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The geomorphic function and characteristics of large woody debris in low gradient rivers, coastal Maine, USA

F.J. Magilligan [a,*], K.H. Nislow [b], G.B. Fisher [c], J. Wright [d], G. Mackey [e], M. Laser [f]

[a] Department of Geography, 6017 Fairchild, Dartmouth College, Hanover, NH 03755, USA
[b] U.S. Department of Agriculture, U.S. Forest Service, Northern Research Station, University of Massachusetts, Amherst, MA 01003, USA
[c] Department of Earth Sciences, Dartmouth College, Hanover, NH 03755, USA
[d] Gulf of Maine Coastal Program, U.S. Fish and Wildlife Service, Falmouth, ME 04105, USA
[e] Department of Marine Resources, Bureau of Sea Run Fisheries and Habitat, Jonesboro, ME 04648, USA
[f] Department of Marine Resources, Bureau of Sea Run Fisheries and Habitat, Augusta, ME 04333-0172, USA

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Abstract

The role, function, and importance of large woody debris (LWD) in rivers depend strongly on environmental context and land use history. The coastal watersheds of central and northern Maine, northeastern U.S., are characterized by low gradients, moderate topography, and minimal influence of mass wasting processes, along with a history of intensive commercial timber harvest. In spite of the ecological importance of these rivers, which contain the last wild populations of Atlantic salmon (*Salmo salar*) in the U.S., we know little about LWD distribution, dynamics, and function in these systems. We conducted a cross-basin analysis in seven coastal Maine watersheds, documenting the size, frequency, volume, position, and orientation of LWD, as well as the association between LWD, pool formation, and sediment storage. In conjunction with these LWD surveys, we conducted extensive riparian vegetation surveys. We observed very low LWD frequencies and volumes across the 60 km of rivers surveyed. Frequency of LWD ≥ 20 cm diameter ranged from 15–50 pieces km^{-1} and wood volumes were commonly < 10–20 m^3 km^{-1}. Moreover, most of this wood was located in the immediate low-flow channel zone, was oriented parallel to flow, and failed to span the stream channel. As a result, pool formation associated with LWD is generally lacking and < 20% of the wood was associated with sediment storage. Low LWD volumes are consistent with the relatively young riparian stands we observed, with the large majority of trees < 20 cm DBH. These results strongly reflect the legacy of intensive timber harvest and land clearing and suggest that the frequency and distribution of LWD may be considerably less than presettlement and/or future desired conditions.

Keywords: Large woody debris; Stream channel; Riparian; Watershed; Habitat; Aquatic ecology

1. Introduction

An extensive literature has emerged in the past decade on the function and importance of large woody debris (LWD) in fluvial systems. From an ecological perspective, LWD serves a vital role in biogeochemical cycling (cf. Bilby, 2003) and is an important structural element in aquatic habitats, providing cover and increasing habitat complexity, with resultant effects on fish and aquatic invertebrate abundance and diversity (cf. Dolloff and Warren, 2003). Geomorphologically, LWD influences pool formation, frequency, and type (Keller and Swanson, 1979; Andrus et al., 1988; Bilby

* Corresponding author.
E-mail address: magilligan@dartmouth.edu (F.J. Magilligan).

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and Ward, 1991; Montgomery et al., 1995; Abbe and Montgomery, 1996; Gurnell and Sweet, 1998; Rosenfeld and Huato, 2003; Kreutzweiser et al., 2005) and is commonly associated with increased sediment storage (Thompson, 1995; May and Gresswell, 2003; Daniels, 2006), enhanced flow resistance (Marston, 1982; Assani and Petit, 1995; Shields and Gippel, 1995; Gippel et al., 1996; Manga and Kirchner, 2000; Curran and Wohl, 2003; Hygelund and Manga, 2003; Bocchiola et al., 2006; Manners et al., 2007), reduced sediment transport (Bilby and Ward, 1989; Nakamura and Swanson, 1993), and increased longitudinal variation of both channel depth and width (Montgomery et al., 2003).

Unlike watersheds in other parts of the U.S., little is known about the function of wood in New England rivers, especially in coastal Maine (Fig. 1). This is an important area ecologically, as rivers in this region possess the few remaining native runs of federally endangered Atlantic salmon (*Salmo salar*) in the U.S. (National Research Council, 2004). Late twentieth century wild runs of Atlantic salmon have been drastically reduced in coastal Maine. These declines have been associated with a wide array of marine, riverine, and terrestrial impacts including overfishing, predation, disease, watershed fragmentation by dams, and habitat loss/degradation (National Research Council, 2004). In the juvenile freshwater phase, it appears that overwinter survival is very low, and factors influencing overwinter success have a strong influence on overall population dynamics (Maine Atlantic Salmon Task Force, 1997; Kircheis, 2001; National Research Council, 2004; National Marine Fisheries Service and U.S. Fish and Wildlife Service, 2005). At this life-history stage, stream salmonids have a strong requirement for cover to provide protection from predators and adverse environmental conditions (Cunjak, 1988), and availability of LWD appears to increase overwinter survival in some circumstances (Roni and Quinn, 2001). However, little information exists on the extent to which LWD provided this function in Maine Atlantic salmon streams.

These coastal watersheds have been heavily affected by historical and contemporary land use disturbance (Lorimer, 1977), especially hillslope and riparian logging that have likely reduced LWD recruitment. For example, based on sawmill surveys of white pine production in Bangor, Maine, from ca. 1830 to 1870 that generated ~8.5 million m^3 of sawtimber, Wilson (2005) estimated a presettlement standing volume of white pine of ~14.1 million m^3 in the Penobscot watershed. Current estimates for a similar region indicate that the presettlement standing volumes of white pine may have been at least three times greater than contemporary large pine volumes in Maine's eastern and northern regions (Wilson, 2005). More recently, harvest volumes have significantly declined, with corresponding increases in stand basal areas and individual tree sizes (USDA Forest Service, 2004). These trends are likely to be particularly manifested, both currently and in the future, in riparian zones because of recent regulation governing the intensity and extent of timber harvest within these zones (Maine Department of Environmental Protection, 2006). However, because of intrinsic lags between forest recovery and the stochastic processes that govern LWD recruitment, LWD recovery lags forest recovery by centuries (Bragg, 2000; Benda et al., 2003). These considerations suggest that current LWD levels are likely to be low, that LWD may have had an important effect on streams that is currently lacking, and that LWD abundance will increase in the future under existing management practices and regulations. However, we currently lack quantitative information on the current abundance, distribution, and functional role of LWD in these systems and on the characteristics of the riparian forests that will serve as LWD sources.

To establish baseline conditions for LWD distribution, abundance, and functional role in Maine rivers, we conducted extensive LWD and riparian forest surveys in seven major coastal Maine river systems (Figs. 1 and 2). We used these data to address four major questions: (i) what is the contemporary frequency, volume, and size distribution of LWD; (ii) how does LWD orientation, in-channel location, and geomorphic role vary longitudinally within and among basins; (iii) do watershed scale controls (such as gradient, flow, or sinuosity) explain the frequency, orientation, and broader distribution of LWD; and (iv) what is the relationship between riparian forest and LWD characteristics? Our primary goal is to contribute to a broader understanding of the role of LWD in reforesting low gradient watersheds where information in the literature is commonly lacking.

2. Geomorphic and geologic setting

Fluvial properties of coastal and Downeast Maine rivers are strongly controlled by geologic processes where, for example, lithologic variation and bedrock strike, in combination with sediment supply from Pleistocene deposits, largely control the quality and frequency of salmon rearing and spawning habitat (Fisher et al., 2006). While there is evidence for early Paleozoic collisional events in northern and western Maine (i.e., Penobscottian and Taconic orogenies), the dominant structural grain of the bedrock and the distribution of metamorphism and plutonic rocks in the state is the result