Summary

A preliminary analysis of the carbon stored and flowing through Oregon’s forests was conducted using Forest Inventory and Analysis (FIA) based data on live and dead trees, forest floor, and mineral soil for the 2001-2015 period. In addition, information about past changes on national forest lands, process rates such as litterfall and decomposition, and the net change in forest product stores were used to provide a range of estimates for gross and net carbon exchange of Oregon’s forests with the atmosphere.

A total of 12,167,082 ha (30,065,488 acres) are classified as forests in Oregon, the largest share 59.9% are in federal ownerships (Forest Service, BLM, and National Park Service), with private and other ownerships (i.e., state, tribal, and other agencies) contributing 36.2 and 3.9%, respectively.

The total store of carbon in Oregon’s forests was estimated to range between 2582 and 2865 Tg C (2847 to 3159 million tons of C). This included stores in above- and belowground live carbon (41.3%), dead wood that is standing, downed, and in coarse roots (10.3%), the forest floor (6.6%), and mineral soil (41.7%). Of the three major ownerships, federal ones stored the most forest carbon (62.5%), private ones next highest (32.6%) and other ownerships the least (4.8%). For some of the pools the difference between the fraction of forests owned and the proportion stored was substantial (live carbon and standing dead), whereas in others the differences were small (dead and downed wood, the forest floor).

The total amount of carbon flowing into Oregon’s forests via photosynthesis was estimated to be 114 to 150 Tg C/y (141 to 165 million tons C/y). Of this approximately 50% was lost within a year to plant respiration, 28% was allocated to short-lived plant parts (leaves and fine roots), and 22% was allocated into longer-lived woody tissues. Gross growth, which represents the latter flow, was estimated to be 27.8 to 29.0 Tg C/y (30.6 to 32.0 million tons C/y) for above- and belowground live woody parts. Natural mortality of woody parts was estimated to be equivalent to 25% of gross growth. Harvest-related mortality was estimated to be equivalent to 40% of gross growth. This indicates that live carbon stores are increasing in Oregon’s forest as a whole, although there was variation among ownerships. Changes in dead and soil pools could only be approximated at this point, but there is evidence that at least on federal lands that the store of dead wood has also been increasing.

If all pools other than the live ones are remaining constant, then the net rate of exchange with the atmosphere would be between 9.4 and 9.8 Tg C/y (equivalent to 34.5 to 35.9 Tg/y of carbon dioxide). However, it is unlikely that the other pools, particularly the dead wood pools, meet the assumption of no change. A sensitivity analysis varying possible changes in dead wood, forest floor, and mineral soil pools suggested that the net change with the atmosphere could range between 5.8 to 15.8 Tg C/y (equivalent to 21.3 to 57.9 Tg/y of carbon dioxide). If the net accumulation from solid wood products
Dead Carbon
Dead carbon was in three forms: dead standing trees, dead and downed trees, and the forest floor. Stores of standing dead trees were based on live biomass equations, included branches and belowground parts (i.e., coarse roots), but did not deduct for losses from respiration or fragmentation. These estimates are therefore too high. To roughly adjust these stores it was assumed that loss of volume and branches related to fragmentation would reduce the store by 50 to 60%. Losses from respiration were taken into account by reducing this store by another 20 to 25%. Combined this would reduce the standing dead store by 60 to 70%. Although these are approximations, they do provide a more accurate estimate than the original assumption of no volume or density losses.

Surface dead and downed fine woody debris (<7.6 cm) was included in the downed woody material. Dead coarse roots belowground were not included in the dead and downed wood. To get some idea of how large this pool might be it was assumed that dead coarse roots were equivalent to 0.1 to 0.2 of the aboveground dead and downed. Yatskov (2015) estimated that dead coarse roots were equivalent to 14% of the dead downed stems. This expansion factor is based on the ratio of live roots to stems for live trees, but it was adjusted downward to account for the fact coarse root decomposition is faster than stem decomposition.

In addition to reporting the values given by the FIA, a lower and upper total estimate for these pools was estimated by adding in or subtracting the mass needed to account for either missing parts (in the case of dead and downed) or lack of fragmentation or other decomposition-related losses. It should be kept in mind that these numbers are underestimates because the dead roots associated with cut stumps were excluded. For some ownerships, such as private ones, there may be a substantial pool of carbon in the form of dead roots associated with cut stumps. However, without some accounting for the volume or mass of stumps, it is nearly impossible to directly estimate this pool size using the FIA inventory. A preliminary estimate of the stump-related pool was made using the amount of historical harvest removals and assuming that stump roots were 15 to 20% of this value and that 5 to 10% was lost each year. By modeling inputs and accounting for losses a rough estimate this store could be made.

The mass of the forest floor represented accumulations of decomposing leaves, buried branches <7.6 cm, and buried dead wood with extensive decay. The flow of carbon leaving this pool was estimated by assuming that 10 to 15% of this pool was lost each year. These values were taken from unpublished data on the rate confined blocks of forest floor decomposed over a 4 year period in western hemlock, Douglas-fir, and ponderosa pine forests. This was contrasted to a rough estimate of the carbon flowing into this pool via litterfall, which was assumed to range between 1 and 2.5 Mg C/ha/y based on unpublished data.

**Soil Carbon**

The stores reported for soil C were to a depth of 1 m, but included the forest floor. Thus using the unadjusted value would double count carbon to some degree. The forest floor stores were not reported for this source of soil C (i.e., the FORCARB model). To approximate the value the forest floor estimate provided by the FIA was subtracted from the initial soil C estimate. The flow of carbon coming into and out of the mineral soil was approximated by assuming 50% of the fine root death eventually entered the
mineral soil pool and that the carbon in mineral soil has an average lifespan of 100 years. The latter is based on an order of magnitude estimate from the literature.
Net Flows

The most certain value in terms of net flows is the net change in live aboveground stores. While this is an important metric, it cannot be assumed to equal the net flow (or rate of change) for the forest. The net change in aboveground stores is not even an accurate estimate of the change in live stores, let alone the forest as a whole.

To get a sense of how uncertain the total net change in forest carbon is I accounted for the missing terms. To add in the gross growth associated with live belowground carbon I assumed this term was equivalent to between 15 and 20% of aboveground gross growth. While natural and harvest-related mortality removes carbon from the live pools it does not necessarily lead to direct losses to the atmosphere. To get some sense of how much mortality-related carbon might be accumulating I used the ratio of net change of dead wood pools reported by Gray and Whittier (2014) to mortality losses reported by Dr. Fried. This is only an approximation, but does indicate that at least for national forest lands that dead wood carbon stores are increasing, which means that mortality is more than replacing losses via decomposition. To get a sense of how much more carbon uptake might be occurring I assumed that all forests are accumulating carbon stores at this rate. There are no data to suggest how much that the forest floor and mineral soil carbon might be changing. In addition to the scenario in which these two pools were assumed to have no net change, I explored cases in which they might increase or decrease by a fixed percentage. I converted these changes into annual values using the approximate timeframe these pools respond to changes (10 years for the forest floor and 100 years for the mineral soil). While these are rough approximations, they do give a sense of whether the sign and magnitude of the overall forest net change is sensitive to changes in these pools.

Results and Discussion

Live Carbon

The FIA inventory conducted in 2001-2010 indicates that a total of 926.6 Tg C (equivalent to 1021.6 million tons) of live tree aboveground carbon was stored in Oregon’s forests. If the belowground tree live carbon is also included another 139 to 185 Tg of C was also stored, bringing the total live tree store to 1,065 to 1,112 Tg C depending on the ratio of below- to above-ground live carbon used. Expressed as a carbon density (i.e., amount of carbon per unit area), the average store live aboveground carbon was 76.2 Mg C/ha (equivalent to 33.98 tons C/acre). Including live tree belowground carbon would bring the average carbon density of total live carbon to 87.6 to 91.3 Mg C/ha. Some additional carbon would be stored in understory plants such as herbs and shrubs. This would likely increase the total live store by less than 5%, but was not considered in this analysis.

Proportional stores of live tree aboveground carbon varied by ownership, but this was largely determined by the area in these ownerships (Figure 1). That is ownerships covering a large area store more carbon. However, federal and ownerships other than federal or private ones stored proportionally more carbon than their area would suggest and private lands stored less.
Figure 1. Proportion of area and live aboveground carbon stores by general ownership.

Expressed as a carbon density, that is on a unit area basis, ownerships other than federal or private ones stored more live aboveground (99 Mg C/ha) and total live carbon (114 to 142 Mg C/ha) than the other two ownerships with (Figure 2). The density of live aboveground carbon was slightly lower on federal lands with 89 Mg C/ha and lower still on private lands (52 Mg C/ha). Including live belowground carbon would increase these values 15 to 20% depending on the expansion factor used.
Figure 2. Carbon density of live aboveground and total live carbon for different ownerships of Oregon’s forests.

The differences in live aboveground carbon density can be explained by examining the flows coming into this pool versus out. These data contrast two periods 2001-2005 and 2010-2015 to determine the net change in the stores, inputs via gross growth (net primary production), and losses via harvest and other forms of mortality.

Based on these data the total gross growth of aboveground woody tissues for Oregon’s forests was 24.2 Tg C/y. If belowground woody parts are included, the gross growth in Oregon’s forests would range between 27.8 and 29.0 Tg C/y. However, this is an underestimate of the total flow into Oregon’s forests because it neglects carbon flowing into leaves and fine roots and also neglects plant respiration. If litterfall ranges between 1.2 to 1.9 Mg C/ha/y, then an additional 14.6 to 23.1 Tg C/y was coming into the live aboveground pools. If the flow into live fine roots is similar, then the total NPP of Oregon’s forests might be 2 to 2.6-fold higher (57 to 75.2 TgC/y). Including the flow of carbon associated with plant respiration would roughly double this value again. This means that the total flow of carbon into Oregon’s forests would have been on the order of 114 to 150 Tg C/y. Although gross growth underestimates that total carbon flow into Oregon’s forests (it is around 22% of the total), it is still a very important metric. This is because roughly half the total carbon flowing into plants is lost via plant respiration within a period of days to weeks. Of the fraction remaining, gross growth represents the flow into woody parts such as stems, branches, and coarse roots which together account for over 95% of the live carbon store. Flows into leaves and fine roots are also important, but do not accumulate large amounts of carbon in their live form (approximately 5% of live stores). They are quite important as
sources of carbon to the forest floor and soil carbon, the latter being a very large fraction of total forest ecosystem carbon stores.

As with live stores, the proportion of gross growth contributed by ownerships was largely determined by their areal extent (Figure 3). However, some of these differences are related to other attributes related to ownership such as soil fertility, forest age structure, and management. This is best seen by comparing gross growth for a standardized area (Figure 4) which indicates that gross growth of aboveground live carbon was lowest on federal lands (1.71 Mg C/ha/y) and highest on lands other than federal or private ones (3.12 Mg C/ha/y). The latter result was related to lands owned by the State as other kinds of public ownerships are slightly above average (2.04 MgC/ha/y). Gross growth of live aboveground carbon on private lands was estimated to be 2.24 Mg C/ha/y, which is above the overall state-wide average of 1.98 Mg C/ha/y.

Figure 3. The proportion of area and gross growth of aboveground live carbon contributed by ownerships of Oregon’s forests.
Losses from live carbon in Oregon’s forest are caused by mortality from cutting and natural causes; these losses cannot be assumed to be emissions to the atmosphere because some of these losses from the live pool are added to the wood products and dead wood pools.

Losses by natural mortality from the live aboveground store were estimated to total 6.4 Tg C/y in Oregon’s forests; equivalent to about 25% of gross growth. Expressed as a fraction of the live aboveground carbon dying, mortality for all forests was 0.7%/y. If mortality related to belowground woody parts is included, then the overall natural mortality flow for Oregon’s forests would range between 7.4 and 7.7 Tg C/y. These estimate neglects losses from leaves and fine roots which if included would increase the estimate by a factor of 4 to 9; total natural mortality of all forms (stems, branches, roots) would range 36.6 to 53.9 Tg C/y. However, these flows do not influence the live store substantially because most of these losses are offset by a similar sized flow into these pools as noted under gross growth.

Federal lands contributed the largest share of mortality losses and proportionally more than expected from area alone (Figure 5). Private lands showed the opposite trend with less of a contribution than area would suggest. These patterns are caused by the higher mortality flow on federal lands, which average 0.67 Mg C/ha/y for aboveground woody parts (Figure 6). The lowest rate of natural mortality of aboveground carbon occurred on private lands, with 0.26 Mg C/ha/y. Overall the average mortality rate of aboveground live carbon was 0.53 Mg C/ha/y and if belowground woody parts were included this flow would be 0.60 to 0.63 Mg C/ha/y.
Expressed as a proportion of live aboveground carbon lost per year, natural mortality ranged between 0.5% per year on private lands and 0.7% per year on federal ones. While this is a 40% difference, the rate on federal lands was within the range expected for forests of the PNW region (i.e., 0.5 to 1% per y).

Figure 5. Proportion of area and natural mortality by ownership in Oregon’s forests.

Figure 6. Average flow caused by natural mortality of live wood by ownership of Oregon’s forests.
Losses from aboveground live carbon related to cutting for harvest in Oregon’s forests were estimated to be 9.6 Tg C/y which is equivalent to approximately 40% of gross growth and approximately 50% higher than natural mortality. If belowground carbon killed by cutting is included this loss from the live carbon store would have ranged between 11 and 11.5 Tg C/y. The value based on state-wide log harvest volume reports was 6.4 Tg C. This discrepancy with the FIA based numbers might be related to the fact not all the cut carbon is necessarily removed from the forests in the form of stems (probably something between 80 to 85% is removed from the forest after cutting). It is also likely that the conversion from log board foot to carbon mass was imprecise given that the conversion factor depends on species, size, age of stands, etc. all which changes over time and space.

The proportion of harvest coming from private and other ownerships was over twice the value that area would suggest (Figure 7). In contrast, harvest cuttings from federal lands are proportionally about 20% that suggested by the proportional area in that ownership. On a per unit area basis for live aboveground carbon, harvest related cuttings on federal lands were 0.14 Mg C/ha/y as opposed to 1.62 and 1.75 Mg C/ha/y on private and other ownerships, respectively (Figure 8). This indicates at least a magnitude of order difference in harvest levels between federal and other ownerships.

![Figure 7](image.png)

**Figure 7.** Proportion of land area and harvest-related cutting by ownership in Oregon’s forests.
Regardless of whether there is mortality via harvest-related cutting or natural causes, both are considered losses from the live store. When combined these losses are estimated to be 15.96 Tg C/y for just the aboveground portion of live carbon. This is equivalent to approximately 65% of the gross growth flow of aboveground live carbon. If belowground losses are also factored in, this total flow could have ranged between 18.3 and 19.1 Tg C/y. When mortality from cutting and natural causes were combined, federal lands contributed less than their area would suggest (Figure 9). Conversely, private and other ownerships contributed more, a trend related to their high rate of harvest-related cutting.
Figure 9. Proportion of area and total losses from live aboveground carbon by Oregon forest ownership.

On a per unit basis, combined flows from live aboveground carbon caused by natural mortality and harvest-related cutting on federal lands (0.81 Mg C/ha/y) were less than half that on private and other ownerships (1.88 and 2.32 Mg C/ha/y, respectively) (Figure 10). The ratio of the stores to the total losses gives an indication of how long carbon resides on average in live aboveground stores. This metric suggests that carbon entering live aboveground carbon resided on average for 58 years in Oregon’s forests, but could reside on average as short a period as 28 years in private lands and as long as 109 years in federal forests (Figure 11). This indicates that despite the fact that the input of live carbon to federal forests is lower than other forests, there is a higher store on federal lands; this is largely related to the very long time that live aboveground forest resides in these forests compared to the other ownerships (almost four times longer).

Subtracting losses via natural mortality and harvest-related cutting from the gross growth flow indicates the net balance for live tree stores. This is equivalent to the net change in these stores which for Oregon’s forests was 8.2 Tg C/y for the aboveground live tree stores. If belowground stores are also considered, the net change in total live stores would range between 9.4 and 9.8 Tg C/y. While this suggests that overall Oregon’s forests are removing carbon from the atmosphere, the changes in other pools storing carbon have to be considered before reaching this conclusion.
Figure 10. Combined flow of live carbon via harvest-related cutting and natural mortality for Oregon’s forests.

Figure 11. Mean retention time of carbon in live aboveground stores in Oregon’s forest. The longer the mean retention time, the higher stores can become assuming that inputs via gross growth are similar.
The proportional contribution ownerships to net change follows proportional area to some degree: federal lands comprise 60% of the area, but 79% of the overall net change in live stores (Figure 12). In contrast, private lands comprise 36% of the area, but 20% of the net change in live stores. For other land ownerships, the proportions of area and net sink are similar.

![Proportion of area and net change in aboveground live stores by ownership of Oregon’s forests.](image)

Considered on a per area basis the rate of net change in live tree aboveground stores was highest on federal lands (0.89 Mg C/ha/y) and lowest on private lands (0.37 Mg C/ha/y) (Figure 13). Interestingly, the net rate of stores change on other ownerships was nearly as high (0.79 Mg C/ha/y) as for those of federal lands despite the high rate of harvest-related cutting. This may be caused by the higher gross growth flow on those lands relative to private and federal ownerships.
Dead wood

Dead wood pools may be either standing or downed. In addition there are belowground dead wood pools in the form of dead coarse roots associated with these two pools. Standing dead stem stores without any adjustment for decomposition losses were estimated to be 101.4 Tg C in Oregon’s forests. If losses associated with volume losses and changes in density associated with decomposition are accounted for, then the total store of carbon associated with standing dead trees would be 30.4 to 40.6 Tg C.

Federal ownerships contributed more to these stores than area suggests, whereas private lands contributed less (Figure 14). Considered on a per unit basis, federal ownerships had substantially higher standing dead tree stores (11.6 Mg C/ha) than private ownerships (2.8 Mg C/ha) (Figure 15). Other ownerships were intermediate between these two extremes (7.6 Mg C/ha). If adjustments for decomposition are made the carbon density in standing dead trees would be roughly 30 to 40% of these values.
Figure 14. Proportion of area and standing dead stem carbon contributed by different ownerships of Oregon’s forests.

Figure 15. Stores of standing dead trees and associated parts in Oregon’s forests.

Downed dead woody aboveground stores were estimated to be 187.5 Tg C in Oregon’s forests. If the dead coarse roots associated with this pool are included, then the store would have been 206.2 to 225 Tg C. In contrast to standing dead wood, downed and dead wood was contributed proportionally similarly to area (Figure 16). Considered on a carbon density basis, downed and dead wood store were highest on ownerships other than federal or private (Figure 17) with a carbon density of 21.8 Mg C/ha. Federal and private ownerships had similar per area stores of downed and dead wood with values of 15.6 and 14.5 Mg C/ha, respectively. The high carbon density on other ownerships appears to be associated with state lands and may have been a legacy of the Tillamook fire.
The combined standing and downed dead wood store in Oregon’s forest when no adjustments are considered was estimated to be 288.9 Tg C. This was equivalent to 31.2% of the live aboveground carbon and within the range expected for conifer forests. If adjustments for missing parts, fragmentation and respiration are included, then the total store in dead wood was estimated to be 246.8 to 255.4 Tg C giving a dead wood to live aboveground wood ratio of 27 to 28%. Dead wood carbon was largely contributed according to the proportional area, although federal lands had somewhat more and private lands somewhat less than area would suggest (Figure 18). Considered on a
per unit area basis, private lands had the lowest carbon density of dead wood (17.3 to 18.2 Mg C/ha) and federal and other ownerships had similar values (22.7 to 27.2 and 28.5 to 29.5 Mg C/ha, respectively). While adjustments for missing parts and decomposition losses generally decreased the stores from the initial estimates, on private lands the stores were increased. This is due to the fact that downed dead wood dominated the dead wood stores on private ownerships and adjustments for that pool were upwards. It should be noted that dead roots associated with stumps resulting from harvest would add another 11 to 36 Tg C: this is equivalent to 4 to 14% of the estimate excluding them.

Figure 18. Proportion of area and dead wood stores contributed by different ownerships of Oregon’s forests.

Figure 19. Stores of dead wood in Oregon’s forests. Lower and upper represent estimates adjusted for missing parts and decomposition losses related to fragmentation and respiration.
Although the potential exists to calculate the net change in dead wood stores in Oregon’s forests, this has yet to be done. Preliminary estimates from Dr. Fried of how downed dead wood was changing based on repeat measurements in FIA plots indicated that these stores were increasing on federal lands, but decreasing on private ones. However, without adding in the stores changes associated with standing dead trees, these estimates are incomplete. A previous estimate by Gray and Whittier (2014) indicated that on national forests there had been an increase in both the standing and downed dead wood pools in the 1995 to 2002 period with a total rate of increase of 0.26 Mg C/ha/y. If this trend has continued since, it strongly suggests that at least some of the mortality flows from live trees are resulting in a net accumulation of carbon in Oregon’s national forests. Dividing this rate of change by mortality losses of 0.67 Mg C/ha/y suggests that approximately 39% of the mortality is resulting in an increased dead wood store. Gray and Whittier (2014) noted that on national forest lands in which cutting had occurred, the amount of dead wood had declined (although they did not report the specific numbers).

An approximate mean retention time of dead wood can be calculated from the ratio of the store in dead wood to the input via natural mortality and harvest-related cutting. This indicated that the mean retention time of carbon in dead wood was at least 26 years (Figure 20). Although there was some variation among ownerships, the main difference appears to be related to the parts included. Considering just stems gave a range in mean retention time of 47 to 58 years. This would correspond to a decomposition rate of 1.7 to 2.1% per year. Including branches and roots gave a range in mean retention time of 26 to 30 years. This would correspond to a decomposition rate of 3.3 to 4% per year. Both sets of decomposition rates are within the range suggested by decomposition studies. More precise estimates could be made of both the mean retention time and decomposition rate if the change in these stores is determined from remeasurement data.

![Figure 20. Mean retention time of dead wood in Oregon’s forests.](image)

Forest floor

The estimate of forest floor carbon stores for Oregon’s forests was 171.8 Tg C. This is equivalent to 18% of the live aboveground store. Combined with dead wood, the forest floor estimates indicate that dead material of all sorts (stems, branches, leaves, roots) is 427 to 444 Tg C.

The amount of forest floor carbon store contributed by ownership largely followed that of the proportional area of ownerships (Figure 21). In terms of carbon density, that is store per unit area, ownerships were similar, although federal and private ownerships (13.9 versus 14.0 Mg C/ha) are lower than other ownerships (16.9 Mg C/ha) (Figure 22).

If one assumes that an equivalent of 10 to 15% of the forest floor is lost each year, the approximate flow of carbon out of this pool equaled 17.2 to 25.8 Tg C/y. Assuming a litterfall rate of 1.2 to 1.9 Mg C/ha/y suggested that 14.6 to 23.1 Tg C/y was dying and being input into this pool. These estimates of flows into the forest floor are relatively close, but their uncertainty is large enough that the net change in this store cannot be estimated. Therefore knowing the net rate of change of this pool as determined by field measures would be essential to resolve the direction and size of forest floor stores changes.

Changes in the forest floor are likely to be small, but to get some sense of the possible effect on the total net change one can assume that this store could or decrease or increase 5 to 10% in a decade. That would suggest a possible loss or gain of 0.8 to 1.6 Tg C/y.

Figure 21. Proportional contribution of area and forest floor stores contributed by different ownerships of Oregon’s forests.
Mineral Soil

The mineral soil carbon store, adjusted to remove the forest floor, was estimated to be 1078.1 Tg C. This largely distributed as expected for area of ownership, although private and other ownerships contributed slightly more than area would suggest (Figure 23). Mineral soil carbon density was lowest on federal ownerships (82 MgC/ha), intermediate on private ownerships (97.9 MgC/ha), and highest for other ownerships (104.7 MgC/ha) (Figure 24). These trends are probably more related to the type of soil and environment than the type of management undertaken on these lands.

There is no indication from these data on the degree mineral soil stores are changing over time. Given the average retention time of mineral soil carbon is on the order of 100 years (meaning an equivalent of 1% is lost each year) and amount of store estimated would lead to an approximate loss of 11 Tg C/y. Assuming that half the input via fine root death was equivalent to the input into mineral soil would indicate an input to mineral soil of 7 to 12 Tg C/y; the upper value being roughly equal to the estimated outflow due to decomposition. As with the forest floor, these estimates of flows in and out are not certain enough to estimate a net change in mineral soil carbon stores.

Losses or gains due to changes in management, disturbance, or climatic regimes might be on the order of a 10 to 20% change over a 100 year period. That would indicate that if negative changes were occurring in all of Oregon’s forests that approximately 1 to 2 Tg C/y would be lost to the atmosphere. This is equivalent to approximately 10 to 20% of the net change in total live carbon stores. To equal the net change in total live carbon stores, losses from mineral soil carbon would have to be 5 to 10-fold higher, values that are unrealistically high as they imply either large cumulative proportional losses (essentially 100% loss over a 100 year period) or timeframes that are too short (10 years for a cumulative proportional loss of 10%).
Figure 23. Proportional store of mineral soil carbon for different ownerships of Oregon’s forests.

Figure 24. Store of carbon in mineral soils of Oregon’s forests to a depth of 1 m.
Total stores

The total amount of carbon stored in Oregon’s forest was estimated to range between 2571 and 2829 Tg C if the carbon associated with stump roots is ignored. If that pool is added then the total would have ranged between 2582 and 2865 Tg C. Proportionally, slightly more was contributed by federal ownerships than area would suggest, whereas slightly less was contributed by private ownerships (Figure 25). Other ownerships also contributed more than area alone would suggest.

![Figure 25. Proportion of total carbon stores in forests contributed by different ownerships.](image)

The carbon density varied among ownerships, with the highest for ownerships other than federal or private (264 to 291 Mg C/ha, respectively) (Figure 26). The lowest was for private lands (190 to 204 Mg C/ha) and federal ownerships were intermediate in terms of carbon density (220 to 246 Mg C/ha). The higher total carbon density for other ownerships was caused by the fact these lands had consistently high stores in most of the pools estimated. The small difference between federal and private ownerships is largely related to the lower mineral soil on the former compared to the latter. That is, the lower stores of live and snag carbon were countered to some degree by higher mineral soil carbon stores on private lands and vice versa.
Figure 26. Carbon density in all forms in Oregon’s forests by ownership.

The majority of carbon stored in Oregon’s forests was in mineral soil (42%), but an almost equal share was stored in live carbon (41%) (Figure 27). Dead wood and forest floor stores comprised the remaining 17%. This cannot be taken to mean that changes in the latter pools are unimportant (see net change section below). That is because while these pools are relatively small, a substantial amount of carbon is flowing through them and small changes in their inputs or mean carbon retention time could lead to large net changes that would have consequence for total forest change. For example, the forest floor comprises 7% of the stores, but the carbon flow going into this pool roughly equals that going into live wood. The higher proportion of mineral stores in private ownerships that federal ones is related to the higher level of harvest for the former. The proportion of stores in the dead wood and forest floor does not appear to be greatly influenced by ownership.

Figure 27. Proportional stores of carbon in Oregon’s forests by major pool and ownership.
Net Balance

Given the lack of information about how pools other than live carbon are changing, it is difficult to determine the exact net carbon balance of Oregon’s forests at this time. However, one can use a series of scenarios to test whether the sign and order of magnitude of the net change is likely to vary if additional information is added. Based on the changes in aboveground live carbon stores the net change in stores was estimated to be 8.2 Tg C/y. Adding in the associated changes in belowground live stores increased the net change in live stores to between 9.4 and 9.8 Tg C/y. If none of the other pools were changing this also would be the net change in the forest. However, it is highly unlikely that the other pools are constant in size. As indicated above, past examinations of the national forests in the PNW suggest that dead wood pools are also increasing. If all forests are increasing at this relative rate, then an additional 2.4 Tg C/y might be added. However, it is more likely that dead wood on private ownerships is either steady or decreasing. If we assume that dead wood is only increasing on federal lands, then an additional 1.9 Tg C should be added to the net change estimate. This would be equal to an increase of less than 1% per year in the dead wood pool. Changes in the forest floor are likely to be small, but either a decrease or increase of 5 to 10% in a decade suggests a possible loss or gain of 0.8 to 1.6 Tg C. One can do similar calculation for mineral soil changes but in this case for a 10 to 20% change in a century. This would indicate a possible annual change in this pool of 1 to 2 Tg C/y. Combining terms to get the lowest and highest estimate gave a range of 5.8 to 15.8 Tg C/y (Figure 28). This would be equivalent to 21.3 to 57.9 Tg/y of carbon dioxide.

![Figure 28. Range of possible net changes in stores in Oregon’s forests using the low and high estimates of net changes for various pools.](image)

If one added in the change in products stores estimated from a process-based model of solid wood products (equivalent to 14% of the stem harvest removals or 1.13 Tg C/y), then the total net uptake of
Oregon’s forest sector would have been 6.9 to 16.9 Tg C/y. That would be equivalent of 25 to 62 Tg carbon dioxide/y. It should be noted that changes in the solid wood products differ by ownerships. The process-based model of wood products suggests that solid wood products associated with federal ownerships are decreasing at a rate of 0.58 Tg C/y; that is harvests are not sufficient to maintain the solid wood products pools associated with these lands. In contrast those associated with private lands are increasing 1.34 Tg C/y. Those with other ownerships are also increasing, but at a rate of 0.22 Tg C/y.

Next Steps

The analysis undertaken in this report could be improved significantly in several ways.

A more complete and precise estimate of stores could be made by:

Accounting for belowground live carbon using species-specific belowground:aboveground ratios.

Adjusting standing dead stores to account for losses in volume and density that are associated with decomposition. Approximate adjustments were made here; more precise ones could be made using the raw data and information about species and decay class.

Estimating the store associated with stump and their roots from field data on the number and size of stumps. While the FIA does not inventory all stumps, harvest records of individual trees in plots might allow one to estimate inputs to this pool that when combined with information about decomposition rates would allow a more precise estimate to be made. Preliminary estimates suggested this is potentially a non-trivial pool of dead carbon.

Use a mineral soils database that does not include the forest floor so that double counting is more precisely eliminated.

A more complete and precise estimate of flow and net balances could be made by:

Directly computing the net rate of change of dead wood pools from FIA data. Given that standing dead and dead and downed pools are reinventoried in FIA plots, a more precise estimate of change is potentially available. While the change in these pools is not as precisely estimated as the live aboveground pools (which are based on tagged trees), they are sufficient to provide reliable estimates of net change.

Gathering more information about the rates of litterfall, decomposition of materials such as leaves, wood, and roots. For pools in which inputs are not directly determined, this information allows one to estimate mean retention time and possible rates of change of stores.

Better estimates of the average life-span of carbon in mineral soil would constrain estimates of the carbon leaving this pool.
References

Terms

Aboveground live carbon - the amount of carbon stored in stem wood and bark, branches, and leaves.

Belowground live carbon - the amount of carbon stored in coarse and fine roots.

Dead and downed wood - this includes dead wood and attached bark greater than 6 mm diameter.

Forest floor - includes decomposing leaves, wood less than 6 mm diameter, and buried wood. This might be considered the organic soil horizon.

Gross growth - equivalent to the net primary productivity (NPP) of woody parts. This is computed from the net change in stores plus any losses associated with natural or harvest-related mortality.

Harvest-related mortality - a flow indicating the amount of tree carbon being killed by cutting activities related to harvest. This does not equal the amount of harvest removals unless all the cut material is removed.

Mean retention time - the average amount of time in years that carbon resides in a pool. This is not the same as the maximum time carbon can reside in a pool.

Mineral soil - this is the organic carbon (as opposed to mineral forms of carbon such as calcium carbonate) in the portion of the soil that is primarily mineral in nature. Typically the concentration of organic carbon in the mineral soil is less than 10%. Values for different depths are reported, in this case the depth was 1 m, which means that the organic carbon in deeper layers was neglected.

Natural mortality - a flow indicating the amount of tree carbon being killed by processes other than harvest including wind, fire, insects, disease, competition.

Net primary production (NPP) - equivalent to gross production for wood related NPP. Essentially the carbon available to offset losses via mortality (natural or harvest related) and to increase live stores.

Standing dead wood - includes stems, branches, and roots associated with trees that are standing. The original values did not account for losses associated with volume or density loss during decomposition. It therefore is an overestimate.

Teragram (Tg) - this is $10^{12}$ grams or a million metric tonnes.