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Abundance, Volume and Distribution of Large Woody Debris along a Northeastern Illinois Stream

[1]Xiaoyong Chen and [2]Mary Carrington
College of Arts and Sciences, Governors State University, Illinois, 60484
[1]xchen@govst.edu (708) 534-4557; [2]mcarrington@govst.edu (708) 534-4532

ABSTRACT

In-stream large woody debris (LWD), defined as dead wood ≥ 10 cm in diameter and ≥ 1 m in length, has played multiple structural and functional roles in aquatic ecosystems. Despite the importance of LWD to fluvial ecosystems, few studies have been conducted in low-gradient Midwestern rivers and streams. In this study, the quantity and characteristics of LWD were investigated in the upper-, middle- and down-stream sections along Thorn Creek located in Northeastern Illinois. The results showed that LWD abundance ranged from 18 to 58 pieces · 100 m^{-1}, LWD volume ranged from 1.87 to 5.37 m^3 · 100 m^{-2}, and total LWD length ranged from 44.2 to 170.0 m per 100 m of stream length in the study sites. The quantity of woody pieces per 100 m of stream length was significantly higher in the down-stream section than in both upper- and middle-stream sections. Over 80% of LWD pieces were ≤ 20 cm in diameter and ≤ 4 m in length. Approximately 90% of wood pieces were in the medium and latter decomposition stages. Most LWD pieces (> 60%) were parallel to the stream-flow in the upper- and middle-stream sections and this percentage decreased to about 50% in the down-stream section. About 50% of wood pieces were located on the streambed and over 10% of LWD entirely spanned the bankfull width in both the upper-stream and middle-stream sections, but these fractions were 60% and 4% in the down-stream section. The highest proportion of LWD was anchored or buried in one streambank in both upper-stream and middle-stream sections, while the highest percentage of LWD was loose within the stream bankfull width in the down-stream section. About 60% of LWD played a functional role in bank stability, pool creation, sediment deposition and trapping smaller woody debris in the study stream and this percentage declined slightly from upper-stream to down-stream. Our results highlight the heterogeneity of LWD distribution in the study region.

INTRODUCTION

In-stream large woody debris (LWD) plays multiple roles in fluvial ecosystems (Harmon et al. 1986; Bilby and Ward 1991; Benda and Sias 2003; Ruiz-Villanueva et al. 2016). LWD affects river morphology and sediment dynamics (Wohl and Scott 2017), supplies energy, food resources and nutrients to fish and other aquatic organisms in streams and rivers (Sweka and Hartman 2006; Gurnell 2014), and offers habitats for various species of animals and microbes (Fetherston et al. 1995). LWD also provides a key linkage between riparian vegetation and streams, which is involved in many important ecological processes such as organic matter deposition, carbon sequestration and nitrogen cycling (Chen et al. 2005; Wohl 2013). As a result, structural and functional characteristics of LWD have been used as significant indicators in the understanding of hydrological, geomorphological and ecological processes in stream systems (Martin et al. 2016). Moreover, LWD addition has become one of the most common stream restoration activities in the Midwest region of the United States (Shields et al. 2003; Alexander and Allan 2006).

The quantity, quality and functional role of LWD in stream systems differ depending on region, stream size, riparian forest characteristics and natural and human disturbances (Gurnell et al. 2000; Chen et al. 2006; Benda and Bigelow 2014; Wohl and Scott 2017). LWD storage in old-growth forested streams is relatively stable as woody debris can be continuously recruited from the surrounding riparian forests (Ralph et al. 1994). Timber harvesting activities and wildfire disturbances cause a temporal fluctuation in LWD stocks and distribution due to alteration of woody debris recruitment from adjacent riparian vegetation (Gomi et al. 2001; Chen et al. 2005). Small streams usually contain more woody debris, and as stream size and flow power increase, abundance of LWD decreases and only the larger more stable pieces are likely to remain in place (Marcus et al. 2002; Chen et al. 2006). Harmon et al. (1986) pointed out that the patterns of LWD distribution along a longitudinal gradient were determined by a combination of fluvial and terrestrial factors. The terrestrial factors might likely dominate in smaller streams and the combined effects of fluvial and terrestrial factors probably operate in larger streams. Despite the importance of LWD in fluvial ecosystems, very little quantitative information about LWD features in Midwestern streams exists (Daniels 2006; Cordova et al. 2007; Martin et al. 2016), and no studies have examined LWD structure and function in northeastern Illinois streams.

To the best of our knowledge, this study was the first to quantify LWD characteristics in northeastern Illinois streams. The present study examines structural and functional characteristics of LWD along Thorn Creek in northeastern Illinois. The specific objectives of the study are (1) to quantify abundance, dimensions and volume of LWD in the studied stream; (2) to characterize decomposition status, orientation and structural features of LWD pieces; and (3) to determine the distribution and features of LWD pieces in the upper-, mid- and down-stream sections along the study stream.

METHODOLOGY

Study Area

Thorn Creek watershed is located about 35 km south of Chicago (Figure 1) and is further sub-divided into four sub-watersheds (Butterfield Creek, Thorn Creek, Deer Creek, and North Creek), each related to one of its major creeks. The Thorn Creek sub-watershed area is about 83 km^2 and the main stream is a 27.4 km-long tributary of the Little Calumet River that travels through Will and Cook counties in northeastern Illinois. Thorn Creek general-

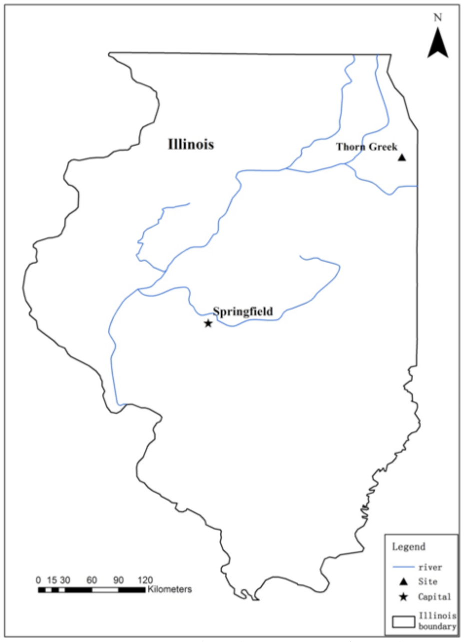

Figure 1. Geographic location of study site in northeastern Illinois, USA.

ly flows from southwest to northeast. Along its path it has cut many deep ravines and valleys. Although width of the creek varies, the creek is usually quite narrow. The study area has a continental climate. Mean annual precipitation is 972.8 mm, with most precipitation in the growing season (April through September) and least during midwinter. The seasonal flow trend of Thorn Creek follows the general precipitation pattern for the area: highest flows in April and the lowest flows in October. The mean annual air temperature is 10.6°C with maximum monthly temperature of 24.2°C in July and a minimum of −4.7°C in January. The bedrock of the Thorn Creek watershed primarily comprises Silurian dolomite and Ordovician Maquoketa shale. The features of the bedrock surface topography generally include coarse grained sediments such as sands and gravels that form important productive aquifers. The soils in the study site are classified as mollisols rich in organic matter and have a black to dark brown color. The major tree species in the study area include basswood (*Tilia americana* L.), slippery elm (*Ulmus rubra* Muhl.), sugar maple (*Acer saccharum* Marsh.) and red oak (*Quercus rubra* L.) in the floodplain forests. The watershed has been formally protected under a Thorn Creek Watershed Based Plan with the goal of protecting and enhancing surface water quality to support uses designated for Thorn Creek by the Illinois Environmental Protection Agency (NIPC 2005).

Field Measurements

Three study reaches, each 500 m in length and parallel to stream flow, were selected along Thorn Creek and they represented upper-stream, middle-stream and downstream sections of the stream. The reaches were selected in areas where the stream-side natural riparian forests were not disturbed by human activities, such as harvesting, road building and burning. Characteristics of the three study reaches are shown in Table 1.

In this study, LWD was defined as any unattached pieces of wood with a size of ≥ 1 m in length and ≥ 10 cm in diameter and located within the bankfull channel. All LWD pieces in the selected reaches were visually identified and directly counted and measured. The volume of each piece (V; m^3) was calculated as $V = \pi \times r^2 \times L$, where π is a constant of 3.1416, r (cm) is the radius of the LWD and L (m) is the length of the piece. Additional characteristics of each LWD piece such as the decay state, orientation, position, stability and function were also recorded.

Five decay classes were used to describe the state of decay of each piece: (1) bark intact (> 95% of bark remaining), limbs and twigs present, round shape with original texture and color; (2) most bark intact (between 75% and 95% of bark remaining), between 50% and 90% of limbs and twigs absent, round shape with original texture and color; (3) trace of bark (between 10% and 50% of bark remaining), >90% of limbs and twigs absent, round shape with smooth texture, surface firm, darkening color; (4) trace of bark (<10% of bark remaining), limbs and twigs absent, irregular shape, surface deteriorating, center solid or patchy, dark color; (5) bark absent, limbs and twigs absent, irregular shape, surface deteriorating, center rotten, dark color. The horizontal orientation of each woody piece was grouped into one of two categories based upon the orientation in relation to the direction of streamflow: (1) perpendicular or close to perpendicular to streamflow (45-135° or 225-315°), (2) parallel or close to parallel to streamflow (135-225° or 45-315°).

The position of each LWD piece in relation to bankfull height of the channel was recorded as having one of three positions: (1) piece was situated entirely below one half of bankfull height; (2) piece was situated above one half of bankfull height; and (3) piece was entirely spanning over the bankfull width. Each piece was grouped into one of four stability categories: (1) greater than bankfull width and either spanning or anchored by both stream banks; (2) anchored or buried in one stream bank; (3) braced by other pieces within the channel bankfull width; (4) loose within the channel bankfull width.

Each LWD piece was also identified as being either functional or non-functional. Functional wood was defined as any piece that played a role in any of the following functions: (1) bank stability, (2) pool creation, (3) sediment deposition, and (4) trapping smaller woody debris (pieces <10 cm in diameter). Non-functional wood was any piece that did not provide any of the functions identified above.

Data Analysis

Student's *t*-tests were used to compare mean

Table 1. Characteristics of study reaches and LWD pieces in upper-, middle- and downstream sections in Thorn Creek, northeastern Illinois.

Item	Upper-stream	Middle-stream	Down-stream
Mean bankfull width (m)	4.1	4.8	8.9
Length of sampled reach (m)	500	500	500
Reach area (m^2)	2048	2404	4443
Total number of LWD pieces	128	91	291
Mean LWD diameter (cm)	16.8	9.4	26.9
Mean LWD length (m)	3.2	2.4	2.9
Abundance (pieces/100 m)	25.6	18.2	58.0
Volume (m^3/100m)	3.35	1.87	5.37
Total LWD length (m/100 m)	81.8	44.2	170.0

LWD abundance, volume and total length per100-m of stream channel width for the different 500-meter stream sections. Results were considered significant if *P*≤0.05.

RESULTS

A total of 509 LWD pieces was found, with 128, 91, and 290 pieces in the upper-, middle-, and down-stream sections, respectively (Table 1). Means of LWD abundance, volume and length per 100 m of reach length were significantly higher (*P*<0.05) in down-stream than in middle-stream sections. No statistically significant differences (*P*>0.05) were found in these LWD quantitative features between upper-stream and middle-stream sections. When compared to the down-stream section, the upper stream section had lower mean LWD abundance (*P*<0.05) and marginally lower mean LWD length (*P*=0.08), but no difference in mean woody volume (*P*>0.05).

More than 80% of the total number of LWD pieces were <20 cm in diameter, but they accounted for only about 40% of the total LWD volume in the three study stream sections (Figure 2 and Figure 3). LWD pieces > 50 cm diameter accounted for about 3% of the total LWD number but they accounted for 38% of the total LWD volume (Figure 2 and Figure 3). In the study stream, about 80% of total LWD pieces were in the < 4 m length class. The pieces > 8 m in length only accounted for about 3% of the total number of LWD (Figure 4).

About 10% of the LWD pieces were in a relatively fresh state of decomposition (Table 2, decay classes 1 and 2). Most of the LWD pieces (> 60%) were in a relatively medium stage of decomposition (decay classes 3 and 4). Over 60% of LWD had a parallel orientation to the stream flow direction in the upper-stream and middle-stream sections (Table 2) and this percentage declined to about 50% in the down-stream section. On average, more than 50% of LWD located in the streambed position in the study sites (Table 3). LWD was found in the position of above one half of bankfull height accounted for about 35% of the total LWD number.

The highest proportion of LWD pieces was anchored or buried in one stream bank in both the upper-stream and middle-stream sections, but the highest percentage of LWD pieces was in loose within the channel bankfull width in the down-stream section (Table 3). About 60% of the total LWD pieces showed a functional role, and this percentage was slightly decreased from the upper-stream to down-stream sections (Table 4).

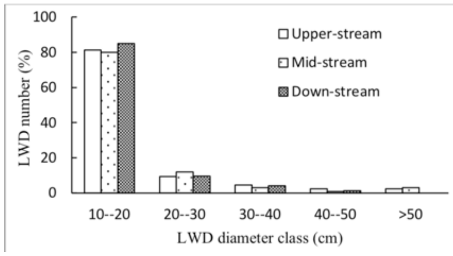

Figure 2. Distribution of LWD number by diameter classes in upper-, middle- and down-stream sections in Thorn Creek stream, northeastern Illinois.

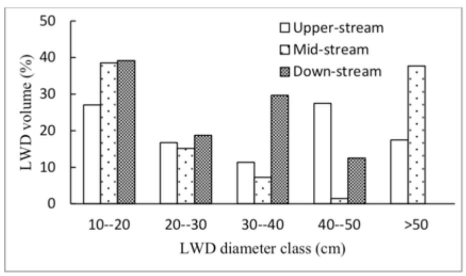

Figure 3. Distribution of LWD volume by diameter class in upper-, middle- and down-stream sections in Thorn Creek stream, northeastern Illinois.

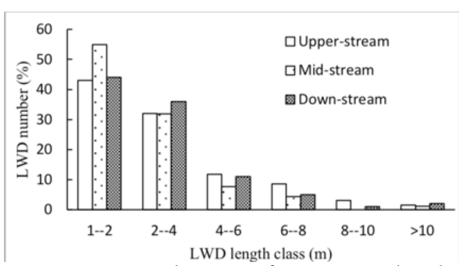

Figure 4. Distribution of LWD number by length class in upper-, middle- and down-stream sections in Thorn Creek stream, northeastern Illinois.

DISCUSSION

One of the important objectives in sustainable management of forested watersheds is to maintain the essential quantity and quality of LWD pieces in aquatic environments. In order to achieve this aim, an understanding of the number, size, distribution and characteristics of LWD in stream networks is a necessary and critical step. Thorn Creek is a stream typical in fluvial and morphological characteristics that is poorly documented in LWD literature for the Midwestern USA. The present results, although preliminary, provide valuable reference for understanding the characteristics and distribution of LWD at the stream scale in this region.

Measurements of LWD abundance in Thorn Creek ranged from 18.2 to 58 pieces · 100 m^{-1}, which were consistent with other results from some other Midwestern rivers and streams. Cordova et al (2007) found that LWD abundance ranged from 9 to 64 pieces · 100 m^{-1} in Ottawa National Forest streams in Michigan. But our numbers were high relative to those reported in other studies conducted in Midwestern and Eastern regions. Marin et al. (2016) reported that LWD loads in the Big River located in southeast Missouri ranged from 4 to11 pieces per 100 meter of steam length. Parker and Hart (2014) reported that density of in-stream LWD ranged from 20 to

Table 2. Percent of LWD in five decay classes and percent LWD oriented parallel or perpendicular to streamflow in upper-, middle- and down-stream sections in Thorn Creek, northeastern Illinois*.

Stream Section	LWD decay class						LWD orientation		
	1	2	3	4	5	Total	Parallel	Perpendicular	Total
Upper-stream	2	11	51	27	10	100	63	38	100
Middle-stream	0	11	26	25	37	100	66	34	100
Down-stream	3	7	37	37	16	100	52	48	100

*LWD decay class: 1. Bark intact (> 95% of bark remaining), limbs and twigs present, round shape with original texture and color; 2. Most bark intact (between 75% and 95% of bark remaining), between 50% and 90% of limbs and twigs absent, round shape with original texture and color; 3. Trace of bark (between 10% and 50% of bark remaining), >90% of limbs and twigs absent, round shape with smooth texture, surface firm, darkening color; 4. Trace of bark (<10% of bark remaining), limbs and twigs absent, irregular shape, surface deteriorating, center solid or patchy, dark color; 5. Bark absent, limbs and twigs absent, irregular shape, surface deteriorating, center rotten, dark color. LWD orientation: Parallel or close to parallel to streamflow (135-225° or 45-315°); Perpendicular or close to perpendicular to streamflow (45-135° or 225-315°).

28 pieces · 100 m^{-1} in southern Appalachian forests in Alabama. Magilligan et al. (2008) documented that LWD loads were 1.1 to 5.5 pieces · 100 m^{-1} in coastal Maine watersheds. When LWD volume was considered, the quantity of LWD volume found in this study (ranged from 1.87 to 5.37 m^3 · 100m-1) was lower than previously reported in Midwestern and Eastern rivers and streams. Loading volumes of in-stream LWD ranged from 7.1 to 31.2 m^3 · 100 m^{-1} in southern Appalachian mountain streams (Hedman et al. 1996). Parker and Hart (2014) reported that density of in-stream LWD volume ranged from 4.8 to 8.3 m^3 · 100 m^{-1} in southern Appalachian forests in Alabama. Williams and Cook (2010) reported LWD loadings of 4 and 18 m^3 · 100 m^{-1} in Cook Forest State Park in Pennsylvania.

The relatively small size of LWD, high number of pieces, and low LWD volume observed in Thorn Creek are likely due to several different factors. Most LWD pieces found in this study stream were < 20 cm in diameter and < 4 m in length, reflecting the size distribution of the bankside riparian vegetation from which the majority of LWD in streams was derived. Riparian forests surveys along Thorn Creek indicated that most of coarse woody debris (>85%), snags (71%) and living trees (60%) in the riparian forests were similarly small, having an average diameter of ≤20 cm (Authors, unpublished data). The topography surrounding Thorn Creek is relatively flat, lacking the rugged topography, high relief and small hills that are dominant LWD recruitment mechanisms in more hilly or mountainous regions (Ruiz-Villanueva et al. 2016).

Longitudinal trends in LWD abundance, volume, length, piece size and position were obvious along Thorn Creek and strongly related to channel width and flow power of the stream. In the upper-stream section, woody pieces were normally anchored or buried in at least one stream bank and involved in enhancing stream bank stability. The proportion of pieces that spanned the entire bankfull channel width was relatively high (Table 3), and the proportion of pieces loose within the channel bankfull width was relatively low (Table 3) due to a narrow bankfull channel width. There was insufficient stream power to move LWD pieces, and LWD would likely

Table 3. Percentage of LWD position and LWD stability in upper-, middle- and down-stream sections in the Thorn Creek stream, northeastern Illinois*.

Stream Section	LWD Position				LWD Stability				
	1	2	3	Total	1	2	3	4	Total
Upper-stream	53	31	16	100	16	41	16	27	100
Middle-stream	52	37	11	100	15	53	1	31	100
Down-stream	60	36	4	100	5	28	10	57	100

*LWD position: 1. Pieces was situated entirely below one half of bankfull height; 2. Pieces was situated above one half of bankfull height; 3. Pieces was entirely spanning over the bankfull width. LWD stability: 1. Greater than bankfull width and either spanning or anchored by both stream banks; 2. Anchored or buried in one stream bank; 3. Braced by other pieces within the channel bankfull width; 4. Loosed within the channel bankfull width).

Table 4. Distribution of LWD pieces in four function categories in upper-, middle- and down-stream sections in Thorn Creek, northeastern Illinois*.

Stream Section	LWD Function Categories						Total
	1	2	3	4	Total Functional	Non-Functional	
Upper-stream	19	6	32	21	78	50	128
%	15	5	25	16	61	39	100
Middle-stream	7	1	32	17	57	34	91
%	8	1	35	19	63	37	100
Down-stream	2	3	46	112	163	128	291
%	1	1	16	38	56	44	100

*LWD function: 1. bank stability; 2. pool creation; 3. sediment deposition; 4. trapping smaller woody debris (pieces <10 cm in diameter). Non-functional wood was any pieces that did not provide any of the functions identified above.

accumulate and become a source of LWD downstream under extreme hydrological events or debris flows (Montgomery and Buffington 1997; Chen et al. 2006; Baillie et al. 2008). In the middle-stream section, as the channel bankfull width increased, the fraction of woody pieces loose within the channel width increased and the percentage of pieces spanning the bankfullchannel width decreased. Moreover, stream power increased with an increase in bankfull channel width and resulted in a reduction of LWD abundance, size and volume. On the other hand, channel bankfull width in the middle-stream section still constrained movement of larger woody pieces and a relatively high proportion of individual LWD pieces >50 cm in diameter was found in this reach (Figure 3). In the down-stream section where mean channel bankfull widths increased to 8.9 m, most pieces were loose within the bankfull channel width and few LWD pieces spanned the bankfull channel width. Under normal conditions, the fluvial power on movement of LWD pieces was diminished in the low-gradient streams and almost half (48%) of all pieces were perpendicular to streamflow direction on the streambed (Table 2). Fluvial processes redistributed LWD pieces into debris dams, which resulted in an increase of LWD abundance in down-stream reaches. Our results of LWD distribution in Thorn Creek were in line with other previous findings derived from studies conducted in the lower-gradient stream and river systems in the Midwestern United States (Cordova et al. 2007; Martin et al. 2016).

In summary, the majority of LWD pieces were small (≤20 cm in diameter and ≤4 m in length), in a mediam decomposition status, situated entirely below one half of bankfull height, and played functions in trapping smaller woody debris and enhancing sediment deposition and bank stability in Thorn Creek. Specifically, when compared to the down-stream section, more LWD in the upper-stream section were orientated parallel to the streamflow, entirely spanned over the channel width, were anchored or buried in one stream bank, and contributed to sediment deposition and bank stability. Our results provide a valuable reference for understanding of LWD characteristics of LWD in Midwestern river systems. Further studies are needed to investigate characteristics and distribution of LWD at a regional scale in the Midwest to develop generalizations of the results presented here. Studies are also needed to examine the dynamics of LWD in response to natural disturbances and human management practices in order to better understand biogeochemical cycles of organic matter in terrestrial and aquatic ecosystems in this region.

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