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Cradle-to-gate life cycle impacts of redwood forest resource harvesting in northern California

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ABSTRACT

The first life cycle impact assessment for redwood (*Sequoia sempervirens*) forest management activities (i.e. a cradle-to-sawmill gate input) including the growing, harvesting, and hauling of redwood sawlogs to a sawmill was completed. In the stump-to-truck timber harvesting analysis, primary transport activities such as skidding and yarding consumed the largest amount of fuel and consequently generated the greatest environmental impacts (50% of the total) compared with the other harvesting stages (felling, processing, and loading). Hauling sawlogs to the sawmill was also a major contributor to total greenhouse gas emissions, representing 20% of total emissions. The most efficient harvest method in terms of fuel consumption per m^3 of wood harvested was the manual ground-based system used in even-aged silvicultural operations, followed by the skyline harvesting methods. Relative to even-aged silvicultural systems, uneven-aged systems, often prescribed to meet environmental goals such as maintaining biodiversity and protecting wildlife habitats, used 20% more fuel per m^3 of redwood sawlogs harvested. This was because uneven-aged systems required an increased number of entries to harvest the same amount of wood as even-aged systems. The cradle-to-gate GHG emissions from redwood forest management activities including growing, harvesting and hauling the logs represent only 14% (17.13 kg CO_2e/m^3) of the total GHG emissions (i.e. cradle-to-grave) associated with redwood decking lumber. The study results showed substantial differences in environmental impacts for the various harvesting operations and silvicultural systems for redwood forest management and operations. Therefore, the life cycle impact assessment results for the various redwood harvesting and silvicultural systems should be carefully considered when evaluating environmental performance of forest management activities along with other objectives.

1. Introduction

Redwood (*Sequoia sempervirens*) is a unique species that has a limited natural range along the coastal zone of northern California (Berrill et al., 2012). Redwood is commonly used to manufacture outdoor decking because of its natural beauty and superior resistance to decay (Wilcox and Piirto, 1976; Clark and Scheffer, 1983). Consumers choose to use redwood decking or comparable products based on a broad range of product attributes including price, quality, durability and intended service application (Ganguly and Eastin, 2009). In recent decades, the burdens that a particular product may impose on human health and the physical environment are receiving increased consideration. In particular there is increased public interest, and an ongoing debate, regarding the environmental impacts associated with the manufacture, consumption, disposal, and re-use of products that originate from the forest (Bowyer et al., 2014).

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To make informed product choices consumers need transparent, scientifically verified, objective information. Life cycle inventory (LCI) and life cycle assessment (LCA) are analytical techniques commonly used to quantify the emission profiles and environmental impacts of a wide range of products, respectively. The LCA process is well defined by international standards (ISO, 2006a; 2006b), and has been used extensively over the past decade to quantify the environmental footprint of wood products (Puettmann and Wilson, 2005), link forest management choices to environmental performance indices in the forest (Lippke et al., 2005; Oneil and Lippke, 2010), and track the carbon consequences of wood product manufacturing and use (Lippke et al., 2010). The Consortium for Research on Renewable Industrial Materials (CORRIM) has documented the LCIs of the major wood products manufactured in the US, but no work has been completed for redwood decking products. Existing wood product data are publicly available from the US LCI Database (2012).

This study reports on the environmental impacts of forest resource management activities including the growing, harvesting, and hauling of redwood sawlogs to the sawmill, referred to as a forest resource cradle-to-gate LCA. The forest resource cradle-to-gate LCA we report on here was part of a larger study (i.e. cradle-to-grave) that included the redwood decking product manufacturing processes, transportation to market, product use, maintenance, and final disposal (Bergman et al., 2013). To assess the comprehensive environmental footprint of redwood decking lumber, the framework for data collection used in prior CORRIM studies was adapted to gather the specific information needed to produce the forest resources LCI for redwood decking.

The LCI and LCA methods measure the inputs and outputs per unit of product manufactured so that it is easy to calculate the embodied energy (the amount of energy required to manufacture a product), emissions to land, air and water, and quantify the impacts those emissions may have on the environment and human health (ISO, 2006a; 2006b).

Forest management activities, including timber harvesting and log hauling in California's forests, are required by law to follow the California Forest Practices Rules which are some of the most stringent regulations found in the United States today (Dicus and Delfino, 2003). In addition, all firms surveyed for this project manage their forests consistent with either Forest Stewardship Council (FSC) or the Sustainable Forestry Initiative (SFI) certification standards which have additional requirements beyond those specified in the California regulations. Given the stringent regulations and certification standards under which redwood forests are managed, there is a high likelihood that the forests harvested to produce redwood decking are sustainably harvested and will be for the foreseeable future. For that reason we did not track carbon increases and decreases in the forest as they are anticipated to be negligible under the sustainable management regimes being practiced in California today. Under these assumptions of sustainable forest management following ASTM International standard D7612-10 (2010) and guide D7480-08 (2014), data were gathered that reflect the current state of production and are reported consistent with the protocols identified in the North American Wood Product Category Rule (PCR; FPInnovations, 2013).

Environmental impacts associated with forest management activities are documented for a wide variety of places and tree species (González-García et al., 2014; Dias and Arroja, 2012; Cambria and Pierangeli, 2012) using life cycle inventory and assessment methodologies. Results, some measured and others simulated, show high variability among regions, species, and management system. For example Dias and Arroja (2012) found a global warming potential (GWP) for growth and harvest of pine and eucalyptus in Portugal from 4.8 to 18.5 kg CO_2e/m^3. Cambria and Pierangeli (2012) report a GWP of 120 kg/m^3 for walnut in Italy and Gonzalez-Garcia et al. (2013) report a GWP of 2.3 kg/m^3 including bark for Douglas-fir plantations in Germany. Data from Johnson et al. (2005) and Oneil et al. (2010) were used to calculate GWP for forest management operations in four US regions (Puettmann et al., 2013a,b,c; Puettmann and Oneil, 2013) and found values ranging from 9.41 to 14.52 kg $CO_2e/m^3$of logs (without bark). Differences in methodology, boundary condition such as including the fencing (Cambria and Pierangeli, 2012), or excluding hauling (Johnson et al., 2005; Oneil et al., 2010) and functional unit definition (i.e. with and without bark) contribute to this variability. Even with uniform boundary conditions, methodology, and functional unit there can still be substantial differences in environmental performance, largely as a result of yield per hectare, management intensity, and harvest system (Johnson et al., 2005; Oneil et al., 2010; Diaz and Arroja, 2012).

No life cycle analysis has been conducted to quantify the environmental footprint of redwood forest management activities in northern California. Redwood growth, management, and harvesting systems have some unique attributes that have not been quantified elsewhere. For example, in certain visually and environmentally sensitive areas, helicopters are used to remove logs from the forest. The life cycle impact of this harvest system had not been quantified before. Unlike other conifer species in North America redwood sprouts from harvested roots therefore the effort and time to regenerate redwood forests is greatly reduced. With these differences in mind, the goal of this study was to estimate the environmental impacts of redwood forest management activities associated with the growing, harvesting, and hauling of redwood sawlogs that are manufactured into redwood decking lumber. Boundary conditions and functional unit used for this study were the same as those used for Johnson et al. (2005) and Oneil et al. (2010), but primary data which was collected on forest operations on a specific species and region was expected to generate more precise results.

2. Methods

The scope of this cradle-to-gate study was part of a larger cradle-to-grave LCA analysis of redwood decking lumber that focused on the life cycle of redwood forest resources (i.e. sawlog production; Fig. 1). This study conforms to internationally-accepted standards (ISO, 2006a, 2006b), used primary data collected from redwood forest landowners, as well as secondary data from the US LCI Database (2012) which was used to model the LCI of redwood forest resources using the SimaPro program. It includes an evaluation of the following components:

- nursery operations to grow redwood tree seedlings
- fill planting of redwood seedlings
- pre-commercial thinning of redwood forests
- commercial thinning of redwood forests
- commercial harvest of redwood sawlogs
- transportation of redwood sawlogs to sawmills

Some forest residues (i.e. logging slash) generated from timber harvest activities were collected, ground up, and transported to local energy plants when the biomass operations were economically feasible. Since the electricity produced from burning redwood forest residues forms part of the regional power grid that supplies electricity to redwood sawmills, the downstream contribution of the logging slash was accounted for in a separate redwood decking LCA analysis. While the redwood forest residues are an important co-product of the cradle-to-grave redwood decking process, they were not modeled as part of the present redwood harvesting life