TITLE: **Pre- and Post-Harvest Stores of Carbon and Nitrogen in a Highly-Productive Forest Site Subjected to Increasing Biomass Removals in Coastal Washington**

AUTHOR(S): Adrian Ares[1], Thomas A. Terry[1], Kathryn B. Piatek[2], Robert B. Harrison[3], Constance A. Harrington[4], Rodney Meade[1], Rick Leon[1], Richard E. Miller[4], Barry L. Flaming[3], Christopher W. Licata[3], Kyle Petersen[3], Brian D. Strahm[3], Harry W. Anderson[4], Leslie C. Brodie[4], and Joseph M. Kraft[4]

Weyerhaeuser Company, Western Timberlands R&D[1], West Virginia University, Division of Forestry[2], University of Washington, College of Forest Resources[3], USDA Forest Service, Pacific Northwest Research Station[4]

BACKGROUND/PURPOSE

The purpose of this note is to document the information presented in a technical poster at the 69th Annual Soil Science Society of America meeting in Salt Lake City, Utah, November 6-10, 2005. The information presented in the note is maintained in poster format for use as a field-tour handout at the Fall River Long-term Site Productivity study site. Details concerning the study design, treatments and experimental methods used in this investigation are fully documented in Ares et al. (in press).

ABSTRACT

Biomass removals during harvesting or site preparation cause changes in C and nutrient stores and potentially affect long-term site productivity. We assessed C and N stores in a highly productive coastal Washington site before and after imposing biomass-removal treatments to a 47-year old Douglas-fir/western hemlock stand. Treatments included removal of commercial bole (BO), bole-only to 5-cm top diameter (BO5), total tree (TT), and total tree plus all legacy woody debris (TT+). Initially, the stand contained similar amounts of C above the mineral soil (292 Mg/ha) as within the mineral soil to 80-cm depth including roots (289 Mg/ha). Carbon stores above the mineral soil by size were: live trees (193 Mg/ha), coarse woody debris including old-growth stumps, snags and logs (65 Mg/ha), forest floor (27 Mg/ha), dead trees/snags (7 Mg/ha), and understory vegetation (0.1 Mg/ha). Carbon in the mineral soil averaged 248 Mg/ha while roots added 41 Mg/ha. Total N in mineral soil and roots was more than ten-fold greater (13,348 kg/ha) than the N store above the mineral soil (1,323 kg/ha). After treatment, C

DISTRIBUTION TO TECHNICAL INFORMATION CENTER	LOCATION TIC	AUTHOR'S SIGNATURE *Adrian Ares, Tom Terry, et al.*	DATE 1/2/07
		AUTHOR'S NAME (Typed) Adrian Ares, Tom Terry, et al.	
PROJECT NO. 5000000207		APPROVED BY (Signature) Christine Dean	DATE 1/4/07

stores above the mineral soil decreased to 129 Mg/ha in BO, 120 Mg/ha in BO5, 63 Mg/ha in TT and 50 Mg/ha in TT+. Post-harvest forest floor C averaged 23 Mg/ha in TT and TT+, against 46 Mg/ha in BO and BO5, and 27 Mg/ha in the pre-harvest stand. Total N above the mineral soil averaged 734 kg/ha in BO and BO5, and decreased to 414 and 353 kg/ha in TT and TT+, respectively, while soil N remained mostly unaltered. Biomass-removal treatments had a significantly greater impact on site C stores than on site N stores because of the large amounts of N in the mineral soil. Site C and N stores were reduced by 42% and 6%, respectively, in the most intensive biomass removal treatment.

INDICATORS OF SCIENTIFIC CONFIDENCE

Category	Lowest Rating Definition	Rating 1	2	3	4	Current Rating	Highest Rating Definition
Literature review	None.			**X**		Literature review provided in companion publication that is cited.	Complete review and benchmarking, summarized in report.
Study approach	Methods development, preliminary experiment, initial observations.			**X**		Standard errors of estimates for biomass, C and N pools are provided in companion publication that is cited.	Hypothesis testing with sufficient power for rejection.
Experimental design	None – observations only			**X**		Four replications at one study location.	Design replicated in both time and space.
Data analysis	Summary of data (means, etc.), no analysis.			**X**		This study documented estimates of biomass and C and N pool means by treatment. No hypothesis testing was involved.	Complete results of either hypothesis testing or parameter estimation.
Review process	Reviewed only be viewing presentation or director.			**X**		External and Internal peer reviews completed.	External review with a referee.
Overall confidence				**X**		Root pools were estimated based on reviewing the literature rather than determining in the field.	

TITLE: **Pre- and Post-Harvest Stores of Carbon and Nitrogen in a Highly-Productive Forest Site Subjected to Increasing Biomass Removals in Coastal Washington**

AUTHOR(S): Adrian Ares[1], Thomas A. Terry[1], Kathryn B. Piatek[2], Robert B. Harrison[3], Constance A. Harrington[4], Rodney Meade[1], Rick Leon[1], Richard E. Miller[4], Barry L. Flaming[3], Christopher W. Licata[3], Kyle Petersen[3], Brian D. Strahm[3], Harry W. Anderson[4], Leslie C. Brodie[4], and Joseph M. Kraft[4]

Weyerhaeuser Company, Western Timberlands R&D[1], West Virginia University, Division of Forestry[2], University of Washington, College of Forest Resources[3], USDA Forest Service, Pacific Northwest Research Station[4]

BACKGROUND/PURPOSE

The purpose of this note is to document the information presented in a technical poster at the 69th Annual Soil Science Society of America meeting in Salt Lake City, Utah, November 6-10, 2005. The information presented in the note is maintained in poster format for use as a field-tour handout at the Fall River Long-term Site Productivity study site. Details concerning the study design, treatments and experimental methods used in this investigation are fully documented in Ares et al. (in press).

INTRODUCTION

- Sustainable forestry requires an understanding of the long-term effects of intensive forest practices on soils and vegetation.
- Excessive removal of organic matter and nutrients in harvest and site preparation can be a factor leading to site degradation and reduction in forest productivity.
- Initial site conditions and subsequent treatment regimes may affect the impacts of intensive forest management on long-term productivity potential.
- Long-term studies such as those of the Long-Term Soil Productivity (LTSP) research network (Figure 1) are crucial to evaluate intensive management effects on different soils and forest types.

OBJECTIVES

- To quantify the biomass, C and N stores in a Douglas-fir (*Pseudotsuga menziesii* Mirb. (Franco))/western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) stand before and after imposing increasing biomass-removal treatments.
- To determine absolute and relative C and N stores removed at harvest for an array of biomass-removal treatments and the N removal "stability ratio" after Evans (1999).

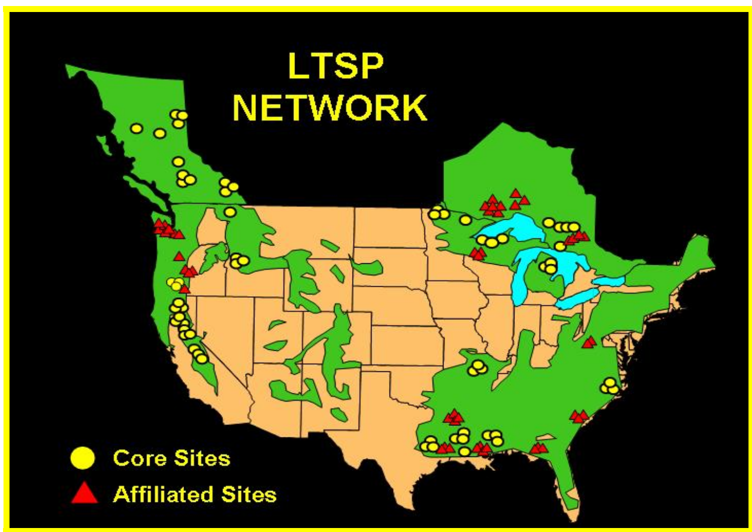

Figure 1. The Fall River research site is an affiliate location of the Long-Term Soil Productivity (LTSP) network.

METHODS

The Research Site

- The site is on the Willapa Hills in Washington coastal range at 330 m elevation (Figure 2).
- Mean annual rainfall is 2300 mm with a short dry period in most summers.
- The soil is a deep silty clay loam Typic Fulvudand of the Boistfort series with high organic matter and water-holding capacity, and inherent low bulk density (Figure 3).

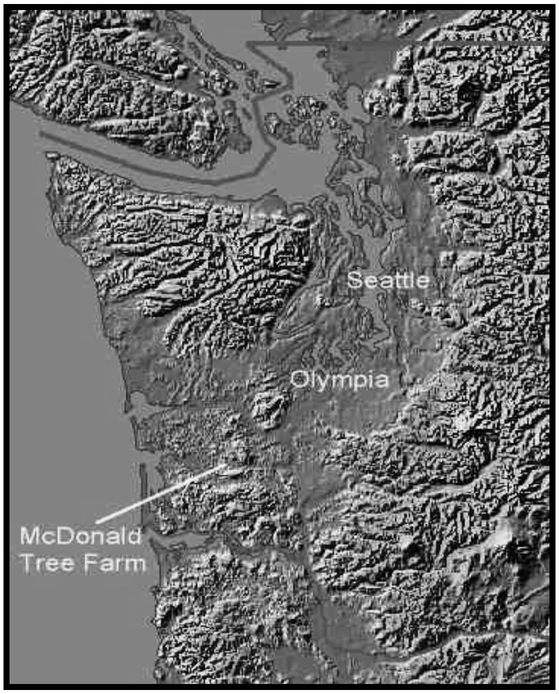

Figure 2. Location of the Fall River research site.

Figure 3. Typical soil profile at Fall River.

Biomass-Removal Treatments

- Commercial bole-only removal **(BO)**
- Bole-only removal up to 5-cm top **(BO5)**
- Total (above ground) tree removal **(TT)**
- Total tree plus all legacy woody debris removal (**TT+)** (Figure 4)

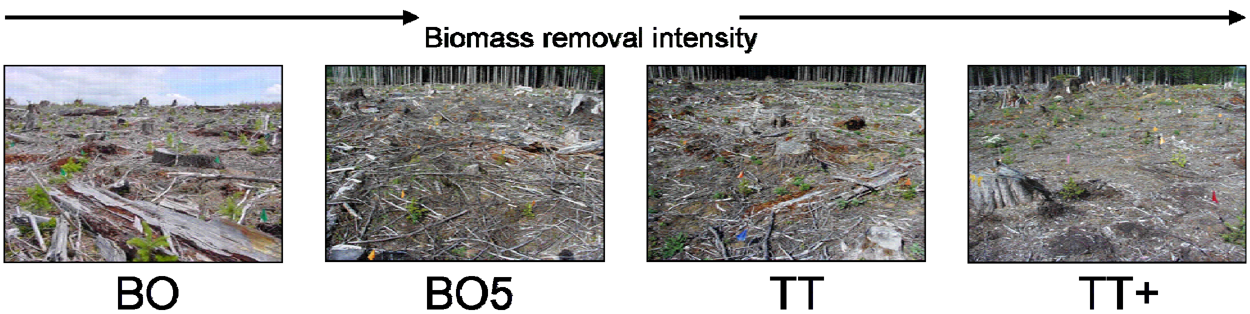

Figure 4. Biomass removal treatments at Fall River.

Pre-Harvest Stand

- 47-year-old Douglas-fir plantation planted at 2188 trees/ha plus volunteer hemlock (Figure 5).
- Douglas-fir Site index of 41-43 m at breast-height age 50.
- Douglas-fir and western hemlock stocking were 303 and 324 trees/ha, respectively.
- Understory dominated by sword fern (*Polystichum munitum* (Kaulfuss) K. Presl) and Oxalis (*Oxalis oregana* Nutt).

Figure 5. The pre-harvest stand at Fall River.

Experimental Design

- Randomized complete block design with four replicates (Figure 6).
- Twelve treatments in total.
- Seven treatments are in place in 2005 including the four biomass-removal treatments.
- Fertilization treatments will be imposed after canopy closure.
- Plots are 30 x 85 m with a 15 x 70 m interior measurement area.

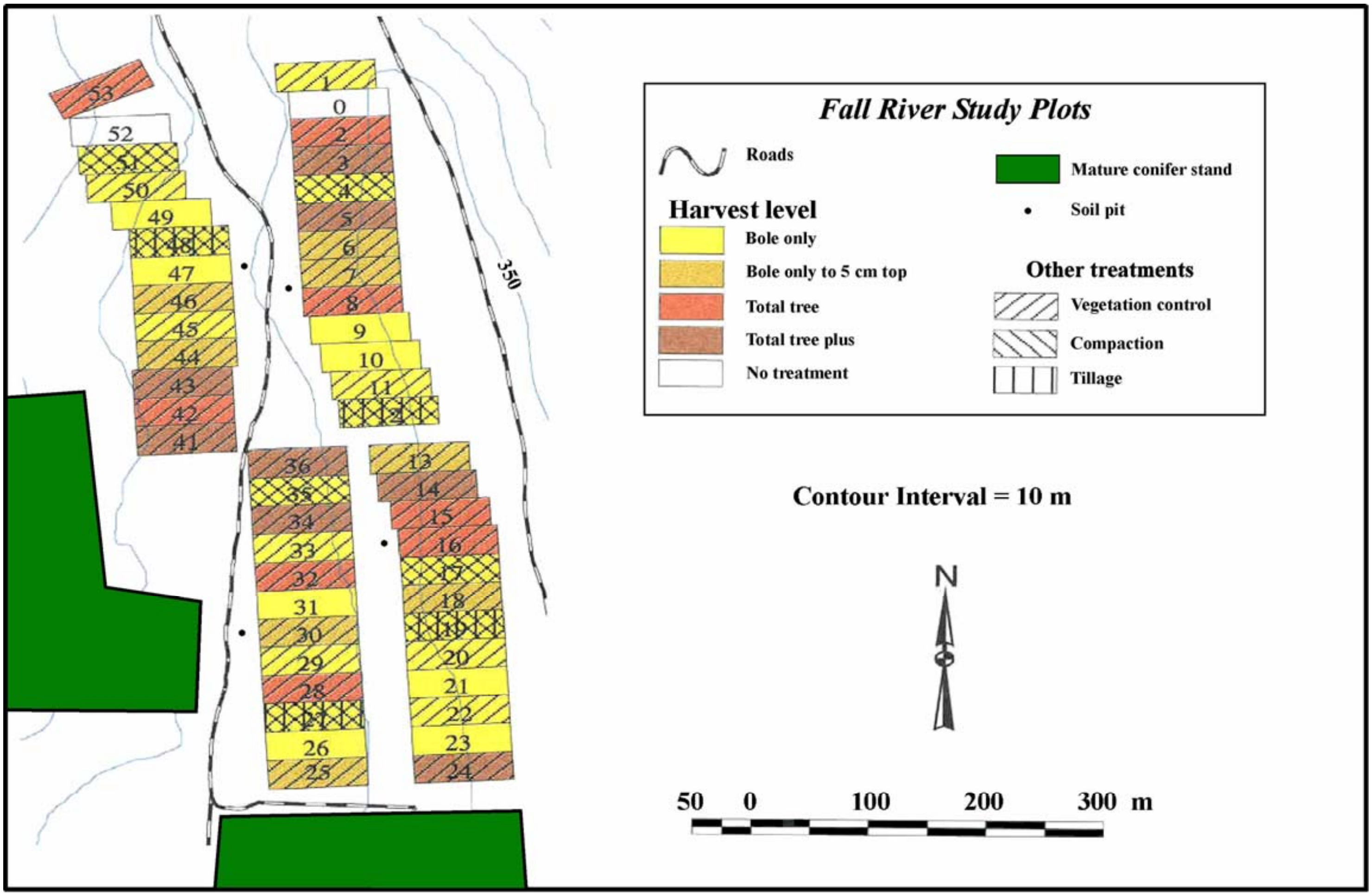

Figure 6. Plot and block arrangement at Fall River.

Measurements

Pre-Harvest

- Bole diameter at 1.3 m aboveground (DBH) was measured on all trees while height was measured on 1440 trees across the DBH range (30 trees per plot).
- Tree above-ground biomass estimated from biomass allometric functions generated from data from felled and biomass sampled trees on site.
- Understory vegetation composition, cover and biomass.

- Coarse woody debris biomass including old-growth stumps (Figure 7) snags and logs by decay class.
- Forest floor depth and biomass by class.
- Carbon and N concentrations in all stores.
- Soil C and nutrients to 80-cm depth.

Post-Harvest

- Coarse woody debris (including old-growth stumps, snags and logs) volume, density and biomass per treatment and decay class.
- Recent stump volume, density and biomass.
- Forest floor depth and biomass by component class (e.g., intact forest floor, red rot, etc.).
- Carbon and N concentrations of all relevant stores.

Figure 7. Large old-growth stump at Fall River.

RESULTS

Pre-Treatment

- Bole wood contained 78% of the C and 39% of the N in the above ground live tree biomass (Table 1).
- Similar C stores above (292 Mg/ha) and within the mineral soil including roots (289 Mg/ha) (Table 2).
- Carbon stores above the mineral soil by size were live trees > coarse woody debris + old-growth logs > forest floor > old-growth stumps/snags > dead trees/snags > understory vegetation **(**Table 2).
- Forest floor was a relatively large N store (453 kg/ha) (Table 2).
- Total N in mineral soil and roots was more than 10-fold greater (13,348 kg/ha) than the N store above the mineral soil (1,323 kg/ha) (Table 2).

Post-Treatment

- Carbon stores above the mineral soil decreased to amounts ranging from 129 Mg/ha in BO to 50 Mg/ha in TT+ (Table 3).
- Total N above the mineral soil averaged 734 kg/ha in BO and BO5, and decreased to 414 and 353 kg/ha in TT and TT+ (Table 3).
- Biomass, C and N removals at harvest varied from 498 to 358 Mg/ha, 244 to 175 Mg/ha, and 925 to 432 kg/ha, respectively (Figure 8).
- Only 3 to 6% of the total pre-harvest N (above ground biomass + soil to 80-cm depth) was removed in the harvest treatments (Table 4).

Table 1. Above ground live-tree biomass, C and N stores in the Douglas-fir/western hemlock stand.

Tree	**Biomass**		**C**		**N**	
portion	*Mg/ha*	*%*	*Mg/ha*	*%*	*kg/ha*	*%*
Foliage	10	2.4	5	2.6	162	26.8
Live branches	29	7.5	14	7.3	63	10.4
Dead branches	13	3.3	6	3.1	21	3.4
Bole wood	309	78.5	150	77.7	234	38.7
Bole bark	33	8.3	18	9.3	125	20.7
Total aboveground	**393**		**193**		**605**	

Table 2. Summary of biomass, C and N stores in the pre-harvest stand.

	Biomass		**C**		**N**	
	Mg/ha	*%*	*Mg/ha*	*%*	*kg/ha*	*%*
Live trees	393	34.2	193	33.2	604	4.1
Dead trees	4	0.4	2	0.4	8	0.0
Snags	10	0.8	5	0.8	30	0.2
Understory vegetation	0.2	0.0	0.1	0.0	5	0.0
Coarse-woody debris [1]	22	2.0	11	2.0	74	0.5
Old-growth stumps/snags	29	2.6	17	3.0	26	0.2
Old-growth logs	73	6.4	37	6.3	122	0.8
Forest floor	71	6.1	27	4.6	453	3.1
Coarse roots [2] (>5 mm)	82	7.1	40	6.8	181	1.2
Small/fine roots [3] (<5 mm) 0-45 cm	4	0.3	1	0.2	25	0.2
Mineral soil 0-80 cm	459[4]	40.0	248	42.7	13,143	89.8
Total	**1148**		**582**		**14,671**	

[1]Excluding old-growth stumps, snags and logs; [2]From allometric equations in Thies and Cunningham, 1996; [3]Calculated from data in Keyes and Grier, 1981; [4]Organic matter.

Table 3. Summary of biomass, C and N stores after forest harvest at Fall River.

	Biomass				C				N			
	Mg/ha				*Mg/ha*				*kg/ha*			
	BO	BO5	TT	TT+	BO	BO5	TT	TT+	BO	BO5	TT	TT+
Coarse-woody debris	60	37	20	2	29	18	10	1	89	76	45	5
Old-growth stumps/snags	35	29	30	47	18	15	15	23	29	29	23	35
Old-growth logs	70	76	28	0	35	39	14	0	114	131	49	0
Recent stumps	5				2				3			
Forest floor	98	103	54	59	45	46	22	24	486	508	294	310
Coarse roots	82				40				181			
Small/fine roots 0-45 cm	4				1				25			
Mineral soil 0-80 cm	459				248				13,143			
Total	**812**	**795**	**681**	**658**	**419**	**409**	**352**	**339**	**14,070**	**14,096**	**13,763**	**13,702**

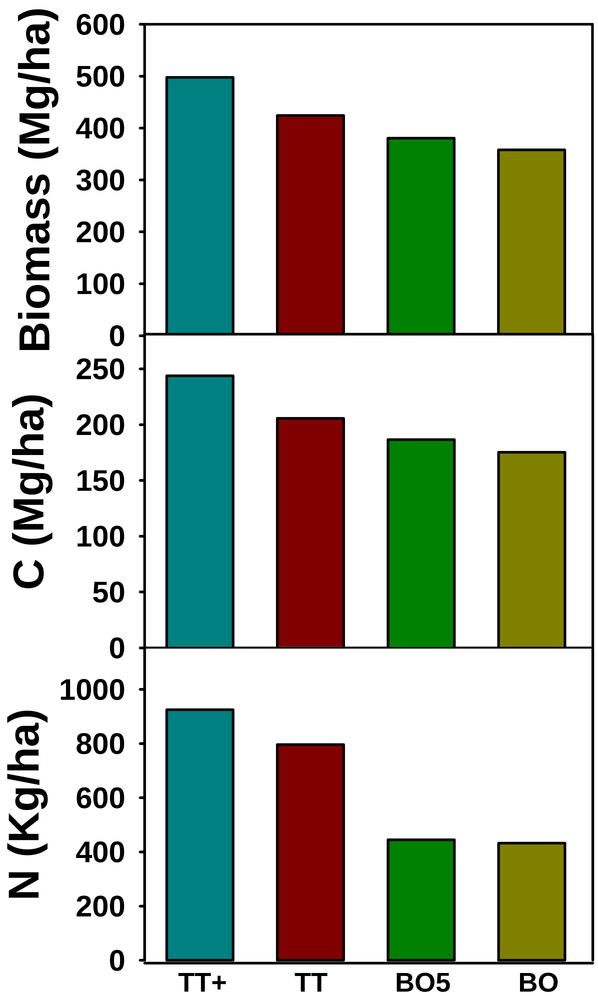

Figure 8. Biomass, C and N removals at harvest at Fall River.

Table 4. How much of the site N capital was spent?

The Stability Ratio (SR) (Evans, 1999) classifies the susceptibility of a soil to nutrient depletion by calculating the ratio of removal to total store

Proposed SR Thresholds

> 0.3 Serious long-term stability concerns
> 0.5 Immediate stability concerns

SR for treatments at Fall River:

BO	0.03
BO5	0.03
TT	0.05
TT+	0.06

CONCLUSIONS

- Biomass-removal treatments had a significantly greater impact on the site C stores than on the N stores because the majority of the site N is in the mineral soil.
- The total tree and total tree plus treatments removed 364 and 493 kg N/ha more, respectively than the bole only treatment.
- Total site N was only reduced by 6% in the most intensive biomass-removal treatment (TT+). Removal in TT+ would have increased to 8% if the forest floor would have also been removed.
- Nitrogen removals at Fall River were significantly lower than the stability-ratio thresholds proposed by Evans (1999) for indicating either immediate or long-term stability concerns (0.03-0.06 vs. 0.3-0.5).
- Assessing the proportion of N in vegetation and forest floor (that is vulnerable to removal by harvest and site preparation) to the total site N pool (above and below ground to rooting depth) needs to be tested as a site N-deficiency risk index.

ACKNOWLEDGEMENTS

We are grateful to NCASI, Olympic Natural Resource Council, University of Washington, Pacific Northwest Stand Management Cooperative, USDA Forest Service Pacific Northwest Research Station, and Weyerhaeuser Company for resource support. We also extend our deep appreciation to many people that assisted at different stages of this project.

REFERENCES

Ares, A., Terry, T.A., Piatek, K.B., Harrison, R.A., Miller, R.E., Flaming, B.L., Licata, C.W., Strahm, B.D., Harrington, C.A., Meade, R., Anderson, H.W., Brodie, L.C., and Kraft, J.M. in press. The Fall River long-term site productivity study in coastal Washington: Site description, experimental design, and biomass, carbon and nitrogen stores before and after harvest. USDA Forest Service, General Technical Report PNW-GTR-691, Pacific Northwest Research Station, Portland, OR, 84 p.

Evans, J. 1999. Sustainability of forest plantations. The evidence: A review of the evidence concerning the narrow-sense sustainability of planted forests. Report Department of International Development, London, UK, 64 p.

Keyes, M.R., and Grier, C.C. 1981. Above- and below-ground net production in 40-year-old Douglas-fir stands on low and high productive sites. Canadian Journal of Forest Research 11: 599-605.

Thies, W.G., and Cunningham, P.G. 1996. Estimating large-root biomass from stump and breast-height diameters for Douglas-fir in western Oregon. Canadian Journal of Forest Research 26: 237-243.