Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales

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Appendix

1. Land-use / land-cover (LULC) maps

We use 19 land use / land cover (LULC) grid maps of the Willamette Basin from the Pacific Northwest Ecosystem Research Consortium (PNW-ERC; http://www.fsl.orst.edu/pnwerc/wrb/access.html). One of the LULC grid maps is from 1990. The remaining 18 maps give LULC patterns under the Plan Trend, Development, and Conservation scenarios for the years 2000, 2010, 2020, 2030, 2040, and 2050. On each map one LULC category is assigned to each 30 x 30 meter pixel. We made one modification to the LULC classifications on the PNW-ERC maps. In a pixel with any conifer forest cover, the conifer forest cover is classified as either i) primarily Douglas fir (DF) or ii) primarily a Douglas fir-spruce-mountain hemlock mix (FSM). The Douglas fir-spruce-mountain hemlock mix was assigned to any conifer forest pixel at an elevation between 1000 and 3300 feet and the Douglas fir cover was assigned to conifer forests at all other elevations. After this modification there are a total of 73 LULC categories found on the 19 PNW-ERC LULC maps listed above. See Table 1 of the appendix for a list of these 73 LULC categories.

In Figures 1 and 2 of the text, LULC area is summarized on maps and a bar graph with LULC categories that are broader and more general than the LULC categories used on the PNW-ERC maps. How PNW-ERC LULC categories were grouped under the broader and more general LULC categories is given in Table 1 of the appendix. These broader and more general LULCs are only used in these two figures; all other mention of LULC categories in the text and the appendix refers to the PNW-ERC classification system. Further, the maps in Figure 1 use 500-hectare hexagon spatial units to represent LULC coverage where each pixel has been assigned to a hexagon.

2. Water Quality Model

This model estimates how much a pixel on the landscape contributes to downstream water impairment (phosphorous pollution). A pixel's contribution is a function of its geomorphology (location in the catchment, slope, soil depth, soil conductivity), its LULC's pollutant loading rating, and the ability of downstream vegetation to filter out phosphorous.

Let $y = 1,\ldots,Y$ index the pixels in catchment. The topographic index for y, λ_y, is equal to,

$$\lambda_y = \log\left(\frac{a_y}{\left(\theta_y^{\%} \times \varphi_y \times k_{iy}^h\right)+1}+1\right) \tag{1}$$

where a_y is the area of the watershed upstream of y where the polygon is defined upstream by the ephemeral stream gradient; $\theta_y^{\%}$ is the percent slope at y; φ_y is the soil depth to an impermeable layer such as bedrock or the average water table depth at y; and k_{iy}^h is the saturated hydrologic conductivity of y's surface given its LULC i. The log operator in equation (1) is base 10. The variable k_y^h provides a means to incorporate changes in λ_y as the LULC on y changes.

Pixel y's Hydrologic Sensitivity Area score (HSA_y) is found by comparing λ_y to its catchment's mean topographic index value. The calculation of HSA_y is inspired by Endreny (2002). Let $\bar{\lambda}$ be the mean topographic index for the catchment that contains y

$$\bar{\lambda} = \frac{\sum_{\forall y'} \log\left(\frac{a_{y'}}{\left(\theta_{y'}^{\%} \times \varphi_{y'}\right)+1}+1\right)}{\sum_{\forall y'} y'} \tag{2}$$

where $\sum_{\forall y'}$ indicates a summation over all pixels in the catchment that includes y where the set $\forall y'$ includes y. The parameter $\bar{\lambda}$ is based exclusively on the catchment's geomorphology. Further,

$$HSA_y = \min\left(\frac{\lambda_y}{\bar{\lambda}}, 1\right) \tag{3}$$

where HSA_y ranges from 0 to 1. High HSA_y scores denote a high hydraulic connectivity to a water body. Pixels with high hydraulic connectivity to a water body have a greater potential to export phosphorous to a water body. Pixel y's actual exportation rate will depend on its LULC.

Pixel-level water quality scores are ranked based on magnitude of phosphorous application and the pixel's potential to export the applied phosphorous. The higher the water impairment score in y, given by W_y, the greater the export of any applied phosphorous to local water bodies. Let,

$$W_y = HSA_y \times pol_{iy} \times \left\{1 - \min\left(eff^*, \sum_{y' \in P_y}\left(filt_{iy'} \times eff\right)\right)\right\} \tag{4}$$

where pol_{iy} is y's phosphorous export coefficient given its LULC category i (Reckhow et al. 1980, Athayde et al. 1983); eff^* is an upper bound on the phosphorus filtration efficiency of any vegetation on the landscape (in this research eff* is set to 80% maximum trapping efficiency (Endreny 2002)); $filt_{iy'}$ is the filtering efficiency of a unit length of vegetation in y given its LULC category i, and eff is the filtering efficiency of a unit length of vegetation on the landscape. The set P_y contains all pixels, indexed by y', that are part of the shortest flow path from y to a water body. The set P_y includes y.

In this paper the only pollutant we model is phosphorous since this is the major limiting nutrient in most freshwater systems and as such is the largest concern for eutrophication. Other pollutants could be modeled as well, such as manure or nitrogen. A natural forest or vegetated buffer is the benchmark associated with highest filtering capabilities (see Endreny 2002).

We calculate W_y for all y in a catchment. Then we repeat this analysis for each catchment on the landscape. Individual pixel scores are summarized at the 500-hectare hexagon unit in the paper's graphs and figures.

3. Storm Peak Modeling

This model estimates the relative contribution of each pixel on the landscape to flows arriving at a specific point of interest in a watershed during peak storm discharge. The estimate is based on the time it takes for water to flow from a given parcel to the point of interest, considering location of the parcel in the watershed, surface roughness, and slope along the travel path.

Let $y = 1,\ldots,Y$ index the pixels in subcatchment c where all subcatchments drain into the main stem of the Willamette river. Let T_y^c measure water's time of travel y to c's outlet:

$$T_y^c = \sum_{\forall y' \in c_y} \left({z_{y'}} \Big/ {r_{iy'} \sqrt{\theta_{y'}^{\%}}} \right) \tag{5}$$

where z_y is the length of y, r_{iy} is the roughness coefficient on y given its LULC i, and $\theta_y^{\%}$ is the percent slope at y. The set $\forall y' \in c_y$ includes all pixels in subcatchment c that are in the flow path from y to c's final drainage point (indexed by y'). The $\forall y' \in c_y$ includes pixel y. The 'c' in equation (5)'s summation term is indexed by y to indicate that the flow path in c may be different for each y. The values assigned to the parameter r_{iy} are based on data from the National Engineering Handbook (Kent 1972). The denominator in equation (5), $r_{iy}\sqrt{\theta_y^{\%}}$, gives overland water flow velocity in y as a function of LULC i.

Let $b = 1,\ldots,B$ index isochrones. Let an arrival time category at c's outlet be given by τ_b:

$$\tau_b \in \left[\frac{(b-1) \times T_{\max}^c}{B}, \frac{b \times T_{\max}^c}{B} \right] \tag{6}$$

where $T_{\max}^c$ is the maximum T_y^c.

Finally, the storm peak management score in y with LULC i is given by,

$$SPM_{iy} = \max \left\{ 0, \frac{\min\left\{ \dfrac{F^{\tau_b}}{\max\left(F^{\tau_b}\right)}, 2 - \dfrac{F^{\tau_b}}{\max\left(F^{\tau_b}\right)} \right\}}{r_{iy}\sqrt{\theta_y^{\%}}} \right\} \tag{7}$$

where $F^{\tau_b} = \sum_{\forall T_y^c \in \tau_b} y$ and $\forall T_y^c \in \tau_b$ includes all y in c that have time of travel times in the bin τ_b. Note that SPM_{iy} is inversely proportional to LULC potential overland flow velocities and directly proportional to pixel temporal distance from the catchment storm peak. SPM_{iy} scores are summarized at the hexagon level in the paper's graphs and figures.

4. Potential Soil Conservation

This model estimates the amount of soil eroded annually from a pixel as given by the Universal Soil Loss Equation (USLE). A pixel's USLE value is a function of its soil characteristics (rainfall erosivity index, erodability of soil), geomorphology (slope length and gradient), its LULC, and its hydrological connection to the larger landscape.

A water flow direction grid for the Willamette Basin landscape was modified by placing zero values at slope break points and within units that are likely streams during a storm event (Renard 1997). Pixel y is a slope break point when $\vec{D}_y^m = 0$ where,

$$\vec{D}_y^m = \begin{cases} 0 & \text{if } \theta_y^{\%drop} < 0.5\theta_y^{\%} \text{ or } a_y \geq a^* \\ \vec{D}_y & \text{otherwise} \end{cases} \tag{8}$$

a_y is as before (see equation 1), a^* is a threshold maximum area, $\theta_y^{\%drop}$ is the percent drop from pixel y to the lowest elevation in a_y, $\theta_y^{\%}$ is percent of slope at y relative to slopes in the surrounding pixels; and $\vec{D}_y$ is flow direction from unit y to the steepest drop in the topography of its upstream watershed.

As mentioned in the water quality model section in this appendix, the contributing upstream drainage area to y (given by a_y) is bounded by the edge or gradient on the landscape where ephemeral streams are likely to form. This boundary is used so that every y is linked to a water body at the height of storm hydrology processes and to reduce scaling problems by defining a spatial extent calculation standard. The parameter a^* is a function of geomorphology and climate that can be obtained by overlaying synthetic streams generated from DEM upon known stream maps. One a^* value is required for each analysis area. In this paper, a default value of 1000 was used for all analysis areas. If the modified flow direction $\vec{D}_y^m$ is equal to 0 then y has no flow direction.

Next, using Stone and Hilborn (2000), a series of equations are used to determine pixel y's slope-length factor (SL_y),

$$N_y = \max\left(0.1, \min\left(0.5, \frac{\theta_y^{\%}}{10}\right)\right); \tag{9}$$

$$\delta_y = \sum_{y' \in \vec{D}_y^m} l_{y'} \text{ ; and} \tag{10}$$

$$SL_y = \left(0.065 + \left(0.0456 \times \theta_y^{\%}\right) + \left(0.006541 \times \left(\theta_y^{\%}\right)^2\right)\right) \times \left(\frac{\delta_y}{22.1}\right)^{N_y} \tag{11}$$

where N_y is a slope adjustment factor, δ_y is the flow length from y to y's break point in slope along parcels y' where the set of y' is determined by $\vec{D}_y^m$, and l_y is a the length of y.

Finally, potential annual soil erosion in pixel y with LULC type i is given by the $USLE$,

$$USLE_{iy} = R_y \times K_y \times SL_y \times C_{iy} \times P_{iy} \tag{12}$$

where R_y is the rainfall erosivity index and is calculated as the kinetic energy of rainfall multiplied by maximum intensity of rain in 30 minutes expressed in cm hr^{-1} (Roose 1996), K_y indicates the erodability of soil in y and is based on the organic matter content and texture of the soil, its permeability and profile structure (Roose 1996), SL_y is given above (Roose 1996); and $C_{iy} \times P_{iy}$ is the product of the plant cover and management factor associated with the specific LULC i on y. $USLE_{iy}$ is a relative score where higher values indicate greater erosion potential.

The R_y index corresponds to the potential erosion risk in y where sheet erosion appears on a bare plot with a 9% slope (Roose 1996). The most fragile soils will have a K value that approximates one (Schwab et al. 1993). The factor SL_y represents a ratio of soil loss under conditions in y to that at a pixel with the standard slope steepness of 9% and slope length of 72.6 feet. The steeper and longer the slope, the higher the risk for erosion (Stone and Hilborn 2000). Erosion risk varies from 0.1 to 5 in the most frequent farming contexts in West Africa, and may reach 20 in mountainous areas (Roose 1996). Agricultural activity is unlikely to occur where higher values are possible. Traditionally, the topographical factor, as with all the factors of USLE, is estimated at a field plot scale. Finally, the factor $C_{iy} \times P_{iy}$ corrects for the observed relationship between erosion on bare soil and erosion under the cropping system, if any, on y. The C portion of $C_{iy} \times P_{iy}$ is a function of plant cover, its production level, and any associated cropping techniques. It varies from 1 on bare soil to 0.001 under forest with a value of 0.01 under grasslands and cover plants and 0.9 under root and tuber crops. The P in the term $C_{iy} \times P_{iy}$ accounts for specific erosion control practices such as contour tilling, contour mounding, or contour ridging. P_{iy} varies from 1 on bare soil with no erosion control to about 0.1 with tied ridging on a gentle slope (Roose 1996). Individual *USLE* pixel scores are summarized at the hexagon level in the paper's figures. Finally, we graph and map potential soil conservation, the inverse of *USLE*. Thus, in our graphs and maps, hexagons with higher potential conservation scores have lower *USLE* scores.

5. Carbon Sequestration Modeling

5.a. Determining LULC Change Dynamics

To estimate carbon sequestration rates over time in hexagon x we first have to estimate the LULC area in x that is established, converted, and remains unchanged from the beginning of one decade to another. This estimation procedure is completed for each LULC category and across all three scenarios. The heuristic for tracking x's area in each LULC category over time is described below.

1. We compared x's LULC distribution in 1990 and 2000 to determine the number of hectares of each LULC category i (i = 1,…,73) that were established in x between 1990 and 2000. Let $n2000_{ix}$ indicate the number of established hectares in LULC i in hexagon x in 2000. For simplicity, we assume 1995 is the year all LULC changes in x between 1990 and 2000 occurred.
2. Similarly we calculated $l2000_{ix}$, the number of hectares in LULC i in x that were converted to another LULC i in 1995.
3. Next we determined the number of hectares of LULC i in x that remained unchanged from 1990 to 2000. If 1990_{ix} indicates the number of hectares in LULC i in x in 1990, the number of hectares in LULC i in x that were carried over to 2000 is given by,
$$coa1990_{ix} = 1990_{ix} - l2000_{ix}. \tag{13}$$
4. We repeated steps 1 and 2 using the 2000 and 2010 LULC maps to determine $n2010_{ix}$ and $l2010_{ix}$: the hectares of LULC i established and lost, respectively, between 2000 and 2010 in x. We assume that these changes took place in 2005.
5. Next we calculated the number of hectares of LULC i in x that remained unchanged from 1990 to 2010. When possible, we assumed that all conversion of LULC i in 2005 ($l2010_{ix}$) occurred on land that had not changed since 1990. Thus, the number of hectares in LULC i in x that remained unchanged from 1990 to 2010 is given by,
$$cob1990_{ix} = \begin{cases} coa1990_{ix} - l2010_{ix} \text{ if } coa1990_{ix} - l2010_{ix} > 0 \\ 0 \text{ if } coa1990_{ix} - l2010_{ix} \leq 0 \end{cases}. \tag{14}$$
Further, the area of LULC i that was established in 1995 ($n2000_{ix}$) and remained on the 2010 LULC pattern was given by,
$$coa2000_{ix} = \begin{cases} n2000_{ix} \quad \text{if } cob1990_{ix} > 0 \\ n2000_{ix} + \left(coa1990_{ix} - l2010_{ix}\right) \quad \text{if } cob1990_{ix} = 0 \end{cases} \tag{15}$$

6. We repeated steps 1 and 2 using the 2010 and 2020 LULC maps to determine $n2020_{ix}$ and $l2020_{ix}$: the hectares of LULC i established and lost, respectively, between 2010 and 2020 in x. We assume that these changes took place in 2015.
7. Next we calculated the number of hectares of LULC i in x that remained unchanged from 1990 to 2020. When possible, we assumed that all conversion of LULC i in 2015 ($l2020_{ix}$) occurred on land that had not changed since 1990. Thus, the number of hectares in LULC i in x that remained unchanged from 1990 to 2020 is given by,

$$coc1990_{ix} = \begin{cases} cob1990_{ix} - l2020_{ix} \text{ if } cob1990_{ix} - l2020_{ix} > 0 \\ 0 \text{ if } cob1990_{ix} - l2020_{ix} \leq 0 \end{cases} \tag{16}$$

Further, the area of LULC i that was established in 1995 ($n2000_{ix}$) and remained on the 2020 LULC pattern was given by,

$$cob2000_{ix} = \begin{cases} coa2000_{ix} \text{ if } coc1990_{ix} > 0 \\ coa2000_{ix} + \left(cob1990_{ix} - l2020_{ix}\right) \text{if} \\ \qquad coa2000_{ix} + \left(cob1990_{ix} - l2020_{ix}\right) > 0 \text{ and } coc1990_{ix} = 0 \\ 0 \text{ if } coa2000_{ix} + \left(cob1990_{ix} - l2020_{ix}\right) \leq 0 \text{ and } coc1990_{ix} = 0 \end{cases} \tag{17}$$

Further, the area of LULC i that was established in 2005 ($n2010_{ix}$) and remained on the 2020 LULC pattern was given by,

$$coa2010_{ix} = \begin{cases} n2010_{ix} \quad \text{if } cob2000_{ix} > 0 \\ n2010_{ix} + coa2000_{ix} + \left(cob1990_{ix} - l2020_{ix}\right) \text{ if} \\ \qquad\qquad cob2000_{ix} = 0 \end{cases} \tag{18}$$

8. We repeated steps 1 and 2 using the 2020 and 2030 LULC maps to determine $n2030_{ix}$ and $l2030_{ix}$: the hectares of LULC i established and lost, respectively, between 2020 and 2030 in x. We assume that these changes took place in 2025.
9. Next we calculated the number of hectares of LULC i in x that remained unchanged from 1990 to 2030. When possible, we assumed that all loss of LULC i in 2025 ($l2030_{ix}$) occurred on land that had not changed since 1990. Thus, the number of hectares of LULC i in x that remained unchanged from 1990 to 2030 is given by,

$$cod1990_{ix} = \begin{cases} coc1990_{ix} - l2030_{ix} \text{ if } coc1990_{ix} - l2030_{ix} > 0 \\ 0 \text{ if } coc1990_{ix} - l2030_{ix} \leq 0 \end{cases} \tag{19}$$

Further, the area of LULC i that was established in 1995 ($n2000_{ix}$) and remained on the 2030 LULC pattern was given by,

$$coc2000_{ix} = \begin{cases} cob2000_{ix} \text{ if } cod1990_{ix} > 0 \\ cob2000_{ix} + \left(coc1990_{ix} - l2030_{ix}\right) \text{if} \\ \qquad cob2000_{ix} + \left(coc1990_{ix} - l2030_{ix}\right) > 0 \text{ and} \\ \qquad\qquad cod1990_{ix} = 0 \\ 0 \text{ if } cob2000_{ix} + \left(coc1990_{ix} - l2030_{ix}\right) \leq 0 \text{ and } cod1990_{ix} = 0 \end{cases} \tag{20}$$

Further, the area of LULC i that was established in 2005 ($n2010_{ix}$) and remained on the 2030 LULC pattern was given by,

$$cob2010_{ix} = \begin{cases} coa2010_{ix} \text{ if } coc2000_{ix} > 0 \\ coa2010_{ix} + \left(cob2000_{ix} + \left(coc1990_{ix} - l2030_{ix}\right)\right) \text{ if} \\ \quad coa2010_{ix} + \left(cob2000_{ix} + \left(coc1990_{ix} - l2030_{ix}\right)\right) > 0 \text{ and} \\ \quad coc2000_{ix} = 0 \\ 0 \text{ if } coa2010_{ix} + \left(cob2000_{ix} + \left(coc1990_{ix} - l2030_{ix}\right)\right) \le 0 \text{ and} \\ \quad coc2000_{ix} = 0 \end{cases} \tag{21}$$

Finally, the area of LULC i that was established in 2015 ($n2020_{ix}$) and remained on the 2030 LULC pattern was given by,

$$coa2020_{ix} = \begin{cases} n2020_{ix} \text{ if } cob2010_{ix} > 0 \\ n2020_{ix} + coa2010_{ix} + \\ \quad \left(cob2000_{ix} + \left(coc1990_{ix} - l2030_{ix}\right)\right) \text{ if } cob2010_{ix} = 0 \end{cases} \tag{22}$$

10. We repeated steps 1 and 2 using the 2030 and 2040 LULC maps to determine $n2040_{ix}$ and $l2040_{ix}$: the hectares of LULC i established and lost, respectively, between 2030 and 2040 in x. We assume that these changes took place in 2035.
11. Next we calculated the number of hectares of LULC i in x that remained unchanged from 1990 to 2040. When possible, we assumed that all loss of LULC i in 2035 ($l2040_{ix}$) occurred on land that had not changed since 1990. Thus, the number of hectares of LULC i in x that remained unchanged from 1990 to 2040 is given by,

$$coe1990_{ix} = \begin{cases} cod1990_{ix} - l2040_{ix} \text{ if } cod1990_{ix} - l2040_{ix} > 0 \\ 0 \text{ if } cod1990_{ix} - l2040_{ix} \le 0 \end{cases} \tag{23}$$

Further, the area of LULC i that was established in 1995 ($n2000_{ix}$) and remained on the 2040 LULC pattern was given by,

$$cod2000_{ix} = \begin{cases} coc2000_{ix} \text{ if } coe1990_{ix} > 0 \\ coc2000_{ix} + \left(cod1990_{ix} - l2040_{ix}\right) \text{ if} \\ \quad coc2000_{ix} + \left(cod1990_{ix} - l2040_{ix}\right) > 0 \\ \quad \text{and } coe1990_{ix} = 0 \\ 0 \text{ if } coc2000_{ix} + \left(cod1990_{ix} - l2040_{ix}\right) \le 0 \\ \quad \text{and } coe1990_{ix} = 0 \end{cases} \tag{24}$$

Further, the area of LULC i that was established in 2005 ($n2010_{ix}$) and remained on the 2040 LULC pattern was given by,

$$coc2010_{ix} = \begin{cases} cob2010_{ix} \text{ if } cod2000_{ix} > 0 \\ cob2010_{ix} + \left(coc2000_{ix} + \left(cod1990_{ix} - l2040_{ix}\right)\right) \text{ if} \\ \quad cob2010_{ix} + \left(coc2000_{ix} + \left(cod1990_{ix} - l2040_{ix}\right)\right) > 0 \\ \quad\quad \text{and } cod2000_{ix} = 0 \\ 0 \text{ if } cob2010_{ix} + \left(coc2000_{ix} + \left(cod1990_{ix} - l2040_{ix}\right)\right) \leq 0 \\ \quad\quad \text{and } cod2000_{ix} = 0 \end{cases} \tag{25}$$

Further, the area of LULC i that was established in 2015 ($n2020_{ix}$) and remained on the 2040 LULC pattern was given by,

$$cob2020_{ix} = \begin{cases} coa2020_{ix} \text{ if } coc2010_{ix} > 0 \\ coa2020_{ix} + \left(cob2010_{ix} + \left(coc2000_{ix} + \left(cod1990_{ix} - l2040_{ix}\right)\right)\right) \\ \quad \text{if } coa2020_{ix} + \\ \quad\quad \left(cob2010_{ix} + \left(coc2000_{ix} + \left(cod1990_{ix} - l2040_{ix}\right)\right)\right) > 0 \\ \quad\quad \text{and } coc2010_{ix} = 0 \\ 0 \text{ if } coa2020_{ix} + \left(cob2010_{ix} + \left(coc2000_{ix} + \left(cod1990_{ix} - l2040_{ix}\right)\right)\right) \leq 0 \\ \quad\quad \text{and } coc2010_{ix} = 0 \end{cases} \tag{26}$$

Finally, the area of LULC i that was established in 2025 ($n2030_{ix}$) and remained on the 2040 LULC pattern was given by,

$$coa2030_{ix} = \begin{cases} n2030_{ix} \text{ if } cob2020_{ix} > 0 \\ n2030_{ix} + coa2020_{ix} + \\ \quad \left(cob2010_{ix} + \left(coc2000_{ix} + \left(cod1990_{ix} - l2040_{ix}\right)\right)\right) \\ \quad\quad \text{if } cob2020_{ix} = 0 \end{cases} \tag{27}$$

12. We repeated steps 1 and 2 using the 2040 and 2050 LULC maps to determine $n2050_{ix}$ and $l2050_{ix}$: the hectares of LULC i established and lost, respectively, between 2040 and 2050 in x. We assume that these changes took place in 2045.
13. Next we calculated the number of hectares of LULC i in x that did not change from 1990 to 2050. When possible, we assumed that all loss of LULC i in 2045 ($l2050_{ix}$) occurred on land that had not changed since 1990. Thus, the number of hectares in LULC i in x that remained unchanged from 1990 to 2050 is given by,

$$cof1990_{ix} = \begin{cases} coe1990_{ix} - l2050_{ix} \text{ if } coe1990_{ix} - l2050_{ix} > 0 \\ 0 \text{ if } coe1990_{ix} - l2050_{ix} \leq 0 \end{cases} \tag{28}$$

Further, the area of LULC i that was established in 1995 ($n2000_{ix}$) and remained on the 2050 LULC pattern was given by,

$$
coe2000_{ix} = \begin{cases} cod2000_{ix} \text{ if } cof1990_{ix} > 0 \\ \\ cod2000_{ix} + \left(coe1990_{ix} - l2050_{ix}\right) \text{if} \\ \qquad cod2000_{ix} + \left(coe1990_{ix} - l2050_{ix}\right) > 0 \\ \qquad \text{and } cof1990_{ix} = 0 \\ \\ 0 \text{ if } cod2000_{ix} + \left(coe1990_{ix} - l2050_{ix}\right) \leq 0 \\ \qquad \text{and } cof1990_{ix} = 0 \end{cases} \tag{29}
$$

Further, the area of LULC i that was established in 2005 ($n2010_{ix}$) and remained on the 2050 LULC pattern was given by,

$$
cod2010_{ix} = \begin{cases} coc2010_{ix} \text{ if } coe2000_{ix} > 0 \\ \\ coc2010_{ix} + \left(cod2000_{ix} + \left(coe1990_{ix} - l2050_{ix}\right)\right) \text{if} \\ \quad coc2010_{ix} + \left(cod2000_{ix} + \left(coe1990_{ix} - l2050_{ix}\right)\right) > 0 \text{ and} \\ \qquad coe2000_{ix} = 0 \\ \\ 0 \text{ if } coc2010_{ix} + \left(cod2000_{ix} + \left(coe1990_{ix} - l2050_{ix}\right)\right) \leq 0 \text{ and} \\ \qquad cod2000_{ix} = 0 \end{cases} \tag{30}
$$

Further, the area of LULC i that was established in 2015 ($n2020_{ix}$) and remained on the 2050 LULC pattern was given by,

$$
coc2020_{ix} = \begin{cases} cob2020_{ix} \text{ if } cod2010_{ix} > 0 \\ \\ cob2020_{ix} + \left(coc2010_{ix} + \left(cod2000_{ix} + \left(coe1990_{ix} - l2050_{ix}\right)\right)\right) \\ \quad \text{if } cob2020_{ix} \\ \qquad + \left(coc2010_{ix} + \left(cod2000_{ix} + \left(coe1990_{ix} - l2050_{ix}\right)\right)\right) > 0 \\ \qquad \text{and } cod2010_{ix} = 0 \\ \\ 0 \text{ if } cob2020_{ix} + \left(coc2010_{ix} + \left(cod2000_{ix} + \left(coe1990_{ix} - l2050_{ix}\right)\right)\right) \leq 0 \\ \qquad \text{and } cod2010_{ix} = 0 \end{cases} \tag{31}
$$

Further, the area of LULC i that was established in 2025 ($n2030_{ix}$) and remained on the 2050 LULC pattern was given by,

$$cob2030_{ix} = \begin{cases} coa2030_{ix} \text{ if } coc2020_{ix} > 0 \\ \\ coa2030_{ix} + cob2020_{ix} + \\ \quad (coc2010_{ix} + (cod2000_{ix} + (coe1990_{ix} - l2050_{ix}))) \\ \qquad \text{if } coa2030_{ix} + cob2020_{ix} \\ \qquad\quad + (coc2010_{ix} + (cod2000_{ix} + (coe1990_{ix} - l2050_{ix}))) > 0 \\ \qquad\qquad \text{and } coc2020_{ix} = 0 \\ \\ 0 \text{ if } coa2030_{ix} + cob2020_{ix} \\ \qquad + (coc2010_{ix} + (cod2000_{ix} + (coe1990_{ix} - l2050_{ix}))) \leq 0 \\ \qquad\quad \text{and } coc2020_{ix} = 0 \end{cases} \tag{32}$$

Finally, the area of LULC *i* that was established in 2035 ($n2040_{ix}$) and remained on the 2050 LULC pattern was given by,

$$coa2040_{ix} = \begin{cases} n2040_{ix} \text{ if } cob2030_{ix} > 0 \\ \\ n2040_{ix} + coa2030_{ix} + cob2020_{ix} \\ \quad + (coc2010_{ix} + (cod2000_{ix} + (coe1990_{ix} - l2050_{ix}))) \\ \qquad \text{if } cob2030_{ix} = 0 \end{cases} \tag{33}$$

5.b. Amount of Carbon Stored in the Hexagon's Biomass and Soil at Time *t*

Each LULC category *i* has two carbon (hereinafter C) storage values. One is B_i, the C stored in *i*'s above and belowground biomass. The second is S_i, the C stored in the first meter of *i*'s soil profile.

B_i is set equal to *i*'s biomass maximum storage capacity of C. This capacity is either given by 1) *i*'s biomass C storage steady-state level (i.e., the level where the amount of C in *i*'s biomass does not change appreciably from year to year) or by 2) *i*'s biomass C storage level just before *i* graduates to another LULC category. For example, in the latter case, if *i* indicates a conifer forest with a stand 0 to 20 years old, B_i is the C stored in a conifer forest with a stand age of 20 years (see Figure A of the appendix). The variable B_i is measured in Mg ha^{-1} units. B_i values for all *i* and their sources are given in Table 2 of the appendix.

A.1. **A.2.**

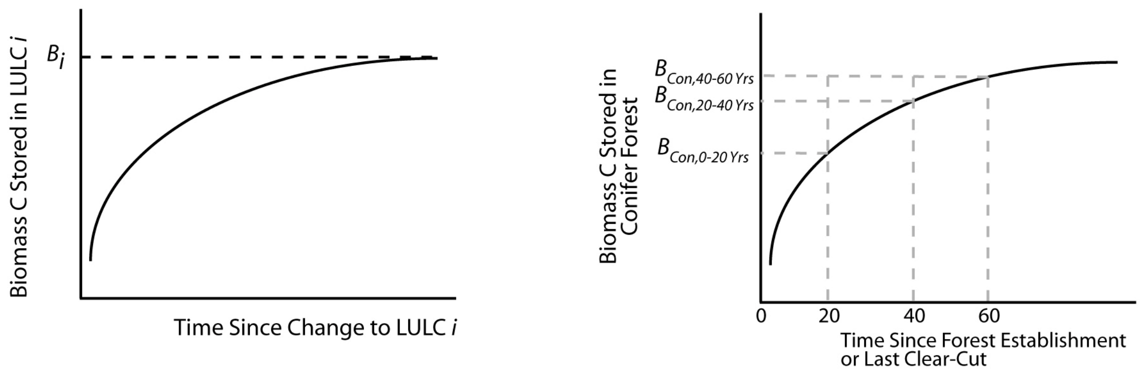

Figure A: Determining B_i. Figure A.1. An illustration of a B_i value that is set equal to i's biomass C storage steady-state level (i.e., i is not subdivided by age classes). **Figure A.2.** An illustration of a B_i value that is set equal to i's biomass C storage level just prior to graduating to another LULC category where the subscript *Con,0-20 Yrs* indicates the LULC conifer forest with trees 0 – 20 years old, *Con,20-40 Yrs* indicates the LULC conifer forest with trees 20 – 40 years old, etc.

S_i is set equal to i's maximum soil C storage capacity. This capacity is either given by 1) i's soil C storage steady-state level or by 2) i's soil C storage level just before i graduates to another LULC category. Like B_i, S_i is measured in Mg ha^{-1} units. S_i values for all i and their sources are given in Table 3 of the appendix.

At any given point in time, an area in LULC i may not have achieved its maximum biomass and soil C storage capacity. In such cases we use the coefficients $\alpha \in [0,1]$ and $\gamma \in [0,1]$ to deflate the LULC's B and S values appropriately. A coefficient value of 0 (i.e., $\alpha = 0$ or $\gamma = 0$) indicates that no C is stored in the area's respective C pool and a coefficient value of 1 (i.e., $\alpha = 1$ or $\gamma = 1$) indicates that the maximum storage capacity has been reached in the area's respective C pool.

5.b.i. Distribution of α and *γ Values*

For each LULC category i a distribution of 20 α coefficient values is determined. The first coefficient value in α_i's distribution is set such that the product $\alpha_i B_i$ is equal to the amount of C stored in the LULC's biomass at its youngest age class. In this research, the youngest age class is 5 years after the LULC has been established on the land (or alternatively, 5 years after a clear-cut of a forest LULC). Additional α_i values are determined for every subsequent 10-year increment up to 195 years since establishment (or alternatively, a clear-cut).

For example, assume one hectare in hexagon x was converted to the LULC category *Conifers 0-20 yrs (DF)* in 2015. On the 2020 decadal map this stand would contain 5-year old Douglas fir trees. According to the biomass C storage curves in Smith et al. (2006), by setting α_i = 0.25, the product $\alpha_i B_i$ equals the biomass C stored in a hectare of *Conifers 0-20 yrs (DF)* that was established five years ago. Assuming this conifer stand is left to grow for another decade, the 2030 biomass C storage value for *Conifers 0-20 yrs (DF)* is given by setting α_i = 0.75. Therefore, the LULC *Conifers 0-20 yrs (DF)*'s first and second values in its α_i distribution are 0.25 and 0.75, respectively (see Figure B). See Table 4 of the appendix for all α_i values for all *i* and a brief note on how the distributions were determined.

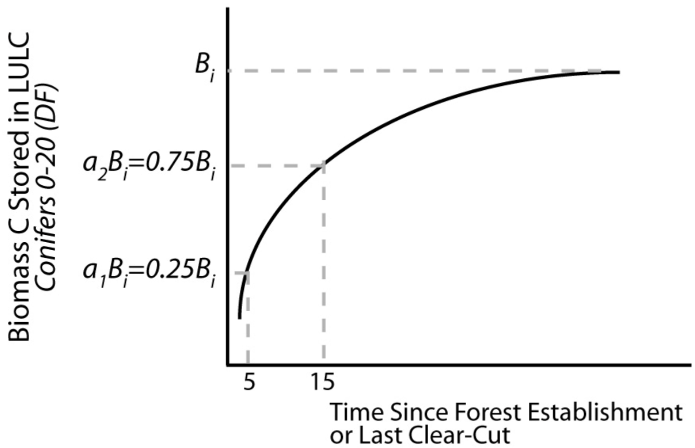

Figure B. Illustration of the use of α_i

For each LULC category *i* a distribution of 6 γ values is also determined. The use of the γ_i coefficients are analogous to the use of the α_i coefficients, except the γ_i coefficients are used to modify S_i. See Table 5 of the appendix for all γ_i values for all *i* and a brief note on how the distributions were determined.

5.b.ii. Assigning α and γ Coefficient Values to LULC in a Hexagon at Time t

Let $t = 0$ be the index year associated with the 1990 LULC map. Let $t = 60$ be the index year associated with a 2050 LULC map. Let the α and γ values assigned to LULC *i* in *x* at $t = 0$ be given by α_{ix}^{q} and γ_{ix}^{p} where *q* and *p* indicate the q^{th} and p^{th} positions in α_i and γ_i's distributions, respectively. The coefficient values used for the LULC *i* area in *x* that did not change between 1990 and 2000 (i.e.., $coa1990_{ix}$; see equation (13)) are α_{ix}^{q+1} and γ_{ix}^{p+1}. Furthermore, the coefficients used for the LULC *i* area in *x* that did not change between 1990 and 2010 (i.e.., $cob1990_{ix}$; see equation (14)) are α_{ix}^{q+2} and γ_{ix}^{p+2}, etc.

Any new LULC *i* area in *x* (e.g., $new2000_{ix}$, $new2010_{ix}$, etc.) is assigned the coefficient values corresponding to α_i^1 and γ_i^1. For each subsequent decade that these post-1990 established LULC areas remain on the landscape (e.g., $coa2000_{ix}$, $cob2000_{ix}$, $coa2010_{ix}$, $cob2010_{ix}$, etc.; see equations (15), (17), (18), (21)), their coefficient values will increase by one position in the coefficients' distributions. For example, if new LULC *i* area is established in *x* in 1995, then coefficient values are α_i^1 and γ_i^1 for that area on the 2000 LULC map. For the portion of this area that remains on the 2010 LULC map, the coefficient values are α_i^2 and γ_i^2.

5.b.iii. Carbon Stored in Hexagon x at Time t

Therefore, the C stored in *x* at time $t = 0$ (i.e., 1990), CS_{x0}, is given by,

$$CS_{x0} = \sum_{i=1}^{I} a1990_{ix} \left(\alpha_{ix}^{q} B_i + \gamma_{ix}^{p} S_i \right) \tag{34}$$

where $a1990_{ix}$ is the area of x in LULC category i in 1990 (i.e., $t = 0$).

The C stored in x in each subsequent decade is given by a series of equations,

$$CS_{x10} = \sum_{i=1}^{I} coa1990_{ix} \left(\alpha_{ix}^{q+1} B_i + \gamma_{ix}^{p+1} S_i \right) + n2000_{ix} \left(\alpha_{i}^{1} B_i + \gamma_{i}^{1} S_i \right) \tag{35}$$

$$\begin{aligned} CS_{x20} = \sum_{i=1}^{I} \Big(& cob1990_{ix} \left(\alpha_{ix}^{q+2} B_i + \gamma_{ix}^{p+2} S_i \right) + \\ & coa2000_{ix} \left(\alpha_{i}^{2} B_i + \gamma_{i}^{2} S_i \right) + \\ & n2010_{ix} \left(\alpha_{i}^{1} B_i + \gamma_{i}^{1} S_i \right) \Big) \end{aligned} \tag{36}$$

$$\begin{aligned} CS_{x30} = \sum_{i=1}^{I} \Big(& coc1990_{ix} \left(\alpha_{ix}^{q+3} B_i + \gamma_{ix}^{p+3} S_i \right) + \\ & cob2000_{ix} \left(\alpha_{i}^{3} B_i + \gamma_{i}^{3} S_i \right) + \\ & coa2010_{ix} \left(\alpha_{i}^{2} B_i + \gamma_{i}^{2} S_i \right) + \\ & n2020_{ix} \left(\alpha_{i}^{1} B_i + \gamma_{i}^{1} S_i \right) \Big) \end{aligned} \tag{37}$$

$$\begin{aligned} CS_{x40} = \sum_{i=1}^{I} \Big(& cod1990_{ix} \left(\alpha_{ix}^{q+4} B_i + \gamma_{ix}^{p+4} S_i \right) + \\ & coc2000_{ix} \left(\alpha_{i}^{4} B_i + \gamma_{i}^{4} S_i \right) + \\ & cob2010_{ix} \left(\alpha_{i}^{3} B_i + \gamma_{i}^{3} S_i \right) + \\ & coa2020_{ix} \left(\alpha_{i}^{2} B_i + \gamma_{i}^{2} S_i \right) + \\ & n2030_{ix} \left(\alpha_{i}^{1} B_i + \gamma_{i}^{1} S_i \right) \Big) \end{aligned} \tag{38}$$

$$\begin{aligned} CS_{x50} = \sum_{i=1}^{I} \Big(& coe1990_{ix} \left(\alpha_{ix}^{q+5} B_i + \gamma_{ix}^{p+5} S_i \right) + \\ & cod2000_{ix} \left(\alpha_{i}^{5} B_i + \gamma_{i}^{5} S_i \right) + \\ & coc2010_{ix} \left(\alpha_{i}^{4} B_i + \gamma_{i}^{4} S_i \right) + \\ & cob2020_{ix} \left(\alpha_{i}^{3} B_i + \gamma_{i}^{3} S_i \right) + \\ & coa2030_{ix} \left(\alpha_{i}^{2} B_i + \gamma_{i}^{2} S_i \right) + \\ & n2040_{ix} \left(\alpha_{i}^{1} B_i + \gamma_{i}^{1} S_i \right) \Big) \end{aligned} \tag{39}$$

$$
\begin{aligned}
CS_{x60} = \sum_{i=1}^{I} \Big(& cof1990_{ix}\left(\alpha_{ix}^{q+6} B_i + \gamma_{ix}^{p+6} S_i\right) + \\
& coe2000_{ix}\left(\alpha_i^6 B_i + \gamma_i^6 S_i\right) + \\
& cod2010_{ix}\left(\alpha_i^5 B_i + \gamma_i^5 S_i\right) + \\
& coc2020_{ix}\left(\alpha_i^4 B_i + \gamma_i^4 S_i\right) + \\
& cob2030_{ix}\left(\alpha_i^3 B_i + \gamma_i^3 S_i\right) + \\
& coa2040_{ix}\left(\alpha_i^2 B_i + \gamma_i^2 S_i\right) + \\
& n2050_{ix}\left(\alpha_i^1 B_i + \gamma_i^1 S_i\right) \Big)
\end{aligned} \tag{40}
$$

5.b.iv. Carbon Stored in Wood that was Harvested from Hexagon x

We also account for the C stored in harvested wood products (HWPs) made from timber harvested from *x*. We assume that managed forestry operations in the Basin have a rotation time of 45 years. We also assume even-age forestry: each year, 1/45th of a managed forest is clear-cut for timber production (Adams et al. 2002). For mathematical simplicity we assume that 1/45th of each hectare in managed forestry are clear-cut every year. For example, assume 100 hectares of *x* have been in managed forestry for 50 years at time $t = 0$ (i.e., 1990). Assume that the first 45 years of the operation involved setting up the even-age rotation system and that no timber was removed. Thereafter, over the years 1986 to 1990, trees were clear-cut (and replanted) from 1/45th of each of the 100 hectares annually (1/45 x 5 x 100 = 11.11 hectares total in the 100 hectare operation). As soon as wood is removed from the forest some of the C stored in the timber is lost; however, a good portion remains trapped in the wood that is used in products such as furniture and paper. The portion of C trapped in HWPs declines as the product ages.

Specifically, the amount of C trapped in harvested wood product (HWP) at time *t* given that the product was made from *x*'s timber is equal to,

$$
HWP_{xt} = \frac{co1990_{MFxt}\, B_{MF}}{45} \sum_{j=1}^{F_{MFxt}} d_j \tag{41}
$$

where F_{MFxt} is the number of years that wood has been removed from *x*'s managed forests as of time *t*, $co1990_{MFxt}$ is the area of *x* that is in managed forestry at time *t* **and** was in managed forestry at time $t = 0$ (i.e., 1990), B_{MF} is the metric tons of C stored in the wood removed from one hectare of a 45 year-old stand of high productivity managed Douglas fir forest, and d_j is the fraction of C in removed wood that remains in HWPs *j* years after the wood was removed from *x*, and the denominator of 45 indicates the assumed rotation time.

The LULC *i* categories that comprise managed forests in the C sequestration model are 1) $i = 26$ (*Forest Closed mixed* (*DF*)); 2) $i = 28$ (*Conifers 0-20 yrs* (*DF*)); 3) $i = 29$ (*Conifers 21-40 yrs* (*DF*)); 4) $i = 30$ (*Conifers 41-60 yrs* (*DF*)); 5) $i = 66$ (*Forest Closed mixed* (*FSM*)); 6) $i = 68$ (*Conifers 0-20 yrs* (*FSM*)); 7) $i = 69$ (*Conifers 21-40 yrs* (*FSM*)); and 8) $i = 70$ (*Conifers 41-60 yrs* (*FSM*)). Thus, the area in managed forestry in *x* at time *t* ($coa1990_{MFxt}$) is given by aggregating *x*'s area in these 8 LULCs.

According to Smith et al. (2006), $B_{MF} = 286.2$. The distribution of variable d_j is a function of the mix of tree species in the managed forestry operation, whether the timber is used for saw wood or pulpwood, and other managed forestry-related variables (see Smith et al. (2006) for details). The distribution of d_j we use is from Smith et al. (2006). The specific distribution of d_j values we use is calibrated for the Pacific Northwest, West region. The distribution of d_j follows a decay function that reaches 0 at $j = 100$. See Table 6 of this appendix for the distribution of d_j values.

Continuing with our managed forestry example, suppose $F_{MFx0} = 5$ ($t = 0$) then,

$$\begin{aligned} HWP_{x0} &= \frac{a1990_{MFx} B_{MF}}{45} d_1 + \frac{a1990_{MFx} B_{MF}}{45} d_2 + \\ &\quad \frac{a1990_{MFx} B_{MF}}{45} d_3 + \frac{a1990_{MFx} B_{MF}}{45} d_4 + \frac{a1990_{MFx} B_{MF}}{45} d_5 \\ &= \frac{a1990_{MFx} B_{MF}}{45} \sum_{j=1}^{5} d_j \end{aligned} \tag{42}$$

where $a1990_{MFx} = 100$ hectares. In other words, each year, starting in 1986, 1/45 of each managed forestry hectare is clear-cut of 45 year-old trees. The product $B_{MF}d_j$ determines how much of the C initially stored in that wood that was clear-cut remains in the resulting HWP j years after the clear cut.

Now assume that 20 managed forestry hectares in x are converted to a non-managed forestry LULC in 1995. At time $t = 10$ (i.e., 2000), HWP_{x10} is given by,

$$HWP_{x10} = \frac{coa1990_{MFx} B_{MF}}{45} \sum_{j=1}^{15} d_j \tag{43}$$

where $coa1990_{MFx}$ is the area of managed forestry in x in 2000 that also existed in x in 1990. In other words, equation (43) accounts for the HWP C stream from the 80 hectares that remain in managed forestry in 2000 (i.e., $t = 10$).

What about the HWP C stream produced by the 20 hectares that were harvested up to 1995? Specifically, C trapped in HWPs made from timber removed from hectares in x no longer managed for timber at time t is given by,

$$LHWP_{xt} = \sum_{k=\{10,20,\ldots,60\}}^{t} \frac{\left(co1990_{MFx,k-10} - co1990_{MFxk}\right) B_{MF} \sum_{g=t-(k-5)}^{F_{MFxt}+t} d_g}{45} \quad \text{for } t \geq 10 \tag{44}$$

where $co1990_{MFkx}$ is the area of managed forestry that existed in x in 1990 and in year k (we assume all managed forestry loses in a hexagon involve land that was in managed forestry in 1990; managed forestry additions after 1990 are not eligible for additional conversion unless necessary to keep gains and losses in an hexagon balanced). Note that $co1990_{MFx,k-10} \geq co1990_{MFxk}$ for all k.

Let us revisit our managed forestry example again. Recall that 20 of the 100 hectares of managed forestry x were converted to another LULC in 1995. Therefore at $\{t = 10, k = 10\}$ we have $co1990_{MFx0} = a1990_{MFx} = 100$ and $co1990_{MFxk} = coa1990_{MFx} = 80$ and equation (44) is equal to,

$$LHWP_{x10} = \frac{(100-80) B_{MF} \sum_{g=5}^{15} d_g}{45} \tag{45}$$

In other words, in 2000 1/45th of each of the 20 converted hectares had been harvested 15 years ago, 1/45th of each of the 20 lost hectares had been harvested 14 years ago, etc. The last 1/45th of a hectare that had been harvested from the converted hectares took place 5 years previous to 2000.

Recall that we assume that all LULC changes take place on the landscape in 1995, 2005, 2015, 2025, 2035, and 2045. Again assuming a managed forestry rotation preparation time of 45 years, post-1990 managed forestry land established after 1995 will not produce any HWP before 2050. However managed forestry area established in 1995 and not subsequently removed before 2050 will have produced HWP from 2040 to 2050. Specifically,

$$AHWP_{x60} = \frac{coe2000_{MFx} B_{MF}}{45} \sum_{j=1}^{10} d_j \tag{46}$$

where $coe2000_{MFx}$ is the number of managed forestry hectares established in 1995 that remain on the landscape in 2050.

v. Total Carbon Stored at Time t from Hexagon x

For t = 0, 10, 20, 30, 40, and 50 the total C stored on a hexagon is,

$$C_{xt} = CS_{xt} + HWP_{xt} + LHWP_{xt} \tag{47}$$

For t = 60, the total stored on a hexagon is given by,

$$C_{x60} = CS_{x60} + HWP_{x60} + LHWP_{x60} + AHWP_{x60}\,. \tag{48}$$

The total C stored on the Basin at time t is,

$$C_t = \sum_{x=1}^{X} C_{xt}\,. \tag{49}$$

We only calculate C_{xt} and C_t for $t = \{0,10,20,30,40,50,60\}$. C_{xt} and C_t for all other t is linearly interpolated using the appropriate time limits. For example, C_{xt} and C_t for t = 16 is linearly interpolated using C_{x10} and C_{x20} and C_{10} and C_{20}.

vi. The Economic Value of Sequestered Carbon

The economic value of sequestered C on hectare x and on the whole landscape at time t > 0 is given respectively, by,

$$V_{xt} = \frac{p}{(1+r)^t (1+s)^t}\left(C_{xt} - C_{x,t-1}\right) \tag{50}$$

and

$$V_t = \sum_{x=1}^{X} V_{xt} \tag{51}$$

where p is the (constant) value of a sequestered metric ton of C, $r \geq 0$ is the financial discount rate, and $s \geq 0$ is the C sequestration discount rate. If positive, the carbon discount rate s reduces the value of p over time. In other words, future C sequestration may be less valuable to society over time.

5.c. Model Results

We generate 5 sets of initial α_{ix}^{q} and γ_{ix}^{p} values. Each set includes a α_{ix}^{q} and γ_{ix}^{p} value for each $\{i,x\}$ combination. There are 6,214 x 73 = 453,622 unique hexagon, LULC category combinations. In the first set of coefficient values a $q \in \{1,2,...,13\}$ value is randomly assigned to each $\{i,x\}$ combination while p is set equal to 6 for each $\{i,x\}$ combination (i.e., we assume that soil C is at its storage capacity across the Basin in 1990). In the second set of α_{ix}^{q} and γ_{ix}^{p} values a $q \in \{1,2,...,13\}$ value is again randomly assigned to each x, i combination while p again is set equal to 6 for each $\{i,x\}$ combination. In the third set of α_{ix}^{q} and γ_{ix}^{p} values we set q equal to 1 and p equal to 6 for all $\{i,x\}$ combinations. In the fourth set of α_{ix}^{q} and γ_{ix}^{p} values we set q equal to 7 and p equal to 6 for all $\{i,x\}$ combinations. Finally, in the fifth set of α_{ix}^{q} and γ_{ix}^{p} values we set q equal to 13 and p equal to 6 for all $\{i,x\}$ combinations.

For each LULC change scenario we calculate CS_{xt} for each x and t = $\{0,10,20,30,40,50,60\}$ combination five times. Each time we calculate the set $\{CS_{xt}\}_{x=1,...,6214;t=0,10,...,60}$ we use a different set of initial α_{ix}^{q} and γ_{ix}^{p} coefficient values as discussed above. For each x, t combination under a scenario we find the average CS_{xt} value across the 5 realized values. The average values are used in our final results.

We generate 5 sets of F_{xMF0}. Each set includes a F_{xMF0} value for each x. In each set a $F_{xMF0} \in \{5,15,25,35,45\}$ value is randomly assigned to each x.

For each LULC scenario we calculate HWP_{xt} for each x and t = $\{0,10,20,30,40,50,60\}$ combination five times and we calculate $LHWP_{xt}$ for each x and t = $\{0,10,20,30,40,50,60\}$ combination five times. We also calculate $AHWP_{x60}$ for each x at t = 60 five times. Each time we calculate the sets $\{HWP_{xt}\}_{x=1,...,6214;t=0,10,...,60}$, $\{LHWP_{xt}\}_{x=1,...,6214;t=10,...,60}$, and $\{LHWP_{x60}\}_{x=1,...,6214}$ we use one of the 5 sets of randomly generated F_{xMF0} values. For each calculated $\{x,t\}$ combination under a scenario we find the average HWP_{xt}, $LHWP_{xt}$, and $AHWP_{x60}$ values across the 5 realized values. The average values are used in our final results.

5.d. Model Caveats

5.d.i. Modeling Simplifications

By tracking C sequestration at the hexagon level instead of the raster cell level we reduce the number of spatial units considered in the MATLAB code that tracks C sequestration on the landscape. By reducing the number of spatial units considered, the code can be executed in a reasonable amount of time. However, by tracking C sequestration at the hexagon level instead of the raster cell level we introduce an uncertain amount of error into our carbon sequestration estimates.

The problem is caused by always assigning the α_{ix}^{1} and γ_{ix}^{1} coefficients to newly established LULCs. In some cases this is appropriate. For example, the B_i, S_i, α_{ix}^{q}, and γ_{ix}^{p} values for the *Forest Closed Conifer* LULCs are constructed so that as a *Forest Closed Conifer* hectare transitions from one age class category to another (e.g., *Conifers 0-20 yrs (DF)* to *Conifers 21-40 yrs (DF)* to *Conifers 41-60 yrs (DF)*, etc.) the C sequestration path approximates the carbon storage curves given in Smith et al. (2006).

However, for some transitions that initial assignment should be α_{ix}^{q} and γ_{ix}^{p} where q and p are greater than 1. For example, assume that a patch of forest classified as *Forest closed conifer 61-80 yrs (DF)* converts to *Upland Forest open (DF)*. On the actual landscapes this transition would involve a thinning of the stand on *Forest closed conifer 61-80 yrs (DF)* but relatively few new plantings (i.e., trees that are 61-80 years old would remain on the landscape). However by assigning α_{i}^{1} to new the newly established LULC *Upland Forest open (DF)* the model assumes thinning **and** younger trees vis-à-vis the previous LULC.

Another example of a problematic transition is natural grassland to natural shrub. Assume that an area is in natural grassland with a biomass C storage coefficient of $\alpha_{natgrass,x}^{8} = 1$.

Therefore, $\alpha^{8}_{natgrass,x} B_{natgrass}$ = 10.15 (see Tables 2 and 4 of the appendix). Now assume that the land transitions to natural shrub. Five years after the change $\alpha^{1}_{natshrub,x} B_{natshrub}$ = 0.04 x 239.4 = 9.58 (see Tables 2 and 4 of the appendix). However, given that $B_{natshrub} > B_{natgrass}$, it is most likely that the transition from natural grassland to natural shrub would involve positive sequestration over the first 5 years, not negative.

Similar transition sequestration path inconsistencies can occur when modeling C sequestration in soil. For example, consider a pixel that is in row crops. Suppose a nearby pixel is in natural grassland. Suppose both cells are converted to pasture at the same time. The soil C sequestration dynamics are such that the cell originally in natural grassland would loss soil C for some years after the transition to pasture. Conversely, the cell formerly in row crops would sequester C in its soil for some years after the transition to pasture. Ideally, our γ^{q}_{ix} coefficients would reflect these opposite C sequestration paths to the pasture soil C maximum capacity storage level. In our C sequestration model however, we assign $\gamma^{1}_{pasture,x} B_{pasture}$ to both grid cells regardless of the cells' different C sequestration dynamics.

The natural solution to this problem is to make the coefficients α^{q}_{ix} and γ^{p}_{ix} for a given area in x a function of the *previous* and new LULC type in that area. However, by tracking LULC change at the hexagon level we do not know which raster cells converted to which use; instead our model exports the total number of raster cells in each LULC in x that was converted, established, and continued. In general, by always assigning α^{1}_{i} and γ^{1}_{i} to newly established LULC areas we **underestimate** the amount of carbon sequestered on the landscape.

In addition, our model **underestimates** the carbon stored in HWP and HWP waste. First, if a forest stand is thinned, clear-cut, and/or selectively harvested i) for agriculture, housing, or infrastructure development or ii) to be cycled back into rotation forestry, the felled logs in all likelihood would be used for HWP. These potential sources of HWP are not included in our model. However, the former set of LULC changes does not occur that often in the Willamette Basin: in the LULC change scenarios we consider, most housing developments occurs on former agricultural land and little to no forest is cleared for agriculture. The latter type of LULC change – cycling forests back into active rotation forestry – does occur some in the Cascades, especially under the Development LULC change scenario.

Our HWP C storage / sequestration model also **underestimates** the amount of C stored in HWP at any time by assuming that it takes 45 years for newly established managed forestry land to produce HWP. In most cases some merchantable timber is produced while a managed forest's overall rotation structure is established.

When assigning market values to hexagons (see section 7 below) we assign managed timber value to some forests that are not considered managed forestry categories in the carbon sequestration model. The value of managed forestry in these areas represents the best approximation of their market value despite are assumption that they are not being actively managed at the time represented by the map. However, if some of these areas are actively managed for timber on any map then once again we may have **underestimated** the C sequestered by these areas by not accounting for the C sequestered in their HWP pool.

Our model also **underestimates** the C stored in HWP at any given time by ignoring timber production prior to 1990. However, because all scenarios are accorded the same amount of pre-1990 HWP C the difference in C sequestration across the three scenarios is not affected by this particular omission. Finally, some HWP waste ends up in landfills. As the HWP waste becomes buried in the landfills, the remaining carbon can be trapped indefinitely (Smith et al. 2006). Our C model also **underestimates** carbon sequestration by not accounting for this landfill HWP waste C.

Finally, all of these sources of underestimation may be countered by our assumption that all C stored in HWP at any given time by assuming that all forests in the LULC categories 1) i = 26 (*Forest Closed mixed* (*DF*)); 2) i = 28 (*Conifers 0-20 yrs* (*DF*)); 3) i = 29 (*Conifers 21-40 yrs* (*DF*)); 4) i = 30 (*Conifers 41-60 yrs* (*DF*)); 5) i = 66 (*Forest Closed mixed* (*FSM*)); 6) i = 68 (*Conifers 0-20 yrs* (*FSM*)); 7) i = 69 (*Conifers 21-40 yrs* (*FSM*)); and 8) i = 70 (*Conifers 41-60 yrs* (*FSM*)) are actively managed for timber production. This is certainly not the case. Some of these areas may have been managed in the past but are no longer actively producing timber and some of these areas are now protected from managed forestry.

We are not certain how C model output would be changed if all of these sources of C sequestration underestimation and overestimation were corrected.

5.d.ii. Land Not Modeled

Except in a few cases, the carbon sequestration model does not consider hexagons that are completely inside urban growth boundaries (UGBs). However, if a hexagon inside a UGB contained natural land cover (e.g., a large park) or agriculture land use on the 1990 LULC map then carbon sequestration dynamics in the entire hexagon was tracked across each scenario. Hexagons that straddle UGBs are considered to be non-UGB parcels by the model and thus had their carbon sequestration dynamics tracked in each scenario.

5.d.iii. Other Issues

The carbon sequestration model could benefit from better data and more realistic modeling. Published regional data on soil and non-woody root biomass carbon sequestration rates as a function of LULC category are sparse. Also carbon sequestration rates on a landscape are greatly influenced by the landscape's disturbance regime (Bond-Lamberty et al. 2007). Currently the InVEST carbon sequestration models do not include probabilistic disturbance events. Carbon sequestration rates are also a function of climate and weather (e.g., Jenny 1980, Coomes et al. 2002, Raich et al. 2006), and land management practices (e.g., fertilizer use on crops, wetland draining practices, see Schuman et al. 2002 and Lal 2002); these factors are missing from our model as well. (Exactly how important climate is in determining carbon sequestration rates is up to debate: "The global pattern in NEP was insensitive to climate and is hypothesized to be mainly determined by nonclimatic conditions such as successional stage, management, site history, and site disturbance." (p. 2510, Luyssaert et al. 2007).)

6. Biodiversity

6.a. Countryside SAR

We use a modified species-area curve equation to determine how well an entire LULC map supports a suite of species on the landscape. Our species-area equation is closely related to the countryside species area relationship (SAR) equation described in Pereira and Daily (2006). Therefore, we likewise call our species-area curve statistic the countryside SAR.

The countryside SAR score for each species s on a LULC map is given by,

$$SAR_{st} = \frac{\left(\sum_{x=1}^{X}\sum_{i=1}^{I} A_{ixt} H_{xs} C_{si}\right)^{z_s}}{\left(\sum_{x=1}^{X} A_x H_{xs}\right)^{z_s}} \tag{52}$$

where A_{ixt} is the area of LULC i in hexagon x at time t (or alternatively, the number of 30 x 30 meter grid cells in x in LULC i at time t), $H_{xs} = 1$ if hexagon x is in s' abiotic niche space and equals 0 otherwise, $C_{si} \in [0,1]$ indicates s' overall breeding and feeding compatibility with LULC category i (i.e., $C_{si} > 0$ indicates that i is habitat for s whereas $C_{si} = 1$ indicates that i is perfectly compatible with s' habitat needs), z_s is the species-area exponent for s, and A_x is the area of x (or alternatively, the number of 30 x 30 meter grid cells in x).

A species' abiotic niche space is composed of the portions of the landscape that the species could be found breeding and feeding in if those areas contained compatible habitat ($C_{si} > 0$). In this paper, a species' abiotic niche space is equivalent to a species' geographic range. In most species-area curve formulations z ranges from 0.11 to 0.64 (Pareira and Daily 2006). The lower z_s is, the slower s' countryside SAR score declines as its habitat is removed from a landscape. Lower z values should be used if it is believed that a species only requires a minimal amount of compatible habitat area on the landscape in order to persist. For simplicity, we assume that all modeled species in the Willamette Basin have the same z value of 0.25, suggesting that all species are relatively insensitive to small losses in habitat.

In equation (52) we normalize the observed species-area relationship value (the numerator) by the species-area relationship value that would result if the species' entire abiotic niche space were in perfectly compatible habitat (the denominator), i.e., $C_s = 1$ for all area in s' abiotic niche space. This normalization puts SAR_{st} on the 0 to 1 scale. Therefore, SAR_{st} can be interpreted as the fraction of total potential support that the LULC map provides at time t for s.

Calculating the relative status of the complete ensemble of modeled species on the landscape at time t is the final step in the countryside SAR calculation. This statistic measures the status of a collection of species on a particular LULC map. The countryside SAR statistic for the ensemble of modeled species at time t is given by,

$$SAR_t = \sum_{s=1}^{S} w_s SAR_{st} \tag{53}$$

where w_s is the social weight associated with s and $\sum_{s=1}^{S} w_s = 1$.

If w_s and z for all s remain constant across all LULC maps evaluated with equations (52)-(53), then SAR_t can be used to rank the relative biodiversity-friendliness of all evaluated LULC maps. If any of these variables change, the relative SAR scores for each landscape should not be directly compared.

In this application we calculate the SAR_t statistic with 24 terrestrial vertebrate species that are threatened in the Basin or react strongly to land-use change in other biological modeling we have done (Polasky et al. 2008). Further, in this analysis $w_s = 1 / 24$ for all s. See Tables 7 and 8 of the appendix for a list of all 24 species and their C_{si} values for all LULC i. All C_{si} and H_{xs} data come from Polasky et al. (2008).

6.a.i. Countryside SAR Sensitivity Analysis

To determine how sensitive countryside SAR results are to changes in C_{si} and $H_{\bullet s}$ values, we use alternative C_{si} and H_{xs} values from Schumaker et al. (2004) to determine SAR_t (equations (52) and (53)). Let C_{si}^a and $H_{\bullet s}^a$ indicate the C_{si} and $H_{\bullet s}$ values, respectively, from Schumaker et al. (2004). The C_{si}^a values were constructed differently from the default C_{si} values used in this analysis. Specifically, the C_{si}^a value assigned to a pixel is a function of the pixel's LULC i and the pattern of LULC and other landscape features near the pixel. The effects that surrounding pixels and landscape features have on habitat in a pixel are codified in a set of adjacency rules that account for edge effects, riparian influence, human disturbance, and other similar factors. Basically, Schumaker et al.'s (2004) C values account for landscape context while ours do not. Let the adjacency rule-adjusted C_{si}^{a} value for a particular pixel in LULC i at time t be given by $\hat{C}_{sipt}^{a}$ where $p = 1,\ldots,P$ indexes pixels. Separate $\hat{C}_{sipt}^{a}$ scores for breeding, feeding, and both activities were calculated. Schumaker et al. (2004) set the range of $\hat{C}_{sipt}^{a}$ from 0 to 10. Therefore, the adjacency rule-adjusted SAR_{st} value for s on LULC map t is given by,

$$\hat{S}AR_{st} = \frac{\left(\sum_{p=1}^{P}\sum_{i=1}^{I} A_p H_{ps}^{a}\left(\hat{C}_{sipt}^{a}/10\right)\right)^{0.25}}{\left(\sum_{p=1}^{P} A_p H_{ps}^{a}\right)^{0.25}} \tag{54}$$

where A_p is the area of pixel p (900 square meters in this analysis), and the divisor of 10 is used to scale $\hat{C}_{sipt}^{a}$ to a unit scale. In all but a few cases, the breeding $\hat{C}_{sipt}^{a}$ scores are used in equation (54); for a few species the combined activity scores were used. Finally, the adjacency rule-adjusted countryside SAR statistic for the ensemble of modeled species at time t is given by,

$$\hat{S}AR_{t} = \sum_{s=1}^{S} w_s \hat{S}AR_{st} \tag{55}$$

where $w_s = 1 / 23$ for each s. The number of species is 23 ($S = 23$) instead of 24 because Schumaker et al. (2004) does not have data on the White-tailed deer (*Odocoileus virginianus*), a species included in our default analysis.

Figure C in the appendix gives percentage changes in landscape biodiversity scores from 1990 to 2050 for the three LULC change scenarios considered in this paper. The bottom line in Figure C ("SAR_t – this study") gives the percentage changes in SAR_t scores (using default C_{si} and H_{xs} values) between $t = 1990$ and 2050. The middle line in Figure C ("$\hat{S}AR_t$ – input data from Schumaker at al. (2004)") gives the percentage changes in $\hat{S}AR_t$ scores (using C_{si}^{a} and $H_{\bullet s}^{a}$ values) between $t = 1990$ and 2050. The top line in Figure C ("Expected Species Persistence – Polasky et a. (2008)") gives the change in the species persistence scores between $t = 1990$ and 2050 from a biodiversity persistence model described in Polasky et al. (2008). This last analysis uses a species persistence model that accounts for species' habitat area needs and dispersal ability on the landscape. The expected species persistence model considers the same set of 24 species from this research.

Despite the differences in input data, the two countryside SAR analyses produce similar results. The model in Polasky et al. (2008) suggests that LULC change scenarios will have more dramatic effects on biodiversity status.

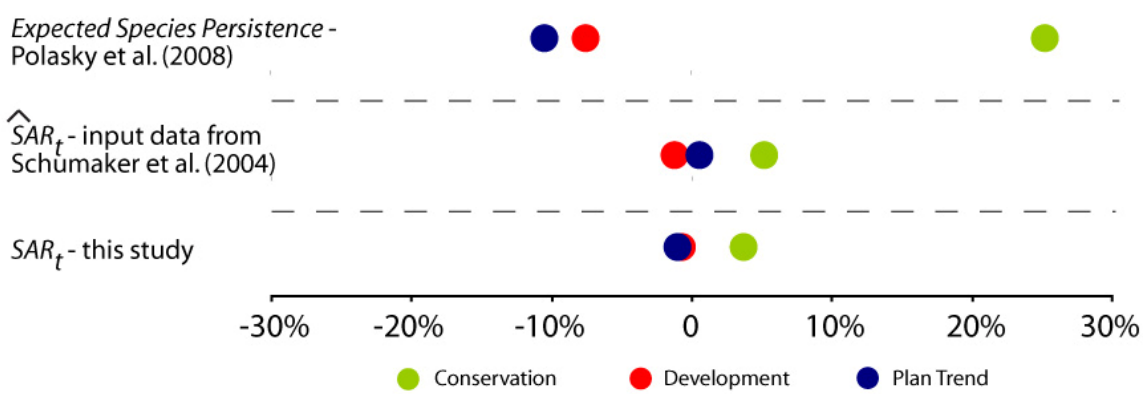

Figure C: Comparison of Biodiversity Conservation Statistics Across Scenarios and Biodiversity Conservation Models.

6.b. Marginal Biodiversity Value (*MBV*) of a Hexagon

6.b.i. Hexagonal Comparisons on a LULC Map

The marginal biodiversity value (MBV) of hexagon x on a given LULC map is a function of i) x's location vis-à-vis the abiotic range space of each modeled species, and ii) x's distribution of compatible habitats vis-à-vis the compatible habitat areas across the rest of the landscape.

As was the case in the countryside SAR model, abiotic niche space (H_{xs}) indicates whether species s could persist in hexagon x if it contained compatible habitat, and compatibility (C_{si}) refers to the degree to which LULC i supports the breeding and feeding activities of species s. Hexagon x's MBV at time t is calculated with two steps:

1. First, we calculate the per-unit-area biodiversity value of each LULC type i for each species s at time t,

$$\hat{C}_{sit} = \frac{C_{si}}{\sum_{x=1}^{X} \sum_{i=1}^{I} C_{si} A_{ixt} H_{xs}}, \quad (56)$$

   where $H_{xs} = 1$ if x is in s' abiotic niche space and equals 0 otherwise and A_{ixt} is the area of LULC i in hexagon x at time t. The numerator of this expression is the compatibility score of s with i and the denominator represents the total amount of effective habitat available to s on the landscape at time t.

2. Next we calculate MBV on x at time t,

$$MBV_{xt} = \sum_{s=1}^{S} w_s H_{xs} \left(\sum_{i=1}^{I} A_{ixt} \hat{C}_{sit} \right) \quad (57)$$

   where w_s is the social weight associated with s and $\sum_{s=1}^{S} w_s = 1$.

The sum of MBV_{xt} over all x (i.e., the entire landscape) is equal to one. As such, MBV_{xt} is an estimate of each parcel's proportional share of landscape-wide biodiversity production at time t.

6.b.ii. Hexagonal Comparisons Across LULC Maps

MBV is a convenient way to compare the biodiversity value of hexagons on a LULC map, but it can be misleading to compare *MBV* values of a particular hexagon across time (i.e., different decadal LULC maps). Because MBV_{xt} is a function of the distribution of LULC types across the entire landscape at time t, its value can change over time even if no LULC changes are made on x. This may provide useful information in some contexts, but it obscures interpretation of whether the biodiversity value of x has been improved or degraded in its own right. We therefore use an alternative statistic that gives relative MBV ($RMBV$) with respect to a baseline landscape. Calculation of $RMBV$ is based on the same input data as MBV, and involves two steps:

1. Using the 1990 LULC map, we calculate $\hat{C}_{si}$ as in equation (56) above. This statistic is denoted as $\hat{C}_{si0}$.
2. Calculate the relative marginal value of biodiversity in x at time $t > 0$,

$$RMBV_{xt} = \sum_{s=1}^{S} w_s H_{xs} \left(\sum_{i-1}^{I} A_{xit} \hat{C}_{si0} \right) \qquad t > 0 \qquad (58)$$

Observe that this formulation always uses the per-unit-area value of each LULC type i as evaluated in the base landscape. This quantity is then applied to the distribution of LULC types across the landscape in future time periods.

Finally, for each scenario other than the 1990 base landscape, we calculate the $RMBV$ ratio for all parcels x as $\frac{RMBV_{xt}}{MBV_{xb}}$ where MBV_{xb} is x's MBV score on the 1990 base map. This ratio of $RMBV_{xt}$ to MBV_{xb} will be greater than 1 if the aggregate per-unit-area value of habitat in x has improved relative to 1990 and less than 1 if the aggregate per-unit-area value of habitat in x has declined relative to 1990.

6.c. Model Caveats

6.c.i. Modeling Simplifications

In this paper we only present InVEST's simpler biodiversity models. Other than abiotic niche space, the biodiversity models presented here do not consider the spatial pattern of habitat on a LULC map. Further, the models described above do not consider the size of habitat patches or how species react to habitat patterns. InVEST does include such spatially explicit species models that have been applied elsewhere (e.g., Nelson et al. 2008, Polasky et al. 2008). Winfree et al. (2005) also present a series of habitat proximity indices that can be used to score a LULC map's support for species. InVEST may incorporate some of these indices in the future.

Finally, as mentioned above, we normalize our countryside SAR score in order to place it on a 0 to 1 scale. This normalization results in greater gains in countryside SAR value per unit of additional habitat for species with small abiotic niche spaces compared to those species with larger abiotic niche spaces. However, the statistic's bias for species with smaller ranges may be appropriate given that range-restricted species tend to have higher extinction risks than large-range species (Angermeier 1995, Newmark 1995, Purvis et al. 2000, Pimm and Brooks 2000, Brooks et al. 2001, Parks and Harcourt 2002, Cardillo et al. 2006).

6.c.ii. Land Not Modeled

The biodiversity model in general does not consider hexagons that are completely inside urban growth boundaries (UGBs). However, if a hexagon inside a UGB contains natural land cover or agriculture land use on the 1990 LULC map, then the hexagon's contribution to countryside SAR and its MBV and RMBV scores are calculated across time in each scenario. Hexagons that straddle UGBs are considered to be non-UGB parcels by the biodiversity model;

thus, they are included in the countryside SAR calculation and their MBV and RMBV scores are tracked over time.

7. Commodity Production Values

7.a. Unadjusted Per-Hectare Market Values in a Hexagon

We consider 11 commodity land-use categories. Using data from Polasky et al. (2008), we determined *x*'s annual per-hectare market value (i.e., revenue from production – cost of production using market prices) for 6 of the 11 commodity land-use categories, including 1) Orchard/vineyard agriculture; 2) Grass seed agriculture; 3) Pasture; 4) Row crop agriculture; 5) Managed forestry; and 6) Rural-residential land use. Except for the rural-residential land-use, market values are based on observed data from the late 1990s and 2000. Rural-residential land-use market values are based on undeveloped rural-residential lot sales from 1980 to 2003. Except for rural-residential land use, per-hectare market values remain constant over time. The market value of rural-residential development increases 2% per annum from 1990 onward. This increase is mitigated by a rural-residential elasticity of demand of -0.75. In other words, for every one percent increase in rural-residential area in the Basin at time *t*, the annual per-hectare market value of rural residential land use at time *t* decreases by 0.75%.

We assume the annual market value of land in 4 of the remaining 5 commodity land-use categories, including 7) Conserved land-use; 8) Other conifer forest; 9) Other forest, and 10) Water or barren, is equal to 0.

The 11th commodity land category is high-density land use (e.g., medium to high density residential, commercial, transportation infrastructure, and industrial land). While the market value of the commodities produced on this land type tends to be very large, we do not have a good model for predicting the value of this land. Thus, for the purposes of this paper, we ignore this land when modeling the market value of commodity production.

Let MH_{cxt} indicate the per-hectare market value of commodity land-use *c* in *x* at time *t*. The spatial distributions of MH_{cxt} values for the first six commodity land-use categories are given in Figure D (values are in constant year 2000 dollars). Only rural-residential per-hectare values change over time. The mapped value of rural-residential housing in the figure corresponds to the year 1990.

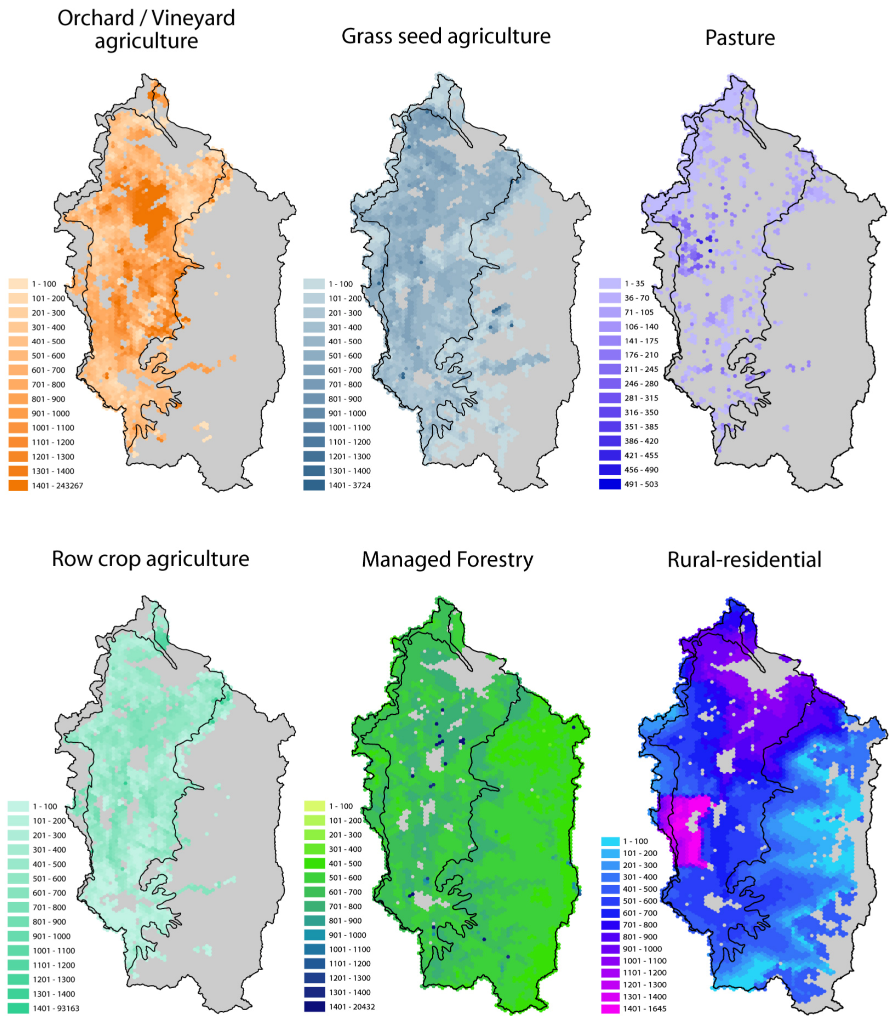

Figure D: Per-Hectare Market Values on the 1990 Landscape for Six Commodity Categories. Gray areas indicate a 0 market value for the commodity at that point on the landscape or a hexagon completely inside an UGB.

7.b. Unadjusted Aggregate Market Value in a Hexagon

We placed each LULC category *i* into one of the 11 commodity land-use categories. The rules used for placing a LULC category into a commodity land-use category are given in Table 9. To determine the aggregate market value of the commodities produced in *x* at time *t* under a given LULC change scenario we solve the following,

$$M_{xt} = \sum_{c=1}^{C} A_{cxt} MH_{cxt} \quad (59)$$

where M_{xt} is *x*'s aggregate market value across the 11 commodity land-uses at time *t* and A_{cxt} is *x*'s area in commodity land-use category *c* at time *t* under the given LULC change scenario.

7.c. Adjusting Aggregate Market Value in a Hexagon

When determining the market value of commodity production for some LULC pattern map we ignore hexagons that are completely inside UGBs regardless of their areal distribution of commodity land-use categories. Otherwise, M_{xt} values are calculated for all hexagons that straddle UGBs or are completely outside of UGBs, In both cases, these last two hexagons are called non-UGB hexagons..

A non-UGB hexagon can have different area in high-density land use at time *t* across the three scenarios. In these cases, a true one-to-one comparison of M_{xt} across scenarios is not possible because the extent of area used to calculate M_{xt} differs across scenarios. For example, a hexagon in some scenario may have greater per-hectare market values than it does in the other two but have the lowest M_{xt} value because a greater proportion of its land is in the ignored land use of high-density development. Therefore, we modify M_{xt} across scenarios to adjust for differences in the extent of high-density development in *x*. First, for each $\{x,t,a\}$ combination we solve the following,

$$AdjM_{xta} = 1 - \left(\frac{\max\limits_{o=\{1,2,3\}} \{D_{xto}\} - D_{xta}}{A_x} \right) \tag{60}$$

where D_{xta} is the amount of high-density land-use in modeled *x* and time *t* under scenario *a* and A_x is the area of land in hexagon *x* (*o* indexes LULC change scenarios as well). Next, we calculate $\hat{M}_{xta} = AdjM_{xta} M_{xta}$ where M_{xta} is the unadjusted total market value in *x* in year *t* under scenario *a* (equation (59)). Therefore, $\hat{M}_{xt}$ for any given scenario *a* is only a function of values in areas of *x* that are not in high-density land-use across in any of the three scenarios. In other words, an area that urbanizes in one or more scenarios in year *t* is not valued by the market value model in any of the scenarios.

By summing across all $\hat{M}_{xt}$ for a given scenario we determine $\hat{M}_t$, the adjusted landscape net return value at time *t*. We determine $\hat{M}_{xt}$ and $\hat{M}_t$ for $t = \{0,10,20,30,40,50,60\}$ under each scenario *a*. $\hat{M}_{xt}$ and $\hat{M}_t$ for all other *t* is linearly interpolated using the appropriate time limits. For example, $\hat{M}_{xt}$ and $\hat{M}_t$ for $t = 27$ is linearly interpolated using $\hat{M}_{x20}$ and $\hat{M}_{x30}$ and $\hat{M}_{20}$ and $\hat{M}_{30}$. Finally, all adjusted market values in year *t* are discounted (divided) by 1.07^{t-1} (a 7% discount rate per annum).

7.d. Model Caveats

Valuation of the commodities produced at time *t* should be a function of the projected commodity prices and production costs at time *t*. In this application we only vary the per-hectare net value of rural-residential land use over time.

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9. Tables

Table 1

PNW-ERC LULC Category ID	PNW-ERC LULC Category	Broader LULC Category Used in Figures 1 and 2 in Text
1	Residential 0-4 DU/ac	Rural-Residential
2	Residential 4-9 DU/ac	Dense Development
3	Residential 9-16 DU/ac	Dense Development
4	Residential >16 DU/ac	Dense Development

PNW-ERC LULC Category ID	PNW-ERC LULC Category	Broader LULC Category Used in Figures 1 and 2 in Text
6	Commercial	Dense Development
7	Comm/Industrial	Dense Development
8	Industrial	Dense Development
10	Residential & Comm.	Dense Development
11	Urban non-vegetated unknown	Dense Development
16	Rural structures	Dense Development
18	Railroad	Dense Development
19	Primary roads	Dense Development
20	Secondary roads	Dense Development
21	Light duty roads	Dense Development
24	Rural non-vegetated unknown	Dense Development
29	Main channel non-vegetated	Dense Development
32	Stream orders 5-7	Dense Development
33	Permanent lentic water	Dense Development
39	Topographic Shadow	Dense Development
40	Snow	Dense Development
42	Barren	Dense Development
49	Urban tree overstory	Dense Development
51	Upland Forest open (DF)	Other Forest
52	Upland Forest Semi-closed mixed (DF)	Other Forest
53	Forest Closed hardwood	Other Forest
54	Forest Closed mixed (DF)	Young Conifer
55	Upland Forest Semi-closed conifer (DF)	Other Forest
56	Conifers 0-20 yrs (DF)	Young Conifer
57	Forest closed conifer 21-40 yrs (DF)	Young Conifer
58	Forest closed conifer 41-60 yrs (DF)	Young Conifer
59	Forest closed conifer 61-80 yrs (DF)	Other Forest
60	Forest closed conifer 81-200 yrs (DF)	Other Forest
61	Forest closed conifer older than 200 yrs (DF)	Old Conifer / Other Natural
62	Upland Forest Semi-closed hardwood	Other Forest
66	Hybrid poplar	Other Forest
67	Grass seed rotation	Grass Seed
68	Irrigated annual rotation	Row Crops
71	Grains	Row Crops
72	Nursery	Orchard / Vineyard
73	Berries & Vineyards	Orchard / Vineyard
74	Double cropping	Row Crops
75	Hops	Row Crops
76	Mint	Row Crops
77	Radish seed	Grass Seed
78	Sugar beet seed	Grass Seed
79	Row crop	Row Crops
80	Grass	Grass Seed
81	Burned grass	Grass Seed
82	Field crop	Row Crops
83	Hayfield	Pasture / Hayfield
84	Late field crop	Row Crops

PNW-ERC LULC Category ID	PNW-ERC LULC Category	Broader LULC Category Used in Figures 1 and 2 in Text
85	Pasture	Pasture / Hayfield
86	Natural grassland	Old Conifer / Other Natural
87	Natural shrub	Old Conifer / Other Natural
88	Bare/fallow	Row Crops
89	Flooded/marsh	Old Conifer / Other Natural
90	Irrigated perennial	Orchard / Vineyard
91	Turfgrass	Grass Seed
92	Orchard	Orchard / Vineyard
93	Christmas trees	Orchard / Vineyard
95	Conifer Woodlot	Other Forest
98	Oak savanna	Old Conifer / Other Natural
101	Wet shrub	Old Conifer / Other Natural
510	Upland Forest open (FSM)	Other Forest
520	Upland Forest Semi-closed mixed (FSM)	Other Forest
540	Forest Closed mixed (FSM)	Young Conifer
550	Upland Forest Semi-closed conifer (FSM)	Other Forest
560	Conifers 0-20 yrs (FSM)	Young Conifer
570	Forest closed conifer 21-40 yrs (FSM)	Young Conifer
580	Forest closed conifer 41-60 yrs (FSM)	Young Conifer
590	Forest closed conifer 61-80 yrs (FSM)	Other Forest
600	Forest closed conifer 81-200 yrs (FSM)	Other Forest
610	Forest closed conifer older than 200 yrs (FSM)	Old Conifer / Other Natural

Table 2

PNW-ERC LULC Cat. ID	LULC Category	*B*	Notes	Source
1	Residential 0-4 dwelling units (DU) / acre	23.20	Assumed to be equal to Urban tree overstory's *B* value	IPCC (2006)
2	Residential 4-9 DU / acre	20.88	Assumed to have 90% of Residential 0-4 dwelling units (DU) / acre's *B* value	IPCC (2006)
3	Residential 9-16 DU / acre	17.40	Assumed to have 75% of Residential 0-4 dwelling units (DU) / acre's *B* value	IPCC (2006)
4	Residential >16 DU / acre	11.60	Assumed to have 50% of Residential 0-4 dwelling units (DU) / acre's *B* value	IPCC (2006)
5	Vacant	0.00		
6	Commercial	0.00		
7	Commercial / Industrial	0.00		
8	Industrial	0.00		
9	Industrial and Commercial	0.00		
10	Residential and Commercial	0.00		
11	Urban non-vegetated unknown	0.00		
16	Rural structures	23.20	Assumed to be equal to Urban tree overstory's *B* value	IPCC (2006)
18	Railroad	0.00		
19	Primary roads	0.00		

PNW-ERC LULC Cat. ID	LULC Category	*B*	Notes	Source
20	Secondary roads	0.00		
21	Light duty roads	0.00		
24	Rural non-vegetated unknown	23.20	Assumed to be equal to Urban tree overstory's *B* value	IPCC (2006)
29	Main channel non-vegetated	0.00		
32	Stream orders 5-7	0.00		
33	Permanent lentic water	0.00		
39	Topographic Shadow	0.00		
40	Snow	0.00		
42	Barren	0.00		
49	Urban tree overstory	23.20	Assumed 2.9 metric tons of carbon are sequestered per hectare tree crown cover per year, assumed that the average tree was 40 years-old, and that 20% of an urban hectare was covered in trees.	IPCC (2006)
51	Upland Forest open (DF)	265.30	Assumed to be 80% Douglas-fir (i.e., λ_i = 0.8, see note below table) and 20% Alder-Maple at stand ages of 125. Assumed to be 40% as dense as the forests described by Smith et al. (2006)'s allometric curves (i.e., ω_i = 0.40, see note below table).	Smith et al. (2006)
510	Upland Forest open (FSM)	195.96	Assumed to be 80% Fir-spruce-mountain hemlock and 20% Alder-Maple at stand ages of 125. Assumed to be 40% as dense as the forests described by Smith et al. (2006)'s allometric curves.	Smith et al. (2006)
52	Upland Forest Semi-closed mixed (DF)	381.61	The average of 60% of Forest Closed hardwood's *B* value and 60% of a 125-year old Douglas fir forest's *B* value.	Smith et al. (2006)
520	Upland Forest Semi-closed mixed (FSM)	316.60	The average of 60% of Forest Closed hardwood's *B* value and 60% of a 125-year old Fir-spruce-mountain hemlock forest's *B* value.	Smith et al. (2006)
53	Forest Closed hardwood	577.63	Assumed to be 25% Douglas-fir and 75% Alder-Maple at stand age of 125.	Smith et al. (2006)
54	Forest Closed mixed (DF)	616.55	Assumed to be 50% Douglas-fir and 50% Alder-Maple at stand age of 125.	Smith et al. (2006)
540	Forest Closed mixed (FSM)	508.20	Assumed to be 50% Fir-spruce-mountain hemlock and 50% Alder-Maple at stand age of 125.	Smith et al. (2006)
55	Upland Forest Semi-closed conifer (DF)	412.81	Assumed to be 95.9% Douglas-fir and 4.1% Alder-Maple at stand ages of 125. Assumed to be 60% as dense as the forests described by Smith et al. (2006)'s allometric curves.	Smith et al. (2006)
550	Upland Forest Semi-closed conifer (FSM)	288.12	Assumed to be 95.9% Fir-spruce-mountain hemlock and 4.1% Alder-Maple at stand ages of 125. Assumed to be 60% as dense as the forests described	Smith et al. (2006)

PNW-ERC LULC Cat. ID	LULC Category	*B*	Notes	Source
			by Smith et al. (2006)'s allometric curves.	
56	Conifers 0-20 yrs (DF)	115.40	Assumed to be 95.9% Douglas-fir; high productivity and high management intensity and 4.1% Alder-Maple at stand age of 20.	Smith et al. (2006)
57	Forest closed conifer 21-40 yrs (DF)	309.29	Assumed to be 95.9% Douglas-fir; high productivity and high management intensity and 4.1% Alder-Maple at stand age of 40.	Smith et al. (2006)
58	Forest closed conifer 41-60 yrs (DF)	472.44	Assumed to be 95.9% Douglas-fir; high productivity and high management intensity and 4.1% Alder-Maple at stand age of 60.	Smith et al. (2006)
560	Conifers 0-20 yrs (FSM)	74.93	Assumed to be 95.9% Fir-spruce-mountain hemlock and 4.1% Alder-Maple at stand age of 20.	Smith et al. (2006)
570	Forest closed conifer 21-40 yrs (FSM)	166.78	Assumed to be 95.9% Fir-spruce-mountain hemlock and 4.1% Alder-Maple at stand age of 40.	Smith et al. (2006)
580	Forest closed conifer 41-60 yrs (FSM)	262.52	Assumed to be 95.9% Fir-spruce-mountain hemlock and 4.1% Alder-Maple at stand age of 60.	Smith et al. (2006)
59	Forest closed conifer 61-80 yrs (DF)	522.68	Assumed to be 95.9% Douglas-fir and 4.1% Alder-Maple at stand age of 80.	Smith et al. (2006)
60	Forest closed conifer 81-200 yrs (DF)	798.84	Assumed to be 95.9% Douglas-fir and 4.1% Alder-Maple at 120% of the stand age of 120.	Smith et al. (2006)
61	Forest closed conifer older than 200 yrs (DF)	909.67	Assumed to be 95.9% Douglas-fir and 4.1% Alder-Maple at 140% of the stand age of 120.	Smith et al. (2006)
590	Forest closed conifer 61-80 yrs (FSM)	344.69	Assumed to be 95.9% Fir-spruce-mountain hemlock and 4.1% Alder-Maple at stand age of 80.	Smith et al. (2006)
600	Forest closed conifer 81-200 yrs (FSM)	555.05	Assumed to be 95.9% Douglas-fir-spruce-mountain hemlock and 4.1% Alder-Maple at 120% of the stand age of 120.	Smith et al. (2006)
610	Forest closed conifer older than 200 yrs (FSM)	629.89	Assumed to be 95.9% Fir-spruce-mountain hemlock and 4.1% Alder-Maple at 140% of the stand age of 120.	Smith et al. (2006)
62	Upland Forest Semi-closed hardwood	346.58	Assumed to be 60% of Forest Closed hardwood's *B* value	Smith et al. (2006)
66	Hybrid poplar	75.05	Assumed that the hybrid poplar stand is planted at a density of 1,111 stems per hectare. Assumed that the stand had an average diameter at breast height between 19.6–24.5 inches. Assumed that the trees were 4 to 13 years-old.	Zabek and Prescott (2006)
67	Grass seed rotation	2.54		IPCC (2006)
68	Irrigated annual rotation	0.00		
71	Grains	0.00		

PNW-ERC LULC Cat. ID	**LULC Category**	***B***	**Notes**	**Source**
72	Nursery	0.00	Assumed to be greenhouse based operations.	
73	Berries and vineyards	45.99	Assumed that the *B* values for Orchard, Irrigated perennial, and Berries and vineyards are equal	IPCC (2006); Kroodsma and Field (2006)
74	Double cropping	0.00		
75	Hops	0.00		
76	Mint	0.00		
77	Radish seed	0.00		
78	Sugar beet seed	0.00		
79	Row crop	0.00		
80	Grass	2.54	In grass lands below ground biomass is the only source of biomass carbon.	IPCC (2006)
81	Burned grass	2.54	In grass lands below ground biomass is the only source of biomass carbon.	IPCC (2006)
82	Field crop	0.00		
83	Hayfield	5.08	In hayfields below ground biomass is the only source of biomass carbon. Assumed to be 50% of Natural grassland.	IPCC (2006)
84	Late field crop	0.00		
85	Pasture	5.08	In pastures below ground biomass is the only source of biomass carbon. Assumed to be greenhouse based operations.	IPCC (2006)
86	Natural grassland	10.15	In natural grasslands below ground biomass is the only source of biomass carbon. Twelve years after CRP grassland restoration in Nebraska the carbon content of the root system was 3.95 Mg C ha^{-1} in the soil's first 20 cm profile (Baer et al. 2002). Tilman et al. (2006) suggest that for the first decade after native grassland restoration, grass roots can sequester between 0.17 to 0.4636 Mg C ha^{-1} yr^{-1} or 1.70 to 4.636 in the first decade in the first 20 cm of soil. Tilman et al. (2006) also suggest that up to 1.02 Mg C ha^{-1} more can be stored in the second decade in the most diverse prairies. Further, "43% more C may be stored in roots between 30 and 100 cm." (p. 1599). All of this adds up to 8.09 Mg C ha^{-1} 20 years after restoration in the first 100 cm of soil of the most diverse prairies.	Baer et al. (2002); IPCC (2006); Tilman et al. (2006)
87	Natural shrub	239.40	Assumed that the *B* values for Natural shrub and Wet shrub are equal	IPCC (2006)
88	Bare/fallow	5.08		IPCC (2006)
89	Flooded/marsh	0.00		
90	Irrigated perennial	45.99	Assumed that the *B* values for Orchard, Irrigated perennial, and Berries and vineyards are equal	IPCC (2006); Kroodsma and Field (2006)
91	Turfgrass	0.00		

PNW-ERC LULC Cat. ID	LULC Category	*B*	Notes	Source
92	Orchard	45.99	Assumed that the *B* values for Orchard, Irrigated perennial, and Berries and vineyards are equal	IPCC (2006); Kroodsma and Field (2006)
93	Christmas trees	20.15	Assumed that 1/3 of an average Christmas tree stand has trees that are 15 years-old, 1/3 of the stand has trees that are 5 years-old, and 1/3 of the stand has trees that are 0 years-old. Used the "Douglas-fir" allometric curve.	Smith et al. (2006)
95	Conifer Woodlot	510.70	Assumed that the average age of the tree stand was 65 years. Used the "Douglas-fir; high productivity and high management intensity" allometric curve.	Smith et al. (2006)
98	Oak savanna	115.53	Assumed to be 20% of Forest Closed hardwood's *B* value	Smith et al. (2006)
101	Wet shrub	239.40	Assumed that the *B* values for Natural shrub and Wet shrub are equal	IPCC (2006)

Notes: For LULC categories *i* with tree coverage, B_i is computed using C storage values from Smith et al. (2006). Smith et al. (2006) gives C storage values as a function of stand age for four types of forests in the Pacific Northwest, West (the Willamette Basin's region): i) Douglas-fir; ii) Douglas-fir; high productivity and high management intensity; iii) Fir-spruce-mountain hemlock mix; and iv) Alder-maple (hardwood). All C storage equations in Smith et al. (2006) assume a closed forest. B_i values for managed forests come from the Douglas-fir; high productivity and high management intensity C storage lookup table. B_i for other forested LULC types is given by, $B_i = \left(\lambda_i B_{i,sw} + (1-\lambda_i) B_{i,hw}\right)\omega_i$ where λ_i is the fraction of forest on LULC *i* that is softwood, $B_{i,sw}$ is the C stored in *i*'s softwood biomass assuming a completely closed forest, $B_{i,hw}$ is the C stored in *i*'s hardwood biomass assuming a completely closed forest, and $\omega_i \in [0,1]$ indicates the degree to which the forest in LULC *i* is closed where $\omega = 1$ indicates a completely closed forest and $\omega = 0$ indicates no tree coverage at all. The softwood forest type assumed when calculating B_i is either Douglas-fir or a Fir-spruce-mountain hemlock mix and is given by LULC *i*. Alder-maple is always the hardwood type. Some λ_i and ω_i data are from Adamus et al. (2000) and Nelson et al. (2008).

Table 3

PNW-ERC LULC Cat. ID	LULC Category	*S*	Notes	Source
1	Residential 0-4 dwelling units (DU) / acre	86.51	Assumed to have grass seed farming's *S* value	IPCC (2006)
2	Residential 4-9 DU / acre	77.85	Assumed to have 90% of grass seed farming's *S* value	IPCC (2006)
3	Residential 9-16 DU / acre	64.88	Assumed to have 75% of grass seed farming's *S* value	IPCC (2006)
4	Residential >16 DU / acre	43.25	Assumed to have 50% of grass seed farming's *S* value	IPCC (2006)
5	Vacant	0.00		
6	Commercial	0.00		
7	Commercial / Industrial	0.00		
8	Industrial	0.00		

PNW-ERC LULC Cat. ID	**LULC Category**	***S***	**Notes**	**Source**
9	Industrial and Commercial	0.00		
10	Residential and Commercial	0.00		
11	Urban non-vegetated unknown	0.00		
16	Rural structures	86.51	Assumed to have grass seed farming's *S* value	IPCC (2006)
18	Railroad	0.00		
19	Primary roads	0.00		
20	Secondary roads	0.00		
21	Light duty roads	0.00		
24	Rural non-vegetated unknown	86.51	Assumed to have grass seed farming's *S* value	IPCC (2006)
29	Main channel non-vegetated	0.00		
32	Stream orders 5-7	0.00		
33	Permanent lentic water	0.00		
39	Topographic Shadow	0.00		
40	Snow	60.72	Assumed to have row crop's *S* value	IPCC (2006)
42	Barren	60.72	Assumed to have row crop's *S* value	IPCC (2006)
49	Urban tree overstory	86.51	Assumed to have grass seed farming's *S* value	IPCC (2006)
51	Upland Forest open (DF)	105.00		Smith et al. (2006)
510	Upland Forest open (FSM)	88.65		Smith et al. (2006)
52	Upland Forest Semi-closed mixed (DF)	105.00		Smith et al. (2006)
520	Upland Forest Semi-closed mixed (FSM)	88.65		Smith et al. (2006)
53	Forest Closed hardwood	115.20		Smith et al. (2006)
54	Forest Closed mixed (DF)	105.00		Smith et al. (2006)
540	Forest Closed mixed (FSM)	88.65		Smith et al. (2006)
55	Upland Forest Semi-closed conifer (DF)	94.80		Smith et al. (2006)
550	Upland Forest Semi-closed conifer (FSM)	62.10		Smith et al. (2006)
56	Conifers 0-20 yrs (DF)	94.80		Smith et al. (2006)
57	Forest closed conifer 21-40 yrs (DF)	94.80		Smith et al. (2006)
58	Forest closed conifer 41-60 yrs (DF)	94.80		Smith et al. (2006)
560	Conifers 0-20 yrs (FSM)	94.80		Smith et al. (2006)
570	Forest closed conifer	94.80		Smith et al. (2006)

PNW-ERC LULC Cat. ID	LULC Category	*S*	Notes	Source
	21-40 yrs (FSM)			
580	Forest closed conifer 41-60 yrs (FSM)	94.80		Smith et al. (2006)
59	Forest closed conifer 61-80 yrs (DF)	94.80		Smith et al. (2006)
60	Forest closed conifer 81-200 yrs (DF)	94.80		Smith et al. (2006)
61	Forest closed conifer older than 200 yrs (DF)	94.80		Smith et al. (2006)
590	Forest closed conifer 61-80 yrs (FSM)	62.10		Smith et al. (2006)
600	Forest closed conifer 81-200 yrs (FSM)	62.10		Smith et al. (2006)
610	Forest closed conifer older than 200 yrs (FSM)	62.10		Smith et al. (2006)
62	Upland Forest Semi-closed hardwood	115.20		Smith et al. (2006)
66	Hybrid poplar	95.04	Assumed to have Orchard's *S* value	IPCC (2006)
67	Grass seed rotation	86.51	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed $F_{LU} = 0.82$, $F_{MG} = 1.08$, and $F_I = 1.11$ where $S = 88 \times F_{LU} \times F_{MG} \times F_I$.	IPCC (2006)
68	Irrigated annual rotation	60.72	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed $F_{LU} = 0.69$, $F_{MG} = 1$, and $F_I = 1$ where $S = 88 \times F_{LU} \times F_{MG} \times F_I$.	IPCC (2006)
71	Grains	60.72	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed $F_{LU} = 0.69$, $F_{MG} = 1$, and $F_I = 1$ where $S = 88 \times F_{LU} \times F_{MG} \times F_I$.	IPCC (2006)
72	Nursery	0.00	Assumed to be greenhouse based operations.	
73	Berries and vineyards	95.04	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed $F_{LU} = 1$, $F_{MG} = 1.08$, and $F_I = 1$ where $S = 88 \times F_{LU} \times F_{MG} \times F_I$.	IPCC (2006)
74	Double cropping	60.72	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed $F_{LU} = 0.69$, $F_{MG} = 1$, and $F_I = 1$ where $S = 88 \times F_{LU} \times F_{MG} \times F_I$	IPCC (2006)
75	Hops	60.72	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed $F_{LU} = 0.69$, $F_{MG} = 1$, and $F_I = 1$ where $S = 88 \times F_{LU} \times F_{MG} \times F_I$.	IPCC (2006)
76	Mint	60.72	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed $F_{LU} = 0.69$, $F_{MG} = 1$, and $F_I = 1$ where $S = 88 \times F_{LU} \times F_{MG} \times F_I$	IPCC (2006)
77	Radish seed	60.72	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed $F_{LU} = 0.69$, $F_{MG} = 1$, and	IPCC (2006)

PNW-ERC LULC Cat. ID	LULC Category	*S*	Notes	Source
			F_I = 1 where *S* = 88 x F_{LU} x F_{MG} x F_I	
78	Sugar beet seed	60.72	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed F_{LU} = 0.69, F_{MG} = 1, and F_I = 1 where *S* = 88 x F_{LU} x F_{MG} x F_I	IPCC (2006)
79	Row crop	60.72	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed F_{LU} = 0.69, F_{MG} = 1, and F_I = 1 where *S* = 88 x F_{LU} x F_{MG} x F_I	IPCC (2006)
80	Grass	86.51	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed F_{LU} = 0.82, F_{MG} = 1.08, and F_I = 1.11 where *S* = 88 x F_{LU} x F_{MG} x F_I.	IPCC (2006)
81	Burned grass	86.51	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed F_{LU} = 0.82, F_{MG} = 1.08, and F_I = 1.11 where *S* = 88 x F_{LU} x F_{MG} x F_I	IPCC (2006)
82	Field crop	60.72	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed F_{LU} = 0.69, F_{MG} = 1, and F_I = 1 where *S* = 88 x F_{LU} x F_{MG} x F_I	IPCC (2006)
83	Hayfield	100.32	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed F_{LU} = 1, F_{MG} = 1.14, and F_I = 1 where *S* = 88 x F_{LU} x F_{MG} x F_I.	IPCC (2006)
84	Late field crop	60.72	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed F_{LU} = 0.69, F_{MG} = 1, and F_I = 1 where *S* = 88 x F_{LU} x F_{MG} x F_I	IPCC (2006)
85	Pasture	100.32	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed F_{LU} = 1, F_{MG} = 1.14, and F_I = 1 where *S* = 88 x F_{LU} x F_{MG} x F_I.	IPCC (2006)
86	Natural grassland	120.38	Assumed to have 120% of pasture's *S* value. This value is corroborated by McLauchlan et al. (2006). "This study shows that soil C accumulates linearly for at least the first 40 years after conversion from agricultural land to grassland [at a rate of 62.0 grams per meter squared per year in the top 10 cm of soil]…The results of this study suggest that the capacity of these former agricultural lands…to store additional soil C will persist for a maximum of 55–75 years after cessation of agriculture (p. 151, McLauchlan et al. 2006). Further, carbon "in soils from 10 to 20 cm depth showed a similar pattern to the soils at 0–10 cm depth, accumulating at the rate of 46.7 grams per meter squared per year." (p. 147). After 50 years of linear sequestration at these rates natural grassland sequesters an additional 54.35 metric tons per hectare of carbon on cropland converted to grassland. Given that cropland has 60.72 tons of carbon per hectare, natural grassland can store up to approximately 120 metric tons of carbon at	IPCC (2006); McLauchlan et al. (2006)

PNW-ERC LULC Cat. ID	LULC Category	*S*	Notes	Source
			its attainable maximum.	
87	Natural shrub	100.32	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed $F_{LU} = 1$, $F_{MG} = 1.14$, and $F_I = 1$ where $S = 88 \times F_{LU} \times F_{MG} \times F_I$.	IPCC (2006)
88	Bare/fallow	100.32	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed $F_{LU} = 1$, $F_{MG} = 1.14$, and $F_I = 1$ where $S = 88 \times F_{LU} \times F_{MG} \times F_I$.	IPCC (2006)
89	Flooded/marsh	149.19		Gorham 1991, 1995; Kasimir-Klemedtsson et al. 1997
90	Irrigated perennial	95.04	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed $F_{LU} = 1$, $F_{MG} = 1.08$, and $F_I = 1$ where $S = 88 \times F_{LU} \times F_{MG} \times F_I$.	IPCC (2006)
91	Turfgrass	86.51	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed $F_{LU} = 0.82$, $F_{MG} = 1.08$, and $F_I = 1.11$ where $S = 88 \times F_{LU} \times F_{MG} \times F_I$	IPCC (2006)
92	Orchard	95.04	Assumed the default carbon content of soil was 88 metric tons / hectare (high activity clay soils). For row crops assumed $F_{LU} = 1$, $F_{MG} = 1.08$, and $F_I = 1$ where $S = 88 \times F_{LU} \times F_{MG} \times F_I$.	IPCC (2006)
93	Christmas trees	94.80		Smith et al. (2006)
95	Conifer Woodlot	94.80		Smith et al. (2006)
98	Oak savanna	115.20		Smith et al. (2006)
101	Wet shrub	100.32		IPCC (2006)

Table 4

PNW-ERC LULC Cat. ID	α_i^1	α_i^2	α_i^3	α_i^4	α_i^5	α_i^6	α_i^7	α_i^8	α_i^9	α_i^{10}	α_i^{11}	α_i^{12}	α_i^{13}
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
4	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
6	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
7	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
8	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
11	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
16	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
18	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

PNW-ERC LULC Cat. ID	α_i^1	α_i^2	α_i^3	α_i^4	α_i^5	α_i^6	α_i^7	α_i^8	α_i^9	α_i^{10}	α_i^{11}	α_i^{12}	α_i^{13}
19	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
21	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
24	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
29	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
32	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
33	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
39	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
40	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
42	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
49	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
51	0.040	0.120	0.200	0.280	0.360	0.440	0.520	0.600	0.680	0.760	0.840	0.920	1.000
52	0.040	0.120	0.200	0.280	0.360	0.440	0.520	0.600	0.680	0.760	0.840	0.920	1.000
53	0.040	0.120	0.200	0.280	0.360	0.440	0.520	0.600	0.680	0.760	0.840	0.920	1.000
54	0.040	0.120	0.200	0.280	0.360	0.440	0.520	0.600	0.680	0.760	0.840	0.920	1.000
55	0.040	0.120	0.200	0.280	0.360	0.440	0.520	0.600	0.680	0.760	0.840	0.920	1.000
56	0.250	0.750	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
57	0.250	0.750	1.000	0.700	0.800	0.900	1.000	1.000	1.000	1.000	1.000	1.000	1.000
58	0.625	0.800	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
59	0.950	0.975	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
60	0.700	0.725	0.750	0.800	0.825	0.850	0.875	0.900	0.925	0.950	0.975	1.000	1.000
61	0.900	0.920	0.925	0.950	0.975	0.990	1.000	1.000	1.000	1.000	1.000	1.000	1.000
62	0.040	0.120	0.200	0.280	0.360	0.440	0.520	0.600	0.680	0.760	0.840	0.920	1.000
66	0.500	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
67	0.700	0.750	0.800	0.850	0.900	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000
68	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
71	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
72	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
73	0.700	0.750	0.800	0.850	0.900	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000
74	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
75	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
76	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
77	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
78	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
79	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
80	0.700	0.750	0.800	0.850	0.900	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000

PNW-ERC LULC Cat. ID	α_i^1	α_i^2	α_i^3	α_i^4	α_i^5	α_i^6	α_i^7	α_i^8	α_i^9	α_i^{10}	α_i^{11}	α_i^{12}	α_i^{13}
81	0.700	0.750	0.800	0.850	0.900	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000
82	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
83	0.700	0.750	0.800	0.850	0.900	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000
84	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
85	0.700	0.750	0.800	0.850	0.900	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000
86	0.700	0.750	0.800	0.850	0.900	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000
87	0.040	0.120	0.200	0.280	0.360	0.440	0.520	0.600	0.680	0.760	0.840	0.920	1.000
88	0.700	0.750	0.800	0.850	0.900	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000
89	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
90	0.700	0.750	0.800	0.850	0.900	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000
91	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
92	0.700	0.750	0.800	0.850	0.900	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000
93	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
95	0.083	0.250	0.417	0.583	0.750	0.917	1.000	1.000	1.000	1.000	1.000	1.000	1.000
98	0.040	0.120	0.200	0.280	0.360	0.440	0.520	0.600	0.680	0.760	0.840	0.920	1.000
101	0.040	0.120	0.200	0.280	0.360	0.440	0.520	0.600	0.680	0.760	0.840	0.920	1.000
510	0.040	0.120	0.200	0.280	0.360	0.440	0.520	0.600	0.680	0.760	0.840	0.920	1.000
520	0.040	0.120	0.200	0.280	0.360	0.440	0.520	0.600	0.680	0.760	0.840	0.920	1.000
540	0.040	0.120	0.200	0.280	0.360	0.440	0.520	0.600	0.680	0.760	0.840	0.920	1.000
550	0.040	0.120	0.200	0.280	0.360	0.440	0.520	0.600	0.680	0.760	0.840	0.920	1.000
560	0.250	0.750	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
570	0.375	0.750	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
580	0.625	0.800	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
590	0.800	0.900	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
600	0.650	0.700	0.750	0.800	0.825	0.850	0.875	0.900	0.925	0.950	0.975	1.000	1.000
610	0.900	0.925	0.950	0.975	0.990	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Notes: $\alpha_i^{14}, \alpha_i^{15}, \ldots = 1.000$ for all *i*. α_i^1 values assume that *i* was established 5 years ago (or tree growth after a clear-cut), α_i^2 values assume that *i* was established 15 years ago, α_i^3 values assume that *i* was established 25 years ago, etc. All α_i values for *i* = 1-49, 89 are all set equal to 1 due to a lack of data. α_i values for *i* = 51-62, 93, 95, 98, 510, 520, 530, 540, 550, 560, 570, 580, 590, 600, 610 are based on allometric curves found in Smith et al (2005). α_i values for *i* = 66 is based on Zabek and Prescott (2006). α_i values for *i* = 87, 101 are assumed to be he same as *i* = 98's. The agricultural LULCs *i* = 67, 73, 80, 81, 83, 85, 88, 90, and 92 are assumed to take up to 60 years to reach their biomass C storage capacity Natural grasslands (*i* = 85) are assumed to have α_i values similar to pasture and grass seed.

Table 5

PNW-ERC LULC Cat. ID	γ_i^1	γ_i^2	γ_i^3	γ_i^4	γ_i^5	γ_i^6

PNW-ERC LULC Cat. ID	γ_i^1	γ_i^2	γ_i^3	γ_i^4	γ_i^5	γ_i^6
1	1.000	1.000	1.000	1.000	1.000	1.000
2	1.000	1.000	1.000	1.000	1.000	1.000
3	1.000	1.000	1.000	1.000	1.000	1.000
4	1.000	1.000	1.000	1.000	1.000	1.000
6	1.000	1.000	1.000	1.000	1.000	1.000
7	1.000	1.000	1.000	1.000	1.000	1.000
8	1.000	1.000	1.000	1.000	1.000	1.000
10	1.000	1.000	1.000	1.000	1.000	1.000
11	1.000	1.000	1.000	1.000	1.000	1.000
16	1.000	1.000	1.000	1.000	1.000	1.000
18	1.000	1.000	1.000	1.000	1.000	1.000
19	1.000	1.000	1.000	1.000	1.000	1.000
20	1.000	1.000	1.000	1.000	1.000	1.000
21	1.000	1.000	1.000	1.000	1.000	1.000
24	1.000	1.000	1.000	1.000	1.000	1.000
29	1.000	1.000	1.000	1.000	1.000	1.000
32	1.000	1.000	1.000	1.000	1.000	1.000
33	1.000	1.000	1.000	1.000	1.000	1.000
39	1.000	1.000	1.000	1.000	1.000	1.000
40	1.000	1.000	1.000	1.000	1.000	1.000
42	1.000	1.000	1.000	1.000	1.000	1.000
49	1.000	1.000	1.000	1.000	1.000	1.000
51	0.900	0.920	0.940	0.960	0.980	1.000
52	0.900	0.920	0.940	0.960	0.980	1.000
53	0.850	0.880	0.910	0.940	0.970	1.000
54	0.900	0.920	0.940	0.960	0.980	1.000
55	1.000	1.000	1.000	1.000	1.000	1.000
56	1.000	1.000	1.000	1.000	1.000	1.000
57	1.000	1.000	1.000	1.000	1.000	1.000
58	1.000	1.000	1.000	1.000	1.000	1.000
59	1.000	1.000	1.000	1.000	1.000	1.000
60	1.000	1.000	1.000	1.000	1.000	1.000
61	1.000	1.000	1.000	1.000	1.000	1.000
62	0.850	0.880	0.910	0.940	0.970	1.000
66	1.000	1.000	1.000	1.000	1.000	1.000
67	1.000	1.000	1.000	1.000	1.000	1.000
68	1.000	1.000	1.000	1.000	1.000	1.000
71	1.000	1.000	1.000	1.000	1.000	1.000

PNW-ERC LULC Cat. ID	γ_i^1	γ_i^2	γ_i^3	γ_i^4	γ_i^5	γ_i^6
72	1.000	1.000	1.000	1.000	1.000	1.000
73	1.000	1.000	1.000	1.000	1.000	1.000
74	1.000	1.000	1.000	1.000	1.000	1.000
75	1.000	1.000	1.000	1.000	1.000	1.000
76	1.000	1.000	1.000	1.000	1.000	1.000
77	1.000	1.000	1.000	1.000	1.000	1.000
78	1.000	1.000	1.000	1.000	1.000	1.000
79	1.000	1.000	1.000	1.000	1.000	1.000
80	1.000	1.000	1.000	1.000	1.000	1.000
81	1.000	1.000	1.000	1.000	1.000	1.000
82	1.000	1.000	1.000	1.000	1.000	1.000
83	0.950	0.960	0.970	0.980	0.990	1.000
84	1.000	1.000	1.000	1.000	1.000	1.000
85	0.950	0.960	0.970	0.980	0.990	1.000
86	0.850	0.880	0.910	0.940	0.970	1.000
87	0.950	0.960	0.970	0.980	0.990	1.000
88	0.950	0.960	0.970	0.980	0.990	1.000
89	0.750	0.800	0.850	0.900	0.950	1.000
90	1.000	1.000	1.000	1.000	1.000	1.000
91	1.000	1.000	1.000	1.000	1.000	1.000
92	1.000	1.000	1.000	1.000	1.000	1.000
93	1.000	1.000	1.000	1.000	1.000	1.000
95	1.000	1.000	1.000	1.000	1.000	1.000
98	0.850	0.880	0.910	0.940	0.970	1.000
101	0.950	0.960	0.970	0.980	0.990	1.000
510	1.000	1.000	1.000	1.000	1.000	1.000
520	1.000	1.000	1.000	1.000	1.000	1.000
540	1.000	1.000	1.000	1.000	1.000	1.000
550	1.000	1.000	1.000	1.000	1.000	1.000
560	1.000	1.000	1.000	1.000	1.000	1.000
570	1.000	1.000	1.000	1.000	1.000	1.000
580	1.000	1.000	1.000	1.000	1.000	1.000
590	1.000	1.000	1.000	1.000	1.000	1.000
600	1.000	1.000	1.000	1.000	1.000	1.000
610	1.000	1.000	1.000	1.000	1.000	1.000

$\gamma_i^7, \gamma_i^8, \ldots = 1.000$ for all *i*. γ_i^1 values assume that *i* was established 5 years ago (or after a clear-cut), γ_i^2 values assume that *i* was established 15 years ago, γ_i^3 values assume that *i* was established 25 years ago, etc. All γ_i values for *i* = 1-49, 66-82, 84, 90-92 are all set equal to 1 due to a lack of data. γ_i values for *i* = 51-62, 93, 95, 98, 510, 520, 530, 540, 550, 560, 570, 580, 590, 600, 610 are based on allometric curves found in Smith et al (2005). The LULCs i = 83, 85-89, and 101 are assumed to take up to 50 years to reach their soil carbon storage capacity.

Table 6

j	d_j	j	d_j	j	d_j	j	d_j	j	d_j
1	0.224321	21	0.120685	41	0.086376	61	0.066466	81	0.053207
2	0.224321	22	0.120685	42	0.086376	62	0.066466	82	0.053207
3	0.224321	23	0.120685	43	0.086376	63	0.066466	83	0.053207
4	0.224321	24	0.120685	44	0.086376	64	0.066466	84	0.053207
5	0.224321	25	0.120685	45	0.086376	65	0.066466	85	0.053207
6	0.180510	26	0.109800	46	0.080434	66	0.062623	86	0.050417
7	0.180510	27	0.109800	47	0.080434	67	0.062623	87	0.050417
8	0.180510	28	0.109800	48	0.080434	68	0.062623	88	0.050417
9	0.180510	29	0.109800	49	0.080434	69	0.062623	89	0.050417
10	0.180510	30	0.109800	50	0.080434	70	0.062623	90	0.050417
11	0.152490	31	0.100706	51	0.075191	71	0.059133	91	0.047980
12	0.152490	32	0.100706	52	0.075191	72	0.059133	92	0.047980
13	0.152490	33	0.100706	53	0.075191	73	0.059133	93	0.047980
14	0.152490	34	0.100706	54	0.075191	74	0.059133	94	0.047980
15	0.152490	35	0.100706	55	0.075191	75	0.059133	95	0.047980
16	0.134186	36	0.093018	56	0.070656	76	0.055997	96	0.045536
17	0.134186	37	0.093018	57	0.070656	77	0.055997	97	0.045536
18	0.134186	38	0.093018	58	0.070656	78	0.055997	98	0.045536
19	0.134186	39	0.093018	59	0.070656	79	0.055997	99	0.045536
20	0.134186	40	0.093018	60	0.070656	80	0.055997	100	0.000000

Table 7

Common Name	**Scientific Name**	**Species ID**
American Bittern	*Botaurus lentiginosus*	20
Canada Goose	*Branta canadensis*	24
Green-Winged Teal	*Anas crecca*	26
Cinnamon Teal	*Anas cyanoptera*	30
Ruddy Duck	*Oxyura jamaicensis*	38
Osprey	*Pandion haliaetus*	40
White-tailed Kite	*Elanus leucurus*	41
Bald Eagle	*Haliaeetus leucocephalus*	42
Northern Harrier	*Circus cyaneus*	43
Northern Goshawk	*Accipiter gentilis*	46
Red-Shouldered Hawk	*Buteo lineatus*	47
Marbled Murrelet	*Brachyramphus marmoratus*	63
Spotted Owl	*Strix occidentalis*	70

Common Name	**Scientific Name**	**Species ID**
Short-eared Owl	*Asio flammeus*	74
Belted Kingfisher	*Ceryle alcyon*	81
Acorn Woodpecker	*Melanerpes formicivorus*	83
Grasshopper Sparrow	*Ammodramus savannarum*	156
Western Meadowlark	*Sturnella neglecta*	163
Common muskrat	*Ondatra zibethicus*	229
Fisher	*Martes pennanti*	238
Wolverine	*Gulo gulo*	242
White-tailed deer	*Odocoileus virginianus*	251
Painted turtle	*Chrysemys picta*	252
Western pond turtle	*Clemmys marmorata*	253

Table 8

LULC Category	Species ID																							
	20	24	26	30	38	40	41	42	43	46	47	63	70	74	81	83	156	163	229	238	242	251	252	253
Residential 0-4 DU/ac	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Residential 4-9 DU/ac	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Residential 9-16 DU/ac	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Residential >16 DU/ac	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vacant	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Commercial	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Comm/Industrial	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industrial	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industrial & Comm.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Residential & Comm.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urban non-vegetated unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rural structures	0	0.5	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	1	0	0
Railroad	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Primary roads	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Secondary roads	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Light duty roads	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rural non-vegetated unknown	0	0.5	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	1	0	0
Main channel non-vegetated	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stream orders 5-7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Permanent lentic water	1	1	1	1	1	0.5	1	0.5	1	0	1	0	0	1	1	0	0	0.5	1	0	0	1	1	1
Topographic Shadow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Snow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barren	0	0	0	0	0.5	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Urban tree overstory	0	0	0	0	0	0	0	0.5	0	0	0.5	0	0	0	0	0	0	0	0	0.5	0.5	1	0	0
Upland Forest open (DF)	0.2	0.3	0.2	0.2	0.3	0.1	0.4	0.2	0.5	0	0.3	0	0	0.4	0.2	0	0.2	0.3	0.2	0.3	0.1	0.9	0.3	0.3
Upland Forest Semi-closed mixed (DF)	0	0	0	0	0	0	0	0.25	0.25	0	0.25	0	0	0	0	0	0	0	0	0.75	0.25	0.75	0	0
Forest Closed hardwood	0	0	0	0	0	0	0.5	0.5	0	0	0.5	0	0	0	0	1	0	0	0	0.5	0	1	0	0

LULC Category	Species ID																							
	20	**24**	**26**	**30**	**38**	**40**	**41**	**42**	**43**	**46**	**47**	**63**	**70**	**74**	**81**	**83**	**156**	**163**	**229**	**238**	**242**	**251**	**252**	**253**
Forest Closed mixed (DF)	0	0	0	0	0	0	0	0.25	0.25	0	0.25	0	0	0	0	0	0	0	0	0.75	0.25	0.75	0	0
Upland Forest Semi-closed conifer (DF)	0	0	0	0	0	0.25	0	0.5	0.25	0.5	0	0.5	0.5	0	0	0	0	0	0	1	0.25	0.5	0	0
Conifers 0-20 yrs (DF)	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	1	0	0.5	0	0
Forest closed conifer 21-40 yrs (DF)	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	1	0	0.5	0	0
Forest closed conifer 41-60 yrs (DF)	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	1	0	0.5	0	0
Forest closed conifer 61-80 yrs (DF)	0	0	0	0	0	0.25	0	0.5	0.25	0.5	0	0.5	0.5	0	0	0	0	0	0	1	0.25	0.5	0	0
Forest closed conifer 81-200 yrs (DF)	0	0	0	0	0	0.25	0	0.5	0.25	0.5	0	0.5	0.5	0	0	0	0	0	0	1	0.25	0.5	0	0
Forest closed conifer older than 200 yrs (DF)	0	0	0	0	0	0.5	0	1	0	1	0	1	1	0	0	0	0	0	0	1	0.5	0.5	0	0
Upland Forest Semi-closed hardwood	0	0	0	0	0	0	0.5	0.5	0	0	0.5	0	0	0	0	1	0	0	0	0.5	0	1	0	0
Hybrid poplar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0.5	0	0
Grass seed rotation	0	0.5	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0.5	0	0	0	1	0	0
Irrigated annual rotation	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Grains	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Nursery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0.5	0	0
Berries & Vineyards	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0.5	0	0
Double cropping	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Hops	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Mint	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Radish seed	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Sugar beet seed	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Row crop	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Grass	0	0.5	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0.5	0	0	0	1	0	0
Burned grass	0	0.5	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0.5	0	0	0	1	0	0
Field crop	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Hayfield	0	0.5	0	0	0	0	1	0	0.5	0	0	0	0	0.5	0	0	0.5	0.5	0	0	0	1	0	0
Late field crop	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Pasture	0	0.5	0	0	0	0	1	0	0.5	0	0	0	0	0.5	0	0	0.5	0.5	0	0	0	1	0	0
Natural grassland	0	0.5	0	0	0	0	0.5	0	1	0	0	0	0	1	0	0	1	1	0	0	0	1	0.5	0.5

LULC Category	Species ID																							
	20	**24**	**26**	**30**	**38**	**40**	**41**	**42**	**43**	**46**	**47**	**63**	**70**	**74**	**81**	**83**	**156**	**163**	**229**	**238**	**242**	**251**	**252**	**253**
Natural shrub	0	0	0	0	0.125	0.25	0.375	0.375	0	0	0.5	0	0	0	0.125	0.25	0	0	0	0.25	0.125	1	0.125	0.125
Bare/fallow	0	0	0	0	0.5	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Flooded/marsh	1	1	1	1	1	0.5	1	0.5	1	0	1	0	0	1	1	0	0	0.5	1	0	0	1	1	1
Irrigated perennial	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0.5	0	0
Turfgrass	0	0.5	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0.5	0	0	0	1	0	0
Orchard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0.5	0	0
Christmas trees	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0.5	0	0
Conifer Woodlot	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	1	0	0.5	0	0
Oak savanna	0	0.5	0	0	0	0	1	0	0.5	0	0.5	0	0	0	0	0.5	0.5	1	0	0	0	1	0.5	0.5
Wet shrub	0	0	0	0	0.25	0.5	0.5	0.25	0	0	0.5	0	0	0	0.25	0	0	0	0	0	0	1	0.25	0.25
Unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Upland Forest open (FSM)	0.2	0.3	0.2	0.2	0.3	0.1	0.4	0.2	0.5	0	0.3	0	0	0.4	0.2	0	0.2	0.3	0.2	0.3	0.1	0.9	0.3	0.3
Upland Forest Semi-closed mixed (FSM)	0	0	0	0	0	0	0	0.25	0.25	0	0.25	0	0	0	0	0	0	0	0	0.75	0.25	0.75	0	0
Forest Closed mixed (FSM)	0	0	0	0	0	0	0	0.25	0.25	0	0.25	0	0	0	0	0	0	0	0	0.75	0.25	0.75	0	0
Upland Forest Semi-closed conifer (FSM)	0	0	0	0	0	0.25	0	0.5	0.25	0.5	0	0.5	0.5	0	0	0	0	0	0	1	0.25	0.5	0	0
Conifers 0-20 yrs (FSM)	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	1	0	0.5	0	0
Forest closed conifer 21-40 yrs (FSM)	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	1	0	0.5	0	0
Forest closed conifer 41-60 yrs (FSM)	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	1	0	0.5	0	0
Forest closed conifer 61-80 yrs (FSM)	0	0	0	0	0	0.25	0	0.5	0.25	0.5	0	0.5	0.5	0	0	0	0	0	0	1	0.25	0.5	0	0
Forest closed conifer 81-200 yrs (FSM)	0	0	0	0	0	0.25	0	0.5	0.25	0.5	0	0.5	0.5	0	0	0	0	0	0	1	0.25	0.5	0	0
Forest closed conifer older than 200 yrs (FSM)	0	0	0	0	0	0.5	0	1	0	1	0	1	1	0	0	0	0	0	0	1	0.5	0.5	0	0

Table 9

Commodity Land-Use Category in Hexagon	**LULC Categories in Hexagon**
Orchard/vineyard agriculture	Nursery; Berries & Vineyards; Irrigated perennial; Orchard; Christmas trees.
Grass seed agriculture	Grass seed rotation; Radish seed; Sugar beet seed; Grass; Burned grass; Turfgrass.
Pasture	Hayfield; Pasture.
Row crop agriculture	Irrigated annual rotation; Grains; Double cropping; Hops; Mint; Row crop; Field crop; Late field crop; Bare/fallow.
Managed forestry	Forest Closed mixed (Douglas fir); Conifers 0-20 yrs (Douglas fir); Forest closed conifer 21-40 yrs (Douglas fir); Forest closed conifer 41-60 yrs (Douglas fir); Forest Closed mixed (Douglas fir-spruce-mountain hemlock mix); Conifers 0-20 yrs (Douglas fir-spruce-mountain hemlock mix); Forest closed conifer 21-40 yrs (Douglas fir-spruce-mountain hemlock mix); Forest closed conifer 41-60 yrs (Douglas fir-spruce-mountain hemlock mix);
Managed forestry*	50% of land in Forest closed conifer 61-80 yrs (Douglas fir); Forest closed conifer 81-200 yrs (Douglas fir); Forest closed conifer 61-80 yrs (Douglas fir-spruce-mountain hemlock mix); Forest closed conifer 81-200 yrs (Douglas fir-spruce-mountain hemlock)
Managed forestry*	10% of land in Upland Forest open (Douglas fir); Upland Forest Semi-closed mixed (Douglas fir); Forest Closed hardwood; Upland Forest Semi-closed conifer (Douglas fir); Upland Forest Semi-closed hardwood; Hybrid poplar; Conifer Woodlot; Upland Forest open (Douglas fir-spruce-mountain hemlock mix); Upland Forest Semi-closed mixed (Douglas fir-spruce-mountain hemlock mix); Upland Forest Semi-closed conifer (Douglas fir-spruce-mountain hemlock mix)
Rural-residential land use	Residential 0-4 DU/ac
Other conifer forest	50% of land in Forest closed conifer 61-80 yrs (Douglas fir); Forest closed conifer 81-200 yrs (Douglas fir); Forest closed conifer 61-80 yrs (Douglas fir-spruce-mountain hemlock mix); Forest closed conifer 81-200 yrs (Douglas fir-spruce-mountain hemlock mix)
Other forest	90% of land in Upland Forest open (Douglas fir); Upland Forest Semi-closed mixed (Douglas fir); Forest Closed hardwood; Upland Forest Semi-closed conifer (Douglas fir); Upland Forest Semi-closed hardwood; Hybrid poplar; Conifer Woodlot; Upland Forest open (Douglas fir-spruce-mountain hemlock mix); Upland Forest Semi-closed mixed (Douglas fir-spruce-mountain hemlock mix); Upland Forest Semi-closed conifer (Douglas fir-spruce-mountain hemlock mix)

Commodity Land-Use Category in Hexagon	LULC Categories in Hexagon
Conserved land use	Forest closed conifer older than 200 yrs (Douglas fir); Natural grassland; Natural shrub; Flooded/marsh; Forest closed conifer older than 200 yrs (Douglas fir-spruce-mountain hemlock mix); Oak savanna; Wet shrub
High-density land use	Residential 4-9 DU/ac ; Residential 9-16 DU/ac; Residential >16 DU/ac; Commercial; Comm/Industrial; Industrial; Residential & Comm.; Urban non-vegetated unknown; Rural structures; Railroad; Primary roads; Secondary roads; Light duty roads; Rural non-vegetated unknown; Urban tree overstory
Water or barren	Main channel non-vegetated; Stream orders 5-7; Permanent lentic water; Topographic Shadow; Snow; Barren

Notes: * These LULC categories are not considered managed forestry categories in the carbon sequestration model. Nonetheless, we use managed forestry market values to assign values to these lands even if we assume that they are not in an actively managed rotation. Unless these areas are conserved, which some of them undoubtedly are, their market value is best approximated by determining the net value of timber on their land (value of timber less the costs of managing and harvesting it).. We account for the conserved land possibilities with these PNW-ERC LULC categories by only valuing a fraction of these lands.