
Addendum: Ecoregion Analysis of Carbon Stores and Fluxes Associated with Oregon’s Forests

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Summary

Examination of forest-related carbon stores, flows, and balances at the level of ecoregions shows marked differences along a moisture availability gradient. In general as moisture availability increases the store per unit area of pools increases and the contribution of an ecoregion to the state-wide total also increases. Management approach also has an impact on ecoregion stores differences. For example, while the Coastal ecoregion has the highest gross growth, it does not have the highest store of live carbon, in part because of the high rate of harvest-related mortality in that ecoregion. High natural mortality losses from live pool in some ecoregions (e.g., west Cascades) largely corresponds to high live carbon stores and not a higher proportional rate. Low rates of natural mortality losses are likely related to higher harvest-related losses (Coastal ecoregion) or low live biomass.

Net change in live carbon stores per unit area is highest in the Coastal and west Cascades ecoregions and lowest in the Blue Mountain and east Cascades ecoregions. Despite ecoregion differences in this variable, all ecoregions are gaining live carbon stores. Given the high rates of natural mortality in the west Cascades and fact dead wood is accumulating on national forests, it is likely that the ecosystem uptake rate for this ecoregion is as high as for the Coastal ecoregion.

Response to ownerships among ecoregions generally followed state-wide patterns for many stores, flows, and balances. For example, harvest-related losses from the live carbon were consistently higher for private ownerships than federal ones across all ecoregions. Conversely, live carbon stores, natural mortality losses, and net change in live carbon were consistently higher for federal ownerships than private ones across all ecoregions. However, there were some variables such as gross growth, dead and downed stores that there was no consistent correlation with ownerships when ecoregions were compared. The latter result means that some state-wide patterns related to ownership may be more strongly influenced by geography than management approach.

Introduction

This report serves as an addendum to the original analysis of forest carbon that was conducted at the state level for different ownerships based on FIA generated data. Specifically, in this report the stores and fluxes for different ownerships at the ecoregion level (e.g. Blue Mountains) was analyzed. Given the many combinations of ecoregion and ownership that are possible (i.e., 18), the figures that are presented contrast differences among ecoregions. However, text is provided to indicate when ownership trends in ecoregions are dissimilar to those found at the state level. More details of differences among ownerships can be found in the accompanying spreadsheets. Finally, given the many
assumptions that are needed to be made to estimate the range of total forest net carbon balances possible I did does not attempt to do this at the ecoregion level. That would be possible in theory, but would require additional research into the range of possible changes in the non-tree pools.

**Methods**

This analysis largely uses the same conversion and correction factors used in the state-wide analysis. There may be more ecoregion specific correction factors, but that would require additional research and would probably not impact the relative ranking of ecoregions (with the exception of the standing dead stores given that drier ecoregions likely have a larger store than indicated). The only significant difference in the conversions was for the net changes data of the live aboveground pools. In this case the state-wide numbers were originally reported in carbon dioxide equivalents per hectare, whereas for the ecoregions the original numbers were in carbon dioxide equivalents in total. I therefore converted the ecoregion numbers to an amount per hectare to make the values similar.

To estimate the stores and fluxes at the ecoregion level I copied the ecoregion level values into the same spreadsheet used to estimate the state-wide estimates. Although some of the correction and expansion factors likely differed by ecoregion (e.g., the below- to aboveground ratios, litterfall rates, and decomposition rates) I did not address these differences in this particular analysis. This probably had the largest impact on the estimate of standing dead stores because in drier ecoregions there is probably a smaller reduction due to volume and density loss than in wetter regions. That is because standing dead trees in the drier ecoregions tend to remain intact and have minimal density loss. Therefore a more realistic estimate for the drier ecoregions probably lies between the unadjusted value and the low adjustment value.

The ecoregions considered included: Blue Mountains, East Cascades, West Cascades, Coastal (i.e., Coast Range), Klamath, and other (which generally represents a state-wide grouping of areas with a low abundance of forest land). These were as defined in the original spreadsheet (Figure 1, Table 1).

I did not estimate the amount of carbon accumulating or being lost from the wood products pools at the ecoregional level, in part because the wood products model used to help make these estimates is a state-wide model and does not reflect ecoregion differences in either in product manufacturing, product use, or most importantly harvest history.

The figures for the most part are of two kinds: 1) how the differences in average per area stores, flows, or balances differ among the ecoregions and 2) how the proportion of the ecoregion total compares to the proportional area of the ecoregion. These are complementary in that if an ecoregion represents proportionally more than its area, it also means that that the store, flow, or balance per unit area is also higher.
Figure 1. Geographical units used to define the ecoregions in original spreadsheets. See Table 1 to determine which geographical unit was placed in each of the ecoregions.

Table 1. Groupings for analysis for OGCW task force (originally Table 6 in spreadsheet).

<table>
<thead>
<tr>
<th>Code</th>
<th>Geographic unit</th>
<th>Ecoregion</th>
</tr>
</thead>
<tbody>
<tr>
<td>M242A</td>
<td>Coast Ranges</td>
<td>Coast Range</td>
</tr>
<tr>
<td>M242B</td>
<td>Western Cascades</td>
<td>West Cascades</td>
</tr>
<tr>
<td>Code</td>
<td>Region</td>
<td>Other</td>
</tr>
<tr>
<td>--------</td>
<td>---------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>M242C</td>
<td>Eastern Cascades</td>
<td>East Cascades</td>
</tr>
<tr>
<td>M261A</td>
<td>Klamath Mountains</td>
<td>Klamath</td>
</tr>
<tr>
<td>M261D</td>
<td>Southern Cascades</td>
<td>Klamath</td>
</tr>
<tr>
<td>342H</td>
<td>Blue Mountain Foothills</td>
<td>Blue Mtns</td>
</tr>
<tr>
<td>M332G</td>
<td>Blue Mountains</td>
<td>Blue Mtns</td>
</tr>
<tr>
<td>242B</td>
<td>Willamette Valley</td>
<td>Other</td>
</tr>
<tr>
<td>331A</td>
<td>Palouse Prairie</td>
<td>Other</td>
</tr>
<tr>
<td>342B</td>
<td>Northwestern Basin and Range</td>
<td>Other</td>
</tr>
<tr>
<td>342C</td>
<td>Owyhee Uplands</td>
<td>Other</td>
</tr>
<tr>
<td>342D</td>
<td>Snake River Basalts and Basins</td>
<td>Other</td>
</tr>
<tr>
<td>342I</td>
<td>Columbia Basin</td>
<td>Other</td>
</tr>
<tr>
<td>M261G</td>
<td>Modoc Plateau</td>
<td>Other</td>
</tr>
</tbody>
</table>
Results

Live Carbon

*Live Carbon Stores.* Live carbon is not distributed among ecoregions the same as the proportional area that they represent (Figure 2). As might be expected forests west of the Cascades Crest store proportionally more carbon than those lying east of this crest. These disparities are reflected in the per unit area store of live carbon (Figure 3). For example of the west Cascades, Coastal, and Klamath per area stores (i.e., carbon densities) are considerably higher than that of the other ecoregions. Per unit area live stores differ substantially among ecoregions: the highest and lowest ecoregion vary by a factor of 3.7. These differences largely reflect the influence of moisture availability on net primary production (NPP) within Oregon, although differences in tree species and nutrient availability also likely play a role as well. As with the state-wide estimates, the inclusion of belowground live parts increases live stores by 15 to 20%. For all ecoregions except Other, federal ownerships have a higher per unit area carbon store and contribute more than proportional area alone would suggest. For the ecoregion Other the private ownerships contribute more than area would suggest.

![Figure 2. Proportional distribution of area and live carbon stores by ecoregion.](image-url)
Gross Growth. The distribution of gross growth (i.e., woody related NPP) also is not even among ecoregions, with the Blue Mountains and east Cascades ecoregions contributing far less and the west Cascades, Coast, and Other ecoregions contributing far more than area would suggest (Figure 4). The Klamath ecoregion contributes slightly less than area would suggest. There is a 5-fold difference among ecoregions in terms of gross production; the highest being the Coastal ecoregion and the lowest being the Blue Mountains. As with live stores this pattern is largely driven by moisture availability.

Mechanistically, the primary driver in differences in live stores is related to differences in gross growth not moisture per se. A comparison of gross growth among ownerships by ecoregion reveals that while at the state-wide level federal ownerships are lower than private ones, this is not necessarily true for all ecoregions. For example, in the Blue Mountain, Coast Range, and Klamath ecoregions the per unit area gross growth is higher for federal ownerships than private ones. The opposite is true for the west Cascades and Other ecoregions. And for East Cascades gross growth on Federal and Private ownerships are approximately equal. This suggests that the higher gross growth on private ownerships than federal ones at the state-wide level is largely related to location and not management per se. That is, private ownerships are concentrated in the productive ecoregions of Oregon such as the west Cascades and Coastal, whereas federal ones are disproportionately occurring in non-productive ones such as the Blue Mountains and east Cascades. This is not to say that management approach has no effect on gross growth, but its effect does not seem to be large enough to overcome the natural variability of ecoregions.
Figure 4. Proportional distribution of area and gross growth by ecoregion.

Figure 5. Average per area gross growth by ecoregion. The “average” ecoregion represents the statewide average.

Natural Mortality. The west Cascades ecoregion appears to contribute far more to natural mortality than its area would suggest, whereas the Blue Mountains less (Figure 6). That is because the per unit value for the former is 3-fold larger than the latter (Figure 7). However, some of these differences are related to the fact that the west Cascades ecoregion has the highest per unit area live carbon stores. Expressed as the annual fraction of live carbon dying of natural mortality causes, the differences among ecoregions are more comparable. For example, the proportion of live carbon dying in the west
Cascades is 0.7% per year, but that in the Blue Mountains is 0.9% per year (Figure 8). The lowest proportional loss occurs in the Coastal ecoregion (0.5% per year), but that is probably more related to the higher losses via harvest than some inherent biological feature of this ecoregion. Natural mortality is lower on private ownerships than federal ones for all ecoregions, which also suggests that differences of live carbon stores are largely determining the size of natural mortality flows. Hence forests with higher natural mortality flows are not necessarily less “healthy”; they just have more live carbon to lose.

Figure 6. Proportional distribution of area and natural mortality by ecoregion.

Figure 7. Average per area natural mortality by ecoregion. The “average” ecoregion represents the state-wide average.
Harvest-related Mortality. The largest share of mortality related to cutting for harvest occurs in the Coastal ecoregion (Figure 9). While this area represents 17% of the area, it accounts for 51% of the state-wide harvest. West Cascades contributes about as much harvest related losses as area, whereas Blue Mountains and East Cascades far less, and Klamath and Other contribute somewhat less. The per unit area harvest-related losses harvest-related losses from live carbon in the Coastal ecoregion are 14 times higher than the Blue Mountains (Figure 10). They are also approximately 3 times higher than the West Cascades or the state-wide average. Expressed as an annual proportion of live carbon being lost related to harvest cutting the Coastal ecoregion also stands out with twice the value of the state-wide average of 1% per year (Figure 11). For all ecoregions private ownerships contribute far more to the harvest-related losses than area suggests and federal lands far less.

Figure 8. Average rate-constant of natural mortality by ecoregion. This is the annual proportion of live carbon being lost via these processes. The “average” ecoregion represents the state-wide average.
Figure 9. Proportional distribution of area and harvest-related mortality by ecoregion.

Figure 10. Average per area harvest-related loss by ecoregion. The “average” ecoregion represents the state-wide average.
Figure 11. Average rate-constant of harvest-related loss by ecoregion. This represents the annual proportion of live carbon being “lost” via this process. The “average” ecoregion represents the statewide average.

Total Live Losses. Combining natural and harvest-related mortality reveals that the Coastal ecoregion contributes far more and the Blue Mountains, east Cascades, and Other ecoregions far less than expected from area (Figure 12). The west Cascades ecoregion also contributes somewhat more and the Klamath ecoregion somewhat less than expected from area alone. These differences are also reflected in the per area total mortality flows, with the Coastal ecoregion having 6 times higher flows than the Blue Mountains and twice that of the state-wide average (Figure 13). Expressed as a proportion of live carbon being lost per year, the Coastal ecoregion is higher than all other ecoregions as well as the statewide average. For the other ecoregions the overall loss terms are in the 1.3 to 1.9% per year range, but for the Coastal ecoregion the value is over 2.5% per year (Figure 14). This explains in part why the Coastal ecoregion does not have the highest live stores despite having substantially higher gross growth than the other ecoregions. Comparing different ownerships within ecoregions indicates that in general private ownerships have higher per unit area total losses and contribute more to total losses than area would suggest. In contrast, federal ownerships have lower losses and contribute less than area would suggest.
Figure 12. Proportional distribution of area and mortality from all causes including harvest by ecoregion.

Figure 13. Average per area mortality from all causes including harvest by ecoregion. The “average” ecoregion represents the state-wide average.
Figure 14. Average rate-constant from all causes including harvest by ecoregion. This represents the annual proportion “lost” from live pool of all forms. The “average” ecoregion represents the state-wide average.

Net Change in Live Stores. The east Cascades and Coastal ecoregions are contributing more to the net change in live stores than area would suggest (Figure 15). In contrast, the Blue Mountains, West Cascades and Other ecoregions contribute less, and the Klamath ecoregion contributes about what would be expected from area. While the per unit area change in net live stores is highest in the west Cascade and Coastal ecoregions, it is positive for all ecoregions (Figure 16). This indicates that, at least for live carbon, there is a statewide increase of live carbon in all ecoregions. There is considerable variation in the per unit area net change in live stores with a 4-fold difference between the highest (Coastal) and lowest (East Cascades) ecoregions. Expressed as a total change for these ecoregions (versus per unit area) there is 6-fold difference. For each of the ecoregions, federal ownerships are contributing more than would be expected from area alone and private ownerships less. All ownership-ecoregions have a positive net change in live carbon, except for other ownerships in the west Cascades. These are evidently losing live carbon at a per unit area value that is about the same as federal ownerships are gaining carbon.
Figure 15. Proportional distribution of net change in live stores by ecoregion.

Figure 16. Average per area net change in live stores by ecoregion. The “average” ecoregion represents the state-wide average.

Dead Carbon

Standing dead. The west Cascades ecoregion has almost twice as much standing dead wood that its area would suggest (Figure 17). In contrast, all the other ecoregions except the Klamath have less. This is likely related to the relatively high rate of natural mortality in the west Cascades and not differences in decomposition rates. In terms of per unit area stores, west Cascades is almost twice the average for the
state (Figure 18). It should be noted that had the lower rate of standing dead decomposition been factored in, the store of standing dead for the Blue Mountain and east Cascades ecoregions might be about twice the value reported for the low adjustment estimate. This would not likely influenced the ecoregion’s relative rankings, but would mean that these two ecoregions per unit area stores would have been similar to the Coastal and Klamath ecoregions. For each of the ecoregions standing dead stores are higher on federal ownerships than on private ones as either a proportion of the state total or on a per unit area basis.

Figure 17. Proportional distribution of standing dead stores by ecoregion.

Figure 18. Average per area in standing dead stores by ecoregion. The “average” ecoregion represents the state-wide average.
Dead and downed. A similar distributional pattern to standing dead exists for dead and downed wood. That is, the west Cascade contributes about 2 times more than area alone would suggest (Figure 19). Expressed on a per unit area basis dead and downed wood is highest in west Cascade and Coastal ecoregions; 50 and 40% higher than the state-wide average, respectively (Figure 20). The relatively high store in the Coastal ecoregion may be related to the high level of harvest-related mortality, whereas in the west Cascades it likely related to the high flow associated with natural mortality. While federal ownerships generally have higher stores than average, in the Coastal and Klamath ecoregions other ownerships is highest, in the east Cascades, west Cascades, and Other ecoregions private is highest.

Figure 19. Proportional distribution of dead and downed stores by ecoregion.

Figure 20. Average per area of dead and downed stores by ecoregion. The “average” ecoregion represents the state-wide average.
Total dead wood. The contribution of total dead wood by ecoregion is similar to that for standing and dead and downed wood (Figure 21). Specifically, the west Cascades and Coastal ecoregions contribute more than their area would suggest and the other ecoregions less. Total dead wood stores on a per unit area basis are highest in the west Cascade ecoregion, but also higher than average in the Coastal ecoregion (Figure 22). Those in the Klamath ecoregion are about at the state average, and the remaining ecoregions are lower. Many of these differences are probably caused by the differences in live carbon, which influences mortality and ultimately the dead wood stores. For all ecoregions except the east Cascades and Other, federal lands contribute more to the dead wood store than private or other ownerships. However, for the east Cascades and Other ecoregions federal and private contributions are close to that predicted from their relative area.

![Total dead wood chart](image)

Figure 21. Proportional distribution of total dead wood stores by ecoregion. This includes standing as well as dead and downed wood.
Figure 22. Average per area of total dead wood stores by ecoregion. The “average” ecoregion represents the state-wide average.

Forest floor. The west Cascades, Coastal, and Klamath ecoregions contribute more to forest floor stores than their area would suggest (Figure 23). The largest differences between stores and proportional area were for the Coastal and Blue Mountains ecoregions, the former being higher than expected and the latter lower. On a per unit area basis, the stores in forest floor follow a moisture availability gradient with the Coastal ecoregion being the highest and the Blue Mountains and Other being the lowest. It is likely that decomposition rates decline along this gradient as well. This suggests that the primary driver of ecoregion differences in the forest floor store is related to production of litter, which should follow the pattern exhibited by gross growth. That is low decomposition rates in the Blue Mountains which should increase forest floor stores are countered to a large degree by decreases in litter production. Conversely, high rates of decomposition in the Coastal ecoregion which should lead to low forest floor stores are being countered by high rates of litter production. Forest floor stores are higher on federal ownerships than private ones within the Blue Mountains, east Cascades, west Cascades, and Klamath ecoregions. In contrast they are higher on private ownerships for the Coastal and Other ecoregions.
Soil Carbon

As with other forms of carbon, that associated with the mineral soil has a higher contribution than area would suggest for the west Cascades, Coastal, and Klamath ecoregions (Figure 25). In contrast, that for the Blue Mountains, east Cascades, and Other ecoregions is lower. However, these differences are not as marked as for dead wood. On a per unit area basis the store of carbon in mineral soil ranges between 60 and 113 Mg C/ha and is lowest in the east Cascades and highest in the Coastal ecoregion. This pattern also follows a moisture availability gradient, however, relatively high store in the Klamath and
Other ecoregions suggest that other controls such as soil texture are also having an influence. Ownership does not appear to be associated with any consistent pattern of mineral soil carbon stores among the ecoregions. For example, federal and private ownerships are about the same for the Blue Mountains, Coast, and east Cascades ecoregions. However, federal stores are higher federal than private in the Klamath ecoregion but lower in the west Cascades and Other ecoregions. Moreover, the per unit area stores do not substantially differ even when they are higher or lower. This suggests that management approach used by the different ownerships has little impact on mineral soil stores. This is in contrast to live and dead stores which generally show a consistent impact of management among ecoregions.

Figure 25. Proportional distribution of mineral soil stores by ecoregion.
Figure 26. Average per area of mineral soil stores by ecoregion. The “average” ecoregion represents the state-wide average.

Total stores. Combining all live, dead and soil stores reveals that the west Cascades, Coastal, and Klamath ecoregions are contributing more to the state-wide carbon stores than their area would suggest (Figure 27). This is especially true for the first two ecoregions. The Blue Mountain, east Cascades, and Other ecoregions contribute less to total carbon stores than their area would suggest. On a per unit area basis there is a 2-fold difference in stores between the ecoregion with the highest (western Cascades) and that with the lowest (Blue Mountains). Both the western Cascades and Coastal total stores are approximately 40% higher than the state-wide average, whereas the Blue Mountain and east Cascades ecoregions are 35% lower than the state-wide average. The overall driver of these total stores differences is largely a moisture availability gradient, although soil texture and fertility, as well as disturbance history are probably important as well at a secondary level. With the exception of the Other ecoregion, federal ownerships have higher total carbon stores than private ones. This suggests that management has a fairly consistent impact of total forest carbon stores.
Figure 27. Proportional distribution of total stores by ecoregion.

Figure 28. Average per area of total stores by ecoregion. The “average” ecoregion represents the statewide average.

While there is variation in the distribution of the major carbon pools among the ecoregions, live and mineral soil stores are consistently the two most abundant pools in terms of carbon (Figure 29). In general, mineral soil carbon is proportionately higher in drier ecoregions (e.g., Blue Mountains) and live carbon is proportionately higher in wetter ecoregions (e.g., west Cascades and Coastal). However, management is also important given that harvest-related mortality can reduce overall stores. This probably explains why the proportion of live carbon is lower in the Coastal ecoregion than the west Cascades. For all ecoregions, private ownerships have a higher proportion of their total stores in mineral soil than live or dead wood than federal ones. This is consistent with the fact harvest removes
live carbon and indirectly reduces dead carbon, but does not impact mineral soil carbon to as great an extent.

Figure 29. Distribution of total carbon stores for each major pool by ecoregion. The “average” ecoregion represents the state-wide average.