Woody biomass availability calculations for the Methow Valley, Washington - a second approximation

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This document extends a separate biomass availability report by the same authors under a contract by Okanogan PUD No. 1.

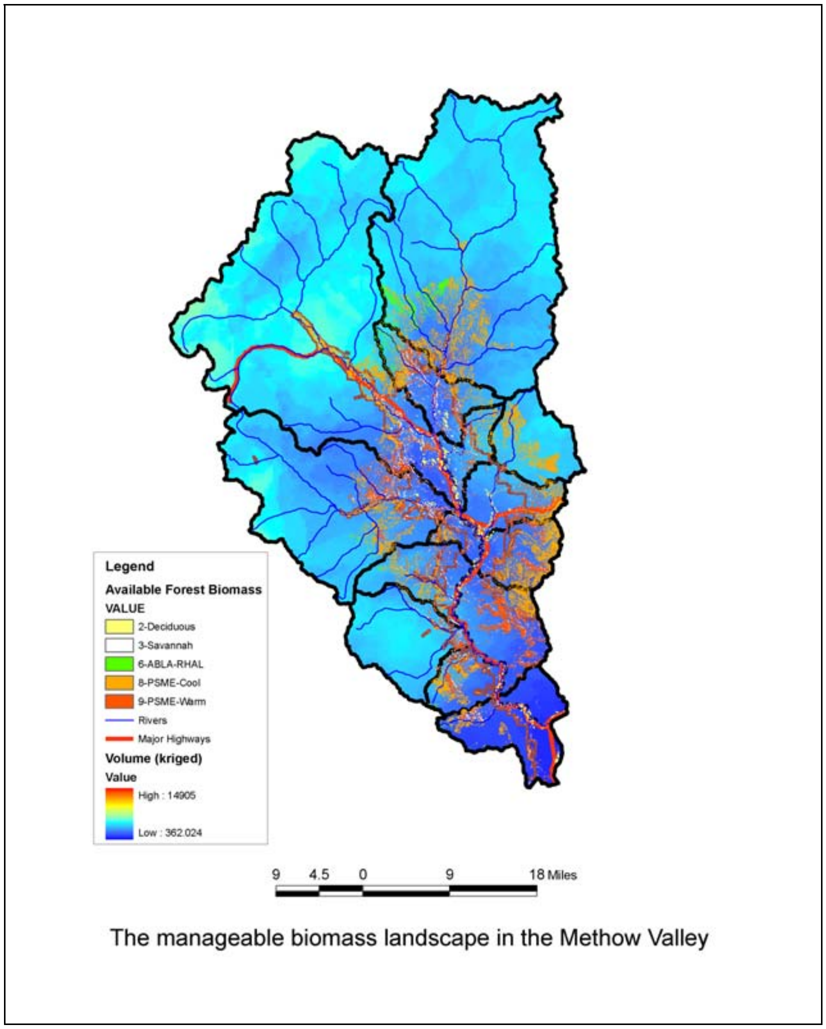

Figure 1. A map of biomass available on the most manageable landscape in the Methow Valley, Washington. Although this map was made before the Tripod fire of 2006 that burned in the northeast part, it would still be the same today since the calculations are based on steady state biomass productivity of the plant associations. The background color is based the maps of Campbell and others (2006), assessment of standing volume. The Methow Valley has a one of the lowest densities of biomass relative to other forested areas in the state, but it still suffers from forest health problems from overstocking by low value trees.

Abstract

Biomass availability was determined in the Methow Valley, Washington using mapped plant associations in conjunction with annual forest yield tables. The land base within this watershed of 1.358 million acres was limited to manageable forest stands by excluding roadless areas, steep slopes, riparian areas, Wilderness and critical wildlife habitat. The available yield of biomass tree stems was determined to be 63,080 bone dry tons/year, of which 66% is on federal lands. Two removal scenarios were developed to determine the rate of biomass removal that could be sustained over a long-term growth cycle of 100 years.

The use of steady-state calculations of biomass productivity is an effective way to help plan to balance forest additions and removals. The input data is readily available and applicable over large areas. The method is unaffected by short-term changes in volume such as that caused by wildfires. Once the annual input to the system is known, the problem is reduced to one of balancing the outputs. Given that there are only five basic methods of removing biomass -- logging, wildfire, controlled fire, microbial decomposition, and to a limited extent, altered sequestration -- this method could facilitate a better understanding of carbon cycling in climate change research.

Background

The study area is the Methow Valley Basin of North Central Washington, a watershed covering approximately 1.358 million acres. Habitats within the watershed span elevations from less than 1,000 feet to over 9,000 feet. The watershed has both unroaded lands and lands that have been roaded and managed for timber production since the early 1900s. Managed forests are primarily lower elevation dry forests dominated by Douglas fir and ponderosa pine while higher elevations support lodgepole pine, Engelmann spruce and subalpine fir.

Available biomass calculations are often based on standing volume (Campbell and others 2006), which are complicated by a discontinuous past logging history, fires and fire suppression. This study uses annual tree volume productivity to determine the biomass availability by plant association. A geographic information system (GIS) was used to identify a manageable land base by eliminating sensitive areas, roadless areas and reserved lands. The annual biomass productivity of this manageable landscape was calculated and used to develop a removal scenario that balances growth and removals over time, while still leaving a reasonable amount of wood on site for habitat needs.

Methods

To develop the annual yield of forest biomass in the Methow Valley, Washington, GIS maps of forest cover types were linked to tables of net annual volume growth.

Biomass tree stem productivity was determined from forest yield tables for Okanogan National Forest plant association groups (PAGs). The growth rates are shown in Table 1.

Table 1. Productivity variables by plant association group (PAG) in cubic ft / ac / yr, with source data referenced.

PAG Zone (NLCD Zone)	Symbol	Productivity (cu ft / ac / yr)	Reference
Silver fir (NLCD= Evergreen)	5 ABAM-TSME	81	Williams and Smith, 1990, average of 3 species in the ABAM/RHAL association: Pacific silver fir 82 cfay, Engelman spruce 123 cfay, and mountain hemlock 39 cfay.
Spruce-fir (west of Chewuch River) (NLCD= Evergreen)	6 ABLA-RHAL	50	Williams and Lillybridge (1983).
Spruce-fir (east and north of Chewuch River) (NLCD= Evergreen)	7 ABLA-VASC	27	Williams and Lillybridge (1983).
Mixed conifer Cool-moist (NLCD= Evergreen)	8 PSME-Cool	35	Williams and Lillybridge (1983); for the PSME/CARU PAG.
Mixed conifer Warm (NLCD=Evergreen)	9 PSME-Warm	46	Bonnor in Baumgartner and Lotan (1991, p. 272); average of all treated plots for XH stands (dry forests; precipitation 16 inches/year 3.2 cu m / ha = 45.7 cu ft /yr.
Open dry conifer (NLCD= Open conifer)	3 Conifer-steppe	12	Williams and Lillybridge (1983); for the PIPO-PSME/AGIN PAG.
Alpine meadow, ABLA-PHEM; PIAL (NLCD= Evergreen)	10 Parkland	5	Williams and Lillybridge (1983); determined as the average of LALY, PIAL, and ABLA/PHEM PAGs.
(NLCD= Deciduous)	2 Deciduous	51	See p. 166, table 8, site 1, Jones et al. (undated).

The spatial analysis of wood productivity was performed in ArcGIS. A watershed boundary layer was developed from the Watershed Administrative Unit (WAU) coverage for Washington State, developed by the Department of Ecology and maintained by Washington State Department of Natural Resources (DNR). Table 2 shows the area of WAUs within the Methow Watershed, WRIA 48, to have an area of 1,358,136 ac.

Table 2. The area of WAUs within the Methow Watershed, WRIA 48.

Wauname	**Wau_**	**Acres**
ALDER CREEK	218	10,270
ALTA LAKE	317	36,882
BEAR CREEK	174	20,060
BENSON CREEK	223	30,335
FRAZER CREEK	196	34,492
FRENCH CREEK	255	47,188
LIBBY CREEK	237	35,497
LIGHTNING CREEK	162	40,237
MAZAMA	50	333,684
MCFARLAND SQUAW CREEKS	290	24,870
METHOW GOLD CREEK	268	58,342
TWISP	179	157,342
WATSON DRAW	299	15,257
WILDERNESS	27	177,091
WILDERNESS	28	297,724
WINTHROP	136	38,865
TOTAL		**1,358,136**

A map layer of forest cover was developed as a grid layer, *nlcd*, using the National Land Cover Dataset (NLCD) in grid format with a 30 m cell size (Vogelmann and others 2001). This layer was used to calculate the initial amount of closed forest within the Methow watershed, using the summed acreage of all cells of type 33-Transitional, 41-Deciduous Forest, 42-Evergreen Forest, 43-Mixed Forest, and 61-Orchards (which includes misclassified cottonwoods and aspens). The amount of open forest could not be determined separately from closed forest using this layer, but at least some of the open forests would be included within the category of 51-Shrubland, which totaled 142,856 ac, or about 10% of the study area.

The forest cover GIS layer was reclassified from the NLCD grid file as grid *nlcd2*, with the following values: 1=Evergreen forest (values 33, 42, 43); 2=Deciduous forest (values 41, 61); 3=Shrubland (values 51); 0=everything else.

The forest cover GIS map was reclassified again to account for open forests in the Methow Valley using the habitat evaluation map from the North Cascades Grizzly Bear Ecosystem Evaluation (Almack and others 1993). Grid *nlcd5* was created from this refinement, with all cells of value 3 (Shrubland) that overlapped cells classified as forest on the grizzly bear map changed to value 4 (open forest). The remaining cells of value 3 were classified as 0 (null). The result of this refinement was to add an additional 82,182 cells representing open forest (ca 1%) to the base forest lands (Table 3).

Table 3. The number of 30 m cells in reclassified forest classes grid *nlcd5*, for the Methow Valley.

Class	Value	Reclassified number of cells
Offsite (null)	0	1,942,612
Evergreen	1	4,018,622
Deciduous	2	63,566
Open forest	3	82,182
TOTAL		6,106,982

The PAGs were dissolved into the following groups and combined with the categories from the *nlcd* map layer of major plant associations. Blank areas were filled in by overlapping with the grizzly bear habitat map. The PSME-Savannah category was created by overlapping the grizzly bear habitat map for types PIPO, PIPO-PSME and PSME-mixed Conifer Eastside over the NLCD map wherever the NLCD map was classified as Shrubland. The layers were merged in the following order: PSME-warm > PSME-Savannah > Parkland > PSME-Cool > ABLA-VASC > ABLA-RHAL > ABAM > Deciduous > Offsite. The result of this procedure produced the gross productivity map layer *mass*, shown in Table 4.

Table 4. Gross wood productivity in the Methow Valley from the grid layer, *mass*.

Value	Label	Count of 30 m cells	Acres	Productivity by PAG (cu ft/ac/yr)	Productivity (cu ft/yr)	Productivity (bone dry tons/yr)
0	0 Offsite (null)	1754968	390,287	0	0	0
2	2 Deciduous	53593	11,919	51	607,846	8,765
3	3 Savannah	111460	24,788	12	297,451	4,289
5	5 ABAM	100430	22,335	81	1,809,105	26,087
6	6 ABLA-RHAL	992471	220,716	50	11,035,781	159,136
7	7 ABLA-VASC	522495	116,198	27	3,137,337	45,240
8	8 PSME-Cool	1055372	234,704	35	8,214,646	118,455
9	9 PSME-Warm	361705	80,440	46	3,700,220	53,357
10	10 Parkland	356079	79,188	5	395,942	5,709
	TOTAL	5,308,573	1,180,574		29,198,329	421,040

A layer of land ownership was developed using data from two DNR layers: Major Public Lands (MPL) and Public Land Survey, Ownership, County, and Administration (POCA). Together these comprise ownership parcels for Federal, State, County, City and Tribal lands within the State of Washington. A land ownership layer for private lands was developed from the Okanogan County parcel database. Additional administrative layers were obtained from the National Forest. These layers were used to develop a manageable land base, grid *mass3*, that excluded reserved lands such as late-successional reserves (LSRs), Scenic Highway, 2006 Roadless Areas and Research Natural Areas (RNAs). Although LSRs are open for timber harvest, they were excluded from this analysis because they have stringent management objectives that would require a longer, more thorough analysis prior to approval of any biomass removal projects. See Table 5 for a summary of the manageable land base.

Table 5. Biomass productivity on the manageable land base. This table shows the Methow Valley annual wood productivity after subtracting off-base lands (Forest Service management zones for Wilderness, LSRs, Scenic Highway, 2006 Roadless Areas and RNAs).

Value	Label	Count	Acres	Productivity by PAG (cu ft/ac/yr)	Productivity (cu ft/yr)	Productivity (bone dry tons/yr)
0	0 Offsite	928,534	206,497	0	0	0
2	2 Deciduous	41,184	9,159	51	467,104	6,736
3	3 Savannah	88,778	19,743	12	236,920	3,416
6	6 ABLA-RHAL	48,537	10,794	50	539,707	7,783
7	7 ABLA-VASC	121,375	26,993	27	728,800	10,509
8	8 PSME-Cool	545,284	121,266	35	4,244,300	61,203
9	9 PSME-Warm	260,485	57,929	46	2,664,746	38,426
	TOTAL	2,034,177	452,381		8,881,577	128,072

A hydrography layer was developed from the Washington Department of Transportation (DOT) hydrography layer. This layer was keyed to identify streams bearing anadromous fish or bull trout. All streams in the DOT layer of perennial streams were initially buffered 50 ft on private lands and 150 ft on federal lands. Anadromous- and bull trout-bearing streams were buffered 100 feet on private lands and 300 feet on federal lands. These buffers were used to exclude cells representing riparian areas from the manageable biomass landscape in grid *mass6* (see Table 6).

A slope layer was created from USGS 10m DEM data. A threshold of 35% slope (20 degrees) was used to exclude steep slopes from the manageable biomass landscape. Cells in the slope grid were resampled to the same extent as the biomass grid (*mass6*). The grid of biomass (*mass6*) was then combined with the grid of slope <20 degrees to create a layer of available, non-controversial biomass stocks in grid *mass9* (Table 7). The volume of biomass in grid *mass9* was segregated into federal or non-federal lands.

Development of a biomass removal scenario over a forest growth cycle

According to Rogers (2003) more than 75% of the Okanogan National Forest is at moderate to high risk of high intensity fire events due to overstocking. Rogers found the quadratic mean diameter (QMD) for high and moderate risk areas of the Okanogan National Forest was 5.3 inches and the mean stems/acre for that area was 1,153 trees/acre (TPA) of which 94.3% (1,087 trees) are less than or equal to 9 inches diameter at breast height (DBH). The mean basal area (BA) of these stands was 114 sq ft/ac.

Rogers use computer simulation to investigate the cost and effectiveness of several hypothetical alternatives for reducing fire hazards and found the most effective was to reduce stands to 45 sq ft/ac BA by thinning from below, with retention of all large pine and larch, resulting in removal of 1,036 TPA.

The next most effective alternative investigated by Rogers was removal of all trees less than 9 inches DBH (9&under), which would remove of 1,087 TPA and leave a residual BA of 71 sq ft/ac. This alternative turned out to be economically impractical.

We developed two biomass removal scenarios designed to balance the rate of removal with the rate of replacement of trees over a growth cycle. Each scenario specified a removal rate that allowed for a reasonable percentage of total growth to be partitioned into slash, biomass, saw timber and material left on site for habitat. Each scenario required making some assumptions about how long a forest growth cycle should be.

For the length of the growth cycle, we substituted the age since fire suppression began, i.e., the settlement period, or about 100 years. Although this figure is an artifice and real trees are often much older than this in a stand, this timeframe accounts for the amount of growth that occurred in these forests absent wildfires. Most low- to moderate-elevation dry forests of this age have missed one or more cycles of fire that would have naturally removed biomass during that interval. For this to be completely true, the landscape should be unburned for the last 100 years. Up until the 2006 Tripod fire, this was essentially true for the Methow study area, with the exception of several large fires that burned in the 1920s and early 1930s over the upper elevations of the Chewuch watershed and to a lesser extent in upper elevations of the Chelan-Sawtooth. While these fires did cover a substantial portion of the study area landscape, they occurred primarily in higher elevation stands that have 100+ year fire frequency intervals. The fires of the 1920s burned only about 10-15 years into the 100-year study window, accounting for less than 20% of the growth since fire suppression. More importantly for this study, the fires of the 1920s and 1930s burned mostly in higher elevation roadless areas that were eliminated from the manageable land base.

One of our biomass removal scenarios was developed by combining Rogers' 45 BA target alternative with her 9&under alternative. This biomass scenario would allow for a BA target of 45 sq ft/ac that could be raised by the addition of available 9-inch and under trees, so long as the BA is raised equivalently, up to a BA of 71 sq ft/ac, providing that only trees less than 9-inch DBH are taken. We assumed that half of the total biomass could be removed as commodities (saw timber, posts and rails or firewood), on the basis of current thinning projects that require economic returns to be viable. The results exclude contributions from slash volume left on the ground, on the assumption that it would be available for burning or removal depending on the land management goals.

Rogers did not provide the volume removed in her 45 BA biomass removal option, so we developed another scenario based on mass estimates of Oneil and Lippke (2009). This study measured the volume of slash piles of existing timber sales to determine the residual biomass remaining after subtracting lumber and residual material left on the ground for habitat. They did not include calculations of standing green trees or snags. They determined the "recoverable biomass" to be 11.6 green tons/acre in sales in dry forests and 19.5 tons/acre in sales in mesic forests. Converted to 50% dry mass, this would be approximately 5.8 and 9.75 bone dry tons/acre, respectively, for dry and mesic forests.

Environmental mitigations would apply to each removal scenario. These are described in a companion to this paper at
www.okanogan1.com/ecology/silvics/wooten-biomass-environmental-effects-2009.pdf

Results

The amount of forest land in the Methow watershed was determined to be 926,109 ac, (Table 6) calculated as the summed acreage of all cells of type 33-Transitional, 41-Deciduous Forest, 42-Evergreen Forest, 43-Mixed Forest, and 61-Orchards (which includes misclassified cottonwoods and aspens). This figure includes 13,407 acres of the land base that was reclassified from shrubland to open forest.

Table 6. Biomass productivity determined after excluding stream buffers.

Value	Label	Count	Acres	Productivity by PAG (cu ft/ac/yr)	Productivity (cu ft/yr)	Productivity (bone dry tons/yr)
2	2 Deciduous	39,295	8,739	51	445,680	6,427
3	3 Savannah	85,008	18,905	12	226,859	3,271
6	6 ABLA-RHAL	44,160	9,821	50	491,037	7,081
8	8 PSME-Cool	508,713	113,133	35	3,959,644	57,098
9	9 PSME-Warm	248,933	55,360	46	2,546,570	36,722
	TOTAL	926,109	205,957		7,669,789	110,598

The manageable biomass landscape was recalculated as 117,022 acres (Table 7) after subtracting off base lands and sensitive areas (Forest Service management zones for Wilderness, LSRs, Scenic Highway, 2006 Roadless Areas and RNAs, steep slopes and riparian areas). In this study, we excluded the system of late-successional reserves that is currently established on the Okanogan National Forest from the available land base. Although these reserves do allow for timber harvest that maintains or improves old growth character, large-scale biomass removal would likely be contested there, complicating predictable removal scenarios.

The biomass productivity from tree stems within the manageable landscape was determined to be 63,080 bone dry tons/year of which 41,845 tons/year is available on federal lands (Table 7). A map of the manageable biomass removal area of 117,022 acres across all ownerships is shown in Figure 1.

Table 7. Annual tree biomass productivity after excluding steep slopes from the calculations.

Vegetation	Acres	Productivity on all lands (bone dry tons/yr)	Productivity on federal lands only (bone dry tons/yr)
2 Deciduous	7,333	5,393	644
3 Savannah	11,178	1,934	707
6 ABLA-RHAL	5,220	3,763	3,763
8 PSME-Cool	62,367	31,477	26,990
9 PSME-Warm	30,923	20,512	9,741
TOTAL	117,022	63,080	41,845

Based on the annual growth rates in the Methow Valley, in order for natural or managed biomass removals to balance the annual growth on the 117,022 acre manageable land base, it would be necessary to remove 63,080 bone dry tons of biomass each year, or about 0.54 dry tons/acre/year.

<u>Biomass removal scenario based on commercial harvest byproducts</u>

Estimates of recoverable biomass from timber sales across all ownerships in Eastern Washington are given in Table A1 of Oneil and Lippke (2009). A harvest removal of 41.0 green tons/ac from commercial timber sales generates a residual biomass of 28.3 tons/acre, of which 11.6 tons/acre is reasonably recoverable given their environmental constraints. Therefore the total amount of harvested trees and recoverable biomass in commercial sales in Eastern Washington dry forests is 52.6 green tons/ac, or approximately 26.3 bone dry tons per acre, of which 22% is recoverable biomass, 50% is harvested commercially, and 28% is left onsite as residual biomass. These calculations do not calculate the contributions from remaining green leave trees, however these volumes are theoretically independent of steady state equilibria. This assumption is discussed in detail below.

If each year's annual growth of 63,080 dry tons was removed at a rate of 26.3 tons per acre in specific project areas, the project areas would need to cover 2,398 ac each year. This rate of removal is close to double the rate that would equal a hypothetical forest growth cycle of 100 years (1,170 ac/yr). Either the size of the project area or the rate of removal would need to be halved in order to be sustainable over a 100-year cycle. Therefore a removal rate of ca 13.1 dry tons per acre, of which 2.9 tons/ac would be recoverable biomass, would be more reasonable under a 100-year scenario.

<u>Biomass removal scenario based on removal as an objective</u>

At the outset of our study, we proposed another scenario based on Rogers (2003) options. This scenario was based on using biomass removal as the management objective, rather than as a byproduct of timber harvest. In this scenario, removal of up to 50% of the commercial wood through timber harvest was still assumed to be feasible, as was the use of controlled burning to remove biomass.

To develop this biomass removal objective scenario, we modified Rogers' 45 BA option to allow for a BA target of 45 sq ft/ac that could be raised by the addition of any available 9-inch DBH and under trees, so long as the BA was raised equivalently, up to a BA of 71 sq ft/ac, which would remove all of the 9-inch DBH and under trees. Rogers did not provide detailed mass estimates of her options, so we were not able to exactly quantify the available biomass volume using this option.

Based on the above targets, a potential removal scenario was specified that would remove 522 trees/ac of biomass with a QMD of 5.3 inches, while still leaving over half of the 9-inch DBH and under trees on site. We estimated a mass for this scenario to be approximately 20 dry tons of biomass per acre, along with another potential 20 tons/ac of commercial timber. This rate of removal is approximately 50% higher than our other removal scenario, but given the different objective, and considering that Rogers' estimates were based on an aggregated standing volume of forestry plots across a broad range of dry and mesic forests, this estimate compares reasonably with the other scenario.

Discussion

This research attempted to answer the question of how much wood could reasonably be removed from a managed forest landscape. We developed two practical biomass removal scenarios across a manageable biomass removal landscape model developed by forest yield tables by stand type. The use of a steady-state growth model simplified the accounting of biomass, and offered a straightforward means of calculating biomass that could also be used in climate change modeling.

Under a biomass removal scenario in which biomass is a byproduct of commercial timber harvest, an annual rate of harvest + biomass removal totaling 13.1 dry tons per acre on 1,170 ac/yr would need to be removed in order to balance forest growth over a 100 year growth cycle. The annual amount of recoverable biomass across a changing 1,170 acre landscape would be 2.9 tons/ac.

A second biomass removal scenario was developed that would remove small stems as a primary objective, with commercial harvest as a secondary objective. This scenario would remove 522 trees/ac of biomass with a QMD of 5.3 inches, while still leaving over half of the 9-inch DBH and under trees on site. We estimated the annual removal mass for this scenario across the same changing 1,170 acre landscape to be approximately 20 dry tons of biomass per acre, along with another potential 20 tons/ac of commercial timber. This rate of removal is approximately 50% higher than our other removal scenario,

The second scenario would be more practical under several conditions: if biomass removal alone became economical, or if incidental harvests could cover the costs, or if biomass removal was accomplished primarily through controlled burning.

This research was designed to answer a what-if question based on a removal scenario that would balance annual wood productivity. Many other removal scenarios can be envisioned that balance removal with growth, including controlled burning, non-commercial removal without timber harvest, or wildfire.

Both of these biomass removal scenarios suggest solutions to the problem of carbon cycling. Without fire or removal of new trees in fire-prone dry forests, trees eventually become overcrowded and susceptible to disease. Forest wood builds up beyond its rate of decay and eventually, either forest function becomes drastically compromised, or an uncontrollable fire consumes the stand.

More research is needed to improve the accuracy of these growth calculations and to further develop practical long-term removal scenarios. Both scenarios presented here were based on published examples. These scenarios can be compared to estimated biomass volumes from the Forest Service Methow District silviculturist (Tom Ketchum, personal communication). They estimated typical forest biomass thinning volumes of 12.5 to 17.5 dry tons/ac of small diameter material, with residual slash and landing piles contributing an additional 2.5 to 7.5 dry tons/ac. Our scenario using biomass removal as an objective lies within the upper limit of this range.

In sawtimber stands where the goal is to remove commercial material >7 inches DBH, the silviculturist estimated the biomass component to be 5 to 10 dry tons/ac and the residual slash and landing piles to contribute an additional 5-10 dry tons/ac. Therefore this would remove at least 25% of biomass from an upper estimate of 20 dry tons/ac of available biomass. This is very close to our scenario of biomass removal as a byproduct of commercial harvest, where 22% biomass is removed from an estimated 26.3 dry tons/ac of total biomass + harvested wood on a harvest site.

The development of potential biomass removal rates on the manageable landscape given here used steady state calculations to develop two long-term removal scenarios. This method makes it possible to ignore the standing volume or disposition of the removed material on the assumption that these quantities do not contribute significantly to net productivity. This is advantageous because these volumes are unpredictable and difficult to quantify, compared to annual yield volume, which is readily available. Our sources were based on unlogged stand inventories from the 1970s and 1980s, that had been affected by over 50 years of fire suppression.

In proposing any type of ecosystem management, a problem arises from the need to define a reference growth stage and future condition. Because our data on productivity was taken for unlogged forest stands, some consideration needs to be given to whether the growth rates would be applicable in managed stands over a hundred year growth cycle.

Most likely the regenerated forest of one hundred years hence will be of a different composition and structure than the original one, due to variable amounts of leave trees and disturbance events that complicate an accurate volume determination. The question is whether the growth rates given in the references are similar to the ones that would be found at the time of biomass removal in a hypothetical 100-year old stand

Recall that 100 years was chosen as a growth cycle because it delineated the period since fire suppression began. It was not meant to represent an actual age of the trees, but rather a time period within which steady state growth rates could be averaged over several partial disturbances or perhaps where one stand-level disturbance occurred in a 100-year period. In reality, some stands would have a few trees well over 100 years old, and many trees less than that, some of which would be second growth regeneration from one or more disturbances within the 100-year period.

The assumption that published growth rates are applicable to this study becomes more plausible if one considers that removals would generally occur at a time when the rate of growth had declined and new live volume in the stand had leveled off. In a climax stand, this would be the point where new growth is matched by attrition, and this is close to that of the forests inventoried in the plant association studies. The Okanogan Plant association guides were developed in the 1970s through the 1990s in stands that were considered late seral. The effects of fire suppression were only 70 to 80 years old, and were not as well understood as they are today. Most of the inventoried stands in the dry plant associations had neither recent management nor recent fire at the time of the inventories, and thus they were likely to have missed at least one fire interval, in which case the productivity estimates would tend to be lower than in a managed stand. On the other hand, some of the older stands would have experienced self-thinning that occurs under crowded growth conditions or with climax forest dynamics.

Regardless of these complications, alternative methods of determining available biomass based on standing volume are even more prone to variability that makes accurate volume calculations difficult. To accurately determine biomass based on standing volume requires large sample inventories under many different managed and unmanaged conditions that must be separately calculated and then summed to yield total volume estimates.

Our methods were coarsely aggregated by plant association, within which there is a large amount of variability. Further research could develop more detailed yield volume estimates to develop more accurate productivity values. More accurate yield volumes could be determined by applying tree density factors to the stands. Regardless of the inherent growth rates, these hypothetical harvest scenarios can be adjusted over time, and modified on the ground, as more is learned about forest growth and succession across the landscape.

These scenarios could be improved by including additional information on the amount of large woody debris that should be left on the ground. Large woody debris is necessary for healthy soil development and ecosystem functions such as wildlife habitat. In wetter forests, wood decay contributes a large share of the natural biomass removal process. The available figures from Oneil and Lippke (2009) that our scenario was based on left 50% of the dispersed slash >5″ in diameter and all of the dispersed slash <5″ in diameter on site. It is likely that the size and amount of this material would need to be amended in site-specific areas depending on habitat needs.

There is still a need to address the unmanaged landscape and climate change is likely to affect these calculations. Although this research was limited to managed lands, the lessons learned are just as true in any ecosystem at any time. Inputs need to balance outputs or else the ecosystem will change unpredictably.

Our problems in managing ecosystems could go a long way toward being solved if we approached forests as steady state systems, and not just a collection of resources. Management options that are based on system function, rather than product output, are likely to be more successful over the long term.

References

Almack, J.A., W.L. Gaines, R.H. Naney, P.H. Morrison, J.R. Eby, G.F. Wooten, M.C. Snyder, S.H. Fitkin, E.R. Garcia (1993). North Cascades grizzly bear ecosystem evaluation. Report to the Interagency Grizzly Bear Committee in fulfillment of requirements identified in the 1982 Grizzly Bear Recovery Plan.

Baumgartner, David; R. Krebill, J. Arnott; G. Weetman (comps). 1985. Lodgepole pine - the species and its management; symposium proceedings, May 8-10, 1984, Spokane, WA.WSU Cooperative Extension, Washington St. Univ.

Baumgartner, David; J. Lotan (comps). 1991. Interior Douglas-fir - the species and its management. Symposium Proceedings, Feb 27-Mar 1, 1990.WSU Cooperative Extension, Washington St. Univ.

Campbell, Sally; Waddell, Karen; Gray, Andrew, tech. eds. 2010. Washington's forest resources, 2002–2006: five-year Forest Inventory and Analysis report. Gen. Tech. Rep. PNW-GTR-800. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 189 p.

Jones, John; N. DeByle; R. Winokur. Wood Resource. pp. 161-167 in Aspen: Ecology and management in the western United States. USDA Gen. Tech. Report GTR-119-161-167 (http://www.fs.fed.us/rm/pubs_rm/rm_gtr119/rm_gtr119_161_167.pdf).

Lillybridge, T.L., B.L. Kovalchik, C.K. Williams, B.G. Smith. 1995. Field guide for forested plant associations of the Wenatchee National Forest. USDA-FS Gen. Tech. Rep. PNW-GTR-359, Pacific NW Res. Sta., Portland, OR.

Oneil, Elaine, Bruce Lippke. 2009. Eastern Washington biomass accessibility: Report to the Washington State Legislature and Washington Department of Natural Resources. Rural Technology Initiative, School of Forest Resources, College of the Environment, University of Washington.

Rogers, Heather K. Investigation of alternative fuel removal strategies, A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science University of Washington, 2003.

Vogelmann, J.E., S.M. Howard, L. Yang, C.R. Larson, B.K. Wylie, N. Van Driel, 2001. Completion of the 1990s national land cover data set for the conterminous United States from Landsat thematic mapper data and ancillary data sources; Photogrammetric Engineering and Remote Sensing, 67:650-652.

Williams, C.K., T.R. Lillybridge. 1983. Forested plant associations of the Okanogan National Forest. USDA-FS Publ. R6-Ecol-132b-1983, PNW Res. Sta., Portland, OR. 140 p.

Williams, C.K.; B. Smith. 1990. Forested plant associations of the Wenatchee National Forest. Draft. USDA-Forest Service, Wenatchee National Forest, Wenatchee, WA.