Dead Wood Is Not Dead:
The Ecological Functions and Management of Dead Wood

by Cuiyin Wu

under the supervision of Professor Lea Johnson
PLSC 480: Management of Urban Forest Edges
The University of Maryland – College Park
Spring 2016

Contents

Background

Citizens find it hard to appreciate the ecological qualities of an unorganized forest landscape because they prefer a neat and orderly appearance even though it may not offer ecological benefits (Tyrväinen et al 2013). Lifeless downed wood or logs give the impression of untidiness and chaos. What the public should understand is the importance of dead wood, rather than basing their preferences on the social norm of aesthetic scenery, and beauty (Nassauer 1995). A lack of education causes misconceptions, for example, that a healthy forest cannot have dead wood (Tyrväinen et al 2013). People believe that dead trees are useless, and in fact detrimental forests (Dudley and Vallauri 2004).

It is imperative to address the ecological functions of dead wood, which are not always clear even to educated eyes (Nassauer 1995; Stokland et al. 2012). This paper provides an overview of the definition of dead wood, the ecological benefits of dead wood to forests and woodlands, dead wood management methods, and dead wood management techniques for urban land managers.

What is Dead Wood?

There are various kinds of dead wood. Veteran trees, snags, stumps, wind-thrown trees, fallen logs, stems and branches are all types of dead wood (Humphrey and Bailey 2012). Wind, fire, disease and pests, and aging contribute to the generation of dead wood in forests and woodlands (Wu et al. 2005).

Veteran trees are old trees with decaying heartwood and hollowing, sometimes with dead wood in the crown. Snags are standing dead trees that are greater than 5cm in diameter and 1.3 meters in height, whereas stumps are greater than 5cm in diameter at the top end and less than 1.3 meters in height (Söderberg et al. 2014). Wind-thrown trees are dead fallen trees, most likely uprooted by strong wind, with exposed roots. Wood harvesting activities produce other types of dead wood such as logs, stems, and branches.

Coarse woody debris (CWD), a term used in scientific and forestry literature is defined by the Long Term Ecological Research Network as sound and rotting logs, snags, stumps, and large branches (located above the soil), which must be larger than 10cm at the widest point (Harmon and Sexton 1996). Compared with fine woody debris (FWD), which is defined as dead woody pieces with a diameter from 0.5cm to 10cm, CWD is much larger in size and weight and carries more significance in dead wood studies (Fasth et al. 2010).

Ecological Benefits of Dead Wood

Dead wood is ecologically important to forests. By slowly releasing carbon back into the atmosphere, dead wood plays a role in long-term carbon storage. Dead wood maintains biodiversity by supporting, sheltering, and feeding many species. It also shapes riparian ecosystems by altering the hydrology and morphology of the river channels, and helping to decrease the speed of flood waters.

Carbon Storage

Dead wood plays a vital role in long-term storage of carbon that is sequestered by plants through photosynthesis. Burning wood takes only a few hours to transform into ashes and carbon dioxide. However, the decomposition of wood can take 100 years and the carbon is slowly released back to the air as the wood decays (Wu et al. 2005). Figure 1 (Stokland et al. 2012) indicates that the remaining biomass of the dead wood is slowly released in five stages of decay. Hence, removing dead wood may cause carbon to release faster, thus affecting long-term storage (Wu et al. 2005).

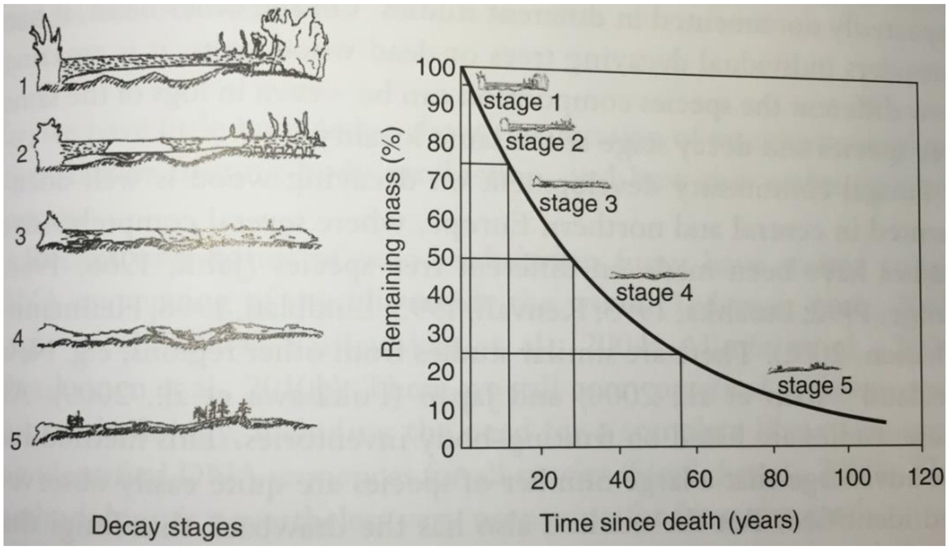

Figure 1 Decay stages and remaining biomass (Stokland et al. 2012)

A moderate but significant amount of carbon is stored in dead wood. Using1990-2007 forest inventory data and the results from long-term ecosystem carbon studies, Pan et al. (2011) estimate that the carbon stored in the dead wood account for eight percent of the total carbon stock in global forests. It is suggested that dead wood, as an easily managed carbon source for land managers, ought to be maintained to contribute to global carbon stock. Carbon stored in the dead wood is important for reducing the greenhouse gases and helping to mitigate the global warming and climate changes.

Maintaining Biodiversity

There is a large amount of literature that indicates that dead wood is beneficial in enhancing the richness of species. Plants, fungi, invertebrates, and vertebrates depend on dead wood in various ways. Wood-decaying fungi and bacteria decompose nutrients in the dead wood and use them as a food source. Wood-boring insects such as flies, termites, and mites also consume dead wood for food (Wu et al. 2005; Stokland et al. 2012). Other species use dead wood for purposes other than nourishment, such as nesting. Birds such as parrots, woodpeckers, and owls dwell in the cavities in snags (Stokland et al. 2012). Species associated with corresponding types of dead wood are listed in Figure 2 (Dudley and Vallauri 2004).

	Typology	Associated wildlife
Living veteran trees	Very old trees with large canopy for perching or nesting	Large raptors like the golden eagle (*Aquila chrysaetos*), black stork (*Cigonia nigra*)
	Cavities on very old trees	Cavity nesters as Tengmalm owl (*Aegolius funereus*) or Ural owl (*Strix uralensis*)
	Deadwood on live trees	For example hoverflies, beetles (*Lucanus cervus*, *Cerambyx cerdo*) and lignicolous fungi
Standing dead trees	Very old trees with large branches, providing perches and nest sites	Birds, squirrels and other species along with bark-eating beetles and their predators
	Standing trunks (snags) of different ages (gradually losing bark and branches)	Colonised by fungi, lichens, ferns and invertebrates and by larger species who bore (like woodpeckers) or take over nesting holes
	Snags with major cavities large enough to shelter large animals	Brown bears
	Young dead trees	Specialised associated fungi and bacteria/algae
Lying timber	Recently fallen logs with bark and twigs present	Associated species include fungi and large longhorn beetles
	Down logs largely intact, wood starting to soften internally, still elevated but sagging	Beetles and fungi continue to be important although species may change
	Down logs without bark or twigs, softening, sinking to the ground	Numerous insect species including flies and beetles, fewer fungi present
	Down logs well decayed, no bark or twigs and entirely on the ground	Insects, specialised fungi
	Down log almost completely decayed, wood powdery but still whole	Woodlice, millipedes, etc. Nurse log facilitating germination of conifers in mountain forest, and of broadleaves like alder in alluvial forests...
	Uprooted trees with root system still attached	Roots can shelter bird nests and insects
Litter to soil and water	Large woody debris	The wood becomes a substrate for many bryophyte species and flowering plants
	Fragments of woody debris including branches, twigs and bark	Specialised species of fungi (e.g. morels and cup fungi) and animals such as springtails and woodlice
	Coarse woody debris in rivers and streams	Algae, fly larvae, breeding fish

Figure 2 Wildlife species associated with dead wood (Dudley and Vallauri 2004)

Together, these species are often referred to as *saproxylic* species, from the Greee, *Sapros* (rotten) and *xylon* (wood). Stokland et al. (2012) defined saproxylic species as:

> any species that depends, during some part of its life cycle, upon wounded or decaying woody material from living, weakened or dead trees.

The value of saproxylic species is significant. Firstly, saproxylic species such as fungi and bacteria replenish nutrients in the soil by decomposing dead wood (Wu et al. 2005). Dead woody materials create islands of high soil fertility (McCavour et al. 2014).

Second, saproxylic species may prevent pest outbreaks since they are the predators and parasitoids of bark beetles that can cause significant damage to forest health (Stokland et al. 2012). Third, each trophic level of the food web that starts with woody material as primary producers is occupied by various saproxylic species (Stokland et al. 2012). A food web with more trophic levels and species is more likely to be resilient to disturbances.

These species are not only ecologically important to forests, but also beneficial to human beings. Fungi are an indispensable and delicious food source which contain nutrients beneficial to people.

Retaining dead wood is of vital importance for saproxylic species. Bouget et al. (2012) pointed out that saproxylic biodiversity such as beetles can be maintained by keeping oak snags, especially large ones, in temperate forests. With a continued supply of dead wood, saproxylic species have habitats and food sources that allow them to thrive in forests.

Dead Wood in Riparian Ecosystems

Riparian areas are the transitional zones between streams and land adjacent to streams, which are important for in improving the stream health (IIhardt et al. 2000). When tree branches or logs fall into the water, they hydrologically and hydraulically influence river channels by enhancing slope stability (Gurnell et al. 1995). Large dead wood stabilizes small streams and diverts water flows by controlling and dissipating the river’s energy, which substantially reduces bank erosion (Gurnell et al. 1995; Rose et al. 2001). By reducing the impacts of fast flow on eroded banks, especially during heavy rainfalls, dead wood stabilizes and shapes the riparian ecosystem (Rose et al. 2001).

Dead wood also helps stabilize stream ecosystems by retaining sediment. Logs in the stream reduce the velocity of the nearby water flow and thus lower the amount of sediments carried by the flow (Naiman et al. 2002). Figure 3 indicates the effects of removing logs on sediment retention in the longitudinal profile of a small stream (Naiman et al. 2002). After the debris dam is removed from the pool, the stored sediments trapped by the logs are tremendously reduced. Stored sediments that are trapped and consolidated by logs are sources of nutritional particles, which are an important part of aquatic wildlife food sources (Rose et al. 2001).

A stable riparian ecosystem plays an important role in relieving the urban stream syndrome—the ecological degradation of streams due to urbanized land (Pickett et al. 2011). Rushing stormwater, the result of impervious surfaces, can wash off sediments on the bank leading to bank erosion. Stream bank erosion accounts for two thirds of the total sediment load in the Chesapeake Bay Watershed (CBW) (Donovan et al. 2015). Placing dead wood in the riparian ecosystems is effective in reducing the erosion and improving stream health.

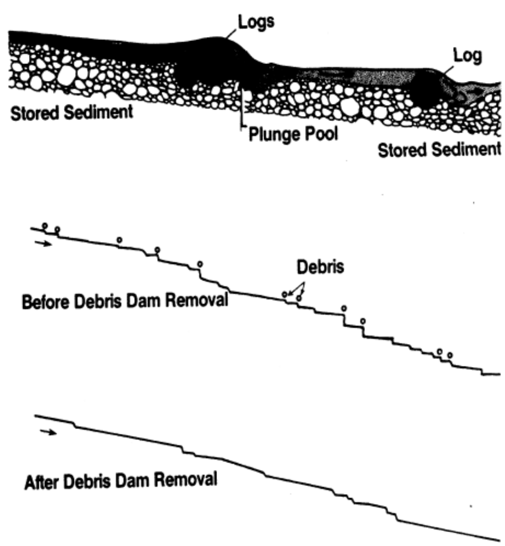

Figure 3. Effects of logs toward stored sediments (Naiman et al. 2002)

A similar example on the roles of dead wood in restoring riparian ecosystems by preserving channel integrity and bank stability can be found in the shallow CBW (Palone and Todd 1998). It is suggested that dead wood should not be removed in the watershed since it acts like a strategic buffer in protecting and enhancing the watershed health by storing large amount of sediments and gravel (Palone and Todd 1998).

Calls for Action—Managing Dead Wood

One of the primary reasons to manage dead wood is to maintain biodiversity in forests. Saproxylic species are one of the most threatened types of organisms due to declining forest areas and lack of dead wood (Stokland et al. 2012). Many of these species depend solely on dead wood, and some even require a specific type of dead wood that makes them more susceptible than others when dead wood is removed (Stokland et al. 2012). Having dead wood in the woodland, can bring wildlife such as wood ducks, chickadees, and downy woodpeckers into our lives.

The World Wildlife Fund has suggested actions for the European government, forest owners, and forest industries to increase veteran trees and dead wood by 2030 to protect saproxylic species biodiversity (Dudley and Vallauri 2004). This section reviews management techniques practiced in other areas. A handbook with thorough study on the area of Chesapeake Bay's riparian ecosystem urges land managers and planners to make wise use of dead wood for ecosystem restoration (Palone and Todd 1998).

Deadwood management methods: United Kingdom

The British government has committed to retain more dead wood in forests to increase biodiversity and ecosystem functions (Hodge and Peterken 1998). Understanding that different woodlands may have different value in maintaining dead wood, Hodge and Peterken (1998) identified five types of woodlands in descending order of dead wood volume.

Based on that identification, Humphrey et al. (2002) adapted and classified four types of woodland. Table 1 lists different strategies to manage dead wood according to the woodland characteristics and type. For the suburban forestry in Columbia, Maryland which is composed of invasive species, the third woodland management strategy, removing the nonnative species and enhancing the health of the overall ecosystem, should be adopted.

Humphrey et al. (2002) also created corresponding benchmark values for land managers to monitor their progress and propose further actions. As an outreach delivery product, this publication is straightforward and easy to comprehend. It focuses on local adaptive management with attainable benchmark values.

Table 1 Specific Strategies for various woodlands (Hodge and Peterken 1998; Humphrey et al. 2002)

	Characteristics of Woodland	Strategy
I.	A mixed of natural forests and woodland plantations	• Enhance the existing dead wood habitats
II.	Traditional forest plantations	• Prepare for the future dead wood supply by deliberately hurting trees
III.	Forest plantations on traditional natural woodland (lack of native species and abundant in invasive species)	• Removal of non-native species • Restore ecosystem
IV.	Newly established forest plantations	• Concentrate dead wood supply within certain areas

In 2012, the UK Forestry Commission published a guide for managing deadwood in forests and woodlands (Humphrey and Bailey 2012). This guide uses an alternative method that classifies the ecological value of the woodlands into High, Medium, and Low ecological value by assessing five factors: existing levels of on-site dead wood, species are associated with dead wood, continuity and diversity of the habitats over time, ecological connectivity, and the history of management (Humphrey and Bailey 2012).

The guide provides detailed and specific management actions for increasing dead wood that are focused on four aspects: collaborating with natural processes, reinforcing existing dead wood, developing new habitat, and enhancing connections between habitats (2012). In this guide, land managers are encouraged to employ these actions to shift the ecological value of land from Low or Medium ecological value to a higher value.

Urban Dead Wood Management

For urban land managers, educating and informing local communities about dead wood is just as necessary as applying the management techniques. Although public attitudes toward dead wood are negative, given adequate information, citizens may eventually support dead wood management (Tyrväinen et al 2013). Study has indicated that communicating ecological benefits of dead wood is effective in improving public attitudes toward dead wood (Tyrväinen et al 2013).

Also, actions such as leaving trunks and snags purposefully on public space should be taken. And finally, dead wood management should be incorporated into other goals such as minimizing risks of public safety.

Research performed in Norway studied public aesthetic preferences about dead wood in forests, and whether images and accompanying information help increase the public acceptance of deadwood (Gundersen and Frivold 2011). The results showed that respondents preferred images of forest with little or no visible dead wood. However, photos with accompanying text explaining the ecological importance of dead wood had higher scores. The public responded to the environmental education and supported dead wood once they comprehended its benefits.

Changing the public views on dead wood is challenging. Tyrväinen et al. suggested that environmental education for citizens should be done at early ages (2003). Collaborating with 4-H programs can be effective in communicating the environmental benefits of dead wood to younger generations.

One effective way to educate the public is to leave logs outside of forests, private gardens, or municipal parks. The World Wildlife Fund believes that this will raise public awareness by helping life return to the citizens' doorsteps (Dudley and Vallauri 2004). The safety risks, such as citizens tripping on logs should be considered, otherwise it will be counterproductive. A comprehensive educational process should be the most effective and meaningful way to help the public realize the vital role of dead wood as well as its proper treatment (Dudley and Vallauri 2004).

Urban land managers should also consider other impacts of managing dead wood. Humphrey and Bailey (2012) advise incorporating dead wood management into other objectives such as minimizing risks to public and worker safety. For example, managers should make sure that dead wood in public areas functions as an educational resource and not as a safety concern.

Works Cited

Bouget, Christophe, Benoit Nusillard, Xavier Pineau, and Charles Ricou. 2012. "Effect of Deadwood Position on Saproxylic Beetles in Temperate Forests and Conservation Interest of Oak Snags." Insect Conservation & Diversity 5 (4): 264–78. doi:10.1111/j.1752-4598.2011.00160.x. http://onlinelibrary.wiley.com/doi/10.1111/j.1752-4598.2011.00160.x/epdf

Donovan, Mitchell, Andrew Miller, Matthew Baker, and Allen Gellis. 2015. "Sediment contributions from floodplains and legacy sediments to Piedmont streams of Baltimore County, Maryland." Geomorphology 235, 88-105. Academic Search Complete, EBSCOhost (accessed May 1, 2016). doi: 10.1016/j.geomorph.2015.01.025

Dudley, N., and Daniel Vallauri. 2004. Deadwood - living forests. Gland, Switzerland: World Wide Fund for Nature. http://assets.panda.org/downloads/deadwoodwithnotes.pdf.

Fasth, B., Harmon, M.E., Woodall, C.W. and Sexton, J., 2010. Evaluation of techniques for determining the density of fine woody debris. http://andrewsforest.oregonstate.edu/pubs/webdocs/reports/detritus/publications/evaluation_of_techniques_FWD.pdf

Gundersen, Vegard, and Lars Helge Frivold. 2011. "Naturally Dead and Downed Wood in Norwegian Boreal Forests: Public Preferences and the Effect of Information." Scandinavian Journal of Forest Research 26 (2): 110–19. doi:10.1080/02827581.2010.536567. http://www.tandfonline.com/doi/full/10.1080/02827581.2010.536567

Gurnell, A. M., K. J. Gregory, and G. E. Petts. 1995. "The Role of Coarse Woody Debris in Forest Aquatic Habitats: Implications for Management." Aquatic Conservation: Marine and Freshwater Ecosystems 5 (2): 143–66. doi:10.1002/aqc.3270050206. http://onlinelibrary.wiley.com/doi/10.1002/aqc.3270050206/pdf

Harmon, Mark E., and Jay Sexton. 1996. Guidelines for Measurements of Woody Detritus in Forest Ecosystems. Vol. 20. US LTER Network Office Seattle (WA). http://andrewsforest.oregonstate.edu/pubs/webdocs/reports/detritus/publications/Guidelines%20for%20Measurements%20of%20Woody%20Detritus%20in%20Forest%20Ecosystems.pdf

Hodge, S. J., and G. F. Peterken. 1998. "Deadwood in British Forests: Priorities and a Strategy." Forestry 71 (2): 99–112. doi:10.1093/forestry/71.2.99. http://forestry.oxfordjournals.org/content/71/2/99.full.pdf+html

Humphrey, J., A. Stevenson, P. Whitfield, and J. Swailes. 2002. "Life in the Deadwood: A Guide to Managing Deadwood in Forestry Commission Forests.," 18 pp. + foldout poster. http://www.forestry.gov.uk/pdf/lifeinthedeadwood.pdf/$FILE/lifeinthedeadwood.pdf

Humphrey J., and S. Bailey. 2012. Managing Deadwood in Forests and Woodlands: Practice Guide. Edinburgh: Forestry Commission.

http://www.forestry.gov.uk/england-managingdeadwood

Illhardt, B.L., E.S. Verry, and B.J. Palik. 2000. Defining riparian areas. In: Verry, E.S. et al. (eds.), Riparian management in forests of the continental eastern United States. Lewis Publishers. New York, NY. pp. 23-42. http://www.srs.fs.usda.gov/pubs/9428

Naiman, Robert J., Estelle V. Balian, Krista K. Bartz, Robert E. Bilby, and Joshua J. Latterell. 2002. "Dead Wood Dynamics in Stream Ecosystems." In Proceedings of the Symposium on the Ecology and Management of Dead Wood in Western Forests, 23–48. http://grwc.info/Assets/Reports/LWD/Dead-wood-Dynamics.pdf.

Nassauer, Joan Iverson. "Messy Ecosystems, Orderly Frames." Landscape Journal 14, no. 2 (1995): 161–70.

Pan, Yude, Richard A. Birdsey, Jingyun Fang, Richard Houghton, Pekka E. Kauppi, Werner A. Kurz, Oliver L. Phillips, et al. 2011. "A Large and Persistent Carbon Sink in the World's Forests." Science 333 (6045): 988–93. doi:10.1126/science.1201609. http://science.sciencemag.org/content/333/6045/988.full

Palone, Roxane, and Albert Todd. "Chesapeake Bay riparian handbook: a guide for establishing and maintaining riparian forest buffers." (1998). http://www.na.fs.fed.us/pubs/misc/riparian_handbook/chesapeake_bay_riparian_handbook.pdf?

Rose, Cathy L., Bruce G. Marcot, T. Kim Mellen, Janet L. Ohmann, Karen L. Waddell, Deborah L. Lindley, and Barry Schreiber. 2016. "Decaying Wood in Pacific Northwest Forests: Concepts and Tools for Habitat Management." Accessed March 14. http://www.fs.fed.us/wildecology/decaid/decaid_background/chapter24cwb.pdf.

Söderberg, Ulf, Sören Wulff, and Göran Ståhl. 2014. "The Choice of Definition Has a Large Effect on Reported Quantities of Dead Wood in Boreal Forest." Scandinavian Journal of Forest Research 29 (3): 252–58. doi:10.1080/02827581.2014.896940. http://pub.epsilon.slu.se/11899/7/soderberg_et_al_150217.pdf

Stokland, Jogeir N., Juha Siitonen, and Bengt Jonsson. 2012. "Introduction"; "Wood decomposition"; "The saproxylic food web"; "Mortality factors and decay succession". In *Biodiversity in Dead Wood*. Ecology, biodiversity, and conservation. New York: Cambridge University Press. http://ebooks.cambridge.org/ebook.jsf?bid=CBO9781139025843

Pickett, Steward TA, Mary L. Cadenasso, J. Morgan Grove, Christopher G. Boone, Peter M. Groffman, Elena Irwin, Sujay S. Kaushal, et al. 2011. "Urban Ecological Systems: Scientific Foundations and a Decade of Progress." *Journal of Environmental Management* 92 (3): 331–62. doi:10.1016/j.jenvman.2010.08.022

Tyrväinen, Liisa, Harri Silvennoinen, and Osmo Kolehmainen. 2003. "Ecological and

Aesthetic Values in Urban Forest Management." Urban Forestry & Urban Greening 1 (3): 135–49. doi:10.1078/1618-8667-00014. http://www.sciencedirect.com/science/article/pii/S161886670470014X

Wu, J., De-xin Guan, Shi-jie Han, Mi Zhang, and Chang-jie Jin. 2005. "Ecological Functions of Coarse Woody Debris in Forest Ecosystem." Journal of Forestry Research 16 (3): 247–52. doi:10.1007/BF02856826. http://link.springer.com/article/10.1007%2FBF02856826

Annotated Bibliography

Bouget, Christophe, Benoit Nusillard, Xavier Pineau, and Charles Ricou. 2012. "Effect of Deadwood Position on Saproxylic Beetles in Temperate Forests and Conservation Interest of Oak Snags." Insect Conservation & Diversity 5 (4): 264–78. doi:10.1111/j.1752-4598.2011.00160.x.

Bouget et al. (2012) compared the species composition and saproxylic richness between oak snags and logs in European temperate forests. The authors pointed out that saproxylic biodiversity such as beetles can be maintained by leaving oak snags, especially large ones, in temperate forests.

This paper supports the statement that retaining dead wood is important for saproxylic species. A continued supply of dead wood provides saproxylic species with habitats and food sources, which allows them to thrive in forests. This paper suggested further studies to develop guidelines for retention. Currently, the guidelines do not quantify the required amount of dead wood for these species to survive.

Donovan, Mitchell, Andrew Miller, Matthew Baker, and Allen Gellis. 2015. "Sediment contributions from floodplains and legacy sediments to Piedmont streams of Baltimore County, Maryland." Geomorphology 235, 88-105. Academic Search Complete, EBSCOhost (accessed May 1, 2016). doi: 10.1016/j.geomorph.2015.01.025

This paper studied the sedimentation problem in the Piedmont streams in the Baltimore County, Maryland, which is part of the Chesapeake Bay Watershed. It concluded that streambank erosion accounts for two thirds of the total sediment load in the Chesapeake Bay Watershed. This fact was referenced in the paper to demonstrate the sedimentation problems in the streams due to the erosion in the slope of the bank. Rushing storm water, the result of impervious surfaces, can wash off sediments on the bank leading to bank erosion.

Dudley, N., and Daniel Vallauri. 2004. Deadwood - living forests. Gland, Switzerland: World Wide Fund for Nature. http://assets.panda.org/downloads/deadwoodwithnotes.pdf.

This public outreach report focuses on protecting saproxylic species that are associated with deadwood. Though, in this paper, the definition of saproxylic species is unclear. The authors emphasize that deadwood in European forests is not enough to support biodiversity and point out the people's perceptions of deadwood are based on unfounded myth. It is helpful to clarify these myths and inform the public what dead wood really is.

This paper recognized that leaving dead wood outside of forests, municipal parks, and homeowners' yards can help life to return to the citizens' doorsteps. This is beneficial in terms of environmental education since it conveys messages of nature supported by dead wood.

Fasth, B., Harmon, M.E., Woodall, C.W. and Sexton, J., 2010. Evaluation of techniques for determining the density of fine woody debris. http://andrewsforest.oregonstate.edu/pubs/webdocs/reports/detritus/publications/evaluation_of_techniques_FWD.pdf

This paper is prepared by the USDA Forest Service and its main focus is to evaluate techniques for determining the density of fine woody debris. The paper defines fine woody debris in contrast to coarse woody debris. Fine woody debris is dead woody pieces with diameter from 0.5 cm to 10 cm. Coarse woody debris is much larger in size and weight and carries more significance in dead wood studies.

Gundersen, Vegard, and Lars Helge Frivold. 2011. "Naturally Dead and Downed Wood in Norwegian Boreal Forests: Public Preferences and the Effect of Information." Scandinavian Journal of Forest Research 26 (2): 110–19. doi:10.1080/02827581.2010.536567.

This paper is an inspiration for public environmental education, designed to change attitude and values. It studied public aesthetic preference for deadwood in forests and whether images with accompanying information increases public acceptance of deadwood. Researchers surveyed respondents' preferences for images of forests with little or no visible dead wood compared to forests with dead wood. They found that respondents prefer images of forests with little or no visible dead wood. However, photos with accompanying text explaining the ecological benefits of dead wood to forests had a higher rating.

This study investigated aesthetic preferences regarding dead and downed wood in Norwegian forests in a web-based questionnaire. The 1,082 respondents were more than 16 years old, from southeastern and central Norway, and represented a cross-section of Norwegian residents. This paper suggests that using public outreach efforts on the ecological benefits of dead wood is effective. The ecological benefits haven't been communicated sufficiently, which suggests that public outreach is needed.

Gurnell, A. M., K. J. Gregory, and G. E. Petts. 1995. "The Role of Coarse Woody Debris in Forest Aquatic Habitats: Implications for Management." Aquatic Conservation: Marine and Freshwater Ecosystems 5 (2): 143–66. doi:10.1002/aqc.3270050206.

This paper explains the ecological role of coarse woody debris (CWD), and focuses on forest aquatic habitats. The definition of CWD is unclear in this paper. Accumulating CWD in streams has different impacts in forest habitats than in terrestrial habitats. When tree branches or logs fall into the water, they hydrologically and hydraulically influence the river channels by altering the direction and speed of the flow. Large dead wood stabilizes small streams by controlling and dissipating the river's energy, which substantially reduces bank erosion. CWD in urban aquatic habitats may not be effective in reducing urban runoff but it reduces the amount of sediment carried into the streams.

Harmon, Mark E., and Jay Sexton. 1996. Guidelines for Measurements of Woody Detritus in Forest Ecosystems. Vol. 20. US LTER Network Office Seattle (WA). http://and.lternet.edu/lter/pubs/pdf/misc/pub2255orig.pdf.

This paper is published by the United States Long Term Ecological Research Network (LTER), which was created by National Science Foundation (NSF). It provided guidelines for measuring coarse woody debris (CWD) in forest ecosystems. The definition of CWD varied among different institutions. To promote the research on CWD, LTER defined CWD as sound and rotting logs, snags, stumps, and large branches (located above the soil), which must be larger than 10 cm at the widest point.

The definition of CWD is a part of the classification of woody detritus that is divided into two categories: below ground and above ground (where CWD belongs). Woody detritus below ground, which has similar ecological functions, is neglected by most research due to its small size and relatively low volume, but it is worth mentioning.

Hodge, S. J., and G. F. Peterken. 1998. "Deadwood in British Forests: Priorities and a Strategy." Forestry 71 (2): 99–112. doi:10.1093/forestry/71.2.99.

This paper examines deadwood as an integral and substantial component of natural forests. The value of deadwood in forest ecosystems can be identified in four aspects: wildlife habitat, ecosystem functions, geomorphological processes, and as an index of ecosystem health.

The authors assign value to maintaining or increasing dead wood in different woodlands in descending order:

1. Ancient semi-natural woods which still supports many saproxylic species

2. Other ancient semi-natural woods and ancient woods converted to plantations
3. Secondary semi-natural woods and long-established plantations
4. Twentieth-century conifer plantation forests
5. New native woodland and broadleaf-conifer mixtures, mostly planted on farmland.

It also lists deadwood management strategies for each category. By reading the descriptions of these five types of land, land managers should be able to classify their own land and apply appropriate strategies.

Humphrey, J., A. Stevenson, P. Whitfield, and J. Swailes. 2002. "Life in the Deadwood: A Guide to Managing Deadwood in Forestry Commission Forests.," 18 pp. + foldout poster.

This is a publication by Forest Enterprise, an agency of the U.K. Forest Commission, provides general guidelines for deadwood management for forest managers, stakeholders, students, and citizens. Humphrey et al. (2002) classified four types of woodland based on Hodge and Peterken's categories (1998). Management priorities were adapted accordingly. Corresponding benchmark values are provided for land managers to monitor progress and propose further actions. As an outreach product, this publication was straightforward and easy to comprehend. It focused on local adaptive management with attainable benchmark values. It also reminds its audience about forest operation management especially for tree health, monitoring, and recording, which are minor but worth mentioning.

Humphrey J., and S. Bailey. 2012. Managing Deadwood in Forests and Woodlands: Practice Guide. Edinburgh: Forestry Commission.

This paper illustrates different types of deadwood using a self-explanatory figure. The authors recommend that managers identify an area's ecological value, low, medium, or high using five broad factors:
1. Current levels of deadwood on site
2. Continuity and diversity of deadwood habitats over time
3. Popular species associated with deadwood
4. Ecological connectivity
5. History of management

Managers and owners are encouraged to consider doing more than the minimum required for each woodland type or area, taking positive action to shift areas of low and medium value to a higher level. The paper also presents examples of low, medium, and high value woodland for deadwood.

Specific management actions to increase deadwood fall into four categories: working with natural processes, protecting and adding value to existing deadwood, creating and expanding deadwood habitat, and improving links between deadwood habitats. The authors suggest that management advice for deadwood should be considered alongside guidance for other aspects of biodiversity and within the context of other priorities such as safety, timber, wood fuel, and recreation.

Illhardt, B.L., E.S. Verry, and B.J. Palik. 2000. Defining riparian areas. In: Verry, E.S. et al. (eds.), Riparian management in forests of the continental eastern United States. Lewis Publishers. New York, NY. pp. 23-42. http://www.srs.fs.usda.gov/pubs/9428

This is a paper, from compiled conference proceedings for a conference in 2000, is a review of several definitions for riparian zones and the potential problems with these definitions. Illhardt et al. defined riparian zones based on function, as the transitional areas between the streams and land adjacent to the streams, which are important for improving stream health.

Naiman, Robert J., Estelle V. Balian, Krista K. Bartz, Robert E. Bilby, and Joshua J. Latterell. 2002. "Dead Wood Dynamics in Stream Ecosystems." In Proceedings of the Symposium on the Ecology and Management of Dead Wood in Western Forests, 23–48. http://grwc.info/Assets/Reports/LWD/Dead-wood-Dynamics.pdf.

This paper discusses the ecological importance of large wood detritus (LWD) in streams, (> 10 cm diameter and > 1 m in length). It starts by summarizing information compiled from literature on the abundance, size, spatial distribution, history, origin, input rates, and models of dead wood in the United States.

The paper shows that LWD is an integral component of stream and river corridors, positively affecting material retention, habitat formation, and productivity. The authors suggest that stream should keep LWD and be ensured of a continued supply of LWD of appropriate size, volume and species, important for maintaining long term integrity of stream and river corridors.

Nassauer, Joan Iverson. "Messy Ecosystems, Orderly Frames." Landscape Journal 14, no. 2 (1995): 161–70.

This paper describes a common problem in landscape planning, that landscapes containing ecological benefits are not appreciated by the public. Nassauer concludes that the problem stems from the fact that cultural values of beauty are not connected with ecological functions. The social norm of aesthetic scenery, the world view of beauty, can generate some unfounded myths. In the case of dead wood, people believe that dead trees are detrimental and useless for forests. As a result, it is imperative to address the ecological functions of dead wood, which are not evident even to educated eyes.

Pan, Yude, Richard A. Birdsey, Jingyun Fang, Richard Houghton, Pekka E. Kauppi, Werner A. Kurz, Oliver L. Phillips, et al. 2011. "A Large and Persistent Carbon Sink in the World's Forests." Science 333 (6045): 988–93. doi:10.1126/science.1201609.

One ecological function of dead wood is its contribution to global carbon storage. This paper uses global forest inventory data and long-term ecosystem carbon studies to estimate global forest carbon deposits. Using 1990-2007 forest inventory data and the results of long-term ecosystem carbon studies, Pan et al. (2011) estimated that the carbon stored in the dead wood accounts for eight percent of the total carbon stock in global forests. It is suggested that dead wood is an easily managed carbon pool for land managers and ought to be maintained to contribute to global carbon stock.

Palone, Roxane, and Albert Todd. "Chesapeake Bay riparian handbook: a guide for establishing and maintaining riparian forest buffers." (1998). http://www.na.fs.fed.us/pubs/misc/riparian_handbook/chesapeake_bay_riparian_handbook.pdf?

This USDA Forest Service handbook for land managers is a guide to maintaining riparian forest buffers in the Chesapeake Bay Watershed. It provides examples of the roles of dead wood in restoring riparian ecosystems: preserving channel integrity and bank stability in the shallow Chesapeake Bay Watershed. It suggests that dead wood should not be removed since it acts as a strategic buffer, protecting and enhancing watershed health by storing large amount of sediment and gravel. The handbook urges land managers and planners to make wise use of dead wood for ecosystem restoration.

Rose, Cathy L., Bruce G. Marcot, T. Kim Mellen, Janet L. Ohmann, Karen L. Waddell, Deborah L. Lindley, and Barry Schreiber. 2016. "Decaying Wood in Pacific Northwest Forests: Concepts and Tools for Habitat Management." Accessed March 14. http://www.fs.fed.us/wildecology/decaid/decaid_background/chapter24cwb.pdf.

This paper summarizes the ecological significance of decaying wood (defined as dead wood in the process of decay) in wildlife habitat and the species supported by decaying wood. The authors focus on the long term energy source input to streams and riparian forests, and argue that nutrients that are trapped and consolidated by logs are sources for nutritional particles, which are an important part of aquatic wildlife food sources. Further, by reducing the impacts of fast flow on eroded banks, especially during heavy rainfalls, dead wood stabilizes and shapes the riparian ecosystem.

Söderberg, Ulf, Sören Wulff, and Göran Ståhl. 2014. "The Choice of Definition Has a Large Effect on Reported Quantities of Dead Wood in Boreal Forest." Scandinavian Journal of Forest Research 29 (3): 252–58. doi:10.1080/02827581.2014.896940.

This paper notes that different countries measure dead wood differently and assesses the impact of different definitions of dead wood in Swedish forests. It argues that adding stumps to the definition would increase the amount of dead wood by 44 percent.

The paper defines snags and stumps using quantitative measures; snags are considered as standing dead trees coarser than 5 cm diameter at the height of 1.3 meters whereas stumps are coarser than 5 cm diameter at the top end and less than1.3 meters in height. Quantitative definition yields accurate data that helps analyze the available amount of dead wood and set up goals for future management.

Stokland, Jogeir N., Juha. Siitonen, and Bengt Gunnar. Jonsson. 2012. Biodiversity in Dead Wood. Ecology, biodiversity, and conservation; Ecology, biodiversity, and conservation. New York: Cambridge University Press.

This book focuses one aspect of the ecological functions of dead wood, the biodiversity of saproxylic species, defined as any species that depends, during some part of its life cycle, upon wounded or decaying woody material from living, weakened, or dead trees. Due to declining forest areas and the lack of dead wood, saproxylic species are one of the most threatened organisms. The authors believe it is imperative to address the ecological functions of dead wood, which are often not evident, even to educated eyes.

The book discusses how various saproxylic species associate with dead wood. Birds (parrots, woodpeckers and owls) dwell in the cavities in the snags. Wood-boring insects such as flies, termites, and mites consume dead wood to fulfill nourishment needs. Saproxylic species may prevent pest outbreak since they are the predators and parasitoids of bark beetles, which can cause significant damage to forest health. Each trophic level of the food web that starts with woody material as primary producers is occupied by various saproxylic species.

Pickett, Steward TA, Mary L. Cadenasso, J. Morgan Grove, Christopher G. Boone, Peter M. Groffman, Elena Irwin, Sujay S. Kaushal, et al. 2011. "Urban Ecological Systems: Scientific Foundations and a Decade of Progress." Journal of Environmental Management 92 (3): 331–62.

doi:10.1016/j.jenvman.2010.08.022

This paper provides an overview of the factors and framework used to study urban ecological systems. It summarizes findings over a decade, including urban stream syndrome. A stable riparian ecosystem plays an important role in relieving urban stream syndrome, which is commonly understood as the ecological degradation of streams due to urbanized land.

Tyrväinen, Liisa, Harri Silvennoinen, and Osmo Kolehmainen. 2003. "Ecological and Aesthetic Values in Urban Forest Management." Urban Forestry & Urban Greening 1 (3): 135–49. doi:10.1078/1618-8667-00014.

The research studied whether aesthetic and ecological values can be combined with the management of urban or community forests. To see if a participatory planning process is effective, respondents were selected from participatory planning group meetings and from among general citizens. They were asked to evaluate photographs of conflict issues in urban forest management: thinning, understory management, and the leaving of dead snags and decaying ground-wood.

The authors propose that environmental education for general citizens should be done at an early age, since any change in attitudes and values toward urban forests requires a relatively long time period. The findings show that younger residents with a higher education and active urban forest users prefer more ecologically-oriented management.

Wu, J., De-xin Guan, Shi-jie Han, Mi Zhang, and Chang-jie Jin. 2005. "Ecological Functions of Coarse Woody Debris in Forest Ecosystem." Journal of Forestry Research 16 (3): 247–52. doi:10.1007/BF02856826.

The author defined coarse woody debris (CWD) as downed wood (logs), large branches, pieces of fragmented wood, stumps, and standing dead trees (snags). Additionally, the article summarizes four sources of coarse woody debris: wind, fire, disease and pests, and aging.

The article summarizes three ecological functions of dead wood: enhancing soil ecology, maintaining biodiversity, and retaining long term carbon budget and storage. The author states that additional quantitative research is needed to elaborate on the ecological needs of CWD when providing technological management guidelines. Future research is needed to understand the decomposition carbon budget process. The author also states that CWD benefits forest soil ecology by providing organic matter and nutrients as well as water and soil conservation. CWD maintains biodiversity by providing habitat for small mammals and arthropods, food, shelter, protection, cover, substrate or climate amelioration. A sufficient small animal population helps sustain forest succession.