Effects of Management on the Amount and Characteristics of Woody Debris in Mixed Stands of Caspian Forests

Farshad Keivan Behjou,[a,]* Omid Ghafarzade Mollabashi,[a] and Neda Amirahmadi[b]

Woody debris (WD), including coarse woody debris (CWD) and fine woody debris (FWD), is an essential structural and functional component of forest ecosystems. This study was carried out in Caspian hardwood forest sites. In this study, the volume and composition of WD were inventoried by line intersect sampling and fixed area plot sampling in unmanaged and managed forests on 6 compartments (3 managed and 3 unmanaged). Estimates of the total volume of WD in managed and unmanaged forests ranged from 11.9 $m^3.ha^{-1}$ to 25.82 $m^3.ha^{-1}$, respectively. The results of independent t tests indicated that the amount of CWD in the unmanaged forests was significantly higher than CWD in the managed ones (t_{22}, 0.05 = 2.64, P = 0.015). Also, the results of independent t tests indicated that the amount of FWD in the managed forests was significantly higher than FWD in unmanaged forests (t_4, 0.05 = 5.07, P = 0.007). In the unmanaged forests, WD in decay classes 3, 4, and 5 accounted for 77% of the total WD volume, but in the managed forests, WD in decay classes 1 and 2 accounted for 87% of the total WD volume. The results suggest preserving the current unmanaged forests (protected forests) and maintaining the structural and functional integrity of woody debris.

Keywords: Woody debris; Forest management; Line intersect method; Mixed stand; Caspian forests

Contact information: a: Department of Range and Watershed Management, Faculty of Agricultural Technology and Natural Resources, University of Mohaghegh Ardabili, Ardabil, Iran; b: Department of Agricultural Management, Faculty of Agricultural Technology and Natural Resources, University of Mohaghegh Ardabili, Ardabil, Iran;
**Corresponding author: keivanbehjoufarshad@gmail.com*

INTRODUCTION

Woody debris (WD), including coarse woody debris (CWD) and fine woody debris (FWD), is an essential structural and functional component of many ecosystems, particularly in mountain forests (Lipan *et al*. 2008; McCarthy and Bailey 1994; Muller and Liu 1991). CWD plays a key role in many aspects of ecosystem functions (BretzGuby and Dobbertin 1996; Habashi 1998; Yan *et al*. 2007; Zolfaghari 2005), both in aquatic systems and on land, including as a habitat for wildlife and fungi, as a nursery site for seedling establishment, and in nutrient cycling and soil stability. CWD includes whole fallen trees, fallen branches, pieces of fragmented wood, stumps, standing dead trees (snags), and logging residues, while FWD mainly consists of small twigs and is much less functional compared to CWD (Lipan *et al*. 2008). The quantity and quality of CWD are fundamental characteristics for increasing our knowledge of natural forest stand dynamics (Motta *et al*. 2006). Forest management can have large impacts on the production and yield of CWD in terrestrial ecosystems (Debeljak 2006; Radtke *et al.* 2009), especially in forest ecosystems

(Jenkins *et al*. 2004). This study compares the amount of CWD in managed and unmanaged forest ecosystems. The coarse woody debris term was coined to incorporate all forms of dead woody material together (Debeljak 2006). It is defined as dead woody material found on the forest floor (*e.g.* logs, fallen limbs, twigs, and woody fruits), belowground material (*e.g.* buried wood and dead woody roots), and standing dead trees or shrubs or their partial remains (*e.g.* snags and stumps) (Pyle and Brown 1999;Woldendorp*et al.* 2002).Over the course of time, a forest ecosystem maximizes accumulation of coarse woody debris (CWD) in order to achieve new optimal adaptations on prevailing environmental factors through building new ecological structures (Debeljak 2006).CWD presents an indispensable element in nutrient cycles and energy flows (Amaranthus *et al.* 1994; Berg 2000), hydrology and soil forming processes, and soil retention capacities (Harmon and Franklin1989).As a result, fine woody debris (FWD) is readily available in most forests, but coarse woody debris (CWD) in managed forests is insufficient (Muller and Bartsch 2009).

Kurbanov and Vorobev (2008) studied the spatial distribution of CWD in pine forests of the Transvolga region in Russia. The results of the study showed that CWD distribution has a tendency toward spatial grouping (clustering), and its stocks increased along with stand age. Motta *et al*. (2006) estimated the amount of CWD in the Valbona forest reserve in the Italian Alps. The results of the study indicated that the mean volume of CWD in the study area was 23.4 $m^3.ha^{-1}$, ranging in the sampling plots between 0.0 and 89.3 $m^3.ha^{-1}$. Sefidi (2007) calculated the amount of CWD in Caspian managed forests. The results indicated that the CWD in the study area ranged from 5.80 to 8.40 $m^3.ha^{-1}$. Lipan *et al*. (2008) estimated woody debris stocks in primary and secondary forests in the subtropical Ailao Mountains in China. The results indicated that the ratios of CWD to FWD were low in the secondary forest (about 1 to 4) but high in the primary forest (about 15). Sefidi and MarvieMohadjer (2010) studied the characteristics of CWD in different successional stages in Caspian forests. The results of the study showed that the volume of CWD followed a general "U-shaped" temporal trend: the highest volume was found in the late successional forest (51.25 $m^3.ha^{-1}$), the lowest in the middle successional forest (25.95 $m^3.ha^{-1}$), and intermediate amounts in the early successional forest (37.05 $m^3.ha^{-1}$). Assessment of CWD following selective logging in Caspian forests by Behjou and Mollabashi (2013) showed that line intersect sampling is the best method for measuring CWD (high efficiency and high accuracy). They estimated the amount of CWD to be 6.46 m^3/ha using line intersect sampling. Harmon *et al.* (2013) estimated carbon concentration of standing and downed woody detritus by examining of 60 samples of tree species from the Northern hemisphere. The mean carbon concentration of 257 study samples was 49.3% with a range of 43.4 to 56.8%. Angiosperms had a significantly lower carbon concentration than gymnosperms, with means of 47.8% and 50.6%, respectively. For whole-stems (*i.e.*, wood and bark), the carbon concentration of gymnosperms significantly increased from 49.3% to 53.5% with decomposition, while angiosperms had no significant change.

This study investigated the amount of WD, species composition, and decay classes of CWD in managed and unmanaged forest stands in Caspian forests in Iran. Very few studies about comparisons of WD between managed and unmanaged forests in Caspian region have been published. Specifically, the amount of WD, species composition, and decay classes of CWD in two different management methods was compared.

EXPERIMENTAL

Materials

Sampling WD (including CWD and FWD) was conducted in Caspian forests, in a 305-ha tract of northern hardwood in six compartments (3 managed and 3 unmanaged) located in the Guilan province during the spring of 2009 (Table 1).The forest composition in Iran is typically composed of the Caspian hardwood type, with mature stands dominated by beech (*Fagus orientalis*), alder (*Alnus subcordata*), maple (*Acer velutinum*), hornbeam (*Carpinus betulus*), and elm (*Ulmus glabra*). At all sites, forests were dominated by beech (*Fagus orientalis*) and hornbeam (*Carpinus betulus*), characteristic of approximately 90% of Caspian forests. In each study area, lines were selected with systematic random sampling.

Table 1. A Description of the Sections Used in the Study

Compart. number	Silvicultural treatment	Area (ha)	Plot type		Plot size/ transect length (m^2/m)	Number of sampled (Transects/plots)	Volume per hectare of living trees ($m^3.ha^{-1}$)	Number per hectare in living trees
			CWD	FWD				
228	Managed	42	transect	plot	100	41	225	164
231		66	transect	plot	100	64	319	175
232		48	transect	plot	100	45	267	176
239	Unmanaged	45	transect	plot	100	44	271	163
240		56	transect	plot	100	55	208	141
241		48	transect	plot	100	48	166	170

Methods

In each stand, a systematic series of sampling points was located for the inventory of WD. At each sampling point, line-intersect (with a line length of 100 m and a random orientation of sample lines) and fixed area plot sampling (10*10 m) were performed to assess CWD and FWD, respectively. For both sampling methods, the slope correction procedure outline of Stahl *et al*. (2002) was followed. Based on the pre-study qualitative assessments of woody debris, 150 transects in managed stands were set up for the CWD survey. This included sections 228, 231, and 232, and 147. Transects also were set up in unmanaged stands, including sections 239, 240, and 242. The fixed area plots were established at the end of established transects to assess FWD. For determining the FWD volume, the dimensions of the pieces were measured. In addition, for assessing CWD, the volumes of individual pieces were calculated using Eq. 1.

$$Y_i(m^3/ha) = \frac{\pi^2}{8L} \times \sum_{j=1}^{m_j} \frac{d_{ij}^2}{\cos \lambda_{ij}} \tag{1}$$

where L is length of line transect (m),d_{ij} is the diameter of CWD piece j crossed by line transect i(m), λ_{ij} is an acute angle from the horizontal of CWD piece j crossed by line transect i(degrees), and Y_i is the volume per hectare based on line transect i (m^3/ha).

In each transect, all species of woody residues with large-end diameters ≥ 10 cm (CWD) that intersected transects, were recorded separately. The length, small-end, and large-end diameter of all pieces of logs and large branches, and height and diameter of the stumps were measured and recorded. Meanwhile, tree species, basal diameter, diameter at breast height (DBH), and decay stages were recorded for all standing dead trees (snags) on each transect.

As a modified decay classification system and class definition, a new modified indirect measurement developed by Rouvinen *et al*. (2002) was used in the field. The main contents are as follows: the dead wood died within 1 to 2 years and the wood is still fresh when investigation takes place (1), the wood begins to decompose and the knife blade penetrates a few millimeters into it (2), the knife blade penetrates 1 to 1.5 cm into the wood (3), the knife blade penetrates 2 to 3 cm into the wood (4), and (5) the knife blade penetrates all the way.

Analysis of variance (ANOVA) and independent t tests were used to determine the effect of management on the volume of WD as well as to determine the density of CWD with respect to decay classes of dominant species. Significance was set at $P < 0.05$.
For applying ANOVA test, the amount of CWD based on the type of CWD was compared in managed and un-managed forest, also for applying t test the amount of FWD was compared between managed and un-managed forest.

RESULTS AND DISCUSSION

Estimates for volume per hectare are given for CWD and FWD by using line intersect sampling and fixed-area plots (Woldendorp *et al*. 2002) in each section in Tables 2 and 3, respectively. The authors had hypothesized that managed stands would have a lower CWD than unmanaged stands (Debeljak 2006). Based on this case, the lowest total amount of CWD was found in managed stands (Table 2).

Table 2. CWD in the Study Region

Section number	Treatment	Forest type	Snags	Stumps	Logs	Branches	Total
			$m^3.ha^{-1}$				
239	Unmanaged	Mixed forest	10.52	2.03	10.30	1.14	22.99
240			7.06	1.70	13.03	1.50	23.29
241			7.66	1.96	7.04	2.10	18.76
228	Managed (selective logging)	Mixed forest	1.44	2.48	3.02	1.01	7.95
231			1.78	3.54	2.20	1.07	8.59
232			1.12	2.78	4.24	1.20	9.34

Based on the ANOVA, there are significant differences between unmanaged sections with respect to the amounts of snags, logs, stumps, and branches ($F_{3, 11, 0.05} = 18.37$, $P = 0.001$). In addition, the results of Tukey's test indicated that the amount of snags and logs were significantly higher than the amount of stumps and branches in unmanaged forests ($F_{3,\,11,\,0.05}$ = 8.28, P = 0.009).Also, the results of ANOVA and Tukey's test indicated that the amount of snags and logs were significantly lower than the amount of stumps and branches in managed forests ($F_{3,\,11,\,0.05}$ = 8.79, P = 0.007). The results of independent t tests indicate that the amounts of CWD in unmanaged forests are significantly higher than the CWD in managed forests ($t_{22,\,0.005}$ = 2.64, P = 0.015) (Table 4) (Debeljak 2006).

The independent t test indicated that the amounts of FWD in managed forests were significantly higher than the FWD in unmanaged forests ($t_{4,\,0.005}$ = 5.07, P = 0.007) (Table 4). Also, the ratio of CWD/FWD in unmanaged forests was 12.5:1, but the ratio in managed forests was 1.9:1.

Table 3. FWD in the Study Region

Section number	Treatment	Forest type	FWD	Total
			$m^3.ha^{-1}$	
239	Unmanaged	Mixed forest	1.55	1.55
240			2.53	2.53
241			1.20	1.20
228	Managed (selective logging)	Mixed forest	3.95	3.95
231			4.59	4.59
232			5.34	5.34

Table 4. ANOVA, Tukey's Test, and Independent t Test for CWD, FWD, and Total WD

WD		Volume per hectare ($m^3.ha^{-1}$)		Type of test
		Unmanaged forest	Managed forest	ANOVA and Tukey's test
CWD*	Snags	8.41^a	1.45^a	
	Stumps	1.90^b	2.93^b	
	Logs	10.12^a	3.15^b	
	Branches	1.58^b	1.09^a	
Total CWD**		22.01^c	8.62^d	Independent t test
FWD**		1.76^e	4.63^f	
Total WD**		23.77^g	13.25^h	
CWD:FWD		12.5:1	1.9:1	-

* Among rows of one column
** Between two columns

The species composition of WD was found to differ between the two silvicultural treatments (managed and unmanaged stands). In comparison, the number of tree species for CWD composition was higher in unmanaged compartments; beech and hornbeam accounted for 60% of the total volume of CWD. In fact, beech had the greatest volume of CWD, reaching 22.11 $m^3.ha^{-1}$; the next highest was 16.91 $m^3.ha^{-1}$, for hornbeam (Table 5), also, in managed compartments, beech and hornbeam accounted for 90% of the total volume of CWD, so that beech had the highest volume of CWD, reaching 15.27 $m^3.ha^{-1}$; the next highest was 8.02 $m^3.ha^{-1}$, for hornbeam (Table 5). The amount of beech and hornbeam in the CWD composition in unmanaged forests (60%) was lower than its amount in unmanaged forests (90%).

Table 5. Species Composition of CWD

Silvicultural treatment	Variable	Type of species					
		Beech	Hornbeam	Maple	Elm	Alder	Other species
Unmanaged forest (3 compartments)	Volume ($m^3.ha^{-1}$)	22.11	16.91	9.77	7.15	2.60	6.50
	Percent (%)	34	26	15	11	4	10
Managed forests (3 compartments)	Volume ($m^3.ha^{-1}$)	15.27	8.02	1.29	0. 26	0.78	0.26
	Percent (%)	59	31	5	1	3	1

The distribution of WD contained all the decay classes varied among the managed and unmanaged forests (Table 6). Generally, the unmanaged and managed forests contained the fully decaying classes (from 1 to 5 classes) of WD. In the unmanaged forests, of the total WD volumes, 23%was accounted for in decay classes 1 and 2, and 77% was found in decay classes 3, 4, and 5. In contrast, in the managed forests, WD in decay classes 1 and 2 was 87% of total WD volume, and decay classes 3, 4, and 5 accounted for 13%.

Table 6. Relative Distribution of Total CWD

Silvicultural treatment	Variable	Decay classes				
		1	2	3	4	5
Unmanaged forest (3 compartments)	Volume ($m^3.ha^{-1}$)	4.55	10.41	14.96	13.66	21.46
	Percent (%)	7	16	23	21	33
Managed forests (3 compartments)	Volume ($m^3.ha^{-1}$)	16.04	6.47	1.55	1.04	0.78
	Percent (%)	62	25	6	4	3

In comparison to unmanaged forests in the Caspian region, the amount of WD was obviously different in managed forests. In addition, CWD was higher in unmanaged than managed forests; in contrast, FWD was higher in managed forests than unmanaged forests (Sefidi and MarvieMohadjer 2010).Some researchers have found that under the presented climatic conditions, beech coarse woody debris (CWD) with a diameter >10 cm decays completely in about 35 years (Muller and Bartsch 2009).

Forest management can have a large impact on the production and yield of CWD in terrestrial ecosystems (Debeljak 2006; Radtke *et al*. 2009). The amount of CWD (22.01 $m^3.ha^{-1}$) in the unmanaged stands of this study was lower than that found in studies such as those of Habashi (1998) or Sefidi and MarvieMohadjer (2010), and was higher than that found by Zolfaghari (2005), in Caspian forest sites. In some studies, such as that of Sefidi (2007), the amount of CWD (8.62 $m^3.ha^{-1}$) was higher in managed stands (Table 7). In addition, the amount of CWD (21.68 $m^3.ha^{-1}$) in the unmanaged stands was lower than its amount in some studies in Caspian forest sites (Habashi 1998; Sefidi and MarvieMohadjer 2010; Zolfaghari 2005).

The species composition of CWD was substantially different among the managed and unmanaged stands in the region. The woody debris species in unmanaged stands was mainly composed of 4 species, including beech, hornbeam, maple, and elm (above 85%); in managed stands, the woody debris was mostly composed of two species, *i.e.*, beech and hornbeam (around 90%). Meanwhile, the highly decayed component of CWD was higher in unmanaged stands than it was in managed stands.

Table 7. Amount of CWD (more than 10 cm in diameter) in Caspian Forests

Study location	Forest type	CWD amount ($m^3.ha^{-1}$)	Successional stage	References
Nour forests	Mixed beech forest	32.67	Late successional	Habashi (1998)
Chelir forests	Beech and hornbeam	16.50	Late successional	Zolfaghari (2005)
Patomforests*	Beech and hornbeam	5.10	Early successional	Sefidi (2007)
Namkhaneh forests*	Beech and hornbeam	3.30	Middle successional	Sefidi (2007)
Gorazbon forests	Beech and hornbeam	25.98	Middle successional	Sefidi (2010)
Hafroud forests	Beech and hornbeam	22.09	Middle successional	Present study
Chafroud forests*	Beech and hornbeam	8.62	Middle successional	Present study

*Managed forests (with logging operations)

CONCLUSIONS

1. The residual accumulation of WD from the managed stands was low, and the accumulation of higher stocks of woody debris requires a long time in the managed stands under selective logging treatments.
2. Management has led to drop in CWD.
3. Reductions in the volume of WD in forests may have negative consequences for endemic populations.
4. In managed forests, determination of the state of decay of woody debris during normal stand inventories is required for sustainable woody debris management.
5. We should be aware of the importance of the interaction between WD, living vegetation, and environmental factors for the forest ecosystem health.
6. By further examining the interplay of WD, managers and ecologists will be able gain new knowledge about the meaning of CWD for forest ecosystem.

ACKNOWLEDGMENTS

The authors would like to thank the administration of the University of Mohaghegh Ardabili for financial support for this project.

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Article submitted: January 19, 2014; Peer review completed: March 27, 2014; Revised version received and accepted: April 26, 2014; Published: May 19, 2014.