American Fisheries Society Symposium XX:XXX–XXX, 2003

Restoring Streams with Large Wood: a Synthesis

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Abstract.—The use of large wood in stream restoration projects has become increasingly popular in the last 20 years. We reviewed more than 30 case studies from different ecoregions and countries (Canada, Germany, Japan, United States) to evaluate the variety of approaches used and assessed their reported success. Wood inputs generally fell into two categories: fixed structural designs or placements where wood was not fixed to one location. Large wood was used in fixed designs in most studies from North America and usually built in or anchored by cables. Few projects attempted to simulate the dynamic processes of wood inputs to the floodplain. Mobile wood placements were mostly used in projects after 1990. They represented 6% of the projects in North America and 55% in Germany, where restoration projects designed with mobile wood can be found even in densely populated (200 people / km^2) rural areas, but only along second- and third-order streams. Few studies attempted to simulate historical amounts and distribution of wood in forested catchments. In most of the studies from rural areas, practical aspects like stream access or the availability of logs dominated the experimental design and placements.

Introduction

Our understanding of the role of instream large wood has undergone significant changes (Gregory 2003; Sedell and Gregory 2003; both this volume). Before the 1970s, large wood was generally considered a nuisance or hazard in streams throughout the world. Large wood was systematically removed from streams to benefit river navigation, prevent or decrease flooding effects, enhance log transportation, and improve fish passage (Maser and Sedell 1994). The consequences included alteration of riparian habitat, changes in nutrient cycles, the simplification of stream channels and the subsequent loss of fish habitat. These consequences have existed for hundreds of years in most European streams and for the last 150 years throughout North America. In Germany (Hering et al. 2000; Reich 2000), and probably in most parts of Europe (Gurnell et al. 1995; Elosegi et al. 1999), wood was removed from both large and small streams to “protect” them from flooding and to accelerate drainage of alluvial farmland.

The role of large wood in streams has been re-examined over the last 30 years. The understanding of that role has fundamentally shifted, as has the treatment of large wood in streams (Bisson et al. 1987). The emerging body of literature documents the role of large wood in structuring the physical template in streams (Abbe and Montgomery 1996; Bilby 2003, this volume), the importance of wood in nutrient cycles (Bisson et al. 1987), and the role of large wood in streams as fish habitat (Roni and Quinn 2001; Zalewski et al. 2003; Dolloff and Warren 2003; both this volume). The growing recognition that large wood is an important component in stream systems worldwide has caused researchers and managers to examine the potential for stream restoration or rehabilitation by adding large wood to streams.

In North America, the use of large wood in stream rehabilitation projects has a long history and probably evolved from work in England more than 100 years ago (Needham 1969). During the 1930s, large wood was used to improve habitat conditions in streams throughout the United States (Hubbs et al. 1932; Tarzwell 1937). This large wood was generally cut into small logs and then configured in various ways to create pools and holding habitat for salmonids. The use of log structures evolved to whole-tree (without rootwad) placements in the late 1970s. Logs were configured as single or multi-log structures in fixed sites by using cable and epoxy anchors tied into the streambed or large boulders (Fontaine 1987). These fixed placements have since evolved into whole-tree structures configured to mimic natural large wood frequencies and distribution throughout the channel (Gregory and Wildman 1998). These structures may be attached at one or more locations or be allowed to move freely in the channel and floodplain. In Germany, and probably in most parts of Europe, logs or trees were also used only in fixed placements to prevent bank erosion (Gunkel 1996), to protect tree plantations (soil bioengineering), or to store sediments in mountain brooks (Karl et al. 1975). The use of unattached whole trees in stream rehabilitation projects emerged during the late 1990s (Reich 2000).

During the last 20 years, interest in restoring stream habitats has been renewed throughout the world (Williams et al. 1997). As the understanding of the importance of large wood has emerged, people have recognized that this key element is missing from many streams. Consequently, a renewed interest has developed in the use of large wood in restoring and rehabilitating streams. This interest has resulted in large wood being placed in streams throughout the world. The large expenditure of time and effort in stream restoration has drawn the attention of the public, scientists, managers, and legislators. Concern over the value of restoration efforts have been raised by several authors (Sedell and Beschta 1991; Frissell and Nawa 1992; Beschta et al. 1995). Concerns with these projects include unclear objectives, design errors, and inadequate monitoring.

Although many projects have been completed, surprisingly little information is available on the success or failure of these projects worldwide. No synthesis is currently available that attempts to summarize the projects that were monitored. The original objectives of this paper were to provide a synthesis of stream restoration work worldwide using large wood and to speculate on the general usefulness of large wood as a restoration tool. Because of limited sample sizes, we will focus on the similarities and contrasts between projects in North America and Germany.

Methods

We compiled literature from a variety of sources including peer-reviewed journal articles, graduate theses, published gray literature, and various administrative reports. We developed a database of 34 papers or reports from restoration case studies that explicitly used large wood in restoration and reported results (Table 1). We attempted to generate information about project goals and objectives, land use, local human population density, year of the restoration, and the extent and type of large wood treatments. Although we tried to find as many published and unpublished reports as possible, we recognize that there may be papers that are not included in the synthesis. Not all information was available for all case studies, but the database was sufficient to draw some general conclusions and comparisons, especially between projects in North America and Germany.

Results and Discussion

We reviewed projects from the United States (17), Germany (11), and Canada (1). Projects occurred from 1976 to 2000, most of them in mountain regions. Forestry was the predominant land use in North America, while 45% of the German sites were surrounded by grassland (Figure 1).

Project goals and objectives were highly variable and fell into the general categories of restoring fish habitat, structural complexity in the channel, channel stability, and channel dynamics (Figure 2). All large-wood restoration projects in North America had goals related to restoring fish habitat, usually in combination with the restoration of structural complexity (81%). In contrast, none of the projects in Germany had fish populations as a stated goal. The primary goals for projects in Germany were was to increase structural complexity in the channel (100%), usually in combination with improvements of the channel dynamics (91%). Only 13% of the projects reviewed in North America addressed the goal of improving channel dynamics (Figure 2). In most of the German projects, the streams were straight-

TABLE 1. Stream restoration projects using large wood.

Country, state	Streams	Reference	Year of restoration
Canada:			
Quebec	NW Montreal	Burgess and Bider 1980	1976
USA:			
California	SF Salmon, EF Salmon, Elk Creek, Indian Creek	Olson and West 1989	1980+
Colorado	NF Poudre, Colo, Walton, Jack, Beaver, St. Vrain	Riley and Fausch 1995	1988
North Carolina	Cunningham Creek	Wallace et al. 1995	1988
Oregon	Deep Creek	Grover 1996	1993
	Elk Creek	House et al. 1991; Crispin et al. 1993	1986–1989
	Grande Ronde, John Day, Tucannon, NF John Day	Taylor 2000	1990+
	Lobster, East, Moon	Solazzi et al. 2000	1990–1991
	Upper Nestuca	House et al. 1991	1986
	Quartz Creek	Gregory and Wildman 1998	1988
	Siuslaw tributaries	Armantrout 1991; Dewberry et al. 1998	1983
	Oregon coastal streams	Nickelson et al. 1992	
	Fish Creek	Reeves et al. 1997	1983
Virginia	NF Stony Creek	Hilderbrand et al. 1998	1992
Washington	NF Porter Creek	Cederholm et al. 1997	1990–1991
	SF Soleduck	Ralston et al. 1992	
	NF Stillaguamish	Abbe and White 2000	1998–1999
Wyoming	Huff Creek, Salt Creek	Binns 1982	1979
	Thomas Fork	Binns 1986	1979–1983
Germany:			
Brandenburg	Demnitzer Mühlenfließ	Kosel and Mutz 2000	2000
Hessen	Asphe	Gerhard and Reich 2001	1998
	Eifa	Reich 2000	1998
	Haberbach	Reich 2000	1998
	Ilsbach	Reich and Gerhard 2002	1998
	Jossklein	Gerhard and Reich 2000	1993
	Lehrsbach	Gerhard and Reich 2001	1998
	Lüder	Gerhard and Reich 2000	1995
	Lummersbach	Reich and Gerhard 2002	1998
	Nitzelbach	Gerhard and Reich 2001	1998
	Aabach	Reich and Gerhard 2002	1998
Japan:			
Hokkaido	Ichibangawa	Yanai, S. Hokkaido Forestry Research Institute, Bibai, Japan, personal communication	1996 + 1998
	Shakotan	Yanai, S. Hokkaido Forestry Research Institute, Bibai, Japan, personal communication	1996 + 1998

ened and severely regulated decades ago. Therefore, the major goal of the projects was to mitigate or to reverse these impacts by the restoration of restoring dynamic processes. Generally, no quantifiable objectives were associated with this goal, so determining if or when the project might be successful was difficult to determine. Note that improving fish habitat often includes

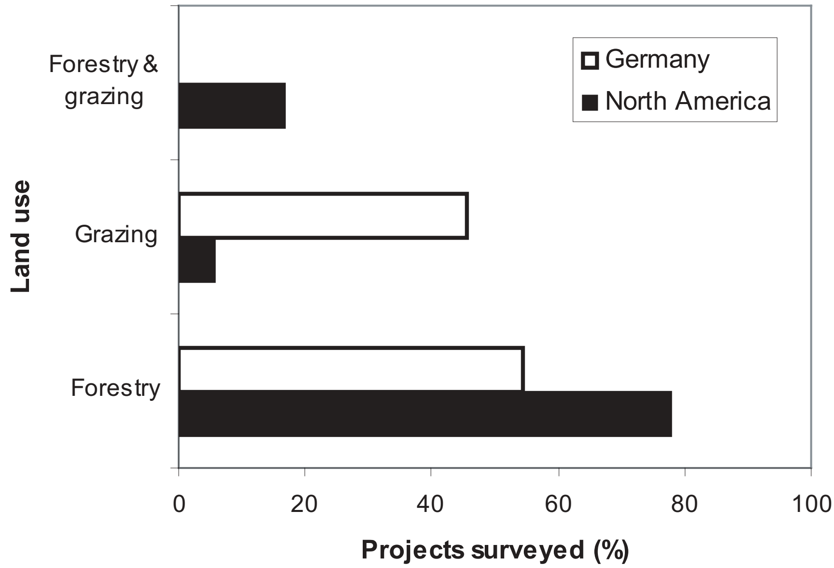

FIGURE 1. Land use in the floodplains or catchments of restoration projects in North America (n = 18) and Germany (n = 11).

improving structural complexity and changing the existing channel dynamics, however. These terms were often used interchangeably in the literature we reviewed.

The physical characteristics of the restoration project sites differed widely. The width of streams where large wood was introduced ranged from 1 to 40 m. In Germany, large wood has been predominantly used in second- and third-order streams, and occasionally in first-order streams (Hering et al. 2000; Reich 2000). Channel wetted width rarely exceeds 4 m (Fig-

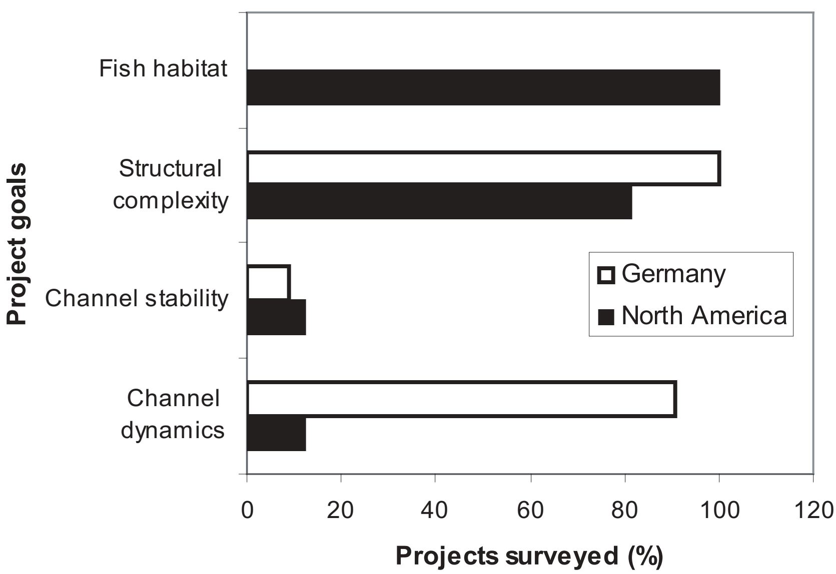

FIGURE 2. Goals of restoration projects in North America (n = 16) and Germany (n = 11).

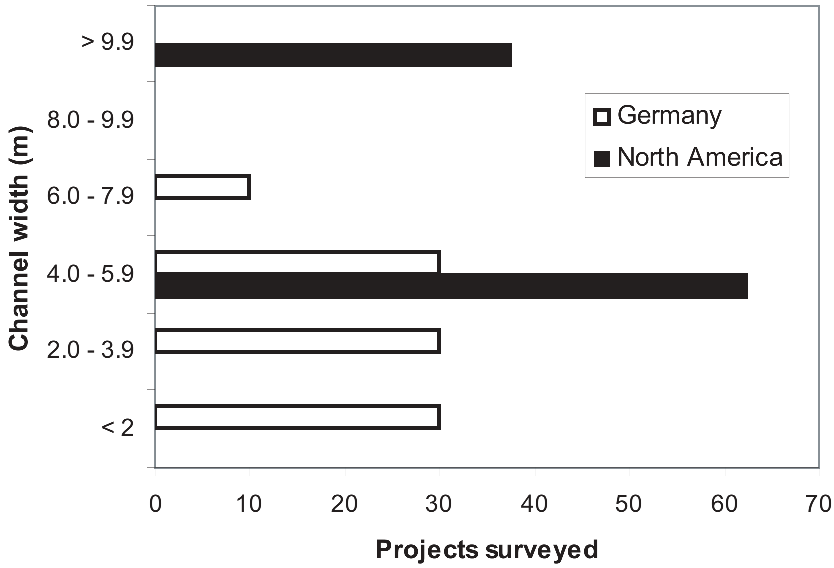

FIGURE 3. Channel width of restoration projects in North America (n = 8) and Germany (n = 10).

ure 3). In contrast, streams in North America were generally wider than 4 m and ranged from 2 m to 40 m. We believe that the difference may be related to the project objectives and the potential threat of transported wood to human inhabitants and property. Because the objective of many American large wood introductions is to restore fish habitat, projects tend to be located in larger, fish-bearing streams. The primary objective for most German projects is to improve channel form, but not necessarily to improve fish habitat. There may be a number of reasons for this. Most German large wood introductions occur in streams that are situated in rural areas with 80–200 inhabitants / km² in the surrounding area. The risk of property damage caused by moving wood is high along all larger streams. Stream restoration with large wood started in smaller streams, where the improvement of the channel form was the dominating goal and the threat to human lives and property is minimal. Restored stream reaches in Germany were generally less than 0.5 km and contained less than five structures, but the restored reaches in North America were generally several kilometers long with numerous structures (Figure 4).

Large wood was placed in streams in one of three ways: (1) fixed structures attached to the bed, the bank, or both using cables or engineered placements; (2) whole trees or logs that were placed as either single pieces or groups of pieces and allowed to move freely at high flows; and (3) structures where large wood was attached to the bed or bank by a cable but cabling was loose enough to allow movements over several meters during high flow (partially mobile). In North America, fixed structures were used in the majority of the studies that were reviewed and were either configured (k-dams, log drops) or cabled in place (Figure 5). Mobile wood placements were mostly used in projects after 1990 and represented 6% of the projects in North America and 55% in Germany. Partially mobile wood placements represented 22% of the North American projects and 18% of the projects in Germany. In some of the North American projects, fixed and mobile structures were combined (Figure 5).

Projects that allowed large wood to move freely throughout the channel have become more common in both North America and Europe. Large wood that is freely allowed to move more closely mimics the wood input and movement processes in forested ecosystems. Whole-tree placements have been used in several areas in North America. Ashbridge (2001) used a combination of whole trees and logs in the East Fork Hood River and Clear Branch in Oregon. Large wood in the East Fork Hood River moved during two separate flood and debris flow events, but this movement was designed as part of the project objectives. Yager (1999) used large trees in the channel as key pieces designed to attract floating

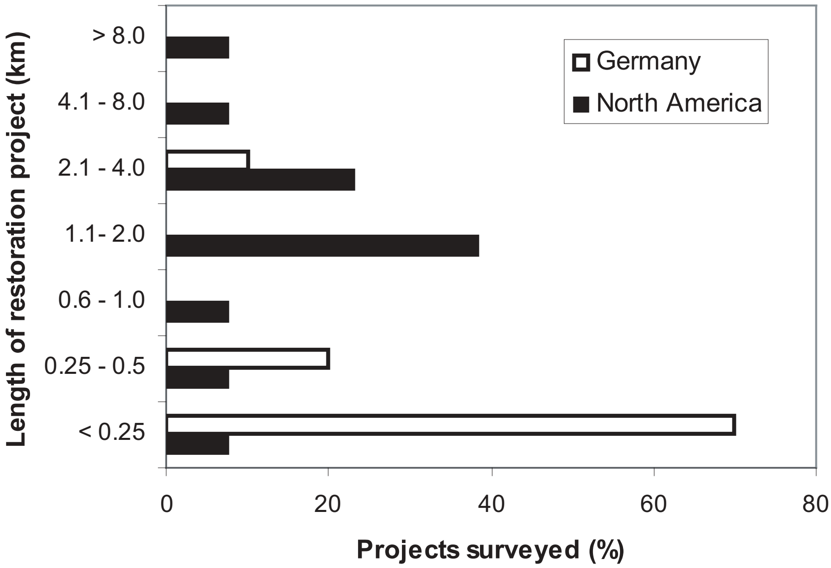

FIGURE 4. Length of restored reaches per project in North America (n = 13) and Germany (n = 10).

woody debris and build more complex debris wood jams. Similar projects have been built in British Columbia (Poulin 2001). Adding large wood to streams in Germany has primarily occurred in relatively small streams where the potential for large extensive movements is low and the risk to downstream facilities is also low. Most of these projects are located along straightened channels, and re-establishing meanders is the major goal (Reich 2000). The reintroduction of mobile large wood in these channels has been shown to speedhastened the re-establishing of channel function and structure (Gerhard and Reich 2000). The very first projects along large German

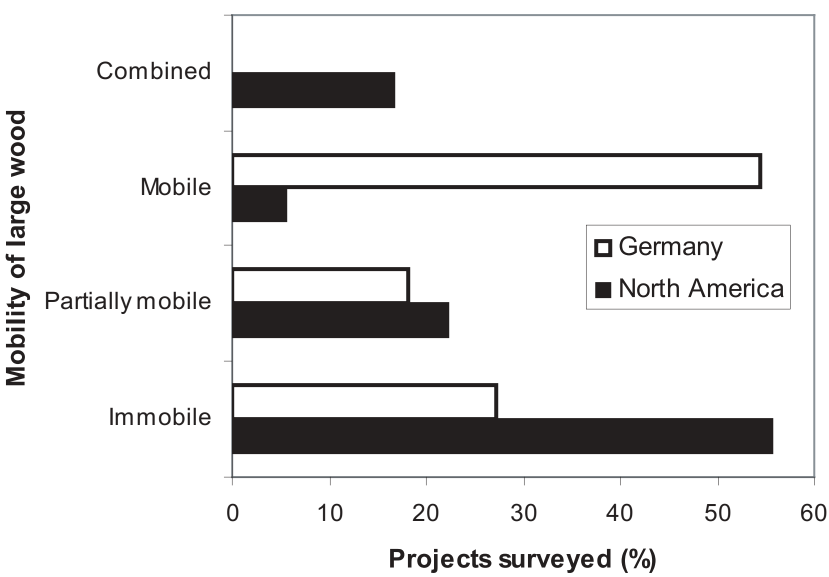

FIGURE 5. Mobility of the large wood in restoration projects in North America (n = 18) and Germany (n = 11).

rivers have been implemented with large wood configured and cabled in place (Völkl et al. 2002).

A wide variety of tree species are used in adding large wood in North America and Germany (Figure 6). In North American projects, native tree species typically represent the native riparian vegetation. Native conifers are the predominant trees used in restoration. In Germany, 82% of the tree species (poplar, spruce) used in the restoration projects were introduced to the adjacent floodplain forests decades ago. Nonnative floodplain forests are now gradually being replaced by native alder, ash, and beech forests, and harvested nonnative trees can be used for restoration projects during this process (Gerhard and Reich 2000).

Restoration projects using large wood generally have different goals in North America and Germany. In Germany, restoration success is based on changes in channel morphology, in substrate diversity, and in the abundance and diversity of aquatic macroinvertebrates (Figure 7). Restoration success in North America is often measured as an improvement in fish habitat and fish populations. Project monitoring results are lacking for many projects in both Europe and North America. In Germany, most projects have been recently implemented, and there are only preliminary results

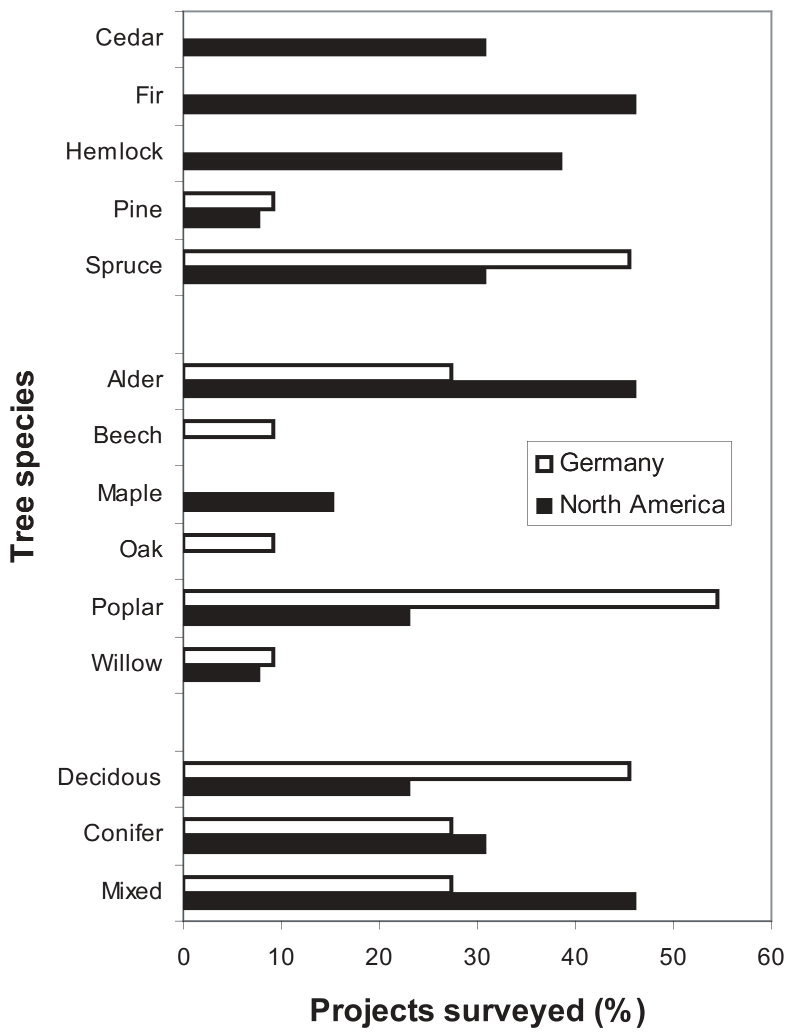

FIGURE 6. Tree species used in large-wood additions in North America (n = 13) and Germany (n = 11).

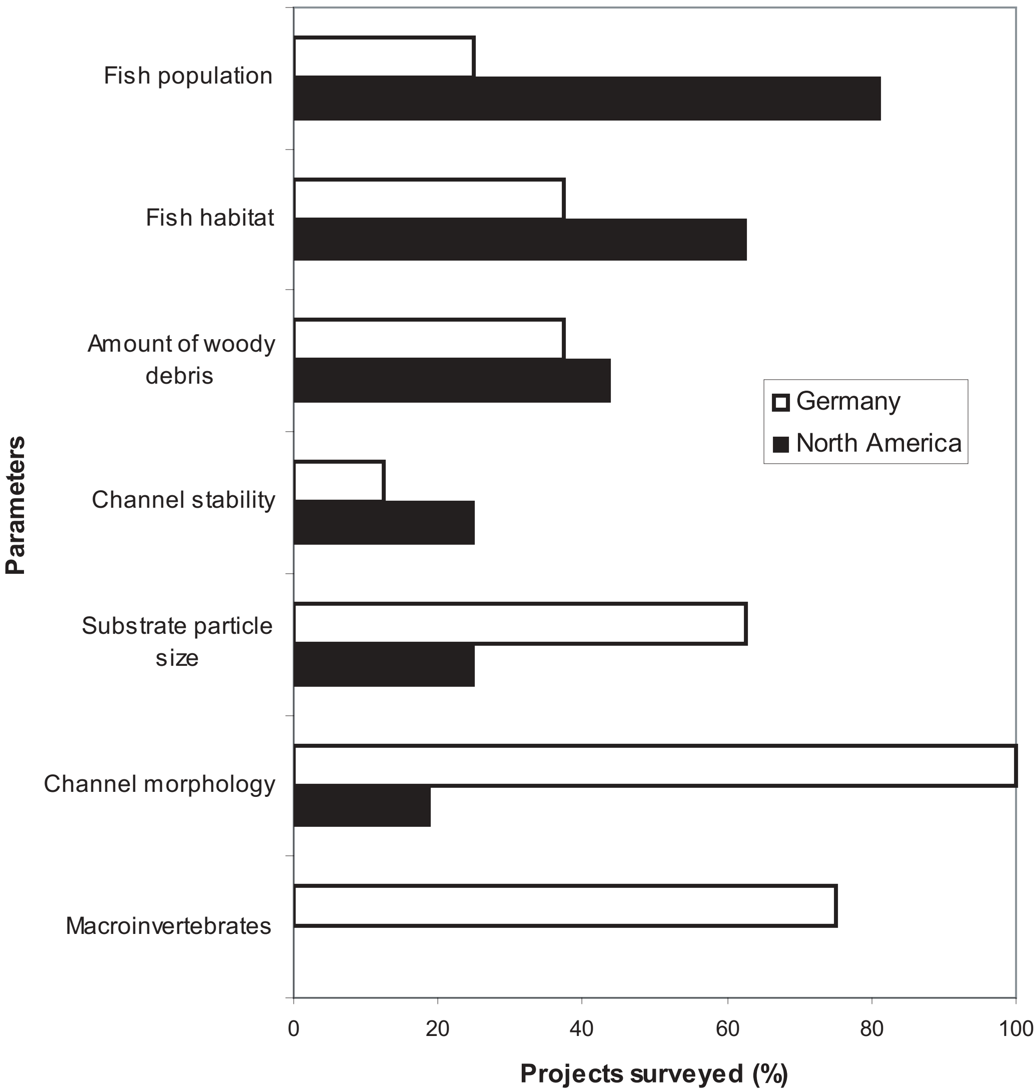

FIGURE 7. Parameters to measure success of wood additions in North America (n = 13) and Germany (n = 8).

(Table 1). It is difficult to measure success on such a short time scale, especially when channel forming floods have not yet occurred. Initial results are encouraging, but success will only be measured by long-term monitoring (Reich and Gerhard 2001). Longer-term results are available in some areas of North America (Reeves et al. 1997; Roper et al. 1997; Dewberry et al. 1998; Gregory and Wildman 1998), but few of these studies have been conducted during a time scale large enough to include multiple high flows or floods. Equally problematic is the lack of clear objectives for some of these projects. It is difficult to evaluate success when one is unsure of the original purpose.

Conclusions

Understanding the role of large wood in streams has undergone a renaissance from when wood was removed from streams as a standard practice to the present where large wood is now recognized as integral to stream and riparian function. In Germany, wood in streams was regarded primarily as a problem or a hazard before 1990. Since then, not only ecologists, but also hydraulic engineers and legislators, have begun to understand the ecological function of wood in streams. The new European water framework directive requires "good conditions" that are "not far from natural conditions" for streams throughout Europe. Clearly, large wood plays an important role to meet the intent of this policy. Although the policy recognizes the importance of large wood in streams, the problem of responsibility for damages caused by large wood is still unsolved. In North America, a similar change in philosophy has appeared over the past two decades. Before the 1970s, large wood was often viewed as an impediment to fish migration and passage, rather than a key component of streams and riparian areas. Changes in state forest practices and federal policy for large wood over the past decade reflect our growing understanding of the importance of large wood.

Large wood is an important tool in stream and riparian restoration. Probably thousands of restoration projects have been implemented that used large wood to change stream channel interactions with the floodplain. Surprisingly, the number of papers and reports documenting the results of using large wood in restoration is disproportionately small. We were able to find few papers that were peer reviewed, in gray literature, or available as graduate theses. Although many administrative reports or file reports are undoubtedly available for local use, they are often inaccessible to the public. We believe that restoration projects must have monitoring plans that document the success or failure of projects and that the results of monitoring must be available to a wide audience if we are to learn from our successes and failures. To measure success or failure, these projects will also require well-articulated, quantifiable objectives that define the parameters to be measured.

Our understanding of the linkage between riparian habitat, floodplains, and stream systems will help to refine the way large wood is used in restoration. As understanding of the role of large wood has changed, the philosophy of the role of large wood in restoration has also changed. The historical retrospective from our work suggests a switch from fixed instream placements to the use of wood in more natural, random groups of large wood free to move in the channel and floodplain. This change in philosophy most probably represents a similar emergence in the science of restoration ecology where the focus is on watershed restoration, rather than simply improving fish-habitat. Large wood additions are most often viewed in the context of stream and riparian function, rather than just fish habitat. Most often, fish-habitat objectives are developed as part of the objectives to restore stream and floodplain function rather than an endpoint. Restoration practitioners recognize that the long-term solution to the lack of large wood in streams is ultimately tied to riparian forest succession (Boyer and Berg 2003, this volume). Large wood additions should generally be viewed as short-term fixes that may need to be sustained for several decades until successional processes in riparian forests can once again operate.

The literature reported here represents the results from stream restoration work in Germany and North America. Other large-wood restoration projects are ongoing in other countries like Austria (Urbanek et al. 1999), Poland (Kaczka, University of Silesia, Sosnowiec, Poland, personal communication), and Japan (Table 1). Undoubtedly, many more restoration projects have not yet been reported worldwide. As the body of literature from these projects grows, we hope that the evidence ultimately points to worldwide recovery of streams and riparian areas.

Acknowledgments

We thank Marc Gerhard, Herbert Diehl, Michael Mutz, Vollmer Consultants (Germany), and Seiji Yanai (Japan) for unpublished data. Dave Heller, Deb Konnoff, and Bob Metzger from the Pacific Northwest United States solicited unpublished papers from a variety of sources.

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