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Riparian forest and instream large wood characteristics, West Branch Sheepscot River, Maine, USA

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ABSTRACT

This study examined riparian forest and instream large wood characteristics in a 2.7 km reach of the West Branch of the Sheepscot River in Maine in order to increase our basic knowledge of these components in a system that is known to have undergone multiple land conversion. The West Branch is approximately 40 km long, drains a 132 km^2 watershed and is vitally important to the remnant population of Atlantic salmon (*Salmo salar*) and other native species. The riparian forest is comprised of relatively small trees with a mean DBH of 21 cm (SD $\pm$ 10.92) with 56% of the trees having a DBH <20 cm. Balsam fir (*Abies balsamea*) and red maple (*Acer rubrum*) are the most common species (54%), and 75% of all trees are short-lived, small diameter species. These data suggest the riparian forest in the West Branch Sheepscot River is dominated by young forest stands, a legacy of land use. During a survey conducted in 2005, 210 pieces of large woody debris (LWD) were identified in the study reach; an average of 78 pieces km^{-1}. The total volume of pieces was 8.5 m^3 or 3.2 m^3 km^{-1} (LWD in this study is defined as pieces $\geq$10 cm in diameter and >2 m in length). The mean diameter of LWD was 17 cm with 75% of all pieces having a diameter <20 cm. Most pieces were oriented parallel or nearly parallel to the channel and did not appear to influence channel morphology. In contrast, larger pieces were more often in perpendicular or nearly perpendicular orientations, and were more likely to have a pool-forming function. Overall, the reach has low levels of stable large wood, which do not have a major influence on stream habitats.

1. Introduction

Removal of the riparian forests along rivers in Maine began over 300 years ago and has continued during multiple land use conversions through the 20th century. Many ecosystem processes and species have been negatively impacted by these riparian conversions, including the critically endangered sea-run Atlantic salmon (*Salmo salar*), which relies on riparian areas to provide essential habitat components for all life stages. Lack of instream large wood, which provides structure and complexity in the stream channel, is one missing habitat component (Fay et al., 2006).

We know little about the dynamics of large wood in Maine systems. Although large wood has been studied on the west coast of the United States and in Europe for over 20 years (Gregory, 2003), it is only recently that efforts have been undertaken in Maine. Magilligan et al. (2008) looked at instream large woody debris (LWD) across seven coastal watersheds in Maine and concluded the lack of large wood is a legacy effect of past land use. In low gradient coastal systems in Maine, such as the Sheepscot River, recruitment of large wood is primarily from the riparian forest, usually within one tree length (<20 m) of the terrestrial/aquatic boundary and is supplied to the stream channel episodically (Gurnell, 2003; Gurnell et al., 2002). Large-scale episodic disturbances, such as weather events (hurricanes and ice storms, for example), logging, and development, affect the amount of wood available to the channel (Naiman et al., 2000; Fetherston et al., 1995).

In this study we looked at instream large wood and riparian stand characteristics in a specific reach in order to increase our basic knowledge of these components in a system that is known to have undergone multiple land conversion. As Magilligan et al. (2008) suggest, large wood in coastal rivers in Maine may be below what occurred pre-settlement and below desired future conditions. Although this study only looked at one reach, the information is needed to guide future research into the dynamics of instream large wood, riparian function, linkages between the riparian forest and instream large wood, and targets for future conditions. The questions this research sought to answer were: (1)

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What are the current characteristics of the riparian forest? (2) What are the current large wood characteristics? To explore these questions, we examined a 2.7 km long reach of the West Branch Sheepscot River.

2. Methods

2.1. Study site

Research was conducted in the West Branch Sheepscot River in mid-coast Maine, USA (Fig. 1) located within the Gulf of Maine DPS for Atlantic salmon. The West Branch and its associated riparian areas experienced the greatest amount of human disturbance between 50 and 250 years ago (Lowden and Gilbert, 1993; Lowden, 1984; Grow, 1975; Dowe, 1954; Donham, 1909). Inland areas were not settled as rapidly as coastal areas, particularly along smaller rivers and tributaries, but the large landowners began surveying their holdings in the late 1790s to early 1800s to encourage settlers to begin "taming" the landscape (Grow, 1975). It is the legacy of this taming of the land that influences the system today. Establishing the condition of the landscape before widespread expansion occurred is difficult because few records exist that describe the landscape prior to this time. In most areas of the Sheepscot River and throughout mid-coast Maine, riparian forests have been harvested multiple times, either to facilitate conversion of the land for agricultural and residential use, or for industry and firewood (Lowden and Gilbert, 1993; Lowden, 1984; Grow, 1975; Dowe, 1954; Donham, 1909). As a result fewer than 100 remnant old growth or primary growth forest have been identified in Maine (Foss, 1999). Structural elements, such as boulders and large wood were removed from stream channels to facilitate the passage of logs downstream to mills and ports on even the smallest of streams (Allin and Judd, 1995). The West Branch is the largest tributary to the Sheepscot River and is 40 km long, draining a 132 km^2 watershed. The West Branch flows from a wetland complex approximately 10 km to the southwest of the headwaters of the

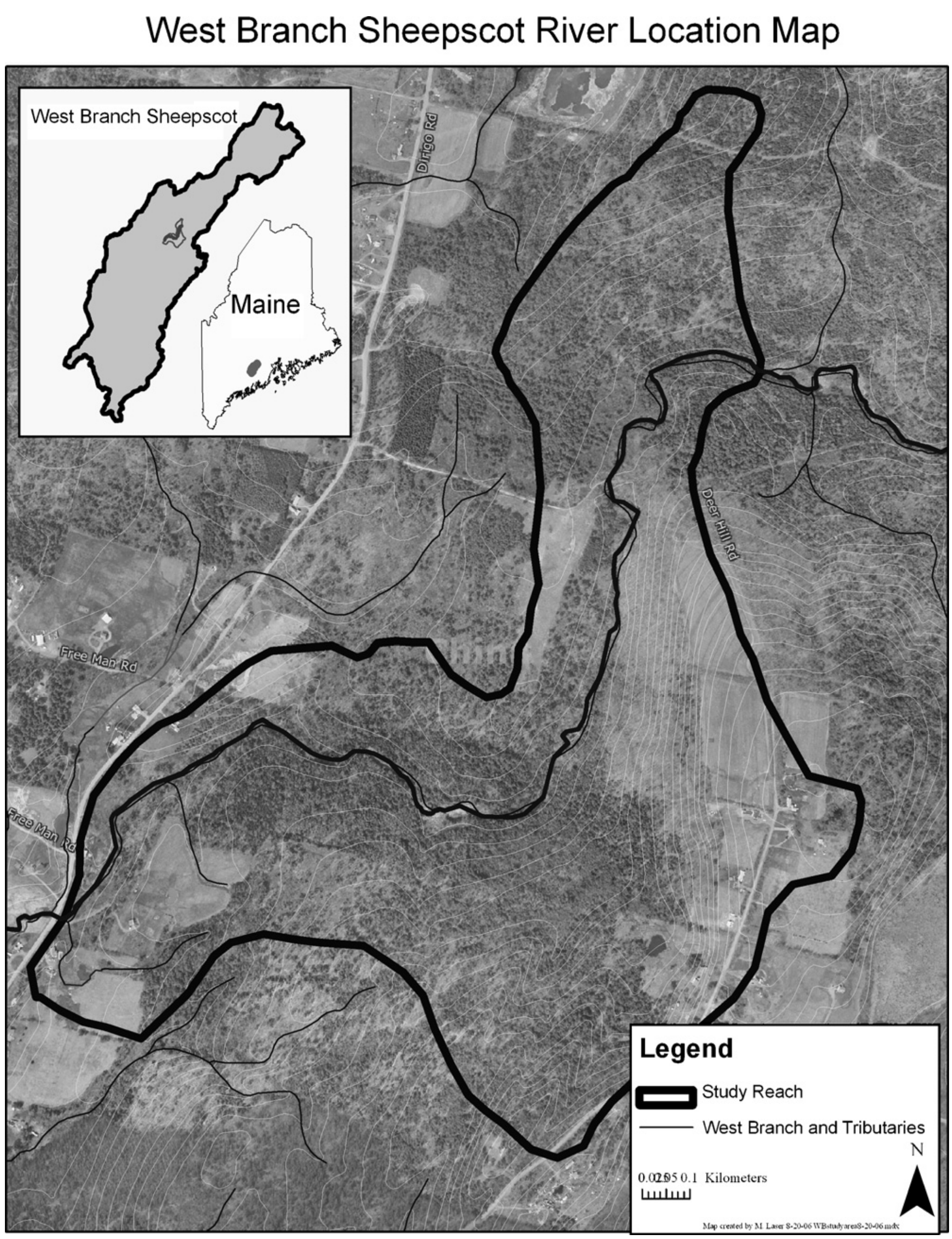

Fig. 1. Location map – West Branch Sheepscot River and the study reach (2.7 km).

main stem of the river. The tributary is vitally important to the remnant population of Atlantic salmon and other native species living in the river and surrounding watershed.

We sampled trees in the riparian area and inventoried instream large wood along a 2.7 km segment of the West Branch. This reach was selected based on several factors: it has the highest gradient in the river, contains almost continuous Atlantic salmon habitat, has a forested riparian zone, and represents 17% of the tributary length. The valley width for this reach is 610 m, a channel slope of 0.43%, a sinuosity of 1.17, and a riffle-pool morphology. The mean bankfull width of the reach is 13 m with an actual wetted width during the survey of 9 m. Data from the closest weather station indicate an average rainfall of 117 cm and an average annual snowfall is 180 cm. Several studies (Meister, 1982; King, 1970; Bryant, 1956) have indicated that low flow in the late summer and early fall is a problem in the Sheepscot River for Atlantic salmon, as low flow prevents adults from moving into spawning areas and reduces habitat quality and quantity for juveniles (Armstrong et al., 2003).

Atlantic salmon habitat requirements change through the species lifecycle (Armstrong et al., 2003; Bardonnet and Baglinière, 2000; Baum, 1997); fry generally need slower moving, shallower waters than do parr or spawning salmon, and substrate that is smaller, on average, than that favored by parr (Table 1). A heterogeneous reach that contains all of these habitat types is important to the survival of the species as a diverse habitat offers more spatial niches for salmon (Heggenes, 1990).

We used descriptive statistics to summarize the data and a Chi-square analysis to describe observed versus expected results. *p*-Values of less than 0.05 were considered significant. Data collection occurred for both protocols simultaneously during a low flow period in October 2005.

2.2. Sampling riparian trees

Belt transects were established perpendicular to the river every 100 m, with an established start point at the beginning of the reach, for a total of 26 transects on each side of the river. Each transect was 5 m wide and 20 m deep starting at the bankfull edge of channel and extending both river left and right at each 100 m interval. Twenty meters was selected as the depth for each transect to accommodate the maximum height of riparian trees, as the majority of large wood is input directly from the adjacent bank. Bankfull indicators included features such as slope breaks, tops of point bars, vegetation changes, and tree lines. The segment was divided into transects on the project GIS and imported to a GPS unit to guide placement in the field. At each 100 m interval, a centerline perpendicular to the stream starting on river left was established using a tape measure. Two temporary posts were established at the bankfull width 2.5 m from the tape, the same method was repeated at the 20 m mark in the riparian zone. The bearing of the line and the transect slope were recorded. Evident breaks in slope were recorded to capture information on flood plain characteristics. All standing trees (living and dead) within the transect having a diameter at breast height (DBH) greater than 12 cm were tallied. Species, DBH and distance from bankfull edge of channel were recorded. Bankfull and wetted channel width was measured at each transect.

Table 1
Reported Atlantic salmon habitat requirements at each life stage (Armstrong et al., 2003; Bardonnet and Baglinière, 2000; Baum, 1997).

	Spawning	Fry	Parr
Mean water column velocity	35–80 cm/s	10–30 cm/s	10–65 cm/s
Water depth	17–76 cm	20–40 cm	20–70 cm
Substrate size	22–200 mm	16–256 mm	64–512+ mm
Dissolved oxygen	>7 ppm	>7 ppm	>7 ppm
Temperature	7–10 °C	7–25 °C	7–25 °C
Adult holding areas			
Pool depth			0.9 m
Distance from spawning area			800 m
Cover			>20%
Dissolved oxygen			>5 ppm
Temperature			<22.8 °C

2.3. Instream large wood inventory

We inventoried the 2.7 km reach for LWD while conducting the riparian survey using the Level 2 Large Woody Debris Survey method (Schuett-Hames et al., 1999), including the supplemental data listed as optional in the manual. To qualify as LWD in this study, pieces had to be dead, have a root system (if present) that no longer supported the stem, have a minimum diameter of 10 cm along two meters of its length and have a minimum of 10 cm extending into the bankfull channel. We surveyed all pieces that met these criteria. We also surveyed for rootwads, jams and key pieces but none were found in the reach. The diameter, type (log or root wad), stability, species (coniferous, deciduous or undetermined), associated pools and length of each piece within and outside the channel in four zones as suggested by Schuett-Hames et al. (1999) were documented. Additional information was collected including orientation, decay class, and associated sediment storage. The orientation of each piece was recorded using categories based on eight 45° quadrants to represent a piece's horizontal position within the bankfull channel (Schuett-Hames et al., 1999). Pieces were recorded as either parallel, perpendicular, downstream, or upstream. Root system or small diameter end direction is not a factor in category parallel or perpendicular orientation. Pieces with the small-diameter end pointed downstream were identified as downstream. Pieces with the small-diameter end pointed upstream were identified as upstream (Schuett-Hames et al., 1999).

3. Results

3.1. Riparian forest characteristics

A total of 365 trees were tallied in the 26 belt transects, located along the 2.7 km study reach. The average basal area per transect was 0.48 m^2/acre. There were slightly more coniferous trees (52%) than deciduous trees (48%). The numbers of trees falling into the two categories (coniferous or deciduous) were 188 and 177 respectively. These numbers did not differ significantly from the expected 182 of each (χ^2 = 0.33, d.f. = 1, p = 0.57). Although deciduous trees had a slightly larger mean DBH (22 cm, SD $\pm$ 8.5) than the coniferous trees (21 cm, SD $\pm$ 12.79), the difference in DBH did not differ significantly from the expected 20 cm mean (χ^2 = 0.018, d.f. = 1, p = 0.89).

Of the coniferous species found in the reach the most prevalent species, balsam fir, is the shortest lived, reaching a maximum age of 200 years (Burns and Honkala, 1990). The majority of balsam firs were under 20 cm in diameter (70%), however, the largest diameter fir found was 37 cm. Eastern white pine is longer lived and grows rapidly, reaching a maximum age of 450 years (Burns and Honkala, 1990). All the eastern white pine had diameters greater than 20 cm; the largest diameter tree was an eastern white pine with a diameter of 104 cm. Eastern hemlock is long lived, up to 800 years, slow growing and the most shade tolerate of all tree species (Burns and Honkala, 1990). Half the hemlock trees were under 20 cm in diameter and the largest individual was 50 cm.

Of the deciduous species found in the reach, the most prevalent was red maple, which is one of the most abundant and widespread tree species in North America. The largest diameter red maple in

Table 2
Detail of riparian forest characteristics by species.

Species	Live trees				Dead trees			
	Count	%	Ave DBH (cm)	m^2/acre	Count	%	Ave DBH (cm)	m^2/acre
Balsam fir (*Abies balsamea*)	134	43%	17	2.64	11	20%	21	0.33
Red maple (*Acer rubrum*)	49	16%	24	1.95	3	5%	21	0.09
White ash (*Fraxinus Americana*)	42	14%	20	1.14	1	2%	13	0.01
Eastern hemlock (*Tsuga canadensis*)	24	8%	22	0.87	5	9%	23	0.18
Miscellaneous deciduous*	22	7%	29	0.87	2	4%	24	0.08
Black cherry (*Prunus serotina*)	17	5%	22	0.56	22	40%	17	0.39
Black ash (*Fraxinus nigra*)	10	3%	21	0.27	1	2%	22	0.03
White pine (*Pinus strobus*)	9	3%	64	2.49	1	2%	38	0.09
Miscellaneous coniferous**	3	1%	27	0.06	2	4%	30	0.05
Unknown coniferous***	0				2	4%	19	0.04
Unknown deciduous***	0				5	9%	27	0.29
Totals	310		27	10.85	55		19	1.58

* Yellow birch, red oak, white birch, American elm, sugar maple, apple, eastern hop hornbeam.
** Red pine and black spruce.
*** Tree species was unknown due to state of decay.

this study was 53 cm, but the majority of the individuals had diameters less than 20 cm (65%) indicating they have not reached maturity (Burns and Honkala, 1990). The majority of white ash, classified as a pioneer species with an overall shade intolerance, was less than 20 cm in diameter (56%), indicating they are less than 40 years old (Burns and Honkala, 1990), with the largest having a diameter of 43 cm. Black cherry is a fast growing, shade intolerant, pioneer species that out competes its associated species for 60–80 years (Burns and Honkala, 1990). The majority of black cherry trees were less than 20 cm in diameter (64%), with the largest diameter reaching 37 cm.

Of the 365 total trees, 310 were live and 55 were dead (Table 2). Balsam fir (43%), red maple (16%), white ash (15%), and eastern hemlock (8%) comprised the majority of live trees. Black cherry (40%), balsam fir (20%), eastern hemlock (9%) and unknown deciduous (9%) made up the majority of dead trees. The differences between the mean basal area and the mean DBH between live and dead trees were not significant. Live trees had a mean DBH of 21 cm and a BA of 10.85 m^2/acre. Dead trees had a mean DBH of 19 cm and a BA of 1.58 m^2/acre.

Balsam fir, although the most commonly occurring live species, had the smallest mean DBH (17 cm, SD $\pm$ 5.57) for live trees. Eastern white pine had the largest mean DBH (64 cm, SD $\pm$ 24.68). The other species mean DBH ranged from 20 to 29 cm (Fig. 2). Dead trees had a different size distribution with the smallest diameter tree species being a white ash at 13 cm, with the largest being a white pine at 38 cm. The most prevalent dead tree species was the black cherry.

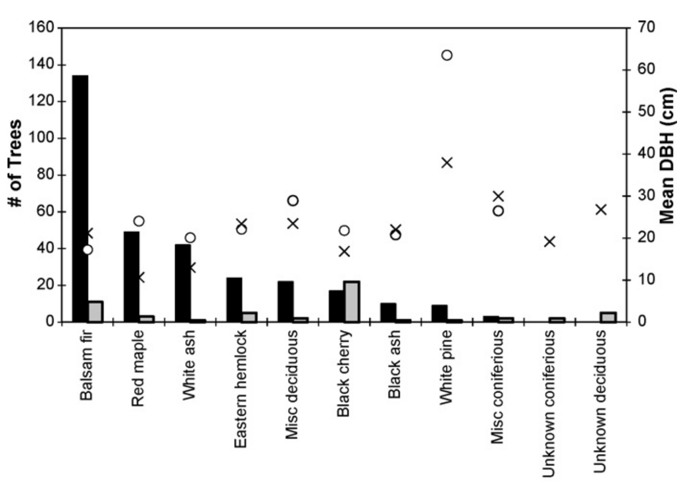

Fig. 2. Number of trees and mean DBH by species and category.

We also looked at differences between live trees, dead trees, and trees located in a known floodplain based on transect slope and distance to the bank edge. The mean distance for live trees was 9.6 m, 9 m for dead trees and 8.9 m for trees located in the floodplain. Both trees were fairly evenly distributed throughout the transects. The transects were broken into 5 m increments and percent of the trees that fell into each category were calculated. A very small majority of trees were located in the 0–4.9 m range, 29% of live trees, 33% of dead trees, 35% of floodplain trees and the remaining were distributed throughout the transect (Table 3).

The percentages of species located in the floodplain (based on a transect slope less than 5%) differ slightly than those found through out the transects (Table 4). Balsam fir (37%) and red maple (13%) are the most prevalent species of the 95 trees found in the floodplain. Lower percentages of white ash and eastern white pine and higher percentages of black ash, eastern hemlock and black cherry were found. In addition, apple, eastern hop hornbeam and two of the three American elm trees were located in floodplain transects.

Table 3
Distribution from the banks edge of percentages of live, dead and floodplain trees.

Distance from bank edge (m)	% of live trees	% of dead trees	% of floodplain trees
0–4.9	29%	33%	35%
5–9.9	24%	20%	24%
10–14.9	23%	25%	18%
15–20	24%	22%	23%

Table 4
Detail of floodplain forest characteristics by species.

Flood plain species	% of total	Average DBH
Balsam fir (*Abies balsamea*)	37%	17
Red maple (*Acer rubrum*)	13%	30
Black cherry (*Prunus serotina*)	12%	18
Black ash (*Fraxinus nigra*)	11%	20
Eastern hemlock (*Tsuga canadensis*)	11%	17
Miscellaneous deciduous*	7%	25
White ash (*Fraxinus Americana*)	5%	21
Yellow birch (*Betula alleghaniensis*)	4%	27
White pine (*Pinus strobus*)	1%	48

* Red oak, apple, white birch, American elm, and eastern hop hornbeam.

Table 5
Large wood statistics.

Size of log (cm)	No. of pieces	LWD per km	Mean diameter (cm)	Mean length (m)	Total volume (m^3)
Logs $\geq 10 < 20$	157	58	14	5	14.19
Logs $\geq 20 < 50$	52	19	25	7	18.26
Logs >50	1	0	72	4	1.63

3.2. Instream large wood

We located a total of 210 pieces of LWD within the 2.7 km reach, an average of 78 pieces km^{-1}. The total volume of pieces was 8.5 m^3 or 3.2 m^3 km^{-1}. Coniferous logs comprised the majority of the pieces (56%), followed by deciduous logs (38%), and logs that were not identifiable by species (6%).

LWD pieces were divided into two diameter categories, $\geq$10 to $<$20 cm and $\geq$20 to $<$50 cm (Table 5). The majority of pieces (75%) fit into the first category, being less than 20 cm in diameter, with a mean length of 5 m (SD $\pm$ 2.47). Most of the remaining pieces were in the second category (25%) with a mean length of 7 m (SD $\pm$ 4.03). Only one piece of LWD (coniferous) measured over 50 cm in diameter (72 cm) and was 4 m long. The mean diameter of all logs was 17 cm (SD $\pm$ 6.94) and the mean length was 6 m (SD $\pm$ 2.97).

The majority of LWD pieces were identified as having a downstream orientation (40%) followed by pieces parallel to the flow (28%); these are the two least stable orientation categories (Table 6). The remaining pieces were split evenly between perpendicular orientation (16%) and pieces with the small-diameter end pointed upstream (16%), both of these orientations are more stable. The pieces per category did differ significantly from the expected even distribution among the categories of 52 each (χ^2 = 34.46, d.f. = 3, $p < 0.005$).

Pieces with the small-diameter end pointed upstream (20 cm, SD $\pm$ 11.25) and pieces perpendicular to the flow (20 cm, SD $\pm$ 7.29) had the largest mean diameter. Pieces parallel (16 cm, SD $\pm$ 4.48) and pieces with the small-diameter end pointed downstream (16 cm, SD $\pm$ 11.25) were almost identical in mean diameters. These results did not differ significantly from the expected mean diameter for all LWD pieces of 17.14 cm (χ^2 = 1.22, d.f. = 3, p = 0.75). Perpendicular pieces had the longest mean length (6 m, SD $\pm$ 3.85) and the largest mean volume (0.3 m^3, SD $\pm$ 0.44) (Table 6). Mean diameters and volumes for the more stable orientations are greater than the less stable pieces and perpendicular pieces are longer than the other categories, though these differences are not significant. Although there are three times as many logs in the smallest category of LWD, there is more volume present in the medium category, owing to a longer mean length. There is also a lack of LWD $>$50 cm.

However, if the length and volume of the logs are grouped by the percentage located within (Zone 1 and 2 in Schuett-Hames et al., 1999) and outside the bankfull width of the channel (Zone 3 and 4 in Schuett-Hames et al., 1999), the mean volume within bankfull width is 0.1 m^3 (SD $\pm$ 0.11; 38% of the total volume) and the mean length is 3 m (SD $\pm$ 2.31; 44% of the total volume) for perpendicular logs. Pieces with the small-diameter end pointed upstream had the highest mean volume in the bankfull channel (0.2 m^3, SD $\pm$ 0.29; 84% of the total volume) and parallel logs had the highest mean length in the bankfull channel (4 m, SD $\pm$ 2.10 or 83% of the total length). These results did differ significantly from the expected even distribution between the lengths of pieces outside and inside of the bankfull width channel of 1.5 m (χ^2 = 307.64, d.f. = 3, $p < 0.005$). These numbers did not differ significantly from the expected even distribution between the mean volume of pieces outside and inside of the bankfull width channel of 0.2 m^3, (χ^2 = 2.56, d.f. = 3, p = 0.46).

Table 6
Distribution of LWD by orientation.

Orientation	No. of pieces	Mean diameter (cm)	Mean length (m)	Mean volume (m^3)
Downstream	85	15.8	5.7	0.1
Parallel	58	15.8	5.2	0.1
Perpendicular	34	19.8	6.3	0.3
Upstream	33	20.3	5.4	0.2

Table 7
LWD stability factors by orientation.

Stability factor	Orientation		
	Total pieces	Parallel and downstream	Perpendicular and upstream
Pinned	86	55%	45%
Unstable	66	83%	17%
Roots	44	77%	23%
Buried	36	47%	53%

Only 15 pieces (7%) had a pool forming function. The majority (46%) of these were associated with the small-diameter end angled upstream, followed by logs perpendicular to the flow (27%) and logs with the small-diameter end angled downstream (20%). LWD pieces parallel to the flow had the least associated pools (7%). These numbers did not differ significantly from an expected even distribution for all orientation categories of 25% (χ^2 = 5.0, d.f. = 3, p = 0.17).

We looked at four stability factors for each piece; roots, buried, pinned or unstable, as well as a combination of the four. In order to determine if stability had an impact on orientation, we combined the parallel and downstream pieces as the least stable categories and perpendicular and upstream as the two more stable orientations and looked at how many pieces there were in each stability category (Table 7). The majority of pieces (n = 86) were pinned with an even distribution between orientations. Buried pieces, although the least numerous (n = 36) also had an even distribution between orientations. There were 66 unstable pieces of which the majority orientation (83%) was either parallel or downstream facing. Pieces with roots (n = 44) also had a majority orientation (77%) that was either parallel or downstream facing.

3.3. Riparian stand and instream large wood characteristics

In an attempt to look at how many pieces of LWD in this reach may be coming from the riparian area, we looked at percentage of the piece that is out of the channel. Of the 210 pieces of LWD, 88 had some percentage outside the channel. There was no difference between species, but the majority of pieces (47%) had the small diameter end pointed downstream, followed by pieces perpendicular to the flow (27%). A slight majority of these pieces had over 75% of the length outside the channel (34 pieces) with 11 pieces located entirely outside the channel.

4. Discussion and management implications

4.1. Riparian forest restoration

The assemblage of species found in the riparian area does not readily fit into a defined forest type (Eyre, 1980), although the region is considered to be northern hardwood. The high proportion ($>$75%) of species which are relatively short-lived, small, and highly fecund, suggests that riparian forests in the West Branch Sheepscot River are dominated by young forest stands. Red maple and balsam fir together comprise 54% of the species found in the riparian area of the study reach and is recognized as a subtype

(Eyre, 1980). In disturbed areas where red maple was once only an associate as part of a mixed hardwood stand, the species has become dominant (Eyre, 1980).

The riparian forest along the reach had a high proportional representation of black cherry and white ash, which are both shade intolerant, early successional species, and low representation of sugar maple, yellow birch, and American beech, which tend to dominate older, late-successional northern hardwood stands. In addition to species composition, small individuals dominated size distributions. The prevalence of black cherry among dead stems in the riparian forest, also leads us to believe this is a relatively young forest in transition.

Knowing the characteristics of the riparian forest provides some insight on potential restoration options. In this reach, as well as other rivers with young riparian forests, restoration requires time. The restoration goal for this reach is to have instream large wood that will affect channel complexity. Promoting tree growth through release is critical in the short term. The data indicates that dead trees, those we would expect to become large wood in the near future, are mostly small diameter early successional species. In the long-term, management actions include promoting growth of longer lived, large diameter species that can act as key pieces (Collins and Montgomery, 2002) including eastern hemlock and eastern white pine, as well as encouraging growth of deciduous trees such as yellow birch (*Betula alleghaniensis*), red oak (*Quercus rubra*), and American elm (*Ulmus Americana*), all of which have the potential to reach diameters of 120 cm or more.

Few remnant old growth sites exist in Maine, but an inventory was completed in the 1980s. The stands identified in this inventory are described in Old Growth in the East: A Survey (Davis, 2003). The age of the stand, rather than size of the trees, is used to delineate old-growth. The ages range from 200 to 360 years. Few of these forests are riparian, and several are located in alpine, sub-alpine, peat land or other poor growing conditions. In addition, as of 1999, there were only 93 identified old growth stands. Of these, only 11 are larger than 50 acres (Foss, 1999). Maine, like most states, does keep a registry of big trees. The DBH for several big trees in Maine are: white ash 197 cm, black cherry 119 cm, balsam fir 63 cm, eastern hemlock 102 cm, red maple 147 cm, and eastern white pine 185 cm (Maine Forest Service, 2008). These are much larger diameter trees than those found in the study reach.

There are several next steps for restoration of this riparian forest. A forest management plan should be developed to include special prescriptions to encourage large wood recruitment. The use of forest growth models that predict large wood may help establish a range of desired future conditions (Meleason and Hall, 2005; Lester et al., 2003). Silvicultural prescriptions should be applied to various stands and monitored. A regular monitoring schedule needs to be established to detect long-term changes. In addition, this study should be replicated in numerous reaches in order to make the linkages between riparian function and large wood dynamics, as this study is limited to only this reach.

4.2. Restoration of instream large wood

It is expected that large wood characteristics represent those found in the riparian forest (Gurnell et al., 2002), a relationship apparent in this study reach where conifers comprised the majority of trees found in the riparian zone as well as identifiable large wood pieces. However, the diameter distribution of large wood in the channel does not mirror the diameter distribution of the trees in the riparian zone, perhaps due to a lag time in recruitment. Because the characteristics of the riparian forest are the main control on the size of wood available as potential large wood, management of the forest has short and long term impacts on the large wood. Given the size and species composition of riparian forest in the study reach, the relative absence of long, large diameter pieces of large wood is not surprising.

The size of available wood is important because it affects a piece's ability to become mobilized or to be retained in the system. The length of large wood is the primary control on stability of a piece in the stream channel (Gurnell, 2003; Gurnell et al., 2002; Braudrick and Grant, 2000; Abbe and Montgomery, 1996; Nakamura and Swanson, 1994). Other factors, such as the presence of root wads, contribute to stability, but length is currently the most relevant in the study reach. The critical dimension is the length of piece to channel-width ratio (Gurnell, 2003; Gurnell et al., 2002). The mean bankfull channel width in the study reach is 13 m (SD $\pm$ 4.82) with a mean active channel width of 9 m (SD $\pm$ 2.49). The mean length of LWD pieces in the study reach is 5.62 m (SD $\pm$ 2.47), a ratio of 0.41 of the bankfull width and a ratio of 0.60 of the active channel width. If the average heights of mature trees found in the riparian zone are used, the ratio ranges from 1.3 to 3.38 (balsam fir and eastern white pine). Abbe and Montgomery (1996) state that large wood tends to be more stable when the piece length is greater than bankfull width in small channels and greater than half the bankfull width in large channels. When more than half the length is located outside of the bankfull channel, pieces also have greater stability (Lienkaemper and Swanson, 1987). Only pieces perpendicular to the current was shown to have a larger percentage outside of the bankfull channel.

Knowing the instream large wood characteristics help in the development of management options, for both in-stream and riparian restoration. Based on the results of this study on the Sheepscot River, additions of large wood can first be targeted in areas with lower channel widths, in order to increase piece stability. In areas with wider bankfull widths, the pieces can be placed with 50% of the length outside the bankfull channel to increase stability. To increase complexity, pieces should be added at all orientations, using both coniferous and deciduous species. Large wood additions should be monitored yearly for response. Future management actions should reflect the evaluation of the results and be adjusted to account for new information. An important knowledge gap that needs to be addressed is the targets for large wood in Maine rivers and further research is required.

4.3. Linkages to Atlantic salmon habitat

The recovery of Atlantic salmon requires adequate conditions for the individual organism, the population, the community to which the population belongs, and the ecosystem in which the community exists. Atlantic salmon require diverse habitats to accommodate different life stages. Key abiotic conditions include depth and velocity of water, substrate size and embeddedness, cover, water temperature, and dissolved oxygen (Armstrong et al., 2003; Bardonnet and Baglinière, 2000; Baum, 1997; Heggenes, 1990). In addition, areas of refugia are critical during stressful conditions, adding another level of habitat requirements. Restoring riparian function through additions of large wood affects the vertical and horizontal structure within the stream channel, leading to increased microhabitat, as added structural elements within the stream channel will lead to diversity in substrate, cover, and velocities (Fay et al., 2006; Nislow et al., 1999). Increased vertical and horizontal structure increases provided greater diversity of habitats, leading to increased niches and partitioning that would accommodate the co-existence of more individuals (National Research Council, 1992; Newson and Newson, 2000; Palmer et al., 1997; Ward et al., 2002).

In order to bridge the gap while the trees in the riparian forest mature, large wood additions could occur in areas where they have the potential to increase channel complexity. Roni and Quinn

(2001) sampled the response in 30 streams in western Oregon and Washington to large wood additions. The total wetted area, number of habitat units, pool area, and number of pools during both summer and winter were higher in the treated reaches (Roni and Quinn, 2001). In a study in the Williams River, NSW, Australia, 20 engineered log jams were placed to simulate natural log jams in a 1.1 km reach that showed an increase in complexity in the channel (Brooks et al., 2004). Improving habitat by restoring riparian function through additions of large wood, through both natural recruitment and placements, is the core of active process-based restoration for Atlantic salmon.

5. Conclusions

We need to consider time scales of decades to centuries to understand natural variability within river systems, to provide a context for the present, and to determine restoration approaches using large wood (Egan and Howell, 2001; Cairns, 1991), but need to act now to begin restoring function. Trees mature slowly in coastal Maine. It takes hundreds of years before they are large enough to affect stream channel morphology (Bragg, 2000). However, when a large tree falls into the stream, the channel structure changes quickly (Dahlström and Nilsson, 2004; Naiman et al., 2000).

The West Branch of the Sheepscot River was disturbed years ago due to removal of the riparian forests. The forest is at an intermediate successional state in providing some riparian function. These stands are more resilient to stochastic weather events and produce large wood too small in size to remain in the channel through high flow events. Throughout the reach trees are mature enough to provide sufficient shade and bank stability, but the main habitat-limiting factor is the lack of input of large wood that would increase structure in the stream channel. Scientists and managers have not yet identified a target functioning state for riparian areas, which is a factor limiting restoration opportunities. The "reference condition" sought in the field of restoration ecology is difficult to ascertain, but restoration needs to be based on what is known about ecosystem processes and land use history, and this study provides a starting point.

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