Restoring Trout Habitat in Difficult to Access Areas Using Mobile Wood Additions

James M. MacCartney[1], John A. Magee[2], and John J. Field[3],
[1]Trout Unlimited, Inc., 54 Portsmouth Street, Concord, NH 03301
[2]New Hampshire Fish and Game Department, 11 Hazen Drive, Concord, NH 03301
[3]Field Geology Services, P.O. Box 985, Farmington, ME 04938

Abstract—The removal of wood from river channels was once a common practice in an effort to reduce flooding and improve transport of timber and other products. River restoration practitioners are increasingly adding large wood into rivers to restore natural channel characteristics and aquatic habitat degraded by these past practices. Most restoration projects use wood in a static manner by anchoring trees and rootwads in place. The use of mobile wood additions—a restoration approach where added wood is allowed to migrate naturally through the channel at high flows—is being pioneered on Nash Stream in northern New Hampshire. While both methods are effective, our implementation and subsequent monitoring shows that mobile wood more closely mimics natural recruitment to, and transport and accumulation within, river systems, and provides a cost-effective method of increasing wood densities in hard-to-reach locations or with limited stands of riparian trees.

Introduction

Wood is a common component in many river systems throughout the world, with forests covering almost one third of the Earth's land surface (Montgomery et al. 2003). Large woody material (LWM) is often the most important structural element in river channels, creating the complex flow hydraulics that can alter channel morphology, increase habitat diversity, and lead to significant sediment storage (Bilby and Ward 1991; Gurnell et al. 2002; Abbe and Montgomery 2003). Large wood within the context of habitat studies on rivers is commonly defined as logs, with or without attached roots, ≥ 10 cm in diameter and ≥ 2.0 m in length (Schuett-Hames et al. 1999).

The geomorphic function of wood in rivers varies with channel size. In steep headwater streams, individual channel-spanning logs can trap smaller wood, detritus, and sediment to form step-pools that define the channel morphology (Montgomery and Buffington 1997). In mid-gradient rivers, LWM may accumulate into various types of log jams that partly or wholly block the channel and are important for forming and altering the spacing of point bars, meander bends, and other channel features (Abbe and Montgomery 1996). In large, low gradient river systems, rafts of LWM can create hydraulic constrictions that elevate water surfaces upstream, increase access to floodplains, and create braided or anastomosing channels (Keller and Swanson 1979; Gurnell et al. 2002).

Wood also plays a critical role, both directly and indirectly, in forming and sustaining the habitat necessary for many aquatic organisms (Naiman et al. 2002). Streams with wood in the channel generally have more complex physical habitat (Benke and Wallace 2003), a greater abundance and richness of macroinvertebrates (Bond et al. 2006), and higher fish populations (Flebbe 1999).

Increasingly, LWM is becoming an important component of stream restoration projects to replenish wood that was previously removed by humans for various reasons. The use of wood in restoration projects increases channel complexity and habitat diversity and is important for improving and reconnecting habitat for salmonids and other species of concern (Kail et al. 2007). Wood also has the potential to be used for infrastructure protection such as on-bank stabilization projects.

Study Site

Nash Stream is a fourth order river, with a watershed area of 115 km^2, located in northern New Hampshire (Figure 1) and drains into the Upper Ammonoosuc River before reaching the Connecticut

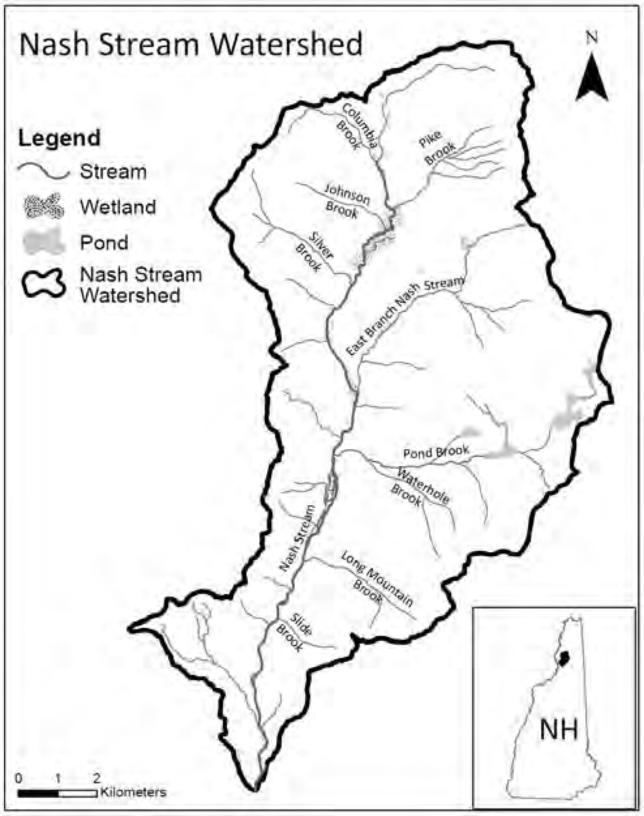

Figure 1. Nash Stream Watershed study area.

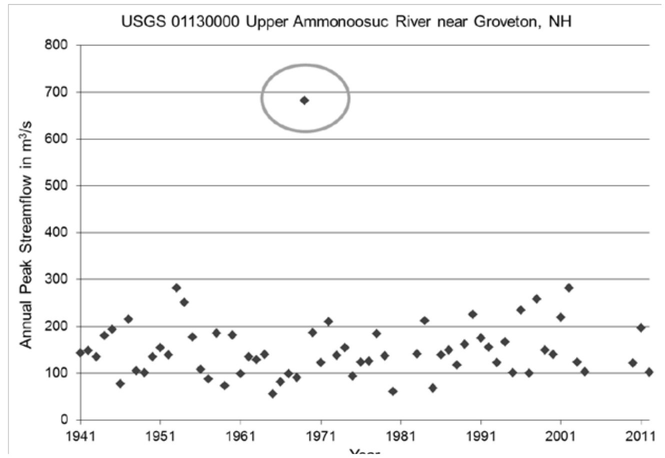

Figure 2. Annual peak streamflow at the USGS Upper Ammonoosuc River gage. The maximum discharge of 682 m^3/s (circled) resulted from a dam break on Nash Stream.

River. We conducted our field study in the 15.1-km reach located downstream (south) of the confluence with Silver Brook. Approximately 90% of the watershed is located within the state-owned Nash Stream Forest, and is characterized by glaciated terrain and a mixed conifer and deciduous forest. This provided an appropriate setting for the field study, because the lack of infrastructure greatly simplified the permitting process and allowed for the movement of unanchored wood with little concern for property damage.

The salmonid species native to Nash Stream are Brook Trout *Salvelinus fontinalis* and Atlantic Salmon *Salmo salar*. However, Atlantic Salmon were extirpated from the watershed in the early 1800s due to overfishing, water pollution, and downstream dam construction on the Connecticut River (Moffitt et al. 1982).

Much of the watershed has been a working forest since the 1850s. In 1900, a dam was completed at Nash Bog to provide headwater storage for driving pulp logs during the spring snowmelt to a nearby mill in Groveton, New Hampshire (NHDRED 1995). The log drives ended in the 1930s, but the timber crib dam and impoundment at Nash Bog were left intact for recreational use. The dam was 8.9 m high and held back a 90.2-ha impoundment. On May 20, 1969, the dam failed catastrophically following a heavy rainstorm on the remaining snowpack, and was never rebuilt.

The dam failure produced the highest flow ever recorded at the U.S. Geological Service gage on the Upper Ammonoosuc River (USGS 2013a) located 300 m downstream of the Nash Stream confluence (Figure 2). The estimated peak discharge at the USGS gage from the dam break was 682 m^3/s, a value that is more than two times greater than any other reported peak at this gage and approximately four times greater than the estimated 500-yr recurrence interval peak flow (167 m^3/s) for Nash Stream (USGS 2013b).

The magnitude of the flood resulted in significant morphological and habitat impacts to Nash Stream including widening of the channel and loss of pools and riparian cover. After the flood, the impacts were further compounded when the channel was straightened and berms were created to reduce future flooding and rebuild the nearby logging road that parallels the stream. In places, the flood stripped bare a swath approximately 100 m wide and more than five times the bank-full channel width. Much of the uprooted riparian forest was deposited up to several kilometers downstream on the floodplain of the Upper Ammonoosuc River.

Many of the bars deposited by the floodwaters consist of boulders up to 2 m in diameter and continue to severely limit lateral channel adjustment. The bars contain limited fines and organic material and are vertically disconnected from the present river channel due to their height above the streambed. As a result, revegetation rates on these bars are very slow which limits canopy cover over, and wood recruitment into, the stream several decades after the flood.

Given the stream's limited capacity for self-adjustment, Trout Unlimited, Inc. and the New Hampshire Fish and Game Department formed a partnership in 2005 to undertake its restoration. A geomorphic assessment of Nash Stream identified numerous potential treatments for improving geomorphic and habitat function such as boulder clusters and engineered log jams, but many of the restoration options were not viable due to remoteness from the haul road and poor access for heavy machinery. This paper describes a large wood replenishment project that is using unanchored, mobile wood additions (MWA) in which trees with attached roots are strategically placed in specific locations and elevations relative to the bank-full stage.

Because of the uncertainties in the mode, distance, frequency, and benefits of unanchored wood movement, we conducted a study of large wood transport and accumulation at Nash Stream. While a primary long-term objective of our research is to understand how MWA are influencing channel morphology and aquatic habitat for a range of salmonid species, here we specifically report on the general flow conditions during which MWA moved in the first 2 years following implementation, the factors influencing wood movement, and the most likely locations of wood accumulation.

Methods

Trees for the MWA were harvested outside the riparian zone near the road or along temporary stream access routes. A 25,000-kg excavator (John Deere 240D) was used to knock over live, whole trees, keeping the rootwads attached, and transport them to locations on the stream where easy access was available upstream of difficult to reach target reaches. Two uniquely numbered, blue anodized aluminum forestry tags were fastened on each tree at breast height with 76-mm aluminum nails. The excavator then placed the trees in the channel oriented parallel to flow and with roots facing upstream. The diameter at breast height (DBH), species, elevation (relative to bank-full), and spatial coordinates were then recorded for each tree placed in the stream.

Three groups of MWA, totaling 48 trees, were installed at five locations along 3.9 km of Nash Stream in 2010 and 2011. The 24 trees of Group 1 were installed in September 2010. The 12 trees of Group 2 were installed in October 2010. The 12 trees of Group 3 were installed in October 2011 (Table 1).

The trees ranged in size from 5 to 34 cm DBH (Figure 3); most fit the definition of large wood by Schuett-Hames et al. (1999). Small diameter trees were intentionally selected for insertion because the primary objective was to ensure their transport to downstream target reaches and avoid overloading the channel with large trees that might impede transport or encourage beaver activity that would preclude or limit the transport of the tagged trees during the study.

Table 1. Count and location of MWA placements at Nash Stream. River km = river kilometer as measured from the confluence with the Upper Ammonoosuc River. Grp = Group. Bkf = bank-full. River km 14.2[a] = bridge at river kilometer 14.37. River km 14.21[b] = boulder bar at river kilometer 14.20.

Location	Number of trees					
River km	Grp. 1	Grp. 2	Grp. 3	At Bkf	< Bkf	Water
14.2[a]	1	1	1	0	0	3
14.2[b]	15	4	3	7	4	11
12.4	5	5	5	2	8	5
10.8	3	2	2	0	0	7
10.3	0	0	1	0	0	1

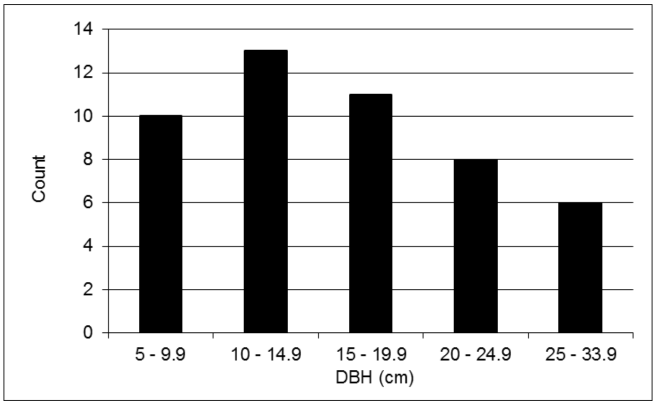

Figure 3. Size range of mobile wood additions to Nash Stream, 2010 and 2011.

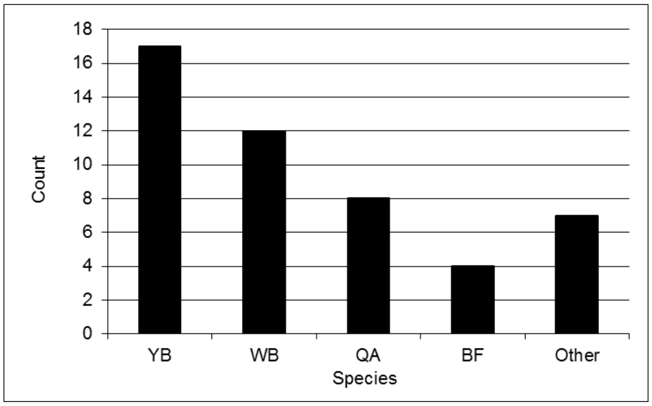

Figure 4. Tree species added to Nash Stream included Yellow birch *Betula alleghaniensis* (YB), White birch *Betula papyrifera* (WB), Quaking aspen *Populus tremuloides* (QA), Balsam fir *Abies balsamea* (BF), and five other species (Other.)

A total of nine tree species were used. The four primary species in descending order of prevalence were: Yellow birch *Betula alleghaniensis* (YB), White birch *Betula papyrifera* (WB), Quaking aspen *Populus tremuloides* (QA), and Balsam fir *Abies balsamea* (BF). Five additional species (Other) were also used: Red maple *Acer rubrum*, Sugar maple *Acer saccharum*, Red spruce *Picea rubens*, Black cherry *Prunus serotina* and Black willow *Salix nigra* (Figure 4).

The trees were deployed at various elevations relative to bank-full to promote release and downstream transport at different flow stages (Figure 5). Twenty-seven trees were placed in the water, 12 were placed on bars at the channel margin, and nine were inserted at bank-full elevation in the active channel.

During three walks of Nash Stream from the upstream-most insertion point to its confluence with

Figure 5. Photo showing MWA were placed at various elevations in Nash Stream to promote transport at different stages during high flow events. Photo by authors.

the Upper Ammonoosuc River between 7 October 2010 and 28 August 2012, in which all observable wood in the bankfull channel and adjacent floodplain was carefully checked for aluminum tags, we recorded the spatial coordinates, elevation relative to bank-full, orientation of roots relative to the bank-full flow direction, and basic geomorphic attributes of the location of each tagged tree during each of the four field visits. We then reviewed the streamflow data from the USGS Upper Ammonoosuc River gage to make an assumption regarding the discharge likely responsible for the transport of the tagged trees.

Based on our experience with the Group 1 trees, in which we are certain that a near bank-full flow moved most of the trees 3 weeks after they were placed into Nash Stream, we assumed that Group 2 and Group 3 trees moved in the first near bank-full or greater event after they were placed into Nash Stream. Whenever possible the field visits were conducted subsequent to known high flow events to determine if the tagged trees moved during those events. Considerable ice forms on Nash Stream during the winter; it is neither possible to locate and positively identify tagged trees during periods of ice nor determine what role ice has played in tree movement.

All streamflow values reported in the results are taken from measurements recorded at the USGS Upper Ammonoosuc gage; Nash Stream is un-gaged. The 2-year recurrence interval peak flow (PK2) was derived from USGS StreamStats (USGS 2013b) and is used in this paper as a surrogate for the bank-full discharge. The PK2 discharge where the wood was installed is approximately 17% of the PK2 streamflow at the USGS gage. Drainage area where the MWA were installed is approximately 10% of the drainage area at the gage (USGS 2013b).

Results

During the study period, the Upper Ammonoosuc River gauge recorded five near bank-full flow events of greater than 90 m^3/s (USGS 2013a). The maximum discharge was 171 m^3/s. All groups moved at or near the PK2 discharge as measured at the USGS Upper Ammonoosuc River gage (140 m^3/s; Figure 6). Estimated PK2 streamflow in the vicinity of where the wood was installed is approximately 23 m^3/s (USGS 2013b).

Three weeks after Group 1 trees were placed into Nash Stream, a 103 m^3/s discharge from a very large rainfall event on October 2, 2010, transported most of the trees. Group 2 moved in mid-April 2011 at a discharge of about 171 m^3/s. Group 3 moved in March 2012 at 93 m^3/s. Much of the wood from Group 1 clustered in just a few locations (Figure 7). Similar transport and accumulation patterns were observed for Groups 2 and 3; large discharge events transported MWA downstream where it tended to accumulate in clusters at valley constrictions or expansions and changes in channel slope or planform, such as at meander bends downstream of straightened channel segments.

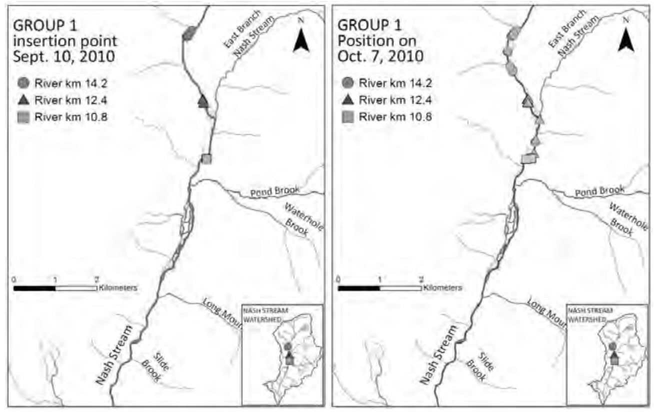

Figure 7. Locations of tagged trees in Nash Stream prior to and after a 103-m^3/s discharge.

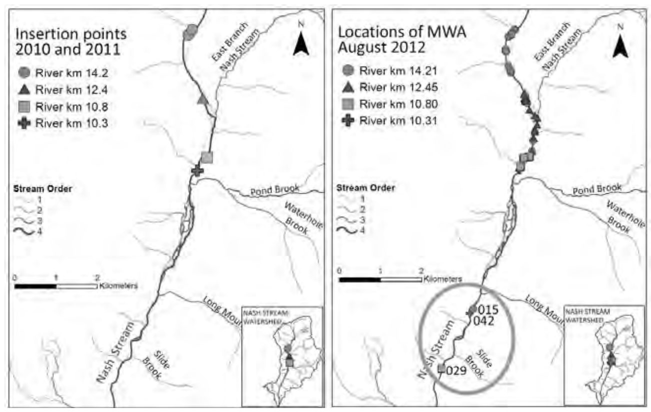

Figure 8. Locations of all three groups of mobile wood in Nash Stream prior to and after transport by high flows. Three trees (circled) moved considerable distances.

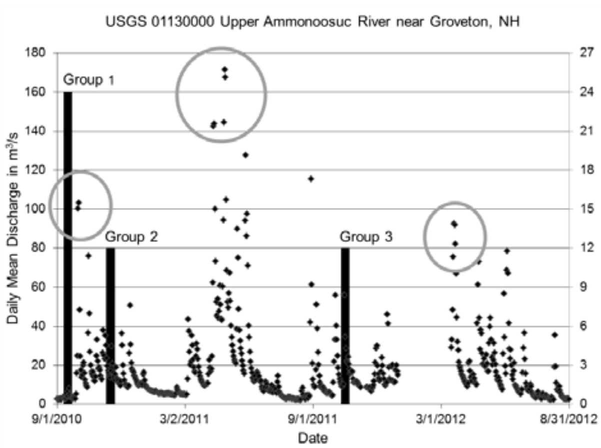

Figure 6. Daily mean discharges for the Upper Ammonoosuc gage. Flows that transported each group of mobile wood are circled.

Monitoring at the end of the study period in August 2012 showed that 92% of the MWA had dispersed from their original insertion points. Some were transported considerable distances; one 7.6-cm White birch moved 7.8 km (Figure 8). Only 6% of the trees moved more than once; none moved more than twice.

There were several apparent trends in the average distance transported and other factors. The MWA tended to travel farther during higher discharges (Figure 9); however, there was a lot of variability in the distances transported within each Group. The range of transport values was 0.00-2.95 km, 0.02-3.23 km, and 0.00-4.07 km for Groups 1, 2 and 3, respectively. Smaller diameter trees tended to move farther than larger trees (Figure 10).

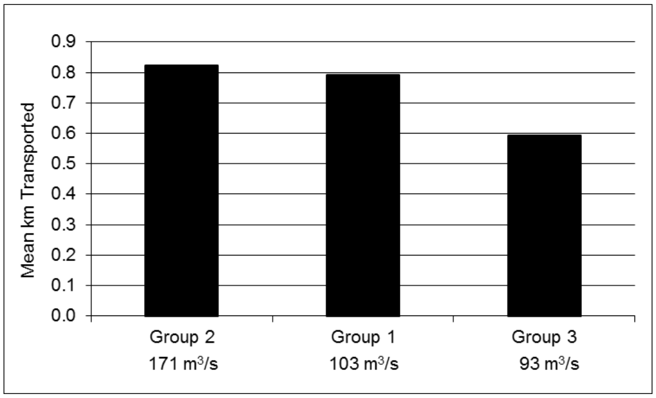

Figure 9. Mean distance that MWA were transported in Nash Stream and daily mean discharge as measured at the Upper Ammonoosuc USGS gage.

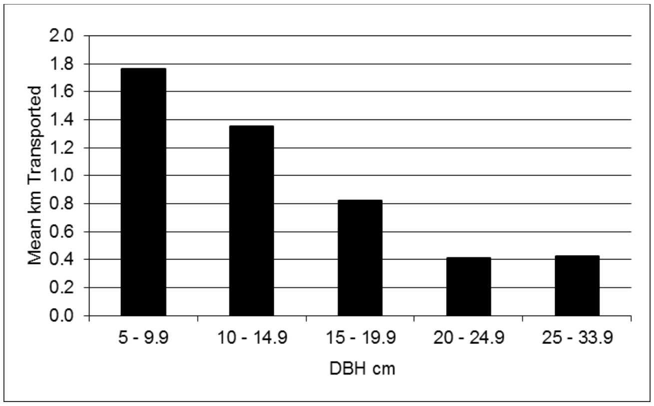

Figure 10. Mean distance trees were transported in Nash Stream and diameter at breast height of the trees.

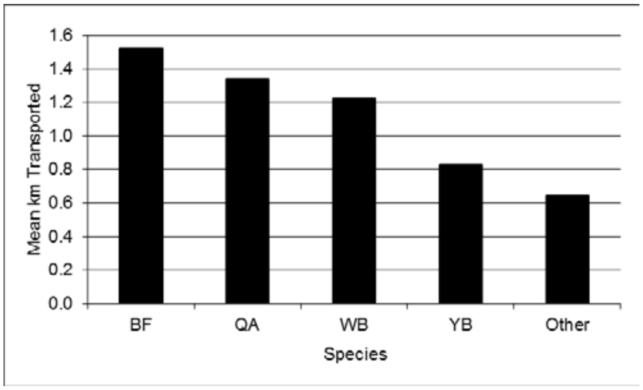

Figure 11. Mean distance trees were transported in Nash Stream and tree species.

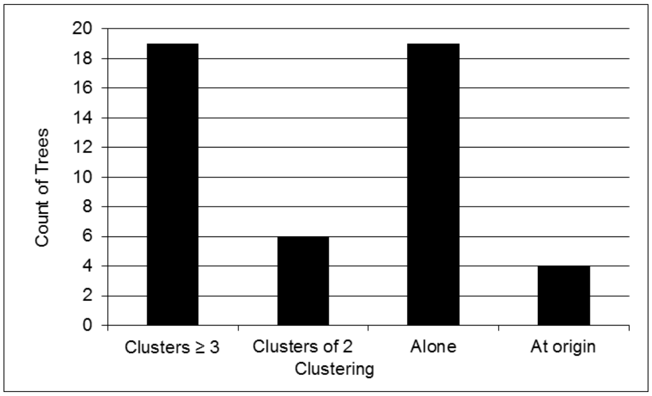

Figure 12. Post-transport clustering of MWA in Nash Stream by end of study period.

We noted that wood density (as reported in Kretschmann 2010) appeared to influence mean transport distance of the trees. Of the four differentiated species, mean transport distance decreased as tree density increased (Figure 11).

Tree elevation relative to bank-full stage at the insertion point was also considered as a possible factor affecting distance transported, but we noted that insertion elevation had no obvious influence on transport distance given that all flows assumed to be responsible for tree movement were at or near the bank-full stage.

By the end of the study period, about half of the trees were deposited with the roots oriented upstream. Nearly half of the trees deposited at bank-full elevation; the rest deposited in the active channel below the bank-full elevation. Slightly more than half of the trees deposited in clusters of two or more while four trees did not move during this study (Figure 12).

Most of the MWA that accumulated in clusters were found in jams at the apex of a bar or on a meander bend. One jam contained eight tagged trees along with additional naturally recruited material and formed at a location where no wood accumulations were present prior to the deployment of MWA (Figure 13). The jam appears to be stable; several key members are buried parallel to flow in former high flow chutes, and new vegetation is established on some of the earliest material recruited. The LWM comprising the jam is providing cover for a newly-formed adjacent lateral pool. In addition, a large gravel bar forming upstream has narrowed the low flow channel, flow complexity has increased in the general vicinity of the wood jam, and the substrate particle sizes are better sorted.

Figure 13. Photo of a meander jam in Nash Stream created by accumulated MWA and additional naturally recruited material. Photo by authors.

Discussion

These two years of data collected on MWA movements allow for preliminary conclusions regarding the efficacy of MWA as a restoration treatment. We found that MWA work; river systems can transport LWM from accessible insertions points to target restoration reaches where wood accumulations increase channel complexity and create salmonid habitat in hard-to-access locations. The initial transport of the whole trees placed into the bank-full channel was during bank-full or near bank-full flow events, likely because water depth was slightly greater than the buoyant depth of the trees, conditions necessary for the transport of wood (Braudrick and Grant 2001). We suspect that deploying wood at different elevations favorably affects the timing of transport during the rising limb of a flood hydrograph and allows for a greater amount of wood loading at each insertion point.

The distance of wood transport appears to be influenced by several factors including discharge, log diameter, and tree species (density). We found transport distance of the trees used in the MWA was inversely related to tree density. Braudrick and Grant (2000) also reported that log density is an important factor in the transport of wood in rivers with higher density logs requiring a greater water depth to become transported. The shorter transport distances and greater water depth needed to transport higher density tree species may be related to the greater likelihood that higher density wood will encounter frictional resistance from various channel features such as the streambed (Abbe and Montgomery 2003).

Most trees only move once before becoming lodged in a stable position or clustering in a large meander or apex jam, as occurs naturally (Abbe and Montgomery 2003), or in flume experiments (Braudrick and Grant 2001). We believe that these retention points can be anticipated. Pairs or larger clusters of MWA, in particular, tend to accumulate where there is a marked change in channel morphology. This particularly important attribute of mobile wood transport may allow restoration practitioners to restore functional LWM without the higher costs of constructing specific log structures. It may also provide practitioners some confidence about the likely fate of the wood installed.

In addition, isolated MWA trees that are not part of a larger cluster, result in smaller, and yet still beneficial, effects on channel complexity and salmonid habitat. They also increase diversity of flow regimes and provide some sorting of substrate when they are partly or wholly submerged. When resting at the bank-full elevation, they can provide cover for pre-existing deep water habitat or create the potential to recruit additional LWM. Isolated MWA also have the potential to be mobilized during future high flow events and transported downstream to become part of a larger cluster.

We believe these findings have several practical applications. Knowing that wood with differing densities tends to move different distances before being deposited in a stable position, lower density trees like Balsam fir might be the species of choice if the target restoration area is far from the insertion point whereas higher density wood such as White birch might be a better choice if the target area is close by. Furthermore, given that wood placed at lower elevation in the channel likely moves before wood staged closer to the bank-full elevation, higher density wood could be placed lower in the channel and lower density wood closer to the bank-full stage if the desire is to form log jams close to the insertion point. In contrast, if the restoration objective is to have isolated pieces of wood distributed over a longer length of stream, then placing lower density wood lower in the channel would be more effective as that would more likely permit the first pieces to move farther downstream without being retained by higher density wood that would move later during the high flow event given their position closer to bank-full.

Wood insertion points can be prioritized based on the knowledge that wood tends to accumulate in areas of rapid geomorphic change such as at valley constrictions, slope breaks, and changes in channel planform. Careful geomorphic mapping can be used to identify areas where wood is likely to accumulate and then decisions made regarding the best location to insert trees as part of a MWA restoration project. While adding wood anywhere on streams where wood has been removed by past human activities is likely to be beneficial, careful study of geomorphic conditions and the patterns of wood movement and accumulation will lead to even greater benefits with less effort and a lower likelihood of unintended damage to adjacent infrastructure.

We suggest that wood used for restoration need not always be anchored, that its movements are largely predictable and stable after the initial transport, and that mobile wood additions are a cost effective tool to create habitat and channel complexity. Our results are consistent with a passive approach to in-stream wood restoration in which it is the process of wood recruitment that is restored (Kali et al. 2007). While MWA is a treatment best suited to watersheds with limited infrastructure like Nash Stream, further research into the patterns of wood movement and accumulation may increase the confidence of restoration practitioners to attempt MWA in a wider array of settings and environments.

Acknowledgments

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