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 productivity. 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
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 habi-
tats for a variety of hardy species (ap-
proximately 80 woody species) and include
various forest types. Pure and mixed orien-
tal beech forests cover 17.6% of the surface
land area and represent 30% of the stand-
ing 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 selec-
tion cutting management on CWD charac-
teristics. 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 base-
line 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 tem-
perate according to De Martonne’s climate
classification, with a mean annual tempera-
ture of 9.4 °C and a mean annual precipita-
tion 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 domi-
nated by Fagus orientalis Lipsky and Carpi-
nus 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 harvest-
ing 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 sys-
tem 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 com-
partment. In total, 40 plots were placed in
the unlogged compartment (#123), and 60
plots were placed in the logged compart-
ment (#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 exam-
ined 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 Hu-
ber’s formula: \( V = \frac{A_H H}{3} \), where \( V \) is the vol-
ume (\( m^3 \)), \( A_H \) 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 deter-
mined 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

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).
original to faded, all of log on ground; DCs, 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 m³ ha⁻¹) was significantly lower (t = 19.06; P < 0.001) than the trees volume in the controlled compartment (306.3 m³ ha⁻¹).

The mean total volume of CWD in the control (45.6 ± 6.8 m³ ha⁻¹) was significantly higher (t = 23.9; P < 0.01) than in the harvested compartment (19.1 ± 5.6 m³ 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.

Table 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.

<table>
<thead>
<tr>
<th>Species</th>
<th>Tree (m³ ha⁻¹)</th>
<th>Snag (m³ ha⁻¹)</th>
<th>Downed logs (m³ ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fagus orientalis</td>
<td>59.3 ± 11.8</td>
<td>78.3 ± 15.7</td>
<td>2.3 ± 0.5</td>
</tr>
<tr>
<td>Carpinus betulus</td>
<td>41.6 ± 8.6</td>
<td>52.1 ± 10.4</td>
<td>2.1 ± 0.5</td>
</tr>
<tr>
<td>Acer insigne</td>
<td>15.1 ± 3.5</td>
<td>29.0 ± 6.2</td>
<td>1.1 ± 0.4</td>
</tr>
<tr>
<td>Acer cappadocicum</td>
<td>14.2 ± 3.5</td>
<td>26.1 ± 6.0</td>
<td>1.2 ± 0.3</td>
</tr>
<tr>
<td>Alnus subcordata</td>
<td>11.0 ± 3.0</td>
<td>17.9 ± 4.5</td>
<td>1.2 ± 0.4</td>
</tr>
<tr>
<td>Acer platanoides</td>
<td>10.7 ± 3.1</td>
<td>16.2 ± 3.7</td>
<td>0.3 ± 0.1</td>
</tr>
<tr>
<td>Quercus castanifolia</td>
<td>10.4 ± 3.0</td>
<td>21.7 ± 4.9</td>
<td>1.1 ± 0.3</td>
</tr>
<tr>
<td>Tilia begonifolia</td>
<td>9.3 ± 2.7</td>
<td>20.0 ± 5.3</td>
<td>0.1 ± 0.1</td>
</tr>
<tr>
<td>Ulmus glabra</td>
<td>5.9 ± 2.1</td>
<td>14.2 ± 2.6</td>
<td>0.1 ± 0.1</td>
</tr>
<tr>
<td>Zelkova carpinifolia</td>
<td>5.2 ± 2.1</td>
<td>13.1 ± 3.0</td>
<td>0.3 ± 0.1</td>
</tr>
<tr>
<td>Fraxinus coriariafolia</td>
<td>2.1 ± 1.0</td>
<td>8.4 ± 1.8</td>
<td>0.2 ± 0.1</td>
</tr>
<tr>
<td>Other species*</td>
<td>3.6 ± 1.7</td>
<td>9.3 ± 2.0</td>
<td>0.4 ± 0.1</td>
</tr>
<tr>
<td>All species</td>
<td>188.4 ± 20.4</td>
<td>306.3 ± 40.9</td>
<td>10.4 ± 6.2</td>
</tr>
</tbody>
</table>

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

**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 Apennine-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 long-time (>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.**

<table>
<thead>
<tr>
<th>Species</th>
<th>RSS (%)</th>
<th>RDT (%)</th>
<th>RDS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Harvested</td>
<td>Control</td>
<td>Harvested</td>
</tr>
<tr>
<td>Fagus orientalis</td>
<td>3.7</td>
<td>5.8</td>
<td>5.4</td>
</tr>
<tr>
<td>Carpinus betulus</td>
<td>4.8</td>
<td>7.5</td>
<td>6.5</td>
</tr>
<tr>
<td>Acer insigne</td>
<td>6.8</td>
<td>8.8</td>
<td>4.0</td>
</tr>
<tr>
<td>Acer cappadocicum</td>
<td>7.8</td>
<td>8.7</td>
<td>2.1</td>
</tr>
<tr>
<td>Alnus subcordata</td>
<td>9.8</td>
<td>11.4</td>
<td>4.5</td>
</tr>
<tr>
<td>Acer platanoides</td>
<td>2.7</td>
<td>11.5</td>
<td>2.8</td>
</tr>
<tr>
<td>Quercus castaneifolia</td>
<td>9.6</td>
<td>8.0</td>
<td>4.8</td>
</tr>
<tr>
<td>Tilia begonifolia</td>
<td>1.1</td>
<td>7.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Ulmus glabra</td>
<td>1.7</td>
<td>8.4</td>
<td>1.7</td>
</tr>
<tr>
<td>Zelkova caprinifolia</td>
<td>5.4</td>
<td>7.1</td>
<td>1.9</td>
</tr>
<tr>
<td>Fraxinus coriariifolia</td>
<td>8.7</td>
<td>5.6</td>
<td>4.8</td>
</tr>
<tr>
<td>Other species</td>
<td>10.0</td>
<td>11.4</td>
<td>5.5</td>
</tr>
<tr>
<td>All species</td>
<td>5.2</td>
<td>7.9</td>
<td>4.6</td>
</tr>
</tbody>
</table>
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 Gulan province forests.

**Snags density**

Snags in the control stand were nearly twice as much as 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 Sagen 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 & Mulder (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 selectively logged area in the lowland Hircanian 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. Successive, 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 m³ ha⁻¹), and logs (32.74 m³ 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 m³ ha⁻¹ in the unmanaged forest and 1.76 m³ 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

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**Fig. 3** - PCA results based on RSS, RTD and RDS values for the harvested area (red triangle) and for the control area (green triangle).
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 Hycarian forests Ghadir Khanaposhani 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 m³ 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 & Sirot 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 Gullan 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 constant 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).

Snap and log dynamic

The snap-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 amount 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 higher RDS in both compartments, though the control showed a lower RDS than the managed compartment, indicating a higher volume of snags. 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 three 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 debris; 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


Single-tree selection cutting effect on CWD in mixed stands


