LARGE WOODY DEBRIS

An Annotated Bibliography

(Annotations Primarily Author Abstracts)

Compiled for the
Region III Forest Practices Riparian Management Committee

by
James D. Durst and Jim Ferguson
Alaska Dept. of Fish & Game, Habitat & Restoration Div.

SUMMARY

Much has been written the past few decades about the beneficial roles that wood, particularly large woody debris (LWD) can play in fish-bearing water bodies. Accordingly, the preservation of short- and long-term sources of LWD plays a central role in the statutory riparian standards of the Alaska Forest Resources and Practices Act. Few studies, however, have taken place on large rivers, on glacial rivers, or in interior Alaska; we found none published on a site with all three characteristics. The purpose of this literature review was to provide information on the roles of LWD using sources most applicable to large rivers, glacial rivers, and Region III.

In smaller or clearer water bodies, LWD plays a direct role in salmonid habitat, particularly for juvenile fish. This is largely related to the spawning and cover-use characteristics of this group of fishes (e.g., Lister and Genoe 1970, Lee 1985, Murphy et al. 1989, Hicks et al. 1991, Inoue and Nakano 1998). The review monograph by Murphy (1995) is the most applicable to Region III of the several volumes available documenting the effects of forestry-related activities on LWD and other aspects of fish habitat and water quality, although its focus is the Pacific Northwest and southeast Alaska. When ice (Jakober et al. 1998) or turbidity (Murphy et al. 1989) provide cover, the roles of LWD can shift from direct to indirect through effects on substrate size, island and side channel formation, and stream bed and bank roughness. The interaction of velocity, turbidity, and cover can result in small-scale differences in habitat suitability for both anadromous and resident fish.

In large streams in Region III, the role for LWD may be more indirect, because water velocities in mainstem channels are often high, and much of the LWD is on bars or jams above the free-flowing water during winter months. In large glacial streams, the chief role of LWD may well be in shaping stream morphology, adding hydraulic roughness to glacial streams, providing bank armoring, contributing to the formation of river bars and islands, and blocking side channels (Fetherston et al. 1995, Abbe and Montgomery 1996, Montgomery et al. 1996, Dudley et al. 1998). Removal of wood in many large rivers since European settlement of North America has resulted in altered channel structure even in large rivers, and the deleterious effects of such removal can be long-term (Maser and Sedell 1994). Because of its size, LWD in large rivers can be more stable than the relatively mobile bed load sediments, and can function as substrate for aquatic invertebrates used by fishes as food. Is has also been hypothesized that

LWD could play an important, but short-term, role during migration by providing eddies where upstream movement is easier and where fish can rest.

A number of data gaps were noted. The general lack LWD data for large, glacial rivers, especially those with seasonal ice cover, is striking when viewed against the large body of literature for smaller, clearer streams in more moderate climates. Basic information needs include data on wood budgets of large rives, and optimal amounts of LWD in stream systems to provide fish habitat functions. Data on these direct and indirect roles of LWD as fish habitat in large rivers, glacial rivers, and during winter are also needed before we will be able to fully assess whether the status quo is above or below optimal, and how LWD can be a limiting factor for fish populations. Specific information on the role of LWD as cover or resting habitat for juvenile and adult anadromous and resident fish species could directly bear on the assessments and recommendations currently being developed by the SCC. A number of publications examined did not provide the size of the LWD being studied, or of the physical and chemical characteristics of the stream or river, and so the applicability of these publications to this review could not be determined.

Annotations in this review are typically authors' abstracts. Citations and annotations came from a variety of sources, including an online search by the Alaska Resources Library and Information Services (Water Resources Abstracts, Fish & Fisheries Worldwide, and Arctic and Antarctic Regions databases, key words "woody debris" and "log jams"), reviewers' personal libraries, and the annotated bibliography in ADF&G Technical Report No. 97-1.

REFERENCES

Abbe, T. B., and D. R. Montgomery. 1996. Large woody debris jams, channel hydraulics and habitat formation in large rivers. Proceedings of International Symposium on Habitat Hydraulics, Trondheim (Norway), 18-20 Aug 1994. Regulated Rivers: Research & Management 12:201-221.

Field surveys document the accumulation of large woody debris (LWD) into structurally distinctive jam types in the alluvial channel of the Queets River on the Olympic Peninsula of north west Washington. Calculations, field observations and historical evidence show that these jams can form stable structures controlling local channel hydraulics and providing refugia for riparian forest development over decades and possibly centuries. Distinctive spatial patterns of LWD, pools, bars and forested islands form in association with particular jam types. The deposition of 'key member' logs initiates the formation of stable bar apex and meander jams that alter the local flow hydraulics and thereby the spatial characteristics of scour and deposition leading to pool and bar formation. Historical evidence and the age structure of forest patches document the temporal development of alluvial topography associated with these jam types. Bar apex jams, for example, are associated with a crescentic pool, an upstream arcuate bar and a downstream central bar that is the focus of forest patch development. Experimental and empirical studies in hydraulic engineering accurately predict channel scour associated with jams. Individual jams can be remarkably stable, providing long-term bank protection that creates local refugia for mature forest patches within a valley floor environment characterized by rapid channel migration and frequent disturbance. Processes controlling the formation, structure and stability of naturally occurring LWD jams are fundamental to the dynamics of forested river ecosystems and provide insights into the design of both habitat restoration structures and ecosystem-based watershed management.

Assani, A. A., and F. Petit. 1995. Log-jam effects on bed-load mobility from experiments conducted in a small gravel-bed forest ditch. Pages 117-126 *in* Poesen, J., G. Govers, and D. Goossens, editors. Experimental Geomorphology and Landscape Ecosystem Changes. Proceedings of a Memorial Symposium for Prof. Jan de Ploey, 22-26 March 1993. Catena 25.

Bed-load transport experiments have been conducted in a steep gravel-bed open ditch. This initially straight ditch has been neglected for many years and looks at present like a second-order natural stream channel. The channel flows through a spruce forest and several log-jams have produced chutes and pools, creating supplementary roughness. The total shear stress has been evaluated using the slope-hydraulic radius product, and the ratio between grain and bed-form shear stresses has been calculated using different methods. The shear stress has also been evaluated from the shear velocities, and this gives a good evaluation of the grain shear stress. Additional experiments have been conducted with marked pebbles to estimate particle mobility and to improve the motion equations. Equations such as $\theta_c = a(D_i/D_{50})^b$, defined by Andrews, apply in these cases but the values of a and b are lower than those produced by this author. In a second stage of experimentation, we have destroyed the log-jams resulting in a diminution of the roughness and critical shear stress (when the total shear stress is used), an increase of the grain shear stress, and thus greater bed particle mobility for the same discharge. It emerges from these experiments that the log-jams contribute to the reduction of bed-load evacuation and explain the very weak bed-load discharge measured by a bed-load trap (0.3 $t/km^2/yr$).

Beschta, R. L., and E. G. Robison. 1990. Characteristics of coarse wood debris for several coastal streams of southeast Alaska, USA. Canadian Journal of Fisheries and Aquatic Sciences 47:1684-1693.

Coarse woody debris (>0.2 mm in diameter and 1.5 m long) was measured along five undisturbed low-gradient stream reaches; volume, decay class, and horizontal orientation in relation to channel flow of first-order, second-order, third-order, and fourth-order coastal streams were determined. Debris was also classified into four influence zones based on stream hydraulics and fish habitats. Average debris length, diameter and volume per piece increased with stream size. Eighty percent of debris volume of the first-order and the smaller second-order streams was suspended above or lying outside the bankfull channel, while less than 40% was similarly positioned in the fourth-order stream. Approximately one- third of all debris was oriented perpendicular to stream flow, regardless of stream size. First-order, second-order, and third-order streams had a higher proportion of recent debris in the channel than the fourth-order stream, most new debris being attributable to a major 1984 windstorm. Tree blowdown had a major influence on debris distribution along the smaller storm reaches. Debris jams and accumulations in the largest stream were formed from floated debris. These characterizations are useful for evaluating the distribution and amount of woody debris associated with land-management activities.

Bilby, R. E., and G. E. Likens. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. Ecology 61:1107-1113.

Removal of all organic debris dams from a 175-m stretch of second-order stream at the Hubbard Brook Experimental Forest in New Hampshire led to a dramatic increase in the export of organic carbon from this ecosystem. Output of dissolved organic carbon (<0.50 ? m) increased 18%. Fine particulate organic carbon (0.50 ? m–1 mm) export increased 632% and coarse particulate organic matter (>1 mm) export increased 138%. Measurement of the standing stock of coarse particulate matter on streambeds of the Hubbard Brook Valley revealed that organic debris dams were very important in accumulating this material. In first-order streams, debris dams contain nearly 75% of the standing stock of organic matter. The proportion of organic mater held by dams drops to 58% in second-order streams and to 20% in third-order streams. Organic debris dams, therefore, are extremely important components of the small stream ecosystem. They retain organic matter within the system, thereby allowing it to be processed into finer size fractions in headwater tributaries rather than transported in a coarse particulate form.

Bragg, D. C., and J. L. Kershner. 1999. Coarse woody debris in riparian zones. Journal of Forestry 97:30-35.

Interdisciplinary cooperation is necessary to ensure long-term sustainability of our nation's forests and restore the processes and function associate with healthy ecosystems. Past models of forest management were often driven by narrow resource objectives and did not consider the variety of natural ecosystems. We believe that large-scale efforts, such as the Northwest Forest Plan and watershed analysis, provide new opportunities for cooperation among natural resource professionals. Prospects for interaction are considerable, since changes in forests have affected most of the riparian zones in North America.

Braudrick, C. A., G. E. Grant, Y. Ishikawa, and H. Ikeda. 1997. Dynamics of wood transport in streams: a flume experiment. Earth Surface Processes and Landforms 22:669-683.

The influence of woody debris on channel morphology and aquatic habitat has been recognized for many years. Unlike sediment, however, little is known about how wood moves through river systems. We examined some dynamics of wood transport in streams through a series of flume experiments and observed three distinct wood transport regimes: uncongested, congested and semi-congested. During uncongested transport, logs move without piece-to-piece interactions and generally occupy less than 10 per cent of the channel area. In congested transport, the logs move together as a single mass and occupy more than 33 per cent of the channel area. Semi-congested transport is intermediate between these two transport regimes. The type of transport regime was most sensitive to changes in a dimensionless input rate, defined as the ratio of log volume delivered to the channel per second (Q sub(log)) to discharge (Q sub(w)); this ratio varied between 0.015 for uncongested transport and 0.20 for congested transport. Depositional fabrics within stable log jams varied by transport type, with deposits derived from uncongested and semi-congested transport regimes having a higher proportion of pieces oriented normal to flow than those derived from congested transport. Because wood input rates are higher and channel dimensions decrease relative to piece size in low-order channels, we expect congested transport will be more common in low-order streams while uncongested transport will dominate higher-order streams. Single flotation models can be used to model the stability of individual pieces, especially in higher-order channels, but are insufficient for modeling the more complex interactions that occur in lower-order streams.

Bren, L. J. 1993. Riparian zone, stream, and floodplain issues: a review. Journal of Hydrology 150:277-299.

In the last two decades, the effects of forest management on streams, riparian zones, and floodplains have become of much interest. In general, there is agreement that such areas should be maintained in a state approximating naturalness, although it is recognised that definition of this state is usually difficult or impossible. A diversity of management effects has been recognised and, in some cases quantified. For upland catchments, issues particularly relate to direct disturbance of the zone, changes in the flow of woody debris into the stream, or disturbance to the environment by effects generated upstream or downstream. For many areas, a particularly important commercial aspect is the definition of a 'stream,' as this can impose many expensive and severe restrictions on management of the land. For large rivers, a common issue is the effect of river management on flooding forests. In each case, the issues are complex, information is difficult to collect, and there are fundamental difficulties in going from anecdotal observation to data. Currently, most information appears to be at a relatively local level, and there is a very inadequate knowledge base to give a more holistic overview, although the concept of 'cumulative effects.' with the effects accumulated over both space and time, has much potential value. There are many opportunities for work in this field.

Bryant, M. D., and J. R. Sedell. 1995. Riparian forests, wood in the water, and fish habitat complexity. Pages 202-224 *in* N.B. Armantrout, editor. Condition of the world's aquatic habitats. Proceedings of the World Fisheries Congress, Theme 1. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi.

Civilization has significantly removed or altered large tracts of riparian forest through agriculture, urbanization, and logging. The result has been a long-term (100 years+) loss of large wood in lotic ecosystems. This has changed the perspective in which rivers and large wood have been viewed. Historical records and undisturbed systems in the Pacific Northwest and Alaska have shown that large wood has been and is abundant in undisturbed streams. Large wood serves to connect the main stream to its floodplain, creates complex channel structure, and forms off-channel habitats and pools. All are in areas of high biological productivity, which is reflected in higher fish numbers. These trends appear to occur on a global basis over a diverse set of ecosystems. Given the continuing loss of riparian forests, management should promote retention of riparian forest. Rehabilitation and restoration of degraded riparian habitat is a long-term process and should re-establish riparian vegetation and reconnect rivers with floodplain processes.

NOTE: The authors provide a good discussion of the role of wood in large river systems, and provided extensive citations.

Bugosh, N., and S. G. Custer. 1989. Effect of a log-jam burst on bedload transport and channel characteristics in a headwaters stream. Pages 203-211 *in* Proceedings of the Symposium on Headwaters Hydrology, American Water Resources Association, Bethesda Maryland.

Hydraulic factors are commonly assumed to exercise primary control on sediment transport in high-gradient headwaters streams. Research in 1983 and 1984 on Squaw Creek, a tributary to the Gallatin River in Montana, has shown that other hydrologic and geomorphic factors are also important. One of these factors is log-jams. A log-jam functions as a sediment storage area and as a local base level. The catastrophic dispersal of an old-jam in the study reach was observed and recorded during 1983. The log-jam broke when discharge was 6.4 cu m/s. A pulse of sediment was released from storage. One side of the channel was filled and channel morphology was altered. As the stream adjusted to the new morphology, average bedload transport was as high as 0.4 kg/m/s. This rate is at least two times the bedload transport rate measured at similar and higher discharges during runoff in 1983 and 1984. Thirty percent of the measured bedload in 1983 moved in a three day period and is directly attributable to the burst of the log-jam. The dispersal of this log-jam and the resulting instantaneous changes in bedload transport parameters had a greater effect on bedload in Squaw Creek more than any other parameter studied. Log-jam breakage affects bedload availability, bedload transport and channel characteristics in headwater streams.

Diehl, T. H., and B. A. Bryan. 1993. Supply of large woody debris in a stream channel. ages 1055-1060 *in* Shen, H. W., S. T. Su, and Feng Wen, editors. Proceedings of Hydraulic Engineering '93 Conference, San Francisco. American Society of Civil Engineers.

The amount of large woody debris that potentially could be transported to bridge sites was assessed in the basin of the West Harpeth River in Tennessee in the fall of 1992. The assessment was based on inspections of study sites at 12 bridges and examination of channel reaches between bridges. It involved estimating the amount of woody material at least 1.5 meters long, stored in the channel, and not rooted in soil. Study of multiple sites allowed estimation of the amount, characteristics, and sources of debris stored in the channel, and identification of geomorphic features of the channel associated with debris production. Woody debris is plentiful in the channel network, and much of the debris could be transported by a large flood. Tree trunks with attached root masses are the dominant large debris type. Death of these trees is primarily the result of bank erosion. Bank instability seems to be the basin characteristic most useful in identifying basins with a high potential for abundant production of debris.

Dudley, S. J., J. C. Fischenich, and S. R. Abt. 1998. Effect of woody debris entrapment on flow resistance. Journal of the American Water Resources Association 34: 1189-1198.

Recent environmental concerns in floodplain management have stimulated research of the effect vegetation and debris have on flow conveyance, and their function in a productive riparian ecosystem. Although the effect of stable, in-channel woody debris formations on flow resistance has been noted by several authors, studies concerning entrapment of detrital debris in vegetation are lacking. Logs, limbs, branches, leaves and other debris transported during flooding often become lodged against bridges, hydraulic structures, trees and vegetation, and other obstacles, particularly in and near the overbank areas. Hydraulic measurements obtained in a channel prior to and following the removal of woody debris indicated that the average Manning's n value was 39 percent greater when woody debris was present. An examination of the drag-velocity relation for vegetation indicated that an increase in the frontal area of debris and/or vegetation results in a nearly proportional increase in Manning's n. The influence of debris on flow resistance decreased as flow depth increased.

Fetherston, K. L., R. J. Naiman, and R. E. Bilby. 1995. Large woody debris, physical process, and riparian forest development in montane river networks of the Pacific Northwest. Geomorphology 13:133-144.

The authors present a conceptual biogeomorphic model of riparian development in montane river networks. The role of physical process in driving the structure, composition, and spatial distribution of riparian forests is examined. The authors classify the drainage network into disturbance process-based segments including: (1) debris-flow and avalanche channels, (2) fluvial and debris-flow channels, and (3) fluvial channels. Riparian forests are shown to be significant in the development of channel morphology through stabilization of active floodplains and as a sources of large woody debris (LWD). LWD is operationally defined as wood >0.1 m diameter and > 1 m length. LWD plays a key role in the development on montane riparian forests. LWD deposited in the active channel and floodplain provides sites for vegetation colonization, forest island growth and coalescence, and forest floodplain development. Riparian forest patterns parallel the distribution of hillslope and fluvial processes through the network. Riparian forest structure, composition, and spatial distribution through the network are driven by the major disturbance processes including: (1) avalanches, (2) debris-flows, and (3) flooding. Riparian forest patterns also reflect the action of LWD in the organization and development of forested floodplains in gravel bedded montane river networks. The focus of the authors' examples are montane river networks of the Pacific Northwest, USA.

France, R. L. 1997. Macroinvertebrate colonization of woody debris in Canadian Shield lakes following riparian clearcutting. Conservation Biology 11: 513-521.

Deployment of litterfall traps revealed that clearcut logging of boreal riparian forests in northwestern Ontario, Canada resulted in a dramatic shift from once dominant conifers to regrowth composed largely of deciduous trees and reduced the allochthonous inputs of small woody debris to lake littoral zones by over 90%. Due to the rarity of macrophytes in these oligotrophic lakes, littoral macroinvertebrates were found to actively colonize woody debris placed within mesh litter bags. The recalcitrant nature of small woody debris in these lakes (average median persistence time of about 5 years estimated from mass loss data) indicates, however, that this important habitat resource will probably never completely disappear in relation to its projected rate of resupply during post-disturbance forest regeneration. Colonization rates of twigs and bark contained within the litter bags were not found to differ between coniferous and deciduous species. This indicates that macroinvertebrates in these boreal lakes are merely opportunistic colonizers of woody debris, probably for its use as either a biofilm substrate or a predation refuge. As a result, shifts in tree species composition following riparian clearcutting should not detrimentally affect the taxa richness or organism abundance of aquatic macroinvertebrates in these lakes.

Gregory, K. J., and R. J. Davis. 1992. Coarse woody debris in stream channels in relation to river channel management in woodland areas. Regulated Rivers: Research & Management 7:117-136.

Although river channel management now generally uses soft rather than hard engineering techniques the considerable research achieved for woodland river channels has not been completely collated with reference to management implications. Research results from 22 research papers show how debris dams have a significant influence upon the morphological, the process and the ecological aspects of channels, vary in their permanence, and differ in stability according to the overall organic matter budget. A summary diagram contrasts the impact of dams on river channel morphology, process and ecology before and after dam removal. Four major types of specific recommendations about the management of channels in woodland areas are identified from 29 research papers are that (1) management should be undertaken against a background knowledge of the behaviour of coarse woody debris under natural conditions and that the organic matter budget should be disturbed as little as possible; (2) logging operations should minimize the amount of disturbance to, and disruption of, channel processes; (3) management should optimize the maintenance of habitat diversity and minimize the ecological disturbance to the channel; (4) in some areas specific management practices may require the introduction of new material into the channel. These recommendations were applied to the New Forest, southern U.K., which has a long history of clearance and management of coarse woody debris and where the requirements for clearance in relation to fish, drainage, and aesthetic impact can be achieved by minimizing the amount of removal of material from the river channel. In managing channels with debris dams in woodland areas, it is desirable to work with the river in a holistic basin context.

Gregory, K. J., A. M. Gurnell, and C. T. Hill. 1985. The permanence of debris dams related to river channel processes. Hydrological Sciences Journal 30:371-381.

Vegetation debris dams occur on average every 27 m of channel in a drainage basin in the New Forest, Hampshire, England, and within less than 12 months 36% changed position or were destroyed and 36% changed character. Such dams significantly affect the timing of flood peaks as they are routed through the channel network; their significance has been demonstrated by preliminary analysis of hydrograph travel times by measurements in a reach at different flow stages, and by measurements before and after dam clearance. There was a difference in travel time of over 100 minutes for the situation with and without dams for a discharge of 0.1 m^3/s but a difference of only 10 minutes for a discharge of 1.0 m^3/s along the same 4028 m channel reach.

Gurnell, A. M., K. J. Gregory, and G. E. Petts. 1995. The role of a coarse woody debris in forest aquatic habitats: Implications for management. Aquatic Conservation: Marine and Freshwater Ecosystems 5:143-166.

1. Throughout the Temperate Forest biogeographical zone, river valleys were once heavily wooded. Fallen trees had a major impact upon river systems by ponding water and storing sediments, and valley floors were characterized by extensive wetlands with networks of minor channels linking to the main channel. Concern for environmental conservation and for the

rehabilitation of damaged aquatic ecosystems has led to research on the links between river channel dynamics and vegetation, and an interest in the use of dead wood for environmentally sensitive engineering approaches to river management. 2. Accumulations of coarse woody debris (CWD) have an impact on the hydrological, hydraulic, sedimentological, morphological and biological characteristics of river channels. These impacts are very significant for the stability and biological productivity of river channels in forested catchments. 3. As a result of the geomorphological and ecological importance of CWD in river channels in forested catchments, such debris requires careful management. In particular indiscriminate removal of CWD should be avoided. 4. In the context of commercial forestry, a sequence of linked management options can be employed to control sediment and organic matter transport within river systems and to enhance channel stability and physical habitat diversity. These management options include selective removal of less stable debris, addition of debris to the river where the natural supply is inadequate, the maintenance of buffer strips of riparian trees which can act as a source of CWD, and the active management of woodland buffer strips to provide a wide range of physical habitat characteristics including light, temperature, flow, sediment transport and substrate conditions, thereby promoting high biological diversity within the river environment.

Gurnell, A. M., and R. Sweet. 1998. The distribution of large woody debris accumulations and pools in relation to woodland stream management in a small, low-gradient stream. Earth Surface Processes and Landforms 23:1101-1121.

This paper focuses upon the natural dynamics of large woody debris (LWD), the impact of management on LWD dynamics, and the impact of LWD removal and channelization on the distribution and size of pools in a British second to third order headwater catchment. The study stream is rather different from those subject to LWD accumulations which have been studied in North America. The most important contrast is that it is surrounded by predominantly deciduous rather than coniferous woodland. In terms of its width (1.8-4.5 m) and gradient (0.013 m/m), it falls within the lower range of channels studied in North America. Nevertheless, there are similarities in LWD dam and pool spacing with some North American studies. The information on LWD dynamics during a period without management and on recovery of LWD dams after clearance covers a 16 year period (1982-1997). The paper illustrates that seven to eight years after clearance the total number of LWD dams has recovered but the most hydraulically active dam type has not recovered to pre-clearance levels. An analysis of geomorphological maps of the channel surveyed in 1982 and 1996/97 shows an overall decrease in the number and size of pools along the section that was cleared of LWD dams. The magnitude of the decrease and the associated adjustments in pools through changes in their size and location differ according to location with respect to a section of the study stream which was channelized in *c*. 1966 and which has subsequently incised its bed.

Hicks, B. J., J. D. Hall, P. A. Bisson, and J. R. Sedell. 1991. Responses of salmonids to habitat changes. American Fisheries Society Special Publication 19:483-518.

In this review paper, the authors examined responses of salmonid populations to a variety of biotic and abiotic changes attributed to timber harvest and road building activities, including changes in the amount and kinds of LWD. LWD changes occur in all stream types and reaches, from small headwater streams to estuaries of large rivers. Important roles attributed to LWD include controlling stream channel morphology, regulating storage and routing of sediment and organic matter, and creating and maintaining fish habitat. The authors note that salmonid abundance is often closely linked to LWD abundance particularly in winter. The diversity of hydraulic gradients and hence microhabitats created by LWD supports greater diversity of coexistent species and age classes within the same stream reach. Removal of nearly all large trees from the riparian zone during logging has lead to long-term reductions in LWD in many larger rivers. The stumps, slash, and other smaller debris left from logging tends to deposit in fewer, larger jams than the larger typical riparian pieces. Unless large-scale events such as extensive blowdown occurs, LWD in the channel will decline until the next generation of trees becomes large enough. This was estimated at 50-100 years for most streams in the Pacific Northwest and southeast Alaska, with streams wider than about 15m requiring at least 60 years.

Hogan, D. L. 1987. The influence of large organic debris on channel recovery in the Queen Charlotte Islands, British Columbia, Canada. Pages 345-353 *in* Erosion and Sedimentation in the Pacific Rim. IAHS Publication No. 165. International Association of Hydrological Sciences, Washington, DC.

In-stream large organic debris (LOD) characteristics were evaluated in unlogged and logged coastal watersheds. The input, storage and output components of LOD budgets, how these are altered in logged and torrented channels and how these changes influence the recovery of disturbed channels were all examined. In small and medium sized watersheds, all components of the LOD budget are altered after logging and debris torrenting. Initially, the size and abundance of debris staged to enter the stream systems are reduced. Reduction in material size leads to a shift in the orientation of debris stored within the channel zone. Consequently, the scouring and trapping functions of debris pieces are altered. A less complex morphology results, including reduced depth, width and sediment texture variability and diminished pool area. The smaller debris is less stable causing an increased tendency for the material to cluster into major debris jams; this jam stores large volumes of clastic sediment upstream and leads to reduced channel stability. Because logging and debris torrenting can affect streambank vegetation for long periods of time, it is possible that the resultant channel disturbances will not be reversed over forest management time scales. (Author's abstract)

Inoue, M., and S. Nakano. 1998. Effects of woody debris on the habitat of juvenile masu salmon (*Oncorhynchus masou*) in northern Japanese streams. Freshwater Biology 40:1-16.

The effects of woody debris on stream habitat of juvenile masu salmon (*Oncorhynchus masou*) were examined at two spatial scales, stream reach and channel unit, for first- to third-order tributaries of the Teshio River in northern Hokkaido, Japan. The 48 study reaches were classified into three distinct types: Coarse-substrate step-pool (CSP), coarse-substrate pool-riffle (CPR) and fine-substrate pool-riffle (FPR) reaches. Each reach type included reaches with different riparian settings, broadly classified as forest (relatively undisturbed forest and secondary forest after fires) or grassland (bamboo bushland and pasture). The reach-scale analyses showed that neither total pool volume nor pool-to-pool spacing was correlated with woody debris abundance in any of the three reach types. Masu salmon density was positively correlated with both woody-debris cover area and total cover area, but not with total pool volume in the reaches. Channel-unit-scale analyses revealed that woody debris reduced non-pool velocity, increased pool depth and retained fine sediment in pools in FPR reaches, where the size of woody debris was very large relative to the substrate material size. However, woody debris did not influence any of the hydraulic variables (depth, velocity, substrate) in either non-pools or pools of CSP and CPR reaches. Habitat use by masu salmon in non-pools or pools was affected by woody-debris cover area or total cover area rather than by hydraulic variables in any of the reach types. The overall results suggest that woody debris in the study area contributed to masu salmon habitat by providing cover at the smaller, microhabitat scale.

Keller, E. A., and T. Tally. 1979. Effects of large organic debris on channel form and fluvial processes in the coastal redwood environment. Pages 169-197 *in* Rhodes, D. D., and G. P. Williams, editors. Adjustments of the Fluvial System. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Large organic debris in streams flowing through old-growth redwood forest sin California significantly influence channel form and fluvial processes in small to intermediate size streams. The role of large organic debris is especially important in controlling the development of the long profile and in producing a diversity of channel morphologies and sediment storage sites. The residence times for the debris in the channel may exceed 200 years. The total debris loading along a particular reach represents a relation between rates of debris entering and leaving the reach. Loading is primarily a function of such interrelated variables as geology, valleyside slope, landslide activity, channel width, discharge, and upstream drainage area. Generally there is an inverse relationship between debris loading and stream size. Large organic debris in steep mountain streams may produce a stepped-bed profile where a large portion of the stream's potential energy loss for a particular reach is expended over short falls or cascades produced by the debris. Approximately 60% of the total drop in elevation over a several hundred meter second-order reach of Little Lost Man Creek is associated with large organic debris. The debris also provides numerous sites for sediment storage. Stored sediment covers up to about 40% of the entire area of the active channel in the study sections. The sediment storage sites or compartments provide an important buffer system that regulates the bedload discharge. The influence of large organic debris on channel form and process in low gradient stream reaches is less than in steeper channels. However, the debris still may affect development of pools and may help stabilize the channel banks. Root mats may armor banks and provide important fish habitats in the form of undercut banks. The stream channel of some low gradient reaches of Prairie Creek, California, may be quite stable. Lateral migration has only been one to two channel widths in the last several hundred years.

Lee, K. M. 1985. Resource partitioning and behavioral interactions among young-of-the-year salmonids, Chena River, Alaska. Master's thesis. University of Alaska, Fairbanks.

The partitioning of habitat and food and the behavioral interactions of young-of-the-year Arctic grayling (*Thymallus arcticus*), chinook salmon (*Oncorhynchus tshawytscha*), and round whitefish (*Prosopium cylindraceum*) were studied in the laboratory and in their natural habitat. Individuals of all three species defended territories. Arctic grayling were the most aggressive of the three and appear to displace round whitefish from their preferred habitat. In sympatry, these is a segregation of habitat use between Arctic grayling and chinook salmon. Stomach content analysis showed an overlap in diet among the three species. Larvae of the three species emerged at different times and sizes, resulting in a size divergence among coexisting species during their first summer. The three species were found to inhabit faster moving and deeper water as they grew, resulting in a spatial separation of the species and a reduced probability of interactions and competition among them. Juvenile chinook salmon readily utilized cover [LWD] when frightened; Arctic grayling and round whitefish did not.

Lisle, T. E., and M. B. Napolitano. 1998. Effects of recent logging on the main channel of North Fork Casper Creek. Pages 81-85 *in* Ziemer, R. R., editor. Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story, USDA Forest Service, Pacific Southwest Research Station, PSW-GTR-168.

The response of the mainstem channel of North Fork Caspar Creek to recent logging is examined by time trends in bed load yield, scour and fill at resurveyed cross sections, and the volume and fine-sediment content of pools. Companion papers report that recent logging has increase streamflow during the summer and moderate winter rainfall events, and blowdowns from buffer strips have contributed more large woody debris (LWD). Changes in bed load yield were not detected despite a strong correlation between total scour and fill and annual effective discharge, perhaps because changes in stormflows were modest. The strongest responses are an increase in sediment storage and pool volume, particularly in the downstream portion of the channel along a buffer zone, where LWD inputs are high. The association of high sediment storage and pool volume with large inputs of LWD is consistent with previous experiments in other watersheds. This suggests that improved habitat conditions after recent blowdowns will be followed in future decades by less favorable conditions as present LWD decays and input rates from depleted riparian sources in adjacent clearcuts and buffer zones decline.

Lister, D. B., and H. S. Genoe. 1970. Stream habitat utilization by cohabiting underyearlings of chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon in the Big Qualicum River, British Columbia. Journal of the Fisheries Research Board of Canada. 27:1215-1224.

This research paper reports the results of field research comparing the habitat distributions of juvenile coho and fall chinook salmon during the first three months of stream life in a river with stabilized flows in British Columbia. The smaller fry of both species occupied marginal areas in association with bank cover, particularly in back-eddies, behind fallen trees, undercut tree roots, and other well-protected areas. Both species preferred locations close to shelter, but adjacent to water of high velocity (40 cm/sec). The largest concentration of fish gradually shifted from marginal to midstream locations, with chinook preceding coho in the shift from margin to midstream. Chinook occupied higher velocity locations than coho, apparently because of their larger size at any given time.

Macdonald, A. and E. A. Keller. 1987. Stream channel response to the removal of large woody debris, Larry Damm Creek, Northwestern California. Pages 405-406 *in* Erosion and Sedimentation in the Pacific Rim. IAHS Publication No. 165. International Association of Hydrological Sciences, Washington, DC.

The removal of large woody debris (LWD) causes a channel form controlled by the remaining randomly distributed large roughness elements (LRE); these may be bends, exhumed or newly introduced woody debris, or bedrock outcrops. In Larry Damm Creek in California, the net result of removal of large woody debris (LWD) accumulations has been the evolution of the channel pattern towards a more 'alluvial' state, stabilized by bends at bedrock outcrops and woody-debris-defended banks. To examine the mechanisms by which LWD controls local energy expenditure ,and consequent patterns of water depth, velocity, and sediment storage, 70 cu m of LWD were removed from Larry Damm Creek, a third-order tributary in the Redwood Creek Watershed. The most notable effects of debris removal were (1) the local increase in water velocity through the vicinity of the debris jams at measured discharges as a result of displaced channel roughness and decreased sinuosity of the low flow thalweg, (2) approximately 100 cu m of sediment that was entrained solely from within the affected reach in the first year after debris removal, and (3) the creation or deepening of pools at bends above and below the two debris jams at the expense of numerous scour pools within the jam. A sediment routing model based on measured scour and fill was used to describe the movement of fine-grained, debris-stored sediment into new storage sites. Channel morphology has stabilized around the following LRE's: major bends in the channel above and below the former location of the debris jams, sediment deposits associated with these bends, and some of the original debris-stored sediment that was stabilized with vegetation prior to channel disturbance.

Maser, C., and J. R. Sedell. 1994. From the forest to the sea: the ecology of wood in streams, rivers, estuaries, and oceans. St. Lucie Press, Delray Beach, Florida.

This book provides a good nontechnical overview of the role and functions of wood in riverine, estuarine, and marine systems, and how humans have affected the roles and quantities of wood in those systems. Part One makes the case that the present situation is quite different from that found before European settlement of North America, and is largely a result of that settlement and the accompanying industrial activities. Chapters in Part Two, From the Forest to the Sea, discuss the sources, functions, and transport of wood along the stream order continuum, from headwaters to large rivers, to estuarine, beach, and open marine environments. The authors discuss the McKenzie, Columbia, and Willamette river systems as case studies, and provide insights into the roles of wood in the open ocean. Part Three, From the Sea to the Forest, follows the pattern of European settlement back upstream from the beaches to the upland forests, with concomitant reduction in woody debris. Historical records provide insights into the large volumes of wood initially at the mouths of large river systems, and removal and use of that wood to assist with construction, fuel needs, and increased navigation. As harvest turned more to live wood, streams and rivers were used as routes for log drives and splash dams were installed to create large enough flood flows to carry logs to mill or market. Each of these activities has left its mark on the abundance and functions of wood in these systems.

McFadden, T., M. Stallion, et al. 1976. Debris of the Chena River. U.S. Army Cold Regions Research and Engineering Laboratory, Technical Report.

Debris over a 44-mile stretch of the Chena River was studied. The study area extended from the first bridge on the Chena Hot Springs Road to the Chena River Flood Control damsite. The purpose of the study was to assess the potential danger to the Chena River Flood Control Dam outlet structure. Debris was catalogued, log jams were measured, and sources of debris were studied. The average size of logs was determined, as well as the number of logs present on the river. The authors concluded that a serious debris problem existed and would remain serious for the foreseeable future. Recommendations for debris handling were made.

Mchenry, M. L., E. Shott, R. H. Conrad, and G. B. Grette. 1998. Changes in the quantity and characteristics of large woody debris in streams of the Olympic Peninsula, Washington, U.S.A. (1982-1993). Canadian Journal of Fisheries and Aquatic Science 55:1395-1407.

The changes were assessed in large woody debris (LWD) abundance and composition at 28 sites in 27 low-gradient Olympic Peninsula streams between 1982 and 1993. The average number of pieces of debris was virtually identical in both years. A significant reduction was found in the total volume of LWD material in the stream sites surveyed. While the mean volume of second-growth derived LWD increased, the increase was insufficient to offset the loss of old-growth derived LWD. The mean volume of old-growth derived LWD for all sites decreased between sample years. The mean diameter of second-growth derived LWD was significantly larger in 1993 than in 1982, although still smaller than old-growth derived pieces. A significant increase was measured in the percentage of LWD pieces rated as highly decayed from 1982 to 1993. Results indicate that the loss of old-growth derived LWD following the removal of old growth riparian forests is initially very rapid, followed by a slower rate of depletion associated with watershed destabilization. Inputs of LWD from second-growth riparian forests up to 73 years old were characterized by small diameter, high mobility, and high decay rates.

Meehan, W. R., W. A. Farr, D. M. Bishop, and J. H. Patric. 1969. Some effects of clearcutting on salmon habitat in two southeast Alaska streams. Institute of Northern Forestry, Pacific Northwest Forest and Range Experiment Station. USDA Forest Service Research Paper PNW-82.

Evaluation of effect of clearcutting on streamflow, suspended sediment, stream temperature, log-debris jams, and indirectly on salmon populations, of two watersheds.

Montgomery, D. R., T. B. Abbe, J. M. Buffington, N. P. Peterson, K. M. Schmidt, and J. D. Stock. 1996. Distribution of bedrock and alluvial channels in forested mountain drainage basins. Nature 381:587-589.

Mountain river networks often consist of both bedrock and alluvial channels, the spatial distribution of which controls several fundamental geomorphological and ecological processes. The nature of river channels can influence the rates of river incision and landscape evolution, as well as the stream habitat characteristics affecting species abundance and aquatic ecosystem

structure. Studies of the factors controlling the distribution of bedrock and alluvial channels have hitherto been limited to anthropogenic badlands. Here we investigate the distribution of channel types in forested mountain drainage basins, and show that the occurrence of bedrock and alluvial channels can be described by a threshold model relating local sediment transport capacity to sediment supply. In addition, we find that valley-spanning log jams create alluvial channels--hospitable to aquatic life--in what would otherwise be bedrock reaches. The formation of such jams depends critically on the stabilizing presence of logs derived from the largest trees in the riverside forests, suggesting that management strategies that allow harvesting of such trees can have a devastating influence on alluvial habitats in mountain drainage basins.

Morsell, J.. 1999. Pogo Project fish and aquatic habitat baseline investigations. Annual Report, 1999 Study Program. Prepared for Teck Resources, Inc., Fairbanks.

The author describes the substrate, and water depth and velocity, characteristics of chinook salmon spawning redds in the Goodpaster River near the Pogo mine project area. Suitable habitats were scattered throughout the area, although redds were also seen to occur in clusters or singly in small "pocket" habitats. The latter were often located against the bank on an outside curve or associated with a topographic anomaly such as a scour pool downstream from a log.

Murphy, M. L. 1995. Forestry impacts on freshwater habitat of anadromous salmonids in the Pacific Northwest and Alaska--requirements for protection and restoration. NOAA Coastal Ocean Program Decision Analysis Series No. 7. NOAA Coastal Ocean Office, Silver Springs, MD.

This synthesis presents a science overview of the major forest management issues involved in the recovery of anadromous salmonids affected by timber harvest in the Pacific Northwest and Alaska. The issues involve the components of ecosystem-based watershed management and how best to implement them, including how to: Design buffer zones to protect fish habitat while enabling economic timber production; Implement effective Best Management Practices (BMPs) to prevent nonpoint-source pollution; Develop watershed-level procedures across property boundaries to prevent cumulative impacts; Develop restoration procedures to contribute to recovery of ecosystem processes; and Enlist support of private landowners in watershed planning, protection, and restoration. Buffer zones, BMPs, cumulative impact prevention, and restoration are essential elements of what must be a comprehensive approach to habitat protection and restoration applied at the watershed level within a larger context of resource concerns in the river basin, species status under the Endangered Species Act (ESA), and regional environmental and economic issues. This synthesis 1) reviews salmonid habitat requirements and potential effects of logging; 2) describes the technical foundation of forest practices and restoration; 3) analyzes current federal and non-federal forest practices; and 4) recommends required elements of comprehensive watershed management for recovery of anadromous salmonids.

Murphy, M. L., J. Heifetz, J. F. Thedinga, S. W. Johnson, and K V. Koski. 1989. Habitat utilization by juvenile Pacific salmon (*Oncorhynchus*) in the glacial Taku River, southeast Alaska. Canadian Journal of Fisheries and Aquatic Science 46:1677-1685.

This research paper reports the results of field studies conducted to determine juvenile salmon use of the lower Taku River in southeast Alaska during summer 1986. Sockeye, coho, and chinook salmon were present within the study area. Chinook salmon were predominantly age 0 (99%) and ranged from 40 to 93 mm FL. Seining was used to estimate fish density. Habitat was classified into two broad categories: river habitats -- main channels, backwaters, braids, channel edges, and sloughs within the active river; and off-channel habitats -- beaver ponds, terrace tributaries, tributary mouths, and upland sloughs on the valley floor.

Mean water velocity was lowest (0-5 cm/s) in sloughs, backwaters, tributary mouths, upland sloughs, and beaver ponds; intermediate (10-21 cm/s) in braids, channel edges, and terrace tributaries; and highest (102 cm/s) in main channels. Main channels, except for channel edges, were assumed too swift (mean, 102 cm/s) to contain rearing salmon. Mean depth ranged from 0.3 m in braids to 1.0 m in beaver ponds and 2.9 m in main channels. Typically, river habitats were turbid (means, 240-400 JTU), whereas off-channel habitats were clear or humic (means, 20-208 JTU). Water temperatures were 2-4°C higher in beaver ponds and upland sloughs than in channel edges, braids, and terrace tributaries.

The distribution of salmon was most closely related to water velocity, and turbidity had a secondary influence. Sockeye and coho densities were highest in still or slow water (<11 cm/s), whereas chinook density was highest in slow-to-moderate current (1 to 20 cm/s). All species were virtually absent from areas with currents greater than 30 cm/s. Differences in water velocity may have masked effects of turbidity. Chinook density was similar in areas of different turbidity.

In the active channel of the lower Taku River, substrate is mostly compacted gravel, sand, and mud, providing little cover from the turbulent flow, and the only suitable habitat occurs along the channel edge. Other studies have shown juvenile chinook salmon can inhabit areas with current as fast as 70 cm/s where coarse substrate (20-40 cm diameter) provided cover from the fast current.

Mean salmon density in the habitat types corresponded to water velocity but also differed between the river and off-channel areas. Chinook primarily were in river habitats with mean velocities of 3 to 15 cm/s, particularly sloughs and channel edges (means, 6-8 fish/100 m^2), and off-channel terrace tributaries and tributary mouths (means, 5-8 fish/100 m^2). Chinook were virtually absent from beaver ponds and upland sloughs (<1 fish/100 m^2).

Nakamoto, R. J. 1998. Effects of timber harvest on aquatic vertebrates and habitat in the North Fork Caspar Creek. Pages 87-96 *in* Ziemer, R. R., editor. Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story, USDA Forest Service, Pacific Southwest Research Station, PSW-GTR-168.

[The author] examined the relationships between timber harvest, creek habitat, and vertebrate populations in the North and South forks of Caspar Creek. Habitat inventories suggested pool availability increased after the onset of timber harvest activities. Increased large woody debris in the channel was associated with an increase in the frequency of blowdown in the riparian buffer zone. This increase in large woody debris volume increased the availability of pools. No dramatic changes in the abundance of young-of-the-year steelhead, yearling steelhead, coho, or Pacific giant salamanders were directly related to logging. High interannual variation in the abundance of aquatic vertebrates made it difficult to contrast changes in abundance between pre-logging and post-logging periods. Changes in channel morphology associated with increased volume of large woody debris in the channel suggest that yearling steelhead, coho, and Pacific giant salamanders may benefit from logging in the short-term because of increased living space. However, over a longer time scale these conditions will probably not persist (Lisle and Napolitano, these proceedings).

Nakamura, F., and F. J. Swanson. 1993. Effects of coarse woody debris on morphology and sediment storage of a mountain stream system in western Oregon. Earth Surface Processes and Landforms 18:43-61.

Effects of coarse woody debris (CWD) on channel morphology and sediment storage were investigated at five sites, representative of first-order to fifth-order streams. In the steep and bedrock-confined stream (first-second order), interaction between the channel and CWD was limited, except where breakage upon falling produced CWD pieces shorter than channel width. Channel widening, steepening and sediment storage associated with CWD were observed predominantly in third- to fifth-order streams. Variation in channel width and gradient was regulated by CWD. In the fifth-order stream, most of the CWD pieces derived from the riparian forest interacted directly with the channel without being suspended by sideslopes. In this system CWD promoted lateral channel migration, but sediment storage was temporary, with annual release and capture.

Napolitano, M. B. 1998. Persistence of historical logging impacts on channel form in mainstem North Fork Caspar Creek. Pages 97-102 *in* Ziemer, R. R., editor. Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story, Ukiah, CA. USDA Pacific Southwest Research Station, Forest Service, PSW-GTR-168

The old-growth redwood forest of North Fork Caspar Creek was clearcut logged between 1860 and 1904. Transportation of logs involved construction of a splash dam in the headwaters of North Fork Caspar Creek. Water stored behind the dam was released during large storms to enable log drives. Before log drives could be conducted, the stream channel had to be prepared by removing all obstructions, including large woody debris jams, from the channel. Comparison of present-day woody debris loading on North Fork Caspar Creek (24 kg m^{-2}) to physically similar streams in old-growth redwood basins (49 to 268 kg m^{-2}) suggests that wood-loading and stability were greatly diminished by historical logging activities and change to second-growth cover. These changes are important, as woody debris creates large-volume, long-term sediment storage sites and diverse aquatic habitat conditions. Although historical logging appears to have caused lasting channel changes, including channel incision, simplification of form, and reduction in sediment storage capability, the significance of habitat-related changes remains unclear.

Piegay, H. 1993. Nature, mass and preferential sites of coarse woody debris deposits in the lower Ain Valley (Mollon reach), France. Regulated Rivers: Research & Management 8:359-372.

Coarse woody debris (CWD) has been examined in a section of the Ain, a sixth order piedmont river with an actively meandering channel and a wooded floodplain. The spatial distribution of CWD, its mass and forms of accumulation are controlled by the hydrodynamics and the retention capacity of the forest. A typology shows the relative importance of woody debris in the mosaic of patches and the essential role of the ecotonal zones. The mass of debris varies from 0.001 t/ha to more than 200 t/ha, but is lower than those observed in certain American rivers. Most of the material is deposited in the margins and forms a narrow debris line. The restocking in woody debris is recent in Europe and tends to diversify the environment. This affects the researcher and the planner. The first considers this transit of material as a useful hydromorphodynamic and biodynamic tool which is easy to evaluate, and the second considers it as a restoring and regenerative vector, the ecological functions of which are recognized. Its effect is stronger today as the watershed area tends to be subjected to a decrease in agricultural activity.

Piegay, H., and A. M. Gurnell. 1997. Large woody debris and river geomorphological pattern: examples from S.E. France and S. England. Geomorphology 19:99-116.

The study of accumulations of dead wood within the fluvial environment has been mainly undertaken in mountain streams and rivers within the Northwestern United States, and particularly in hydrosystems which have experienced little riparian vegetation cutting or disturbance by man. Appraisals of the spatial variability in the physical character of accumulations of dead wood has mainly highlighted the volumes of large woody debris (LWD) accumulations and the local channel morphological properties induced by their presence. The spatial variability in the accumulation and processing of organic material forms one of the central concepts of the River Continuum Concept, which characterises the occurrence and processing of organic material, of which LWD is an important component, according to a longitudinal gradient along a river's course. Some studies have extended the concept by illustrating the importance of the lateral dimension, particularly in large rivers with extensive floodplains, and by relating the occurrence of dead wood to fluvial morphodynamics. However, to date there has been no synthesis of the relationship between LWD and the geomorphic pattern of the river channel.

Although the research literature shows that the routine clearance of wood from water courses is not an environmentally-sympathetic strategy, within Europe LWD accumulations are usually seen as a river management problem and are routinely cleared from river channels. This paper addresses these physical and applied aspects of the role of LWD. It presents an analysis based upon semi-natural hydrosystems in S.E. France and S. England. The forested corridors discussed are currently or have recently been maintained. They are essentially young and so produce relatively small amounts of woody debris in relatively small-sized individual pieces in comparison with the rivers studied in North America. Using observations from these example river corridors, the relationship between rivers of a particular size and geomorphic pattern and the dynamics of dead wood is described and evaluated. Major contrasts in the role of LWD are found between small, single thread rivers, and larger, piedmont, braided and wandering rivers. Some points of synthesis concerning the ecological, hydraulic and morphological impacts of dead wood are drawn from these examples, and are used as a basis for proposing some simple maintenance rules.

Richards, C., L. B. Johnson, and G. E. Host. 1996. Landscape-scale influences on stream habitats and biota. Conference Workshop on the Science and Management for Habitat Conservation and Restoration Strategies (HabCARES) in the Great Lakes, Kempenfelt, Barrie, ON (Canada). Canadian Journal of Fisheries and Aquatic Sciences 53(Supplement 1):295-311.

The relative influence of geologic versus anthropogenic attributes of catchments on stream ecosystems was examined in 45 catchments of a river basin in central Michigan. Each catchment was characterized by land use, surficial geology, elevation, and hydrography, and summaries of these data were related to physical habitat characteristics that had the greatest influence on macroinvertebrate assemblages. Partial redundancy analysis revealed that geologic and land-use variables had similar magnitudes of influence on stream habitats. Of the geologic variables, catchment area, proportion of lacustrine clays, and glacial outwash materials had the strongest influence on physical habitat, particularly on channel dimensions. Row-crop agriculture and the presence of wetlands were the most important land-use variables, particularly influencing amounts of woody debris. Stream buffers (100 m) were more important than whole catchment data for predicting sediment-related habitat variables; however, channel morphology was more strongly related to whole catchments. Results suggest that catchment-wide geology and land-use characteristics may be more important than stream buffers for maintaining or restoring stream ecosystems. These techniques can be used to develop biologic signatures of catchment condition that discriminate causal factors influencing the biodiversity and health of stream ecosystems.

Sedell, J. R. Undated. Report on salvage logging observations on the Chickamin and Unuk rivers, Misty Fiords National Monument, Tongass National Forest. USDA Forest Service Pacific Northwest Forest and Range Experiment Station, Forest Science Laboratory. Corvallis, Oregon.

This report documents observations on salvage logging effects on salmonid habitat made in the field in late July on the Unuk and Chickamin Rivers. Data from Alaska Department of Fish and Game has been examined and results summarized concerning fish utilization of habitats created by log jams, downed trees, and rootwads. Oblique air photos have been examined to attempt to determine the relative stability of downed trees versus root wads without boles. The results of the Chickamin and Unuk Rivers are related to other studies on rivers in the Pacific Coast region where large downed trees and fish habitat have been examined. An alternative to present salvage logging practices is presented.

Swanson, F.J., and G. W. Lienkaemper. 1978. Physical consequences of large organic debris in Pacific Northwest streams. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, General Technical Report PNW-69.

Large organic debris is a principal factor determining the biological and physical character of small and intermediate-sized streams in forested landscapes of the Pacific Northwest. Debris enters streams by blowdown, undercutting of streambeds, and mass movement processes on adjacent hillslopes. Water and sediment routing in channels is controlled by large debris which may create a stepped profile. Stream energy is thereby dissipated at the relatively short, steep sections of channel so that much of the stream area may have a gradient less than the overall gradient of the valley bottom. Debris in streams created habitat for aquatic organisms both by serving directly as a substrate and by modifying streamflow to form depositional areas. Large pieces of debris reside in streams for decades and even longer than a century. This long residence time results in a continuing concentration of debris in streams during the 100+ years of stand recovery following wildfire, except when debris torrents flush channels. Management activities directly alter debris loading by addition or removal of material and indirectly by increasing the probability of debris torrents and by removing standing streamside trees.

Ward, G. M., and N. G. Aumen. 1986. Woody debris as a source of fine particulate organic matter in coniferous forest stream ecosystems. Canadian Journal of Fisheries and Aquatic Sciences 43:1635-1642.

The potential contribution of woody debris to fine particulate organic matter pools (0.45 mu m less than or equal to FPOM < 1 mm) was investigated in a coniferous forest stream ecosystem in western Oregon. Studies of vertical distribution indicated that most fine wood is concentrated within 0.3 m of the stream bottom, while large wood is more evenly distributed up to 0.7 m. Lignin concentrations of large wood, soil, and FPOM were very similar. Erosion rates of wood surfaces ranged between 0.5 and 11 $mm \cdot yr^{-1}$ depending on decay state of the log. Using conservative estimates of processing rates, woody debris could be a source for approximately 90 $g \cdot m^{-2} \cdot yr^{-1}$ of FPOM.

Young, W. J. 1991. Flume study of the hydraulic effects of large woody debris in lowland rivers. Regulated Rivers: Research & Management 6:203-211.

As part of a study investigating the hydraulic effects of large woody debris (LWD) in lowland rivers, a series of small-scale experiments were conducted in a rectangular glass-walled recirculating flume. These experiments were undertaken to determine the order of magnitude of the increase in flood levels caused by LWD at different positions within a channel cross-section. Position variables considered in these experiments were height above bed, angle to flow direction, and separation distance in the direction of flow. This study was undertaken to quantify the hydraulic benefits (primarily reduced flood levels) gained by the removal of LWD from lowland rivers, which is a common practice in several countries. From an integrated river management perspective it is necessary to weigh any hydraulic benefits of LWD removal up against the environmental costs of faunal habitat, and possible geomorphic instability. The results of these experiments indicate the levels of LWD commonly occurring in the lowland rivers of southeastern Australia seldom cause any significant effect on flood levels. However, where LWD occur at channel constrictions, or where unusually high densities of LWD are present, the effect on flood levels will be significant.