has a reduced capacity to keep the total limited to 40 MW. We maintained an integer value for name plate capacity, with 8 MW at Bowman on Highway 80, 7 MW at Camptonville on Highway 49, and 7 MW at Camino on Highway 50. Maximum demand remains the same at 320,000 BDT/year, although with the practical reduction for 90 percent/75 percent on capacity and forest-direct, real consumption might be closer to 232,000 BDT/year.

Case D: This case reduces facility count to the Loyalton location and just one new facility at the Highway 80 location (Figure 4) near Bowman (Table 12), now with generating capacity at 22 MW.

TABLE 10. Case B expanded capacity with facilities at Loyalton (reopened) and new plants on Highway 80 near Bowman and Highway 50 near Camino.

Company	City	Name Plate Capacity (MW)	Operating Capacity	Forest Direct	Consumption/Year (BDT)	
					Max. Demand	Practical Example
ARP Loyalton	Loyalton	18	90%	75%	144,000	107,000
Hwy. 80	Bowman	11	95%	75%	88,000	62,700
Hwy. 50	Camino	11	95%	75%	88,000	62,700
					320,000	**232,400**

TABLE 11. Case C expanded capacity with facilities at Loyalton, Bowman, Camino, and a third new facility on Highway 49 near Camptonville.

Company	City	Name Plate Capacity (MW)	Operating Capacity	Forest Direct	Consumption/Year (BDT)	
					Max. Demand	Practical Example
ARP Loyalton	Loyalton	18	90%	75%	144,000	107,000
Hwy. 80	Bowman	8	95%	75%	64,000	45,600
Hwy. 50	Camino	7	95%	75%	56,000	39,900
Hwy. 49	Camptonville	7	95%	75%	56,000	39,900
					320,000	**232,400**

TABLE 12. Case D expanded capacity with facilities at Loyalton and a single new facility at the Highway 80 Bowman location, now with a higher capacity of 22 MW.

Company	City	Name Plate Capacity (MW)	Operating Capacity	Forest Direct	Consumption/Year (BDT)	
					Max. Demand	Practical Example
ARP Loyalton	Loyalton	18	90%	75%	144,000	107,000
Hwy. 80	Bowman	22	95%	75%	176,000	125,400
					320,000	**232,400**

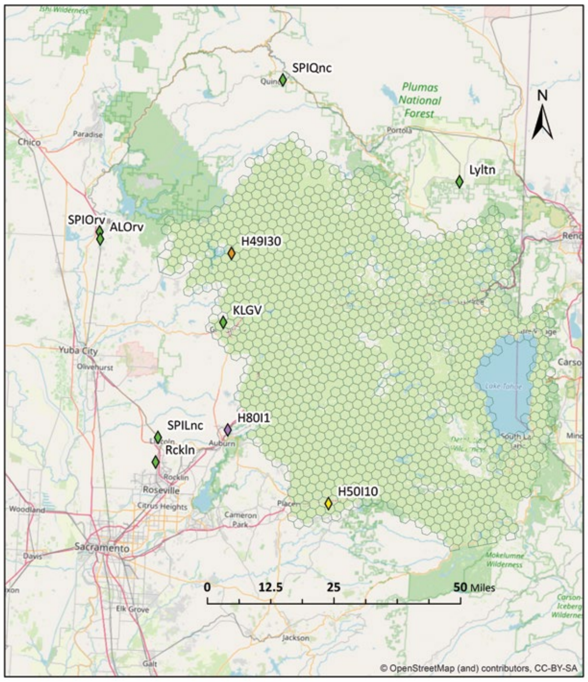

FIGURE 4. Existing sawmill and biomass facility locations (green-filled diamonds) form the TCSI core area, with three new locations for facilities within or near the study region (open diamonds). The location H49I30 (orange) is near Camptonville on Hwy. 49 and participates in Case C. The location H80I1 (green) is near Bowman on Hwy. 80 and participates in Cases B, C, and D. The location H50I10 (pink) is near Camino on Hwy. 50 and participates in Cases B and C.

4.4 Economic Impacts of Capacity Expansion

Does locating increased processing capacity within the study region substantially change biomass economics for currently operational facilities? Are certain cases better?

To answer the questions that motivate this section, and to standardize comparisons across scenarios and among cases within a scenario, we calculated several summary economic quantities, including delivered-log price, logging cost, haul cost, and stumpage price:

Stumpage = Delivered Price - Logging Cost - Haul Cost (Equation 1).

Delivered-log values were assigned from confidential contemporary log prices (Table 13; French Meadows Project, TNC, 2018) and logging costs from the area (MB&G regional data; French Meadows Project, Pers. Comm. Robert Galliano). Logging costs for sawtimber vary by logging system (tractor vs. cable) and by volume removed (Table 14); logging costs for biomass are $13/BDT for small trees and/or dead trees, with no extra cost for biomass from sawtimber tops (Mason, Bruce & Girard and The Beck Group, 2019).

TABLE 13. Delivered-log and biomass prices for the Lake Tahoe region.

Species	$/BDT	$/MBF			
	Biomass	6″-8″	8″-16″	16″-20″	>20″
DF	$40	$450	$450	$450	$450
IC	$40	$550	$550	$550	$550
PN	$40	$400	$400	$400	$400
PP	$40	$400	$400	$400	$400
SP	$40	$400	$400	$400	$400
WF	$40	$400	$400	$400	$400

TABLE 14. Logging costs for sawtimber vary by volume extracted per acre (MBF/acre) and by logging system, with more expensive logging costs for cable-ground and less expensive costs for tractor-ground.

MBF/acre	$/MBF	
	Tractor	Cable
3 to 5	$180	$280
6 to 9	$150	$250
10 to 14	$125	$210
15 to 19	$110	$190
20 to 29	$100	$180
30 to 34	$100	$170
35 to 39	$90	$170
40 +	$90	$160

There is a 0.8 scalar factor reduction applied to yield of dead biomass, imposed *in addition to decomposition*, reflecting typical losses from breakage during handling. A cost of $20/BDT is incurred for chipping biomass, which is added to logging cost both for small-tree biomass and for sawtimber tops. Haul costs were set at $88 per hour (Mason, Bruce & Girard and The Beck Group, 2019), assuming 4.97 MBF Scribner short-log scale per load for sawtimber, using long-log loads, and 12.5 BDT per chip-van load for biomass. The number of loads produced in each stand was calculated as the quotient of total MBF of BDT and the per-load values in the previous sentence. Haul cost for both sawtimber and biomass includes 0.75 hours of cumulative idle time for load-up at landing and unload at mill. Haul costs are two-way; that is, the one-way travel time multiplied by two to reflect the inbound (empty) trip and the outbound (full) trip.

In the next four subsections, we report the economics of biomass and sawtimber for each scenario and case, expressed as total stumpage value for the 20-year model period. This total stumpage assessment is the sum over time (four five-year periods) and over all of the participating stands in each scenario and case as determined by the optimization. For Scenario 1, we also include a series of maps showing biomass stumpage value for aggregates of stands in one-mile hexagons for each combination of case and period (§4.4.1); analogous map series for the higher-order scenarios are available in Appendix D.which can be provided upon request.

4.4.1 Scenario 1 Economic Summary

In the business-as-usual scenario, silvicultural regimes were specified to yield around 190,000 MBF/year, comparable to recent harvests reported to CA BOE. In this scenario, we engineered 179,761 MBF of non-cedar sawtimber and 11,427 MBF of incense cedar (Table 15). The CA BOE cannot collect reliable statistics on biomass harvests, so we do not benchmark biomass yields to published values. Instead, we take a conservative approach and limit biomass harvest to the live fraction only and sourced only from tractor-ground.[11] In these economic calculations, dead biomass is always excluded, although in practice there may be extensive salvage operations in the region, particularly after wildfire events. Scenario 1 yielded 70,756 BDT live biomass, which at $40/BDT is valued at $2.83 million before considering logging and haul costs. Total forest costs are not necessarily a straightforward multiplication of logging and chipping costs. Some portion of live biomass is from small trees, which incur logging costs, while the remainder is from the tops of sawtimber trees, which arrive "free" at the landing with the sawtimber. Chipping costs are incurred for all biomass. Together, in-forest costs for the live biomass fraction would be $1.645 million, and this material would fill 5,660 chip vans. Sawtimber and cedar values are substantially higher, at $74.03 million and $6.29 million, respectively (Table 15), with forest costs approximately one-third of the delivered value.

TABLE 15. Potential production of live biomass (BDT), sawtimber (MBF), and cedar (MBF) from Scenario 1, emulating the previous five-year average harvest from CA BOE data averaged from 2014–2018.

Case	Product	Produced by Scenario			Forest Costs	Loads (N)
		Units	Value	Delivered		
All	Live Bio.	70,756	$2,830,235	100%	$1,645,262	5,660
All	Sawtimber	179,761	$74,034,818	100%	$26,508,153	36,169
All	Cedar	11,427	$6,285,079	100%	$1,699,422	2,299

Under current business conditions, operational facilities have enough collective processing capacity to accommodate the total regional production of live biomass and sawtimber. This is represented by Scenario 1 Case A, where the only operational biomass processing facility is the Rio Bravo Rocklin location. Its total likely actual biomass consumption is 100,000 BDT/year (Table 9), while live biomass production from the study region is around 70,000 BDT/year (Table 16). Current sawtimber capacity is also in excess of annual production for Scenario 1, so all saw and cedar products can be processed.

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[11] Comparable assumption made in the High Hazard Fuel Study. The higher cost of logging on cable-ground means deployment only on logging sites where the removed material is of sufficiently high value to offset operational costs.

TABLE 16. Live biomass, sawtimber, and cedar from Scenario 1, with economic summary by case. Delivered units, value, costs (forest and haul), and total stumpage value are annual, homogenizing differences across periods.

Case	Product	Unit	Delivered		Costs		Stumpage	
			Units	Value	Forest	Haul	Value	$/unit
A	Live Bio.	BDT	70,756	$2,830,235	$1,645,262	$2,297,445	($1,112,472)	($15.72)
B	Live Bio.	BDT	70,756	$2,830,235	$1,645,262	$1,586,472	($401,500)	($5.67)
C	Live Bio.	BDT	70,756	$2,830,235	$1,645,262	$1,422,130	($237,157)	($3.35)
D	Live Bio.	BDT	70,756	$2,830,235	$1,645,262	$1,828,868	($643,895)	($9.10)
All	Sawtimber	MBF	179,761	$74,034,818	$26,508,153	$13,933,303	$33,593,363	$186.88
All	Cedar	MBF	11,427	$6,285,079	$1,699,422	$1,136,291	$3,449,367	$301.85

Focusing on live biomass, the amount of production remains constant in each case; since capacity exceeds production, 100 percent of the live biomass can always be dispatched to facilities. The cases substantially differ, however, in terms of biomass stumpage. Delivered value and forest costs are constant—this model values all biomass at $40/BDT, and forest costs remain the same across cases. The differences among cases result from changes to total haul cost with the introduction of new facilities. In the base Case A, with only a single operational facility at Rocklin, total haul cost is $2.297 million per year. Total annual biomass stumpage in Case A is negative, at -$1.112 million, and corresponds to a per-unit stumpage of -$15.72/BDT. Negative stumpage indicates that combined haul and forest costs exceed product value. For Case A, the haul distance to Rocklin is quite substantial for most stands. Rocklin is outside the study region to the west (Figure 4), and we see the most positive stumpage at the stand level where transport distances are shortest, along the western ends of Highways 49 and 80 (Figure 5). The most excessively negative stumpage, which approaches -$35, occurs for stands on the eastern edge of the study region, from which biomass must travel the farthest to reach Rocklin in Case A (Figure 5).

Alternative cases change the transportation logistics to great effect. Stumpage is still negative in Case B; with the reopened 18 MW Loyalton facility and two additional 11 MW plants on Highways 80 and 50, it improves to -$401,000/year, or -$5.67/BDT (Table 16). With the shorter haul distances to Loyalton, stands on the east side of the study region attain some positive stumpage (Figure 6), as well as those along Highway 80 and Highway 50. Although positive stumpage seems to occur in Case B, much of this positively valued material is only marginally greater than $0 at short distance from facility locations, so the extremely negative stumpage from elsewhere in the study area pushes overall stumpage below $0. Total and per-unit stumpage for the biomass dispatched to each facility for every combination of scenario, case, and period is available in Appendix E.which can be provided upon request. Note that total biomass (including dead) cannot be accommodated even in Scenario 1 Case A.

Truck unloading wood chips. © imantsu/iStock

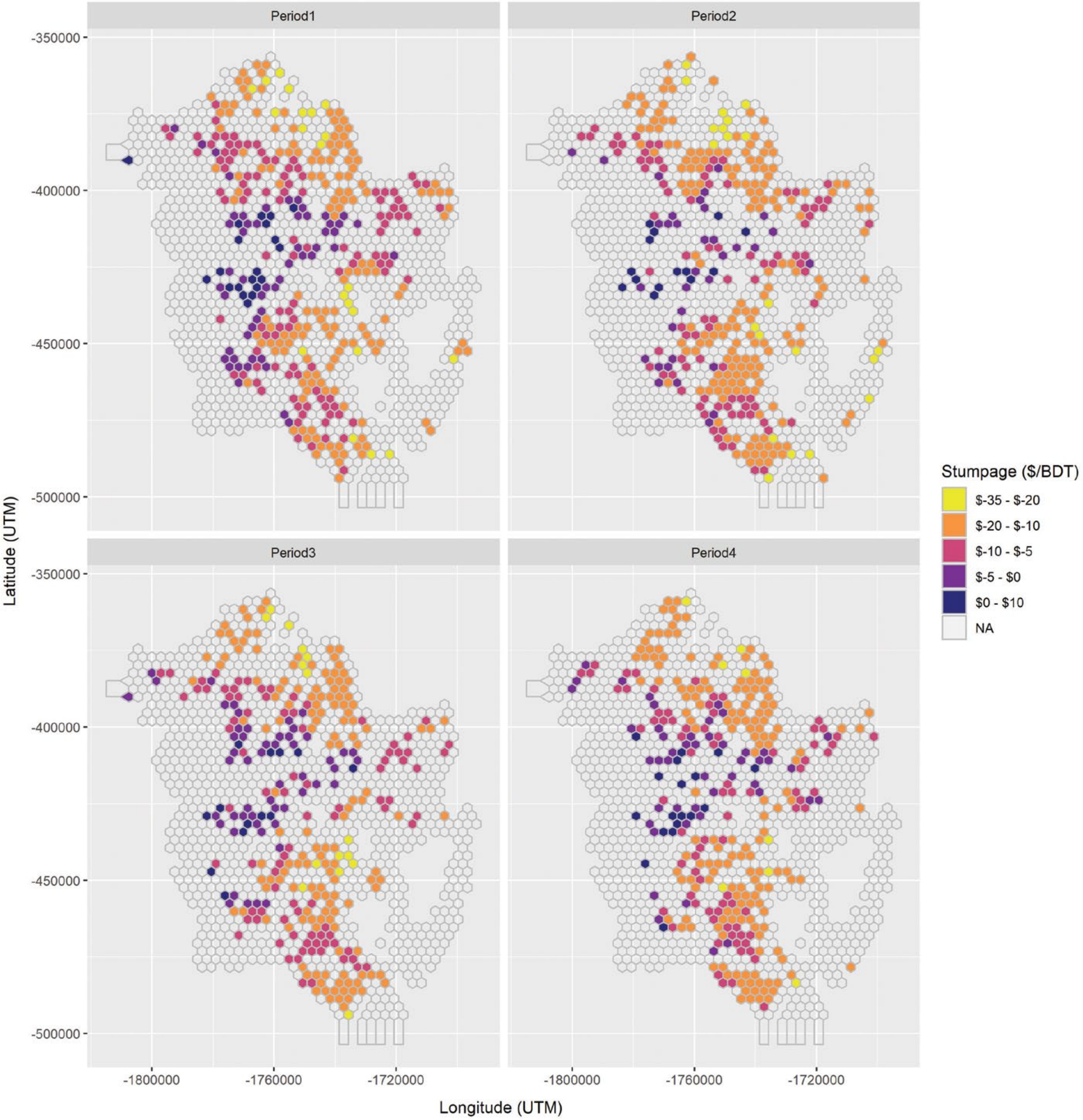

FIGURE 5. Live biomass stumpage for one-mile-stand-aggregate hexagons in Scenario 1 Case A for each five-year period. Lighter colors indicate more negative stumpage, with minimum values as low as -$35/BDT, where the cost of logging, hauling, and chipping outweighs the value of the material. Positive stumpage is indicated by purple or blue color fill, with values as high as $10/BDT in areas closer to destination facilities.

Case B improves stumpage per unit by more than $10/BDT, but the case nonetheless remains with negative stumpage overall. The new facilities are along Highway 80 and Highway 50, so stands to the north or deep in the mountains are still subject to long haul distances and therefore extensively negative stumpage.

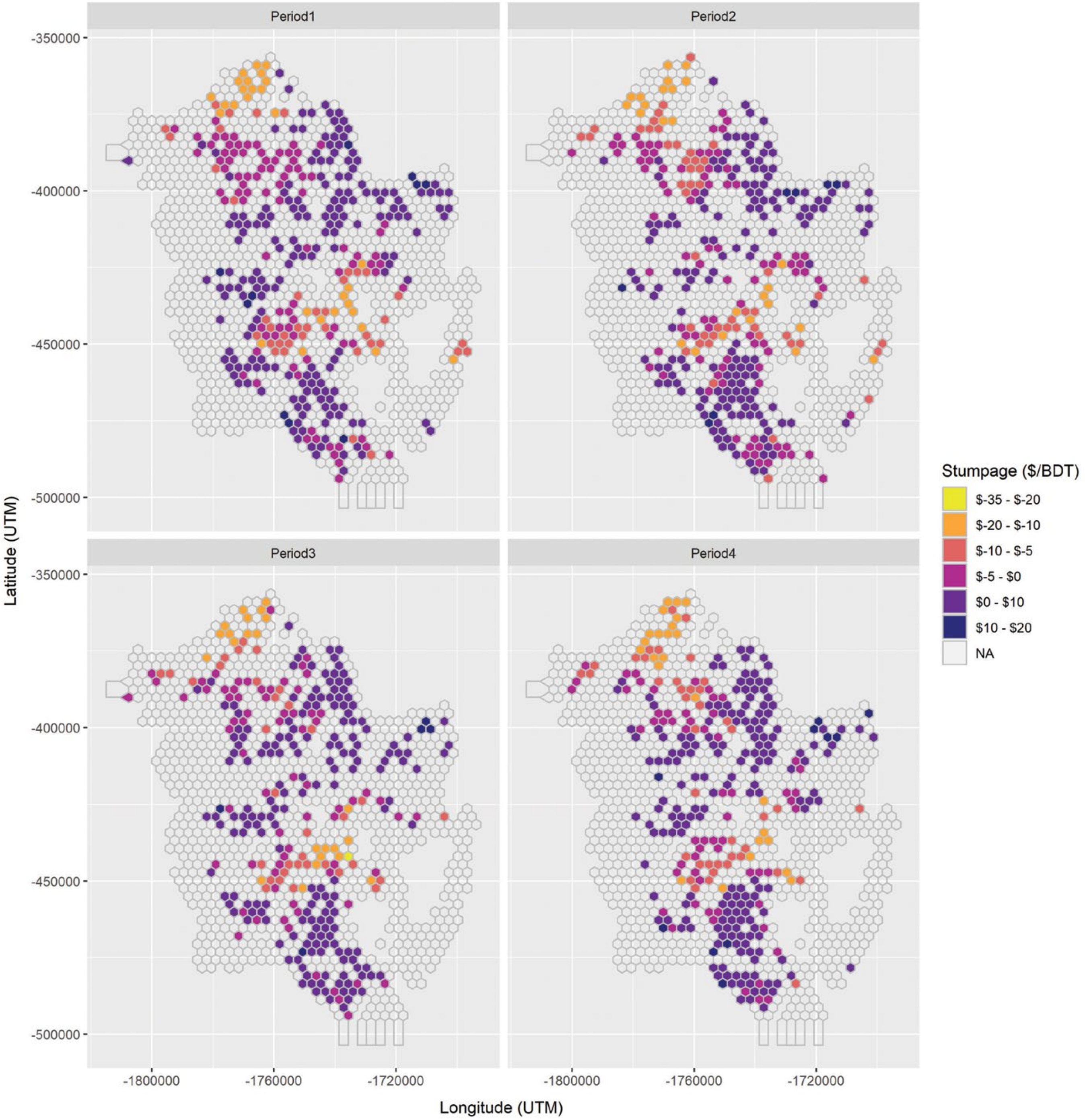

FIGURE 6. Live biomass stumpage for stand-aggregate hexagons in Scenario 1 Case B for each five-year period.

Case C introduces the greatest number of facilities, with a new location near Camptonville along Highway 49. The generating capacity overall remains constant, and each new facility is either 7 MW (Highways 49 and 50) or 8 MW (Highway 80). Reduced haul costs with three destinations in the study area result in the least negative stumpage of all, at -$3.35/BDT (Table 16). Quite a few stand aggregates show positive stumpage in areas closest to each new facility; this is most pronounced for the Highway 49 location (Figure 7), where stumpage approaches $20/BDT for some stands. Overall stumpage for the Highway 49 facility is positive for most periods (see §4.5), yet even Case C has negative stumpage regionally.

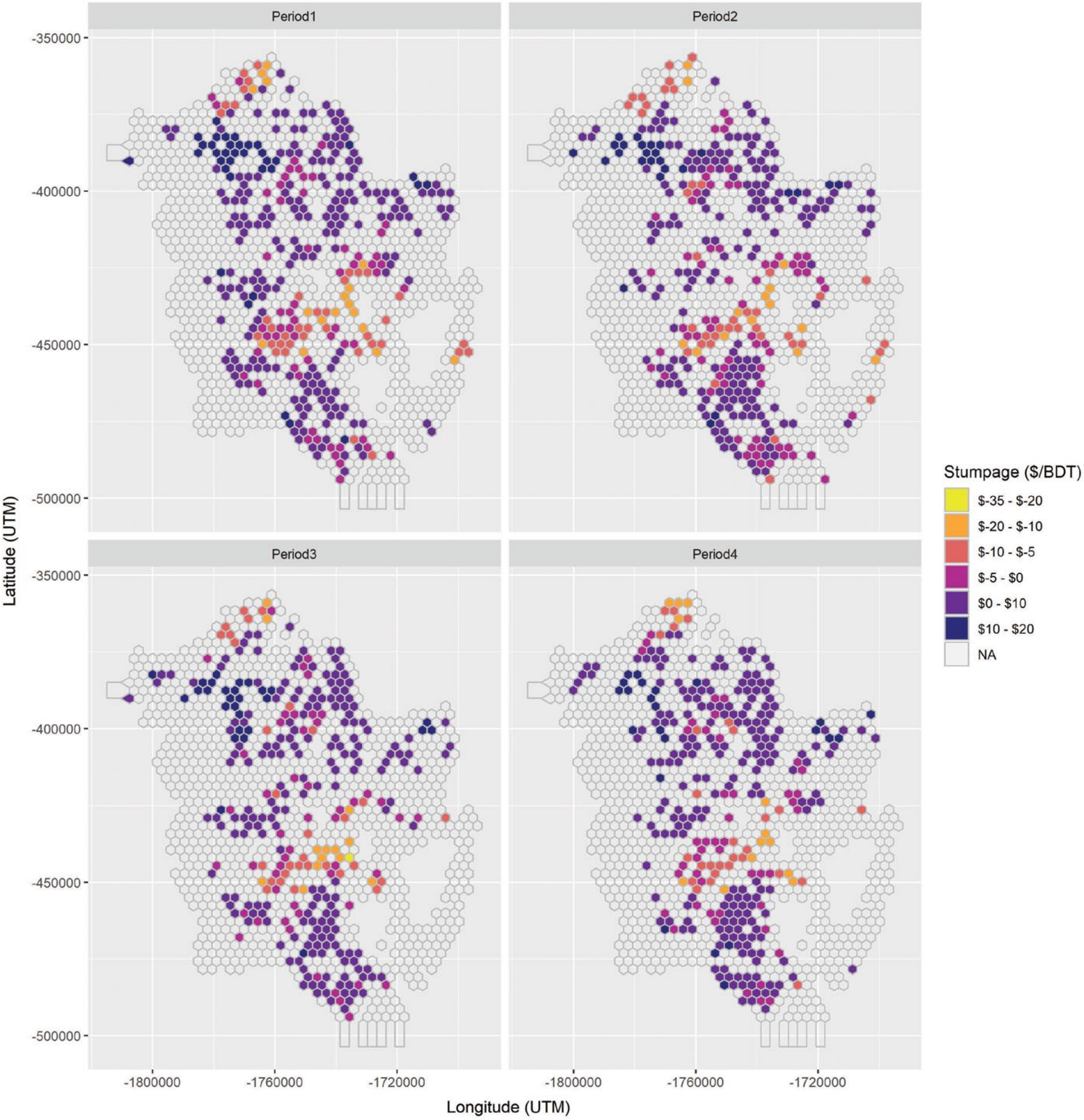

FIGURE 7. Live biomass stumpage for stand-aggregate hexagons in Scenario 1 Case C for each five-year period.

Case D retains the 22 MW new generating capacity in the study area but concentrates it into a single facility on the western edge along Highway 80 near Bowman. Stumpage nearest to this location indeed shows positive value (Figure 8), but overall stumpage drops to -$643,000 and -$9.10/BDT (Table 16), lower than both Cases B and C. Although centrally located, the Highway 80 location is more distant from most of the restoration activity than either the Highway 49 or Highway 50 locations.

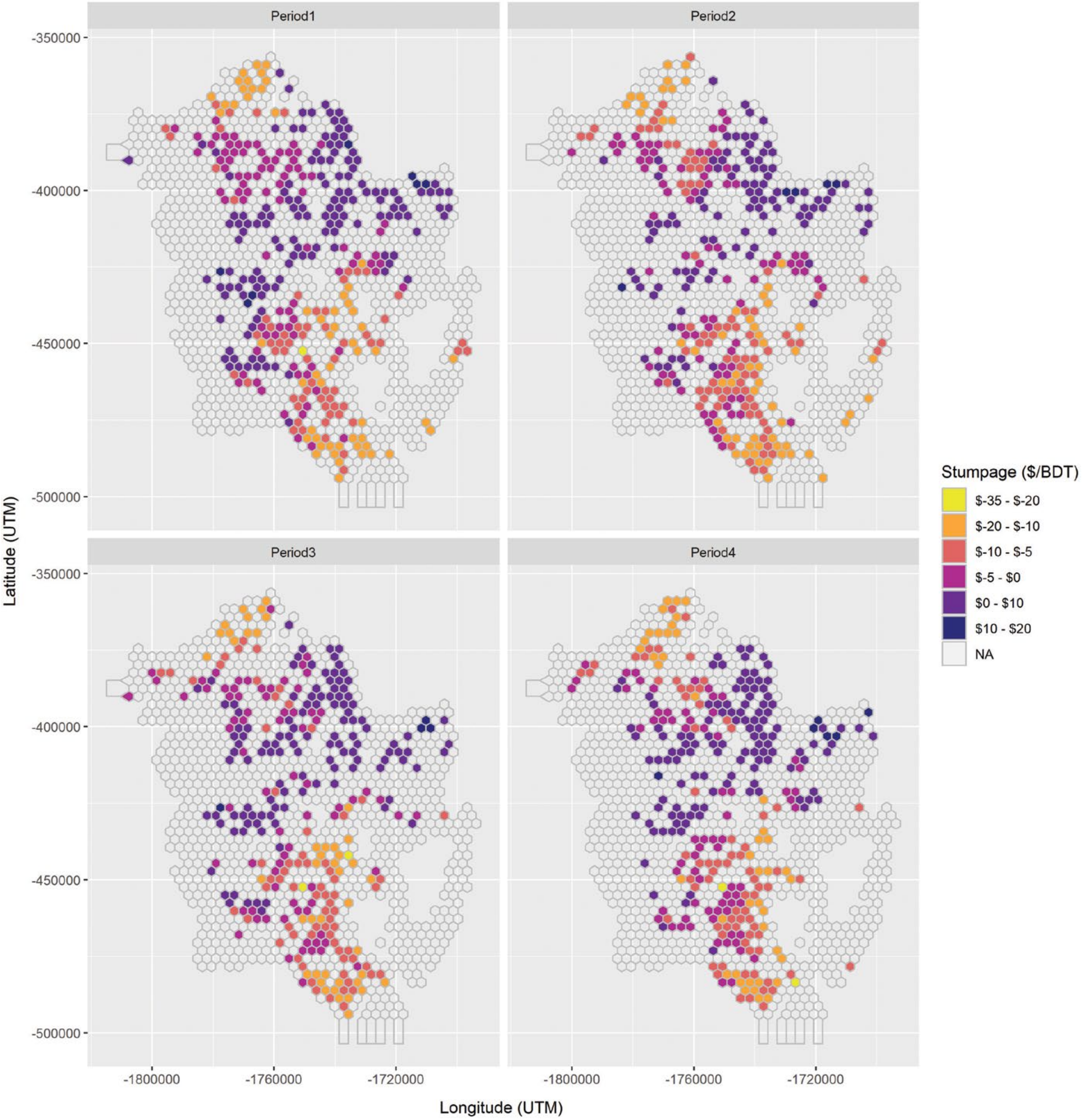

FIGURE 8. Live biomass stumpage for stand-aggregate hexagons in Scenario 1 Case D for each five-year period.

4.4.2 Scenario 2 Economic Summary

Scenario 2 introduces the objective of completing forest restoration treatments that reduce risk to infrastructure from wildfires ignited in the Defense and Threat Zones. Annual production of live biomass increases by nearly 20,000 BDT to 88,990 BDT (dead biomass production would be substantially higher, Table 8); sawtimber production increases to 210,000 MBF, and cedar increases to 11,789 MBF (Table 17). This level of production does not exceed processing capacity overall, so essentially all harvest is dispatched to facilities.

TABLE 17. Potential production of live biomass (BDT), sawtimber (MBF), and cedar (MBF) from Scenario 2.

Case	Product	Produced by Scenario			Forest Costs	Loads (N)
		Units	Value	Delivered		
A	Live Bio.	88,990	$3,559,590	94%	$2,087,558	7,119
B,C,D	Live Bio.	88,990	$3,559,590	100%	$2,087,558	7,119
All	Sawtimber	210,032	$86,560,945	100%	$32,518,543	42,260
All	Cedar	11,789	$6,483,777	100%	$1,888,814	2,372

There is a slight under-delivery of 94 percent for Case A live biomass overall. In periods 1 and 2, live biomass harvest (Table 8) does exceed the Rocklin processing capacity (Table 9), but Rocklin is the only available destination, so less than 100 percent of the yield can be dispatched. In alternative cases, the additional biomass-to-electricity-generating capacity can accommodate the period 1 and 2 yield spike, so all production is dispatched.

Stumpage follows a similar pattern to Scenario 1, with the lowest value in Case A of -$15.00/BDT. In alternative cases, the negative magnitude decreases slightly, bringing per-unit stumpage closer to $0, with the highest value of -$3.19/BDT (Table 18). Additional biomass production over a wider area in the study region means that transportation distances are, on average, slightly lower to all facilities. For example, haul costs in Scenario 1 Case A were $2.297 million to transport 70,756 BDT (Table 16), or $32.47/BDT, whereas the Scenario 2 Case A haul cost was $2.637 million to transport 83,756 BDT (Table 18), or $31.49/BDT, nearly $1.00 cheaper. Case C again shows the highest stumpage, though it is still negative.

TABLE 18. Live biomass, sawtimber, and cedar from Scenario 2, with economic summary by case. Delivered units, value, costs (forest and haul), and total stumpage value are annual, homogenizing differences across periods.

Case	Product	Unit	Delivered		Costs		Stumpage	
			Units	Value	Forest	Haul	Value	$/unit
A	Live Bio.	BDT	83,756	$3,350,238	$1,969,278	$2,637,402	($1,256,441)	($15.00)
B	Live Bio.	BDT	88,990	$3,559,590	$2,087,558	$1,969,423	($497,391)	($5.59)
C	Live Bio.	BDT	88,990	$3,559,590	$2,087,558	$1,755,563	($283,530)	($3.19)
D	Live Bio.	BDT	88,990	$3,559,590	$2,087,558	$2,266,957	($794,925)	($8.93)
All	Sawtimber	MBF	210,032	$86,560,945	$32,518,543	$16,431,545	$37,610,857	$179.07
All	Cedar	MBF	11,789	$6,483,777	$1,888,814	$1,142,974	$3,451,989	$292.82

4.4.3 Scenario 3 Economic Summary

Prioritizing forest health in the General Forest Zone, Scenario 3 produces more live biomass across all periods than can be processed at the single existing operational facility at Rocklin. Averaged across periods, 113,835 BDT live biomass are produced in each year in this scenario, although periods 1 and 3 produce 143,254 BDT/year and 123,793 BDT/year, respectively, both well above the average. In addition, this scenario and the next produce a substantial majority of dead biomass in period 1, yielding 592,213 BDT. This excess is not captured in this economic analysis since we are focusing conservatively on live biomass, but it should be factored in to supply considerations. Sawtimber harvests also exceed capacity in period 1, so only 95 percent of total production can be dispatched over the 20-year interval (Table 19).

TABLE 19. Potential production of live biomass (BDT), sawtimber (MBF), and cedar (MBF) from Scenario 3.

Case	Product	Produced by Scenario			Forest Costs	Loads (N)
		Units	Value	Delivered		
A	Live Bio.	113,835	$4,553,399	88%	$2,647,046	9,107
B,C,D	Live Bio.	113,835	$4,553,399	100%	$2,647,046	9,107
All	Sawtimber	278,204	$114,452,103	95%	$44,819,109	55,977
All	Cedar	15,743	$8,658,700	100%	$2,571,999	3,168

Stumpage increases for all cases in Scenario 3, above -$14/BDT in Case A and maximized in Case C, at -$3.05/BDT (Table 20). Note that although production exceeds Rocklin's 100,000 BDT/year capacity in every period, for Case A the model can nonetheless dispatch only 99,835 BDT per year. The algorithm is set to deliver biomass *not to exceed* capacity. As biomass is derived from discrete stands aggregated into one-mile hexagons, the available configurations may not always sum to 100 percent of the volume in discrete combinations, causing this marginal under-delivery (Table 20).

TABLE 20. Live biomass, sawtimber, and cedar from Scenario 3, with economic summary by case. Delivered units, value, costs (forest and haul), and total stumpage value are annual, homogenizing differences across periods.

Case	Product	Unit	Delivered		Costs		Stumpage	
			Units	Value	Forest	Haul	Value	$/unit
A	Live Bio.	BDT	99,835	$3,993,418	$2,330,553	$3,089,304	($1,426,439)	($14.29)
B	Live Bio.	BDT	113,835	$4,553,399	$2,647,046	$2,558,773	($652,419)	($5.73)
C	Live Bio.	BDT	113,835	$4,553,399	$2,647,046	$2,253,130	($346,777)	($3.05)
D	Live Bio.	BDT	113,835	$4,553,399	$2,647,046	$2,893,267	($986,914)	($8.67)
All	Sawtimber	MBF	262,936	$108,078,448	$42,584,696	$20,538,324	$44,955,428	$170.98
All	Cedar	MBF	15,743	$8,658,700	$2,571,999	$1,527,367	$4,559,335	$289.61

4.4.4 Climate Resilience Economic Summary

The final forest restoration, Scenario 4, emphasizes climate resilience, treating a total of 1.02 million acres over 20 years. Live biomass is produced in excess of processing capacity in Case A, but the alternative cases introduce adequate electricity-generating capacity to process all of the live biomass harvest. As with Scenario 3, the dead biomass harvest is substantially larger in the early periods, exceeding 679,000 BDT in period 1. While this conservative economic analysis of live biomass suggests that all harvest can be processed, if the analysis were to include the dead fraction in early periods, capacity would be inadequate. Sawtimber-processing capacity is also insufficient for all of the Scenario 4 production, with just 89 percent dispatched (Table 21). In this scenario, the largest harvests were in periods 1 and 4, where sawtimber yields were above 300,000 MBF/year (Table 7), approaching the total regional mill capacity of 337,000 MBF/year (Table 9), without considering sawtimber source outside the study region.

TABLE 21. Potential production of live biomass (BDT), sawtimber (MBF), and cedar (MBF) from Scenario 4.

Case	Product	Produced by Scenario			Forest Costs	Loads (N)
		Units	Value	Delivered		
A	Live Bio.	114,665	$4,586,610	85%	$2,662,207	9,173
B,C,D	Live Bio.	114,665	$4,586,610	100%	$2,662,207	9,173
All	Sawtimber	280,983	$115,608,979	89%	$45,455,801	56,536
All	Cedar	15,930	$8,761,546	100%	$2,608,891	3,205

The climate resilience scenario produced the largest amount of biomass and sawtimber overall, so it also achieved the best stumpage rates in general. Case C had the maximum stumpage, still negative at -$2.98/BDT (Table 22), or $0.07 higher than in Scenario 3 (Table 20). Case A showed lower stumpage than Scenario 3 Case A, but there were differences in annual dispatch patterns to Rocklin due to the harvest locations, so that reduction is not inconsistent with increased harvest. Cases are still ranked, best to worst, C, B, D, A, reflecting the extent to which haul costs are reduced by the deployment of additional capacity at the greatest number of locations.

TABLE 22. Live biomass, sawtimber, and cedar from Scenario 4, with economic summary by case. Delivered units, value, costs (forest and haul), and total stumpage value are annual, homogenizing differences across periods.

Case	Product	Unit	Delivered		Costs		Stumpage	
			Units	Value	Forest	Haul	Value	$/unit
A	Live Bio.	BDT	97,158	$3,886,330	$2,263,373	$3,015,200	($1,392,243)	($14.33)
B	Live Bio.	BDT	114,665	$4,586,610	$2,662,207	$2,578,001	($653,598)	($5.70)
C	Live Bio.	BDT	114,665	$4,586,610	$2,662,207	$2,266,063	($341,661)	($2.98)
D	Live Bio.	BDT	114,665	$4,586,610	$2,662,207	$2,912,150	($987,747)	($8.61)
All	Sawtimber	MBF	249,652	$102,620,345	$40,616,427	$19,126,510	$42,877,408	$171.75
All	Cedar	MBF	15,930	$8,761,546	$2,608,891	$1,544,319	$4,608,335	$289.29

4.5 Location Advantages

Do certain facility locations support more favorable stumpage values? Are there differences by scenario, case, and period?

In the previous section, we reported that Case C achieved maximum stumpage value across all scenarios, though per-unit stumpage overall was always negative. In this section, we explore stumpage by scenario, case, and period for each biomass facility location. Cases A, B, and D, which had substantially negative per-unit stumpage overall, also have negative stumpage at the facility level and for every period (Table 23). In contrast, Case C has occasional positive stumpage for the hypothetical facility on Highway 49 in some periods and scenarios (Table 23). This location is in closest proximity to more continuously forested lands with a relatively high proportion of operable areas, so the resource density is higher. In Scenario 1, the Camptonville location achieves positive stumpage in periods 1 and 3. For the other scenarios, which yield more biomass from expanded restoration, this location has positive stumpage in all periods except 2 (Table 23). The hypothetical facility near Camino on Highway 50 manages a maximum stumpage of -$0.92 in Scenario 2 Cases B and C in period 4 (Table 23) but never breaks into positive stumpage territory.

TABLE 23. Average biomass stumpage ($/BDT) for each combination of scenario, case, facility, and period.

Scenario	Case	Facility	Stumpage ($/BDT) by Period				Scenario	Case	Facility	Stumpage ($/BDT) by Period			
			1	2	3	4				1	2	3	4
1	A	Rckln	($15.14)	($15.97)	($15.68)	($16.14)	3	A	Rckln	($11.73)	($15.07)	($15.44)	($14.92)
1	B	Lyltn	($4.18)	($5.47)	($4.80)	($4.88)	3	B	Lyltn	($5.67)	($5.33)	($5.30)	($3.75)
1	B	Rckln	($17.14)	($17.72)	($17.60)	($12.70)	3	B	Rckln	($14.71)	($18.90)	($17.48)	($15.68)
1	B	TCSI50	($6.28)	($2.65)	($2.20)	($2.70)	3	B	TCSI50	($1.81)	($2.78)	($5.60)	($2.11)
1	B	TCSI80	($5.94)	($7.32)	($7.08)	($7.37)	3	B	TCSI80	($4.55)	($6.61)	($7.54)	($7.59)
1	C	Lyltn	($2.58)	($3.70)	($2.87)	($2.28)	3	C	Lyltn	($4.54)	($3.14)	($2.84)	($2.18)
1	C	TCSI49	$1.29	($0.85)	$0.82	($0.37)	3	C	TCSI49	$0.87	($2.13)	$0.55	$2.23
1	C	TCSI50	($6.28)	($2.65)	($2.20)	($2.70)	3	C	TCSI50	($1.81)	($2.78)	($5.60)	($2.11)
1	C	TCSI80	($5.31)	($6.30)	($7.03)	($6.68)	3	C	TCSI80	($3.99)	($5.49)	($7.00)	($7.01)
1	D	Lyltn	($5.75)	($5.72)	($4.80)	($5.02)	3	D	Lyltn	($7.97)	($6.05)	($5.35)	($3.77)
1	D	Rckln	($17.14)	($17.72)	($17.60)	($12.70)	3	D	Rckln	($14.71)	($18.90)	($17.48)	($15.68)
1	D	TCSI80	($8.70)	($9.89)	($9.95)	($10.46)	3	D	TCSI80	($6.90)	($8.76)	($10.68)	($9.96)

Scenario	Case	Facility	Stumpage ($/BDT) by Period				Scenario	Case	Facility	Stumpage ($/BDT) by Period			
			1	2	3	4				1	2	3	4
2	A	Rckln	($12.87)	($16.51)	($15.98)	($14.70)	4	A	Rckln	($10.80)	($15.99)	($16.92)	($13.85)
2	B	Lyltn	($6.06)	($6.32)	($5.23)	($2.65)	4	B	Lyltn	($5.50)	($5.46)	($5.58)	($3.80)
2	B	Rckln	($15.23)	($17.97)	($16.39)	($17.67)	4	B	Rckln	($14.46)	($19.68)	($17.45)	($16.21)
2	B	TCSI50	($2.72)	($3.86)	($3.59)	($0.92)	4	B	TCSI50	($1.85)	($2.81)	($6.19)	($2.36)
2	B	TCSI80	($6.63)	($7.12)	($7.08)	($5.87)	4	B	TCSI80	($4.30)	($6.89)	($7.42)	($7.57)
2	C	Lyltn	($5.29)	($4.69)	($3.72)	($1.61)	4	C	Lyltn	($4.45)	($3.00)	($3.13)	($2.11)
2	C	TCSI49	$0.66	($0.93)	$1.58	$1.39	4	C	TCSI49	$1.26	($2.68)	$0.35	$2.17
2	C	TCSI50	($2.72)	($3.86)	($3.59)	($0.92)	4	C	TCSI50	($1.85)	($2.81)	($6.19)	($2.36)
2	C	TCSI80	($6.72)	($6.11)	($4.89)	($5.01)	4	C	TCSI80	($3.55)	($5.89)	($6.70)	($7.01)
2	D	Lyltn	($9.45)	($7.13)	($5.85)	($2.89)	4	D	Lyltn	($7.80)	($5.91)	($5.59)	($3.93)
2	D	Rckln	($15.23)	($17.97)	($16.39)	($17.67)	4	D	Rckln	($14.46)	($19.68)	($17.45)	($16.21)
2	D	TCSI80	($9.53)	($10.26)	($9.59)	($7.25)	4	D	TCSI80	($6.67)	($9.02)	($10.54)	($10.09)

This analysis suggests three classifications among tested locations: those that achieve some positive stumpage, those with borderline negative stumpage, and those with substantially negative stumpage. The hypothetical facility on Highway 49 is the only location that routinely achieved positive stumpage; this location only participated in Case C, with positive stumpage in two periods in Scenario 1 and three periods in the higher-order scenarios (Figure 10). The Loyalton facility and the hypothetical location on Highway 50 near Camino share the next rank, still showing negative stumpage but only a few dollars per BDT below zero (Figure 10). Both the hypothetical location on Highway 80 near Bowman and the Rio Bravo Rocklin facility have extremely negative live biomass stumpage, partly due to competition from the other facilities but primarily because they are farther away from areas receiving the most restoration treatment.

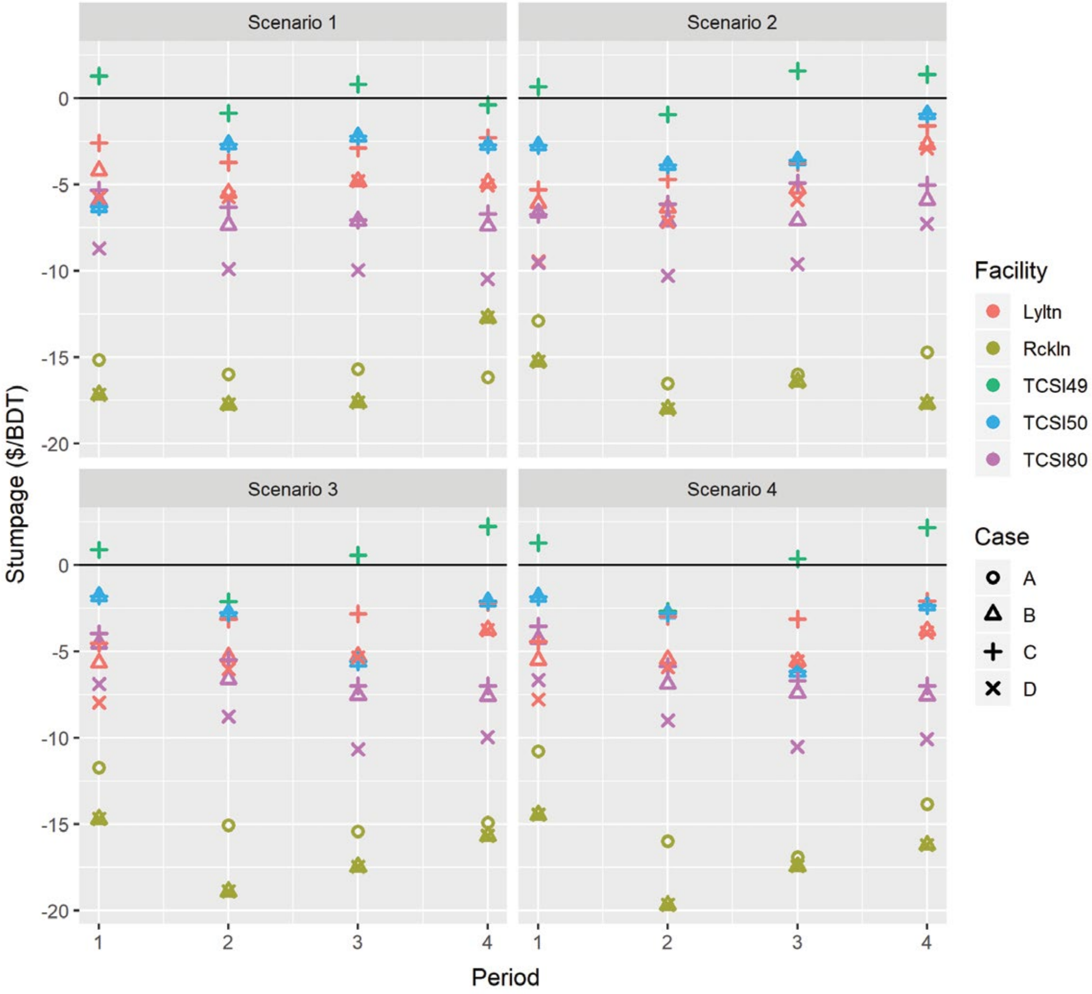

FIGURE 10. Per-unit stumpage for live biomass delivered to each facility, including the existing location at Rocklin (olive green) and the hypothetical locations: reopened Loyalton (salmon), Hwy. 80 near Bowman (pink), Hwy. 50 near Camino (blue), and Hwy. 49 near Camptonville (light green).

Live biomass stumpage for Rocklin is universally lower than any other facility because it is located farthest west outside the study area. Loyalton is relatively close to volume from the east side of the Highway 80 corridor, so it fares better than the hypothetical TCSI Highway 80 location, which, although closer to the larger electricity customer base and potential employees, is nonetheless somewhat farther away from most of the potential restoration feedstock.

The most favorable locations in terms of stumpage value are the hypothetical TCSI Highway 49 and Highway 50 locations, with nearly mostly positive stumpage values on Highway 49 and only slightly negative stumpage on Highway 50. A set of detailed tables with numeric values of live biomass stumpage, delivered value, logging and haul costs, and total biomass delivered per year is available in Appendix E.

5.0 CONCLUSIONS

How might construction of new biomass-processing capacity in the TCSI study region improve the economics of forest restoration?

To review, the two main objectives of this study were to project timber and biomass yields from forest restoration activities under several scenarios and to compare the value of harvested timber with alternative configurations of biomass-processing capacity. Forest restoration was modeled in FVS using silvicultural regimes defined by the USFS, with sawtimber yield converted to log products suitable for regional processors and biomass classified by source, live versus dead. Existing regional timber-processing capacity was provided by The Beck Group; alternatives for new biomass-electricity-generating capacity were selected by TNC in consultation with The Beck Group and MB&G. Supply economics were compared using stumpage value, or the difference between delivered value and the costs of logging, chipping (biomass only), and haul.

Additional sawmilling capacity was not explored in this economic analysis. While forecasting sawtimber supply and estimating stumpage value remain integral components of this analysis, we found relatively low additional sawtimber yields from forest restoration treatments. Restoration-derived sawtimber may exceed core demand in certain periods under higher order scenarios, but regional mills have combined maximum capacity that could accommodate these higher production levels. Siting a new sawmill within the TCSI study region would impact existing markets in ways that this analysis cannot completely assess. TNC decided, therefore, to analyze the economic implications of additional biomass facilities but no new sawmills.

Existing biomass-processing capacity cannot profitably support TCSI forest restoration. Some months after this study began, the biomass electricity facility at Loyalton (American Renewable Power), to the northeast of the study region, ceased operations and entered Chapter 7 bankruptcy proceedings. Loyalton is relatively close to a significant portion of the timber and biomass yields, in particular the North Yuba watershed. Loss of this biomass-processing capacity has a strong negative impact on biomass stumpage values. The only remaining operational biomass-electricity-generating facility near the study area is Rio Bravo at Rocklin. The haul distance to Rocklin imposes negative stumpage value on a significant majority of the biomass that expanded forest restoration activities would produce, absent additional processing options. At current harvest levels, live biomass stumpage at Rocklin over the next 20 years averages below zero, at -$15.73 with a biomass price of $40/BDT. Loyalton, in contrast, had a substantial haul advantage. In the business-as-usual scenario, 20-year-average live biomass stumpage is -$4.83, so that facility could more easily source enough nearby material.

New capacity could rely on live biomass, but dead biomass is too abundant and ephemeral at advanced pace and scale. Continuing recent harvest levels, 3.6 times more dead biomass than live biomass could be harvested in the next five years, dropping to 2.8 times, 1.7 times, and 0.7 times in subsequent five-year periods. Dead biomass availability declines over time because the material in early periods comprises the 2015–2018 mortality event, but this deteriorates by model period 2, after which dead biomass derives from background mortality rates. These ratios are similar for scenarios with advanced pace and scale of restoration. Facility operators and forest planners are faced with the challenge of selecting initial capacity that can both accommodate the initial spike in overall biomass availability and anticipate the long-term decline.

Mitigating transportation costs could promote forest restoration. Beyond funding new processing capacity, public or private investments should consider unintended dynamics. For example, the CA BioRAM program aims to increase salvage of the HHZ by supporting the price of electricity generated from HHZ-qualifying fuels (Mason, Bruce & Girard and The Beck Group, 2019). Biomass facilities are incentivized to find the least expensive qualifying fuels and maximize the difference between power revenues and fuel expenditures. Practically, this means that facilities source as much material as possible from nearby HHZ areas, leaving distant areas, such as most of the TCSI region, underserved. Logging and chipping are fixed costs of restoration, but hauling is a variable cost. Investment directly in haul costs could make material from more distant stands economically viable, whereas investment in higher power prices or lower logging costs would have no mechanism to favor restoration silviculture in relatively inaccessible areas.

Supply estimates in this analysis are conservative. First the Rx specified by the USFS are restoration-focused, and the model optimization was focused on residual stand structure. Silviculture with higher yields and an optimization on volume could increase both sawtimber and biomass yields. Higher sawtimber yield could support the biomass portion, allowing that the market can absorb greater production. Higher biomass yield could underwrite new facilities with higher MW capacity, which operate more efficiently and have a better track record with investors. Second, these economic calculations use live biomass, but the dead biomass fraction is up to 10 times greater in certain scenarios and periods. Whereas demand from new capacity may not be met in all combinations with live biomass, dead biomass can fill some of this deficit.

Expanded biomass infrastructure could catalyze forest restoration on more than 600,000 acres in the TCSI region that would otherwise be at higher risk from wildfire, drought, and disease. The amount of forestland that can ultimately be restored depends on the timber- and biomass-processing capacity in and around the region. Although TNC estimates that approximately 1.4 million acres need restoration, necessary treatments can only be practically implemented on operable areas, chiefly on USFS land, and to the extent markets exist for the timber produced. Scenario 4 in this analysis proposes silvicultural activities on 1.02 million acres of operable forested lands, of which 610,857 acres represent restoration silviculture. The pace and scale of forest restoration in the TCSI area would be enhanced by the introduction of new biomass-processing capacity. Locations for new infrastructure that balance logistics, past track record of biomass processing, and transportation infrastructure constraints include the towns of Camptonville (Highway 49), Bowman (Highway 80), and Camino (Highway 50). Further scoping to determine the practical or investment limitations regarding these locations should be undertaken.

Specialized, small-scale sawmilling infrastructure could offset costs of forest restoration, but further investigation is needed. Based on 2015–2017 average harvest volumes by County (BBER 2019), we see the "Secondary North" counties produced 41% more volume that the TCSI Core Counties (Table 24). While we expect most of this northern volume is delivered to northern mills (i.e. SPI Anderson, SPI Burney), it is reasonable to assume that at least some of portion of the volume is delivered to SPI's Quincy and Lincoln mills, which are the same sawmills that service the TCSI landscape. If true and assuming all sawmills in the region are operating at or near capacity, any significant increase in TCSI saw log volumes derived from forest restoration, could potentially displace limited milling capacity for commercially harvested logs from private timberlands). While harvest volumes are generally less in the "Secondary South" counties, the same dynamic can be expected, with most of the regional volume delivered to southern mills (e.g. SPI Sonora, SPI Chinese Camp) but a portion of the SPI Lincoln bound volume potentially competing with an increased supply of TCSI derived logs.

While regional sawmills may have limited capacity to absorb increased saw log volume from TCSI, the magnitude of this flexibility needs further investigation. Were existing mills unable, for any reason, to purchase saw logs sourced from the TCSI region, a bottleneck in mill infrastructure could quickly develop, slowing or halting progress on USFS thinning projects.

TABLE 24. Regional average harvest volumes for TCSI Core area and north and south secondary areas. Source: CA State Board of Equalization via UM BBER (Bureau of Business and Economic Research)

County	TCSI Region	2015–2017 Average Mbf Harvest		
		Total	Private	Public
Sierra County	Core	14,296	9,573	4,723
Nevada County	Core	14,318	11,210	3,107
Placer County	Core	39,726	26,429	13,297
El Dorado County	Core	104,664	82,331	22,333
Yuba County	Core	16,117	13,328	2,789
	Core Subtotal:	**189,121**	**142,871**	**46,250**
Plumas County	Secondary—North	105,960	77,953	28,008
Tehama County	Secondary—North	40,752	36,878	3,874
Lassen County	Secondary—North	64,156	56,795	7,362
Butte County	Secondary—North	55,285	54,816	469
	North Subtotal:	**266,153**	**226,441**	**39,712**
Calaveras County	Secondary—South	40,174	39,877	297
Tuolumne County	Secondary—South	71,179	34,381	36,798
Mariposa County	Secondary—South	9,292	8,426	865
Amador County	Secondary—South	4,673	3,988	685
	South Subtotal:	**125,318**	**86,673**	**38,646**
	Total:	**580,592**	**455,985**	**124,608**

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