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Long-term effects of single-tree selection cutting management on coarse woody debris in natural mixed beech stands in the Caspian forest (Iran)

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Coarse woody debris (CWD) has a wide range of ecological and conservation values such as maintaining biodiversity in forest ecosystems. Each forest management method can have a detrimental effect on stand structure and CWD. We analyzed the volume and density of live trees and CWD (snags and downed logs) over a long-term (30 years) selection-logging managed compartment (harvested), and compared these with values obtained from an unlogged compartment (control) in the Iranian Caspian forests. Results showed that the volume and density of live trees and CWD in the harvested area was significantly lower than in the control area, especially large size trees and CWD, very decayed CWD, and rare tree species. The ratio of snags volume to total standing volume (RSS) was significantly higher in the control (7.9%) than in the harvested area (5.2%), and the ratio of downed logs volume to trees volume (RDT) in the control area (6.3%) was significantly higher than in the harvested area (4.6%), while the ratio of downed logs volume to snags volume (RDS) was significantly higher in the harvested area (83.6%) than in the control (74%). Based on the obtained results, we recommend selection cutting forests to be managed based on CWD management plans, including appropriate cutting cycles (15-30 years) and retention of large-diameter (DBH > 75 cm) and cavity trees as a suitable habitat for many wildlife species.

Keywords: Coarse Woody Debris, Snag, Biodiversity, Selective Logging, Caspian Forest

Introduction

Coarse Woody Debris (CWD) includes standing dead trees (snags) and downed logs on the forest floor (Sefidi et al. 2013). They are an important environmental element and are essential for maintaining biodiversity in forest ecosystems (Wisdom & Bate 2008). CWD plays an important role in supporting wildlife and assisting ecological processes (Corace et al. 2010, Hanberry et al. 2012). Wildlife use CWD for nesting, roosting, foraging, perching, and territorial displays (Lučan et al. 2009, Wisdom & Bate 2008). CWD has a wide range of ecological values in forest ecosystems, offering habitat for many living organisms (Lučan et al. 2009, Hanberry et al. 2012), providing carbon sequestration (Matsuzaki et al. 2013) and forest productivity preservation, as well as contributing to soil development and to nutrient cycles (Strukelj et al. 2013). CWD is an important component of wildlife habitat, and it is critical for the maintenance of biodiversity, soil organic matter and long-term site productivity (Tavankar et al. 2013, Picchio et al. 2016). CWD provides habitat including foraging sites, hiding and thermal cover, den sites, nesting, and travel corridors for a variety of species (Rose et al. 2001). Some of the species that use CWD are game animals, but many others are insectivorous non-game birds and mammals that help control forest pests. Snags with internal pockets of decay provide insulated and protected nest, roost, or den sites (Rose et al. 2001). Other types of snags, colonized by invertebrates, provide a rich foraging resource (Wisdom & Bate 2008). Research indicates that many forest insects are kept at low levels by insectivorous birds and small mammals that eat insects during all or part of their life cycle. In addition, many species of amphibians, reptiles, insects, plants, fungi, lichens, and bacteria are dependent on CWD, all being important components of forest diversity. The potential benefits to wildlife from the retention of CWD are dependent on several factors. Size, species, level of decay, and location affect the usefulness of deadwood to wildlife. In view of the demonstrated importance of CWD, some land-management agencies have management standards requiring the retention of specified numbers and kinds of CWD to provide habitat for wildlife.

Forest practices such as shorter rotations, firewood removal, timber stand improvement and insect and disease control efforts have limited the number of snags and downed logs available for wildlife habitat. Forest managers attempt to minimize decay and mortality of trees to reduce the

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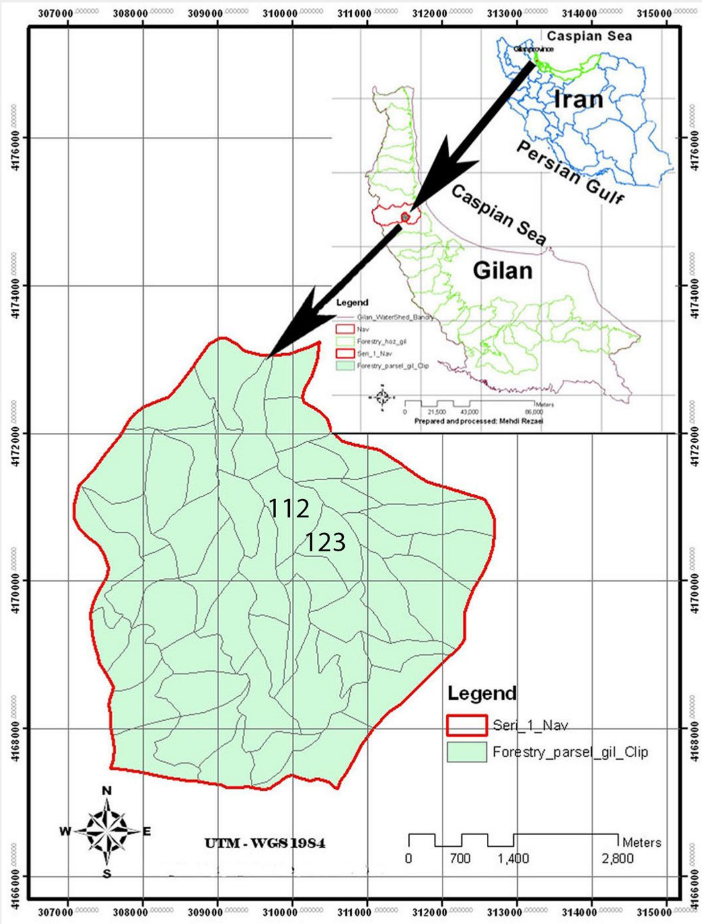

Fig. 1 - Geographic location of the study area. The two studied compartments are labeled with their inventory number (#112: managed stand;#123; un managed/control).

risk of insect and disease outbreaks and fire and logging hazards, as well as to maximize the space available for superior growing stock. Managing for quality saw timber with the single tree selection system often reduces the number of cavity trees and snags, which are removed under an intensive timber management regime (Perry & Thill 2013).

Intensive stand management usually involves the removal of diseased or deadwood. Timber harvest and human access (characterized by the distance to nearest town or road) can have substantial effects on snag density (Wisdom & Bate 2008). Maintaining snags in suitable abundance and different stages of decay is critical to the preservation of biodiversity and the sustained functioning of forest ecosystems (De Long et al. 2008).

Iranian Caspian ("Hyrcanian") forests are the most valuable forests in Iran, covering about 2 million ha in the south coast of the Caspian Sea and on the northern slopes of the Alborz mountain range, from sea level to 2800 m altitude. They are suitable habitats for a variety of hardwood species (approximately 80 woody species) and include various forest types. Pure and mixed oriental beech forests cover 17.6% of the surface land area and represent 30% of the standing volume in these forests (Tabari et al. 2005). Industrial harvesting occurs only in the Caspian forests, which are generally managed by selection cutting system.

The aim of this study was to investigate the long-term effect of single-tree selection cutting management on CWD characteristics. Density, volume, decay class and species of snags and logs were analyzed in beech stands in the Iranian Caspian forests. A better understanding of the amount and the dynamics of coarse woody debris both in protected areas and actively managed forests will help providing a valuable baseline for sustainable management goals.

Material and methods

Study area

The study area was located in the Nav forests (latitude: 37° 38′ 34″ to 37° 42′ 21″ N; longitude: 48° 48′ 44″ to 48° 52′ 30″ E) in the Guilan province, north of Iran (Fig. 1). The elevation in the study area ranges from 850 m to 1100 m a.s.l. The climate is temperate according to De Martonne's climate classification, with a mean annual temperature of 9.1 °C and a mean annual precipitation of 1050 mm in the period 1990-2008. Vegetation period lasts for 7 months on average. The original vegetation of this area is an uneven-aged mixed forest dominated by *Fagus orientalis* Lipsky and *Carpinus betulus* L., with the companion species *Alnus subcordata* C.A. May, *Acer platanoides* L., *Acer cappadocicum* Gled., *Ulmus glabra* Huds., and *Tilia rubra* DC. The soil at the study site is classified as a brown forest (*Alfisols*), well-drained, and the soil texture varies between sandy clay loam to clay loam.

Two adjacent compartments, namely, #123 (unharvested/control, 43 ha) and #112 (harvested, 63 ha), were selected within the study area for data collection (Fig. 1 – Tavankar et al. 2013). In general, the forests in the district are managed as a mixed-uneven aged high forest with single and group selective cutting regimes, but the compartment #123 has been protected as control forest since 1965, and no harvesting activities were carried out therein since then. Contrastingly, in the last 50 years the compartment #112 was harvested three times, the first using a shelter wood system and two times by applying a selection cutting system. The last selective logging in compartment #112 has been carried out in 2008 with semi-mechanized harvesting (felling of trees and extraction of logs were performed by chainsaw and Timberjack 450 C wheeled skidder, respectively).

Data collection

Circular sample plots with an area of 0.1 hectare were established within the study area based on a systematic grid (100 × 100 m) using a random start point in each compartment. In total, 40 plots were placed in the unlogged compartment (#123), and 60 plots were placed in the logged compartment (#112). At each plot the diameter at breast height (DBH) of all tree species was measured, and their stem volumes were calculated by local volume tables. Snags (DBH ≥ 10 cm) and downed logs (widest point ≥ 10 cm and length ≥1 m) were examined in each plot. For each sampled snags and downed logs, we recorded the species, DBH, height, volume, percentage of bark cover, and decay class. Species of snag was determined from bark characteristics. The DBH was recorded to the nearest cm using a DBH tape. The height of snags and the length of downed logs were measured with a meter stick. For snags taller than 4 m, a clinometer was used to estimate the height. Volume was calculated by the Huber's formula: $V=A_mH$, where V is the volume (m^3), A_m is the mid-point cross-sectional area (m^2) and H is the height (m). Bark coverage was visually estimated to the nearest 5%. Snag decay was determined based on 5 classes (Corace et al. 2010): DC1, recently dead trees with intact tops and the majority of fine branching present, structure is round, leaves and bark present, cambium is still fresh, wood solid, wood color is original; DC2, trees with loose bark, intact tops, and most of the fine branches, heartwood sound, leaves absent, bark present, larger twig present, trunk shape is round, wood solid, wood color is original, cambium decayed; DC3, trees with <50% of coarse branches and <50% bark, sapwood missing, heartwood mostly sound, leaves absent; DC4, trees with broken tops and few or no coarse branches, heartwood decayed soft, leaves absent, bark often absent, wood color is

Tab. 1 - Mean (± standard deviation) volume of trees, snags and downed logs of different species in harvested (#112) and control (#123) stands. (*): Other species include: *Mespilus germanica* L., *Prunus avium* L., *Pyrus communis* L., *Sorbus torminalis* L., *Prunus divaricata* Ledeb.

Species	Tree (m^3 ha^{-1})		Snag (m^3 ha^{-1})		Downed logs (m^3 ha^{-1})	
	Harvested	Control	Harvested	Control	Harvested	Control
Fagus orientalis	59.3 ± 11.8	78.3 ± 15.7	2.3 ± 0.5	4.8 ± 1.1	3.2 ± 1.4	4.3 ± 1.4
Carpinus betulus	41.6 ± 8.6	52.1 ± 10.4	2.1 ± 0.5	4.2 ± 1.2	2.7 ± 0.8	3.1 ± 1.6
Acer insigne	15.1 ± 3.5	29.0 ± 6.2	1.1 ± 0.4	2.8 ± 0.8	0.6 ± 0.1	1.2 ± 0.7
Acer cappadocicum	14.2 ± 3.5	26.1 ± 6.0	1.2 ± 0.3	2.5 ± 0.9	0.3 ± 0.1	1.4 ± 0.6
Alnus subcordata	11.0 ± 3.0	17.9 ± 4.5	1.2 ± 0.4	2.3 ± 0.7	0.5 ± 0.1	1.3 ± 0.4
Acer platanoides	10.7 ± 3.1	16.2 ± 3.7	0.3 ± 0.1	2.1 ± 0.6	0.3 ± 0.1	1.1 ± 0.4
Quercus castaniefolia	10.4 ± 3.0	21.7 ± 4.9	1.1 ± 0.3	1.9 ± 0.5	0.5 ± 0.1	1.6 ± 0.5
Tilia begonifolia	9.3 ± 2.7	20.0 ± 5.3	0.1 ± 0.1	1.6 ± 0.4	0.1 ± 0.0	1.1 ± 0.4
Ulmus glabra	5.9 ± 2.1	14.2 ± 2.6	0.1 ± 0.1	1.3 ± 0.3	0.1 ± 0.0	1.0 ± 0.3
Zelkova caprinifolia	5.2 ± 2.1	13.1 ± 3.0	0.3 ± 0.1	1.0 ± 0.2	0.1 ± 0.0	1.2 ± 0.4
Fraxinus coriarifolia	2.1 ± 1.0	8.4 ± 1.8	0.2 ± 0.1	0.5 ± 0.1	0.1 ± 0.0	1.1 ± 0.5
Other species*	3.6 ± 1.7	9.3 ± 2.0	0.4 ± 0.1	1.2 ± 0.1	0.2 ± 0.1	1.0 ± 0.3
All species	188.4 ± 20.4	306.3 ± 40.9	10.4 ± 6.2	26.2 ± 8.4	8.7 ± 5.4	19.4 ± 5.9

original to faded, all of log on ground; DC5, trees with broken tops and no coarse branches, trunk shape is round to oval, wood is fragmented and powdery, heavily faded, log wholly on ground.

Data analysis

The ratio (RSS) of snags volume to all stand volume (trees and snags) was calculated for each snag species and for each compartment as a snag-creativity index (snag-dynamic indicator). For downed-log creativity, the ratio of downed-logs volume to volume of standing live trees (RDT) was also used. For comparing snag longevity, the ratio of downed-logs volume to snags volume (RDS) was calculated for each snag species and for each compartment. After checking data for normality (Kolmogorov-Smirnov test, α=0.05) and homogeneity of variance (Levene test, α=0.05), the means of CWD (snag and downed log) density and characteristics (volume, DBH and height) were compared using independent samples *t*-test and one-way ANOVA in the logged and unlogged compartments. Multiple comparisons among means were made using the Duncan's test (α=0.05). Principal Components Analysis (PCA) was applied for the descriptive analysis of the ratios (RDT; RDS; RSS) between the two management systems. All statistical analyses were carried out using the software SPSS® v. 19.0 (IBM, Armonk, NY, USA).

Results

CWD and living trees

The mean (± standard deviation, SD) volume of standing live trees and CWD (snags and downed logs) in the harvested and control compartments are shown in Tab. 1. In both compartment, dead wood was present as logs and snags, but snags contributed more to the total dead wood volume than logs. The volume of trees in the harvested compartment (188.4 m^3 ha^{-1}) was significantly lower (t = 19.06; P < 0.001) than the trees volume in the controlled compartment (306.3 m^3 ha^{-1}).

The mean total volume of CWD in the control (45.6 ± 6.8 m^3 ha^{-1}) was significantly higher (t = 23.9; P < 0.01) than in the harvested compartment (19.1 ± 5.6 m^3 ha^{-1}). Both the snags volume and the downed-logs volume in the control (#123) were significantly higher (P < 0.01) than the harvested compartment (#112). Standing and downed CWD volume was twice as much in the control than in the harvested compartment. In terms of the volume of living trees, CWD was 10% in the managed area and 15% in the control.

Tree species composition and CWD were similar between compartments. *Fagus orientalis* and *Carpinus betulus* showed the largest volume of trees, snags and downed logs in the two compartments. The allocation of CWD in the harvested compartment was 54.5% on snags and 45.5% on downed logs, while in the control compartment the share of snags and downed logs was 57.5% and 42.5%, respectively.

Snag density

Snag density decreased with increasing DBH classes in the harvested and control compartments (Fig. 2). Snag density in the control was higher than in the harvested compartment in every DBH classes. Densities of large snags (DBH > 75 cm) in the control and harvested compartments were 4.6 and 0.7 stem ha^{-1} respectively. The mean (± SD) densities of snags in the control and harvested compartments were 25.1 ± 9.0 and 14.3 ± 5.3 stem ha^{-1}, respectively (t = 16.6; P < 0.001).

Size class distribution of snags and logs

The mean (± SD) volumes of CWD in size classes are shown in Tab. 2. In the control compartment, the snag and downed-log volume was higher than in the harvested one, and increased with increasing the size class. In the harvested compartment, the highest volume of snag and downed log was observed in the size class 50 to 75 cm. Also, the volume of snag and downed log raised to the 50-75 cm size class and then it

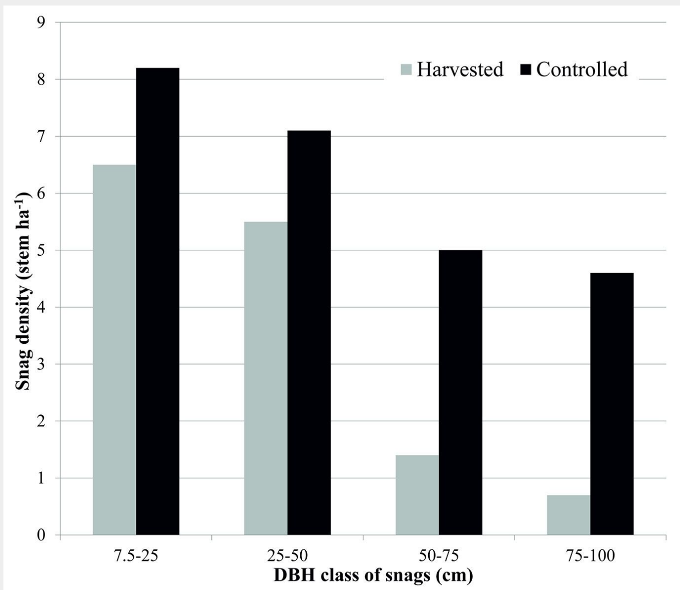

Fig. 2 - Snag density in the different DBH classes for the harvested and control stands.

Tab. 2 - Mean (± standard deviation) volume of CWD in the size classes in the harvested and control stands.

CWD	Size class (cm)	Harvested	Control	t	*P*-value
Snag (m^3 ha^{-1})	10-25	1.4 ± 1.1	1.5 ± 0.9	0.99	0.321
	25-50	1.9 ± 1.2	2.1 ± 0.9	0.82	0.413
	50-75	5.3 ± 2.9	7.2 ± 2.5	3.51	0.001
	75-100	1.8 ± 1.6	15.4 ± 5.2	18.40	0.000
Downed logs (m^3 ha^{-1})	10-25	1.7 ± 1.1	1.8 ± 0.9	0.48	0.633
	25-50	2.3 ± 1.1	2.5 ± 1.0	0.56	0.602
	50-75	3.5 ± 2.3	5.1 ± 2.6	3.41	0.001
	75-100	1.2 ± 0.7	10.0 ± 3.9	17.01	0.000

Tab. 3 - Mean (± standard deviation) volume of CWD in their decay classes in the harvested and control stands.

CWD	Decay class	Harvested	Control	t	*P*-value
Snag (m^3 ha^{-1})	DC1	2.3 ± 1.2	2.3 ± 0.8	0.15	0.582
	DC2	2.5 ± 1.3	2.5 ± 0.8	0.18	0.601
	DC3	3.1 ± 1.5	3.6 ± 1.0	0.26	0.381
	DC4	1.5 ± 0.5	5.7 ± 1.5	6.47	0.001
	DC5	1.0 ± 0.4	12.1 ± 3.2	16.54	0.000
Downed logs (m^3 ha^{-1})	DC1	1.1 ± 0.6	1.5 ± 0.4	1.20	0.096
	DC2	1.1 ± 0.5	1.8 ± 0.5	1.64	0.064
	DC3	1.3 ± 0.6	1.8 ± 0.6	1.52	0.073
	DC4	2.0 ± 0.9	5.2 ± 1.1	7.82	0.005
	DC5	3.3 ± 1.1	9.1 ± 3.0	10.06	0.000

decreased in the last size class.

Both snag volume and downed-log volume were significantly higher in the control than in the harvested compartment only in the two larger classes.

CWD volume distribution in decay classes

The mean (± SD) volumes of CWD in each decay class are shown in Tab. 3. In the control compartment the snags volume increased with increasing decay class (DC), while in the harvested compartment the snags volume decreased with increasing DC. The volumes of downed logs increased with increasing decay class in both compartments. The volumes of snags and downed logs in the control compartment were higher than in the harvested compartment in every decay class, but significant differences were found only for decay classes DC4 and DC5.

The overall CWD showed a different distribution pattern in the two stands. In each decay class the rate of volume was more or less the same in the harvested compartment. Only 41% of the decayed wood volume was found in DC4 and DC5. Contrastingly, In the control stand the volume in each decay class was increasing from DC1 to DC5, with 70% of the CWD volume being in DC4 and DC5.

CWD dynamics

Values of RSS, RDT and RDS are shown in Tab. 4. The RSS value for all species in the control compartment (7.9%) was significantly higher ($t = 5.7$; $P < 0.001$) than that observed in the harvested compartment (5.2%). The highest RSS value (11.5%) was observed for *Acer platanoides* in the control. Similarly, the RDT value for all species in the control stand (6.3%) was significantly higher ($t = 3.0$; $P < 0.023$) than that of the harvested compartment (4.6%). The RDS value, for comparing snag and log volume, was higher in the harvested compartment than the control (83.6% *vs.* 74%, respectively).

The results of PCA applied to ratio values (RSS, RDT and RDS – Fig. 3) showed a negative relationship between the presence, abundance and complexity of CWD and the intensity of forest management applied.

Discussion

CWD and living trees

Our results indicate that in the long term forest management significantly affects CWD in natural beech stands of Iranian Caspian forests, both in terms of presence and quality of deadwood. The deadwood volume decreases from multifunctional and extensive management to intensive forest management, which is usually associated with lower CWD amounts (Paletto et al. 2014).

Forestry operations affect the recruitment of CWD by harvesting the future CWD (Kenefic & Nyland 2007, De Groot et al. 2016). In our study the CDW and live tree volumes were higher in the control, unlogged area. Similar results were observed by Lombardi et al. (2008) in an Apenine-Corsican montane beech forest and by Christensen et al. (2005) in beech mixed forests of Central Europe. They found that the total dead wood volume and the dead to live wood ratio was highest for longtime (>50 years ago) established montane reserves.

Tab. 4 - Values of RSS (ratio of snags volume to total standing volume), RDT (ratio of volume of downed logs to volume of trees), and RDS (ratio of volume of downed logs to volume of snags) in the harvested and control stands.

Species	RSS (%)		RDT (%)		RDS (%)	
	Harvested	Control	Harvested	Control	Harvested	Control
Fagus orientalis	3.7	5.8	5.4	5.5	139.1	89.6
Carpinus betulus	4.8	7.5	6.5	5.9	128.6	73.8
Acer insigne	6.8	8.8	4.0	4.1	54.5	42.9
Acer cappadocicum	7.8	8.7	2.1	5.4	25.0	56.0
Alnus subcordata	9.8	11.4	4.5	7.3	41.7	56.5
Acer platanoides	2.7	11.5	2.8	6.8	100	52.4
Quercus castaniefolia	9.6	8.0	4.8	7.4	45.4	84.2
Tilia begonifolia	1.1	7.4	1.1	5.5	100	68.7
Ulmus glabra	1.7	8.4	1.7	7.0	100	76.9
Zelkova caprinifolia	5.4	7.1	1.9	9.2	33.3	120.0
Fraxinus coriarifolia	8.7	5.6	4.8	13.1	50.0	220.0
Other species	10.0	11.4	5.5	10.7	50.0	83.3
All species	5.2	7.9	4.6	6.3	83.6	74.0

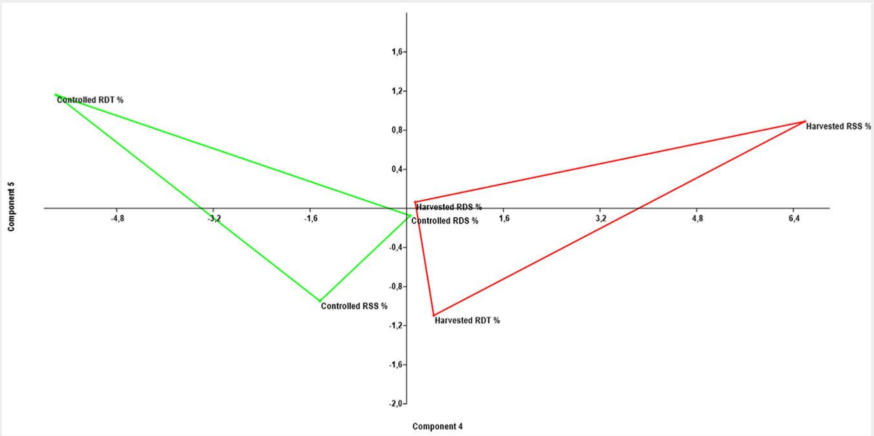

Fig. 3 - PCA results based on RSS, RTD and RDS values for the harvested area (red triangle) and for the control area (green triangle).

In southern Italian forests of *Quercus frainetto* under different management conditions and evolutionary stages, Barreca et al. (2008) observed that, in addition to the management, the presence of deadwood was affected by grazing and deadwood collection by the local population. In a beech forest located in a central Apennines fully protected area, Coppini & Hermanin (2007) investigated a forest area with heterogeneous structure stemming from no logging activities since the middle 20th century and progressive abandonment of grazing, finding different amounts of deadwood as a result of increased human activities.

The single-tree selection cutting method adopted in Hircanian forests reduced the density and volume of snags and downed logs. The effect of three cutting practices were studied by Pamerleau-Couture et al. (2015), who noted no differences between uneven- and even-aged stands, though in the latter a lower deadwood basal area was observed. Castagneri et al. (2010) in montane mixed forests of Eastern Italian Alps reported that CWD characteristics were influenced by elevation and the time elapsed since the last human intervention, as well as by live tree density (in terms of basal area) and harvesting. The long-term effects of logging activities (even selective) are related to the lower amount not only of the left deadwood, but also of the nesting cavity trees available (Müller et al. 2007).

Snags and logs in our study area showed the same species composition of the living trees, and this was similar in managed and unmanaged compartments. These findings are in accordance with those reported by Tavankar et al. (2014) in an unmanaged compartment of the Caspian Forest, but in contrast with those by Behjou et al. (2014) who found differences due to forest management in the Guilan province forests.

Snags density

Snags in the control stand were nearly twice as much than in the harvested compartment. Similar results were reported by Wisdom & Bate (2008) in the Rocky Mountains forests. They found that stands with long history of no timber harvesting had 3 times the density of snags as compared to stands selectively harvested. Russell et al. (2012) in the Acadian forest in Maine, Kenefic & Nyland (2007) in northern hardwood stands in central New York, Sefidi & Marvie Mohadjer (2010) in hardwood mixed forest in Alborz mountain of Iran, Abkenari et al. (2012) in the Caspian forests, and Behjou et al. (2014) in hardwood mixed forest in northern Iran also found similar results. Moreover, Tavankar et al. (2014) found a more even distribution of snag diameters in a fully protected area than in a selectively logged area located in the Caspian lowland forests.

Hansen et al. (1991) reported that snag densities were 3-5 times greater in unharvested *vs.* clearcut plots for age classes 40-79 and 80-200 years old. Martin & Barrett (1983) reported mean snag densities of 26.5 and 21.7 snags ha^{-1} respectively, in the upper and lower portions of the Saghen Creek Watershed in northern Nevada. Carmichael & Guynn (1983) studied snag density in four cover types (*e.g.*, cove hardwoods, upland hardwood, pine-hardwood, and pine plantation) in the Upper Piedmont of South Carolina; snag density was greatest in upland hardwood stands (50.3 snags ha^{-1}) and least in pine plantations (21.3 snags ha^{-1}). Ohmann et al. (1994) quantified snag densities and characteristics across a range of stand conditions and forest types in northwestern USA (Oregon and Washington States), and reported that snag density increased with each successional stage in the temperate coniferous and conifer-hardwood forest types. Moriarty & McComb (1983) surveyed two watersheds in central USA (Kentucky), reporting average snag densities of 18.0 and 14.8 snags ha^{-1} at two different study sites. McComb & Noble (1980) obtained similar results (14.1 snags ha^{-1}) for managed forests in Connecticut (USA). McComb & Muller (1983) investigated snag density in old-growth forests in southeastern Kentucky (USA), finding a mean density of 44.2 snags ha^{-1}.

In the Caspian mixed forest, Ghadiri Khanaposhtani et al. (2013) studied the effect of forest logging on avian communities, finding 6.66 ± 0.37 and 4.32 ± 0.42 snag ha^{-1} in control and harvested stands, respectively. They underlined that species diversity is mostly correlated with the number of dead trees and that woodpeckers, especially Black Woodpecker and Green Woodpecker, utilize preferably snags with more than 25 cm DBH. Finally, Tavankar et al. (2014) reported 38.4 snags ha^{-1} in a fully protected area and 23.7 snags ha^{-1} in a selective logged area in the lowland Hyrcanian forest.

Size class distribution of snags and logs

Although both logged and unlogged stands showed all size and decay classes, different patterns of CWD distribution in size and decay classes were detected, related to forest management.

The volume and density of large-size CWD was significantly higher in the control than the harvested compartment. Forest management activities affect tree density acting on natural tree mortality. Senescent, dying or standing dead trees are CWD sources which are usually harvested to avoid pest problems and fire hazards, as well as to maximize the commercial value of the harvest. However, management methods, abundance and characteristics of CWD are highly variable among regions and are dependent on forest type, successional stage, and climate.

Our results agree with the generalization of Nilsson et al. (2002), based on the literature on North America and Europe old-growth temperate and boreal forests. They suggest that the volume of dead wood is directly proportional to the productivity of old-growth forests, and that about 10% of all standing trunks (including high stumps) are dead, but this proportion increases for the larger trees. In the Mazandaran Province in Iran, Sefidi & Marvie Mohadjer (2010) examined the amount of dead wood in mixed beech forests in late, middle and early successional stages. They found that the CWD volumes differed among successional stages in beech dominated forests, with the late-successional forest having the highest CWD volume (51.25 m^3 ha^{-1}), and logs (32.74 m^3 ha^{-1}) being the major contributors. A survey of Abkenari et al. (2012) on dead wood amount in northern Iranian forests estimated dead wood volume to be 2.55 m^3 ha^{-1} in the unmanaged forest and 1.76 m^3 ha^{-1} in the managed forest.

Besides the total amount, also the species, distribution among size classes and the state of decomposition affect the ecological value of deadwood. Our results showed that the managed stands had the lower number and volume of snags and logs in the higher size and decay class. Indeed, the CWD volume in the higher size class (DBH > 75 cm) of the control area was more than 8 times that of the harvested stand. Likewise, the number of snags with DBH > 75 cm in the control area was 6.5 times higher than that observed in the harvested stand. These results clearly indicate the effect of forest management on CWD, in that natural mortality of trees is replaced by harvesting. In general, large snags (size class > 75 cm) represent the most important cavity source for nesting birds, and are more ecologically meaningful than small snags as they can be used by a wider variety of species. For example, in the Hyrcanian forests Ghadiri Khanaposhtani et al. (2012) found that high volumes of coarse woody debris (especially large snags) and dense canopy cover are suitable habitat features for the black woodpecker, *Dryocopus martius*. Similarly, the American marten in the north-eastern US prefers forests with larger downed logs (large-end diameter 21 ± 0.8 cm) and snag volumes of more than 10 m^3 ha^{-1} (Payer & Harrison 2003).

From an ecological point of view, snags with large diameter are particularly important, due to their richness in microhabitats (Ziaco et al. 2012) and their slower decay compared to downed dead wood (Boulanger & Sirois 2006, Zielonka 2006).

CWD decay classes

In this study, different patterns of CWD distribution in the decay classes were observed between harvested and control areas. Significant differences between the managed and unmanaged stands were found only in the higher decay classes (DC4 and DC5). The higher amount of snags and logs volume in higher decay classes of the control stand may be explained by the absence of harvesting disturbances therein since 1965. In fact, patterns of snag dynamics due to natural disturbances are markedly different from those due to harvest. In the Guilan province (northern Iran), the CWD volume in the DC4 and DC5 decay classes was 7% and 54% in managed and unmanaged stands, respectively (Behjou et al. 2014). In this study, the unlogged stand had probably more consistent and slower-decaying CWD inputs compared to the harvested stand. Indeed, the larger amount of thicker trunks and branches observed in the unmanaged stand suggests a longer decomposition time as compared with the harvested stand (Müller-Using & Bartsch 2009).

Snag and log dynamic

The snag-creativity index (RSS) was significantly higher in the unlogged than in the logged compartment (7.9 % *vs.* 5.2%, respectively). Other authors noted that density (in terms of basal area or higher volume) is related to a higher level of CWD. At the species level, *Tilia begonifolia, Ulmus glabra* and *Acer platanoides* showed the lowest RSS in the logged compartment and higher RSS in the unlogged compartment. This evidence may reflect a higher harvesting rate for these species, which were preferably extracted from the managed stand in the previous single-tree selection cutting period.

The RDS value is influenced by snag longevity and reflects the log dynamics in the analyzed compartments. We found a higher RDS value for the managed stand compared to the unmanaged one (83.6% *vs.* 74%, respectively), likely due to a lower volume of snags in the logged area. Differences in RDS were more evident at the species level, as a consequence of different wood durability, size and growth rate among different species (Angers et al. 2012). A clear example is beech, which showed a high RDS in both compartments, though the control showed a lower RDS than the managed compartment, indicating a higher volume of snag. This is consistent with the observation of Müller-Using & Bartsch (2009), who found an increasing transition time between decay classes as CWD decay progressed in beech. Moreover, the transition in the last decay class needs almost half of the total transition time.

Previous studies on snag longevity have identified tree species, tree size, decay stage, crown scorch, and stand density as important factors in determining the snag longevity (Everett et al. 1999). Therefore, we recommend snags of various sizes, decay classes and species to be left in managed stands. Rotting wood found on the forest floor and later integrated in the soil by decomposition provides seedbeds for a variety of tree, shrub, and herbaceous species as well as rooting medium that retains moisture during dry periods. Further, single snags scattered over large forest areas may not provide enough nesting and foraging habitat for many species.

Conclusion

The amount and characteristics of CWD in Iranian Caspian forests are affected by single-tree selection cutting management. A reduction in volume and density of snags and downed logs in selectively logged forests may have negative consequences for wildlife. Therefore, we recommend selection cutting forests to be managed based on CWD management plans including appropriate cutting cycles (15-30 years) and retention of large-diameter (DBH > 75 cm) and cavity trees as a suitable habitat for many wildlife species. Further, snag management affects the CWD distribution in different decay phases over time. As snags are future downed wood, the retention of large trees as future snags is recommended in managed forests to sustain wildlife populations that depend on these resources. A careful management of dead wood in actively managed forests may contribute to the conservation of biodiversity at the local level, and may allow to connect productive stands with forest area aimed to conservation (Mason & Zapponi 2015).

Sustainable forest management requires information about volume and distribution of CWD in size and decay classes. The levels and distribution of CWD in selection managing forests must be consistent to those found in similar natural communities.

List of abbreviations

CWD: coarse woody cebris; DBH: diameter at breast height; RSS: ratio of snags volume to total standing volume; RDT: ratio of downed logs volume to trees volume; RDS: ratio of downed logs volume to snags volume.

References

Abkenari KT, Akbari F, Pilehvar B (2012). Effect of intervention and type of forest management on quality and quantity characteristics of dead wood in managed and reserve forests: a case study. Journal of Forestry Research 23 (3): 413-418. - doi: 10.1007/11676-012-0278-9

Angers VA, Drapeau P, Bergeron Y (2012). Mineralization rates and factors influencing snag decay in four North American boreal tree species. Canadian Journal of Forest Research 42 (1): 157-166. - doi: 10.1139/X11-167

Barreca L, Cutini A, Mercurio R (2008). Dead wood characterisation in *Quercus frainetto* stands in Calabria (Southern Italy). Forest@ 5 (1): 187-194. [in Italian with English summary] - doi: 10.3832/efor0527-0050187

Behjou FK, Mollabashi OG, Amirahamdi N (2014). Effect of management on the amount and characteristics of wood debris in mixed stands of Caspian forest. BioResources 9 (3): 4108-4116.

Boulanger Y, Sirois L (2006). Postfire dynamics of black spruce coarse woody debris in northern boreal forest of Quebec. Canadian Journal of Forest Research 36 (7): 1770-1780. - doi: 10.1139/x06-070

Carmichael DB, Guynn DC (1983). Snag density and utilization by wildlife in the upper Piedmont of South Carolina. In: Proceedings of the Symposium "Snag Habitat Management". Flagstaff (AZ, USA) 7-9 Jun 1983. General Technical Report RM-99, Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, Fort Collins, CO, USA, pp. 107-110. [online] URL: http://www.fs.fed.us/rm/pubs_rm/rm_gtr099.pdf#page=113

Castagneri D, Garbarino M, Berretti R, Motta R (2010). Site and stand effects on coarse woody debris in montane mixed forests of Eastern Italian Alps. Forest Ecology and Management 260 (9): 1592-1598. - doi: 10.1016/j.foreco.2010.08.008

Christensen M, Hahn K, Mountford EP, Odor P, Standovar T, Rozenbergar D, Diaci J, Wijdeven S, Meyer P, Winter S, Vrska T (2005). Dead wood in European beech (*Fagus sylvatica*) forest reserves. Forest Ecology and Management 210: 267-282. - doi: 10.1016/j.foreco.2005.02.032

Coppini M, Hermanin L (2007). Restoration of selective beech coppices: a case study in the Apennines (Italy). Forest Ecology and Management 249: 18-27. - doi: 10.1016/j.foreco.2007.04.035

Corace RG, Seefelt NE, Goebel PC, Shaw HL (2010). Snag longevity and decay class development in a recent Jack Pine clearcut in Michigan. Northern Journal of Applied Forestry 27 (4): 125-131.

De Groot M, Eler K, Flajšman K, Grebenc T, Marinšek A, Kutnar L (2016). Differential short-term response of functional groups to a change in forest management in a temperate forest. Forest Ecology and Management 376: 256-264. - doi: 10.1016/j.foreco.2016.06.025

De Long SC, Sutherland GD, Daniels LD, Heemskerk BH, Storaunet KO (2008). Temporal dynamics of snags and development of snag habitats in wet spruce-fir stands in east-central British Columbia. Forest Ecology and Management 255 (10): 3613-3620. - doi: 10.1016/j.foreco.2008.02.043

Everett R, Lehmkuhl J, Schellhaas R, Ohlson P, Keenum D, Riesterer H, Spurbeck D (1999). Snag dynamics in a chronosequence of 26 wildfires on the east slope of the Cascade Range in Washington State, USA. International Journal of Wildland Fire 9 (4): 223-234. - doi: 10.1071/WF00011

Ghadiri Khanaposhtani M, Kaboli M, Karami M, Etemad V (2012). Effect of habitat complexity on richness, abundance and distributional pattern of forest birds. Environmental Management 50: 296-303. - doi: 10.1007/s00267-012-9877-7

Ghadiri Khanaposhtani M, Kaboli M, Karami M, Etemad V, Baniasadi S (2013). Effects of logged and unlogged forest patches on avifaunal diversity. Environmental Management 51 (3): 750-758. - doi: 10.1007/s00267-012-9979-2

Hanberry BB, Hanberry P, Demarais S, Jones JC (2012). Importance of residual trees to birds in regenerating pine plantations. iForest 5: 108-112. - doi: 10.3832/ifor0616-005

Hansen AJ, Spies TA, Swanson FJ, Ohmann TL (1991). Conserving biodiversity in managed forests. BioScience 41 (6): 382-392. - doi: 10.2307/1311745

Kenefic LS, Nyland RD (2007). Cavity trees, snags, and selection cutting: a northern hardwood case study. Northern Journal of Applied Forestry 24 (3): 192-196. [online] URL: http://www.ingentaconnect.com/content/saf/njaf/2007/00000024/00000003/art00006

Lombardi F, Cherubini P, Lasserre B, Tognetti R, Marchetti M (2008). Tree rings used to assess time since death of deadwood of different decay classes in beech and silver fir forests in the central Apennines (Molise, Italy). Canadian Journal of Forest Research 38 (4): 821-833. - doi: 10.1139/X07-195

Lučan RK, Hanák V, Horáček I (2009). Long-term re-use of tree roosts by European forest bats. Forest Ecology and Management 258 (7): 1301-1306. - doi: 10.1016/j.foreco.2009.06.032

Martin SH, Barrett RH (1983). The importance of snags to Pine Marten habitat in the Northern Sierra Nevada. In: Proceedings of the Symposium "Snag Habitat Management". Flagstaff (AZ, USA) 7-9 Jun 1983. General Technical Report RM-99, Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, Fort Collins, CO, USA, pp. 114-116.

Mason F, Zapponi L (2015). The forest biodiversity artery: towards forest management for saproxylic conservation. iForest 9: 205-216. - doi: 10.3832/ifor1657-008

Matsuzaki E, Sanborn P, Fredeen AL, Shaw CH, Hawkins C (2013). Carbon stocks in managed and unmanaged old-growth western red cedar and western hemlock stands of Canada's inland temperate rainforests. Forest Ecology and Management 297: 108-119. - doi: 10.1016/j.foreco.2012.11.042

McComb WC, Noble RE (1980). Effects of single-tree selection cutting upon snag and natural cavity characteristics in Connecticut. Transactions of the Northeast Section of the Wildlife Society 37: 50-57.

McComb WC, Muller RN (1983). Snag densities in old-growth and second-growth Appalachian forests. Journal of Wildlife Management 47 (2): 376-382. - doi: 10.2307/3808510

Moriarty JJ, McComb WC (1983). The long-term effect of timber stand improvement on snag and cavity densities in the Central Appalachians. In: Proceedings of the Symposium "Snag Habitat Management". Flagstaff (AZ, USA) 7-9 Jun 1983. General Technical Report RM-99, Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, Fort Collins, CO, USA, pp. 40-44. [online] URL: http://www.fs.fed.us/rm/pubs_rm/rm_gtr099.pdf#page=46

Müller J, Horton T, Pretzsch H (2007). Long-term effects of logging intensity on structures, birds, saproxylic beetles and wood-inhabiting fungi in stands of European beech *Fagus sylvatica* L. Forest Ecology and Management 242: 297-305. - doi: 10.1016/j.foreco.2007.01.046

Müller-Using S, Bartsch N (2009). Decay dynamic of coarse and fine woody debris of a beech (*Fagus sylvatica* L.) forest in Central Germany. European Journal of Forest Research 128 (3): 287-296. - doi: 10.1007/s10342-009-0264-8

Nilsson SG, Niklasson M, Hedin J, Aronsson G, Gutowski JM, Linder P, Ljungberg H, Mikusiński G, Ranius T (2002). Densities of large living and dead trees in old-growth temperate and boreal forests. Forest Ecology and Management 161 (1-3): 189-204. - doi: 10.1016/S0378-1127(01)00480-7

Ohmann JL, McComb WC, Zumrawi AA (1994). Snag abundance for primary cavity nesting birds on nonfederal forest lands in Oregon and Washington. Wildlife Society Bulletin 22 (4): 607-620. [online] URL: http://www.jstor.org/stable/3783086

Paletto A, De Meo I, Cantiani P, Ferretti F (2014). Effects of forest management on the amount of deadwood in Mediterranean oak ecosystems. Annals of Forest Science 71 (7): 791-800. - doi: 10.1007/s13595-014-0377-1

Pamerleau-Couture E, Krause C, Pothier D, Weiskittel A (2015). Effect of three partial cutting practices on stand structure and growth of residual black spruce trees in north-eastern Quebec. Forestry 88 (4): 471-483. - doi: 10.1093/forestry/cpv017

Payer DC, Harrison DJ (2003). Influence of forest structure on habitat use by American marten in an industrial forest. Forest Ecology and Management 179 (1-3): 145-156. - doi: 10.1016/S0378-1127(02)00517-0

Perry RW, Thill RE (2013). Comparison of snag densities among regeneration treatments in mixed pine-hardwood forests. Canadian Journal of Forest Research 43 (7): 619-626. - doi: 10.1139/cjfr-2013-0005

Picchio R, Spina R, Calienno L, Venanzi R, Lo Monaco A (2016). Forest operations for implementing silvicultural treatments for multiple purposes. Italian Journal of Agronomy 11: 156-161.

Rose CL, Marcot BG, Mellen TK, Ohmann JL, Wadell KL, Lindley DL, Schreiber B (2001). Decaying wood in Pacific Northwest Forests: concepts and tools for habitat management. Oregon State University Press, Corvallis, OR, USA, pp. 580-623.

Russell MB, Kenefic LS, Weiskitte AR, Puhlick JJ, Brissette JC (2012). Assessing and modeling standing deadwood attributes under alternative silvicultural regimes in the Acadian forest region of Maine, USA. Canadian Journal of Forest Research 42: 1873-1883. - doi: 10.1139/x2012-131

Sefidi K, Marvie Mohadjer MR (2010). Characteristics of coarse woody debris in successional stages of natural beech (*Fagus orientalis*) forests of Northern Iran. Journal of Forest Science 56 (1): 7-17. [online] URL: http://www.researchgate.net/publication/256293231

Sefidi K, Marvie Mohadjer MR, Mosandl R, Copenheaver C (2013). Coarse and fine woody debris in mature Oriental Beech. Natural Areas Journal 33 (3): 248-255. - doi: 10.3375/043.033.0303

Strukelj M, Brais S, Quideaua SA, Angers VA, Kebli H, Drapeau P, Oh S (2013). Chemical transformations in downed logs and snags of mixed boreal species during decomposition. Canadian Journal of Forest Research 43 (9): 785-798. - doi: 10.1139/cjfr-2013-0086

Tabari M, Fayaz P, Espahbodi K, Staelens J, Nachtergale L (2005). Response of oriental beech (*Fagus orientalis* Lipsky) seedlings to canopy gap size. Forestry 78 (4): 443-450. - doi: 10.1093/forestry/cpi032

Tavankar F, Bonyad AE, Iranparast Bodaghi A (2013). Effects of snags on the species diversity and frequency of tree natural regeneration in natural forest ecosystems of Guilan. Iranian Journal of Plant Researches 26 (3): 267-280.

Tavankar F, Picchio R, Lo Monaco AR, Bonyad AE (2014). Forest management and snag characteristics in Northern Iran lowland forests. Journal of Forest Science 60 (10): 431-441. [online] URL: http://www.researchgate.net/publication/285965223

Wisdom MJ, Bate LJ (2008). Snag density varies with intensity of timber harvest and human access. Forest Ecology and Management 255 (7): 2085-2093. - doi: 10.1016/j.foreco.2007.12.027

Ziaco E, Di Filippo A, Alessandrini A, Baliva M, D'Andrea E, Piovesan G (2012). Old-growth attributes in a network of Apennines (Italy) beech forests: disentangling the role of past human interferences and biogeoclimate. Plant Biosystems 146 (1): 153-166. - doi: 10.1080/11263504.2011.650729

Zielonka T (2006). Quantity and decay stages of coarse woody debris in old-growth subalpine spruce forests of the western Carpathians. Poland. Canadian Journal of Forest Research 36 (10): 2614-2622. - doi: 10.1139/x06-149