Advances in Bioresearch
Adv. Biores., Vol 7 (5) September 2016: 145-153
©2016 Society of Education, India
Print ISSN 0976-4585; Online ISSN 2277-1573
Journal's URL:http://www.soeagra.com/abr.html
CODEN: ABRDC3
ICV Value 8.21 [2014]

Advances in Bioresearch

ORIGINAL ARTICLE

Modeling decay rate of dead wood of a European hornbeam (*Carpinus Betulus*) in a deciduous forest in North of Iran

Fatemeh Alidadi[1], Kiomars Sefidi[2]*, MohammadrezaMarvi- Mohadjer[1], Vahid Etemad[1]
[1]Department of Forestry, Faculty of Natural Resources, University of Tehran, Tehran, Iran
[2] Faculty of Agriculture Technology and Natural resources, University of MohagheghArdabili, Ardabil, Iran
* Corresponding author: kiomarssefidi@gmail.com

ABSTRACT
The Decay rates of dead wood were estimated and used to model the decay of hornbeam stumps in a deciduous forest in North of Iran. We measured the remaining fraction of stump from 36 dead wood of hornbeam. In the samples tree species, stump diameters and decay stage of dead wood were recorded. Single-exponential modeling used for describing the decay rate. The results showed that the single-exponential model appropriately describe a decay trend in hornbeam's dead wood (R=0.87) based on the variation of dead wood density through the time. According to the results, the hornbeam's dead wood decay constant calculated 0.182 in a year and the required period for decaying 95% of dead woods of hornbeam's CWD under the ruling conditions in Caspian forests is about 16 years under the presented climatic conditions. Furthermore, with the levels of decay increasing, density is reduced (R=0.89) and there is a significant difference between the density of dead wood in years and different decay stages. There is also a significant difference between the annual decay rate and decay classes, as the annual decay rate is reduced with time (R=0.86) and decay stages (R=0.81) increasing. Overall, if the providing dead wood pool is necessary to support forest ecosystem integrity in a managed forests, these results revealed dead wood of hornbeam can be remain about 16 within stands.
Key words: Decomposition, Decay constant Wood density, Forest dynamics, Ecosystem

Received 19/07/2016 Accepted 02/09/2016

How to cite this article:
F Alidadi, K Sefidi, M Marvi- Mohadjer, V Etemad. Modeling decay rate of dead wood of a European hornbeam (*Carpinus Betulus*) in a deciduous forest in North of Iran. Adv. Biores. Vol 7 [5] September 2016: 145-153. DOI: 10.15515/abr.0976-4585.7.5.145153

INTRODUCTION

Advanced methods for preserving natural resources and environment have changed attitude of silvics toward managing forests so called close-to-nature forestry. In fact, close-to-nature forestry is a method, a viewpoint, a philosophy or thinking to manage a forest where each element has its own function and position. Natural developments of forest stands are considered in close-to-nature forestry aiming at modeling to manage these stands. Protection of forests as a major source of genetic reserve is highly considered in the form of preserving biodiversity of plant species and recognizing the role of dead woods. Realizing the ecological importance of dead woods led them to be considered as an important element in performance of forest ecosystems and changed into an indivisible component in forest management [1]. One of the important issues in forest health is to preserve some trees until reaching the decay stage; many studies proved that dead woods are very important for the health and fertility of a forest [2, 3].
European hornbeam (*Carpinusbetulus.*) is a common tree species in an old growth forests with considerable litter inputs into the forest floor. It is a small to medium-size tree reaching heights of 15–25 meters and often has a fluted and crooked trunk. The bark is smooth and greenish-gray, even in old trees.
Deadwoods are considerably under the influence of the flow of material, energy, and nutrients in the forest ecosystem. Nutrients are released from free dead woods gradually within a long period; therefore, as a natural fertilizer, they improve fertility of forest ecology [4]. In fact, during decay process, dead woods will host many fauna and improve biodiversity in a forest. On the other hand, it will help to return minerals to soil during this process. During decay process, biologic breath is a key for determining quality of dead wood cycle and its participation in carbon cycle across a region and on a global scale. The dead wood decay process is considered as a major ecological process in a forest that depends on different

factors such as type of wood as a habitat for organisms, biochemical interactions, components and compositions of wood and microorganism, and the invertebrates participating in decomposition process [5]. Important factors in decaying dead woods are complicated, reciprocal and interrelated. It is impossible to prove which key factor can be the simulating factor of decomposition. It is totally related to the conditions of an environment. Various tree species decay at different rates. One of the questions for which silvics and ecologists are attempting to find an appropriate answer is the time dead woods stay in a forest. The decay process of dead woods was studied in some part of European forests, tropical regions and boreal forests. Studying the European beech (*Fagussylvatica* L) dead woods in Germany showed that a complete decay of beech dead woods last 35 years [6]. A time study by Yatskov *et al*. [7] on the dead woods decay in Russian boreal forests showed that the average density for stages one to five of the dead woods is between 0.51 to 0.08 g/ cm^3.
However, no research has discussed time changes of dead woods and their decay process yet. Iran's north forests are managed through *close-to-nature* method and preserving dead woods is of crucial importance aiming to maintain biodiversity in the forests. Therefore, studies on this important element may help recognition and improvement of managerial methods, especially in Iran's northern forests. This research was conducted aiming at finding appropriate quantitative information on decay changes of hornbeam dead woods of northern forest as the major objective. Other objectives of the study include modeling and quantifying decomposition process and decomposition rate in hornbeam dead woods and determining the time required for the decay of hornbeam dead woods.

MATERIALS AND METHODS

The Study area

The study area is in the University of Tehran's Experimental Forest at Noushar on slopes of the Alborz Mountains at an elevation of 200-2200 m in northern Iran (south of the Caspian Sea). The compartments number 207, 220, 208, 221, and 223 in the Namkhaneh district of Kheiroud Research and educational Forest (36°27'-36°40'N and 51°32'-51°33'E) were selected for conducting the research (Figure1). Annual rainfall and temperature of the region are 1380 mm and 16.5°C, respectively. In this area, cold weather and snow usually start late autumn and continue into early spring. The mean of relative humidity in different months is about 75 percent with the maximum and minimum amount in March and July, respectively.

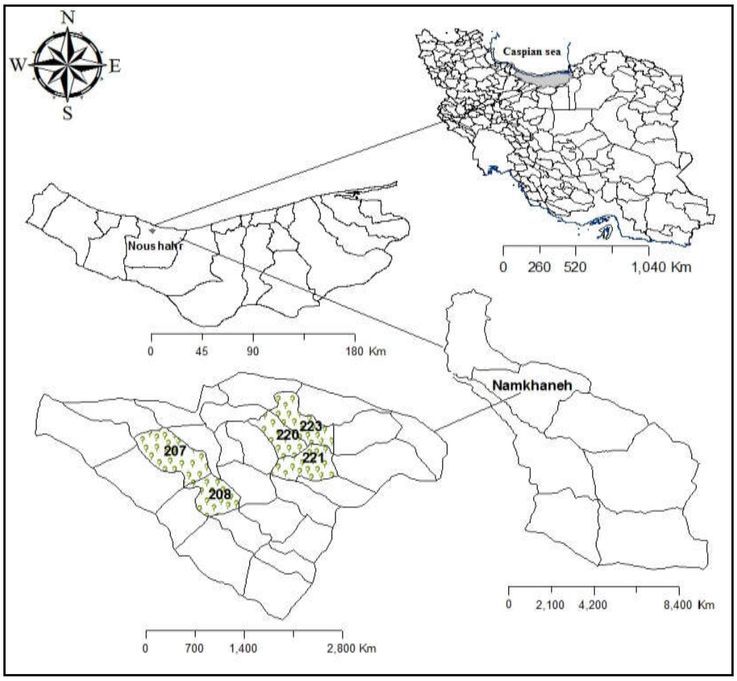


Figure1.The location of the study area at the Caspian forest, sand in the northern Iran

Field sampling

Data collection and filed sampling was done in 2012. In order to create homogeneity of environmental conditions, attempts were made to select sample plots from sites with the similar condition to minimize the effect of micro factors. Homogeneity of environmental factors was only considered at the macro levels. The study areas were selected with respect to the information related to their forest management plan and time of logging. It is important to know logging time because it can be used for discovering the staying duration of stumps as an indicator of dead woods in nature [8]. To do this, use chronological order method and cooperation of a logging team in the field, 6 stumps were selected randomly among the trees of each logging period in each compartment from the 1985, 2000, 2004, 2008, 2011,2012 years, which were respectively cut and removed 27, 12, 8, 4, 1, 0 years ago. Tree species, diameters, and decay stages were recorded red. A chainsaw was used for taking samples from the young stumps and cutting a 5×5×5 cm cubic radial cut of wood in two perpendicular directions from the cross-section of each stump. Samples of the middle-aged stumps were taken using an ax and samples of the stumps with very high rates of decay were taken manually. The samples were classified with respect to their decay rate, put into special sacks to retain moisture, and taken to a laboratory. Decay classes were defined according to Albrecht [9]as Class 1 (recently dead), Class 2 (bark loose with some decay in the sapwood), Class 3 (decay obvious throughout the secondary xylem) and Class 4 (woody debris mixing with soil, little structural integrity).

Data Analysis

Generally, decomposition rate is expressed by a *K* constant that shows volume loss percentage, mass or density over time [10, 11]. Wet volumes of the cubic samples were calculated using mathematical relations of cubature. Volumes of the irregularly shaped samples were calculated by floating on water [12]. The fresh weight of the samples was measured using 0.001 gram digital scales. The samples were then placed into an oven at 80°C for 24 hours. Dry weight of each sample was measured [6]. Finally the bulk density of the samples was calculated as per (g/cm^3) using (1-3) formula:

$$\rho = m/v \qquad (1)$$

Where m is the dry weight of wood and V is volume of fresh wood.

Different mathematical models are extensively used for simulating decomposition patterns and estimating decomposition rates of dead woods [10]. This research used exponential distribution model [13] of formula (3) for decomposition process and wood decay. Decomposition rate hypothesis (average constant of wood decay) in this model is based on the ratio of the remaining matters over time [4].

$$D_t = \ln D_0\, e^{-kt} \qquad (2)$$

The annual decomposition rate was calculated using Formula (2) and obtained as

$$K = (LnD_0 - LnD_t)/t \qquad (3)$$

In this relation, D_t is bulk density at t time. D_0 is the primary bulk density. K is mean of annual decay of wood.

The required time for decaying 95% of wood content was calculated by Formula (3).

$$T_{95} = -\ln\frac{0.05}{k} = \frac{3}{k} \qquad (4)$$

In this relation, T_{95} is the time required for decaying 95% of wood content and k is the average coefficient of wood decay.

One- way ANOVA was used for determining significance of the difference between the level of decay, decay constant and density in different years. Multivariate regression was used for presenting the decay model of hornbeam dead wood. Kolmogorov-Smirnov test and Leven's test were used for examining normality of data distribution and equality of variance. If needed, data normalization would be performed in a statistical software environment (at significance level of 0.05). An exponential regression model was used for presenting a decomposition rate model and the changes made to the wood specification during decomposition period using SPSS (Ver. 20).

RESULTS

In total, 36 decaying stumps of *C.betulus* were selected; two samples of each stump were chosen. As expected, the data analysis proved a significant relationship among the collected samples, decay constant in different years, and different levels of decay. Table (1) explains the test statistics. These two factors have differences significantly among levels of decay.

Results showed that the mean of hornbeam bulk density reduces with the decay stages increasing. The effect of this process on reduction of decay level II is more considerable than decay level I. Mean of density in decay levels II and III is almost constant; however, density has a considerable downtrend in the last decay level.

The exponential regression model was applied to present a model for decomposition rate and changes made in wood specifications during the decomposition time (Table 4).
Results showed that the density of hornbeam species decreases over time. A slight increase of density 12 years after decay time is evident. On hornbeam, the exponential model defines density changes well. It is clear that approximately 76% of density changes are expressed by decay period duration in the fitted model.
The study of decomposition rate changes in different years in hornbeam showed that decomposition rate is considerably reduced in a clear process over time. About 75% of the changes are estimated in this constant using the exponential model. Variance of data is very high in the early years; however, it reduces considerably over time.
There is a specified relation between density and decay grade and about 80% of changes are estimated in this constant using the exponential model. As shown in Figure 3, density, reduced with the decay level increasing. Variance of data at decay level 1 is high. A slight increase of density is seen at decay level III.
An almost certain exponential relation is between decomposition constant and decay level in hornbeam. About 66% of changes in decomposition constant is estimated by decay level using the exponential model.
According to results in the study area decay rate is highly affected by temperature. There is a strong linear relation between rate of decay and temperature. About 81% of decay rate is defined by mean of annual temperature (Fig 4). We also Rainfall effect on the annual decay rate in hornbeam dead woods was studied. The results showed that rainfall at different decay rates has a significant difference, but no strong relation was discovered between these two factors.

Table 1. Results of one-way ANOVA's of density and decay rate in different years and decay stage of CWD

	Density- years		Density- decay stage		Decay rate- years		Decay rate- decay stage	
Hornbeam	F	*p*	F	*P*	F	*p*	F	*p*
	72.09	0.001<	15.21	0.001<	22.60	0.001<	82.00	0.001<

Table 2.The Mean of bulk density of the decay stages in the dead wood of *C.betulus*

Decay Class	Density (g cm^{-3})
	Mean ± SD
I	0.51± 0.11
II	0.30 ± 0.05
III	0.33± 0.05
IV	0.13± 0.03

Table 3. Trend fitting, decay constants, and time required for the loss of 95% mass of dead wood

Sp	Function	r^2	P	K	t_{95}
Hornbeam Dead wood	$Y=e^{-kt}$	0.75	0.0001<	0.182	16

Table 4. Multiple regressions, model building of decay rate in different classes, K is the mean of annual decay of wood.

Steps	Function	R^2	F	P
Density× years	$D= 0.892 * e^{(-0.317* t)}$	0.76	105.753	<0.0001
k× years	$K= 0.792 * e^{(-0.433* t)}$	0.75	83.361	<0.0001
Density× decay class	$D= 0.703*e^{(-0.373*DC)}$	0.80	136.153	<0.0001
K× decay class	$K= 0.561 * e^{(-0.495* DC)}$	0.66	55.678	<0.0001

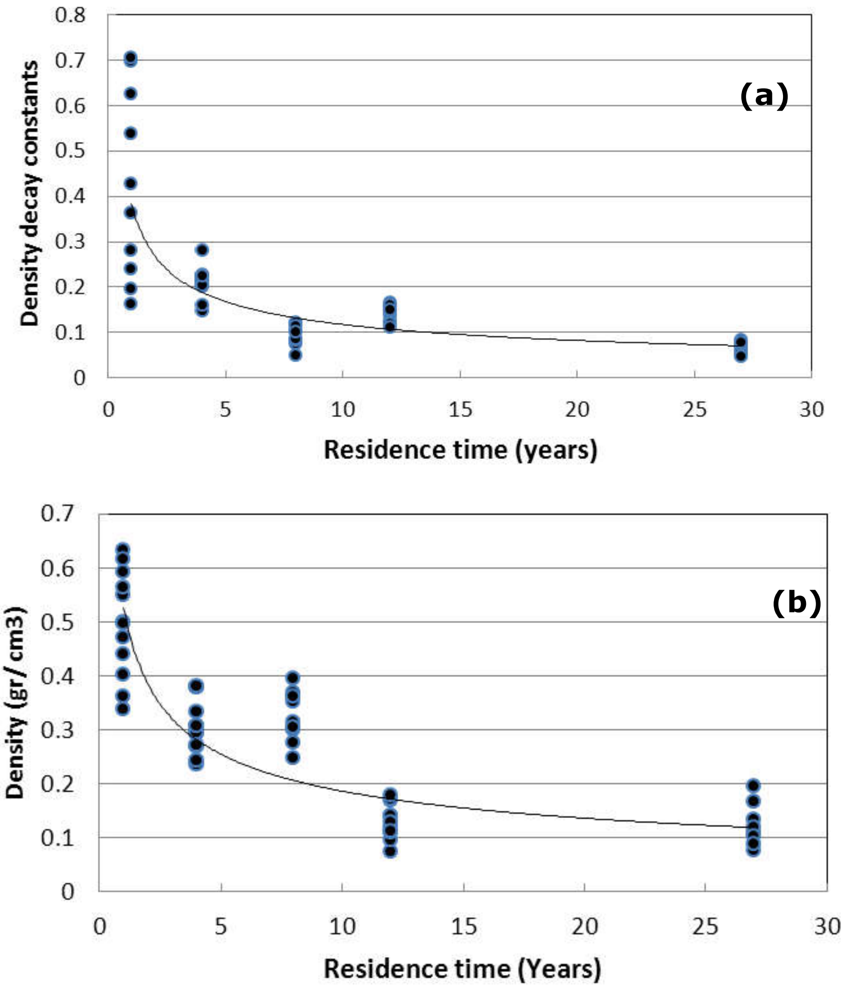
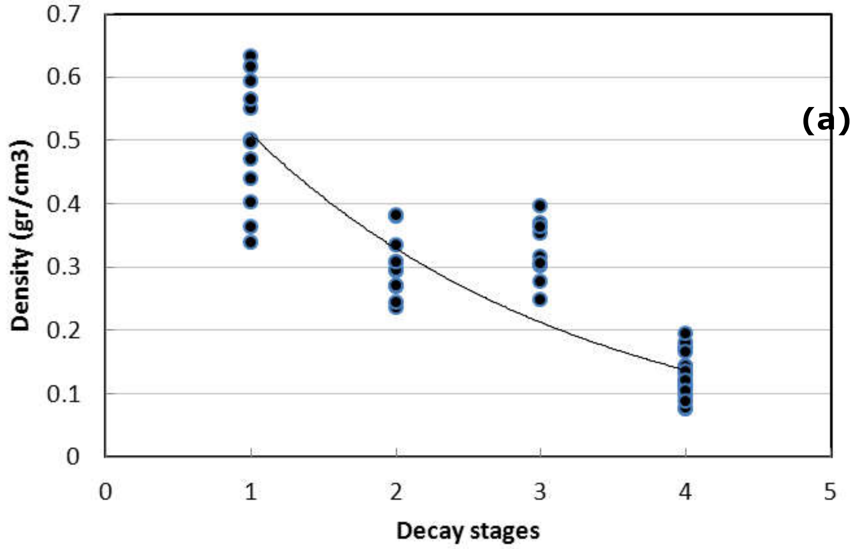


Figure 2. Mean decay constants (k) for dead wood mass (a), density, during different durations (b).



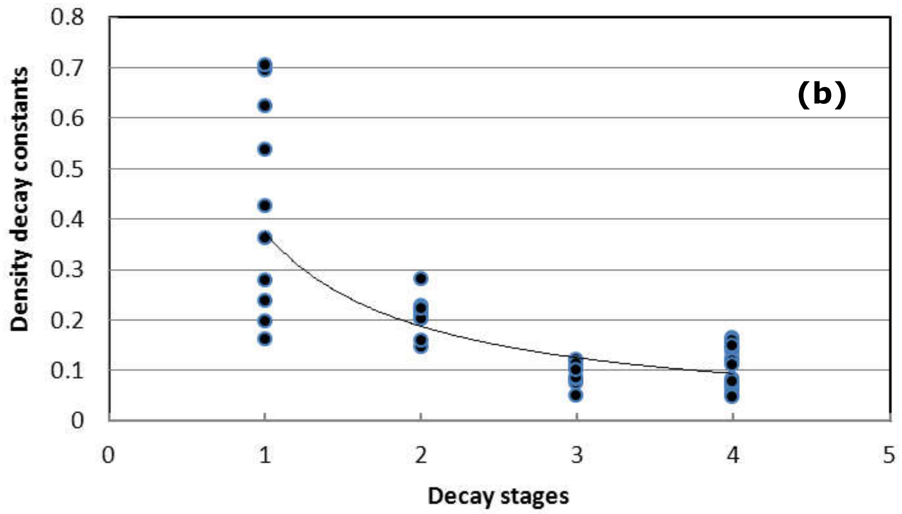


Figure3. Mean decay constants (k) for dead wood density (a), and dead wood density, in different decay stages (b).

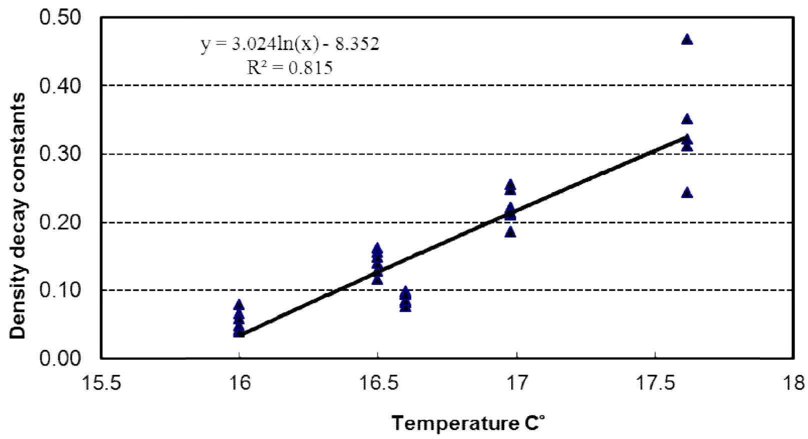


Figure 4. A linear relation between rate of decay and temperature

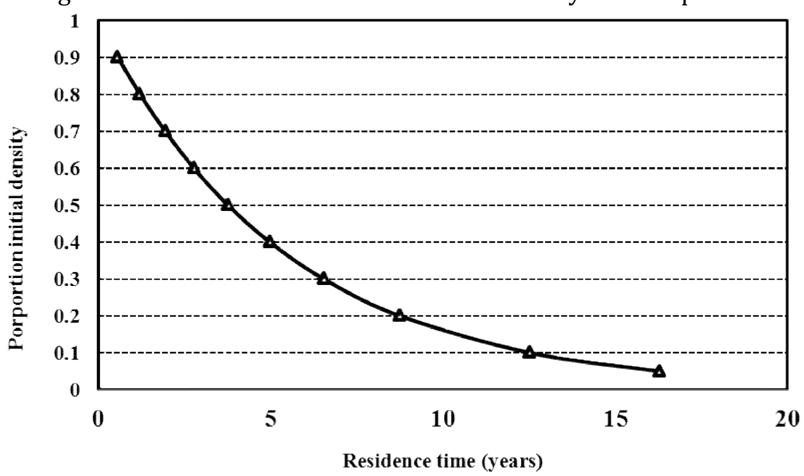


Figure5. Percentage mean of the initial density of hornbeam dead wood during decay. ($y=e^{-0.184x}$, $r^2=0.75$).

DISCUSSION

The decomposition of fallen dead woods is a complicated process, which is a combination of physio-biochemical processes. Its main process is a loss of mass of materials during biochemical decomposition and leaching that can be quantified by measuring volume and weight of dead wood. Deadwoods are decomposed during degradation by decomposer organisms such as of sporocarps macrofungi. This process reduces density of their primary materials [14, 15]. Determining the amount of reduced mass is the most common method to examine dynamic of the decay process [16-18, 10]. Scientists proved a direct relationship between mass reduction and relative bulk density [19].To do so, it is possible to use bulk density changes to explain the decomposition process [18].

As it is easy to measure it, its primary amount is not varied much among species [20, 4] bulk density changes over time were used in this research for determining decay dynamic. Results revealed that decay changes in hornbeam dead woods approximately follow the negative exponential model over time based on density changes. Most studies also reported exponential model of density during the decay process. Mean of density in the study of Müller Using and Bartsch [6] reduced during the first 12 years of decomposition, whereas volume is reduced linearly during all decomposition period. Results showed that about 70% of the components in hornbeam species decay after 8 years. Similar to the earlier research, hornbeam density reduced with the decay levels increasing [10]. A similar process was also reported for the conifer tree species of in the United States [10]. Consistent with the studies of Müller Using and Bartsch [6], density reduces directly after death and this process increases slightly 8 years after the beginning of decay. It might be due to climatic changes and annual humidity increase. A considerable density reduction was observed in classes 1 to 3 in the study of Müller Using and Bartsch [6]; then density reached a constant value. Results also indicate that density reduction in decay levels I and II is considerable; however, density reduction process falls down and it reaches an almost constant value by advancing decay and increasing decay processes. According to our findings annual decomposing rate of hornbeam is 0.182. It should be considered that different factors affect decay and its rate. They include type of wood, temperature, wood humidity, annual precipitation, physical and chemical nature of wood surface, physical condition of dead wood, and population of fungal and animal decomposers [10,4, 21, 22]. based on the results, the required period for decaying of 95 % of total dead wood (T_{95}) of hornbeam dead wood with density of 0.6938 before decay and average density of 0.2867 during decay in the mixed forest of north of Iran is 16 years. The earlier studies show that the tree species with lower density decay considerably faster than the ones with higher density [10]. Of course, it completely depends on environmental conditions and the local factors effective in decay. For instance, *Burserasimaruba (L) sarg* with density of 0.25and *Beaucarnea pliabilis (Baoker) Rose* with density of 0.33 have T_{95} of 6 to 8 years. In addition, the higher the decay rate is, the shorter is the time for losing 95% of dead woods components. It was proved in different studies [4]. Yang *et al.* [23] proved that the periods required for losing 95%of components for *C. chinensis*, *C. superba*, *C. concinna* species are 27, 20, and 19 years, respectively. While decay rates for *C. chinensis*, *C. superba*, *C. concinna* are 0.1095, 0.1486, and 0.1570, respectively. This study discussed the effect of mean of temperature and mean of annual rainfall on decay rate of hornbeam dead woods. The results show a strong relation between temperature increase and decay rate, as 85% of decay rates in hornbeam are affected by temperature changes. Temperature affects decomposition rate, as life and activity of microbes and invertebrates are more at higher temperatures, decomposition rate become higher [23]. Decay rate increases significantly at the mean temperature of 12°C or 13°C [4]. Yin [24] used tree species parameters, temperature and rain in his model and showed that a temperature rise of 2°C increases density reduction severity from 9 to 55%. Research of Garrett *et al* [21] showed that roots are significantly decayed sooner in the regions with higher average annual temperature as compared with the regions with lower temperature. The results showed that the effect of temperature on decay rate exceeds the effect of rainfall and no clear and significant relation was found between rainfall and decay rate. It might be due to the fact that data variance is high at the beginning of decay and very high and very low humidity may limit organisms' activity on wood. Naesset [25] found out that higher diameters have more contact with ground and the contact accelerates decomposition, as it increases humidity in the dead woods and makes a direct contact with soil decomposing fauna. It provides fungal communities with water and nutrients more conveniently. However, Mackensen *et al.* [4] stated a reversed relationship between decomposition rate and dead woods diameter in *P.menziesii* and *Tsuga heterophylla* and about 60% of the changes of decomposition diameter is defined by dead woods diameter as the greater the dead woods diameter is, the lower decomposition rate will be. It is due to reduction of area to volume ratio in high diameters, which is followed by lower exchange of gas and water for a decomposing community [26, 27]. Another reason is the increase of the volume of the degradable part inside wood in high diameters [28]. A large part of dead woods are formed inside the wood of many species, which are decomposed relatively later, as they contain fungicide and pesticide extracted substances and may have further density.

Research results show that keeping dead woods in a forest is necessary for the conservation forest ecosystems health and preservation of biodiversity of its ecosystems. As they have a slower decay rate, they may reserve carbon and other nutrients in forest ecosystem [29, 23] and prevent the global temperature rise through carbon sequestration. Consequently, knowing the staying time of dead woods in forests may assist foresters in sustainable management of a forest and preserve biodiversity. Therefore, it is necessary to conduct comprehensive studies for a long time and carry out multidimensional studies on dead woods. The Results of this study may be used for managing hornbeam dead woods in similar habitats. However, it is necessary to conduct these studies on different climates, soils, and species. To carry out the following studies more accurately, it is also proposed to measure and consider the different factors effective in decay such as soil temperature, air relative humidity, slope and direction, the effect of gaps in decay intensity separately for each dead wood.

CONCLUSION

Today, it is clear that dead woods play a crucial role in dynamics of forest ecosystems. Therefore, knowing their decay dynamics may provide forest managers and ecologists with useful information for preserving biodiversity and making equilibrium among different dead woods and their decay process.

REFERENCES

1. Marage D, Lemperiere G, (2005). The management of snags: a comparison in managed andunmanaged ancient forests of the Southern FrenchAlps. Ann ForSci 62:135–142.
2. MarvieMohadjer MR, (2011). Silviculture. Tehran: University of Tehran Press. 387 pp.
3. Sefidi K, Etemad V, (2015). Dead wood characteristics influencing macrofungi species abundance and diversity in Caspian natural beech (*Fagusorientalis*Lipsky) forests. Forest Syestems. In press.
4. Mackensen J, Bauhus J, (2003). Density loss and respiration rates in coarse woody debris of *Pinusradiata*, *Eucalyptus regnans* and *Eucalyptus maculata*. Soil BiolBiochem 35: 177-186.
5. Rayner A DM, Boddy L., (1988). Fungal Decomposition of Wood, its Biology and Ecology.Chichester, UK: John Wiley & Sons Ltd, 587 pp.
6. Müller SU, Bartsch N, (2009). Decay dynamic of coarse and fine woody debris of a beech (*Fagussylvatica L.*) forest in Central Germany. Eur J For Res128: 287- 296.
7. Yatskov M, Harmon ME, Krankina O, (2003). A chronosequence of wood decomposition in the boreal forests of Russia. Can J Forest Res 33: 1211-1226.
8. Tobin B, Black K, McGurdy L, Nieuwenhuis M, (2007). Estimates of decorates of components of coarse woody debris in thinnned Sitka spruce stands. Forestry 80: 455-469.
9. Albrecht L, (1990). Principles, objectives and methodology of forest ecology research in natural forest reserves. Bavarian Ministry of State for Nutrition, Agriculture and Forestry, Müchen.
10. Harmon ME, Franklin JF, Swanson FJ, Sollins P, Gregory SV, Lattin JD, Anderson NH, Cline SP, Aumen NG, Sedell JR, Lienkamper GW, Cromack J, Cummins KW, (1986). Ecology of coarse woody debris in temperate ecosystems. Advance Ecology Restoration 15: 133-302
11. Swift MJ, Heal OW, Anderson JM, (1979). Decomposition in terrestrial ecosystems. Blackwell Scientific, Oxford, UK, 372 pp.
12. Yeboah D, (2011). Variation in carbon content of tropical tree species from Ghana. Thesis, Michigan Technological University.
13. Olson JS, (1963). Energy Storage and the Balance of Producers and Decomposers in Ecological Systems. Ecology 44: 322-330
14. Fahey TJ, Arthur MA, (1994). Further studies of root decomposition following harvest of a northern hardwoods forest. For Sci40: 618-629.
15. Laiho R, Prescott CE, 1999. The contribution of coarse woody debris to carbon, nitrogen, and phosphorus cycles in three Rocky Mountain coniferous forests. Can J Forest Res 29: 1502-1603.
16. Christensen O, (1977). Estimation of standing crop and turnover of dead woodin a Danish oak forest. Oikos 28: 177–186.
17. Sollins P, (1982). Input and decay of coarse woody debris in coniferous stands in western Oregon and Washington. Can J For Res 12: 18–28.
18. Arthur MA, Fahey TJ, 1990. Mass and nutrient content of decaying boles in an Engelmann spruce-subalpine fir forest, Rocky Mountain National Park, Colorado. Can J For Res 20: 730–737.
19. Christensen O, 1984. The states of decay of woody litter determined by relative density. Oikos 42: 211-219.
20. Frangi JL, Richter LL, Barrera MD, Aloggia M, 1997. Decomposition of Nothofagus fallen woody debris in forest of Tierra Del Fuego, Argentina. Can J Forest Res 27: 1905-1102.
21. Garrett LG, Kimberley MO, Oliver GR, Pearce SH, Beets PN, (2012). Decomposition of coarse woody roots and branches in managed *Pinusradiata* plantations in New Zealand – A time series approach.For EcolManag 269: 116-123.
22. Beets PN, Hood IA, Kimberley MO, Oliver GR, Pearce SH, Gardner JF, (2008). Coarse woody debris decay rates for seven indigenous tree species in the central North Island of New Zealand. For EcolManag 256: 548-557.
23. Yang FF, Li YL, Zhou Gi, Wenigmann KO, Zhang DQ, Wenigmann M, Liu SZ, Zhang QM, (2010). Dynamics of Coarse Woody Debris and Decomposition Rates in an Old-Growth Forest in Lower Tropical China. For EcolManag 259: 1666-1672.

24. Yin X, (1999). The decay of forest dead wood: numerical modeling and implications based on some 300 data cases from North America. Oecologia 121:81-98.
25. Naesset E, (1999). Decomposition rate constants of *Piceaabies* logs in southern Norway. Can J Forest Res 29: 372-381.
26. Harmon ME, Cromack K, Smith BG, (1987). Coarse woody debris in mixed-confer forests, Sequoia National Park, California.Can J Forest Res 17: 1265-1272.
27. Harmon ME, Franklin JF, Swanson FJ, et al, 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15: 133-302.
28. Harmon ME, Krankina ON, Sexton J, (2000). Decomposition vectors: a new approach to estimating woody detritus decomposition dynamics Can J For Res 30(1): 76–84.
29. Guo LB, Bek E, Gifford RM, (2006). Woody debris in a 16-year old *Pinusradiata* plantation in Australia: mass, carbon and nitrogen stocks, and turnover. For EcolManag 228: 145-151.