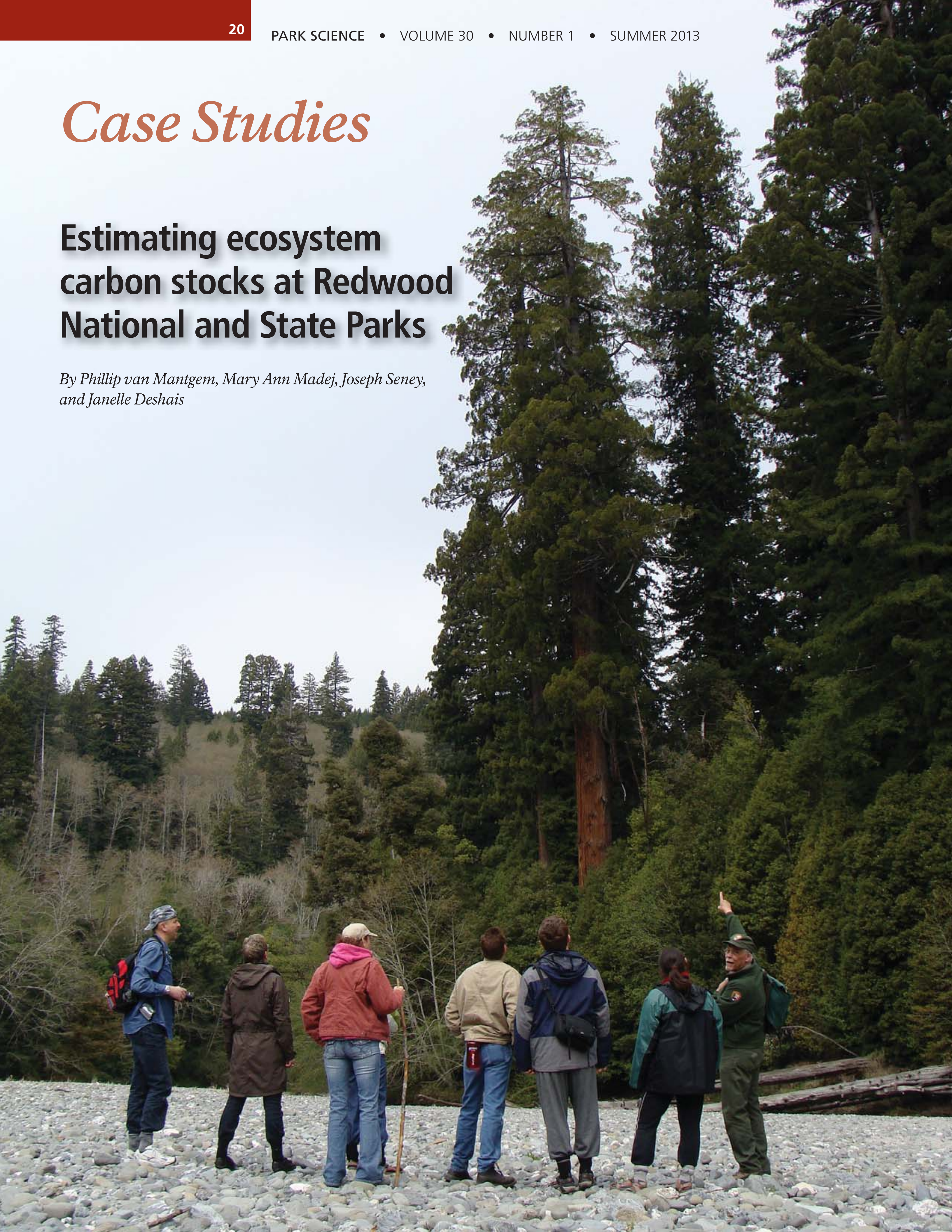
Case Studies



Estimating ecosystem carbon stocks at Redwood National and State Parks

By Phillip van Mantgem, Mary Ann Madej, Joseph Seney, and Janelle Deshais

Abstract

Accounting for ecosystem carbon is increasingly important for park managers. In this case study we present our efforts to estimate carbon stocks and the effects of management on carbon stocks for Redwood National and State Parks in northern California. Using currently available information, we estimate that on average these parks' soils contain approximately 89 tons of carbon per acre (200 Mg C per ha), while vegetation contains about 130 tons C per acre (300 Mg C per ha). Restoration activities at the parks (logging-road removal, second-growth forest management) were shown to initially reduce ecosystem carbon, but may provide for enhanced ecosystem carbon storage over the long term. We highlight currently available tools that could be used to estimate ecosystem carbon at other units of the National Park System.

Key words

carbon accounting, climate change, management, mitigation

RAPID CLIMATE CHANGE IS forcing fundamental changes in the stewardship of protected areas. Emissions of greenhouse gases (primarily carbon dioxide, CO_2) into the atmosphere have led to increases in global temperatures of 1.1°F (0.6°C) over the past 50 years (IPCC 2007). Warming trends are expected to exacerbate the effects of other ecosystem stressors, such as air pollution, exotic species (including introduced diseases), and disruptions of historical disturbance regimes. Much greater impacts from climate change are almost certain in coming decades, although predicting the exact conditions for a particular location is beyond our ability.

How should we manage natural areas in the face of these threats? It may be possible to encourage landscapes that can adapt to change (e.g., by altering fire management practices; Nydick and Sydoriak 2011) or are better able to withstand changing conditions (for examples see Millar et al. 2007). At the same time it is becoming increasingly important to prevent natural areas from contributing to greenhouse gas emissions. This represents an aspect of mitigation that may be new to National Park Service (NPS) managers, and one that could fit into the NPS Climate Change Response Strategy (NPS 2010).

Figure 1 (left). Visitors on a guided hike contemplate tree height and forest structure at Redwood National and State Parks.

NPS PHOTO

Terrestrial ecosystems store vast amounts of carbon, on the order of 2,200 to 2,800 billion tons C (2,000 to 2,500 billion Mg; 1 Mg = 1 megagram = 10^6 g = 1 metric ton) (Houghton 2007). By comparison, the atmosphere is estimated to contain approximately 880 billion tons C (800 billion Mg C). Much of the terrestrial carbon is found in soil and is relatively insensitive to most, but not all, land management practices occurring in national parks (see "Road removal" below). But in some terrestrial ecosystems, particularly forests, a large proportion of ecosystem carbon is stored in vegetation (Bonan 2008). The carbon pool (or "stock") held in live vegetation is vulnerable to sudden release following major disturbances such as drought, insect outbreaks, and fire (Kurz et al. 2008). As live vegetation dies and decomposes, the carbon held in once-living biomass is eventually released back into the environment and contributes to further climatic changes. Protecting forested landscapes in national parks is especially important, as some of these sites may hold extremely large amounts of carbon (e.g., old-growth forests).

Reducing greenhouse gas emissions in national park operations is already a priority (e.g., NPS Climate Friendly Parks Program), but managing ecosystem carbon stocks is a relatively new consideration. In some cases maintaining carbon stocks will be in direct conflict with other management goals, for example removing invasive species such as tamarisk and Russian olive trees, which may contain substantial carbon. Often, the connection between management actions and their ultimate effects on carbon stocks is less clear. For example, prescribed fire may directly release large amounts of CO_2 via combustion and tree mortality. But burning may result in a landscape more resistant to future wildfire, which could otherwise release large amounts of carbon (this carbon accounting may not apply over large scales; see Campbell et al. 2011). Considering management outcomes for carbon stocks is likely to become more common in the future, but tools necessary to do so are still under development.

A first step in understanding management effects on ecosystem carbon stocks is to inventory and monitor these stocks, although they are notoriously difficult to measure. Given limited budgets and staff, how can park managers assess ecosystem carbon stocks and their changes over time? In this case study we present our estimates of ecosystem carbon stocks in soils and vegetation at Redwood National and State Parks ("the parks"), California. We also consider changes to these stocks directly linked to park management (and some of the uncertainties associated with our estimates). We describe the methods we used with the intention that our work might be useful to managers interested in similar assessments.

Redwood National and State Parks: A brief history

Redwood National and State Parks share a joint mission to protect coastal redwood ecosystems along California's northern coast. The parks contain the largest area of unlogged redwood forest, home to the world's tallest tree, the coast redwood (*Sequoia sempervirens*, fig. 1, page 20, and cover). This tree species can reach massive sizes and its wood decomposes very slowly, so old forests containing these trees can contain very high levels of vegetative biomass (and therefore carbon). For example, the highest-ever biomass (per unit area) in any forest was recorded in an old-growth redwood stand approximately 100 miles (177 km) south of the parks (Busing and Fujimori 2005). However, approximately half of the land base of the parks (roughly 79,000 acres or 32,000 ha) is composed of second-growth forests that were heavily logged prior to park ownership. The second-growth areas pose management problems, as tractor logging and associated road building (standard forest practice at the time of harvest) severely damaged watersheds and resulted in forests that are only slowly regenerating.

Although Redwood National and State Parks are relatively small, estimating carbon stocks and changes to these stocks poses three challenges. First, the parks span several geologic, climatic, and soil conditions, with habitats ranging from estuaries, freshwater rivers, and coastal dunes to grasslands, open oak woodlands, and coniferous forests. Second, old-growth redwood forests contain some of the highest concentrations of biological carbon of any terrestrial system, making accurate carbon assessments difficult to obtain. Third, landscape-scale restoration treatments that have been in operation since 1978 to restore damaged watersheds and forests have had major effects on carbon stocks (see "Management Effects," page 24). With this diversity of history and legacy issues and physical and biological systems, Redwood National and State Parks can be thought of as a microcosm for many other areas in the western United States, making the approaches we present here potentially useful to other parks.

Taking stock of carbon stocks (where's the carbon?)

Soils

First-order estimates of soil carbon at most parks can be derived from data in existing soil surveys or ecological inventories (as a starting point see http://nature.nps.gov/geology/soils/SRI.cfm). We used data from the recently completed Soil Survey of Redwood National and State Parks to estimate soil carbon in these parks (USDA-NRCS 2008). Eighty-seven soil map units and 442 soil components are mapped in the parks. To measure soil carbon, scientists need to know organic and inorganic carbon contents, bulk density, percentage of rock fragments, and thickness of horizons for each soil component to a depth of about 5 to 6.5 feet (1.5 to 2 m). All these soil properties are available for each soil component in contemporary soil survey reports.

Average carbon content varied among soil map units and soil components, ranging from 5 tons per acre (11 Mg per ha) in floodplain soils with little vegetation cover to 209 tons per acre (468 Mg per ha) in moist redwood forests with a thick herbaceous understory. Overall, approximately 13 million tons (12 million Mg) of carbon is stored in soils of Redwood National and State Parks, or an average of 95 tons per acre (213 Mg per ha) (fig. 2). A comparison of the soil organic carbon stock values of different vegetation types in the parks shows that soil carbon stocks generally decrease with increasing landscape instability and distance from the ocean (which relates to plant productivity).

Vegetation

We combined cover data from the parks' vegetation map with estimates of carbon content for vegetation types from publicly available online tools. Specifically, we used the U.S. Forest Service (USFS) Carbon On-Line Estimator (COLE) (NCASI 2011), NASA's carbon modeling tool, and estimates for live forest carbon provided by the NASA–Carnegie Ames Stanford Approach (CASA) (Potter et al. 2008). COLE uses USFS Forest Inventory and Analysis (FIA) data and standard allometric equations (describing the relationships between tree size and shape) to estimate carbon by forest type (i.e., species composition and age class). Users can define the scope of the FIA data from local to national, although sample sizes (number of FIA plots used) may be very small for specific locales. We used data at the county level, representing a trade-off between locally derived data and sample size (we used a sample size of approximately 20 FIA plots per major forest type). The CASA model uses remotely sensed vegetation cover data with FIA-derived estimates of carbon content per unit area of vegetation type throughout the continental United States.

Based on COLE, carbon held in vegetation at Redwood National and State Parks was estimated to be 19 million tons C (17 million Mg) (average = 133 tons per acre or 299 Mg C per ha), of which 13 million tons (12 million Mg) was standing wood (live and dead) (12 million tons C [11 million Mg] was live C only) (fig. 3). The per area estimates of forest carbon are somewhat lower than has been reported elsewhere for coastal redwood forests (Gonzalez et al. 2010), likely because of the high representation of relatively young recovering forests at the parks. The CASA model gave a much higher estimate of live forest car-

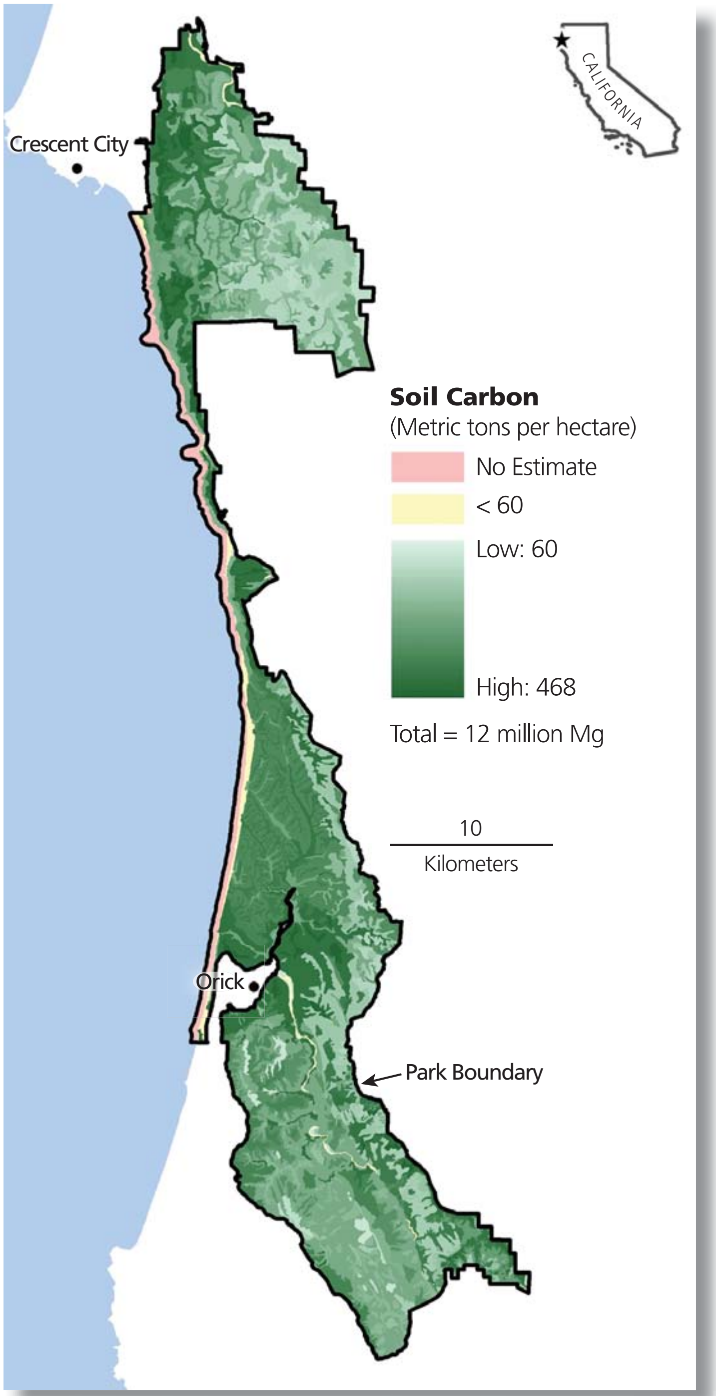


Figure 2. Map of soil carbon stocks at Redwood National and State Parks.

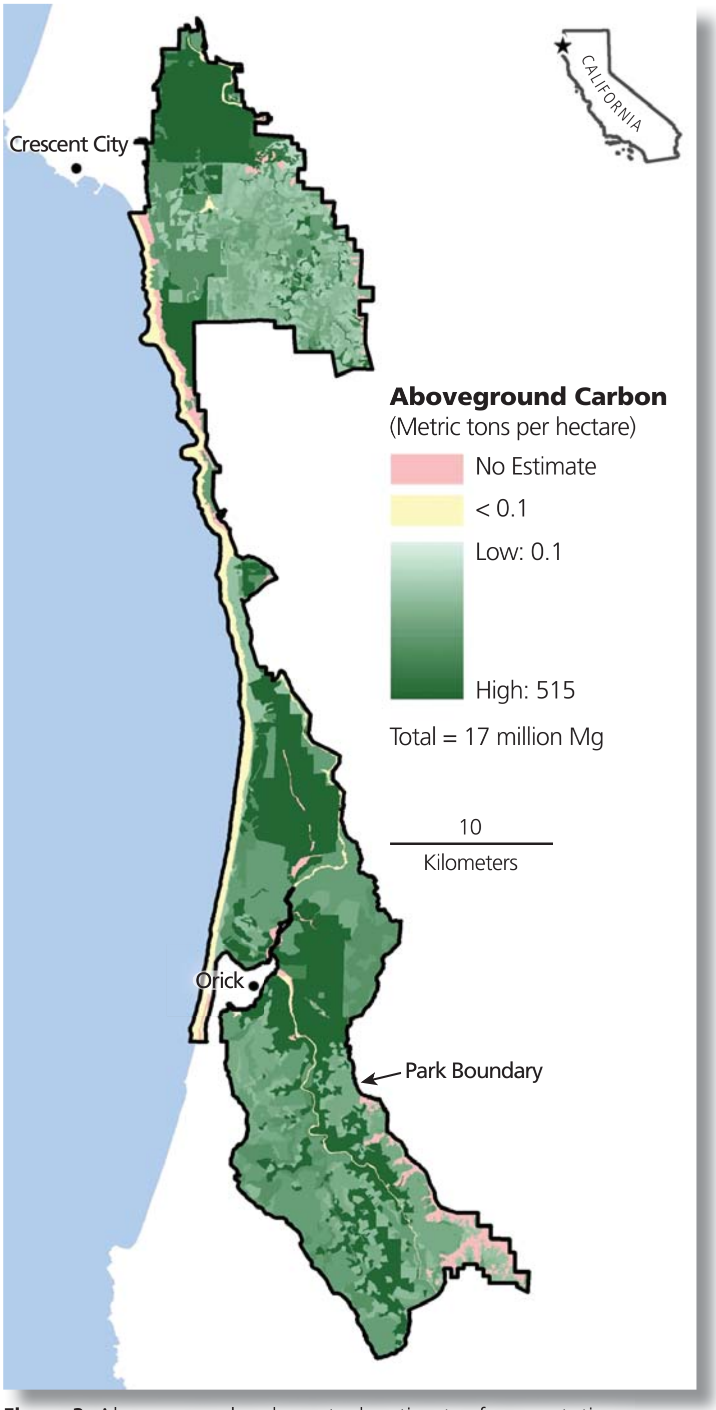


Figure 3. Aboveground carbon stock estimates for vegetation at Redwood National and State Parks. We derived estimates from lookup tables generated in COLE (see text) and applied these estimates to the parks' best available vegetation data.

bon, 65 million tons C (59 million Mg C), over five times the amount of the COLE estimate. The largest discrepancy between these models was for old-growth redwood forests (e.g., maximum live C, COLE = 185 tons per acre [415 Mg C per ha], CASA = 1,229 tons per acre [2,756 Mg per ha]). We suspect that CASA may overestimate carbon in old-growth redwood forests, as it was tuned to a forest stand at Humboldt Redwoods State Park that contains the highest carbon density ever measured (National Park Service, Patrick Gonzalez, climate change scientist, personal communication, 12 May 2013).

Management effects on carbon stocks at Redwood National and State Parks

Restoring degraded landscapes is a primary mission of Redwood National and State Parks. Precisely because these management activities are designed to influence the parks' ecosystems at large scales, they also have the potential to meaningfully influence ecosystem carbon stocks. Important programs in this context at national parks are fire management and mechanical fuel treatments; at Redwood National and State Parks two other programs have larger influences on carbon storage, road removal and forest thinning. While the immediate effect of these activities is the release of carbon from the removal of vegetation, we were interested in the long-term effects of these programs.

Road removal

Since 1978, Redwood National Park has been decommissioning or removing legacy logging roads, which contribute high sediment loads to salmon-bearing rivers. Such work commonly results in ecological benefits, but it also produces CO_2 through the use of heavy equipment and vegetation removal. We examined 135 park project reports and contracts covering the period 1979 to 2009 to determine volumes of road fill excavated from stream channels, volumes of material reshaped and transported on road prisms, and hours of heavy equipment work (Madej et al. 2013).

We contacted heavy equipment vendors (for bulldozers, dump trucks, etc.) to estimate fuel consumption rates. We used park reports to calculate work hours. Forests cut along the road corridor contributed to carbon emissions through decomposition. Timber harvest records and historical aerial photographs provided the ages of second-growth forests adjacent to the decommissioned road reaches. We estimated the carbon content of various stand ages for these second-growth redwood forests using COLE, based on county-level FIA records. Carbon savings from reforestation (carbon content of vegetation regrowth) were based on COLE estimates for California red alder forests, a typical early successional forest type in the parks.

Using this method, we estimated a total carbon cost for treating 264 miles (425 km) of road to be 25,000 tons C (23,000 Mg C), with increasing emissions from vegetation removal in later years as forests matured (fig. 4). Total savings as of 2009 were 75,000 tons C (68,000 Mg C). Savings ultimately may be greater; we currently cannot account for potential soil carbon savings from landslide risk reduction. The ratio of cost to savings will vary by ecosystem type and road-removal methodology, but the carbon-budget methodology outlined here should be transferable to other systems.

Second-growth forest thinning

The typical vegetation in second-growth forests at Redwood National and State Parks is dense, even-aged Douglas fir (*Pseudotsuga menziesii*) stands with simple canopy structure and little understory development. The parks' vegetation management staff is applying thinning treatments to accelerate the development of these forests to mature, old-growth conditions (where forests contain trees from a range of sizes and ages, dominated by coast sequoia). While thinning will likely help achieve second-growth restoration goals in terms of forest structure (size, arrangement, and tree species composition), the consequences for forest carbon are not clear. Forest thinning, by definition, will remove carbon from the system. However, the enhanced growth of remaining trees may offset these losses. Additional carbon offsets are possible because the small trees that are removed are typically used as biofuels, replacing fossil fuels for electricity generation. Long-term storage of larger harvested wood is possible with some durable forest products (e.g., building materials, furniture). Is carbon sequestration compatible with these management actions?

It is becoming increasingly important to prevent natural areas from contributing to greenhouse gas emissions.

We used forest inventory data from the parks and a standard forest development model (FVS, http://www.fs.fed.us/fmsc/fvs/) to project the outcome of current thinning prescriptions: no action, low-intensity thinning (25% basal area removal), and moderate-intensity thinning (40% basal area removal). In all prescriptions coast redwood is not removed. These projections suggest that over the long term, increased tree growth in treated stands may allow thinned and unthinned stands eventually to contain similar forest carbon

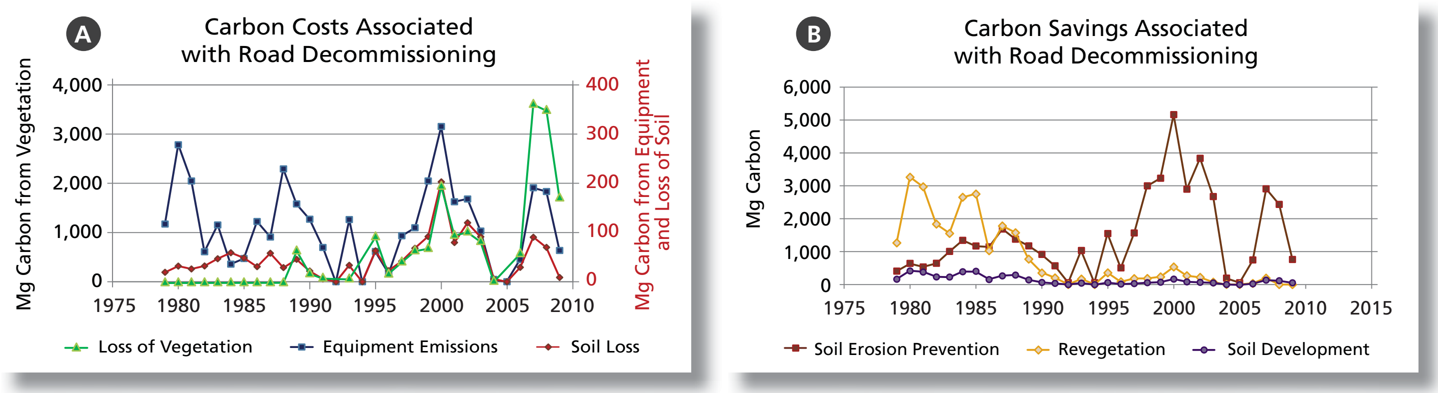


Figure 4. Carbon costs (A) and savings (B) associated with road decommissioning in Redwood National and State Parks as of 2009 (from Madej et al. 2013).

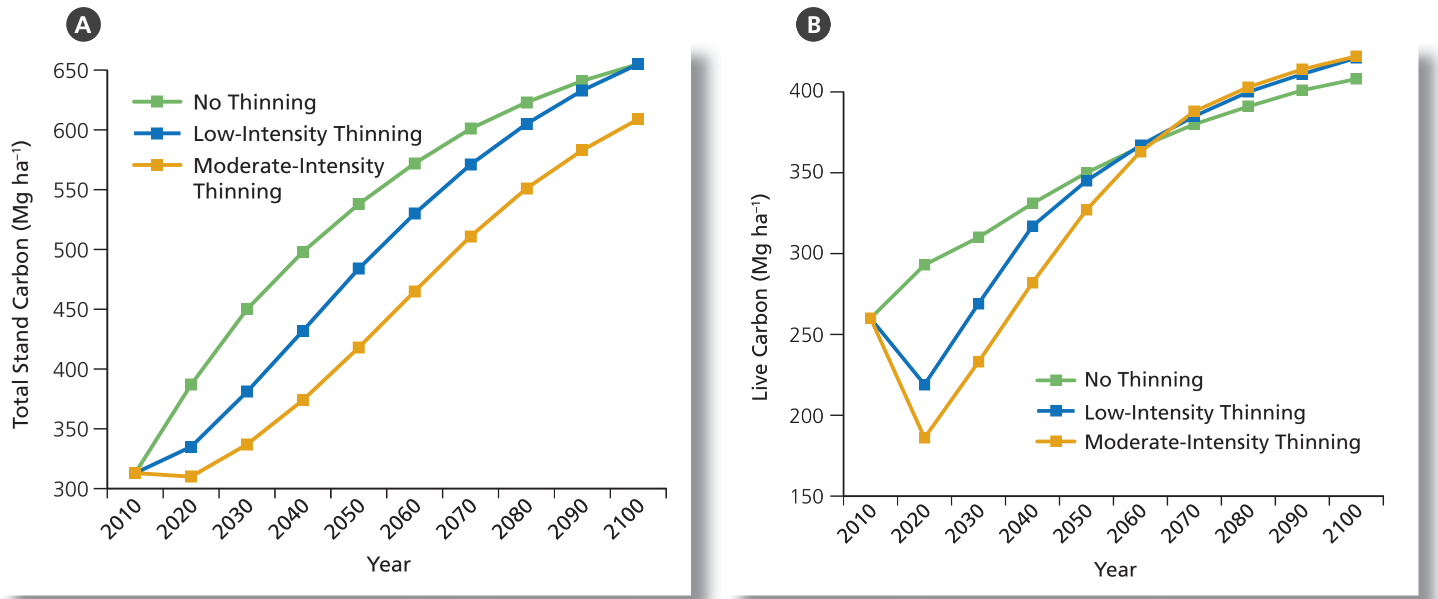


Figure 5. Average projected total (A) and live (B) forest carbon for baseline (no thinning), 25% (low intensity) and 40% (moderate thinning) basal area removal treatments in Redwood National and State Parks second-growth forests.

stocks (fig. 5). Unusual for the National Park System, contractors cover the cost of the project by selling the harvested materials as biofuels or as durable wood products.

Conclusions

The consideration of ecosystem carbon stocks is important as national parks seek to reduce greenhouse gas emissions (e.g., Climate Friendly Parks Program). Protecting current ecosystem carbon stocks may be the primary consideration for managers in this context. However, management actions may have substantial intended and unintended effects on carbon stocks.

Accounting for carbon emissions from park operations is relatively simple compared with measuring ecosystem carbon stocks and management effects on these stocks, and obtaining precise estimates requires increasingly substantial amounts of effort and expense. Our first-order estimates required roughly 100 hours of staff time, after the data were assembled and quality checked. However, once these data are in place, multiple tools are available for managers who wish to evaluate parkwide biological carbon stocks.

Acknowledgments

We thank the many people involved with collecting field data. Patrick Gonzalez, Dave Roemer, and Jeff Selleck provided helpful comments on the manuscript. This project was supported by the National Park Service, Pacific West Region. Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. government.

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