Annotated Bibliography on the Ecology, Management, and Physical Effects of Large Woody Debris (LWD) in Stream Ecosystems

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PREFACE

This annotated bibliography focuses on large woody debris (LWD) and its interaction with stream ecosystems. Some references do not deal directly with stream systems, but were included by the author, as they were felt to be relevant.

Individuals looking for sources on nutrient cycling as it pertains to LWD will find this bibliography a good starting point, but a considerable body of work remains to be found in the library. To limit the scope of this bibliography, the author did not include many of these sources.

Whenever possible, sources were located and abstracts obtained from electronic databases (BIOSIS, ISI Web of Science). Sources older than 1985 were found using Biological Abstracts and through conventional "bootstrapping" methods.

All of the references in this bibliography can be found on the campus of the University of California, Berkeley scattered through the Doe (Main) library, Marian Koshland Biosciences and Natural Resources library , Earth Sciences and Map library, and the Kresge Engineering library.

References are listed by author with an associated number. The index is a list of general topics with number(s) corresponding to the source.

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1. Abbe, T. B. and D. R. Montgomery. 1996. Large woody debris jams, channel hydraulics and habitat formation in large rivers. Regulated Rivers: Research and Management 12: 210-221.

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 northwest 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 documents 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.

2. Adenlof, K. A. and E. E. Wohl. 1994. Controls on bedload movement in a Sub-Alpine Stream of the Colorado Rocky-Mountains, USA. Arctic and Alpine Research 26: 77-85.

East St. Louis Creek drains 8 km^2 of alpine and subalpine terrain in the Colorado Rocky Mountains. Mean annual peak discharges of approximately 0.6 $m^3 s^{-1}$ occur during the summer, when the majority of the sand- to cobble-size bedload is transported along the steep channel. Repeat sampling of depth, velocity, and suspended and bedload sediment at 12 cross sections indicated significant correlations between both suspended and bedload sediment movement, and discharge, although sediment movement was highly variable at equivalent discharges. Correlations between sediment movement and velocity were not significant. Sediment entrainment relations suggest that present peak flows generate bed shear stress values close to critical threshold values for the D84 of the bed-surface layer. The majority of the sampled bedload was finer grained than the bed sediments. This may be explained by the presence of either a censored layer (which does not require mobilization of the coarse fabric), or a pavement, from which only a few coarse particles are entrained at any instant. It is hypothesized that East St. Louis Creek has a pavement. The lack of correlation between shear stress values and sediment movement indicates either that the use of hydraulic variables averaged across the entire cross section is insufficient to differentiate incipient motion, or that cross-sectional flow characteristics are not as important as reach-scale controls on sediment movement. Bedload appears to come primarily from valley-bottom and in-channel sources, particularly when the bed is disturbed by the movement of woody debris. Woody debris in the channel traps and stores bedload and acts as a major local control on temporal and spatial patterns of bedload movement.

3. Allen, R. B., P. W. Clinton, and M. R. Davis. 1997. Cation storage and availability along a Nothofagus forest development sequence in New Zealand. Canadian Journal of Forest Research 27: 323-330.

Soil cations and pH were determined in relation to the development of even-aged (10, 25, 120, and > 150-year-old stands) mountain beech (*Nothofagus solandri* var. cliffortioides (Hook.f.) Poole) forest after catastrophic canopy disturbance. Live stem biomass varied from 1 to 273 Mg/ha between the seedling (10 years) and pole (120 years) stages, respectively, but was less in the mature stage (> 1 50 years; 245 Mg/ha). Coarse woody debris mass declined monotonically from 168.7 Mg/ha in the seedling stage to 23.7 Mg/ha in the mature stage. Total cation (Ca, Mg, and K) storage in wood (live stem biomass plus coarse woody debris) was highest in the pole stage and least in the sapling stage (25 years) because sapling stands had low stem biomass and only intermediate levels of woody debris. This matched high soil cation availability in the sapling stage and low availability in the pole stage. Between these stages soil pH declined and inorganic monomeric aluminum increased. The seedling and mature stages often had intermediate levels of soil-available cations and pH. This study does not support the hypothesis that sequestering of cations in aggrading biomass necessarily results in a monotonic decline in soil cation availability as forests develop; instead mountain beech exhibits a bimodal pattern for soil cations. The reciprocal oscillation of nutrients between living wood, deadwood, and the soil contributes in a major way to these patterns.

4. Amaranthus, M., J. M. Trappe, L. Bednar, and D. Arthur. 1994. Hypogeous fungal production in mature Douglas-fir forest fragments and surrounding plantations and its relation to coarse woody debris and animal mycophagy. Canadian Journal of Forest Research 24: 2157-2165.

Production of hypogeous fungi (truffles) in high-elevation, 180-year-old mature forest fragments of *Pseudotsuga menziesii* (Mirb.) Franco was compared with surrounding regenerated clearcuts ranging from 4 to 27 years since harvest at two study areas. Thirty pairs of plots, one of each pair in soil, the other in brown-cubical-rotted coarse woody debris (CWD), were searched for truffles in each stand during four periods; August and November 1990, and February and May 1991. Overall analysis of presence/absence of truffles using log-linear models revealed that CWD and mature forest status of stands each significantly influence truffle occurrence. Mature forest fragments had greater percent frequency of occurrence and truffle number and dry weight than did plantations. Truffle numbers and dry weight were 30 and 20 times greater, respectively, in mature forests than in plantations. The plantations did not differ significantly among each other for any parameter. CWD yielded higher numbers and biomass of truffles than soil in the mature forest, but production in plantations did not differ between substrates. The total dry weight of truffles in CWD exceeded that in soil by more than 10 times in mature forests. Of 21 truffle species found, 13 were only in the mature forest and 8 only under coarse woody debris. Forest practices that emphasize the retention of mature trees and coarse woody debris promote the abundance and diversity of truffles, which are integral and functionally important members of forest ecosystems.

5. Andrus, C. W., B. A. Long, and H. A. Froehlich. 1988. Woody debris and its contribution to pool formation in a coastal stream 50 years after logging. Canadian Journal of Fisheries and Aquatic Management 45: 2080-2086.

Large quantities of woody debris persisted 50 yr after logging and fire in stream channels of a small coastal Oregon watershed. Debris from the current stand represented only 14% of total debris volume and 8% of debris volume responsible for creating pools. Study results indicate that riparian trees must be left to grow longer than 50 yr to ensure that an adequate, long-term supply of woody debris is available to stream channels. Debris from previous stands plays a crucial role in the interim and should not be removed from stream channels.

6. Angermeier, P. L. and J. R. Karr. 1984. Relationships between woody debris and fish habitat in a small warmwater stream. Transactions of the American Fisheries Society 113: 716-726.

Abundance of woods debris was manipulated in a small Illinois [USA] stream to determine the importance of this material to fish. When a stream reach was divided along midchannel, and debris was added to one side, but removed from the other, fish and benthic invertebrates were usually more abundant on the side with woody debris than on the cleared side. In further experiments during a low-flow year (1980), debris removal was followed by rapid decreases in water depth and occurrence of benthic organic litter, and increases in current velocity and proportion of sand bottom. These changes were less apparent in unaltered reaches during 1980, and in all reaches during 1981, which was a high-flow year. Artificial debris was colonized by many invertebrates, including chironomids, trichopterans and ephemeropterans. Most large fish (age 2+) avoided reaches without debris; some smaller fish (such as johnny darter) preferred them; preferences for reach treatments were stronger in 1980 than in 1981. The adaptive significance of associations between fish and woody debris appeared more closely related to the advantages of camouflage than those of increased food availability or protection from strong currents. Extensive removal of woody debris may disrupt structure and function in small streams, especially low-gradient ones. If the biological integrity of stream resources is to be maintained despite agricultural and urban uses, less disruptive management protocols will need to be employed.

7. Assani, A. A. and F. Petit. 1995. Log-jam effects on bed-load mobility from experiments conducted in a small gravel-bed forest ditch. Catena 25: 117-126.

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(Di/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).

8. Aumen, N. G., C. P. Hawkins, and S. V. Gregory. 1990. Influence of woody debris on nutrient retention in catastrophically disturbed streams. Hydrobiologia 190: 183-192.

The role of woody debris in nutrient cycling was investigated in two catastrophically disturbed streams in the Pacific Northwest that had been subjected to large inputs of wood. One study site in each catchment had all woody debris removed (take section), while the debris in the other study site was left intact (leave section). Nitrate, phosphate and chloride (a conservative tracer) were released in each section and nutrient retention was monitored at downstream stations. Phosphate was removed from solution more than nitrate, probably due to the high N:P ratio in the stream water. However, there were no major differences in nutrient retention between the take and leave sections. In contrast, experiments in recirculating chambers showed that woody debris and cobbles exhibited higher nitrate and phosphate uptake per unit surface area than sand/gravel or fine particulate organic matter. The high uptake rates of woody debris and cobbles may be related to their suitability for colonization by heterotrophic microorganisms and algae. Wood may not influence nutrient retention significantly at the reach level because of its low surface area relative to other substrates. However, wood may be very important at small spatial scales because of its high uptake activity.

9. Baillie, B. R., T. L. Cummins, and M. O. Kimberley. 1999. Measuring woody debris in the small streams of New Zealand's pine plantations. New Zealand Journal of Marine and Freshwater Research 33: 87-97.

To assess the impact of harvesting on woody debris volumes in streams, a method was required with sufficient precision to provide meaningful evaluation and comparison of pre- and post- harvest levels of woody debris. Before harvest, woody debris volumes were measured in 24 first- to third-order stream sites in New Zealand's mature pine plantations (22-34 years of age). An adaptation of the Van Wagner line intersect method was used to measure the small woody debris 1-9 cm in diameter (SWD). All large woody debris greater than or equal to 10 cm in diameter (LWD) was measured for diameter and length. Woody debris volumes in the stream channel ranged from 2 to 345 m^3 ha^{-1}, averaging 112 m^3 ha^{-1} (±34, 95% confidence interval (CI). Woody debris surface areas averaged 2883 m^2 ha^{-1} (±688), range 220-6769 m^2 ha^{-1}. Most of the woody debris volume (87%) was composed of LWD. Sixty-seven percent of the woody debris volume was located above the stream, the remainder was lying in-stream or on the floodplain. Woody debris volumes in streams of mature pine plantations in New Zealand were similar to woody debris volumes in streams of temperate native forests in New Zealand and North America. These sites will be remeasured after harvest to identify any changes in woody debris characteristics.

10. Battaglia, L. L., R. R. Sharitz, and P. R. Minchin. 1999. Patterns of seedling and overstory composition along a gradient of hurricane disturbance in an old-growth bottomland hardwood community. Canadian Journal of Forest Research 29: 144-156.

Disturbance patterns and species composition in the seedling and canopy layers were examined across the range of post-hurricane damage in an old-growth bottomland hardwood forest. Canopy coverage, tip-up number and area, snags, and coarse woody debris were quantified in plots along randomly oriented transects established in bottomland hardwood stands and mixed *Pinus taeda* L. bottomland hardwood stands. Wilcoxon rank sum tests of these individual disturbance features indicated greater disturbance in plots containing the early successional species, *Pinus taeda*, than in mixed bottomland plots without it. Principal components analysis (PCA) using these features illustrated much overlap between the two assemblages and suggested a continuum of canopy and soil disturbance conditions from windthrows along axis I and a continuum of canopy disturbance due to snag formation along axis II. Woody seedlings and trees were inventoried in 30 plots spanning the range of disturbance. Seedling species richness exhibited a rank order increase along axis I. Floristic trends in both seedling and tree layers were significantly correlated with disturbance represented by PCA axis I scores. Removal from the canopy and lack of successful recruitment of *Pinus taeda*, a former canopy dominant, suggest that the hurricane has shifted this old-growth floodplain forest to a different successional state.

11. Beaty, K. G. 1994. Sediment transport in a small stream following two successive forest fires. Canadian Journal of Fisheries and Aquatic Sciences 51: 2723-2733.

The transport of stream bedload sediment was monitored continuously in a small stream from 1975 to 1982 following forest fires in 1974 and 1980. The stream is located in the east subcatchment (170 ha) of Lake 239 in the Experimental Lakes Area, northwestern Ontario. Precipitation, stream discharge, bedload transport, and concentration of suspended materials were measured quantitatively and organic debris was observed and collected. Bedload transport increased 20-fold following the first fire and threefold after the second. Particle sizes tended to increase during the period of study. Bedload data suggest a recovery period of 5-6 yr following the first fire and a shorter one following the second. A mass budget of material load transported in a single year following recovery indicated a dominance of dissolved load (87%), followed by suspended load (10%), and bedload (3%).

12. Beechie, T. J. and T. H. Sibley. 1997. Relationships between channel characteristics, woody debris, and fish habitat in northwestern Washington streams. Transactions of the American Fisheries Society 126: 217-229.

Relationships between large woody debris (LWD) and pool area or pool spacing varied with channel slope and channel width for streams in second-growth forests in northwest Washington. Pool spacing (expressed as the number of channel widths between pools) decreased as number of woody debris increased in both moderate-slope ($0.02 < \text{slope} < 0.05$) and low-slope ($0.001 < \text{slope}$ less than or equal to 0.02) channels, but the relationship was stronger in moderate-slope channels. Percent pool was also more strongly correlated with woody debris volume in moderate-slope channels than in low-slope channels. Multiple-regression analyses showed that pool spacing and percent pool were correlated with an interaction term between LWD abundance and channel slope, suggesting that the influence of LWD on pool formation changes with channel slope.

Analysis of pool-forming mechanisms indicated that low-slope channels are less sensitive to LWD abundance because pools are formed by mechanisms other than LWD when LWD abundance is low. Size of LWD that formed pools increased with increasing channel width, but was not related to channel slope. Percent gravel (proportion of the bed in patches of gravel 16-64 mm in diameter) was best explained by channel slope and channel width, and there was no significant relationship between woody debris and percent gravel. A regression between median particle size of sediment on the stream bed and basal shear stress showed that the relationships among percent gravel, channel width, and channel slope are adequately explained by the channel's capacity to transport particles of various sizes.

13. Benke, A. C. and J. B. Wallace. 1990. Wood dynamics in coastal plain blackwater streams. Canadian Journal of Fisheries and Aquatic Sciences 47: 92-99.

We quantified woody debris in the river swamps of the sixth order Ogeechee River and several smaller tributaries in the Coastal Plain of the southeastern USA, compared swamp wood with woody debris in the channel, and studied wood movement in the swamp and main channel over 20 mo. Woody debris in the Ogeechee River swamps was relatively low (0.362-0.880 kg ash-free dry mass (AFDM)/m^2) in comparison to several mixed temperate deciduous forests. Similarly, wood in the tributary swamps was low (mean = 0.82 kg AFDM/m^2) and there were no trends along the river continuum. Wood in the channels of both the Ogeechee (6.46 kg AFDM/m^2) and a fourth order tributary (2.24 kg AFDM/m^2) were significantly higher than found in their adjacent floodplains. Woody debris appeared to increase in stream channels from smaller tributaries to the sixth order river, opposite of that observed in other river systems. Tagging of logs showed that only 17% of wood in the Ogeechee channel had moved after 3 major floods, much less than in the swamps (21-84%). The abundance and stability of woody debris in the main channel allows it to be a major habitat type and source of food for both riverine invertebrates and fishes. The fate of most swamp wood appears to be decomposition and fragmentation, rather than import to the river channel.

14. Berg, N., A. Carlson, and D. Azuma. 1998. Function and dynamics of woody debris in stream reaches in the central Sierra Nevada, California. Canadian Journal of Fisheries and Aquatic Sciences 55: 1807-1820.

In 1993, we located, measured, and tagged almost 1700 woody debris pieces on six streams in California's central Sierra Nevada. The stability, geomorphic function, and use by fish for cover of each piece were recorded. In 1994 and 1995, piece movement was quantified and new debris pieces were measured. In the 60 study reaches, debris was not influential in shaping channel morphology and fish cover. Although woody debris was often associated with habitat units, few pieces deflected flow or contributed to the formation of pools or steps. Fish used deep water as cover more often than debris or any other cover type. Medium-sized debris was, however, used in a greater proportion than its availability to fish. Little sediment was stored by debris, and five large pieces stored 85% of the sediment volume measured. Debris frequency and volume did not differ significantly by channel type. After a low stream flow year (1993-1994), few pieces had moved and few new pieces were identified. After a high-flow season (1994-1995), 31% of the pieces had either moved or were not found and new pieces represented over 5% of the originally surveyed volume of wood.

15. Beschta, R. L. 1979. Debris removal and its effects on sedimentation in an Oregon Coast Range stream. Northwest Science 53: 71-77.

The removal of large organic debris obstructing anadromous fish passage in a Coast Range steam in Oregon accelerated downcutting of previously stored sediments. As a result, turbidity and suspended sediment levels increased during several storms after debris removal. Streamflow eroded more than 5,000 m^3 of sediment along a 250 m reach the first winter after debris removal. Therefore, fisheries managers who want to remove debris jams from streams must consider the stored sediments that will be scoured from the stream beds and deposited downstream.

16. 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 form a 175 m stretch of a second-order stream of 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 um) increased 18%. Fine particulate organic carbon (0.50 µm-1 mm) export increased 632% and coarse particulate organic matter (>1 mm) export increased 138%.
Measurement of the standing stock of coarse particulate organic 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 organic matter 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 downstream in a coarse particulate form.

17. Bilby, R. E. 1981. Role of organic debris dams in regulating the export of dissolved organic and particulate matter from a forested watershed. Ecology 62: 1234-1243.

An organic debris dam is an accumulation of organic matter in a stream which constricts water flow. Debris dams trap sediments in the pool formed upstream from them and the dam structure itself collects particulate organic matter.
This study was done at the Hubbard Brook experimental Forest, in New Hampshire, to examine the relative importance of these structures in retention of sediment and organic matter in a small stream ecosystem. An experimental approach was used in which all organic debris dams were removed from a 175m section of second-order stream, just above a gauging weir. The material being exported form the watershed was separated into three six categories: dissolved matter (<0.5 m), fine particulate matter (0.5m to 1 mm), and coarse particulate matter (> 1 mm). Export of each size fraction was monitored for at least 1 year prior to dam removal, and for 1 year following removal.
Following dam removal, export of dissolved matter increased slightly due to in increase in the concentration of dissolved organic carbon in the stream water during periods of high discharge. Fine particulate matter export increased dramatically at high discharges following dam removal; concentration in some instances achieved values five times higher than any observed before dam removal. Coarse particulate matter export also was greatly increased.
Calculating dissolved matter and particulate matter export form the watershed, with and without organic debris dams, showed that dam removal brought about a 6% increase in

the export of dissolved matter and 500 % increase in the export of both fine and particulate and coarse particulate matter.

18. Bilby, R. E. 1984. Removal of woody debris may affect stream channel stability. Journal of Forestry 82: 609-613.

Several western states mandate the removal of logging debris from streams in order to prevent accumulations impassable to anadromous fish. Monitoring a small western Washington stream revealed large changed in channel structure during the first high flow after cleaning. Nearly 60 percent of the monitored pieces of debris moved during this storm, channel cross sections were substantially altered by movement of stored sediment, and the number, area, and volume of pools decreased. The degree of channel rearrangement was greater than in a comparable undisturbed stream. Subsequent storms caused much less debris movement and channel change than the first high flow, even though some of the later flows were of greater magnitude. An interim guide to stream cleaning is prescribed.

19. Bilby, R. E. and J. W. Ward. 1989. Changes in characteristics and function of woody debris with increasing size of streams in western Washington. Transactions of the American Fisheries Society 118: 368-378.

In second-to-fifth order streams that drain old growth timber in western Washington, characteristics and function of woody debris changed in relation to stream size. Average diameter, length, and volume of pieces of wood increased as stream size increased, whereas the frequency of occurrence of woody debris decreased. In streams with channel widths less than 7 m, 40% of the pieces of debris were oriented perpendicularly to the axis of flow; in streams with channel widths over 7 m, more than 40% of the pieces were oriented downstream. The types of pools most commonly associated with pieces of wood changed from plunge pools in small streams (42%) to debris scour pools in larger systems (62%). Pool area was correlated with the volume of the piece of wood forming the pool in streams of all sizes. However, this relationship was most evident in larger channels. Nearly 40% of the pieces of wood in channels less than 7m wide were associated with sediment accumulations. Less than 30% of the pieces retained sediment in channels from 7 to 10m wide, and less than 20% retained sediment in channels greater than 10m wide. Surface area of sediment accumulations and the volume of the piece of wood forming the accumulation were related in all streams, but the relationship was clearest in the larger channels. Accumulations of particulate organic matter associated with woody debris were more frequent in small streams but were larger in large streams. No relationship was observed between the volume of fine particulate organic matter accumulated by a piece of wood and the piece of wood's volume.

20. Bilby, R. E. and J. W. Ward. 1991. Characteristics and function of large woody debris in streams draining old-growth, clear-cut, and second-growth forests in southwestern Washington. Canadian Journal of Fisheries and Aquatic Sciences 48: 2499-2508.

Amount of large woody debris (LWD) surveyed in 70 stream reaches flowing through old-growth, clear-cut, and second-growth forests decreased with increasing stream size for all stand types but was greatest at old-growth sites. Average piece volume was larger at old-growth sites than at other stand types in streams > 10 m wide, but no differences were seen in smaller streams. Scour pools accounted for 90% of the wood-associated pools at second-growth and clear-cut sites but only 50% at old-growth sites, which contained more pools than other stand types, particularly for larger streams. Pool size was

similar for all stand types in smaller streams, but averaged 10 m^2 in streams > 10 m wide at old-growth sites and 4 m^2 for other stand types. Pool size was similar for all stand types in smaller streams. Sediments and fine organic matter retained by woody debris decreased with increasing stream size for all stand types, but old-growth sites contained greater amounts of both materials than other stand types. The frequency of pool formation, the type of pool formed, and sediment accumulations were influenced by the amount of fine debris associated with LWD. Changes in LWD amount, characteristics, and function occurred very rapidly following removal of streamside vegetation.

21. Bilby, R. E. and P. A. Bisson. 1998. Functioning and distribution of large woody debris. In River Ecology and Management. Naiman R.J. and R. E. Bilby (Eds). New York, Springer**:** 324-346.

Wood is a more abundant in streams in the Pacific coastal ecoregion than in streams anywhere else in North America. Abundance of large woody debris (LWD) decreases with increasing channel size. Size of large woody debris pieces increases with channel size.

Input of large wood in stream channels occurs as a result of chronic bank cutting windthrow, and stem suppression. Catastrophic occurrences, such as debris torrents, floods, and fires, can deposit large quantities of wood in channels in short periods of time.

Large woody debris is removed from stream channels by leaching, microbial decomposition, fragementation by invertebrates, physical fragementation, and downstream transport. The relative importance of these processes varies with stream size.

Large woody debris is a primary determinant of channel form in small streams, creating pools and waterfalls and affecting channel width and depth. Wood has less effect on channel form in larger streams.

The presence of large woody debris facilitates deposition of sediment and accumulation of finer organic matter. Dramatic increases in sediment and organic matter export occur immediately following removal or disturbance of LWD.

Particulate organic matter accumulated by large woody debris is an important food source for stream dwelling invertebrates. Addition of wood to channels causes increased abundance of macroinvertebrates and changes species composition.

Pools formed by large woody debris in streams are an important habitat for many species of stream fishes. Fish also use large woody debris as a source of cover.

Sediment accumulated by woody debris provides a substrate for establishment of early successional plant species. Large woody debris in riparian areas provides an important germination site for several conifer species.

The quantity of woody debris in channels in the Pacific coastal ecoregion has decreased over time as a result of various land use practices including removal of wood for navigation and fish passage, splash damming, and clearing of riparian trees.

22. Birkeland, G. H. 1996. Riparian vegetation and sandbar morphology along the lower Little Colorado River, Arizona. Physical Geography 17: 534-553.

The distribution of riparian vegetation in relation to channel morphology is poorly understood in canyon rivers, which are characterized by in-channel fluvial sediment deposits rather than flood plains. This study focuses on vegetation and sandbar characteristics in two reaches of the lower Little Colorado River canyon in Arizona-one reach with ephemeral flow from the watershed, and another with perennial baseflow from a spring. Both reaches have been colonized by the exotic *Tamarix chinensis*, a riparian species known for its geomorphic influence on river channels. On the basis of a sampling of 18 bars, results show that vegetation frequency and density is significantly greater in

the perennial study reach. However, sandbar morphology variables do not differ between reaches, despite a significantly narrower and deeper ephemeral channel. Hydraulic calculations of flood depths and Pearson correlations between bar and vegetation variables indicate reach-specific bio-geomorphic relationships. In the ephemeral reach, higher bars are less affected by flood inundation, support older vegetation, and may be more stable habitat for vegetation. In the wider perennial reach where bars are lower and more expansive, vegetation patterns relate to bar size, Tamarix being most common on the largest bars. Overall results suggest that (1) vegetation variation relates to baseflow hydrology, (2) bar formation relates to high discharge events, and (3) vegetation patterns respond to, rather than influence, sandbar form in this canyon riparian system.

23. Bisson, P. A., R. E. Bilby, M. D. Bryant, C. A. Dollof, G. B. Grette, R. A. House, M. L. Murphy, K. V. Koski, and J. R. Sedell. 1987. Large woody debris in forested streams in the Pacific Northwest: past, present, and future. In Streamside Management: Forestry and Fishery Interactions. E. O. Salo and T. W. Cundy (Eds). Seattle, Washington, University of Washington, Institute of Forest Resources**:** 143-190.

This paper reviews the form, function, and management of woody debris in streams, and reaches three major conclusions: (1) Large woody debris enhances the quality of fish habitat in all sizes of stream, (2) Removal of most trees in the riparian zone during logging, combined with thorough stream cleaning and short-rotation timber harvest, has altered the sources, delivery mechanisms, and redistribution of debris in drainage systems, leading to changes in fish population abundance and species composition, (3) there is an urgent need for controlled field experiments and long-term studies that focus on the protection of existing large woody debris in steam channels and the recruitment of new debris for the surrounding forest.

Woody debris has long been considered a potential source of logjams that could block river navigation, water based log transport, and the upstream passage of salmon and trout on their way to spawning grounds, but it is now understood to play an important role in the creation and maintenance of fish habitat throughout entire rivers. Although wood itself eventually enters the food web of the stream ecosystem as it gradually decays, the major importance of debris lies in its structural characteristics and the way these features influence channel hydraulics. Physical processes associated with debris in steams include the formation of pools and other important rearing areas, control of sediment and organic matter storage, and modification of water quality. Biological properties of debris created structures can include blockages to fish migration, provision of cover from predators and form high streamflow, and maintenance of organic matter processing sites within the benthic community. The location and principal roles of woody debris change throughout the river system. In steep headwater streams where logs span the channel, debris creates a stepped longitudinal profile that governs the storage and release of sediment and detritus, a function that facilitates the biological processing of organic inputs from the surrounding forest. When the stream channel becomes too wide for spanning by large logs, debris is deposited along the channel margins, where it often forms the most productive fish habitat in main-stem rivers. In all but the smallest streams there is some degree of clumping, although the size and spacing of debris clumps generally increase in a downstream direction. Debris related fish habitat can be found anywhere in small forested streams. In large rivers it is primarily associated with debris accumulation along the margins and secondary channel systems of the floodplain, although is also occurs behind and under very large pieces (intact boles and root wads) along main-stem gravel bars.

Changes in tree species composition, abundance, and input rates to streams resulting from forest management practices have differed according to location in the watershed, and many physical and biological processes have been altered by these changes in the river

system's debris load. Several questions have not been full explored, particularly with regard to the long term consequences of streamside management for debris recruitment. Yet the majority of studies of streams in second-growth forests have demonstrated that the input of large, potentially stable debris from second-growth stands in which nearly all large merchantable trees had been harvested was significantly reduced relative to debris inputs form old-growth stands. Other studies have shown that loss of large debris has led to a shift in stream habitat composition that favored underyearling steelhead (*Salmo gairdneri*) and cutthroat trout (*S. clarki*) at the expense of the older tout age classes as well as both underyearling and yearling coho salmon (*Oncorhynchus kisutch*). Loss of debris has also reduced overwinter survival of all species. In order to develop procedures that will protect existing instream debris, as well as provide a continued supply of the proper quantity and quality of large woody debris for the future, it will be necessary to test scientifically a variety of management options over a wide range of stream sizes. Many management procedures have been proposed, including techniques for removing slash from stream channel after logging, determining the configuration of buffer strips, selective harvesting within the streamside management zone, and deliberately adding debris to streams for habitat enhancement. Evaluation of these proposals will require a great deal of time and effort, as well as the cooperation of many resource management organizations. However, long-term research is essential in view of the complexity of debris management issues.

24. Bjornn, T. C., S. C. Kirking, and W. R. Meehan. 1991. Relation of cover alterations to the summer standing crop of young salmonids in small southeast Alaska streams. Transactions of the American Fisheries Society 120: 562-570.

Summer abundance of young coho salmon *Oncorhynchus kisutch*, steelhead *O. mykiss*, and Dolly Varden *Salvelinus malma* was assessed in small streams on Prince of Wales Island, Alaska, in an attempt to measure the response of these fish to various types of cover alterations. The standing crop of subyearlings decreased during summer, but none of the decrease could be attributed to the changes in cover we made. Subyearling coho salmon (about 75% of the fish present) did not respond either to the removal of natural riparian vegetation or to the addition of simulated riparian canopy, large boulders, woody debris, or simulated undercut banks. Localized movements within the streams were sufficient to provide relatively rapid recolonization of the experimental habitat units. The forms of cover we evaluated were relatively unimportant in regulating abundance of young coho salmon in small streams.

25. Boehne, P. L. and J. R. Wolfe, Jr. 1986. Use of explosives to add large organic debris to streams. North American Journal of Fisheries Management 6: 599-600.

Large conifers were felled by gel dynamite to increase the number of large organic debris pieces in an Oregon Cascade Mountain stream. Dynamited root masses generally consisted of one to six large roots extending about 25-75 cm from the tree base. This technique appears to be useful for stream enhancement where heavy equipment access is not possible and large conifer "blowdowns" are desired.

26. Boulton, A. J. and L. N. Lloyd. 1991. Macroinvertebrate assemblages in floodplain habitats of the lower River Murray, South Australia. Regulated Rivers: Research and Management 6: 183-202.

Macroinvertebrates were sampled in seven microhabitats (submerged woody debris, reeds, sedges, inundated grass, floating aquatic vegetation, lignum, and the unvegetated littoral) at thirteen sites representing six macrohabitats (single temporary and permanent ox-bow lakes (billabongs), fast and slow-flowing anabranches, backwaters, and the main channel) of the River Murray, and Australian lowland river. Sites were sampled in spring 1988, shortly after floodwaters had receded. Most of the 95 taxa collected were aquatic insects. Detritivores were most abundant in all macrohabitats except the temporary billabong where predators predominated. Scrapers were only abundant in the permanent billabong. The temporary billabong harbored the most species and individuals whereas slowly-flowing anabranches contained the fewest species and individuals. At the macrohabitat level, most taxa and individuals occurred in stands of aquatic vegetation. The unvegetated littoral zone was the most depauperate microhabitat. Multivariate analyses illustrated the distinctiveness of the faunal assemblage found in the temporary billabong. Subsequent analyses of the permanently inundated macrohabitats indicated gradients related to current velocity and the extent to which the sites were continuous with the main river. Current velocity apparently determined assemblage composition at the macrohabitat scale whereas the structural complexity of submerged vegetation operated at the microhabitat scale. The relatively large number of taxa collected from this area emphasizes the importance of a range of macrohabitats and microhabitats to faunal diversity in a floodplain ecosystem. Although there was little faunal overlap between billabongs and the main river, billabongs probably serve as refuges for many lentic taxa that rely upon regular inundation to survive. Surveys of floodplain rivers for management purposes must include samples from aquatic habitats adjacent to the main channel because the fauna of the floodplain is potentially most threatened by regulation and alteration of the flooding regime.

27. Boussu, M. F. 1954. Relationship between trout populations and cover on a small stream. Journal of Wildlife Management 18: 229-239.

The preference of trout for stream areas with protective cover has been recognized for a long time. In England, For example, establishment of artificial "lies," which act as shelter for trout, has been practiced for many years. Greeley (1936), Tarzwell (1937, 1938), and Shetter, Clark, and Hazzard (1946) are among those who have investigated the influence of cover on trout in this country. Their studies have shown that stream improvement, including artificial cover, can lead to an increase in number and size of trout in a given section of stream. Physical improvements used on streams often incorporate shelters along with deflectors, low dams, and other structures. While there is considerable information on the overall effect of stream improvement, little quantitative data have been presented on the extent to which various types of cover affect trout populations. The present study is concerned with the relation between trout populations and (1) the various kinds of natural cover in a small stream, (2) the effect of partial or complete removal of natural cover, and (3) the application of artificial cover to areas naturally devoid of such protection.

28. Bragg, D. C. 1997. Simulating catastrophic disturbance effects on coarse woody debris production and delivery. USDA Forest Service, General Technical Report, INT-373.

For decades, coarse woody debris (CWD) recruitment has remained a largely unknown component of riparian zone management. The integration of the Forest Vegetation Simulator (FVS) and a mechanistic CWD recruitment post-processor (CWD) provided insights into some of the factors involved in CWD delivery through the comparison of two simulated catastrophic disturbances (a spruce beetle outbreak and a clearcut) and an unmanipulated old-growth control. Compared to the old-growth control, spruce beetle impacted riparian forests varied the timing and increased the overall delivery of CWD, while the clearcut reduced delivery and instream loads for many years. This exercise also suggested that natural catastrophic disturbance in riparian forests may bolster CWD recruitment, a process that could prove beneficial in the recovery of CWD depauperate streams. Bragg, D. C. 1997. Simulating catastrophic disturbance effects on coarse woody debris production and delivery. Forest Vegetation Simulator Conference: 148-156. USDA Forest Service.

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

In managing coarse woody debris, foresters, fishery biologists, wildlife managers, geomorphologists, recreation specialists, and policy personnel have many opportunities to coordinate watershed planning, cooperatively utilize natural patterns and processes, and improve socioecological systems. Past (and even present) management of riparian debris has been inconsistent. But a growing body of biophysical evidence, coupled with growing acceptance of ecosystem management on public lands, gives hope that together we can sustain this vital component of ecosystem integrity.

30. 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_{log}) to discharge (Q_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. (C) 1997 by John Wiley & Sons, Ltd.

31. 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 recognized that definition of this state is usually difficult or impossible. A diversity of management effects has been recognized 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.

32. Bretschko, G. 1990. The dynamic aspect of coarse particulate organic matter (CPOM) on the sediment surface of second order stream free of debris dams (Ritrodat-Lunz study area). Hydrobiologia 203: 15-28.

The importance of allochthonous organic matter for low order streams is described. Oberer Seebach is a second order stream, draining an uninhabitated and densely forested catchment. Because of flood control the channel is free of debris dams since more than a century. The study site is characterized. Main emphasis is laid on the riparian vegetation and the distribution of dry and overflown channel areas in space and time. Amounts of leaf material, deposited on the sediment surface of the channel are significantly larger during defoliation (20 days) and shortly afterwards ("accumulation period", 6.64 (110 days) and 29.42 g m^2 DW (133 days, a mean of five years) for wet and dry areas, respectively) than during the rest of the year ('intermediate period', 0.98 and 3.94 g m^2 (mean of five years) for wet and dry areas, respectively). Woody debris is too scarce to increase the retention capacity. Deposition of leaf material depends on the interaction of input (wind-drift and bank run off, 124 and 85 g m^2 for the accumulation and intermediate period, respectively), discharge regime and the relationship between dry and wet channel areas. Periodically inundated areas increase the retention capacity of the stream channel and are comparable with the interrelationship between stream and floodplain.

33. Brown, G. W. 1974. Fish habitat. In Environmental effects of forest residues management in the Pacific Northwest: a state-of-knowledge compendium. O. P. Cramer (Ed). Portland, Oregon, USDA Forest Service. **PNW-124:** E1-E15.

Accumulation of residue in stream channels occurs naturally in large amounts, particularly in old growth forests. Residue volumes may triple in streams after timber is felled without buffer strips or other special measures designed to minimize accumulations. Although most of the large residue may be yarded out of the stream, fine residue may remain at levels higher than before logging. Fine residues affect fish habitat by reducing dissolved oxygen levels in surface water and by interfering with the circulation of surface and intergravel water. Large residues affect fish habitat by influencing stream hydraulics, the stability of bed and banks during "flush-outs," and by blocking fish migration. Residue removal from streams must be done with care in order to minimize damage to fish habitat. Vegetation immediately adjacent to the stream is important to the aquatic habitat, influencing both water temperature and food supply for the fish. Protecting this streamside vegetation during logging and residue treatment is essential on valuable fish streams. The greatest single research need in the area of logging residue and fish habitat is the integration of studies concerned with logging method or residue treatment and those concerned with aquatic biology over a wide range of forest-stream-logging situations. Key areas of research are the impact of various logging methods on residue accumulation and on fish populations and the impact of residue accumulation on debris avalanches or "flush-outs."

34. Brown, P. M., W. D. Shepperd, S. A. Mata, and D. L. McClain. 1998. Longevity of windthrown logs in a subalpine forest of central Colorado. Canadian Journal of Forest Research 28: 932-936.

The number of years since tree death for wind-thrown logs of lodgepole pine (*Pinus contorta* var. latifolia Engelm.) and Engelmann spruce (*Picea engelmannii* Parry) was used to examine the longevity of this component of coarse woody debris in an old-growth subalpine forest in the central Rocky Mountains. Death dates of downed logs were determined by dendrochronological cross-dating methods. We were able to determine death dates for 73 logs from both species, the oldest being a lodgepole pine dead 139 years ago. Sound lodgepole pine and Engelmann spruce logs lying on the ground persisted for many decades with a majority of their volume intact. No difference was seen in decay classes of logs collected from two primary study sites on opposite (north and south) exposures. There was also no significant difference in decay classes between the two species, although lodgepole pine logs were in general older than Engelmann spruce logs within any decay class. There was little decrease in the specific gravity of wood remaining in logs with time, although there was a corresponding greater loss of wood volume.

35. Brown, S., J. Mo, J. K. McPherson, and D. T. Bell. 1996. Decomposition of woody debris in Western Australian forests. Canadian Journal of Forest Research 26: 954-966.

Changes in mass and nutrients in experimental logs of six tree species during 5 years of exposure in the three major forest production regions of southwest Western Australia were measured to determine how climate, substrate quality, and substrate size interact to regulate decomposition of woody debris in this Mediterranean-type climate. Branch (3-5 cm in diameter) and bole (10-15 cm in diameter) material of the six species was set out in representative areas of a regenerating clear-cut *Eucalyptus diversicolor* F. Muell. wet sclerophyll forest, selectively cut *Eucalyptus marginata* Donn ex Smith dry sclerophyll forest, and clear-cut areas of a former *Pinus pinaster* Aiton plantation. Experimental logs were collected at about 0.5, 2, and 5 years after placement and were separated into bark and wood components. Samples of initial material were analyzed for moisture content, water-soluble and NaOH-soluble extractives, and nutrient concentrations (N, P, K, Ca, and Mg). At each collection, moisture content and changes in mass and nutrient concentration were determined for the sample logs. *Eucalyptus calophylla* R.Br. the major associate of the two native forests, lost the most mass during this time, up to 65% of the initial mass (decomposition coefficient k 0.22 year-^{1}). Decomposition was least in *P. pinaster* and *E. marginata*, at about 24-26% of original mass (k 0.05 year-^{1} and 0.07 year-^{1}, respectively). Mass losses were greatest in Manjimup, the wettest site, and least at Gnangara, the driest site, but differences in overall levels of decomposition were small despite the range in climatic moisture regimes. Small logs decomposed faster than large logs. Changes in nutrient concentrations occurred in all logs at all sites, indicating activity by decomposer organisms and (or) leaching losses. Nitrogen was the only element to be immobilized over the 5-year period. Mineralization rates were of the order P approximate seq Ca < Mg < K. Concentrations of compounds extractable in cold water and NaOH decreased during the 5 years of exposure. Differences in decomposition rates were partly explained by initial concentrations of N only; there appeared to be no relationship between decomposition and concentration of the other elements and extractives.

36. Bryant, M. D. 1980. Evolution of large, organic debris after timber harvest: Maybeso Creek, 1949 to 1978. USDA Forest Service, General Technical Report, PNW-101.

The Maybeso Creek valley was logged from 1953 to 1960. Stream maps showing large accumulations of debris and stream channel features were made in 1949 and updated in 1960. The objectives of this paper are to document the effects of natural and logging debris on channel morphometry and to examine the fate of logging debris during and after logging. Map sections from 1949 through 1963 are examined and compared with a ground survey in 1978 of debris accumulations.
Natural conditions before logging revealed sparse accumulations of large debris scattered throughout the stream; these accumulations increased in number and density during logging. Natural material appeared to be well controlled and stable; whereas, logging debris was floatable. Year-to-year changes in accumulations were noted throughout the period of logging from 1953 to 1969. Fewer accumulations were observed in 1978 than in 1949, before the start of logging. Further studies are needed to quantify physical changes and to relate these changes to salmon habitat.

37. Bryant, M. D. 1983. The role and management of woody debris in west coast salmonid nursery streams. North American Journal of Fisheries Management 3: 322-330.

Debris removal is a frequently used management technique for small streams in logged watersheds, but many steam-cleaning techniques overlook important habitat requirements of juvenile salmonids. Reviews of some past management practices show little systematic evaluation or monitoring of physical or biological effects. A review of several studies (most of them not associated with debris removal) shows the importance of woody debris as salmonid habitat. The role of organic debris in small stream systems is discussed and a set of criteria for debris removal is proposed.

38. Bryant, M. D. 1985. Changes 30 years after logging in large woody debris and its use by salmonids. USDA Forest Service, General Technical Report, RM-120.

Changes in large woody debris in fourth and fifth-order salmon streams with logged, unlogged, and partially logged riparian zones are documented from maps--for 1949 to 1960--and from field surveys done in 1983 and 1984. Over the 30-year period, most changes in the amount of large woody debris occurred in the logged systems, but in 1983 the amount of large woody debris in the logged systems was less than that observed before logging in most categories. Amounts of large woody debris in the other streams remained relatively stable. Thirty years after logging, habitat formed as a result of large debris provides important rearing areas for juvenile salmonids. Results from this study emphasize the importance of managing riparian zones as a source of large organic debris.

39. Bryant, M. D. and J. R. Sedell. 1995. Riparian forests, wood in the water, and fish habitat complexity. Condition of the World's Aquatic Habitats, Proceedings of the World Fisheries Congress, Theme 1, Bethesda. MD: American Fisheries Society.

Civilization has significantly removed or altered large tracts of riparian forests 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 systems. Large wood serves to connect the main stream to its floodplain, creates complex channel structure, and forms offchannel 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.

40. Buskirk, S. W., M. Yiqing, X. Li, and J. Zhaowen. 1996. Winter habitat ecology of sables (*Martes zibellina*) in relation to forest management in China. Ecological Applications 6: 318-325.

The sable (*Martes zibellina*), a little-known forest carnivore of the Asian taiga, has undergone reductions in distribution and abundance that have been attributed, in part, to habitat changes resulting from forest management. Like its circumboreal sibling species, the "boreal forest martens" (*M. martes*, *M. melampus*, and *M. americana*), the sable has been hypothesized to select for forest attributes associated with late successional stages, and to respond negatively to reductions in the amount of physical structure near the ground, especially the loss of large tree holes. The sable now is endangered in China. To investigate how forestry practices in northern China, which emphasize extensive selective cutting of large-diameter larch (*Larix gmelini*), affect behavioral preferences of sables, and to test for hypothesized ecological similarities among the boreal forest martens, we studied habitat selection by sables in the Daxinganling Mountains, Heilongjiang, People's Republic of China, for three winters. We sampled topographic and vegetative features of three study sites by systematically located plots. We studied sable selection of habitats while traveling by following sable trails in snow, and while resting by locating sables with telemetry. Sables selected for (preferred) sites with dense tree canopy, mixed tree species dominants, and high densities and diameters of larch tree holes. Sables were more selective of habitat for resting than for traveling, like other martens (*M. americana*). Sables were indifferent to attributes of hardwood trees (*Betula* sp.) in their habitat, but preferred mixed tree species stands to single species stands. The sable responds negatively to the absence of tree canopy, of large live trees, and of coarse woody debris, and resembles other boreal forest martens in its habitat associations. The sable may be a useful model for examining the responses of vertebrates to forestry practices in boreal east Asia. Conserving late successional stands of conifer forest appears crucial to the persistence of the sable in China.

41. Carey, A. B. and M. L. Johnson. 1995. Small mammals in managed, naturally young, and old-growth forests. Ecological Applications 5: 336-352.

Forest managers in the Pacific Northwest are faced with new challenges of providing for all wildlife in managed forests. Our objective was to elucidate the factors governing the composition and biomass of forest floor mammal communities that are amenable to management. We sampled small mammal communities in forests of various management histories on the Olympic Peninsula and contrasted our results with those of other large studies in the Pacific Northwest. Forest floor mammal communities in forests > 35 yr old in the Western Hemlock Zone of Washington and Oregon are composed of 5-8 characteristic species. These include *Sorex trowbridgii* (numerically the most dominant); one species each of *Clethrionomys* vs, the *Sorex vagrans* complex, and *Peromyscus*; and *Neurotrichus gibbsii*. Species composition changes from south to north, and the communities on the Olympic Peninsula contain two or three additional species compared to communities to the south. Communities in naturally regenerated and clearcutting regenerated (managed) young forests are similar in composition to those in old growth; old growth, however, supports 1.5 times more individuals and biomass than managed forest. Community diversity seems related to the south-north moisture-temperature gradient that is reflected in increased diversity of canopy conifers, development of forest floor litter layers, accumulation of coarse woody debris, and abundance of herbs, deciduous shrubs, and shade-tolerant seedlings (as opposed to understories dominated by evergreen shrubs). Previous work found few habitat variables that were good predictors of species abundance in natural young and old-growth stands. Naturally regenerated young stands had higher levels of coarse woody debris than old growth. Managed stands had much lower abundance of coarse woody debris and tall shrubs than old growth.

Understory vegetation (herbs and shrubs) and coarse woody debris accounted for a major part of the variation in abundance of six of eight species in managed stands, but only two species in old growth. Management of Western Hemlock Zone forest for conservation of biodiversity and restoration of old-growth conditions should concentrate on providing multispecies canopies, coarse woody debris, and well-developed understories.

42. Carlson, J. Y., C. W. Andrus, and H. A. Froehlich. 1990. Woody debris, channel features, and macroinvertebrates of streams with logged and undisturbed riparian timber in northeastern Oregon, USA. Canadian Journal of Fisheries and Aquatic Sciences 47: 1103-1111.

Macroinvertebrate communities and several aspects of fish habitat were examined for 16 northeastern Oregon stream segments, 11 with undisturbed riparian forests and five where 26-54% of the riparian forest had been harvested 6 to 17 yr previously. Amounts of woody debris in streams and pools formed by the debris were similar between undisturbed and logged sites. Pool volume was inversely related to stream gradient and directly related to the amount of woody debris in the stream. Stream surface substrate composition was not significantly different between streams in logged and undisturbed areas. Macroinvertebrate density was 20 to 113 percent greater at the logged sites and diversity was similar at logged and undisturbed sites. Macroinvertebrates were most abundant at lower elevation streams and at streams that were shaded less by the surrounding vegetation. Timber harvesting activities do not appear to have damaged aquatic insect habitat and pool abundance was not altered, suggesting the habitat's carrying capacity for fish was not affected.

43. Cederholm, C. J., R. E. Bilby, P. A. Bisson, T. W. Bumstead, B. R. Fransen, W. J. Scarlett, and J. W. Ward. 1997. Response of juvenile coho salmon and steelhead to placement of large woody debris in a coastal Washington stream. North American Journal of Fisheries Management 17: 947-963.

Many fish habitats have been altered in Pacific Northwest streams and rivers over the past century by a variety of land use practices, including forestry, urbanization, agriculture, and channelization. There are research and management needs for evaluation of the effectiveness of rehabilitation projects intended to enhance stream fish habitat recovery. The response of populations of juvenile coho salmon *Oncorhynchus kisutch* and steelhead *O. mykiss* to addition of large woody debris (LWD) was tested in North Fork Porter Creek (NFPC), a small coastal tributary of the Chehalis River, Washington. The NFPC was divided into three 500-m study sections; two sections were altered with two approaches (engineered and logger's choice) to adding LWD, and the third was kept as a reference site. Immediately after LWD addition, the abundance of LWD pieces was 7.9 times greater than the pretreatment level in the engineered site and 2.7 times greater in the logger's choice site; abundance was unchanged in the reference site. Subsequent winter storms brought additional LWD into all three study sites. In the years that followed, the amount of pool surface area increased significantly in both the engineered and logger's choice sites, while it decreased slightly in the reference site. After LWD addition, winter populations of juvenile coho salmon increased significantly in the engineered and logger's choice sites, while they remained the same in the reference site. There were no significant differences in the coho salmon populations during spring and autumn within the reference, engineered, or logger's choice sites. The coho salmon smolt yield from the engineered and logger's choice sites also increased significantly after LWD addition, while it decreased slightly in the reference site. After LWD addition, the reference site and the engineered site both exhibited increases in age-0 steelhead populations; however, the population in the logger's choice site did not change. There

was no difference in age-1 steelhead abundance among sites, or before and after enhancement during any season. Winter populations of juvenile coho salmon and age-0 steelhead were related inversely to maximum and mean winter discharge.

44. Cederholm, C. J., D. B. Houston, D. L. Cole, and W. J. Scarlett. 1989. Fate of coho salmon (*Oncorhynchus kisutch*) carcasses in spawning streams. Canadian Journal of Fisheries and Aquatic Sciences 46: 1347-1355.

We examined the levels of retention and utilization of 945 coho salmon (*Oncorhynchus kisutch*) carcasses released experimentally into seven spawning streams on the Olympic Peninsula, Washington [USA]. Most carcasses were retained in the streams and in adjacent forests, few were flushed beyond 600 m. Organic debris caught and held many carcasses. Much of the fish mass was consumed by 22 species of mammals and birds. The distances that carcasses drifted appeared to be related directly to the occurrence of freshets and inversely to debris load and carnivore scavenging. The capacity of many streams and rivers to retain carcasses has probably been reduced by human activities. The importance of coho carcasses to populations of carnivores and to the dynamics of lotic food webs merits additional study.

45. Cederholm, C. J. and N. P. Peterson. 1985. The retention of Coho salmon *Oncorhynchus kisutch* carcasses by organic debris in small streams. Canadian Journal of Fisheries and Aquatic Sciences 42: 1222-1225.

Twenty marked coho salmon (*Oncorhynchus mykiss*) carcasses were placed in each of nine small streams on the Olympic Peninsula of Washington during the fall-winter spawning period. Distribution of the carcasses in 500 m of stream below each release site was followed for 4 wk. One week after placement, 78 of the 180 carcasses were found in the nine study reaches; 80% were found in the first 200 m downstream of the release sites. A general positive trend was observed between the number of carcasses retained and the amount of debris in the stream channel ($r = 0.61$). Terrestrial animals rapidly consumed carcasses during the experiment, and removed many of them to the riparian zone.

46. Christensen, D. L., B. R. Herwig, D. E. Schindler, and S. R. Carpenter. 1996. Impacts of lakeshore residential development of coarse woody debris in north temperate lakes. Ecological Applications 6: 1143-1149.

Coarse woody debris (CWD) is a critical input from forested watersheds into aquatic ecosystems. Human activities often reduce the abundance of CWD in fluvial systems, but little is known about human impacts on CWD in lakes. We surveyed 16 north temperate lakes to assess relationships among CWD, riparian vegetation, and shoreline residential development. We found strong positive correlation between CWD density and riparian tree density ($r^2 = 0.78$), and strong negative correlation between CWD density and shoreline cabin density ($r^2 = 0.71$) at the whole-lake scale. At finer spatial scales (e.g., between sampling plots), correlations between CWD and riparian vegetation were weaker. The strength of relationships between CWD and riparian vegetation was also negatively influenced by the extent of cabin development. Overall, there was significantly more CWD in undeveloped lakes (mean of 555 logs/km of shoreline) than in developed lakes. Within developed lakes, CWD density differed between forested sites (mean of 379 logs/km of shoreline) and cabin-occupied sites (mean of 57 logs/km of shoreline). These losses of CWD will affect littoral communities in developed north temperate lakes for about two centuries. Because CWD is important littoral habitat for

many aquatic organisms, zoning and lake management should aim to minimize further reductions of aquatic CWD and woody vegetation from lakeshore residences.

47. Christensen, M. and J. Emborg. 1996. Biodiversity in natural versus managed forest in Denmark. Forest Ecology and Management 85: 47-51.

During recent millennia the biodiversity patterns of the Danish forests have changed. Many of the rare or threatened species in Denmark are related to habitats characteristic of natural forest ecosystems. By comparing the structure and dynamics of natural and managed forests the following key elements related to biodiversity were identified: woody debris, forest heterogeneity, (successional) continuity and water. To incorporate these elements into modem forest management, a change in attitude and practice is needed. Education and training will be an important part of this move towards sustainability.

48. Clark, D. F., D. D. Kneeshaw, P. J. Burton, and J. A. Antos. 1998. Coarse woody debris in sub-boreal spruce forests of west-central British Columbia. Canadian Journal of Forest Research 28: 284-290.

An evaluation of how coarse woody debris (CWD) changes in quantity and quality during stand development was conducted using a 426-year chronosequence of 71 stands in sub-boreal forests in British Columbia. Additional characteristics of CWD were determined in 14 of the stands. Most stands are fire initiated and input from the predisturbance stand is critical in controlling the amounts and characteristics of CWD within young stands. Log volume declines from over 100 m^3/ha in young stands (0-50 years) to just over 60 m^3/ha in stands from 51 to 200 years old, and then increases to greater than 140 m^3/ha in the oldest (greater than or equal to 400-year-old) stands. Mean snag basal area is highest (31.6 m^2/ha) in young, postfire stands, decreases to a very low value (2.0 m^2/ha) in stands 51-100 years old, and then reaches a second maximum (12.1 m^2/ha) in stands that are 201-250 years old; it declines slightly in very old stands. The high snag basal area in stands 201-250 years old coincides with the successional transition from lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. latifolia Engelm.) to stands dominated by subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and interior spruce (hybrids of *Picea glauca* (Moench) Voss and *Picea engelmannii* Parry). Stand age, characteristics of the predisturbance forest, and the disturbance history of stands subsequent to stand initiation all appear to be very important in determining variation in both the quality and quantity of CWD in these sub-boreal forests.

49. Collins, B. D. and G. R. Pess. 1997. Critique of Washington's watershed analysis program. Journal of the American Water Resources Association 33: 997-1010.

We evaluate Washington's program of watershed analysis with respect to its goals as a cumulative effects assessment method, adaptive management, and a restoration tool. We also evaluate the program as a framework for implementing ecosystem management. A strength of the cumulative effects assessment method is in identifying and reducing the dominant, direct physical effects of forest land uses on salmonid habitat. This could be further strengthened by more emphasis on identifying problems that can be immediately remedied (e.g., identifying road erosion and landslide trigger sites; correctly locating fish-bearing waters, and identifying anthropogenic fish passage impediments). More effectively assessing and integrating changes from more than one type of input to streams, including all relevant inputs, and examining whether assumptions about those inputs are scientifically defensible, will also improve the cumulative effects assessment.

Treating experimentation more formally, including placing a greater emphasis on monitoring the outcome of prescriptions, and determining the scientific defensibility and certainty level of prescriptions, will strengthen adaptive management. As a watershed restoration tool, the program needs defined goals and critical assessment methods (e.g., of historic productive capacity of aquatic habitat). To be consistent with ecosystem management, analyses need to be integrated into a larger spatial scale, and to include all relevant land uses and effects within that scale; objectives for various stream "inputs" need to be evaluated with respect to managing for ecological integrity and the ability to provide a measurable standard.

50. Collins, B. D. and G. R. Pess. 1997. Evaluation of forest practices prescriptions from Washington's watershed analysis program. Journal of the American Water Resources Association 33: 969-996.

In Washington's watershed analysis program, scientific analysts identify watershed areas that are sensitive to forest practices. Land managers then develop watershed-specific rules or "prescriptions" that condition forestry activities in those sensitive areas. Prescriptions are intended to provide greater protection than existing, or "standard," roles where necessary to avoid cumulative effects on public aquatic resources (fish habitat and public works). To assess strengths and opportunities for improving Washington's watershed analysis, we evaluate prescriptions from 20 analyses conducted from 1993 to 1995. We ask: (1) Are prescriptions watershed specific, compared to the general, or "standard" forest practices rules? (2) Are prescriptions scientifically sound? (3) What promotes or limits development of watershed-specific and scientifically sound prescriptions? We find: (I) Prescriptions tend to be similar to standard rules. One reason is that some components of the scientific assessment methodology incorporate approaches or assumptions from the standard rules, some of which are untested or unsupported. Another reason is that while other assessment methods are not patterned after the standard rules, resulting prescriptions do not necessarily integrate assessment information. (2) Many prescriptions lack a scientific rationale and are unproved in meeting their stated objectives. Despite the experimental nature of many prescriptions, they generally lack an evaluation component. (3) Washington's watershed analysis can be strengthened by: testing assumptions of some scientific assessment methods; basing prescriptions more rigorously on scientific assessment data and published scientific literature; and addressing uncertainty in whether prescriptions meet their objectives.

51. Crispin, V., R. House, and D. Roberts. 1993. Changes in instream habitat large woody debris and salmon habitat after the restructuring of a coastal Oregon stream. North American Journal of Fisheries Management 13: 96-102.

Elk Creek [USA], a drainage of 26.6 km^2 that historically has been severely degraded by logging, floods, and stream cleaning, was restructured in 1986, 1987, and 1989. In all, 106 full-spanning and 94 partial-spanning structures were installed along 4.2 km of stream. An upstream reach of 0.5 km was left untreated. Inventories of stream habitat conditions and large woody debris conducted in 1985 and 1990 (i.e., before and after restructuring), showed that restructuring caused substantial changes favoring suitable habitat for coho salmon *Oncorhynchus kisutch*; meanwhile, the untreated reach became less favorable for rearing coho salmon. Stream surface area and water volume, respectively, increased 74 and 168% in the treated reach, and 8 and 37% in the untreated reach. Surface area of pool and suitable off-channel habitat, the most important summer and winter rearing components for coho salmon juveniles, increased nearly fivefold in the treated reach at summer low flow. In the treated reach, which had a mature riparian area,

newly recruited large woody debris was 52% greater in mean length and 60% greater in mean diameter than in the untreated reach, which had a previously logged riparian area. Whereas in the treated reach suitable summer habitat for coho salmon increased fivefold and suitable winter habitat increased sixfold, in the untreated reach suitable summer habitat decreased by half and no winter habitat was available.

52. Culp, J. M., G. J. Scrimgeour, and G. D. Townsend. 1996. Simulated fine woody debris accumulations in a stream increase rainbow trout fry abundance. Transactions of the American Fisheries Society 125: 472-479.

Habitat for young-of-the-year rainbow trout *Oncorhynchus mykiss* was enhanced in a fourth-order stream during August-October 1991 by the addition of wooden structures that simulated accumulations of fine woody debris (FWD). The experiment represented a two-factorial design with the presence or absence of FWD bundles and time since debris introduction as factors. Immediately after FWD placement, fry density, individual biomass, fry condition factor, and total fry biomass were similar in treated and untreated sites. As the experiment progressed, density and total fry biomass significantly increased at treated but not at untreated sites. Individual biomass and condition factor did not differ between treated and untreated areas, and they were affected only by time since FWD placement. Because individuals at treated and untreated sites were the same size, added FWD did not affect an individual's net rate of energy gain. Rather, we hypothesize that the FWD provided structurally complex habitat that acted as a refuge from predators and as sites from which foraging forays were staged. Adding FWD to a stream can increase carrying capacity for trout fry, and adult population density may increase as a result.

53. Davis, R. J. and K. J. Gregory. 1994. A new distinct mechanism of river bank erosion in a forested catchment. Journal of Hydrology 157: 1-11.

It has been thought that the two main processes responsible for river bank retreat are the removal of particles or layers of material by flow erosion or sloughing and collapse by slumping. A third process, involving the development of a subsurface cavity after washout of gravels which is succeeded by slow subsidence of a segment of the former channel bank, has been identified at a site in the New Forest, southern England. The process was monitored over a 9 month period, and was observed to be assisted by the hydrological effects of a dam of coarse woody debris across the channel. As these dams occur frequently, the process is likely to have occurred elsewhere along channels in forested areas.

54. Diehl, T. H. and B. A. Bryan. 1993. Supply of large woody debris in a stream channel. Proceedings of the National Conference of Hydraulic Engineers, San Francisco, CA: 1055-1061. 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 productions. 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 trunks is primarily the result of bank erosion.

Bank instability seems to be the most useful in identifying basins with a high potential for abundant production of debris.

55. Diehl, T. H. 1997. Potential Drift Accumulation at Bridges. US Department of Transportation, Federal Highway Transportation, FHWA-RD-97-028.

Drift (floating debris) increases lateral forces on bridges and promotes scour. This report presents the results of a study of drift accumulation at bridges performed by the U.S. Geological Survey from 1992 through 1995, in cooperation with the Federal Highway Administration. The study included a review of published literature on drift, analysis of data from 2,577 reported drift accumulations, and field investigations of 144 drift accumulations.

The potential for drift accumulation depends on basin, channel, and bridge characteristics. Drift that accumulates at bridges comes primarily from trees undermined by bank erosion. Rivers with unstable channels have the most bank erosion and the most drift. Most drift floats along the thread of the stream. Logs longer than the width of the channel accumulate in jams, or are broken into shorter pieces.

Drift accumulates against obstacles such as bridge piers that divide the flow at the water surface. Groups of obstacles separated by narrow gaps trap drift most effectively. Drift accumulation begins at the water surface, but an accumulation may grow downward to the stream bed through accretion. A drift accumulation on a single pier grows no wider than the length of the longest logs it contains. The gap between two piers is not blocked by drift unless individual logs can reach from pier to pier. Design features to reduce the potential for drift accumulation include adequate freeboard, long spans, solid piers, round (rather than square) pier noses, and pier placement away from the path of drift.

56. Dolloff, C. A. 1986. Effects of stream cleaning on juvenile coho salmon and Dolly Varden in southeast Alaska [USA]. Transactions of the American Fisheries Society 115: 743-755.

This paper describes the effects of selective removal of woody debris on populations of juvenile coho salmon *Oncorhynchus kisutch* and Dolly Varden *Salvelinus malma* in two small streams on Prince of Wales Island, Alaska, during the summers of 1979-1981. These streams contained debris left when surrounding forests were clear-cut in the late 1960s. Debris smaller than 60 mm in diameter and larger debris not embedded in the stream channel were manually removed from half of the study reach on each stream in 1979 by state-of-the-art techniques. Immigration and emigration of fish from the study sections and intrastream movements were very limited after an initial period of population adjustment in the spring regardless of treatment. Population densities and production of both species were typically higher in sections where debris accumulations had not been removed. Production of age-O+ and age-1+ coho salmon and age-1+ and age-2+ Dolly Varden during the June-September period ranged from 0.70 to 2.22 g/m^2 in the cleaned sections and from 0.84 to 2.10 g/m^2 in the uncleaned sections. Carrying capacities for both species were lower in cleaned sections despite the use of selective techniques for removing woody debris.

57. Dolloff, C. A. and G. H. Reeves. 1990. Microhabitat partitioning among stream-dwelling juvenile coho salmon, *Oncorhynchus kisutch*, and Dolly Varden, Salvelinus malma. Canadian Journal of Fisheries and Aquatic Sciences 47: 2297-2306.

Microhabitat use and partitioning among age 0+ and 1+ coho salmon, *Oncorhynchus kisutch*, and age 0+, 1+ and 2+ Dolly Varden, *Salvelinus malma*, was studied in small (< 2 m wide), natural steams on Prince of Wales Island, Alaska, and in laboratory stream channels. Coho salmon occupied midwater positions that they defended from other fish. Dolly Varden were more closely associated with the stream bottom and were seldom territorial. For each species, the depth of water, depth of focal point, and distance to nearest fish increased with fish size, whereas the distance to nearest cover decreased as fish size increased. Most fish selected focal point velocities between 0.0-9.0 cm/s^{1}. Woody debris was the most frequently used cover type and most fish occurred over gravel substrates ranging from 2-100 mm particle diameter. Habitat use by each species in the laboratory was similar to the pattern observed in the field. Each species occupied similar habitats both when alone and when the other species was present. Although habitat use by juveniles of coho salmon and Dolly Varden overlapped among several key parameters, each species primarily exploited resources not readily available to or selected by the other in the natural streams we studied.

58. Dolloff, C. A., P. A. Flebbe, and M. D. Owen. 1994. Fish habitat and fish populations in a southern Appalachian watershed before and after Hurricane Hugo. Transactions of the American Fisheries Society 123: 668-678.

Habitat features and relative abundance of all fish species were estimated in 8.4 km of a small mountain stream system before and 11 months after Hurricane Hugo crossed the southern Appalachians in September 1989. There was no change in the total amount (area) of each habitat type but the total number of habitat units decreased and average size and depth of habitat units increased. Transport and sorting of streambed sediments was evident from the increased proportion of habitat units in which cobbles and small boulders were the most common constituents. Large woody debris more than doubled from 228 to 559 pieces/km of stream channel. At the watershed scale, there were only minor changes in the fish community 11 months after the hurricane. Eleven species were found both before and after the storm, and most species were uncommon. Among common species, densities increased in riffles for darters *Etheostoma* spp., increased in pools for blacknose dace *Rhinichthys atratulus*, and were largely unaffected for rainbow trout *Oncorhynchus mykiss*. The results of this case study suggest that the effects of catastrophic disturbances on fish habitat and populations depend on the predisturbance condition of instream and riparian habitat, timing of the disturbance, and life histories of individual species.

59. Dolloff, C. A., H. E. Jennings, and M. D. Owens. 1997. A comparison of basinwide and representative reach habitat survey techniques in three southern Appalachian watersheds. North American Journal of Fisheries Management 17: 339-347.

We compared estimates of stream habitat at the watershed scale using the basinwide visual estimation technique (BVET) and the representative reach extrapolation technique (RRET) in three small watersheds in the Appalachian Mountains. Within each watershed, all habitat units were sampled by the BVET; in contrast, three or four 100-m reaches were sampled with the RRET. The number of pools was higher and the number of cascades was lower when estimated by the RRET than they were when estimated by the BVET, whereas the average areas of all habitat types estimated by the RRET were smaller. At the watershed scale, eight out of nine estimates of total habitat area by habitat type derived from the RRET were outside the 95% confidence intervals derived from the BVET. Depth estimates were consistently smaller with the RRET than with the BVET. Large woody debris estimates with the RRET were less than with the BVET in two of three watersheds and were greater in one watershed. We observed that the degree to which habitat in a RRET assessment reflects conditions at a larger scale depends on the selection of representative reaches. Habitat estimates based on the BVET were a more accurate reflection of conditions existing in the three small southern Appalachian watersheds than estimates derived from the RRET. The BVET permitted greater amounts of habitat to be surveyed with known accuracy and precision.

60. 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: 1189-1197.

Recent environmental concerns in floodplain management have stimulated research of the effect vegetation and debris have on now 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.

61. Duncan, W. F. A. and M. A. Brusven. 1985. Energy dynamics of three low-order southeast Alaska [USA] streams: allochthonous processes. Journal of Freshwater Ecology 3: 233-248.

Allochthonous processes of three low-order southeast Alaska streams, exhibiting a range of riparian vegetation and successional stages occurring before and after logging, were compared. Leaf-litter traps were used to estimate annual litter input. Leaf processing rates were measured by confining known amounts of leaf material in litter bags. Instream woody debris and stored and transported organics were also estimated. Annual litter inputs ranged from 52 g AFDW/m^2 on a clearcut watershed to 295 g AFDW/m^2 on a logged and deciduously revegetated watershed. All deciduous species tested (red alder - *Alnus rubra*, black cottonwood - *Populus trichocarpa*, salmonberry - *Rubus spectabilis*)

had fast post-leaching processing rates (k > 0.01), while western hemlock (*Tsuga heterophylla)* was processed slowly (k < 0.005). The logged watersheds contained the largest amount of woody debris. Stored particulate organic matter (POM) was generally 2 or more times greater in depositional than erosional areas. Seasonal changes in stored POM were most obvious in erosional areas. Transported POM was highest in a logged watershed revegetated with deciduous riparian species. The results of this study suggest that logged watersheds, with extensive riparian regeneration, potentially increase the allochthonous energy base of streams in southeast Alaska.

62. Elliott, S. T. 1986. Reduction of a Dolly Varden (*Salvelinus malma*) population and macrobenthos after removal of logging debris. Transactions of the American Fisheries Society 115: 392-400.

Logging debris resident for five or more years in small streams of southeastern Alaska [USA] is frequently removed to improve salmonid habitat. This practice was evaluated for its effects on juvenile anadromous Dolly Varden *Salvelinus malma* and macrobenthos populations in a small spring-fed stream during 1973-1981. Debris, consisting of limbs, needles, and fragmented logs, was removed by hand from the entire stream in July 1976. The surface area, number, and size of pools was reduced thereafter, and the water velocity increased. Macrobenthos density and invertebrate drift decreased 60-90% immediately after debris removal but returned to pretreatment levels in 1977. The Dolly Varden population decreased from 900 to less than 100 fish by 1978 and then fluctuated sharply between late 1978 and 1981. After 1978, Dolly Varden averaged 27 mm less in length and their biomass decreased from 12.5 to 3.9 g/m^2. Decrease in fish standing crop occurred in two stages: (1) an initial loss of larger fish due to reduced habitat: (2) loss of smaller individuals during November freshets thereafter. This study indicates that removal of old logging debris does not improve habitat and can result in smaller rearing populations. Old debris should not be removed unless a block to migrating adult spawners or impairment of water quality can be demonstrated.

63. Elmore, W. and R. L. Beschta. 1988. The fallacy of structures and the fortitude of vegetation. California Riparian Systems Conference, University of California, Davis: 117-119. USDA Forest Service.

Given time and proper management conditions, degraded rangeland streams can often produce by natural means the same results that we expect from streambank stabilization and fisheries enhancement structures. Advantages of using vegetation and natural recovery processes include: 1) costs are likely to be lower and 2) a wide range of benefits can accrue to a recovered stream. Structures tend to lock a stream channel in place whereas vegetation allows incremental changes in channel characteristics as flow and sediment loads vary. Healthy riparian vegetation can replace itself in perpetuity, providing a resiliency which keeps banks adjusted to channels --even shifting ones. Improved management of streamside vegetation, not structural additions to channels, offers the most promise for developing valuable and productive riparian systems.

64. Elosegi, A., J. R. Diez, and J. Pozo. 1999. Abundance, characteristics, and movement of woody debris in four Basque streams. Archiv Fur Hydrobiologie 144: 455-471.

We studied the amount, size and dynamics of woody debris in 4 reaches of the Aguera stream catchment (northern Iberian Peninsula): three sites (1st-, 2nd- and 3rd-order) surrounded by deciduous forests, and one 1st-order site under a plantation of *Eucalyptus globulus*. From July 1995 to February 1997, on six occasions, all wood pieces larger than 1 cm in diameter were measured; logs (diameter > 5 cm) were tagged and their positions recorded. The volume of wood was relatively low and decreased downstream: 13,700 cm^3/m^2 at the headwater deciduous site, 490 cm^3/m^2 in the 2nd-order reach, and 100 cm^3/m^2 in the 3rd-order reach. The woody standing crop at the headwaters within eucalyptus plantations was only 960 cm^3/m^2. The average size of individual pieces decreased downstream. The mobility of logs was lowest in the headwaters: 47 % of the logs tagged in the 1st-order reaches moved during the year, 86 % in the 2nd-order reach, and 76 % in the 3rd- order reach. Temporal variations were small and associated with sporadic events such as floods or human activities. Mid and low reaches of Basque streams have few old-growth riparian forests, and most fallen logs are removed; this results in low amounts of wood, thus limiting the role of woody debris in organic matter retention or habitat diversity. Similarly, plantations of eucalyptus seem to result in low volume and small size of woody debris in the headwaters.

65. Evans, B. F., C. R. Townsen, and T. A. Crowl. 1993. Distribution and abundance of coarse woody debris in some southern New Zealand streams from contrasting forest catchments. New Zealand Journal of Marine and Freshwater Research 27: 227-239.

Greater amounts of coarse woody debris (CWD) occurred in streams from old native forests than in streams from young native and pine forests in southern New Zealand. The size of CWD in the streams generally reflected the age of the surrounding vegetation. More wood was present in pool than in non-pool sections of old native forest streams and the frequency of pools per unit length formed by woody debris was greatest in these streams. The volumes of pools formed by wood and those formed by inorganic substrates were similar. Amounts of woody debris in these streams were relatively small compared to values recorded from North America.

66. Everett, R. A. and G. M. Ruiz. 1993. Coarse woody debris as a refuge from predation in aquatic communities an experimental test. Oecologia (Berlin) 93: 475-486.

This study demonstrates experimentally that coarse woody debris (CWD) can provide refuge from predation in aquatic habitats. In the Rhode River subestuary of Chesapeake Bay, Maryland, (USA), we (1) measured the abundance of CWD, (2) examined the utilization of CWD by mobile epibenthic fish and crustaceans, and (3) tested experimentally the value of CWD as a refuge from predation. CWD was the dominant above-bottom physical structure in shallow water, ranging in size from small branches (< 2 cm diameter) to fallen trees (> 50 cm diameter). In response to experimental additions of CWD, densities of common epibenthic species (*Callinectes sapidus, Fundulus heteroclitus, Fundulus majalis*, *Gobisosoma bosc*, *Gobiesox strumosus, Palaemonetes pugio*, and *Rithropanopeus harrisii*) increased significantly compared to control sites without CWD. In laboratory experiments, grass shrimp (*P. pugio*) responded to predatory fish (*F. heteroclitus* and *Micropogonias undulatus*) by utilizing shelter at CWD more frequently than in the absence of fish. Access to CWD increased survivorship of grass

shrimp in laboratory and field experiments. These experimental results (1) support the hypothesis, commonly proposed but untested for freshwater habitats, that CWD can provide a refuge from predation for epibenthic fish and invertebrates and (2) extend the recognized functional importance of CWD in freshwater to estuarine and marine communities. We hypothesize that CWD is an especially important refuge habitat in the many estuarine and freshwater systems for which alternative physical structure (e.g., vegetation or oyster reefs) are absent or in low abundance.

67. Fausch, K. D. and T. G. Northcote. 1992. Large woody debris and salmonid habitat in a small coastal British Columbia stream. Canadian Journal of Fisheries and Aquatic Sciences 49: 682-693.

Sections of a small coastal British Columbia stream that had previously been cleaned of large woody debris (LWD) were compared with sections where most debris was left and with others where debris had been relatively undisturbed for at least 40 yr. Three sections where debris had been removed had simple habitat that was less sinuous, wider, and shallower and had less pool volume and overhead cover than four sections with more complex habitat where debris was retained. Habitat in four relatively undisturbed sections was generally similar to complex sections. Most pools in all sections were scour or plunge pools formed by LWD or large roots oriented perpendicular to the flow or angled downstream. Standing crop (kilograms per hectare) and individual weights of age 1+ and older coho salmon (*Oncorhynchus kisutch*) and cutthroat trout (*O. clarki*) were significantly greater ($P < 0.02$) in complex than in simple sections. Biomass of age 1+ and older salmonids was closely related to section pool volume ($r^2 = 0.92$, $P = 0.0006$). Projections based on this model and average habitat conditions suggest that during 1990 a total of 8.0 kg of salmonid biomass, 5 times the current stand crop, was foregone in the 332-m simple reach due to prior debris removal.

68. 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.

We present a conceptual biogeomorphic model of riparian forest development in montane river networks. The role of physical process in driving the structure, composition, and spatial distribution of riparian forests is examined. We 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 the stabilization of active floodplains and as sources of large woody debris (OLWD). LWD is operationally defined as wood > 0.1 m diameter and > 1 m length. LWD plays a key role in the development of 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 our examples are montane river networks of the Pacific Northwest, USA.

69. Flebbe, P. A. and C. A. Dolloff. 1995. Trout use of woody debris and habitat in Appalachian wilderness streams of North Carolina. North American Journal of Fisheries Management 15: 579-590.

Wilderness areas in the Appalachian Mountains of North Carolina are set aside to preserve characteristics of both old-growth and second-growth forests and associated streams. Woody debris loadings, trout habitat, and trout were inventoried in three southern Appalachian wilderness streams in North Carolina by the basin-wide visual estimation technique. Two streams in old-growth wilderness areas contained more large woody debris (LWD, diameter > 10 cm) and more and smaller pools and riffles than did a stream in a second-growth area managed as wilderness. Furthermore, the size distribution of woody debris in the second-growth stream was skewed to smaller size-classes than that in the old-growth streams. Brook trout *Salvelinus fontinalis*, rainbow trout *Oncorhynchus mykiss*, and brown trout *Salmo trutta* in the three streams were always found in habitat units that had large amounts of LWD but were present in only 70-90% of the large number of units with little or no LWD. In the absence of high fishing pressure, the stream with large amounts of LWD supported higher trout density and biomass than the stream with little or no LWD. These old-growth streams provide a benchmark against which recovery of previously disturbed streams may be compared. Furthermore, if the goal for restoration of trout habitat is to recreate old-growth stream conditions, these two old-growth wilderness streams provide a basis for selecting appropriate amounts and sizes of LWD.

70. Flebbe, P. A. 1999. Trout use of woody debris and habitat in Wine Spring Creek, North Carolina. Forest Ecology and Management 114: 367-375.

Wine Spring Creek basin, in the mountains of North Carolina's Nantahala National Forest, is an ecosystem management demonstration site, in which ecological concepts for management and restoration are tested. Large woody debris (LWD) is an important link between streams and the adjacent riparian forest, but evidence for the connection between LWD and trout in southern Appalachian streams is limited. Woody debris loadings, trout habitat, and brook trout (*Salvelinus fontinalis*) and rainbow trout (*Oncorhynchus mykiss*) were inventoried for the entire 9.8 km that trout occupy in Wine Spring Creek. Compared to two reference streams in North Carolina old-growth forests, Wine Spring Creek had less LWD, evidence of conditions associated with mid-successional riparian forests. More units in Wine Spring Creek lacked LWD altogether and accumulations of two or more pieces of LWD were less common than was the case in the reference watersheds. On average, about 71% of pools and riffles in Wine Spring Creek were occupied by trout, compared to about 90% in reference streams. Trout nearly always occupied pools with at least two pieces of LWD, but rates of occupancy for pools with one or no LWD pieces and riffles were unusually low compared to reference streams. Habitats on the lower and middle reaches on the mainstem of Wine Spring Creek had highest trout numbers and were nearly always occupied by trout. In these reaches, riparian ages were older and stream habitat had abundant LWD or boulder substrate. Upper reaches of Wine Spring Creek and its tributaries, however, were characterized by less mature riparian forest, less LWD and Little boulder substrate, low rates of trout occupancy, and lower trout numbers. These conditions are the basis for an LWD addition experiment in headwater reaches.

71. France, R., H. Culbert, C. Freeborough, and R. Peters. 1997. Leaching and early mass loss of boreal leaves and wood in oligotrophic water. Hydrobiologia 345: 209-214.

Following immersion in water, allochthonous litter undergoes a process of substantial leaching that is difficult to quantify yet important to exclude from analyses of the role of macroinvertebrates in subsequent breakdown. Laboratory experiments which measured the aqueous release of total phosphorus and dissolved organic carbon from undried leaves (deciduous and coniferous) and woody debris (twigs and bark) revealed that the period of leaching is a prolonged process developing over weeks. Immersion of litter from 6 species of riparian trees in 4 oligotrophic Canadian Shield lakes demonstrated that undried leaves lost 6 to 18% of their mass after 2 wk, and woody debris experienced 0.2 to 27% mass loss after 7 wk. Studies concerned with quantifying the role of macroinvertebrates in the breakdown of allochthonous litter in lentic water should therefore disregard such mass losses.

72. Frangi, J. L., L. L. Richter, M. D. Barrera, and M. Aloggia. 1997. Decomposition of nothofagus fallen woody debris in forests of Tierra del Fuego, Argentina. Canadian Journal of Forest Research 27: 1095-1102.

We report the decay constants of fallen fine (< 1 cm in diameter) and coarse (greater than or equal to 1 cm) woody debris of the southern beeches lenga (*Nothofagus pumilio* (Poepp. et Endl.) Krasser), nire (*Nothofagus antarctica* (Forst.) Oerst.), and guindo (*Nothofagus betuloides* (Mirb.) Oerst.) in Tierra del Fuego, Argentina. The decomposition of small branches (< 1 cm) was assessed with the nylon mesh bag technique. A tethered-branch method was used for the decomposition of branches 1-16 cm in diameter of nire and guindo incubated in the field for a period of approximately 4 years. For large lenga branches (8-17 cm) and holes (19-60 cm), we used a chronosequence method, using a 3.5- to 55-year series of natural field incubations. Small lenga branches decayed faster ($k = 0.47\ year^{-1}$) than those of fire ($k = 0.23\ year^{-1}$) and guindo ($k = 0.17\ year^{-1}$). For branches 1 cm, decomposition rates of the species were not significantly different, but diminished with diameter increase. The rate of change of k versus diameter was significantly greater for lenga. In the full range of lenga wood diameters studied, k decreased exponentially with diameter (k = 0.55-exp(-0.177-diameter)) attaining a nearly constant value ($k = 0.010\ year^{-1}$) between 30 and 60 cm. Residence time increased from 2 to 100 years for small branches to large boles, respectively. There was no lag time for decomposition initiation. The decay constants for large lenga branches and boles appeared similar to or slightly greater than those of cold temperate conifers and less than those of hardwoods of the cold and warm temperate zones of the Northern Hemisphere.

73. Fries, C., O. Johansson, B. Pettersson, and P. Simonsson. 1997. Silvicultural models to maintain and restore natural stand structures in Swedish boreal forests. Forest Ecology and Management 94: 89-103.

Almost all productive Swedish forests have been managed for timber production for a long period of time. More sensitive so-called red-listed species are today restricted to small remnant habitats in a managed landscape matrix. It has been hypothesized that natural biodiversity can be maintained if forest management mimics natural processes, blends natural structures and includes natural composition into the production forest. The most important restoration measures in Swedish boreal forests for promoting biodiversity are to increase the number and quality of undisturbed forests, the amounts of coarse woody debris, the number of deciduous trees, and to introduce fire as an ecological

process. On the basis of current knowledge of natural forest dynamics, we here present management options for three major site types in boreal Sweden which mimic natural dynamics better than traditional forestry. In the natural stages, the sites carried (1) Scots pine forest, (2) deciduous or Norway spruce dominated forest, and (3) Norway spruce forest regenerated by so-called gap dynamics, respectively. The flora and fauna that characterize the first two, fire-influenced sites are considered relatively well-adapted to the kind of large-scale disturbances characterizing forestry. On these sites, therefore, the modifications proposed are within today's approach to applying the clear felling system. Sites that seldom experience fire may host species extremely sensitive to large-scale disturbances. If such sites are to be used for timber production, modified forestry practices using selection or shelterwood systems with relatively dense shelterwoods are suggested.

74. Froehlich, H. A. 1970. Logging debris: managing a problem. Forest Land Uses and Stream Environment, Corvallis, Oregon: 112-117. Oregon State University.

Floatable debris in forested watersheds is produced by both natural and human action. The natural accumulation of organic debris and its subsequent flushing by periodic flood events are discussed. The frequency of major flood events since 1861 was examined and found to occur at an average of only eight-year intervals. Flood damage studies show that one of the major contributors to storm damage is non-manufactured debris. Studies were reviewed which show that logging debris adds significantly to the natural debris and often aggravates the flood damage. The impact of this debris movement on the forest road system and a number of management techniques were discussed. A plan for reducing road and culvert damages is recommended.

75. Ganey, J. L. 1999. Snag density and composition of snag populations on two National Forests in northern Arizona. Forest Ecology and Management 117: 169-178.

Snags (standing dead trees) provide important habitat for forest wildlife, as well as a source of coarse woody debris important in forest succession. Because of their importance, some land-management agencies have standards for snag retention on lands under their jurisdiction (e.g. U.S. Forest Service, British Columbia Ministry of Forestry). Despite these guidelines, however, little information is typically available on snag numbers or dynamics on these lands. As part of a long-term effort to monitor snag dynamics, snag populations were sampled on 114 1-ha plots randomly located across six Ranger Districts on two National Forests in northern Arizona. Sixty plots were located in ponderosa pine forest, with the remainder in mixed-conifer forest. Small snags and snags in later decay classes numerically dominated snag populations. Because large snags are most useful to forest wildlife, this suggests a need to retain large trees as future snags. Only 6.7 and 16.7% of plots in ponderosa pine and mixed-conifer forest, respectively, met or exceeded current U.S. Forest Service standards for retention of large snags (defined as snags greater than or equal to46 cm in diameter at breast height and 9 m in height) in this geographic region. Even plots with no evidence of timber or fuelwood harvest seldom met targets for retention of large snags, however. Only 30 and 32% of unlogged plots met or exceeded standards in ponderosa pine and mixed-conifer forest, respectively. This suggests that current standards for snag retention may be unrealistic, and that those standards may need to be reconsidered. Snag guidelines should be based on an understanding of both, snag dynamics and the requirements of snag-dependent wildlife species.

76. Gippel, C. J. 1995. Environmental hydraulics of large woody debris in streams and rivers. Journal of Environmental Engineering-ASCE 121: 388-395.

Although awareness of the habitat value of large woody debris in streams has promoted a more environmentally sensitive approach to its management, present guidelines are largely intuitive and do not contain advice for conducting quantitative hydraulic investigations. This review of the literature provides information to assist management, and highlights deficiencies in current knowledge. Hydraulically, debris act as large roughness elements that provide a varied flow environment, reduce average velocity, and locally elevate the water-surface profile. This can significantly increase flood travel time. The significance of debris is scale-dependent. For example, the hydraulic effects are often drowned out in a large flood on a large river. Some hydraulic models can be used to predict the effect of debris removal or reinstatement. A challenge for research is the development of a hydraulically and biologically meaningful definition of debris geometry that can be readily used in the field. When more is known about the physical and biological significance of debris in rivers, a detailed cost-benefit analysis on its management should be undertaken.

77. Gippel, C. J., B. L. Finlayson, and I. C. O'Neill. 1996. Distribution and hydraulic significance of large woody debris in a lowland Australian river. Hydrobiologia 318: 179-194.

The line-intersect technique was used to measure the loading of large woody debris in a 1.8 km reach of the Thomson River, Victoria (catchment area of 3540 km^2). A debris census (measuring every item present) was done over 0.775 km of this reach. The transect technique over-estimated the actual loading revealed by the census. The loading of debris greater than or equal to 0.01 m in diameter for the total 1.8 km reach was 0.0172 m^3/m^2, which is higher than that measured in many headwater streams in other parts of the world. The volume loading of debris measured from low level aerial photographs was only 4.8% of the value estimated by the line-intersect technique. The line-intersect estimates were biased due to non-random orientation of debris in the stream (causing estimated errors of +8% for across the channel. The mean item of debris (greater than or equal to 0.1 m in diameter) had a trunk basal diameter of 0.45 m, a length of 7.4 m, and volume of 0.7 m^3. The riparian trees and the in-channel debris were of similar dimensions. The debris tended to be close to the bed and banks and was oriented downstream by the flow at a median angle of 27 degree. Because of this orientation, most debris had a small projected cross-sectional area, with the median value being only 1 m^2. Thus, the blockage ratio (proportion of projected area of debris to channel cross-sectional area) was also low, ranging from 0.0002 to 0.1, with a median value of 0.004. The average item of debris, which occupied only 0.4% of the cross-section, would have minimal influence on banktop flow hydraulics, but the largest items, which occupied around 10%, could be significant. Judicious re-introduction of debris into previously cleared rivers is unlikely to result in a large loss of conveyance, or a detectable increase in flooding frequency.

78. Goebel, P. C. and D. M. Hix. 1996. Development of mixed-oak forests in southeastern Ohio: A comparison of second-growth and old-growth forests. Forest Ecology and Management 84: 1-21.

Traditionally, studies of forest development have independently focused on the compositional and structural differences of second-growth and old-growth forests. However, few studies have attempted to use current old-growth forest ecosystems as a benchmark with which to compare the composition, structure, and dynamics of a surrounding matrix of sequentially aged second-growth forests. In order to examine the development of mixed-oak forests we compared the composition, structure, and stand dynamics of seventeen relatively undisturbed second-growth forests (70-149 years old) with four old-growth forests (at least 150 years old) on south-facing ecological landtypes (ELTs) in southeastern Ohio. All living and dead trees over 10.0 cm dbh and coarse woody debris over 10.0 cm mid-diameter were inventoried on 500 m^2 plots. Saplings and seedlings were sampled on nested 100 m^2 and 2 m^2 subplots, respectively. Principal components analysis (PCA) was used to support the assumption that study sites had similar soils and physiography. Overstory species richness was greatest in the younger second-growth stands, and significantly differed among age classes. Five species of oaks (*Quercus* spp.) dominated the overstories of all stands. However, white oak (*Quercus alba* L.) canopy importance value (IV) ((relative dominance + relative density)/2) significantly differed among stands; it ranged from 35.5% in stands 70-89 years old to 86.1% in stands 130-149 years old, while it comprised 46.5% of the old-growth canopies. Pignut hickory (*Carya glabra* (Mill.) Sweet.) canopy IV tended to be less in the second-growth than in the old-growth stands. Whereas oaks dominated the overstories of the second-growth and old-growth stands, they were almost absent from the sapling layer of all stands (less than 5% of the total densities). The sapling layers of all age classes were comprised of shade-tolerant species. For example, American beech (*Fagus grandifolia* Ehrh.) sapling relative density significantly differed between the 70-89 year old stands (6.3%) and the stands at least 150 years old (23.9%). Even though densities of oak saplings were low, the relative densities of oak seedlings were much greater, suggesting adequate oak advance regeneration. Few significant differences in stand structure (e.g. basal area, density, mean diameter, canopy closure) or standing and fallen coarse woody debris were detected between the second-growth and old-growth forests. Detrended correspondence analyses (DCA) appeared to represent a gradient of increasing white oak IV with acre. Although indices of old-growth attributes have proven successful in discriminating between second-growth and old-growth ecosystems in other regions of North America, our results suggest that such an index would not work well in mixed-oak forests. Canopies dominated by a mixture of oaks, in conjunction with a majority of canopy individuals at least 150 years old, may be the best indicators of old-growth conditions on south-facing landtypes in southeastern Ohio.

79. Goodburn, J. M. and C. G. Lorimer. 1998. Cavity trees and coarse woody debris in old-growth and managed northern hardwood forests in Wisconsin and Michigan. Canadian Journal of Forest Research 28: 427-438.

The effects of uneven-aged management on the availability of coarse woody debris habitat were examined in northern hardwood forests (with and without a hemlock component) in north-central Wisconsin and adjacent western Upper Michigan. Snags, cavity trees, fallen wood, and recent tip-up mounds in 15 managed uneven-aged (selection) stands were compared with levels in 10 old-growth stands and six unmanaged even-aged second-growth stands. Amounts of coarse woody debris in selection stands were generally intermediate between old-growth and even-aged stands. Density of snags > 30 cm DBH in northern hardwood selection stands averaged 12/ha, approximately double that found in even-aged northern hardwoods, but only 54% of the level in old-

growth northern hardwoods. Highest densities of snags > 30 cm DBH occurred in old-growth hemlock-hardwood stands, averaging over 40 snags/ha. For combined forest types, the volume of fallen wood (> 10 cm in diameter) was significantly lower in selection stands (60 m^3/ha) and even-aged stands (25 m^{-3}/ha) than in old-growth stands (99 m^3/ha). Volume differences were even more pronounced for large-diameter debris (> 40 cm). Cavity tree density in selection stands averaged 11 trees/ha, 65% of the mean number in old-growth stands. Densities of snags (> 30 cm DBH) and large-diameter cavity trees (> 45 cm) present in selection stands exceeded current guidelines for wildlife tree retention on public forests.

80. Gowan, C. and K. D. Fausch. 1996. Long-term demographic responses of trout populations to habitat manipulation in six Colorado streams. Ecological Applications 6: 931-946.

Fish communities in high-elevation, Rocky Mountain streams consist of only one or a few trout species, so these streams are ideal for quantifying how physical habitat manipulation influences population biology. Managers often alter habitat structure in hopes of increasing the number or size of fish in a population, but this practice has not been rigorously evaluated, and the mechanisms involved are not well understood. We measured fish abundance and habitat conditions in each half of 500-m study reaches in six streams for 2 yr before and 6 yr after installing 10 low log weirs in a randomly designated half (treatment section). Mean depth, pool volume, total cover, and the proportion of fine substrate particles in the stream bed increased in treatment sections within 1 to 2 years, whereas habitat in adjacent controls remained unchanged. Abundance and biomass of adult fish, but not juveniles, increased in treatments relative to controls in all streams. Recaptures of trout that were individually tagged and others that were batch marked revealed that immigration was primarily responsible for increased adult abundance and biomass, whereas no biologically significant differences occurred for recruitment. survival, or growth. Few (< 5%) immigrants to treatment sections came from adjacent controls, indicating that the increased adult abundance did not result simply from fish redistributing within the study reach, but was caused instead by immigration from beyond the reach boundaries. Immigration to control sections was frequent as well, leading us to conclude that fish movement was common, contrary to most literature on stream trout. We also detected a high degree of concordance in fish abundance fluctuations within and among streams, suggesting that regional factors influenced fish populations over large spatial scales. Our research shows that log weirs increase trout abundance, but only if other management activities assure that fish dispersal remains unimpeded within the drainage.

81. Gray, A. N. and T. A. Spies. 1995. Water content measurement in forest soils and decayed wood using time domain reflectometry. Canadian Journal of Forest Research 25: 376-385.

The use of time domain reflectometry to measure moisture content in forest soils and woody debris was evaluated. Calibrations were developed on undisturbed soil cores from four forest stands and on point samples from decayed logs. An algorithm for interpreting irregularly shaped traces generated by the reflectometer was also developed. Two different calibration equations were needed to estimate volumetric moisture content at the four sites, but commonly implicated soil characteristics (organic matter content, bulk density, and soil texture) could not fully account for the differences between calibrations. The calibrations differed from previously published calibrations for mineral and organic soils. Estimation of moisture content in decayed wood was possible with a single significant regression. The standard errors of estimate for volumetric water content were less than 0.02 m^3/m^3 or the soil calibrations and just over 0.06 m^3/m^3 for the decayed

wood calibration. We found we could reliably interpret most traces from field samples using an automated algorithm, but had to use a modified algorithm for one of the sites. This study suggests a need to calibrate time domain reflectometry measurements for individual forest sites and advises caution when using systems that have preprogrammed calibration and trace analysis routines.

82. Graynoth, E. 1979. Effects of logging on stream environments and faunas in Nelson. New Zealand Journal of Marine and Freshwater Research 13: 79-109.

The effects of various logging practices on stream environments and faunas were studied at Golden Downs State Forest in Nelson. Comparisons were made between the features of a control stream with an unmodified forest catchment and three streams whose catchments had been affected by different logging practices. Measurements were made of stream flow, water temperature, streambed sedimentation, suspended sediment and dissolved solids concentrations, and the abundance of benthic invertebrates and fishes. Clearfelling to the stream's edge, together with inappropriate roading and bridging techniques, caused great changes in stream environments and faunas. Excessive amounts of waste timber and soil entered streams and streambed loads, and suspended sediment and dissolved solid concentrations increased. In comparison to the control stream water temperatures increased in summer by up to 6.5 degrees C and decreased in winter by as much as 2.5 degrees C. In one stream the benthic invertebrate fauna was greatly modified; there was a reduction n the abundance of Plecoptera and certain Ephemeroptera nymphs, and an increase in the abundance of oligachaetes, chironomids, and Deleatidium nymphs. Fishes, *Galaxias divergens* and *Anguilla dieffenbachi*, were also reduced in numbers in this stream.
In January 1971, numerous brown trout (*Salmo trutta*) and other fishes died in the Motueka River, and there are indications that this was due in part to low dissolved oxygen concentrations following excessive sedimentation of the river bed cased by unsatisfactory logging practices. In general, the physical and chemical changes found in the stream environments were similar to those found overseas, but those noted in the invertebrate and fish fauna were rather different, e.g. logging had different effects on the abundance of Diptera, Ephemeroptera, and Trichoptera, and on trout survival and migration. The data collected will be of some value in assessing the effects of this type of logging on other streams and their biotas in the Nelson region.
A protective buffer strip of unlogged vegetation was left alongside one stream and the remainder of the catchment was clearfelled. In comparison to the other streams there was relatively little change in the aquatic environment and fauna. Although stream flows and nitrate concentrations were considerably higher than in the control stream, these differences may have been natural and not a consequence of the logging operations. Similar results have been found overseas, and it is concluded that provided measures are taken to reduce erosion, buffer strips will be effective in reducing the effects of logging operations on stream environments and their faunas in other forests.

83. 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 and 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 recommendation about the management of channels in woodland areas are identified from 29 research papers. These recommendations are 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.

84. Gregory, K. J. and R. J. Davis. 1993. The perception of riverscape aesthetics: An example from two Hampshire rivers. Journal of Environmental Management 39: 171-185.

Although the public perception of landscape aesthetics should be considered in environmental management, previous studies of riverscapes have given insufficient attention to rivers in woodland areas. In such woodland areas it is desirable to know how the unmanaged river channels are regarded aesthetically, and whether the presence of coarse woody debris affects the perception of riverscape aesthetics. This study used carefully selected photographs of type sites representing different types of woodland channel, together with some channels affected by urbanization, all in south-central England. After an initial pilot study, a data set was obtained from a total of 199 largely student responses to a set of 20 photographic slides in three groups of geography undergraduates, psychology undergraduates and research students and staff. In addition to analysis of these responses, the slides were rated by two independent operators according to their natural character, and the content of each of the 20 photographs was analysed quantitatively so that a regression analysis could relate the quantitative variables established for each photograph to the reaction of the respondents. The most natural woodland channels containing debris are not the most highly rated, and, according to the regression equations, the assessment of channel colour, reflecting water quality and the percentage of channelized bank are the two best single predictors of overall scenic aesthetic preference. In woodland areas, the general preference is for channels which do not have in-channel debris, but the advantages of retaining such debris should be considered in channel management strategies and an improvement in the public appreciation of the significance of such debris in woodland river channels could preferably be made.

85. Gregory, K. J., R. J. Davis, and S. Tooth. 1993. Spatial-distribution of coarse woody debris dams in the Lymington Basin, Hampshire, UK. Geomorphology 6: 207-224.

Debris dams of coarse woody debris have a significant influence on channel processes in forested areas but few detailed studies have been made of variations within a single basin. Results from previous research are standardised and show that average variations throughout basins include densities of debris dams up to 40 per 100 metres of channel and can involve a loading value of up to 225 kg per m^2 of channel. Variations have been ascribed to distance downstream, to channel width, to land-use effects, to felling, and to the management of coarse woody debris in streams. This study of the Lymington Basin, 110.4 km^2 in drainage area, shows that the input of storm debris resulting from blowdown accounts for 45% of the gross load. The remaining 55% net load varies according to distance downstream, to land use with the greatest loads in deciduous woodland areas, and according to management removal of debris from streams and multiple regression equations are provided. It is deduced that as a consequence of long-term management the present channel debris may be as little as 7% of the total net load that could have been present if no management had occurred.

86. Gregory, S. V., G. A. Lamberti, D. C. Erman, K. V. Koski, M. L. Murphy, and J. R. Sedell. 1987. Influence of forest practices on aquatic production. In Streamside Management: Forestry and Fishery Interactions. E. O. Salo and T. W. Cundy (Eds). Seattle, Washington, University of Washington, Institute of Forest Resources: 233-255.

Management of streamsides for fishery resources requires a thorough knowledge of the structure and major processes of stream ecosystems. Management of streamside forests must be based on functional perspective of riparian zones that integrates geomorphic processes, terrestrial plant succession, and aquatic ecology. Forestry practices potentially alter solar radiation, water temperature, sediment, nutrient, and litter inputs, woody debris, and channel structure--all of which influence the habitat and nutritional resources of aquatic organisms. Primary producers are generally stimulated by canopy removal and the increases in nutrients and temperature that often accompany timber harvest, but instability of stream sediments may decrease plant abundance. Microbial processes may be enhanced by increases in nutrients, detrital quality, and temperature, but microorganisms may be negatively affected by a decreased quantity of detritus or decreased oxygen concentrations. The ability of streams to retain algae and litter inputs for food resources and retain sediments for habitat is determined by channel complexity, especially accumulation of woody debris. Aquatic insects and other invertebrates respond to changes in habitat and food resources. Sedimentation and decreased substrate stability may decrease the abundance of aquatic insects. Herbivores benefit from stimulation of aquatic plants; detrivores may be negatively affected by the changes in detritus. Frequently, insect community structure shifts toward organisms that are more likely to drift, thereby increasing the availability of food for salmonids. Salmonids also more efficiently capture prey items in open areas where light intensities are greater. These potential benefits may be negated if thermal tolerances are exceeded by temperature increases, if sediments blanket rearing and spawning habitat, or if winter habitat is reduced. Changes in habitat, food, or temperature may also alter fish community structure and potentially increase competition with the species of interest. Streams in harvested watersheds may therefore be more productive, but the abundance and distribution of organisms in these streams may fluctuate more than in streams in mature forests. Resource objectives must be clearly defined before fishery resources can be effectively managed in forest ecosystems. The landscapes and biotic communities of terrestrial and aquatic ecosystems are intricately linked, and effective management must acknowledge and incorporate such complexity.

87. Gregory, S. V., G. A. Lamberti, and K. M. S. Moore. 1989. Influence of valley floor landforms on stream ecosystems. California Riparian Systems Conference, University of California, Davis: 3-9. USDA Forest Service.

A hierarchical perspective of relationships between valley floor landforms, riparian plant communities, and aquatic ecosystems has been developed based on studies of two fifth order basins in the Cascade Mountains of Oregon. Retention of dissolved nitrogen and leaves were approximately 2-3 times greater in unconstrained reaches than in constrained reaches. Both valley floor landforms and riparian plant communities influenced the abundance of primary producers. Abundances of cutthroat and rainbow trout in unconstrained reaches were approximately twice those observed in constrained valley floors. Valley floors are one of the most physically dynamic components of the landscape, incorporating major agents of terrestrial disturbance and fluvial disturbance. These corridors are major routes for the flux of water, sediments, nutrients, and species. Because of their unique properties, valley floors play an important role in landscape ecology.

88. Grizzel, J. D. and N. Wolff. 1998. Occurrence of windthrow in forest buffer strips and its effect on small streams in northwest Washington. Northwest Science 72: 214-223.

Retaining streamside buffers has become a common way of protecting streams during timber harvest operations. Trees within forest buffers help stabilize streambanks, provide shade, and serve as a source of large woody debris. However, buffer trees are often subject to increased levels of windthrow which may impair some buffer functions. Forty (40) forest buffers bordering small, non-fish bearing streams in northwest Washington were assessed to quantify the level and in-stream effects of windthrow 1 to 3 years after clearcut harvest of adjacent timber. On average, windthrow affected 33 percent of buffer trees and ranged-from 2 to 92 percent across the 40 sites. Sixty-seven percent of windthrown trees fell to the north, northeast, or northwest, while only three percent of the total fell towards the south. Large woody debris present in streams at the time of harvest was significantly larger than debris recruited as a result of buffer windthrow (t-test; $p<0.01$). Windthrow increased total in-stream large woody debris piece counts by 52 percent. Seventy-five percent of in-stream large woody debris pieces recruited to streams post-harvest were suspended above the bankfull channel while four percent stored sediment. Seventeen percent of uprooted trees delivered sediment to stream channels. The average volume input was 0.16 cubic meters per uprooted tree and 0.48 cubic meters per 100 meters of stream channel at 39 sites where mass wasting did not occur. At most sites, the volume of sediment input to streams was small relative to the amount stored behind obstructions. Large woody debris was the primary component of 93 percent of in-stream obstructions which stored sediment.

89. Guby, N. A. B. and M. Dobbertin. 1996. Quantitative estimates of coarse woody debris and standing dead trees in selected Swiss forests. Global Ecology and Biogeography Letters 5: 327-338.

Coarse woody debris and standing dead trees play a crucial role in biodiversity and the functioning of forest ecosystems. Little information is currently available concerning the amount and distribution of coarse woody debris in Swiss forests, and little is known about the relative abundance of lying dead trees and standing dead trees in managed and unmanaged forests. In this study, data were collected from eleven sites in order to assess the volume and the decay stages of coarse woody debris and of standing dead trees. There were substantial differences in deadwood volume between sites, but sampling variability was high. The amount of dead wood found in the study sites was substantially smaller than the estimated amount from studies in virgin forests and in the range of values found for other managed and unmanaged forests in Europe. Most of the dead wood material belonged to young decay states. As expected, there was more dead wood in unmanaged than in managed stands, and in mature stands as compared with young stands. In particular, most unmanaged stands had significantly more standing dead trees than most managed stands, indicating that, in Switzerland, diseased and dead trees are removed by salvage cutting.

90. Gurnell, A. M. and K. J. Gregory. 1995. Interactions between seminatural vegetation and hydrogeomorphological processes. Geomorphology 13: 49-69.

Within Britain lowland heaths and floodplain forests are rapidly disappearing from the landscape. This paper considers the hydrogeomorphological significance of these two types of semi-natural vegetation cover using research results gathered from a drainage basin in the New Forest, southern England. Whilst heathland vegetation communities are closely adjusted to the soil water hydrological regime, floodplain forests have a distinctive and significant influence on the geomorphology of river channels. Both of these types of interaction are not only of hydrogeomorphological interest, but provide an essential foundation for the effective management and restoration of catchments and rivers containing these types of vegetation cover.

91. Gurnell, A. M., K. J. Gregory, and G. E. Petts. 1995. The Role of 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 pending 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.

92. Gurnell, A. 1997. The hydrological and geomorphological significance of forested floodplains. Global Ecology and Biogeography Letters 6: 219-229.

Within river corridors, the distribution of plant species and communities is heavily influenced by hydrological and geomorphological processes. Furthermore, the vegetation can have a direct influence on the detailed character and rate of hydrogeomorphological processes. This paper reviews such interactions at a variety of spatial scales ranging from vegetation gradients across entire floodplains from hillslope to river channel, to the local influences of bank vegetation and in-channel accumulations of woody debris.

93. 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 (1.8-4.5m) and gradient (0.013m m^{-1}), 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. (C) 1998 John Wiley & Sons, Ltd.

94. Gurtz, M. E., G. R. Marzolf, K. T. Killingbeck, D. L. Smith, and J. V. McCarthur. 1988. Hydrologic and riparian influences on the import and storage of coarse particulate organic matter in a prairie stream. Canadian Journal of Fisheries and Aquatic Sciences 45: 655-665.

The hydrologic regime and zonation of riparian vegetation influenced the quantity and quality of coarse particulate organic matter (CPOM; > 1 mm) stored in the channel and upper bank of a prairie stream. In a 5.4-km intermittent reach of the South Branch of Kings Creek on Konza Prairie, Kansas [USA], total annual import was lowest in headwater reaches and increased downstream. Total storage of benthic CPOM in the dry channel and on the bank before the flow period was highest in the fourth- and fifth-order gallery forest zone (999 g ash-free dry mass/m^2) and less in upstream reaches (320-341 g/m^2). These longitudinal patterns of CPOM annual import and storage (before the flow period) were opposite those predicted by the river continuum concept for streams draining forested regions. Following flow, headwater channels had more CPOM (291 g/m^2) than downstream reaches. On the bank, storage was always highest in downstream reaches. Composition of CPOM both in the channel and on the bank varied with changes in riparian vegetation; grass tissues dominated in headwater channels, while wood and leaves of trees and shrubs were more abundant downstream. During the flow period, storage of CPOM increased only in headwater channels, where retention was high despite the lack of woody debris. In this intermittent prairie stream, benthic CPOM may not contribute consistently to the terrestrial/aquatic linkages that are suggested in the river continuum concept because of (1) a paucity of large CPOM sources (e.g. trees, shrubs) in the upper reaches and (2) a hydrologic regime that reduces the amount, as well as the predictability, of stored CPOM. The biota of prairie streams must have opportunistic food gathering and reproductive strategies to take advantage of variable food resources in a flow environment that is itself very unpredictable.

95. Hagan, J. M. and S.L. Grove. 1999. Coarse woody debris. Journal of Forestry 97: 6-11.

Dead wood is usually the last thing foresters and forest products companies want to see in their forests. However, before humans discovered so many practical uses of wood, dead and dying trees were basic to forest development. Not surprisingly, many plants and animals evolved dependencies on dead wood. Today, with maintaining biodiversity a primary goal of forest management, foresters are confronted with seemingly contradictory goals. prevent or minimize agents that damage trees, but also maintain biodiversity, including the species that need dead wood.

96. Hairston-Strang, A. B. and P. W. Adams. 1998. Potential large woody debris sources in riparian buffers after harvesting in Oregon, USA. Forest Ecology and Management 112: 67-77.

Twenty-one riparian buffers on private lands in Oregon were measured after harvest using the 1994 revised Oregon Forest Practices Rules to determine their ability to contribute large woody debris (LWD) to streams for fish habitat. On average, 51% of the trees retained in riparian buffers after harvest currently would be capable of adding debris at least 20 cm diameter and 1.5 m length to the channel. Assuming 30% of trees are windthrown over 10 years and that trees fall in random directions, the riparian buffers would be expected to add an average of 0.6 trees per 100 m (1.9 trees per 1000 ft) of stream as LWD over 10 years. Analysis showed significantly greater LWD inputs ($p<0.05$) when the likelihood of more frequent windthrow on riparian terraces and of trees tending to fall downhill on steep slopes are considered. On the sites investigated and with the information available, considering tree lean did not significantly increase expected LWD delivery. More data on windthrow rates and direction are needed to confirm the analyses. Depending on longevity, the expected frequency of LWD pieces could remain within ranges observed in undisturbed stands.

97. Hall, J. D. and R. L. Lantz. 1968. Effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams. Symposium on Salmon and Trout in Streams, University of British Columbia: 355-375. Institute of Fisheries, University of British Columbia.

The effects of two patterns of Douglas-fir logging on water quartile and fish populations have been studied in three coastal headwater streams. Clearcut logging of an entire watershed of 71 hectares (175 acres) is being compared to clearcutting in patches on a larger watershed of 304 hectares (750 acres) where about 30 percent of the area has been harvested and a strip of timber left along the stream. The third watershed of 203 hectares (500 acres) will remain unlogged as a control. Pre-logging studies began in 1958, access roads were constructed in 1965, and logging took place in 1966.
Substantial changes in temperature and dissolved oxygen content of stream water followed logging in the entirely clearcut watershed. A maximum temperature of 30 Celsius and a maximum diurnal fluctuation of 19 Celsius were recorded. Comparable pre-logging maximums were 16 Celsius and 1.5 Celsius, respectively. Dissolved oxygen levels of surface and intragravel water dropped below 2 mg/l during logging operations. Survival of coho salmon and cutthroat trout in the clearcut watershed has not been affected by logging, but the significance of the effect cannot yet be fully evaluated. No significant changes in the fish population or its habitat have been noted in the patch-cut watershed. Studies will continue for several years to evaluate long-term effects of logging on the stream and to determine the period of recovery.

98. Halpern, C. B., S. A. Evans, C. R. Nelson, D. McKenzie, D. A. Liguori, D. E. Hibbs, and M. G. Halaj. 1999. Response of forest vegetation to varying levels and patterns of green-tree retention: An overview of a long-term experiment. Northwest Science 73: 27-44.

Timber harvest with retention of Live ("green") trees, snags, and logs is now a standard practice on federal "matrix" lands within the range of the northern spotted owl. Although specific guidelines have been adopted for the levels and spatial configurations of retained structures, neither the ecological assumptions that underlie these recommendations nor the outcomes of these practices have been rigorously tested. The Demonstration of Ecosystem Management Options (DEMO) study examines the responses of forest ecosystems in the Pacific Northwest to varying levels (percentage of basal area) and patterns (dispersed versus aggregated) of green-tree retention. In this paper we describe vegetation studies that form the foundation of this long-term, interdisciplinary experiment. We review the results of retrospective analyses and simulation models which suggest that even minimal levers of retention may have important effects on forest development. We describe the characteristics of the DEMO sites, the experimental design, and the principal variables of interest (stand structure, tree regeneration and growth, and understory composition and diversity). We speculate about the silvicultural and ecological responses of forests to varying levels and patterns of retention and focus in particular on the dynamics of the forest understory. We anticipate strong contrasts among treatments in the establishment of early-seral, open-site species, and in the persistence of shade-tolerant plants associated with older forests or forest-interior environments. Short-term responses are likely to be driven by Variation in the distribution and intensity of harvest disturbance. Longer-term trends are expected to reflect the effects of contrasting patterns of canopy retention. We conclude by discussing some of the scientific challenges faced in designing and implementing large-scale, interdisciplinary experiments.

99. Hanchet, S. M. 1990. Effect of land use on the distribution and abundance of native fish in tributaries of the Waikato River in the Hakarimata Range, North Island, New Zealand. New Zealand Journal of Marine and Freshwater Research 24: 159-172.

The effect of land use on fish community structure was examined at fifty-five sites in tributaries draining exotic, indigenous forest and pastoral catchments in the Hakarimata range in March and April 1987. Using a model containing percentage woody debris, temperature, and substrate coarseness, 76% of the sites were classified into correct land uses by discriminant analysis. This indicated that differences in stream habitat, and hence of the fish fauna, were related to effects of changed land use rather than other confounding physical or geographical features of the streams in the catchments. Tributaries in indigenous forest were numerically dominated by banded kokopu (*Galaxias fasciatus*) and longfinned eel (*Anguilla dieffenbachii*), with redfinned bully (*Gobiomorphus huttoni*) and giant kokopu (*G. argenteus*) occasionally being caught. Pastoral streams below the forest generally supported higher densities and contained more species including the forested species above, Cran's bully (*G. basalis*), and shortfinned eel (*A. australis*). As the amount of indigenous forest in the catchment decreased the fauna became less abundant and less diverse and was dominated by both species of eel and Cran's bully.

100. Harmon, M. E, J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. R. Sedell, G. W. Lienkamper, et al. 1986. Ecology of coarse woody debris in temperate ecosystems. In Advances in Ecological Research. A. MacFadyen and E. D. Ford (Eds). New York, NY, Harcourt Brace Jovanovich. **15:** 133-302.

1. Coarse woody debris is an important component of temperate stream and forest ecosystems. We have reviewed the rates at which CWD is added and removed from ecosystems, the biomass found in stream and forests, and many functions that CWD serves.
2. CWD is added to ecosystems by numerous mechanisms, including wind, fire, insect attack, pathogens competition, and geomorphic processes. Despite the many long-term studies in tree mortality, there are few published rates of CWD input on (mass/area)/time basis. Most ecological studies have not measured CWD input over a long enough period or a large enough area to give accurate estimates. Input rates measured in temperate ecosystems range from 0.12 to 14.9 Mg/ha/year and vary greatly over time and space.
3. Once CWD enters the detrital food web, it is decomposed by a large array of organisms and physical processes. Although respiration-caused losses have been the focus of many studies, CWD is also significantly transformed physically and chemically. Movement of CWD, especially in streams, is also an important but poorly documented mechanism whereby CWD is lost from ecosystems. Many factors control the rate at which CWD decomposes, including, temperature, moisture, the internal gas composition of CWD, substrate quality, the size of the CWD, and the types of organisms involved. However, the importance of many of these factors has yet to be established in field experiments.
4. The mass of CWD in an ecosystem ideally represents the balance between addition and loss. In reality, slow decomposition rates and erratic variation in input of CWD cause the CWD mass to deviate markedly from steady-state projections. The mass of CWD in stream and forest ecosystems varies widely, ranging between 1 and 269 Mg/ha. Many differences correspond to forest type, with deciduous-dominated systems having generally lower biomass than conifer-dominated systems. However, conifer-dominated systems with low productivity also have low CWD mass. Stream size also influences CWD mass in lotic ecosystems, while successional stage dramatically influences CWD mass in both aquatic and terrestrial settings.
5. CWD performs many functions in ecosystems, serving as autotrophic and heterotrophic habitat and strongly influencing geomorphic processes, especially in streams. It is also a major component of nutrient cycles in many ecosystems. We have reviewed these many functions and conclude that CWD is an important functional component of stream and forest ecosystems.
6. Humans have greatly affected the amount of CWD found in temperate ecosystems by removing CWD and by changing the rate of input and the rate and pattern of loss. In some cases, human influences have been so pervasive that natural conditions are difficult to define. Management practices concerning CWD often have not been based on the numerous beneficial roles this material plays in ecosystems. Better scientific understanding of these functions and the natural factors influencing CWD dynamic should lead to more enlightened management practices.

101. Harmon, M. E., K. Cromack, Jr., and B. G. Smith. 1987. Coarse woody debris in mixed-conifer forests, Sequoia National Park, California USA. Canadian Journal of Forest Research 17: 1265-1272.

The decay rate of *Abies concolor* (Gord. And Glend.) Lindl. logs and cover, mass, and volume of logs and snags in six mid-elevational forest stands of Sequoia National Park, California, are reported. Based on a chronosequence, Abies concolor boles have a decay rate constant of 0.05/year and a half-life of 14 years. A decay classification system was developed for *Abies concolor*, *Calocedrus decurrens* (Torr.) Florin, *Pinus jeffreyi* Grev. and Balf., and *Pinus lambertiana* Dougl. logs. Dimensions taken form maps of six permanent plots were combined with decay-class information to estimate volume, mass, and projected cover of logs and snags. Total mass ranged from 29 Mg/ha in a *Pinus jeffreyi* forest to 400 Mg/ha in a *Sequioadendron giganteum* (Lindl.) Buchh. dominated stand. Volume, projected cover, and nitrogen storage exhibited patterns similar to mass, ranging form 84 to 1160 m^3/ha, 3.1 to 9.3% and 41 to 449 to kg/ha, respectively.

102. Harmon, M. E., J. Sexton, B. A. Caldwell, and S. E. Carpenter. 1994. Fungal sporocarp mediated losses of Ca, Fe, K, Mg, Mn, N, P, and Zn from conifer logs in the early stages of decomposition. Canadian Journal of Forest Research 24: 1883-1893.

The export of mass and nutrients associated with the formation of fungal sporocarps during the first 7 years of decomposition of logs of four conifer species (*Abies amabilis* Dougl. ex Forbes, *Pseudotsuga menziesii* (Mirb.) Franco, *Thuja plicata* D. Don, and *Tsuga heterophylla* (Raf.) Sarg.) was investigated in western Oregon. Abundance of the most common fungal species, *Naematoloma capnoides* (Fr.:Fr.) P. Kumm, differed significantly with log species; the fungus was most abundant on Abies and least abundant on Thuja. Fungi increased concentrations of N, K, and P over those found in associated logs by as much as 38, 115, and 136 times, respectively. Thus, a fair proportion of the initial N (0.9-2.9%), K (1.8-4.5%), and P (1.9-6.6%) was transported out of logs via sporocarps at a time when immobilization would have been predicted from critical element ratios (e.g., C/N).

103. Harmon, M. E., S. L. Garman, and W. K. Ferrell. 1996. Modeling historical patterns of tree utilization in the Pacific Northwest: Carbon sequestration implications. Ecological Applications 6: 641-652.

We have developed a model, HARVEST, that predicts the mass of woody detritus left after timber harvest in Pacific Northwest forests from 1910 to the present. Inputs to the model include the species, diameter at breast height, and age distribution of trees; the minimum tree size to be harvested; the minimum top diameter; and stump height and slope steepness. Model output includes the absolute amount and the proportion of bole biomass removed as well as that left as stumps, tops, breakage, and decay. The model also predicts the biomass of nonmerchantable parts such as branches, coarse roots, and fine roots left after harvest. Model predictions were significantly correlated to residue levels reported in the literature over this period. Both model output and historical data indicate that the total amount of aboveground woody residue left after logging has decreased at least 25% over the last century. This means that release of carbon to the atmosphere from woody residue has decreased by a similar amount.

104. Harr, R. D. 1976. Hydrology of small forest streams in western Oregon. USDA Forest Service, General Technical Report, PNW-55.

The hydrology of small forest streams in western Oregon varies by time and space in terms of both streamflow and channel hydraulics. Overland flow rarely occurs on undisturbed soils. Instead, water is transmitted rapidly through soils to stream channels by displacement of stored soil water. Drainage networks expand and contract according to the interaction between precipitation characteristics and soil's capability to store and transmit water. Drainage networks are more extensive in winter than in summer. Streamflow may be 1,000 to 3,000 times greater during winter storms than during summer low flow. A stream' kinetic energy varies along with streamflow. Channel width and depth, heterogeneity of bed material and the accumulation of large organic debris affects the dissipation of kinetic energy. Clearcutting can increase relatively small peak flows, but forest roads and extensive areas of soil compacted by other means may increase large peak flows. Both road building and clearcutting can cause soil mass movements which can drastically alter a stream's channel hydraulics by adding debris or scouring the channel to bed rock. Removal of naturally occurring organic debris that has become part of a stable channel can accelerate bed and bank erosion.

105. Hartman, G. F., J. C. Scrivener, and T. E. McMahon. 1987. Saying that logging is either "good" or "bad" for fish doesn't tell you how to manage the system. The Forestry Chronicle 159-164.

A 16-year multi-disciplinary watershed study at Carnation Creek, British Columbia, revealed that different activities in a forest harvest program had different impacts on the physical and biological components of the system. Changes in stream temperature, as a result of logging and a climatic warming trend, and changes in the distribution and volume of woody debris in the channel caused complex sequences of processes to influence salmonid production in both a positive and negative manner. The influence depended on the type of physical change, the fish species and its life history stage, and on the elapsed time after the logging activity. Some direct implications of the research to the problems of managing in the face of complexity are discussed

106. Harvey, B. C. 1998. Influence of large woody debris on retention, immigration, and growth of coastal cutthroat trout (*Oncorhynchus clarki clarki*) in stream pools. Canadian Journal of Fisheries and Aquatic Sciences 55: 1902-1908.

Over 4 months and about 1 year, coastal cutthroat trout (*Oncorhynchus clarki clarki)* > age-1 in Little Jones Creek, California, remained at similar rates in pools with and without large woody debris. This result was based on attempts in July and November 1995 to collect and tag all fish in 22 pools and three collections of fish from the same pools in November 1995, May 1996, and August 1996. Retention of fish appeared to be greater in pools with large woody debris in May 1996. The presence of large woody debris in pools did not influence immigration or growth of cutthroat trout. However, both immigration and growth increased downstream over the 3850 m study reach. Low retention and substantial immigration of cutthroat trout into experimental pools indicate that movement is important in the dynamics of this population. First- and second-order channels appear to be important sources of fish for the third-order study reach, while the study reach may export significant numbers of fish to downstream reaches accessible to anadromous fish.

107. Hauer, F. R. 1989. Organic matter transport and retention in a blackwater stream recovering from flow augmentation and thermal discharge. Regulated Rivers: Research and Management 4: 371-380.

Organic and inorganic seston, benthic organic matter and woody debris were studied in a blackwater stream/floodplain system recovering from flow augmentation and thermal discharges. The stream had received cooling waters from two nuclear reactors from the mid-1950s to 1968, resulting in flows over 10 times eater than normal and temperatures that exceeded 70.degree C. Channel morphology was markedly altered, woody debris was removed or buried, and floodplain vegetation was destroyed. Fifteen years after termination of cooling water discharges, the stream continued to exhibit many characteristics of a disturbed system. Compared to an undistributed reference stream, the recovering stream had substantially less benthic organic matter, fewer snags and debris dams, and transported more organic and inorganic seston of all size fractions examined. Because of the importance of these biophysical factors in the structural morphology of blackwater streams, it is hypothesized that complete recovery will not be realized until the floodplain forest has matured and large woody debris is contributed to the stream channel.

108. Hawkins, C. P, J. L. Kershner, P. A. Bison, M. D. Bryant, L. M. Decker, S. V. Gregory, D. A. McCullough, C. K. Overton, G. H. Reeves, R. J. Steedman, and M. K. Young. 1993. A hierarchical approach to classifying stream habitat features. Fisheries 18: 3-12.

We propose a hierarchical system of classifying stream habitats based on three increasingly fine descriptions of the morphological and hydraulic properties of channel geomorphic units. We define channel geomorphic units as areas of relatively homogeneous depth and flow that are bounded by sharp gradients in both depth and flow. Differences among these units provide a natural basis for habitat classification that is independent of spatial scale. At the most general level of resolution, we divide channel units into fast- and slow-water categories that approximately correspond to the commonly used terms "riffle" and "pool." Within the fast-water category, we identify two subcategories of habitats, those that are highly turbulent (falls, cascades, chutes, rapids and riffles) and those with low turbulence (sheets and runs). Slow-water habitats include pools formed by channel scour (eddy pools, trench pools, midchannel pools, convergence pools, lateral scour pools and plunge pools) and those formed behind dams. Dammed pools include those obstructed by debris dams, beaver dams, landslides and abandoned channels. We consider back- waters as a type of dammed pool. Fishes and other stream organisms distinguish among these habitats at one or more levels of hierarchy. Habitats defined in this way represent an important habitat template on which patterns of biological diversity and production form. We believe that a hierarchical system of classification will facilitate understanding of biotic-habitat relationships in streams and lead to more effective methods of evaluating the effects of environmental change on stream ecosystems. Refining the criteria by which habitats are distinguished, quantifying how different species use different habitats, and integrating the ways biota respond to habitat variation should facilitate the emergence of a theory of stream habitat organization.

109. Hax, C. L. and S. W. Golladay. 1998. Flow disturbance of macroinvertebrates inhabiting sediments and woody debris in a prairie stream. American Midland Naturalist 139: 210-223.

We studied the effect of an engineered flow disturbance on macroinvertebrates in an intermittent N Texas stream. To augment a drinking water supply, water is being diverted through the natural stream channel. Quantitative sampling of sediments and woody debris was conducted immediately before water diversion, immediately after and periodically during recovery, for three diversion events over a 2 yr period. Reduction in total density of macroinvertebrates was dependent on type of substrate, averaging 76% in sediments as compared with 66% on woody debris. Recovery was rapid for most taxa, which often reached predisturbance density in less than 1 mo. For the entire macroinvertebrate assemblage in 1992 and chironomids only in 1991, resilience was greater on woody debris than on sediments. Compared with sand, the common inorganic substrate in this stream, woody debris was more stable, due in part to its retention by debris dams. It appears that woody debris is an important refuge and source of recolonizers to this sandy prairie stream after flow disturbances.

110. Hedin, L. O. 1990. Factors controlling sediment community respiration in woodland stream ecosystems. Oikos 57: 94-105.

In shaded woodland streams, sediment community respiration is an important measure of decomposition of organic matter. In situ rates of community respiration were measured in sediments from shaded woodland streams at the Hubbard Brook Experimental Forest (HBEF), USA, by estimating rates of CO_2 production in low-disturbance benthic chambers. Rates of sediment community respiration (range: 26-340 mg C/m^2/d) were closely correlated with amounts of sediment organic matter, but not with water column DOC or sediment size structure. Analysis of literature data indicated similar couplings between community respiration and sediment organic matter in other streams and in lakes and marine systems. However, respiration per unit organic matter was 23-fold higher in lakes and marine systems than in woodland streams, apparently due to differences in quality of organic matter (algae and macrophytes vs terrestrial detritus). In HBEF streams, community respiration was elevated in sediments of organic debris dams, suggesting that organic debris dams are focal sites of metabolism and nutrient regeneration in the stream channel.

111. Hedman, C. W., D. H. Van Lear, and W. T. Swank. 1996. In-stream large woody debris loading and riparian forest seral stage associations in the southern Appalachian Mountains. Canadian Journal of Forest Research 26: 1218-1227.

Large woody debris (LWD) is an important ecological component of mountain streams. However, the relation of LWD loading and riparian forest composition is poorly understood in the southern Appalachians. In this study, 500-m reaches of 11 riparian forest-stream systems representing a 300-year sere were inventoried and measured to obtain quantitative estimates and descriptions of in-stream LWD. Loading volumes ranged from 7.1 to 31.2 m^3/100 m of stream, or between 3.6 and 13.2 kg/m^2. LWD loadings were highly variable during midseral stages of plant community succession, primarily because of the wide range in loading of American chestnut (*Castanea dentata* (Marsh.) Borkh.). Loadings increased linearly in late-successional through old-growth systems over a 165-year interval. Eastern hemlock (*Tsuga canadensis* (L.) Carriere) and American chestnut were the most dominant carry-over LWD species in midsuccessional stream systems. Loading of eastern hemlock LWD increased from midsuccessional

through old-growth stages as the species became dominant in the riparian forest. Without carry-over debris, LWD loadings would be extremely low in midsuccessional stream systems. American chestnut was a major component of LWD in midsuccessional stream systems, despite the fact that it has been unavailable for recruitment for decades.

112. Heede, B. H. 1972. Flow and Channel Characteristics of Two High Mountain Streams. USDA Forest Service, Research Paper, RM-96. USDA Forest Service.

Steps provided by logs fallen across the channel added to flow energy reduction. The streams required an additional number of gravel bars to adjust to slope. Average step length between logs and gravel bars are strongly related to channel gradient and median bed material size. More bars formed when fewer numbers of logs were available. Although these are "rushing mountain streams," most values for flow velocities ranged between 0.5 and 2.5 feet per second. Exponents of function expressing rate of change of depth or velocity, respectively, with discharge, indicated that dynamic stream equilibrium was attained. Implications for forest management are that sanitation cuttings (removal of dead and dying trees) would not be permissible where dynamic stream equilibrium exists and bed movement should be minimized.

113. Heede, B. H. 1985. Channel adjustments to the removal of log steps: and experiment in a mountain stream. Environmental Management 9: 427-432.

Fallen trees and their large debris often form log steps in small mountain stream, where they are incorporated into the hydraulic geometry. The hypothesis here was that these log steps take the place of gravel bars that otherwise would have been required for channel slope adjustment. In this experiment, the treated as well as the control stream were located in virgin mixed conifer forest and until the study began, no human activity had interfered with the natural developments. All log steps were removed from a stream and the formation of new log steps prohibited by periodic removal of fallen trees and branches. Five years later, 74 % of all removed log steps had been replaced by gravel bars, thus proving the hypothesis that increased bedload movement was required to offset the loss of log steps. Implications are that streamside forests should be managed so that they provide a steady supple of debris for channel stability.

114. Heede, B. H. 1985. Interactions between streamside vegetation and stream dynamics. USDA Forest Service, General Technical Report, RM-120.

Interrelationships between vegetation and hydrologic processes in riparian ecosystems must be considered by managers before they attempt to alter these natural systems. A 5-year experiment demonstrated that logs that fall across the channel from streamside forests dissipate flow energy, maintain stability, decrease bedload movement, and increase water quality.

115. Heifetz, J., M. L. Murphy, and K. V. Koski. 1986. Effects of logging on winter habitat of juvenile salmonids in Alaskan [USA] streams. North American Journal of Fisheries Management 6: 52-58.

Effects of logging on preferred winter habitats of juvenile salmonids in southeastern Alaskan streams were assessed by comparing the area of preferred winter habitat in 54 reaches of 18 streams. Three types of streams were sampled at each of six locations: a stream in a mature, undisturbed forest; a stream in a clear-cut but logged on at least one bank; and a stream in a clear-cut area with strips of forest (buffer strips) along the stream bank. To identify preferred winter habitats, we classified stream areas in 12 of 18 streams into discrete habitat type and compared the density of salmonids within these habitat types with average density of the entire reach. Most wintering coho salmon (*Oncorhynchus kisutch*), Dolly Varden (*Salvelinus malma*), and steelhead (*Salmo gairdneri*) occupied deep pools with cover (i.e., upturned tree roots, accumulations of logs, and cobble substrate). Riffles, glides, and pools without cover were not used. Seventy-three percent of all pools were formed by large organic debris. Reaches in clear-cut areas without buffer strips had significantly less area of pool habitat than old-growth reaches. Buffer strips protected winter habitat of juvenile salmonids by maintaining pool area and cover within pools. In some cases, blowdown from buffer strips added large organic debris to the stream and increased the cover within pools.

116. Hickin, E. J. 1984. Vegetation and river channel dynamics. Canadian Geographer 28: 111-126.

The physical science of fluvial geomorphology is flawed because it ignores processes that are not easily quantifiable and physically manipulable. The influence of vegetation on river behavior and fluvial geomorphology is a set of these processes. Vegetation may exert significant control over fluvial processes and morphology through five mechanisms: flow resistance, bank strength, bar sedimentation, formation of log-jams, and concave bank bench deposition. Examples of these mechanisms, Largely drawn form the Squamish River in British Columbia, are presented, and implications for future research are briefly discussed.

117. Hilderbrand, R. H., A. D. Lemly, C. A. Dolloff, and K. L. Harpster. 1997. Effects of large woody debris placement on stream channels and benthic macroinvertebrates. Canadian Journal of Fisheries and Aquatic Sciences 54: 931-939.

Large woody debris (LWD) was added as an experimental stream restoration technique in two streams in southwest Virginia. Additions were designed to compare human judgement in log placements against a randomized design and an ummanipulated reach, and also to compare effectiveness in a low- and a high-gradient stream. Pool area increased 146% in the systematic placement and 32% in the random placement sections of the low-gradient stream, lending support to the notion that human judgement can be more effective than placing logs at random in low-gradient streams. Conversely, the high-gradient stream changed very little after LWD additions, suggesting that other hydraulic controls such as boulders and bedrock override LWD influences in high-gradient streams. Logs oriented as dams were responsible for all pools created by additions regardless of stream or method of placement. Multiple log combinations created only two pools, while the other seven pools were created by single LWD pieces. Total benthic macroinvertebrate abundance did not change as a result of LWD additions in either strewn, but net abundances of Plecoptera, Coleoptera, Trichoptera, and Oligochaeta

decreased, while Ephemeroptera increased significantly with the proportional increase in pool area in the low-gradient stream.

118. Hilderbrand, R. H., A. D. Lemly, C. A. Dolloff, and K. L. Harpster. 1998. Design considerations for large woody debris placement in stream enhancement projects. North American Journal of Fisheries Management 18: 161-167.

Log length exerted a critical influence in stabilizing large woody debris (LWD) pieces added as an experimental stream restoration technique. Logs longer than the average bank-full channel width (5.5 m) were significantly less likely to be displaced than logs shorter than this width. The longest log in stable log groups was significantly longer than the longest log in unstable groups. The distances moved by dis placed logs demonstrated a quadratic relationship associated with log length; longer logs moved less often, but they moved farther when entrained in the current than the majority of mobile smaller logs. Log stability did not differ between a treatment section with randomized placement of LWD and a section in which LWD was placed systematically to best modify channel habitats. Channel scouring typically occurred around LWD oriented as ramps and as dams perpendicular to stream flow; aggradation occurred above and below pieces oriented as dams angled to the current. Microscale channel responses to LWD additions varied.

119. Hogan, D. L., S. A. Bird, and M. A. Hassan. 1998. Spatial and temporal evolution of small coastal gravel-bed streams: influence of forest management on channel morphology and fish habitats. In Gravel-Bed Rivers in the Environment. P. C. Klingeman, R. L. Beschta, P. D. Komar and J. B. Bradley (Eds). Highlands Ranch, Colorado, Water Resources Publications: 1701-1720.

Spatial and temporal response of stream channels to natural and forest management-related disturbance was studied in 12 watershed, including 34 internal sub-basins, in the Queen Charlotte Island of British Columbia, Canada. These coastal watersheds have a range of logging histories and the channels have experienced natural landslide impacts spanning more than a century. Longitudinal surveys covered along 44 km of channel, including 1193 and 1547 channel widths in forested and logged watersheds, respectively. A direct link exists between landslide occurrence and channel morphology. Landslides initiate large woody debris (LWD) jams in these streams. Logging on steep hillslopes accelerates landslide frequency with a corresponding increase in the number of recently formed debris jams. Specific morphological changes occur upstream and downstream of the jams, impacting fish spawning, egg incubation, and rearing habitats. Streams associated with these young jams are characterized by extensive riffles, shallow pools, less stable bars and in increased frequency, extent and duration of dry channel beds; all contribute to fish habitat degradation.
Influence of debris jams on channel morphology changes over time as jams deteriorate. Channel morphology is radically altered during the first decade following landslide inputs but begins to resemble undisturbed conditions after approximately 35 years. Complex and diverse channels are typical after 50 years. Historical forest management of coastal watersheds has led to a shift in the age distribution of LWD jams. Future management must ensure that any shift in landslide frequency, and therefore debris jam age distribution, be minimized to maintain channel and fish habitat integrity.

120. Horvath, T. G. and G. A. Lamberti. 1997. Drifting macrophytes as a mechanism for zebra mussel (*Dreissena polymorpha*) invasion of lake-outlet streams. American Midland Naturalist 138: 26-36.

Veligers spawned from lake populations are thought to be the major means for spread of zebra mussels (*Dreissena polymorpha*) into outflowing rivers. We hypothesized, however, that adult zebra mussels attached to lake macrophytes could enter outflowing streams by 'rafting' on uprooted macrophytes originating in lakes. Drifting macrophytes were collected on three occasions (8-h, mid-channel, seine samples) from Christiana Creek (the outflow of invaded Christiana Lake, southwestern Michigan). On average, 2620 adult mussels entered the stream per day attached to plants, mostly on wild celery (*Vallisneria americana*). To measure experimentally the transport of macrophytes, 50 *V. americana* plants were tagged with flagging tape, released and recollected (N = 5 releases). Average transport distance of macrophytes was 333 m, and the presence of attached mussels did not affect transport distance. Woody debris was the most important retention item, entrapping 85% of the released macrophytes. Drift of macrophytes from upstream lakes provides a mechanism by which adult zebra mussels can invade outlet streams, but retention appears to limit downstream transport to relatively short distances. Regardless, high potential survival of adult mussels compared to veligers suggests that adult drift on macrophytes is an important component of riverine invasion.

121. House, R. A. and P. L. Boehne. 1986. Effects of instream structures on salmonid habitat and populations in Tobe Creek, Oregon. North American Journal of Fisheries Management 6: 38-46.

Tobe Creek, Oregon was studied in 1982 and 1983 to compare physical and biological differences between a young-alder stream section logged and cleaned of large debris 20 years ago and mature mixed-conifer section unlogged and containing large amounts of large woody debris. Stream enhancement techniques were used in 1982 to simulate large woody debris in the logged alder section to try to increase salmonid use. Large woody debris in the channel caused the development of secondary channel, meanders, pool, and undercut banks in the unlogged, mature conifers, stream section. These elements were noticeably missing in the young alder section. The mature conifer section had more than twice as many pools and 19 times the amount of spawning gravel compared to the young alder section. Salmonid biomass was significantly greater in the mature-conifer than the young alder secion prior to stream enhancement; after enhancement, no significant difference was found. Prior to enhancement, three times as many coho salmon (*Oncorhynchus kisutch*) and trout fry (cutthroat trout and steelhead) were living n the mature-conifer stream section. There was a positive correlation between coho salmon numbers and the presence of large woody debris the study revealed that structure is most likely a more important factor than shade governing a stream's capacity for producing salmonids.

122. Humphries, P., P. E. Davies, and M. E. Mulcahy. 1996. Macroinvertebrate assemblages of littoral habitats in the Macquarie and Mersey rivers, Tasmania: Implications for the management of regulated rivers. Regulated Rivers: Research and Management 12: 99-122.

Littoral habitats in large rivers are influenced to varying degrees by changes in discharge. Irrigation abstractions can increase the amount of habitat that would naturally be dewatered during low flow periods and therefore it is important to have some knowledge of the potential impact this may have on riverine macroinvertebrates. The macroinvertebrate assemblages of common littoral habitats in riffles, pools and runs in two reaches each of the Macquarie and Mersey Rivers, northern Tasmania, Australia were compared from samples collected during the low flow and irrigation season, between December 1991 and April 1992. The area under water of these habitats, riffle substrata, macrophyte beds and coarse woody debris, responded differently to changes in discharge. Within a reach, the same taxonomic groups often dominated the total number of macroinvertebrates for all habitats, but there were differences in the proportions contributed by these taxa to the different habitats. In general, taxa characteristic of slow-flowing or lentic habitats, such as ostracods and amphipods, were dominant in macrophyte beds in pools and runs, whereas taxa such as larval elmid beetles and hydropsychid caddisflies were dominant in riffles. A substantial component of the fauna from each habitat within a reach was unique to that habitat, but there was always a similar number of taxa common to all habitats. Classification and ordination grouped samples from both rivers firstly by habitat and secondly by month and reach. Total density and family richness of invertebrates differed by reach, habitat and month in both rivers, except for richness in the Mersey River where habitat was not significant. Differences in densities and numbers of invertebrate families among habitats were not consistent between reaches for each river. This study has highlighted the differences in macroinvertebrate assemblages of several littoral habitats in two lowland rivers in Tasmania. Differences in taxonomic composition, density and richness among habitats within reaches strongly imply the uniqueness of these habitats in terms of the invertebrate faunas that occupy them. We suggest that if maintenance of biotic diversity is an aim of instream flow management, water allocations that address low flows should place a high priority on the maintenance of a diversity of habitats.

123. Hutcheson, J. and D. Jones. 1999. Spatial variability of insect communities in a homogenous system: Measuring biodiversity using Malaise trapped beetles in a *Pinus radiata* plantation in New Zealand. Forest Ecology and Management 118: 93-105.

Insect communities of second rotation *Pinus radiata* stands in Kaingaroa forest were characterised using Malaise trapped beetles. Samples were collected from the part of the adult beetle activity period previously shown to deliver best discrimination of samples from New Zealand habitats. Eight trap-sites within a 14-year-old *Pinus radiata* stand provide indications of community variation within this relatively homogenous forest environment. Single trap-sites in adjacent younger (five-year-old) and older (30-year-old) stands provided initial intra-rotation comparison. Beetle assemblages from the three stand ages were unable to be discriminated using similarity or diversity indices, but were clearly distinguishable using divisive cluster analysis. Age of stands was of primary importance in distinguishing clusters, with those from the five-year-old stand being most dissimilar. Clustering of catches from within the 14-year-old stand was influenced more by week of capture (temporal variation) than trap-site (spatial variation). Within the 14-year-old stand, variation of abundance was associated with dominant detritivore species, and the extent and proximity of debris resources. Species richness was more constant, although considerable variation in component species was recorded. Trophic structure

was also relatively consistent, with anomalous apparent variation possibly due to ignorance of species life histories. Successional processes were apparent within the insect samples over the rotation. The majority of the beetle assemblage from the 30-year-old stand were present at mid-rotation, but relative abundance of component species had changed. Beetle assemblages from all three age classes of stands were dominated by endemic detritivore species, reflecting the constant addition of woody debris within this rapid growing exotic vegetation system.

124. 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.

1. 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 forty-eight 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). 2. 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. 3. 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. 4. The effects of woody debris on habitat at the reach- and channel-unit scales in the study area were less than those indicated by previous work in the Pacific Northwest, North America, owing to the relatively small size of the riparian trees. However, the overall results suggested that woody debris in the study area contributed to masu salmon habitat by providing cover at the smaller, microhabitat scale.

125. Jakober, M. J., T. E. McMahon, R. F. Thurow, and C. G. Clancy. 1998. Role of stream ice on fall and winter movements and habitat use by bull trout and cutthroat trout in Montana headwater streams. Transactions of the American Fisheries Society 127: 223-235.

We used radiotelemetry and underwater observation to assess fall and winter movements and habitat use by bull trout *Salvelinus confluentus* and westslope cutthroat trout *Oncorhynchus clarki lewisi* in two headwater streams in the Bitterroot River drainage, Montana, that varied markedly in habitat availability and stream ice conditions. Bull trout and cutthroat trout made extensive (> 1 km) downstream overwintering movements with declining temperature in the fall. Most fish remained stationary for the remainder of the study (until late February), but some fish made additional downstream movements (1.1-1.7 km) in winter during a low-temperature (< 1 degree C) period marked by anchor ice formation. Winter movement was more extensive in the mid-elevation stream where frequent freezing and thawing led to variable surface ice cover and frequent supercooling (< 0 degree C). Habitat use of both species varied with availability; beaver ponds and pools with large woody debris were preferred in one stream, and pools with boulders were preferred in the other. Trout overwintered in beaver ponds in large (N = 80-120), mixed aggregations. In both streams, both species decreased use of submerged cover

following the formation of surface ice. Our results indicate that (1) continued activity by trout during winter is common in streams with dynamic ice conditions and (2) complex mixes of habitat are needed to provide suitable fall and winter habitat for these species.

126. Jurajda, P. 1999. Comparative nursery habitat use by 0 + fish in a modified lowland river. Regulated Rivers Research & Management 15: 113-124.

The use of nursery habitats by 0 + fish in a lowland channelized and regulated stretch of the River Morava (Czech Republic), was assessed by electrofishing, using the point abundance sampling method. In the period 1991-1993, a total of 71 sites were sampled during late summer. Changes in the character of spawning sites and nursery habitats after channelization and regulation did affect the fish community structure. Shoreline nursery zones were reduced to only two basic mesohabitat types: boulder bank and sand-gravel beach. 0 + fish have limited habitat choice, but chi-squared analysis revealed some segregation of nursery areas. Generally, the dominant species did not show any habitat preferences (*Rutilus rutilus*), or preferences changed from year to year (*Leuciscus cephalus*, *Gobio gobio* and *Rhodeus sericeus*). Rare rheophilic species had more strict habitat requirements and used sand-gravel beaches as nurseries. Of the environmental variables studied (woody debris, vegetation, periphyton, silt and current), only areas with emergent vegetation played a significant role as nursery habitats.

127. Keddy, P. A. and C. G. Drummond. 1996. Ecological properties for the evaluation, management, and restoration of temperate deciduous forest ecosystems. Ecological Applications 6: 748-762.

Given that many of the original deciduous forests of North America have disappeared over the last few centuries, our challenge is to preserve remnant forests, restore altered forests, and harvest managed forests in a sustainable manner. To do so, we need to identify macroscale properties that can easily monitor the condition of the eastern deciduous forest as a whole. We offer 10 possible properties: (1) tree size: (2) canopy composition; (3) quantity and quality of coarse woody debris; (4) number of spring ephemeral species in the herbaceous layer; (5) number of typical corticulous bryophyte species; (6) density of wildlife trees; (7) fungi; (8) avian community: (9) number of large carnivores; and (10) forest area. We have assigned to each property a control (or normal) value, an intermediate value, and a heavily altered value. These values are based on the existing literature. These 10 properties would: (1) allow us to recognize, rank, and protect high-priority forest sites for conservation; (2) tell us whether changes in a forest are in the direction of restoration or toward further alteration; and (3) enable us to evaluate different harvesting methods so we can select those that cause the least alteration to forests.

128. Keenan, R. J., C. E. Prescott, and J. P. Kimmins. 1993. Mass and nutrient content of woody debris and forest floor in western Red Cedar and western Hemlock forests on northern Vancouver Island. Canadian Journal of Forest Research 23: 1052-1059.

Biomass and C, N, P, and K contents of woody debris and the forest floor were surveyed in a adjacent stands of old-growth western red cedar (*Thuja plicata* Donn) - western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) (CH type), and 85-year-old, windstorm-derived, second-growth western hemlock - amabilis Fir (*Abies amabilis* (Dougl.) Forbes) (HA type) at three sites on northern Vancouver Island. Carbon concentrations were relatively constant across all detrital categories (mean = 556.8 mg/g); concentrations of N and P generally increased, and K generally decreased, with increasing degree of

decomposition. The mean mass of woody debris was 363 M-/ha in the CH and 226 Mg/ha in the HA type. The mean forest floor mass was 280 Mg/ha in the CH and 211 Mg/ha in the HA stands. Approximately 60% of the forest floor mass in each forest type was decaying wood. Dead woody material above and within the forest floor represented a significant store of biomass and nutrients in both forest types, containing 82% of the aboveground detrital biomass, 51-59% of the N, and 58-61% of the detrital P. Forest floors in the CH and HA types contained similar total quantities of N, suggesting that the lower N availability in CH forests is not caused by greater immobilization in detritus. The large accumulation of forest floor and woody debris in this region is attributed to slow decomposition in the cool, wet climate, high rates of detrital input following windstorms, and the large size and decay resistance of western red cedar boles.

129. Keller, E. A. and F. J. Swanson. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes and Landforms 4: 361-380.

Stream channel development in forested areas is profoundly influenced by large organic debris (logs, limbs and rootwads greater than 10 cm in diameter) in the channels.
In low gradient meandering streams large organic debris enters the channel through bank erosion, mass wasting, blowdown, and collapse of trees due to ice loading. In small streams large organic debris may locally influence channel morphology and sediment transport processes because the stream may not have the competency to redistribute the debris. In larger streams flowing water may move large organic debris, concentrating it into distinct accumulations (debris jams). Organic debris may greatly affect channel form and process by: increasing or decreasing stability of stream banks; influencing development of midchannel bars and short braided reaches; and facilitating, with other favourable circumstances, development of meander cutoffs.
In steep gradient mountain streams organic debris may enter the channel by all the processes mentioned for low gradient streams. In addition, considerable debris may also enter the channel by way of debris avalanches or debris torrents. In small to intermediate size mountain streams with steep valley walls and little or no floodplain or flat valley floor, the effect of large organic debris on the fluvial processes and channel form may be very significant. Debris jams may locally accelerate or retard channel bed and bank erosion and/or deposition; create sites for significant sediment storage; and produce a stepped channel profile, herein referred to as organic "stepping," which provides for variable channel morphology and flow conditions.
The effect of live or dead trees anchored by rootwads into the stream bank may not only greatly retard bank erosion but also influence channel width and the development of small scour holes along the channel beneath tree roots. Once trees fall into the stream, their influence on the channel form and process may be quite different than when they were defending the banks, and, depending on the size of the debris, size of the stream, and many other factors, their effects range from insignificant to very important.

130. Keller, E. A. and T. Tally. 1979. Effects of large organic debris on channel form and fluvial processes in the Coastal Environment. Adjustments of the Fluvial System: Tenth Annual Geomorphology Symposium, Binghamton, New York: 361-390. Kendall Hunt Publishing.

Large organic debris in streams flowing through old-growth redwood forests in California significantly influences channel form and fluvial processes in small to intermediate 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 time for the debris in the channel may exceed 200 years.

The total debris loading along a particular channel reach represents a relation between rates of debris entering and leaving the reach. Loading is primarily a function of such interrelated variables as geology, valley-side 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 if undercut banks. The stream channel of some low gradient reaches of Prairie Creek, California, may be quite stable. Lateral migration has been one to two channel widths in the last several hundred years.

Management of streams in the coastal redwood environment so as to minimize adverse effects while maximizing anadromous fish habitat should consider the entire fluvial system. Managers should use natural stream processes to regulate channel conditions rather than strive for absolute control by artificial means.

131. Keller, E. A. and A. MacDonald. 1983. Large Organic Debris and Anadromous Fish Habitat in the Coastal Redwood Environment: The Hydrologic System. California Water Resources Center, University of California, Davis, Technical completion report.

This research on effects of large organic debris on stream channel form and process relevant to anadromous fish habitat was along three lines of inquiry. First, new ways to evaluate discrete hydrologic environments, such as pools, riffles and debris accumulations were developed. Experiments completed provided basic data to test a model useful for predicting hydraulic geometry of pools and riffles. These experiments will help managers develop design criteria for construction or improvement of fish habitat in channel restoration projects. Similar hydrologic experiments in Redwood National Park, have been completed to evaluate the stream power associated with organic steps and defines a sediment buffer system that modulates the movement of bedload through the fluvial system.

A second line of inquiry involved debris removal experiments in Redwood National Park. Significant hydrologic and morphologic changes occurred as a result of the debris removal. Results of the debris pulling experiment suggest that the stream now is more sluggish and has less hydrologic variability than prior to the debris removal.

The third line of inquiry was a comparative study between undisturbed streams flowing through old growth redwood forest with those impacted by timber harvesting. Large organic debris (greater than 10 cm in diameter) is equally effective on controlling gross channel form in both undisturbed and disturbed channels, but there is a difference in the size and quantity of debris, channel morphology, and thus anadromous fish habitat. There is a higher percentage of unstable stored sediment in disturbed basins and sediment storage sites tend to be filled more often. Once storage sites are full, sediment may be transported more directly through the channel to downstream sites, producing a sediment pollution problem.

132. Keller, E. A., A. MacDonald, T. Tally, and N. J. Merrit. 1985. Effects of large organic debris on channel morphology and sediment storage in selected tributaries of Redwood Creek, northwestern California. In Geomorphic Processes and Aquatic Habitat in the Redwood Creek Basin, Northwestern California. K. M. Nolan, H. M. Kelsey and D. C. Maron (Eds). Vicksburg, MS, US Geological Survey.

Large organic debris (stems greater than 100mm in diameter) exerts a major control on channel form and process, and thus on anadromous fish habitat, in streams draining coastal redwood forests. Total debris loading for a particular channel reach represents the relation between rates of debris entering and leaving the reach and is primarily a function of the following interrelated variables: number and size of trees in the vicinity of the channel, rate of decomposition, geology, valley-side slope, landslide activity, channel width, discharge, and upstream drainage area. Approximately two-thirds of the variability of the debris loading in old-growth forests may be explained by variability of the number of mature redwood trees per hectare within 50 m of the channel. Generally, there is an inverse relationship between debris loading and upstream drainage area, but in some instances third-order reaches may have a higher loading than adjacent second- or fourth- order reaches.

Effects of large organic debris on channel morphology and sediment storage tend to be complex for several reasons. First, large organic debris may reside in the stream channel for centuries and is a permanent part of the fluvial system. Minimum residence times for more than 30 individual pieces of large organic debris have been determined by dendrochronology, and about half of these exceed 100 years, with the oldest exceeding 200 years. Second, large organic debris exerts considerable control over channel morphology, particularly in the development of pools. In headwater regions of drainage basins, nearly all the pools may be either directly formed by or significantly influenced by large organic debris. As the size of stream increases, the percentage of pools formed by large organic debris decreases, but debris still may significantly influence the morphology of the pool environment. Third, large organic debris produces numerous sediment storage sites, supporting a sediment buffer system that modulates the routing of sediment through the fluvial system. A volume of sediment equivalent to approximately 100 to 150 years of average annual bedload is stored in debris-related sites along Little Lost Man Creek, and a volume equivalent to about 50 to 100 years of average annual bedload is available for future storage. Finally, large organic debris in steep streams significantly concentrates potential energy expenditure over short reaches where accumulations of debris exist. In headward reaches of drainage basins, approximately 30 to 60 percent of the total decrease in elevation of the channel may be associated with large organic debris. Thus, energy is dissipated at these locations, where it might otherwise cut a more deeply incised channel with unstable and eroding banks.

The study of large organic debris in streams is pertinent to two interrelated management problems brought about by road building and timber harvesting in northwestern California: (1) reduction of sediment pollution and (2) restoration and enhancement of anadromous fish habitat. In the management of streams to maximize production of

anadromous fish habitat in the coastal redwood environment, the role of large organic debris should be considered. Large organic debris in unusually large amount may block fish migration and cause adverse channel erosion. However, within limits, large organic debris is necessary for streams to sustain healthy population of anadromous dish; its presence provides habitat diversity, sites for organic nutrient processing, and a modulated release of sediment to trunk streams. Therefore, managers of stream-clearing operations must carefully weigh the benefits of locally stabilizing streambanks, opening up anadromous fish habitat, or marketing merchantable timber against the potential dangers of losing hydrologic variability and mobilizing large quantities of sediment stored in conjunction with large organic debris.

133. Kershner, J. L., C. M. Bischoff, and D. L. Horan. 1997. Population, habitat, and genetic characteristics of Colorado River cutthroat trout in wilderness and nonwilderness stream sections in the Uinta Mountains of Utah and Wyoming. North American Journal of Fisheries Management 17: 1134-1143.

Colorado River cutthroat trout *Oncorhynchus clarki pleuriticus*, once common in the upper Green River and Colorado River watersheds, are currently limited to less than 1% of their former range and exist in isolated subdrainages in Colorado, Utah, and Wyoming. We compared stream populations, habitat, and genetic features of Colorado River cutthroat trout (CRCT) in wilderness and nonwilderness areas of the Uinta mountains, Utah-Wyoming. Densities of adult CRCT were significantly higher in wilderness reaches than in nonwilderness reaches, while densities of juvenile fish showed no difference. Lengths and weights of juvenile and adult CRCT were significantly higher in wilderness reaches than in the nonwilderness reaches. Adult habitat quality, as measured by the percent pool habitat, percent undercut bank, mean particle size, and mean stream depth, was significantly higher in wilderness reaches. Large woody debris and the hydraulic retention of the stream were positively related to juvenile abundance and were both higher in nonwilderness reaches. Hybridization indices were considered low in all streams on the north slope of the Uinta mountains. The highest numbers of hybrids between rainbow trout *Oncorhynchus mykiss* and cutthroat trout were found in streams that were most recently exposed to stocking. Streams within a designated wilderness in the Uinta mountains represent some of the highest quality habitat for CRCT and exhibit minimal anthropogenic fragmentation. Wilderness areas may represent some of the last, best opportunities for managing this subspecies within relatively large, intact blocks of habitat.

134. Kinley, T. A. and N. J. Newhouse. 1997. Relationship of riparian reserve zone width to bird density and diversity in southeastern British Columbia. Northwest Science 71: 75-86.

British Columbia forestry guidelines require riparian management areas of 20 to 50 m width between small streams and cutblocks, composed of reserve zones (no timber harvest) and/or management zones (limited timber harvest). Guidelines in Kootenai National Forest, Montana, limit forest harvesting for 30 m adjacent to permanent streams. As one step in providing a basis to assess such guidelines, we compared (1) habitat structure between spruce-dominated riparian forest and pine-dominated upland forest, (2) breeding bird characteristics (density of detections, species richness, species diversity and species equitability) between riparian and upland forest, and (3) breeding bird characteristics between riparian reserve zones of various widths (averaging 70, 37, or 14 m wide). The study occurred in the Montane Spruce biogeoclimatic zone of southeastern British Columbia. In relation to upland forest, riparian forest had greater tall shrub and

canopy cover, but fewer live trees. Snag density, low shrub cover, and coarse woody debris did not differ at $P < 0.05$. The two habitat types did not differ in mean bird species richness per site, but riparian forest had greater species diversity and species equitability, greater density of all species combined, and greater density of three individual species. The density of all birds combined, all riparian-associated birds combined, and three of the four riparian-associated species increased with increasing reserve zone width. Species diversity and species equitability did not differ significantly among treatments. The widths of riparian management areas required under current British Columbia and Kootenai National Forest guidelines are considerably narrower than the widest category of reserves investigated in this study (70 m). Our data indicate that prescribed riparian management areas under current guidelines will have lower densities of total birds and of riparian-associated birds than if reserves were required to average 70 m in width.

135. Kozel, S. J., W. A. Hubert, and M. G. Parsons. 1989. Habitat features and trout abundance relative to gradient in some Wyoming streams [USA]. Northwest Science 63: 175-182.

Channel gradient has been shown to have a negative relation to trout standing stocks indicating that separation of stream channels into gradient classes may provide a better understanding of the relationships between habitat and trout abundance. Our major objective was to determine if there are significant differences in habitat features and standing stocks of trout > 100 mm between two classes of channel gradient, low (0.1-1.4% channel slope) and moderate (1.5-4.0%). We also determined statistical relations between habitat features and trout standing stocks in each class of channel for unaltered streams on the Medicine Bow National Forest, Wyoming. Low-gradient reaches were found to have deeper nearshore water depths, more undercut banks, and more trench pools than moderate-gradient reaches, while moderate-gradient reaches had more cobble substrate, dammed pools formed by woody debris, and plunged pools. The mean standing stock was 267 kg/ha in low-gradient reaches and 102 kg/ha in moderate-gradient reaches. Habitat features correlated with trout standing stocks differed between the two gradient classes. Our results demonstrate that separation of stream segments into reaches of similar gradient are important in identifying features of trout habitat that are otherwise obscured by variation over a wider gradient range.

136. Krankina, O. N., M. E. Harmon, and A. V. Griazkin. 1999. Nutrient stores and dynamics of woody detritus in a boreal forest: Modeling potential implications at the stand level. Canadian Journal of Forest Research 29: 20-32.

Concentrations of 14 chemical elements (Al, B, C, Ca, Cu, Fe, K, N, Mg, Mn, Na, P, S, Zn) were measured in wood and bark of 126 sample trees representing different stages of decomposition in three major tree species of northwestern Russia: Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.), and birch (*Betula pendula Roth*.). Changes in nutrient stores in decay classes were calculated with adjustments for the loss of density and volume by dead trees. Although the concentration of many nutrients increased relative to the estimated initial level, the total amount of most nutrients contained in dead trees declined with decay. For example, nitrogen stores declined from decay class 1 to 4 by 45% for birch, 39% for spruce, and by 60% for pine. The rate and pattern of these losses varied by nutrient and by species and were primarily related to the patterns of bark loss. Pine lost bark early in the process of decomposition and released many essential nutrients (i.e.,N, P, Ca) at the early stages, while birch retained most of its bark throughout the decomposition process and lost nutrients more gradually. The temporal dynamics of N, Ca, and K loss in pine were examined using a chronosequence approach, and the results were used in stand-level modeling. The analysis of modeling

results suggests that, in northwestern Russia, post-disturbance release of nutrients from woody detritus can potentially supply a large proportion of the net N, Ca, and K accumulation in live forest biomass.

137. Kruys, N., C. Fries, B. G. Jonsson, T. Lamas, and G. Stahl. 1999. Wood-inhabiting cryptogams on dead Norway spruce (Picea abies) trees in managed Swedish boreal forests. Canadian Journal of Forest Research 29: 178-186.

We surveyed the quantity and quality of dead Norway spruce (*Picea abies* (L.) Karst.) trees and wood-inhabiting cryptogams in a managed boreal forest landscape in northern Sweden. Size and decay of dead trees was related to substrate utilization by wood-inhabiting species. Coarse woody debris (CWD) was surveyed along 34 strip transects. CWD and wood-inhabiting cryptogams were surveyed in eight circular plots at each site. A total of 6195 spruce CWD units occurred along strip transects and 809 spruce CWD units in circular plots. On average 2.2 m^3/ha spruce CWD was found on the plots. The majority (63%) of the transect CWD units were <10 cm diameter and in early to intermediate decay stages. Sixty-eight wood-specific species of fungi, lichens, mosses, and hepatics occurred on the plots. Of these, 13 occurred on greater than or equal to5% of the 809 CWD units surveyed for wood-inhabiting species. Eight species occur on the Swedish red lists, indicating that such species are indeed uncommon in managed forests. Red-listed species showed strong preferences for large diameter CWD and CWD in late decay stages, i.e., substrates that are poorly represented in managed forests. Frequently occurring species, however, showed utilization patterns that correspond with the distribution of the substrate types.

138. Lee, P. 1998. Dynamics of snags in aspen-dominated midboreal forests. Forest Ecology and Management 105: 263-272.

This research focuses on the dynamics of snags within aspen-dominated (*Populus tremuloides* Michx.) boreal forests within Alberta. Data from Alberta Lands and Forest Service permanent sample plots (PSP) were analyzed to determine densities, size distributions, input rates, falldown rates, and longevity patterns of snags (greater than or equal to 10 cm DBH). The mean density of snags in 20 to 39-yr-old stands was 18.1 snags per ha increasing to 61.6-99.8 snags per ha in stands up to 100 + yrs. In general, size distributions of trees and snags exhibited a reversed J-shaped size distribution. In stands < 40 yrs of age, size distributions of snags lagged behind trees. However, as the stand aged and self-thinning of small trees was supplemented by the death of canopy codominants, the size distribution of snags began to increasingly overlaps with that of trees. Overall snag input rates varied from 0.08-8.2% of trees per annum, larger values were associated with older stands and/or smaller trees. Snag falldown rates varied from 9-21% of snags per annum depending upon stand age. Falldown rates exhibited a U-shaped pattern with rates decreasing in 60 to 79-yr-old stands. Snag longevity patterns exhibited a negative sigmoidal shape with an initial period of relative stability for approximately 5 yrs after death, afterwards the probability of falldown increased with a greatest falldown occurring between 10 to 20 yrs after death.

139. Leland, H. V. 1995. Distribution of phytobenthos in the Yakima River basin, Washington, in relation to geology, land use, and other environmental factors. Canadian Journal of Fisheries and Aquatic Sciences 52: 1108-1129.

Benthic-algal distributions in the Yakima River, Washington, basin were examined in relation to geology, land use, water chemistry, and stream habitat using indicator-species classification (TWINSPAN) and canonical correspondence analysis (CCA). Algal assemblages identified by TWINSPAN were each associated with a narrow range of water-quality conditions. In the Cascade geologic province, where timber harvest and grazing are the dominant land uses, differences in community structure (CCA site scores) and concentrations of major ions (Ca and Mg) and nutrients (solute P, SiO_2 and inorganic N) varied with dominant rock type of the basin. In agricultural areas of the Columbia Plateau province, differences in phytobenthos structure were based primarily on the degree of enrichment of dissolved solids, inorganic N, and solute P from irrigation-return flows and subsurface drainage. Habitat characteristics strongly correlated with community structure included reach altitude, turbidity, substratum embeddedness (Columbia Plateau), large woody-debris density (Cascade Range), and composition and density of the riparian vegetation. Algal biomass (AFDM) correlated with composition and density of the riparian vegetation but not with measured chemical-constituent concentrations. Nitrogen limitation in streams of the Cascade Range favored nitrogen-fixing blue-green algae and diatoms with endosymbiotic blue-greens, whereas nitrogen heterotrophs were abundant in agricultural areas of the Columbia Plateau.

140. Lewis, S. L. 1969. Physical factors influencing fish populations in pools of a trout stream. Transactions of the American Fisheries Society 98: 14-19.

The relationship between fish populations and physical parameters of pools was studied in Little Prickly Pear Creek, Montana, during the summers of 1965 and 1966. The pools were mapped and their fish populations sampled. Surface area, volume, depth, current velocity, and cover accounted for 70 to 77% of the variation in numbers of trout over 6.9 inches total length. Most of the variation was the result of differences in current velocity and cover. Cover was the most important factor for brown trout, and current velocity for rainbow trout. The density of all trout per unit area of pool surface and cover increased significantly as current velocity became greater. Deep-slow pools with extensive cover had the most stable trout populations with brown trout showing greater stability than rainbow trout. The importance of cover to trout is discussed in terms of security and photonegative response and current velocity in terms of space-food relationships.

141. Lienkaemper, G. W. and F. J. Swanson. 1987. Dynamics of large woody debris in streams in old-growth Douglas-fir forests. Canadian Journal of Forest Research 17: 150-156.

Transfer of large woody debris (> 10 cm diameter) from old-growth Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) forests into five first- to fifth-order stream reaches (drainage areas of 0.1 to 60.5 km^2) has ranged from 2.0 to 8.8 Mg/ha/year, in 7- to 9-year study periods. Amounts of large debris in these streams range from 230 to 750 Mg/ha, with generally lower values in larger channels. The addition of woody debris is widely scattered in time and space and comes mainly from single trees rooted away from the streambank. We infer that wind is a major agent for entry of wood into these streams. Downstream movement of debris is strongly related to length of individual pieces; most pieces that moved were shorter than bankfull width.

142. Likens, G. E. and R. E. Bilby. 1982. Development, maintenance, and role of organic-debris dams in New England streams. USDA Forest Service, General Technical Report, PNW-141.

We propose that the formation of organic-debris dams on streams depends primarily on the size of tree (log) available. After disturbance, organic-debris dams are at first diminished and then form on larger and larger stream channels as the terrestrial ecosystem develops, and as a result, the regulation of erosion and transport of dissolved and particulate material from the landscape is enhanced. The species compositions and phase of development of hardwood forests also may affect the occurrence on longevity of organic-debris dams. Steady-state amounts of organic matter in stream channels may reflect the stream order, as well as the developmental phase of the terrestrial ecosystem.

143. Lisle, T. E. 1986. Effects of woody debris on anadromous salmonid habitat, Prince of Wales Island, southeast Alaska [USA]. North American Journal of Fisheries Management 6: 538-550.

The effects of woody debris on anadromous salmonid habitat in eight streams on Price of Wales Island, southeast Alaska, were investigated by comparing low-gradient (1-9%) first- or second-order streams flowing through either spruce-hemlock forests or 6-10-year-old clear-cuts, and by observing changes after debris was selectively removed from clear-cut reaches. Woody debris decreased the rate of shallowing as discharge decreased, thus helping to preserve living space for fish during critical low-flow periods. Debris dams were more frequent in clear-cuts streams (14.9/100 m), which contained more debris, than in forested streams (4.2/100 m). As a result, total residual pool length (length when pools are filled with water but there is no flow) and length of channel with residual depth greater than 14 cm--the depth range occupied by 84% of coho salmon (*Oncorhynchus kisutch*)--were greater in clear-cut streams than in forested streams. Greater volumes of woody debris in clear-cut streams produced greater storage of fine sediment (< 4-mm diameter) unless the stream gradient was sufficiently high to flush sediment from storage. One-half of the debris dams broke up or were newly formed over a 3-year period, which suggests that they usually released sediment and woody debris before the pools they formed were filled with sediment. Woody debris removal of decreased debris-covered area, debris dam frequency, and hydraulic friction in some cases but, in others, these variables were unaffected or recovered within 2 years after erosion and adjustment of the streambed. No consistent differences in pool dimensions were found between treated and untreated clear-cut reaches. Comparisons of habitat in forested and clear-cut streams suggested that removing debris from clear-cut streams reduced salmonid carrying capacity. Retention and natural reformation of debris dams in cleared reaches prevented the expected deterioration of habitat. However, the removal and destabilization of existing woody debris may cause depletion of debris before riparian trees can regrow and furnish new material to the clear-cut streams.

144. Lisle, T. E. 1986. Stabilization of a gravel channel by large streamside obstructions and bedrock bends, Jacoby Creek, northwestern California. Geological Society of America Bulletin 97: 999-1011.

Jacoby Creek (bed width = 12m; bankfull discharge = 32.6 m3/s) contains stationary gravel bars that have forms and positions controlled by numerous large streamside obstructions (bedrock outcrops, large woody debris, and rooted bank projections) and bedrock bends. Bank-projection width and bar volume measured in 104 channel segments 1 bed-width long are significantly cross-correlated at lags of -1, 3, and 4, indicating the tendency for large obstructions and bends to form bars 3 to 4 bed-widths downstream and 1 bed-width upstream. All of the 18 bars downstream of large obstructions or bends in the study reach were along the obstruction side of the channel or outside bank of the bend. Most of the pools (85%) were next to large obstructions or in bends; conversely, 92% of large obstructions or bends had pools. Comparison of the volume of four bars with volumetric bar changes and volume of bedload transported during four high flow events suggest that rates of sediment transport were sufficient of cause major changes in bars during bankfull events. The only important channel changes observed in 4 yr, however, have been associated with the movement of large woody debris and with changes in the angel at which the flow approaches an obstruction.
A general model is proposed that large obstructions and non-alluvial bends stabilize the form and location of gravel bars. Bars are stabilized by two related mechanisms.
1. Large obstruction and bends cause intense, quasi-steady, secondary circulation in scour holes that terminate upstream bars at fixed locations. Obstruction width, channel deflection, scour-hole width, and bed width were measured at 26 obstructions. These data show that obstructions wider than approximately one-third of the bed show that obstructions wider than approximately one-third of the bed form pools spanning the entire channel and, thus, terminated bars; smaller obstructions form "scour holes" contained with a single bar.
2. Bars are deposited upstream of large obstructions and sharp bends because of backwater reductions in stream power. Bars are deposited downstream because flow energy is expended around obstructions and beds and because the flow expands downstream of constrictions that result from large obstructions.
The formation of bars and pools inherent in many gravel channels can, thus, be enhanced and fixed in position by flow structures set up around large obstructions and bends formed of resistant materials.

145. Little, R. L., D. L. Peterson, and L. L. Conquest. 1994. Regeneration of subalpine fir (*Abies lasiocarpa*) following fire: Effects of climate and other factors. Canadian Journal of Forest Research 24: 934-944.

Subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) regeneration following fire was studied at two locations that burned in 1902 northeast of Mount Rainier, Washington. Tree establishment dates were compared with local climatic records using multiple and logistic regression to identify potential relationships between seasonal climate and annual tree establishment. The influence of microsite features on forest regeneration was also explored. Little regeneration occurred in the first 30 years after the fires, and most trees established in the 1950s, 1977, 1983, and 1989. The dominance of trees < 50 cm tall at both sites indicates that trees are continuing to establish on these bums. Establishment is positively correlated with warm, dry springs with low snow accumulation, and cool, wet summers with some variation in significant monthly climate between sites. Tree establishment following fire is greater near other trees and woody debris than other microsite features, however, the microsites available and used for tree establishment may change over time as snags fall and trees establish. More than 50% of the recently

established trees (< 50 cm tall) are located near larger trees and shrubs, and few (< 10%) trees are growing in exposed mineral soil. Older trees (> 50 cm tall) are frequently observed near woody debris. The response of subalpine fir regeneration to changes in climate will depend on the magnitude and seasonality of changes in weather, especially during spring. Tree establishment may be enhanced if there is less snow accumulation and a longer growing season. However, warmer, drier summers could result in additional moisture stress to seedlings, especially at sites with high solar radiation (south and west aspects) and well-drained soils.

146. Lundquist, J. E. 1995. Pest interactions and canopy gaps in ponderosa pine stands in the Black Hills, South Dakota, USA. Forest Ecology and Management 74: 37-48.

Gap frequency and size, cause (predisposing factors, killing agents, and tree response), and coarse woody debris composition (snags and downed logs) were assessed in three stands differing in management history. Disturbance agents were usually coupled concurrently and sequentially. A qualitative model (relational diagram) developed to display these interactions and the activity distributed among different disturbance pathways suggests that management activity (1) diminishes pest-caused structural diversity in the forest ecosystem, (2) decreases functional diversity associated with interacting diseases, insects and other disturbance agents, and (3) alters the abundance and decomposition distribution of dead wood.

147. Macmillan, P. C. 1988. Decomposition of coarse woody debris in an old-growth Indiana [USA] forest. Canadian Journal of Forest Research 18: 1353-1362.

Decay rates of *Quercus sp*., *Carya sp*., *Fagus grandifolia* and *Acer sp.* coarse wood debris in an old-growth southern Indiana forest were 0.018, 0.035, 0.019, and 0.045 per year, respectively, based on changes in density over a span of 25 + years. Their respective biomass values were 15, 2.3, 0.2, and 0.4 t/Ha. The greatest differences in decay rates of cellulose were between maple (high) and oak (low), and of lignin were between beech (high) and oak (low). Carbon to nitrogen ratios approached 100 and nitrogen to phosphorus ratios approached 20 in the older age-classes. On average, oak, hickory, beech, and maple logs contained 1.66 1.10, 0.14, and 0.19 kg nitrogen and 0.056, 0.070, 0.005, and 0.016 kg phosphorus, respectively. Meentemeyer's model based on actual evapotranspiration predicted a decay rate of 0.80 per year, which is 27 times larger than the decay rates calculated on changes in density. Fragmentation loss rates for these four genera were estimated to be 0.288, 0.802, 1.171, and 0.338 per year, respectively. Decay rates based on diameter of coarse woody debris ranged form 0.0027 to 0.0337 per year. All these factors are important in understanding the process of decay of coarse woody debris in this forest. The roles of fragmentation in the decay of coarse woody debris and of fungitoxic extractives need more study.

148. Madej, M. A., W. E. Weaver, and D. K. Hagans. 1994. Analysis of bank erosion on the Merced River, Yosemite Valley, Yosemite National Park, California, USA. Environmental Management 18: 235-250.

Channel changes from 1919 to 1989 were documented in two study reaches of the Merced River in Yosemite National Park through a review of historical photographs and documents and a comparison of survey data. Bank erosion was prevalent and channel width increased an average of 27% in the upstream reach, where human use was concentrated. Here, trampling of the banks and riparian vegetation was common, and banks eroded on straight stretches as frequently as on meander bends. Six bridges in the upper reach constrict the channel by an average of 38% of the original width, causing severe erosion. In the downstream control reach, where human use was minimal, channel widths both decreased and increased, with a mean increase of only 4% since 1919. Bank erosion in the control reach occurred primarily on meander bends. The control reach also had denser stands of riparian vegetation and a higher frequency of large woody debris in channels. There is only one bridge in the lower reach, located at the downstream end. Since 1919, bank erosion in the impacted upstream reach contributed a significant amount of sediment (74,800 tonnes, equivalent to 2.0 t/km^2/yr) to the river. An analysis of 75 years of precipitation and hydrologic records showed no trends responsible for bank erosion in the upper reach. Sediment input to the upper reach has not changed significantly during the study period. Floodplain soils are sandy, with low cohesion and are easily detached by lateral erosion. The degree of channel widening was positively correlated with the percentage of bare ground on the streambanks and low bank stability ratings. Low bank stability ratings were, in turn, strongly associated with high human use areas. Channel widening and bank erosion in the upper reach were due primarily to destruction of riparian vegetation by human trampling and the effect of bridge constrictions on high flow, and secondarily to poorly installed channel revetments. Several specific recommendations for river restoration were provided to park management.

149. Malanson, G. P. and D. R. Butler. 1990. Woody debris, sediment, and riparian vegetation of a subalpine river, Montana, USA. Arctic and Alpine Research 22: 183-194.

The relationships among woody debris, composition of vegetation, topography, and sediment on ten gravel bars along a Montana river are examined in order to test a hypothesis of positive feedback leading to reduced rates of sediment transport. Plant species diversity is related to the area, sediment, and woody debris of bars. Several variables were significantly correlated and significant regressions of vegetative composition on sediment, topography, and debris resulted. The amount of woody debris, however, is not a statistically significant function of topography, sediment, or vegetation. Large amounts of wood debris are located both on low, barren, apparently new gravel bars, and on higher bars, where fine sediment is deeper and more mature stands of vegetation exist. Analyses of systems of linear equations representing hypothetical pathways of causality regarding vegetation, woody debris, topography, and sediment were not statistically significant. We suggest that time, a variable not amenable to measurement in this system, is an important direct control of processes at every step of the causal chain in such a way that its effects cannot be subsumed by any of the other variables. A disequilibrium condition in which the operations of mesoscale ecological processes are superimposed on sedimentological processes with macroscale components may also explain why the correlations are not maintained when ordered into a system.

150. Malanson, G. P. and J. A. Kupfer. 1993. Simulated fate of leaf litter and large woody debris at a riparian cutbank. Canadian Journal of Forest Research 23: 582-590.

Leaf litter and woody debris are important sources of carbon for stream ecosystems, but the patterns of such inputs are variable. To clarify the processes that may lead to such variations, we modified a computer simulation model of forest dynamics to record the production, transport, and decomposition of leaf litter and woody debris given conditions found on a floodplain. The species chosen represent those of floodplains in the central Mississippi River valley, United States. We examined differences in model results when the conditions simulated were (i) a floodplain forest interior or a riparian cutbank edge, (ii) high or low flood regimes, and (iii) with or without the direct removal of material by flood flows. Projections of productivity of floodplain interior sites were similar to those observed in other studies in comparable areas. The inclusion of edge effects increased litter and debris production significantly. There were differences in how material produced was apportioned: there was a greater input to the river that had edge effects and, trivially, flood removal; there was greater on-site storage otherwise. Interaction effects were found because of the dependence on initial productivity. This simulation indicates that the particular local effects of hydrological and geomorphological processes will affect the fate of carbon on floodplains and reveals the importance of a spatially explicit conceptualization of forest dynamics.

151. Maridet, L., H. Piegay, O. Gilard, and A. Thevenet. 1996. River wood jams: an ecological benefit? A factor of natural risks? Houille Blanche-Rev. Int. 51: 32-38.

In order to preserve the stream flow capacity, the French Government always recommends the cleaning of riparian vegetation and the removing of coarse woody debris and the small risk of these structures in rural area. The "do nothing", "rehabilitation" and "localized manipulation" notions appear now in different management options. In this paper, we propose a synthesis on the risk due to coarse woody debris (inundation and erosion) and on their ecological role. We conclude the article by proposing a few management recommendations of these woody structures.

152. Marra, J. L. and R. L. Edmonds. 1994. Coarse woody debris and forest floor respiration in an old-growth coniferous forest on the Olympic Peninsula, Washington, USA. Canadian Journal of Forest Research 24: 1811-1817.

Carbon dioxide evolution rates for downed logs (coarse woody debris) and the forest floor were measured in a temperate, old-growth rain forest in Olympic National Park, Washington, using the soda lime trap method. Measurements were taken every 4 weeks from October 22, 1991, to November 19, 1992. Respiration rates for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and westem hemlock (*Tsuga heterophylla* (Raf.) Sarg.), logs were determined for decay classes 1-2, 3, and 5 in two diameter classes. Overall, western hemlock logs respired at a rate 35% higher (4.37 g $CO_2/m^2/day$) than Douglas-fir logs (3.23 g $CO_2/m^2/day^1$). Respiration rates for decay class 1-2 logs of both species were similar to decay class 5 logs (4.46 and 4.07 g $CO_2/m^2/$ day, respectively), but decay class 3 logs respired at a lower rate (3.23 g $CO_2/m^2/day$). Seasonal patterns of respiration rates occurred, particularly for decay class 1 and 2 western hemlock logs where monthly averages ranged from a low of 2.67 g $CO_2/m^2/day$ in February 1992 to a high of 8.30 g CO_2/m^2day in September 1992. Rates for decay class the summer drought characteristic of the Pacific Northwest. Large-diameter western hemlock logs in decay

class 1-2 had higher respiration rates than small-diameter logs, whereas large-diameter decay class 3 western hemlock logs had lower respiration rates than small-diameter logs.

153. Marra, J. L. and R. L. Edmonds. 1996. Coarse woody debris and soil respiration in a clearcut on the Olympic Peninsula, Washington, U.S.A. Canadian Journal of Forest Research 26: 1337-1345.

Coarse woody debris (CWD) and soil respiration rates were measured using soda lime traps on a clearcut site in the Hoh River Valley on the west side of the Olympic Peninsula, Washington. The influence of species of CWD (western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)), decay class, and log diameter on respiration rates was determined. CWD and soil respiration were measured every 4 weeks from October 1991 to November 1992 along with CWD and soil temperature and moisture contents. Western hemlock logs respired at a significantly higher rate (4.05 g CO_2/m^2/day) than Douglas-fir logs (2.94 g CO_2/m^2/day). There were no significant differences between respiration rates for decay classes 1-2, 3, and 5 logs (4.47, 3.69, and 4.28 g CO_2/m^2/day, respectively), and there was no strong relationship between CWD respiration rate and log diameter. The highest average respiration rate was from the soil in the clearcut (5.22 g CO_2/m^2/day). Averaged for the year, log and soil respiration rates in the clearcut site were similar to those in an adjacent old-growth forested site. However, seasonal fluctuations were greater on the clearcut site. Higher summer respiration rates and lower winter rates observed on the clearcut relative to the old-growth site appeared to be driven more by temperature than by moisture. Clear-cutting also resulted in higher summer CWD and soil temperatures and lower winter temperatures compared with the old-growth site.

154. Martin, D. J., L. J. Wasserman, and V. H. Dale. 1986. Influence of riparian vegetation on posteruption survival of coho salmon (*Oncorhynchus kisutch*) fingerlings on the west-side streams of Mount St. Helens, Washington [USA]. North American Journal of Fisheries Management 6: 1-8.

The 1980 eruption of Mount St. Helens impacted salmon streams on the west side of the mountain primarily by debris and mud deposits; depositions of ash and large wood were relatively minor disturbances. We examined factors related to juvenile coho salmon (*Oncorhynchus kisutch*) disappearance during the summer and winter months of 1981 and 1982. Correlations exist between the survival of anadromous fish instream vegetative debris cover, and water temperature. Summer mortality was related to high stream temperatures and cause debris to be retained. Tree growth data suggest trees will be tall enough to effectively shade the third- and fourth-order streams in 5-20 years, and that it will be 50-75 years before the trees are large enough to create organic debris structures when they fall into a stream. These results imply that management activities that promote large organic debris will enhance fish survival.

155. Marzolf, G. R. 1978. The potential effects of clearing and snagging on stream ecosystems. US Fish and Wildlife Service, Biological Services Program, FWS/OBS-78/14.

Clearing and snagging, the removal of obstructions from streams to increase the channel's capacity to convey water, is conducted to drain floodplains for agriculture, to protect citizens from floods, or to maintain navigable waterways.
This review examines the widely held contention that such stream alteration reduces fish population and is otherwise detrimental to the use of stream ecosystems. It was prepared for use in assessing the ecological impact of clearing and snagging projects. Because of the lack of direct quantitative evidence about clearing and snagging effects, the mechanisms involved in producing the effects are discussed indirectly as potential effects.
Recent concepts in stream ecosystem function relate the functions of different groups of stream organisms to organic matter synthesis and degradation in various sizes and types of streams. This review emphasizes the roles obstructions (typically removed by clearing and snagging) exert on these stream ecosystem functions. Recent literature allows one to identify potential effects of clearing and snagging on stream function. Some effects are obvious when viewed in this process-oriented context while others are less clear. For example, an obvious potential effect of clearing and snagging would be to decrease the rate at which organic matter loads are degraded by the stream system. A less obvious potential effect would be the effects of clearing and snagging on the plankton in streams. The depression of fish populations by clearing and snagging potentially occurs in two ways: 1) through alteration of the nature and abundance of the organisms utilized by fishes as food, and 2) by direct effects on fish behavior (territoriality) and reproduction (spawning areas).
This review identified some potential ecological impacts of clearing and snagging, but does not yield quantitative predictions of the impacts. Pertinent recent literature on stream ecosystem function is reviewed and has much application in impact assessment. Parameters which could be measured for quantitatively evaluating the ecological effects of specific clearing and snagging projects are described.

156. Maser, C. and J. M. Trappe. 1984. The seen and unseen world of the fallen tree. USDA Forest Service, General Technical Report, PNW-164.

Large, fallen trees in various stages of decay contribute much-needed diversity to terrestrial and aquatic habitats in western forests. When most biological activity in soil is limited by low moisture availability in summer, the fallen tree-soil interface offers a relatively cool, moist habitat for animals and a substrate for microbial and root activity. Intensified utilization and management can deprive future forests of large, fallen trees. The impact of this loss on habitat diversity and on long-term forest productivity must be determined because managers need sound information on which to base resource management decisions.

157. Maser, C., R. F. Tarrant, J. M. Trappe, and J. F. Franklin. 1988. From the forest to the sea: a story of fallen trees. USDA Forest Service, General Technical Report, PNW-GTR 229.

Large, fallen trees in various stages of decay contribute much-needed diversity of ecological process to terrestrial, aquatic, estuarine, coastal beach, and open ocean habitats in the Pacific Northwest. Intensive utilization and management can deprive these habitats of large, fallen trees. This publication presents sound information for managers making resource management decisions on the impact of this loss on habitat diversity and on ecological processes that have on impact long-term ecosystem productivity.

158. Maser, C. and J. R. Sedell. 1994. From the Forest to the Sea: the Ecology of Wood in Streams, Rivers, Estuaries, and Oceans. Delray Beach, FL, St.. Lucie Press.

In Part I, The Present: A Severed Connection, some current actions, including damming streams and rivers, which prevents the driftwood they once carried from reaching the sea, are considered. Without driftwood, stream channels and coastal sand dunes are destabilized and wood is eliminated from the food chains of estuaries and the deep-sea floor. Once plentiful driftwood is rapidly being replaced with such human-derived garbage as non-biodegradable plastic.
In Part II, From the Forest to the Sea: Source, Function, and Transport of Driftwood, the journey taken by water and wood from the mountains to the ocean is told. Through this story, derived from over a decade of research by many people, the vital role of driftwood in streams, rivers, estuaries, and the open ocean is described. Although no specific dates are given, the story is set prior to the settlement of the Pacific Northwest by Europeans in order to establish a sense of how the pre-settlement ecosystem might have functioned and to set the stage for Part III.
In Part III, From the Sea to the Forest: Settlement, a look at the collision of European culture and settlement with the environment of the New World is provided. Settlement, which began at the coast and progressed inland up the rivers and streams, began immediately to affect the waterways and ancient forests of the Pacific Northwest, contributing to current environmental crises. Although we look at the Pacific Northwest as a specific chapter in the history of the New World, the principles discussed apply to all of North America--indeed to all the world.

159. Mattson, K. G., W. T. Swank, and J. B. Waide. 1987. Decomposition of woody debris in a regenerating clear-cut forest in the southern Appalachians USA. Canadian Journal of Forest Research 17: 712-721.

Mass losses were estimated for coarse (>5cm) and fine (≤5cm) woody debris (CWD and FWD, respectively) during the first 67 years following clear cutting of a mixed hardwood forest at the Coweeta Hydrologic Laboratory in the Southern Appalachians of North Carolina. Estimates were based on (I) precut forest biomass, (ii) volume and density of CWD and mass of FWD at year 1, and (iii) woody density changes of CWD by year 6 and mass changes of FWD by year 7. Mass estimates of CWED at years 0, 1, and 6 were 91.2, 74.8, and 53.0 Mg/ha, respectively. Mass estimates of FWD at years 0, 1, and 7 were 30.3, 21.3, and 7.8 Mg/ha, respectively. Decay constants (k) for mass losses were relatively high compared with other studies of wood decomposition, 0.083 and 0.185/yr for CWD and FWD, respectively, and 0.108/year and for total (CWD + FWD) debris. Mass loss of CWD occurred largely through wood density decreases and bark fragmentation. CO_2-efflux estimates accounted for over 90% of the CWD density loss and for two-thirds (40.4 Mg/ha) of the total debris mass loss. The remaining mass loss of

total debris (20.3 Mg/ha) is a source of large, organic matter inputs to the forest floor via solution fluxes and fragmentation and CWD bark and FWD. The large variation in wood-density loss among logs was examined statistically as a function of various decay factors. Density loss varied by more than 10-fold among tree species. Density loss rates were 40% higher in logs on the ground versus those off the ground, 100% higher in logs with observable fungi versus those without fungi, and 40% higher in logs that occurred in plots with south and east aspects versus those in plots with west aspects.

160. McCarthy, B. C. and R. R. Bailey. 1994. Distribution and abundance of coarse woody debris in a managed forest landscape of the central Appalachians. Canadian Journal of Forest Research 24: 1317-1329.

Coarse woody debris (CWD) is integral to the functioning and productivity of forested ecosystems. Standing snags and large logs on the forest floor affect soil processes, soil fertility, hydrology, and wildlife microhabitat. Few data are available pertaining to the distribution and abundance of CWD in the managed hardwood forests of the central Appalachians. We surveyed 11 stands, at various stages of development (succession) after clear-cutting (< 2, 15-25, 65-90, > 100 years old), to evaluate the density, volume. and biomass of trees, snags, and logs under the local forest management regime. As expected, density, volume, and biomass of CWD (stems greater than or equal to 2.5 cm diameter) were greatest in young stands (< 2 years old) immediately following clear-cutting; the vast majority of CWD existed as relatively labile, small-diameter, low decay state logging slash. Young stands retained a few large logs in advanced decay states but observations suggest that these elements were often disturbed (i.e., crushed) by logging equipment during the harvest process. Crushed logs do not function ecologically in the same capacity as large intact logs. A marked decline in CWD was observed in young pole stands (15-25 years old) as slash decomposed. These stands were characterized by a high density of young hardwood stump sprouts in the overstory while maintaining a moderate amount of CWD in middle size and decay states on the forest floor. More mature hardwood stands (65-90 years old) generally exhibited a decrease in live-stem density and an increase in basal area, accompanied by a slight increase in CWD. Commercial thinning presumably limits the contribution of large CWD to the forest floor. This was most clearly evident in the oldest stands (> 100 years old) where large CWD was not widely observed. A striking feature across all stands was the near absence of logs in large size classes (> 65 cm diameter) and a paucity of logs in mid to late decay stages. We discuss our data in the context of hardwood forest structure and management in the central Appalachians.

161. McDade, M. H., F. J. Swanson, W. A. McKee, J. F. Franklin, and J. Van Sickle. 1990. Source distances for coarse woody debris entering small streams in western Oregon and Washington [USA]. Canadian Journal of Forest Research 20: 326-330.

Coarse woody debris from streamside forests plays important biological and physical roles in stream ecosystems. The distance from stream bank to rooting site was determined for at least 30 fallen trees at each study site on 39 streams in the Cascade and Coast ranges of Oregon and Washington. The study sites varied in channel size (first- through third-order), side-slope steepness (3 to 40.degree.), and age of surrounding forest (mature or old-growth stands). The distribution of distances from rooting site to bank was similar among streams, with 11% of the total number of debris pieces originating within 1 m of the channel and over 70% originating within 20 m. Stands with taller trees (old-growth

conifers) contributed coarse woody debris to streams from greater distances than did with shorter (mature) trees.

162. 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 Sciences 55: 1395-1407.

We assessed the changes 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 (P = 0.98) in both years (50.7 versus 50.6). However, we found a significant (P less than or equal to 0.01) reduction in the total volume of LWD material in the stream sites surveyed (51.7 m^3/100 m in 1982 to 38.2 m^3/100 m^1 in 1993). While the mean volume of second-growth derived LWD increased from 3.6 to 10.9 m^3/100 m^1 (P < 0.01), 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 from 48.1 to 27.4 m^3/100 m^1 between sample years (P < 0.01). The mean diameter of second-growth derived LWD was significantly larger in 1993 than in 1982, although still smaller than old-growth derived pieces. We measured a significant increase in the percentage of LWD pieces rated as highly decayed from 1982 to 1993. The 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.

163. McMahon, T. E. and G. F. Hartman. 1989. Influence of cover complexity and current velocity on winter habitat use by juvenile coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 46: 1551-1557.

Winter habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) varied with cover type and flow level in outdoor stream channels. Cover utilization and the number of fish remaining in stream channels increased significantly as cover complexity increased. Most fish emigrated during a simulated freshet unless the most complex cover (low velocity, shade, and wood debris combined) was available. At both high and low flows, emigration occurred primarily during the rapid decline in light levels at twilight. Most coho formed aggregations beneath cover, exhibiting feeding and aggression at temperatures as low as 2.5.degree. C. We conclude that (1) social interactions, in concert with habitat features, influence the abundance of coho salmon within specific stream habitats in winter, and (2) structural complexity of wood debris is an important consideration for management practices designed to protect or enhance winter habitat for this species.

164. McMahon, T. E. and L. B. Holtby. 1992. Behaviour, habitat use, and movements of coho salmon (*Oncorhynchus kisutch*) smolts during seaward migration. Canadian Journal of Fisheries and Aquatic Sciences 49: 1478-1485.

Coho salmon (*Oncorhynchus kisutch*) smolts formed aggregations in pools with large woody debris during their migration downstream and into the Carnation Creek estuary, British Columbia [Canada]. Smolts utilized the estuary throughout the smolt run, with periods of high outmigration coinciding with spring tides which brought warmer, more saline water in the estuary. Smolt abundance in the stream and estuary was positively related to debris volume, and 82% of the 1260 smolts observed during underwent counts

occurred within 1 m of debris. Debris volume and smolt density were significantly lower in clearcut than in buffered stream sections. Our observations support the need to retain and manage large woody debris for smolt habitat in streams and estuaries.

165. Megahan, W. F. 1982. Channel sediment storage behind obstructions in forested drainage basins draining the granitic bedrock of the Idaho batholith. USDA Forest Service, General Technical Report, PNW-141.

Data on sediment storage behind obstructions were collected on seven forested, mountain drainage basins in the Idaho Batholith for a 6-year period from 1973-1978. Four of the drainage basins were undisturbed throughout the study period, one contained an old road, and two were logged during the course of the study. The total volume of sediment stored behind obstructions varied between drainage basins and years in response to changes in bankfull channel width and annual peal-flow rates, respectively. Logs were the most important type of obstruction because they had the greatest longevity and stored the greatest amount of sediment. An average of 15 times more sediment was stored behind obstructions than was delivered to the mouths of the drainages as annual average sediment yield. Logging reduced total channel-sediment storage behind obstructions because many natural obstructions were destroyed by felling and subsequent clearing operations to remove logging debris from channels. Storage behind obstruction is an important component of the overall sediment routing through forested drainage basins. Accordingly, erosion and sedimentation monitoring must be carefully designed to avoid misinterpretation. Also, some guidelines are presented to help minimize the change in channel-sediment storage caused by timber harvest.

166. Menzel, M. A., W. M. Ford, J. Laerm, and D. Krishon. 1999. Forest to wildlife opening: Habitat gradient analysis among small mammals in the southern Appalachians. Forest Ecology and Management 114: 227-232.

We examined relative abundance as well as richness, diversity, and evenness values of shrews and rodents along habitat gradients associated with fescue (*Festuca spp.)*-dominated wildlife opening/forest ecotones in five high elevation, northern hardwood communities in western North Carolina. During 12000 trap-nights, we collected 831 small mammals. Smoky shrews (*Sorex fumeus*), pine voles (*Microtus pinetorum*), white-footed mice (*Peromyscus leucopus*), and woodland jumping mice (*Napaeozapus insignis*) exhibited no significant differences along the wildlife opening/forest gradient. The relative abundances of masked shrews (*S. cinereus*) and red-backed voles (*Clethrionomys gapperi*) were highest along the edge ecotone between wildlife openings and the forest gradient. Relative abundance of deer mice (*Peromyscus maniculatus*) increased with increasing distance from the wildlife opening/forest edge. Measures of coarse woody debris (CWD), an important habitat component for many small mammal species, showed a strong gradient for increased loading from the wildlife openings to the forest interior. Abundance of deer mice was strongly positively correlated with CWD loadings. Our results show that habitat generalists such as the masked shrew respond favorably to the microhabitat heterogeneity produced along an edge.

167. Minshall, G. W., C. T. Robinson, and D. E. Lawrence. 1997. Postfire responses of lotic ecosystems in Yellowstone National Park, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 54: 2509-2525.

Wildfire is a major large-scale disturbance affecting terrestrial landscapes and lotic ecosystems in many regions of the world. We examined environmental and biological responses of 20 streams in Yellowstone National Park, U.S.A., over 5 years following extensive wildfires in 1988. Streams of burned catchments displayed increases in dissolved nitrate-nitrogen following the fires. Summer water temperatures often exceeded 20 degree C in small (first- and second-order) streams of burned catchments compared with < 15 degree C in their unburned counterparts. Habitat heterogeneity decreased in streams of burned watersheds as demonstrated by changes in substrate embeddedness and near-bed velocities. Substantial alteration of channels and major restructuring and movement of large woody debris occurred in fire-impacted but not reference streams. Transported and benthic organic matter, mostly charcoal, increased in burned sites. No major changes were found in macroinvertebrate density, biomass, or richness, although significant changes occurred in relative abundances of miners, gatherers, and scrapers of burned sites. Chironomidae abundance was greater initially (postfire years 1-3), followed by later increases (postfire years 3-5) by the mayfly *Baetis bicaudatus* in burned sites compared with reference streams. Our findings demonstrate an integral relationship over time between a stream and its catchment, following large-scale disturbances such as wildfire.

168. 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 channel, 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.

169. Montgomery, D. R. and J. M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin 109: 596-611.

A classification of channel-reach morphology in mountain drainage basins synthesizes stream morphologies into seven distinct reach types: colluvial, bedrock, and five alluvial channel types (cascade, step pool, plane bed, pool riffle, and dune ripple), Coupling reach-level channel processes with the spatial arrangement of reach morphologies, their links to hillslope processes, and external forcing by confinement, riparian vegetation, and woody debris defines a process-based framework within which to assess channel condition and response potential in mountain drainage basins, Field investigations demonstrate characteristic slope, grain size, shear stress, and roughness ranges for different reach types, observations consistent with our hypothesis that alluvial channel morphologies reflect specific roughness configurations adjusted to the relative magnitudes of sediment supply and transport capacity, Steep alluvial channels (cascade and step pool) have high ratios of transport capacity to sediment supply and are resilient to changes in discharge and sediment supply, whereas low-gradient alluvial channels (pool riffle and dune ripple) have lower transport capacity to supply ratios and thus exhibit significant and prolonged response to changes in sediment supply and discharge, General differences in the ratio of transport capacity to supply between channel types allow aggregation of reaches into source, transport, and response segments, the spatial distribution of which provides a watershed-level conceptual model linking reach morphology and channel processes, These two scales of channel network classification define a framework within which to investigate spatial and temporal patterns of channel response in mountain drainage basins.

170. Montgomery, D. R., J. M. Buffington, R. D. Smith, K. M. Schmidt, and G. Pess. 1995. Pool Spacing in Forest Channels. Water Resources Research 31: 9.

Field surveys of stream channels in forested mountain drainage basins in southeast Alaska and Washington reveal that pool spacing depends on large woody debris (LWD) loading and channel type, slope, and width. Mean pool spacing in pool-riffle, plane-bed, and forced pool-riffle channels systematically decreases from greater than 13 channel widths per pool to less than 1 channel width with increasing LWD loading, whereas pool spacing in generally steeper, step-pool channels is independent of LWD loading. Although plane-bed and pool-riffle channels occur at similar low LWD loading, they exhibit typical pool spacings of greater than 9 and 2-4 channel widths, respectively. Forced pool-riffle channels have high LWD loading, typical pool spacing of <2 channel widths, and slopes that overlap the ranges of free-formed pool-riffle and plane- bed channel types. While a forced pool-riffle morphology may mask either of these low-LWD-loading morphologies, channel slope provides an indicator of probable morphologic response to wood loss in forced pool-riffle reaches. At all study sites, less than 40% of the LWD pieces force the formation of a pool. We also find that channel width strongly influences pool spacing in forest streams with similar debris loading and that reaches flowing through previously clear-cut forests have lower LWD loading and hence fewer pools than reaches in pristine forests.

171. Monzyk, F. R., W. E. Kelso, and D. A. Rutherford. 1997. Characteristics of woody cover used by brown madtoms and pirate perch in coastal plain streams. Transactions of the American Fisheries Society 126: 665-675.

We measured or described microhabitat characteristics of woody debris accumulations (i.e., structural complexity, cavity space, stem diameter, suspended and benthic leaves, depth, inside and outside flow, undercut bank, and lateral position) found in headwater coastal plain streams of central Louisiana. Debris characteristics at sites used as diurnal cover by adult brown madtoms *Noturus phaeus* and pirate perch *Aphredoderus sayanus* were compared with characteristics at unoccupied debris sites. Woody debris used by brown madtoms was characterized as having greater cavity space, structural complexity, and suspended leaves. Additionally, brown madtoms more frequently occupied debris areas located beneath undercut banks or next to areas of high flow. Of all the habitat variables, undercut bank and cavity space showed the strongest relationship with the presence of brown madtoms in woody debris. Brown madtoms demonstrated no significant difference in use of debris characteristics between small (34-83 mm TL), medium (84-101 mm TL), and large (102-140 mm TL) size-groups. Relative to unoccupied sites, pirate perch more frequently occupied sites with benthic leaves and leaves suspended within the debris. Debris in deep water with undercut banks and slow inside flows were also used more by this species regardless of its size-group. The structural complexity of debris at sites occupied by large and medium size pirate perch (59-95 mm TL) was significantly greater than that at unoccupied sites and at sites occupied by small pirate perch (27-58 mm TL). Overall, submerged debris tended to have specific physical characteristics that acted as important determinants in diurnal habitat use of these two structure-associated fishes.

172. Moore, K. M. S. and S. V. Gregory. 1988. Response of young-of-the-year cutthroat trout to manipulation of habitat structure in a small stream. Transactions of the American Fisheries Society 117: 162-170.

In Mack Creek [USA] a third-order stream flowing through a 450-year-old coniferous forest in Oregon's Cascade Mountains, population size of young-of-the-year cutthroat trout Salmo clarki was positively correlated with length of stream edge and area of lateral habitat. Lateral habitats included backwaters and eddies at the margin of the channel that made up 10-15% of total stream area. Lateral habitat area was reduced at higher or lower streamflow, but the length of channel perimeter formed by lateral habitats was never less than twice the length of the reach. In an experimental manipulation of lateral habitat before the emergence of young fish from the redd, an increase in lateral habitat area of 2.4 times the area observed in control reaches resulted in a 2.2-times greater density of age-0 cutthroat trout. Young-of-the-year fish were virtually eliminated from stream sections with reduced area of lateral habitat. Growth was not affected by the greater density of fish in reaches with enhanced lateral habitat.

173. Morris, D. M., J. P. Kimmins, and D. R. Duckert. 1997. The use of soil organic matter as a criterion of the relative sustainability of forest management alternatives: A modeling approach using FORECAST. Forest Ecology and Management 94: 61-78.

The purpose of this study was to evaluate the usefulness and sensitivity of parameters that describe various soil organic matter characteristics for the evaluation of harvesting impacts on ecosystem function, using an ecosystem-level, hybrid simulation model (FORECAST, a model developed from its predecessor FORCYTE- 11). Four separate sets of forest management options were applied to, both a simulated unmanaged Douglas-fir forest (with a high accumulation of forest floor, coarse woody debris, and the nutrients contained therein) and to a simulated Douglas-fir forest growing on a site depleted in organic matter and nutrients. These four options consisted of the combination of two rotation lengths (40 vs. 80 years), and two levels of biomass utilization (full-tree vs. conventional tree length harvest). Based on the model simulations, productivity on the previously unmanaged site dropped significantly (to 59% of the value for the original, unmanaged forest) by the end of the second 40 year rotation when subjected to an intensive management option (40 year rotation, full-tree harvesting). However, a rapid drop in the active soil pool of decomposing organic matter occurred and was not rebuilt. As a result of this reduction in the size of the active soil pool, nitrogen deficiencies (N-demand greater than N-uptake) occurred in the subsequent rotations. In contrast, the initially nutritionally degraded site responded positively to an intermediate level of management (80 year rotations, stem-only harvesting), with a steady increment in the active soil organic matter pool size over the 240 year simulation period. This response indicates that sites degraded by past activities generally have the ability to recover (aggrade) if put under a less demanding management regime. Change in the mass and dynamics of active soil organic matter provides a more rapid and sensitive parameter than tree growth when attempting to assess the sustainability of management alternatives. Examples are presented which illustrate the importance of the starting state condition, as well as the management system being applied, when attempting to assess the sustainability of management alternatives.

174. Muller, R. N. and Y. Liu. 1991. Coarse woody debris in an old-growth deciduous forest on the Cumberland Plateau, southeastern Kentucky. Canadian Journal of Forest Research 21: 1567-1572.

Volume and mass of coarse woody debris (> 20 cm diameter) in an old-growth forest on the Cumberland Plateau in southeastern Kentucky averaged 66.3 m^3/ha and 21.8 Mg/ha, respectively. Coarse woody debris was patchily distributed among 80 sample plots (0.04 ha each), with 10 plots containing 39% of the total mass. Coarse woody debris mass was inversely, although not strongly, related to plot basal area. While 23 species contributed to the accumulation of coarse woody debris, five accounted for 72% of the total mass. These included *Quercus prinus* L. (25% of the total), *Fagus grandifolia* L. (16%), *Quercus alba* L. (12%), *Castanea dentata* (Marsh.) Borkh. (11%), and *Quercus velutina* Lam. (9%). The few studies of coarse woody debris in old-growth deciduous forests of North America suggest a regional pattern of accumulation correlated with temperature. In warmer regions, old-growth deciduous forests accumulate a mass in the range of 22-32 Mg/ha, while in cooler ecosystems, coarse woody debris ranges from 34 to 49 Mg/ha.

175. Murphy, M. L., J. Heifetz, S. W. Johnson, K. V. Koski, and J. F. Thedinga. 1986. Effects of clear-cut logging with and without buffer strips on juvenile salmonids in Alaskan streams [USA]. Canadian Journal of Fisheries and Aquatic Sciences 43: 1521-1533.

To assess short-term effects of logging on juvenile *Oncorhynchus kisutch*, *Salvelinus malma*, *Salmo gairdneri*, and *Salmo clarki* in southeastern Alaska, we compared fish density and habitat in summer and winter in 18 streams in old-growth forest and in clearcuts with and without buffer strips. Buffered reaches did not consistently differ from old-growth reaches; clear-cut reaches had more periphyton, lower channel stability, and less canopy, pool volume, large woody debris, and undercut banks than old-growth reaches. In summer, if areas had underlying limestone, clear-cut reaches and buffered reaches with open canopy had more periphyton, benthos, and coho salmon fry (age 0) than old-growth reaches. In winter, abundance of parr (age > 0) depended on amount of debris. If debris was left in clear-cut reaches, or added in buffered reaches, coho salmon parr were abundant (10-22/100m^2). If debris had been removed from clear-cut reaches, parr were scarce (< 2/100 m^2). Thus, clear-cutting may increase fry abundance in summer in some streams by increasing primary production, but may reduce abundance of parr in winter if debris is removed. Use of buffer strips maintains or increases debris, protects habitat, allows increased primary production, and can increase abundance of fry and parr.

176. Murphy, M. L. and K. V. Koski. 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. North American Journal of Fisheries Management 9: 427-436.

Natural rates of input and depletion of large woody debris LWD in southeast Alaska streams were studied to provide a basis for managing streamside zones to maintain LWD for fish habitat after timber harvest. Debris was inventoried in a variety of stream types in undisturbed old-growth forest; 252 pieces of LWD were dated from the age of trees of growing on them. Longevity of LWD was directly related to bole diameter: small LWD (10-30 cm in diameter) was less than 110 years old, whereas large LWD >60 cm in diameter) was up to 226 years old. Assuming equilibrium between input and depletion of LWD in streams in old-growth forests and exponential decay of LWD, we calculated input and depletion rates form mean age of LWD. Input and depletion rates were inversely proportional to LWD diameter and ranged from 1%/year for large LWD in all stream types to 3%/year for small LWD in large, high energy, bedrock, controlled streams. A model of changes in LWD after timber harvest (which accounted for depletion of LWD and input from second-growth forest) indicated that 90 years after clear-cut logging without a stream-side buffer strip large LWD would be reduced by 70% and recovery to prelogging levels would take more than 250 years. Because nearly all LWD is derived from within 30 m of the stream, the use of a 30-m wide, unlogged buffer strip along both sides of the stream during timber harvest should maintain LWD.

177. Myers, T. and S. Swanson. 1997. Variability of pool characteristics with pool type and formative feature on small Great Basin rangeland streams. Journal of Hydrology 201: 62-81.

Land managers and stream restorationists often set goals or complete designs including specifications for pools that are unrealistic because of a lack of knowledge of the potential conditions of the stream. Using 36 study sites on 17 rangeland streams in Nevada in the western United States, we determined relationships among pool and nonpool length, gradient, pool spacing, pool type and formative feature and stream type. Step pools primarily were formed by boulders while backwater pools were formed by coarse woody debris, This led to most pools being randomly located because structural pool-forming features are too large to move by the flows on these small streams. Montgomery and Buffington (1993) stream type associated with pool type and feature because of the direct linkage between the stream type definitions and pool features, Pool spacing varied only with Montgomery-Buffington stream type presumably because of its linkage with pool type and formative feature. Pool length varied with both Rosgen (1994) and Montgomery-Buffington stream type because of the relations between stream type and pool type and feature. Meander bend pools tended to be deeper because they form in erosive, fine substrate and because the spacing of forced pools may not be optimal which leads to sedimentation. Pool area did not vary with stream type but did with various formative features and pool and nonpool length, Variation of pool area with gradient and ln(gradient) was significant but explained much less variation than did other parameters. Meander bend dominated reaches had the highest pool area. The variability of results and the dependence of pool measures on pool type and formative feature indicates that strict adherence to published equations or expectations due to stream type should be avoided. Land managers should set goals for pool measures based on site specific conditions rather than perceived aquatic species needs or stream type. (C) 1997 Elsevier Science B.V.

178. Myers, T. J. and S. Swanson. 1996. Long-term aquatic habitat restoration: Mahogany Creek, Nevada, as a case study. Water Resources Bulletin 32: 241-252.

We compared the recovery from abusive grazing of aquatic habitat due to different range management on two geomorphically similar rangeland streams in northwest Nevada. Managers excluded livestock from the Mahogany Creek watershed from 1976 to 1990 while allowing rotation of rest grazing on its tributary Summer Camp Creek. Bank stability, defined as the lack of apparent bank erosion or deposition, improved through the study period on both streams, but periodic grazing and flooding decreased stability more on Summer Camp Creek than flooding alone on Mahogany Creek. Pool quantity and quality on each stream decreased because of coarse woody debris removal and sediment deposition during a drought. Fine stream bottom sediments decreased five gears after the removal of livestock, but sedimentation increased during low flows in both streams below road crossings. Tree cover increased 35 percent at both streams. Thus, recovery of stability and cover and decreased sedimentation are compatible with rotation of rest grazing on Summer Camp Creek. Width/depth ratio and gravel/cobble percent did not change because they are inherently stable in this stream type. Management activities such as coarse woody debris removal limited pool recovery, and road crossings increased sedimentation.

179. Myers, T. J. and S. Swanson. 1996. Temporal and geomorphic variations of stream stability and morphology: Mahogany Creek, Nevada. Water Resources Bulletin 32: 253-265.

Detailed studies of long-term management impacts on rangeland streams are few because of the cost of obtaining detailed data replicated in time. This study uses government agency aquatic habitat, stream morphologic, and ocular stability data to assess land management impacts over four years on three stream reaches of an important rangeland watershed in northwestern Nevada. Aquatic habitat improved as riparian vegetation reestablished itself with decreased and better controlled livestock grazing. However, sediment from livestock disturbances and road crossings and very low stream flows limited the rate of change. Stream type limited the change of pool variables and width/depth ratio, which are linked to gradient and entrenchment. Coarse woody debris removal due to previous management limited pool recovery. Various critical- element ocular stability estimates represented changes with time and differences among reaches very well. Ocular stability variables tracked the quantitative habitat and morphologic variables well enough to recommend that ocular surveys be used to monitor changes with time between more intensive aquatic surveys.

180. Myers, T. J. and S. Swanson. 1997. Precision of channel width and pool area measurements. Journal of the American Water Resources Association 33: 647-659.

The precision of width and pool area measurements has rarely been considered in relation to downstream or at section hydraulic geometry, fisheries studies, long-term or along a continuum research studies, or agency monitoring techniques. We assessed this precision and related it to other stream morphologic characteristics. Confidence limits (95 percent) around mean estimates with four transects (cross-sections perpendicular to the channel centerline) ranged from ±0.4 to 1.8 m on streams with a width of only 2.2 m. To avoid autocorrelation, transects should be spaced about three channel widths apart. To avoid stochastic inhomogeneity, reach length should be about 30 channel widths or ten transects to optimize sampling efficiency. Precision of width measurements decreased with decreased depth and increased with stream size. Both observations reflect variability caused by features such as boulders or coarse woody debris. Pool area precision increased with pool area reflecting increased precision for flat, wide streams with regular pool-rime sequences. The least precision occurred on small, steep streams with random, boulder or coarse woody debris formed pools.

181. Nakamura, F. and F. J. Swanson. 1994. Distribution of coarse woody debris in a mountain stream, western Cascade range, Oregon. Canadian Journal of Forest Research 24: 2395-2403.

The distribution of coarse woody debris in a fifth-order Cascade Range (Oregon) stream system was examined from a geomorphic point of view. The number, volume, location, orientation, decay class, and pool formation roles of coarse woody debris were investigated. The processes of coarse woody debris production, transport, and storage, which vary with channel and valley floor geomorphology, are responsible for the pattern of coarse woody debris distribution on valley floors. Channel width and sinuosity are the main factors that control production, storage sites, and hydrologic effects of coarse woody debris. The amount of coarse woody debris and the number of pool-forming pieces are relatively high in wide, sinuous reaches, where a complex structure of floodplains and riparian forests develops in association with a braided channel pattern.

These relations are transferable to other systems with similar relations of coarse woody debris piece length to channel width.

182. Nakamura, F. S. 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.

183. Narver, D. W. 1970. Effects of logging debris on fish production. Forest Land Uses and Stream Environment, Corvallis, Oregon: 101-111. Oregon State University.

Stream salmonids (8 species of Pacific salmon, trout, and char) are discussed in relation to their environmental requirements and the possible impact of logging debris on their production. The emphasis is on small streams because of their great importance as nursery and spawning areas for certain species and because they may be more susceptible to damage than larger streams or rivers. Extensive use is made of pertinent literature. It is concluded that accumulation of logging debris in small streams can have serious consequences on the production of salmonid fishes.

184. Niemela, J. 1999. Management in relation to disturbance in the boreal forest. Forest Ecology and Management 115: 127-134.

Disturbances and the consequent habitat heterogeneity are natural features of the boreal forest. Natural disturbances occurring at the level of populations, communities and ecosystems (meters to kilometers and years to hundreds of years), that is, at the 'meso-scale' may provide useful guidelines for forest management. This approach is based on the assumption that species are adapted to the disturbance regime of the forest-type that they occupy. However, natural disturbance and human-caused disturbance, such as clear-cutting, may differ substantially in their ecological effects. Potential differences occur on several scales. On the stand scale, removal or destruction of important habitat structures, such as coarse woody debris, during traditional clear-cutting may affect species. On the landscape scale, fragmentation may cause local extinctions and hamper the recolonization of maturing sites by old-growth specialists. The effect of these differences on boreal biota needs to be assessed. On the stand scale, the degree of recovery (resilience) of populations and communities after human-caused disturbance versus natural disturbance, that is, the succession process, could be a useful criterion when developing new forestry methods. On the landscape scale, it is important to maintain enough patches of suitable habitat for the old-growth species in order to prevent local extinctions and to promote recolonizations. Natural landscapes could be used as a reference here. In conclusion, although possibilities of matching forestry with maintenance of taiga biota through development of harvesting methods that mimic natural disturbance seem reasonably good, there is an urgent need to establish criteria for the assessment of the success or

failure of such methods. The resilience of forest ecosystems as reflected in population changes of surrogate taxa after disturbance could be used to guide management.

185. O'Connor, M. D. 1986. Effects of Logging on Organic Debris Dams in First Order Streams in Northern California. Master of Science. University of California, Berkeley, CA, 90 pages.

Intensive survey of portions of nine northern California headwater (first order) streams determined the abundance of organic debris dams (ODD's) and their influence on channel morphology. ODD's are accumulations of woody debris of fallen trees that completely of partially obstruct stream flow. Sediment is deposited on the upstream side. These accumulations of sediment and woody debris become semi-permanent features that retard the rate of material transport downstream.
ODD's were much less influential in one of the three regions examined. Forest productivity and topography appeared to be responsible for these differences. Six of the twelve stream reaches surveyed were disturbed, five by timber harvest and one by debris torrent. It was inferred that timber harvest caused changes in the abundance of ODD's in adjacent streams. Apparent decreases in abundance were most frequently observed. Channel disturbance caused by felling timber and yarding logs, by bulldozer activity, and by haphazard disposal of unmerchantable woody debris appeared to be partly responsible for changes in ODD abundance. My observations of the streams in 1985 (12 to 14 years after timber harvest), together with descriptions of stream conditions one to three years after harvest, were helpful inferential tools.
An indirect measure of stream retentiveness, interaction with the riparian zone at bankfull discharge, was correlated with species diversity of aquatic macroinvertebrate communities. Abundance of ODD's was the chief criterion of determining the degree of bankfull-riparian interaction. Hence, ODD's appeared to be the dominant morphologic feature of many steep headwater streams in forest ecosystems. Inventory and analysis of ODD's and channel morphology appeared to be a promising approach to meeting management objectives for headwater streams.

186. Palik, B., S. W. Golladay, P. C. Goebel, and B. W. Taylor. 1998. Geomorphic variation in riparian tree mortality and stream coarse woody debris recruitment from record flooding in a coastal plain stream. Ecoscience 5: 551-560.

Large floods are an important process controlling the structure and function of stream ecosystems. One of the ways floods affect streams is through the recruitment of coarse woody debris from stream-side forests. Stream valley geomorphology may mediate this interaction by altering flood velocity, depth, and duration. Little research has examined how floods and geomorphic features interact to control debris recruitment from riparian forests. With this in mind, we examined debris recruitment resulting from tree mortality during a record flood in a Georgia (U.S.A.) stream. We quantified debris characteristics as related to riparian geomorphology, and we examined the influence of floods on the structure of stream- side forests. The flood killed, and recruited into the stream debris pool, an average of 22 trees/km. Variation in recruitment was related to geomorphology; mortality was highest in reaches having narrow valleys and high elevations of riparian landforms, while it was lowest in reaches having wide valleys and low landform elevations. Species differed in probability of mortality; three taxa, out of 47, contributed 75% of new debris to the stream. The structure of stream-side forests reflected the influence of floods on tree mortality; forests along constrained reaches lack small individuals. Our results suggest that constrained reaches are the primary sources of debris during large floods, while unconstrained reaches function as debris sinks. Debris characteristics may be linked to floods through tree demography. Specifically, large

floods have the potential to limit future recruitment of larger-sized susceptible species into the stream, by limiting the number of small trees that grow into the canopy.

187. Palmer, M. A., P. Arensburger, A. P. Martin, and D. W. Denman. 1996. Disturbance and patch-specific responses: The interactive effects of woody debris and floods on lotic invertebrates. Oecologia (Berlin) 105: 247-257.

Disturbance may play an important role in generating patterns of abundance and distribution of biotic assemblages, particularly if its impact differs among habitat patches. Despite much speculation concerning the probable importance of spatial variation in the response of stream fauna to flooding, empirical work on patch-specific responses to spates is largely lacking. Floods typically reduce the abundance of lotic invertebrates dramatically in open-channel areas. We conducted a set of experiments to determine if faunal abundances are less affected in patches more sheltered due to the presence of woody debris dams. Specifically, we tested two hypotheses using chironomids and copepods living in a warm water, 4th order stream: (1) the effect of flooding on the fauna varies between patches associated with debris dams versus the open channel, and (2) the absence of woody debris in a stream impedes faunal recovery throughout the channel following floods. We tested the first hypothesis by quantifying faunal abundances prior to, during, and following two floods in four patch types: mid-channel sandy patches distant from dams, coarse sediments associated with dams, fine sediments associated with dams. and leafy debris in dams. The second hypothesis was tested by removing all of the woody debris from two stretches of the stream and comparing the impact of a flood on fauna in debris-removed versus control stretches. Across all of the eight study dams, there were patch specific faunal responses to two floods. Removal of woody debris from the stream did not prevent faunal recovery throughout the channel: however, the presence of woody debris dams did confer greater resistance of fauna to floods (as measured by no decrease in abundance during flooding) in two patch types. Abundances of chironomids and, to a lesser extent, copepods in the leafy debris of dams and in fine sediment patches associated with some dams either did not change or increased during floods. despite the fact that abundances in the dominant patch type of the stream (the sandy mid-channel) were reduced by 75-95%. All instances of faunal increase were limited to fine sediment patches associated with dams, thus entire dams cannot be labeled as flow refugia per se. Statistically, we distinguished fine patches which accumulated animals during floods from the other fine patches based on two physical attributes. Patches accumulating animals were all characterized by low water flux and near-bed flow. which likely contributed to the retention and/or passive deposition of animals. Whole dam attributes (e.g. dam size or complexity) were not useful in predicting which of the dams would accumulate animals in their fine sediments during flooding. Although structural complexity - here in the form of wood and leafy debris - is clearly important in generating biotic pattern in many ecosystems, our work underscores the need to understand what processes are responsible for the link between physical structure and biotic pattern.

188. Petersen, R. C., Jr., K. W. Cummins, and C. M. Ward. 1989. Microbial and animal processing of detritus in a woodland stream. Ecological Monographs 59: 21-40.

The detritus standing crop, microbial respiration, and macroinvertebrate biomass were examined in monthly samples from the riffle sections of a first-over woodland stream. Total detritus was remarkably constant; the average (with 95% CL) ash-free dry mass standing crop was 426.4 ±85.9 g/m^2 over the 14 mo of the study. Throughout the year benthic detritus was dominated by fine particulate detritus (< 1 mm), which made up 68.9% of the total ash-free dry mass. Woody debris made up 8%, whole leaves 3.5% and leaf fragments and other coarse particulate detritus accounted for 19.7% of the total standing crop. Decreases in standing crop were attributable to microbial respiration, macroinvertebrate assimilation, and downstream export. Microbial respiration annually removed 150% of the average standing crop, with the major effect on the smallest particle size category. Macroinvertebrate assimilation, defined as the sum of respiration and growth, removed 11.6% of the detritus standing crop annually. Shredders accounted for 20% of total animal assimilation, with the remaining 80% attributable to collectors and grazers. Based on monthly changes, it appears that total detritus standing crop is the result of the past discharge regime, which determines the overall amount of detritus present, and the rate of biological (microbial and invertebrate) processes, which determine the size and quality of the detritus particles. This suggests that detritus in streams, while strongly affected by both biotic and abiotic factors, may be in equilibrium within physical and biological constraints such that an annual steady-state system exists, similar to that for soil systems.

189. Phillips, E. C. 1994. Habitat preference and seasonal abundance of trichoptera larvae in Ozark streams, Arkansas. Journal of Freshwater Ecology 9: 91-95.

Trichopterans were collected from both coarse woody debris (CWD) and benthic habitats from three streams in northwest Arkansas from February 1992 through February 1993. Overall density of caddisflies was significantly greater in benthic habitats than on CWD. Trichopteran larvae had significantly greater densities during summer and fall than during winter and spring. *Lype diversa* was the only species that showed a preference for decay stage and was collected in greatest densities on wood with loose bark or on decayed wood with many interstitial spaces. No species tested showed a preference for volume of biofilm. However, on wood with bark remaining, wood with bark or rough texture produced greater densities of caddisflies than did wood with smooth bark.

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

Coarse woody debris (CWD) has been examined i 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 form 0.110t/ha to more than 200t/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. The affects the researcher and the planner the first consider 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 generative vector, the ecological functions of which are recognized. Its effect is stronger today as the watershed area tends to be subjects to a decrease in agricultural activity.

191. Piegay, H. 1997. Interactions between floodplain forests and overbank flows: Data from three piedmont rivers of southeastern France. Global Ecology and Biogeography Letters 6: 187-196.

Spatial variations of flow are described and explained within the forested margins of three Rhone river tributaries during floods that occurred in 1992, 1993 and 1994. Observations were made on the scale of riparian forest corridors with cross-sectional analysis, and also on the scale of vegetation units located in the upstream reaches of floodplain channels using a 4000 m^2 sampling plot. The study of floodplain cross-sections does not always confirm relationships between flow depth and altitude or distance from the sampling point to the active channel. Orientation of flow slope varies too much from one site to another and often within each site. Water can flow from the river channel into the forest and vice versa. Floodplain channels characterized by a flow depth higher than flow depths observed in neighbouring forests laterally supply their margins. On the vegetation patches of the Mollon site (Ain river), flood overflows are affected by a line of coarse woody debris (CWD) which changes location from year to year. Thus. position, orientation and form or floodplain microchannels varied from one year to the next. Floodplain vegetation can be described as a patchwork influenced by overbank flows, which are in turn affected by floodplain topography, vegetation hydraulic roughness, and by the supply and orientation of CWD. An interactive relationship thus exists between discharge and the forest. This relationship gives rise to a great variety of biogeomorphological processes which may be interpreted as pertinent indicators of the lateral connectivity of forested floodplain rivers.

192. Piegay, H. and A. M. Gurnell. 1997. Large woody debris and river geomorphological pattern: Examples from SE 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 a 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 constrasts in the role of LW D 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.

193. Piegay, H. and N. Landon. 1997. Promoting ecological management of riparian forests on the Drome River, France. Aquatic Conservation: Marine and Freshwater Ecosystems 7: 287-304.

1. Riparian forests, because of their multiple ecological and dynamic functions, have become a subject of particular interest for managers. This is the case in France following the Water Law of 3 January 1992 and the development of the "Schema Directeur d'Amenagement et de Gestion des Eaux (SDAGE)" (Planning and Management-Master Plan-of Water Resources) in various subcatchments of the Rhone. Within this framework, the major themes of ecologically integrated riparian forest management have been developed on a 110 km section of the Drome river, a piedmont tributary of the middle Rhone river, in south-eastern France. 2. The geographical expansion, diversity and evolution of riparian forest within this section of the Drome since 1948 have been studied. The transport of woody debris, which is characteristic of forest hydrosystems, has also been taken into consideration as managers were concerned by its recent increase. 3. The recently developed vegetation corridor, measuring nearly 710 ha, is threatened by reduced bedload availability leading to channel incision and the disconnection of the floodplain from the active band of the channel, as well as reduced vegetation renewal. 4. Several management proposals have been put forward in an effort to maintain riparian ecosystem dynamics without simultaneously increasing flooding and erosion risk: (i) legal measures to conserve the most functional sections, (ii) replanting a vegetation corridor at least 5 m wide in farming areas, (iii) impeding the breaking-up of the most interesting vegetation corridors into small parcels of land, (iv) urgently encouraging the regeneration of vegetation margins and renewed sediment transport, namely by creating artificial overflow channels in forested areas or by clearing certain sectors of the active channel. 5. It has been proposed that vegetation maintenance and logjam removal, today recognized as detrimental from an ecological standpoint, be conducted selectively on the basis of management appraisals of certain sectors. Certain reaches will no longer be subject to maintenance on the grounds of their great ecological value and because of their low risk of flooding impacts. (C) 1997 John Wiley & Sons, Ltd.

194. Piegay, H., A. Citterio, and L. Astrade. 1998. Interactions between large woody debris and meander cut-off (example of the Mellon site on the Ain River, France). Zeitschrift Fur Geomorphologie 42: 187-208.

The Ain River, a 6th order tributary of the upper Rhone River, is characterized by free-meandering and a corridor of riparian forest. Along the concave banks, notably in the upstream part of overbank flow channels, sedimentation and jams of large woody debris (LWD) are interactive. This study focuses on the meander bend of Mellon which has shown downstream migration (10-15 m/yr) since 1963. Four annual field measurement campaigns were conducted on a sampling plot of 4,000 m^2 located in the upstream part of an overbank flow channel. Topography, sediment mosaics, LWD jam masses, forms and orientations have been studied. A GIS raster was used to quantify phenomena and interannual trends. We observe a strong regeneration of the floodplain: an annual bank mobility of 10- 20 m/yr and gravel bar migration into the forest. Nevertheless, the main

forms are stable from one year to another and the annual lowering of the forest surface is slight (2-6 cm/yr). Although LWD masses are stable during the period studied (15.6- 19 t/ha), the debris line formed by the jams is very mobile, being broken up and restored differently during each flood. Total LWD mass and mean mass per jam decrease from the bank to the forest. Each jam modifies the topography and increases the granulometric variability around it. Nevertheless, LWD jams and the presence of the stands of trees also explain the interannual stability of the main floodplain forms. Finally, the interannual modification of the main channel pattern greatly influences the orientation of microforms and LWD jams.

195. Piegay, H. and R. A. Marston. 1998. Distribution of large woody debris along the outer bend of meanders in the Ain River, France. Physical Geography 19: 318-340.

The distribution of large woody debris (LWD) was studied along the concave outer bend of three meanders in the Ain River, a 195-km-long tributary of the upper Rhone River. The Ain River is a sixth-order channel dominated by a gravel-cobble bed substrate that meanders through a floodplain covered largely by riparian forest vegetation. The mass of LWD was measured in a 15-m-wide forest band along the three meander bends, with total loads calculated to be 56.1 t ha^{-1} at the Mellon study site, compared with 22.9 and 21.5 t ha^{-1} at the study sites of Bublane and Blyes, respectively The distribution of LWD within any one meander concavity was dependent on three main variables: (1) the position of the concavity in relation to the main flow axis, (2) the height of the bank, and (3) the presence and position of overbank flow channels in the concavity. The type of vegetation community along the channel margin is nondiscriminating, favoring the conclusion that the LWD comes mainly from upstream of the bends rather than locally. The relative influence of each variable is contrasted between the three study sites. The total LWD deposited along concavities was most strongly controlled by meander-bend geometry. The supply areas for LWD, located a few kilometers upstream from the study sites, were also found to influence total LWD along concavities. Findings from this study are applicable to managing instream large woody debris as part of ongoing efforts to restore alluvial forests along French rivers.

196. Piegay, H., A. Thevenet, and A. Citterio. 1999. Input, storage and distribution of large woody debris along a mountain river continuum, the Drome River, France. Catena 35: 19-39.

Large woody debris (LWD) input, storage and distribution were studied along the Drome River, a French Alpine river with an active shifting channel and a well-developed riparian forest. LWD input from the floodplain is low: 669.6 mg $year^{-1}$ between 1948 and 1971 and 569.3 mg $year^{-1}$ between 1971 and 1991. Based on estimates of average LWD mass per study plot, a range of 766-2122 mg $year^{-1}$ of LWD were stored within the active channel (e.g., unvegetated bars and low-flow channel; 60 km course covering 492 ha). LWD accumulations are mainly observed on gravel bars at a limited number of preferential sites. They are relatively rare and are randomly distributed in the low- flow channel. Consequently, LWD location is mainly associated with the decrease of flow level in shallow sectors. In the low- flow channel, LWD stop-en-route is primarily caused by in- channel structures such as boulders or vegetated islets. General geomorphological factors (e.g., pattern, slope, etc.) provide less explanation of LWD distribution. Moreover, the residence time of LWD accumulations on the Drome River is short (LWD storage = 1.3-3.7 times the annual LWD input from the floodplain) and their

morphogenic role is negligible: few of the accumulations are buried or characterized by vegetation shoots and associated pools. (C) 1999 Elsevier Science B.V. All rights reserved.

197. Pope, K. L. and D. W. Willis. 1997. Environmental characteristics of black crappie (Pomoxis nigromaculatus) nesting sites in two South Dakota waters. Ecology of Freshwater Fish 6: 183-189.

A biotelemetry study was undertaken during spring 1995 to identify black crappie (*Pomoxis nigromaculatus*) nesting sites in two South Dakota water bodies. Individually coded ultrasonic transmitters were implanted into the body cavity of 15 adult male black crappie in each water body prior to spawning. Available habitat characteristics were recorded at 75 randomly selected sites within each water body, and habitat characteristics at nesting sites were recorded for each male black crappie believed to be nesting. Of the habitat characteristics analyzed, only substrate firmness did not differ (P=0.79) between water bodies. In Richmond Lake, black crappie selected nesting sites with live cattails (*Typha spp.)* that were protected from prevailing south winds. In Brant Lake, black crappie selected nest sites with vegetation (usually woody debris) and silty substrate that had warmer water and were protected from wind and waves. It appeared that black crappie nested in the most protected areas available.

198. Preston, C. M., J. A. Trofymow, J. Niu, and C. A. Fyfe. 1998. 13CPMASS-NMR spectrometry and chemical analysis of coarse woody debris in coastal forests of Vancouver Island. Forest Ecology and Management 111: 51-68.

The coastal forests of British Columbia have large accumulations of coarse woody debris, and information on this pool is considered essential in developing sustainable management practices. We characterized coarse woody debris (7-12 and >12 cm diameter) in forest chronosequences of four age classes located on the eastern and western sides of Vancouver Island. For three species (Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg), western red cedar (Thuja plicata Donn.)) and unidentified samples, increases in decay class (I to V, assigned in the field) were associated with decreasing density, and small increases in concentrations of C, N, and P Sulfur concentrations (0.6-2.4 g/kg) were higher than those found elsewhere for wood and did not show any significant changes with decay class. 13C nuclear magnetic resonance spectroscopy with cross polarization and magic-angle spinning (13C-CPMAS-NMR) was used to analyze organic components in a subset of samples >12 cm. Logs up to decay class III generally showed little change in composition or a slight increase in polysaccharide C. After this, polysaccharide was lost more quickly and logs of decay class V were composed almost entirely of lignin, a pattern consistent with decay by brown-rot fungi. However, two samples of western red cedar decay class III and IV showed accumulation of polysaccharide, the pattern expected from white-rot fungi. The results of the density, chemical and NMR analysis indicate that for management purposes, a system with fewer decay classes would suffice.

199. Pyle, C. and M. M. Brown. 1999. Heterogeneity of wood decay classes within hardwood logs. Forest Ecology and Management 114: 253-259.

As forest floor coarse woody debris (CWD) decays, it changes from solid wood to material without a recognizable origin. Decaying logs provide a progression of woody habitat substrates that contribute to the diversity of species and ecological processes in the forest. For studies of the habitat values of logs, decaying logs typically are assigned to one of the five classes with Class V being highly decayed lop that have lost their cylindrical shape and are composed primarily of powdery wood. In a study made in *Quercus* hardwood and mixed hardwood stands of the University of Connecticut Forest, near Storrs, CT, we examined the range and variability in actual decay classes present within logs assigned to decay class groups I, II, III, or IV. The proportions of all the decay classes found in each of 125 logs were estimated from measurements of the length and diameters of each different sector of decay within a log. The homogeneity of within-log decay classes varied by overall decay class group with the decay class III logs and group being the most variable. We compare our results to an idealized continuum of decay and conclude that by virtue of being in the middle of the decay sequence, class III is expected to be the most variable. We recognize that although the overall pattern of our results may be considered typical relative to the idealized continuum, the specific proportion of decay class variability from any one study represents site- and time-specific conditions not likely to typify "average" conditions in a broader geographic area. Our results indicate that variability of decay state within a given log is generally to be expected, and, from this we infer within-log variability in species and ecological functioning.

200. Quinn, J. M., A. B. Cooper, R. J. Davies-Colley, J. C. Rutherford, and R. B. Williamson. 1997. Land use effects on habitat, water quality, periphyton, and benthic invertebrates in Waikato, New Zealand, hill-country streams. New Zealand Journal of Marine and Freshwater Research 31: 579-597.

Water quality, habitat, and biota were compared during spring amongst c. 100 m reaches on 11 streams draining pasture, native (podocarp-broadleaf) forest, and exotic pine forest established on pasture 15 years previously. Differences were greatest between the pasture and native forest streams. Only 1-3% of incident light reached native and pine forest streams whereas 30% reached pasture streams. Pasture streams had 2.2 degree C higher mean temperature than the native streams, and 5-fold higher nitrate, 30-fold higher algal biomass, and 11-fold higher gross photosynthesis. Native streams were 60% wider than pasture, with pine streams intermediate. Pine and pasture streams had 3-fold higher suspended solids and fine sediment stored in the streambed than native streams. Woody debris volume was 17-fold greater in pine than pasture streams, with native streams intermediate. Invertebrate taxa richness did not differ between land uses. Community composition differed most between pasture and native forest, with pine forest streams intermediate. Invertebrate densities were 3-fold higher in pasture than native streams, mainly because of more chironomids and snails, but mayflies, stoneflies, and caddisflies densities were 2-3-fold higher in forest streams than pasture.

201. Quinn, T. P. and N. P. Peterson. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon (*Oncorhynchus kisutch*) in Big Beef Creek, Washington. Canadian Journal of Fisheries and Aquatic Sciences 53: 1555-1564.

Wild juvenile coho salmon (*Oncorhynchus kisutch*) were individually marked in October 1990 and 1991 to evaluate the effects of habitat complexity and fish size on over-winter survival in Big Beef Creek, Washington. Habitat complexity was quantified for the habitat unit where the fish were collected and, in 1991, also for the 500-m reach downstream from the collection site. Survival, estimated from recovery of marked smolts at the stream's mouth, differed between years (25.4 and 46.2%) and also varied among habitat units and reaches within years. Survival was at most weakly correlated with complexity of the habitat units but was strongly correlated with the quantity of woody debris and density of habitat units in the 500-m reach, and distance from the estuary. Because distance covaried with habitat complexity, we could not ascertain which factor had the primary influence on survival. In addition, larger fish generally survived at a higher rate than smaller individuals. However, fish tagged above William Symington Lake were smaller in the fall but larger as smolts and had higher survival rates than those tagged below the lake. Taken together, these results reveal complex relationships between size, habitat, and growth that may affect over-winter survival and subsequent life-history events.

202. Ralph, S. C., G. C. Poole, L. L. Conquest, and R. J. Naiman. 1994. Stream channel morphology and woody debris in logged and unlogged basins of western Washington. Canadian Journal of Fisheries and Aquatic Sciences 51: 37-51.

Channel morphology and habitat characteristics of stream segments draining unharvested old-growth forests were compared with those from streams within intensively and moderately logged basins. Sites covered a broad geographic range in western Washington State and were stratified by basin area and channel gradient. Although the number of pieces of large woody debris (LWD) within stream channels was unaffected by timber harvest, there was a clear reduction in LWD size in harvested basins. Timber harvest also resulted in a shift in location of LWD towards the channel margins, outside the low-flow wetted width of the channel. Given the natural variation from stream to stream, we conclude that simple counts of instream LWD and channel units (habitat types) are not useful as management objectives. Instead, these attributes should be used collectively as indicators of the complexity and stability of in-stream habitat with respect to the specific channel and valley geomorphology.

203. Rhoades, F. 1986. Small mammal mycophagy near woody debris accumulations in the Stehekin River Valley, Washington [USA]. Northwest Science 60: 150-153.

The digestive tracts of 32 small mammals (*Sorex monticolus, Peromyscus maniculatus, Microtus longicaudus,* and *Clethrionomys gapperi*) trapped near woody debris piles were examined for presence and abundance of spores of hypogeous, epigeous and wood-inhabiting fungi. All animals contained fungal spores, usually in abundance high enough to suggest that each animal had recently consumed fungi. Spores of hypogeous fungi were the most abundant, especially those of genera Alpova and Rhizopogon.

204. Rhoads, B. L. 1994. Fluvial geomorphology. Progress in Physical Geography 18: 588-608.

At the Third International Geomorphology Symposium, Derald Smith (1993) posed the question, "where do we go from here?" to fluvial geomorphologists. His own response to this question is apprehensive, emphasizing that our discipline is in serious danger of becoming a backwater science if it does not change its current practices. Although the concerns he raises deserve consideration, Smith's trepidation seems somewhat overstated. The large number of articles reviewed in these progress reports over the last several years attests to the vitality of fluvial geomorphology. The acknowledgements in these articles indicate that the overall level of research support is at least holding steady and may be increasing. Collaborations among fluvial geomorphologists are on the rise and members of our discipline are increasingly participating in multidisciplinary efforts. Moreover, considerable attention is being given to the scientific foundation of geomorphology (Baker, 1993; Rhoads, 1994a; Rhoads and Thorn, 1994).
This alternative assessment is not meant to imply that fluvial geomorphologists should be complacent; the discipline certainly could benefit from initiatives that increase its visibility within the general arena of science (Rhoads, 1994b). However, before we jump on the "big science" bandwagon, we should have a clear sense of disciplinary identity and the relationship of that identity to other sciences and to public policy imperatives (e.g., Graf, 1993). The most critical challenge confronting fluvial geomorphologists today is to devise effective strategies for integrating a diverse assortment of research that spans a broad range of spatial and temporal scales. Such strategies will not only improve our understanding of landscape dynamics on the Earth and other planets but will also enhance disciplinary unity and position us to play a major role in investigations on complex, multiscale environmental problems. Intradisciplinary collaboration may be the key to successful variable-scale research initiatives; however, at present most collaborations occur among fluvial geomorphologists working on similar issues at similar scales

205. Richards, C., L. B. Johnson, and G. E. Host. 1996. Landscape-scale influences on stream habitats and biota. Canadian Journal of Fisheries and Aquatic Sciences 53: 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.

206. Richardson, J. S. 1992. Coarse particulate detritus dynamics in small, montane streams of southwestern British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 49: 337-346.

The dynamics of coarse particulate organic matter (CPOM) were studied for 2 yr in three second-order streams in the Coast Range of British Columbia [Canada]. Estimates of direct litterfall ranged from 201 to 481 g ash-free dry mass/m^2/yr. The magnitude of deciduous leaf litter input was similar among streams. Input of conifer needles to a stream with an old-growth canopy was higher than in two streams which drained second-growth forests. There was over a 60-fold seasonal change in deciduous leaf standing stock, but woody debris and total CPOM showed less seasonal variation. Decomposition of alder leaf packs in two of the streams showed a large temperature-dependent component and significant differences between streams, with the more retentive stream having lower rates of decomposition. From estimates of input and decay rates, models of leaf loss were made to predict benthic standing stocks of deciduous leaf litter. Comparisons of the model predications with actual measures indicate that 70-94% of leaf material was unaccounted for and presumably lost from the study reach by export, floodplain deposition, and burial. The seasonal changes in standing stock of CPOM emphasize the variation in food supply potentially available to detritivorous stream organisms.

207. Richmond, A. D. and K. D. Fausch. 1995. Characteristics and function of large woody debris in subalpine Rocky Mountain streams in northern Colorado. Canadian Journal of Fisheries and Aquatic Sciences 52: 1789-1802.

Large woody debris has been well studied in coastal forests of the Pacific Northwest, but little is known of its role in Rocky Mountain streams. Large woody debris was measured in 11 undisturbed streams draining subalpine old-growth forests in north central Colorado to assess abundance, characteristics, and function. Although large woody debris in Colorado had smaller diameter, length, and volume than in the Pacific Northwest, its abundance and function were similar. The majority of pools (76%) were plunge and dammed pools formed by large woody debris, most of which spanned the channels perpendicular to stream flow. Smaller streams had a greater proportion of such perpendicular pool-forming pieces than larger streams. Four disturbed streams had significantly less and smaller large woody debris than undisturbed streams. Flows in larger undisturbed streams were capable of moving large woody debris, so pieces were more often located at the stream margins, oriented diagonally, or distributed in clumps than in smaller streams. Individual pools were larger and deeper in larger streams, but their size was not related to the size of large woody debris pieces forming them. Therefore, the function of large woody debris in forming fish habitat in small Rocky Mountain streams is strongly influenced by the stream's location within the watershed.

208. Rikhari, H. C. and S. P. Singh. 1998. Coarse woody debris in oak forested stream channels in the central Himalaya. Ecoscience 5: 128-131.

This study examines the quantity of coarse woody debris (CWD) and its distribution for *Quercus* spp. of different diameter and decay classes in two stream channels passing through an oak (*Quercus* spp.) forest located at an elevation of 1900-2230 m above mean sea level in the central Himalaya, India Total mass of CWD varied between 9.42 and 35.30 mg/ha, of which Quercus spp. alone accounted for 74 to 100% at six different sites. With few exceptions, mass of CWD increased with increasing size of CWD and the reverse trend was observed for a number of wood pieces/logs. Surface area/volume ratio for *Quercus* spp. across the six sites varied between 5 and 105. Wood density decreased

with increasing decay of CWD. Most of the CWD mass (about 55- 100%) was distributed in intermediate decay classes.

209. Riley, S. C. and K. D. Fausch. 1995. Trout population response to habitat enhancement in six northern Colorado streams. Canadian Journal of Fisheries and Aquatic Sciences 52: 34-53.

We examined the effects of log drop structures on trout populations in six small, remote Rocky Mountain streams. Angling pressure was low on all streams, and most anglers killed no fish. Log drop structures were installed in 250-m treatment sections in summer 1988, and results were compared with adjacent 250-m control sections during 1987-1990. The structures caused marked changes in habitat, including greatly increased pool volume, decreased current velocity, and increased depth and cover. After the structures were installed, abundance and biomass of age-2 and older trout (and often age-1 trout) increased in all six streams, but there was no evidence that trout were in better condition or grew to larger sizes in most streams. Recaptures of tagged trout in two streams showed that the logs did not result in increased growth or survival of resident trout, although recaptures of fin-clipped trout in other streams suggested that apparent survival may have increased temporarily in treatment sections. Low recapture rates of marked trout and high percentages of unmarked adults indicated that immigration rates were high, suggesting that movement is an important mechanism to account for the increase in trout populations after habitat enhancement in these streams.

210. Ringvall, A. and G. Stahl. 1999. Field aspects of line intersect sampling for assessing coarse woody debris. Forest Ecology and Management 119: 163-170.

Due to modern forestry practises, the amount of coarse woody debris has decreased considerably in Swedish forests. Since many threatened species depend on this substrate, assessment of it is central in the monitoring of forest ecosystems. The plot- based methods normally used for timber cruising tend to be inefficient when the objects of interest are sparse and, consequently, line intersect sampling is an interesting alternative for assessing coarse woody debris on the ground. With this method there is a risk that the surveyor, without being conscious about it, tends to move towards or away from a log instead of following a straight line. The result is biased estimates. In this paper, a field test concerning the surveyors' influence on estimates is presented. Line intersect sampling for assessing coarse woody debris was tested by ii surveyors in four old conifer stands in northern Sweden. The study did not indicate any systematic differences between surveyors in their way of performing the inventory, although for the surveyors as a group a negative bias was found. The bias was, however, only due to a large underestimation in one single stand, meanwhile the measurements in the other stands were close to reference values. Random measurements errors are, however, likely to be introduced. The conclusion is that systematic errors should not be a major problem in line intersect sampling but that the dimensioning of surveys should consider the random error component introduced by surveyors.

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

Coarse woody debris (> 0.2 m 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-, second-, third-, and fourth-order coastal streams were determined. Debris was also classified into four influence zones based on stream hydraulics and fish habitat. 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-, second-, and third-order streams had a higher proportion of recent debris in the channel than the fourth-order stream (greater than or equal to19 vs. 8%), most new debris being attributable to a major 1984 windstorm. Tree blowdown had a major influence on debris distribution along the smaller stream 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.

212. Robison, E. G. and R. L. Beschta. 1990. Coarse woody debris and channel morphology interactions for undisturbed streams in southeast Alaska, USA. Earth Surface Processes and Landforms 15: 149-156.

Coarse woody debris and channel morphology were evaluated for five low-gradient streams that ranged form first to fourth order (0.7 to 55 km^2 watershed area). Debris volumes were directly related to variations in bankfull width. Woody debris was associated with 65 to 75 percent of all pools and the relative proportion of types of pools (i.e. plunge, lateral scour, etc.) varied with stream size. High variability in channel depths and widths was common. The results provide benchmark values of woody debris loadings and channel morphology for undisturbed coastal Alaskan systems

213. Robison, E. G. and R. L. Beschta. 1990. Identifying trees in riparian areas that can provide coarse woody debris to streams. Forest Science 36: 790-801.

The natural fall of trees into mountain streams provides coarse woody debris that can improve fish habitat and influence stream morphology. Geometric and empirical equations, based on tree size and distance from the stream, were used to determine the conditional probability of a tree's adding coarse woody debris to a stream. Additional equations were developed to relate this probability to basal area factor. For conditions in the Pacific Northwest, Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) was selected to illustrate how the equations can be used for varying tree sizes and probabilities. After selecting a probability and determining basal area factor by these equations, resource managers can use prisms or wedge devices before timber harvesting in riparian areas to identify specific trees that can potentially add woody debris to the stream.

214. Rumble, M. A. and S. H. Anderson. 1996. Microhabitats of Merriam's turkeys in the Black Hills, South Dakota. Ecological Applications 6: 326-334.

Merriam's Turkeys (*Meleagris gallopavo merriami*) are associated with ponderosa pine *(Pinus ponderosa*) forests in the western United States, but are not native to the ponderosa pine forest of the Black Hills, South Dakota. The Black Hills population was established by transplanting birds from New Mexico and Colorado between 1948 and 1951. Despite being outside its original range, this population provides a unique opportunity to assess mechanisms of habitat selection because the age of the population is known and literature indicates that it is more productive than other populations. We studied microhabitats of Merriam's Turkeys in the Black Hills, South Dakota between 1986 and 1991. We found few differences in microhabitats among diurnal time periods or between sexes. Cluster analysis of variables at turkey microhabitats indicated two groups, broadly interpreted as summer and winter microhabitats. Winter microhabitats of turkeys had less understory vegetation and more overstory cover than random sites, which in turn had less understory and more overstory cover than summer microhabitats. Both random sites and winter microhabitats had higher basal area of ponderosa pine than summer microhabitats. Summer microhabitats had trees with the largest dbh. Random sites had more small and large woody debris than sites used by turkeys. Tree density at random sites was more than two times greater than at winter microhabitats and more than three times greater than at summer microhabitats. Turkeys preferred southern exposures during winter. Production of pine seed, a major food item of turkeys, differed among years. There was a strong relationship between abundance of pine seeds and microhabitats selected by turkeys. Basal area of microhabitats between October and March was positively correlated with annual ponderosa pine seed production. Abundance of ponderosa pine seeds at turkey microhabitats during this period was at least four times the estimated average annual production. Management prescriptions for ponderosa pine of basal area less than or equal to 18 m^2/ha will reduce winter habitat for turkeys. Summer habitats are more compatible with timber management goals for ponderosa pine in the Black Hills.

215. Runciman, J. B. and T. P. Sullivan. 1996. Influence of alternative conifer release treatments on habitat structure and small mammal populations in south central British Columbia. Canadian Journal of Forest Research 26: 2023-2034.

This study was designed to test the hypothesis that conifer release treatments would simplify habitat structure and reduce small mammal populations in forest plantations. A secondary objective was to examine some important demographic characteristics, for selected small mammal species, that may be affected by changes in habitat. We examined the effects of manual cutting and cut-stump applications of glyphosate herbicide on vegetation, woody debris, and small mammal populations from 1991 to 1994 in young mixed-conifer plantations of south central British Columbia, Canada. The experimental design consisted of 9 separate and independent plantations: 3 controls, 3 manual treatments, and 3 cut-stump treatments. Total volumes of herbs, shrubs, coniferous trees, and woody debris were not affected by manual or cut-stump treatments for conifer release. Both treatments reduced total volumes of deciduous trees in the first posttreatment year. However, deciduous tree volumes on manual treatments had largely returned to pretreatment levels by the second posttreatment year. There were no significant ($P > 0.05$) effects of manual or cut-stump treatments on the population size of deer mice (*Peromyscus maniculatus* Wagner), yellow-pine chipmunks (*Tamias amoenus* J.A. Allen), southern red-backed voles (*Clethrionomys gapperi* Vigors), or long-tailed voles (Microtus longicaudus Merriam). The response of meadow voles (*Microtus pennsylvanicus* Ord) was variable. Sex ratios, body weights, reproduction, recruitment,

and survival of deer mice remained similar on treatment and control plantations throughout this study. Changes in habitat structure up to 2 years posttreatment did not appear to exceed the tolerance of small mammal populations for early successional change.

216. Sachs, D. and P. Sollins. 1986. Potential effects of management practices on nitrogen nutrition and long-term productivity of western hemlock stands. Forest Ecology and Management 17: 25-36.

The FORCYTE-10 computer model, developed by J.P. Kimmins and K. Scoullar for Douglas-fir forests in British Columbia, was modified to simulate growth and nutrient cycling of coastal western hemlock stands. Initial calibration indicated that predicted yield was extremely sensitive to the rate of mineralization of soil organic matter (SOM), variation in SOM C:N ratio with site quality, the soil extractable NO3-:NH4+ ratio, and the decomposition rate and N mineralization pattern of large and medium-size roots and woody debris. The predictions suggested that yield and SOM remain stable under a management system consisting of six successive 90-year rotations. More intensive utilization (e.g., shorter rotations, whole-tree harvesting and commercial thinning) causes depletion of soil and forest floor nitrogen and a small decline in site productivity in later rotations.

217. Schroeder, P. E. and J. K. Winjum. 1995. Assessing Brazil's carbon budget: I. Biotic carbon pools. Forest Ecology and Management 75: 77-86.

Brazil contains the world's largest expanse of tropical forest, but its forests are experiencing high levels of conversion to other uses. There is concern that releases of CO_2 and other greenhouse gases resulting from deforestation will contribute to global climate change. The total amount of C that could be released by deforestation depends upon the amount currently contained in the terrestrial biota and soils. Knowledge of the areas of Brazil's major ecosystems and land use types and their C densities was used to estimate the total amount of C stored in vegetation, litter and coarse woody debris, and soils. The total estimated C pools were (58-81) times 10-9 Mg C in vegetation, (6-9) times 10-9 Mg C in litter and coarse woody debris, and about 72 times 10-9 Mg C in soil. Over 80% of the vegetation pool was contained in the closed tropical moist forests of Brazil.

218. Scott, M. C. and P. L. Angermeier. 1998. Resource use by two sympatric blank basses in impounded and riverine sections of the New River, Virginia. North American Journal of Fisheries Management 18: 221-235.

Smallmouth bass *Micropterus dolomieu* and spotted bass *M. punctulatus* are sympatric in riverine and impounded sections of the New River, Virginia. Resource use (habitat and food) by the two species was investigated to determine patterns and extent of resource partitioning and how those patterns might differ between lotic and lentic environments. Growth and body condition were also measured to assess performance of populations of the two species in the study areas. Diet analyses showed that similar prey were consumed by the two species. Habitat use differed along a lotic-lentic gradient; spotted bass were predominant in the impoundment, and smallmouth bass were more abundant in the river. Spatial segregation also occurred within river and impoundment habitats. In the impoundment, smallmouth bass were concentrated in areas with steep dropoffs and rocky substrates, and in the river, they used shoreline areas more than midriver areas. Spotted bass were widely distributed in the impoundment but were most common in areas featuring fine substrate that had woody debris and bank vegetation as cover types. In the

river, spotted bass were largely restricted to the banks, to areas away from high current velocities, and to areas with fine substrate, woody debris, and overhanging bank vegetation. We observed higher catch rates for spotted bass in the river section downstream from the impoundment than in the section upstream of the lake, whereas the converse was true for smallmouth bass. Measures of physiological well-being for both species were near regional norms in both river and impoundment. Normal condition in populations of the two fishes, combined with the similarity in diets, indicated that food availability was adequate in the study area and that competitive pressures were not intense during the study period. Ecological segregation of the species appeared to be along the spatial rather than the trophic axis.

219. Sedell, J. R., F. J. Swanson, and S. V. Gregory. 1984. Evaluating fish response to woody debris. Pacific Northwest Stream Habitat Management Workshop, Humboldt State University, Arcata, California: 222-245. American Fisheries Society, Western Division.

Fish respond favorably to debris in streams. Pristine streams contain vast amounts of large wood in their channels and along their edges. For decades the principal tool for fish habitat management has been debris jam removal. We examine the evidence for evaluating the role of coarse woody debris ploys in the geomorphology of streams, specifically: longitudinal profiles, channel patterns and position, channel geometry, sediment and organic matter storage, and channel dynamics. From this physical template we examine the fisheries implications of coarse woody debris (CWD): blockage to migration, water quality, and summer and winter rearing habitat. The issue of current management practices for providing wood inputs to streams is discussed in terms of the question how much wood is enough.

220. Sedell, J. R. and W. S. Duval. 1985. Influence of forest and rangeland management on anadromous fish habitat in western North America, volume 5: water transportation and storage of logs. USDA Forest Service, General Technical Report, PNW-186.

Environmental effects of water transportation of logs in western North America include the historical driving of logs in rivers and streams, and the current dumping, sorting, transportation, and storage of logs in rivers and estuaries in British Columbia and southeastern Alaska.
The historical discussion focuses on habitat losses and volumes of logs transported by water, both freshwater and marine. Many changes in stream-channel structure and habitat simplification still exist today, nearly 100 years after river driving activities have ceased.
The environmental effects of current log handling on the physical habitat, water quality, plant communities, benthic and intertidal invertebrates, and fish are reviewed. Information gaps are identified and needed research is recommended.
The environmental effects of log handling are generally localized. Regional differences in intensity of aquatic and marine log transportation are discussed for Oregon, Washington, British Columbia, southeastern Alaska, Idaho, Montana, and California, to provide perspective on the volume of logs transported and areal extent of the estuarine and river habitat allocated to log transfer and storage. The most intense aquatic log handling occurs in British Columbia, Oregon, and Washington.
Guidelines and recommended practices developed in the 1970's by a west coast task force are described. These recommended guidelines minimize adverse environmental impacts.

221. Sedell, J. R., G.H. Reeves, F. R. Hauer, J. A. Stanford, and C. P. Hawkins. 1990. Role of refugia in recovery from disturbances: modern fragmented and disconnected river systems. Environmental Management 14: 711-724.

Habitats or environmental factors that convey spatial and temporal resistance and/or resilience to biotic communities that have been impacted by biophysical disturbances may be called refugia. Most refugia in rivers are characterized by extensive coupling of the main channel with adjacent streamside forest, floodplain features, and groundwater. These habitats operate at different spatial scales, from localized particles, to channel units such as pools and riffles, to reaches and longer sections, and at the basin level. A spatial hierarchy of different physical components of a drainage network is proposed to provide a context for different refugia. Examples of refugia operating at different spatial scales, such as pools, large woody debris, floodplains, below dams, and catchment basins are discussed. We hope that the geomorphic context proposed for examining refugia habitats will assist in the conservation of pristine areas and attributes of river systems and also allow a better understanding of rehabilitation needs in rivers that have been extensively altered.

222. Shields, F. D. and N. R. Nunnally. 1984. Environmental aspects of clearing and snagging. Journal of Environmental Engineering 110: 152-165.

Clearing and snagging is used as an economical technique for reducing the frequency and duration of high frequency flooding in environmentally sensitive locations. Riparian vegetation and the organic debris it produces influence stream morphology, water quality, and aquatic and terrestrial ecosystems. Complete clearing and snagging has detrimental effects on these stream characteristics. Modified clearing and snagging is less damaging to the environment. Major modifications involve: (1) Selective removal and disposal of trees and snags based on size location, condition, and habitat value; (2) labor intensive construction techniques; (3) access controls; and (4) work scheduling to avoid fish spawning or other environmentally sensitive periods. Guidelines for modified clearing and snagging are discussed, and analytical approaches to estimating effects of vegetation and snags on flow resistance are reviewed.

223. Shields, F. D. and R. H. Smith. 1992. Effects of large woody debris removal on physical characteristics of a sand-bed river. Aquatic Conservation: Marine and Freshwater Ecosystems 2: 145-163.

1. Removal of large woody debris (LWD) is one of the most widely practised stream alterations, particularly in sand-bed rivers of the southeastern USA. Selective removal of LWD has been proposed as an alternative to orthodox non-selective clearing in order to conserve ecological resources, but methods for comparing hydraulic and environmental effects of selective and non-selective removal have not been developed. Conservation of stream habitats requires quantification of LWD removal impacts on physical habitat. 2. Physical characteristics of straightened, sand-bed reaches of the South Fork Obion River in western Tennessee, USA that were rich in LWD were compared with those in similar reaches where debris had recently been removed using selective removal guidelines. 3. The mean volume of LWD per unit water volume was 0.0545 in the uncleared reaches, but nearly 60% lower (0.0225) in the cleared reach. 4. A simple technique for predicting hydraulic roughness in channels with varying amounts of LWD was developed. Hydraulic roughness, as measured by the Darcy-Weisbach friction factor, was about 400% greater in uncleared reaches at base flow but declined to a level about 35% greater than for the cleared reaches at higher flows. Predicted friction factors were within 35% of measured friction factors at higher flows. 5. Physical habitat diversity in this channelized

sand-bed stream was strongly related to the density of LWD. Flow conditions in the uncleared reaches were more heterogeneous than in the cleared reach, especially at low flow. At low flow, uncleared reaches tended to be shallower, have lower velocities, slightly finer bed material, and more heterogeneous conditions overall. Shannon indices based on depth and velocity were an average of 48% higher in uncleared reaches. 6. Bed sediments underneath and immediately adjacent to LWD formations were finer and contained more organic matter than sediments distant from LWD. However, when all bed samples were considered, organic content was positively correlated with median grain size.

224. Shields, F. D., C. M. Cooper, and S. S. Knight. 1993. Initial habitat response to incised channel rehabilitation. Aquatic Conservation: Marine and Freshwater Ecosystems 3: 93-103.

1. Incised stream channel aquatic habitats typically are severely degraded. After the primary knickpoints or knickzones have passed, base flows are limited to shallow channels flanked by sandy berms within the enlarged high-flow channel. Riparian vegetation, woody debris and pool habitat are in short supply, and stream systems become disengaged from their floodplains. 2. We hypothesized that habitat recovery might be accelerated in channels that have incised and are regaining equilibrium through deposition of sandy berms by placing rock spurs in the channel and by planting woody vegetation on the berms. On the basis of literature review and a pilot study, planting designs were developed for a large-scale field experiment: 2550 1.5 m long cuttings of native willow (*Salix* spp.) 2-25 cm in diameter were planted 1- 1.2 m deep along the base-flow channel of an incised stream. A ridge of stone was placed on the water side of the plantings, and 17 rock spurs were constructed by extending existing spur dikes from the opposite bank. 3. Woody cover along the treated bank increased from 38% to 66% of bankline after one growing season. Survival of individual plantings was reduced from an estimated 60% to an observed 34% by competition from the exotic kudzu vine, *Pueraria lobata*. Mean depth and mean scour hole depth, corrected for stage variation, increased 44% and 82%, respectively. Mean scour hole width increased 130%. The mean length of fish and the number of fish species approximately doubled, while the total weight of fish captured by a unit of sampling effort increased by an order of magnitude.

225. Shields, F. D., C. M. Cooper, and S. S. Knight. 1995. Experiment in stream restoration. Journal of Hydraulic Engineering-ASCE 121: 494-502.

Aquatic habitats in a deeply incised sand-bed channel were modified by adding 1,380 t of stone and planting dormant willow posts. Restoration structures (groin extensions and longitudinal toe protection) were designed as complements to existing channel stabilization works. Prior to restoration, base-flow aquatic habitats were characterized by uniform conditions, little woody debris or riparian vegetation, shallow depths, and sandy bed material. The stage-discharge relationship, channel geometry, and bed material size were unaffected by restoration, but the average depth of scour holes adjacent to extended groins increased from 32 cm to 72 cm, and pool habitat in the lower half of the study reach increased from 2.9% to 14% of water surface area. Median water depth at base flow increased from 9 cm to 15 cm. Woody vegetation cover on one side of the channel increased from 38% to 78%. Fish numbers tripled, median fish size increased by 50%, and the number of species increased from 14 to 19. Groin extensions experienced partial failure due to erosion of sand from underneath stones.

226. Shields, F. D. and C. J. Gippel. 1995. Prediction of effects of woody debris removal on flow resistance. Journal of Hydraulic Engineering-ASCE 121: 341-354.

A simple technique for predicting the Darcy-Weisbach friction factor for river channels with varying amounts of large woody debris was developed. First, debris density is determined based on measurement or visual estimation of cross-sectional areas of debris formations in the plane perpendicular to flow. The Darcy-Weisbach friction factor is then computed using debris density, channel geometry, and the debris drag coefficient. The debris drag coefficient may be computed from a power function with experimentally determined coefficients. For verification of the proposed procedure, debris density and friction factors were measured in river reaches in western Tennessee, and southeastern New South Wales, Australia. Friction factors computed using the procedure were within 30% of measured values for straight, sand-bed reaches and within 38% of measured values for sinuous, gravel-bed reaches. The computational procedure explained 84% of the variance in observed values.

227. Shirvell, C. S. 1990. Role of instream rootwads as juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Oncorhynchus mykiss*) cover habitat under varying streamflows. Canadian Journal of Fisheries and Aquatic Sciences 47: 852-861.

Coho salmon fry (*Oncorhynchus kisutch*) and steelhead parr (*O. mykiss*) occupied previously in infrequently-used mid-channel areas of Kloiya Creek, British Columbia, Canada, once artificial rootwads were placed there. Ninety-nine percent of all coho salmon fry and 83% of steelhead parr occupied positions downstream of natural or artificial rootwads during artificially created drought, normal, and flood streamflows. Fish associated with rootwads regardless of distance from shore, but steelhead parr preferred rootwads away from shore while coho salmon fry preferred rootwads next to shore. Coho salmon fry increased their use of natural rootwads where currents were slow during floods, while steelhead parr increased their use of artificial and natural rootwads where light remained low during droughts. Young fish apparently selected areas having slower water 80% of the time because they provided shelter from adverse current, and areas having reduced light intensities 20% of the time because they provided protection from predators. Juvenile coho salmon and steelhead in Kloiya Creek selected locations with slower water velocities and reduced light intensities irrespective of the physical structure that caused them.

228. Sippola, A.. L. and P. Renvall. 1999. Wood-decomposing fungi and seed-tree cutting: A 40-year perspective. Forest Ecology and Management 115: 183-201.

The effects of logging on wood-decomposing *Basidiomycetes* were studied in the boreal forests in northern Finland. The study area consisted of pine forest sites felled 3, 18 and 42 years before our study. The species composition of fungi in cut plots was compared to that of uncut old-growth forest sites. Altogether, 47 species were recorded on 570 logs. The species compositions reflected the amount and quality of coarse woody debris (CWD) available in the stands. In the old-growth stands, the species diversity was high, but the distribution of fungi was strongly affected by the patchy occurrence of CWD. Pioneer white-rot fungi predominated in the 3-year old logging sites. In the 40-year old logging sites, the number of species on the logging waste was 50-60% lower than in the old-growth forests, but the residual CWD from the pre-logging time still hosted a large portion of the species of the virgin forests. The species regarded as old-growth forest

indicators showed different ecological tolerance to the effects of logging: the majority was confined only to naturally produced CWD, while some species were able to invade logging waste. The results showed that some polypores known to prefer old-growth forest habitats can survive for decades in managed forests. However, the species diversity of lignicolous fungi after logging greatly depended on the availability and diversity of decaying wood created before the management.

229. Sippola, A. L., J. Siitonen, and R. Kallio. 1998. Amount and quality of coarse woody debris in natural and managed coniferous forests near the timberline in Finnish Lapland. Scandinavian Journal of Forest Research 13: 204-214.

Amount and structural characteristics of coarse woody debris (CWD) were studied in 44 stands of old-growth and managed coniferous forests in Finnish Lapland. The average volume of CWD in old-growth forests varied from 19 m^3 ha^{-1} in pine forests to 60m^3 ha^{-1} in herb-rich spruce-dominated forests. The volumes of living and dead timber were highly correlated, the most productive sites having the highest volumes. In old-growth forests about 60-70% of the CWD was logs, 30-40% standing dead trees and snags, and 3.5-7% stumps and branches. The amount of CWD decreased considerably in clear-cutting, but increased or remained the same in seed-tree and selective cuttings In the short term. However, the accumulation rate of new dead material was greatly reduced after cutting. In 40-year-old seed-tree cutting areas the new supply of CWD, created by recent disturbance and mortality, was less than 1% of the respective amount in old-growth forest. All cutting methods reduced standing dead trees and snags considerably.

230. Smith, R. D., R. C. Sidle, and P. E. Porter. 1993. Effects on bedload transport of experimental removal of woody debris from a forest gravel-bed stream. Earth Surface Processes and Landforms 18: 455-468.

Experimental removal of woody debris from a small, gravel-bed stream in a forested area resulted in a four-fold increase in bedload transport at bankfull discharge. This was caused by increased transportability of sediment previously stored upslope of debris buttresses or in low-energy hydraulic environments related to debris. Bank erosion delivered additional sediment to the channel, and transport energy was increased by an inferred increase in the component of total boundary shear stress affecting grains on the bed. Increased transport following debris remo val in May 1987 continued throughout the entire autumn storm season through late November 1987, indicating persistent adjustment of the stream bed and banks despite marked response to earlier flows as large as bankfull. Stream bed adjustments included development of a semi-regular sequence of alternate bars and pools, many of which were spaced independently of former pool locations.

231. Smith, R. D., R. C. Sidle, P. E. Porter, and J. R. Noel. 1993. Effects of experimental removal of woody debris on the channel morphology of a forest, gravel-bed stream. Journal of Hydrology 152: 153-178.

Experimental removal of woody debris from a small, gravel-bed stream in a forested basin resulted in dramatic redistribution of bed sediment and changes in bed topography. Removal of debris changed the primary flow path, thereby altering the size and location of bars and pools and causing local bank erosion and channel widening. Marked bed adjustments occurred almost immediately following experimental treatment in May 1987 and continued through to the end of the study period in 1991. Increased bed material mobility was attributable to destabilization of sediment storage sites by removal of debris but-tresses, elimination of low-energy, backwater environments related to debris, and an inferred increase in boundary shear stress resulting from the removal of debris-related flow resistance. In contrast to these changes, which favored sediment mobilization, deposition was favored by the elimination of debris-related scouring turbulence and by increased flow resistance from a developing sequence of alternate bars. A more regularly spaced sequence of alternate bars replaced the pretreatment bar sequence, whose location, size, and shape had been strongly influenced by large woody debris as well as by bank projections and channel curvature. Following initial readjustment of the stream bed during the first posttreatment year, loss of scouring turbulence and increased flow resistance from alternate bars resulted in deposition of approximately 44 m^3 of sediment within the 96 m study reach. The loss of 5.2 m^3 to bank erosion left a net increase in sediment storage of 39 m^3. Mean spacing of thalweg cross-overs and pools did not change measurably following debris removal, although variability of spacing between thalweg cross-overs tended to decrease with time as the location of bars stabilized. No consistent pattern of change in mean residual depth of pools or in distribution of depths occurred within the first 4 years following debris removal.

232. Sollins, P. 1982. Input and decay of coarse woody debris in coniferous stands in western Oregon and Washington. Canadian Journal of Forest Research 12: 18-28.

At 10 locations in Oregon and Washington, tree mortality resulted in dry matter transfer of 1.5 - 4.6 Mg/ha/yr of boles and branches to the forest floor and 0.3 - 1.3 Mg/ha/yr of large diameter roots directly to the mineral soil. The first value is about the same as that reported for leaf fall in similar stands; the second value generally is smaller than that reported for fine root turnover. Results are based on measurements by the U.S. Forest Service spanning 1--46 years and areas as large as 42 ha. Values based on intervals <10 years were highly variable and potentially misleading.
At an old-growth Douglas-fir stand in Washington, fallen boles accounted for 81 Mg/ha, standing dead for 54 Mg/ha. Density of fallen boles averaged from 0.14 to 0.27 g/cm^3 depending on decay state. Values were lower than some previously reported because (1) our sample included small diameter fallen boles that tend to decay rapidly, and (2) we measured density with techniques that minimized compaction and shrinkage.
The decay at the old-growth stand, calculated indirectly by dividing bole mortality (megagrams per hectare per year) by the amount (megagrams per hectare) of fallen wood and standing dead woody material, was 0.028/yr. This rate, three to five times those previously calculated directly from change in density alone, was almost identical to values calculated elsewhere from change in both volume and density. Decay rates based on change in density alone include only respired and leached material and exclude the large amount of material lost in fragmentation. This study shows the value of permanent plots, undisturbed by salvage logging, for retrospective studies of decomposition, nutrient cycling, and productivity.

233. Spalding, S., N. P. Peterson, and T. P. Quinn. 1995. Summer distribution, survival and growth of juvenile Coho Salmon under varying experimental conditions of brushy instream cover. Transactions of the American Fisheries Society 124: 124-130.

Woody debris is an important feature of streams, and its presence and abundance have been correlated with the abundance, growth, and survival of juvenile salmonids, To investigate the proximate mechanisms linking brushy woody debris to salmonid fishes, we determined, over a 1-month period in summer, the spatial distribution of juvenile coho salmon *Oncorhynchus kisutch* introduced into an outdoor experimental stream containing riffle-pool units that had one of four different levels of instream brushy-debris complexity. We then equalized the fish density in each unit and monitored fish growth and survival over a 15-week period. Coho salmon distribution, growth, and survival varied greatly but were not consistently related to the complexity of brushy debris.

234. Spetich, M. A. and G. R. Parker. 1998. Distribution of biomass in an Indiana old-growth forest from 1926 to 1992. American Midland Naturalist 139: 90-107.

We examined the structural and spatial distribution of woody biomass in relationship to disturbance in an Indiana old-growth deciduous forest over a 66-yr period. Analysis was done on the core 7.92 ha of a 20.6-ha forest in which every tree 10 cm dbh and over has been tagged and mapped since 1926. Five years are compared-1926, 1976, 1981, 1986 and 1992. Dry weight of living biomass for the 7.92-ha area for these 5 years was 154 Mg/ha, 207 Mg/ha, 220 Mg/ha, 216 Mg/ha and 211 Mg/ha, respectively Biomass of dead trees was 1 Mg ha^{-1} yr^{-1} from 1977 through 1981; 4 Mg ha^{-1} yr^{-1} from 1982 through 1986; and 3 Mg ha^{-1} yr^{-1} from 1987 through 1992. Biomass of trees that died between 1976 and 1992 was greatest for midseral species. Living biomass of dominant early to midseral species is declining while that of late seral species is increasing. In 1926 biomass of trees 10 to 25 cm diam consisted of 14% *Quercus* spp. and 12% *Acer saccharum.* By 1992 biomass in this diameter range consisted of 1% *Quercus* spp. and 43% *A. saccharum.* Equilibrium patch size was estimated for biomass at each of the five inventory dates to determine ii there was a change. Equilibrium patch size for biomass was estimated to be 0.64 ha during all five inventory dates based on the coefficient of variation (CV) of biomass for 16 different grid cell sizes. Grid cell size refers to tile size of adjacent cells in a grid that covered the entire study area. The grid with the smallest cells had cells of 0.01 ha. This grid of 0.01-ha cells was aggregated to 15 additional grid cell sizes, where the largest grid cell size was 1.98 ha. CV for all grid cell sizes was highest in 1926 due to effects of prior grazing. There data indicate an increase in deadwood biomass, a drift in stand composition, recovery from grazing by an increase in small diameter trees and no change in equilibrium patch size over the five inventory dates.

235. Spies, T. A. 1998. Forest structure: A key to the ecosystem. Northwest Science 72: 34-39.

Forest structure is both a product and driver of ecosystem processes and biological diversity. It has become apparent in recent years that changes in forest structure as a result of management for timber production have undesirable consequences for other components of forest ecosystems. The objective of this paper is to provide an overview of what we have learned about the ecological roles of forest structure in the Pacific Northwest and how forest structure changes as a result of disturbance and succession. Forests are structurally diverse, but many structures derive from the same processes of disturbance and growth. Consequently. measurements on a few structural attributes can be used to estimate many other structural conditions. Particularly important components of forest structure include live-tree sizes, vertical foliage distributions, horizontal variation in canopy density and coarse woody debris. Knowledge of the ecological roles of these structures has increased in recent years and we now have a general understanding of how these structures change during succession. Although the ecological values of forest structures are now more widely appreciated. we still have many significant knowledge grips including me ecological roles of belowground structure, woody debris. and landscape pattern.

236. Spies, T. A., J. F. Franklin, and T. B. Thomas. 1988. Coarse woody debris in Douglas-fir forests of western Oregon and Washington [USA]. Ecology (Tempe) 69: 1689-1702.

Amounts and structural characteristics of coarse woody debris (CWD) were examined in relation to stand age and site moisture condition in 196 *Pseudotsuga menziesii* stands in western Oregon and Washington. Stands ranged from 40 to 900 yr old, and most, if not all, originated after fire. In a chronosequence from the Cascade Range, the amount of CWD followed a U-shaped pattern for stands < 500 yr old, with moderate levels of (92 Mg/ha) in stands < 80 yr old, lowest levels (< 50 Mg/ha) in stands 80-120 yr old, and highest levels (173 Mg/ha) in stands 400-50 yr old. After 500 yr the amounts of CWD declined to intermediate levels. In the southern Coast Range, lowest levels (32 Mg/ha) of CWD were in the youngest stands (60-80 yr), primarily because they inherited little CWD from the preceding (prefire) stands. In the Cascade range, levels of CWD inherited from preceding stands were highest in young stands and declined to near zero by 250 yr. The overall decay rate constant (k) for snags and logs in the Cascade Range, calculated indirectly from the chronosequence, was 0.029 yr^{-1} . Volume and biomass of CWD differed significantly in old-growth stands (> 200 yr old) among site moisture classes. Dry sites averaged 72 Mg/ha, moderate sites 137 Mg/ha, and moist sites 174 Mg/ha. The dynamics of CWD were modeled for three fire histories, each beginning with an initial fire in an old-growth stand but differing in number and severity of subsequent fires. All three models exhibited low values of CWD between 80 and 200 yr. The lowest and most prolonged minimum in CWD during succession occurred when additional fires burned early in succession, which probably happened preceding many stands in the southern Coast Range. The results of the study indicate that a steady-state condition in CWD may not be reached for > 1000 yr, and that the nature and timing of disturbance play a key role in the dynamics of CWD in the region.

237. Stahl, G. 1998. Transect relascope sampling - A method for the quantification of coarse woody debris. Forest Science 44: 58-63.

A method for the quantification of coarse woody debris in terms of the total length of downed material is presented. The method combines relascope and line intersect sampling theory. Estimation is based on a count of downed logs using a relascope instrument along survey lines. In cost-efficiency comparisons with line intersect and circular plot sampling, the proposed method was found to be a competitive alternative.

238. Steel, E. A., R. J. Naiman, and S. D. West. 1999. Use of woody debris piles by birds and small mammals in a riparian corridor. Northwest Science 73: 19-26.

Woody debris piles, a natural component of rivers draining the coastal forests of the Pacific Northwest, provide a unique resource in the riparian-river corridor. We describe the distribution of woody debris piles on the Skykomish River, Washington, and examine their use by birds and small mammals. We found an average of one debris pile per 15 m of river bank; the inside of these piles was significantly cooler than the ambient environment. Over sixteen bird species were observed using the debris piles while other bird species in the area were never observed on the debris piles. The overall species richness of small mammals was greater at debris piles (9 species) than at reference sites in nearby areas without woody debris (I species). On cobble bars, there was a greater abundance of small mammals at debris piles than at reference sites. We conclude that debris piles may provide valuable resources to both birds and small mammals particularly on otherwise barren cobble bars.

239. Stewart, B. A. and B. R. Davies. 1990. Allochthonous input and retention in a small mountain stream, South Africa. Hydrobiologia 202: 135-146.

Allochthonous input and benthic coarse particulate organic matter (CPOM) standing stocks were investigated in a first-order stream in South Africa between May 1984 and April 1985. Monthly falls in the stream of all litter types (total) ranged from 11 (September) to 79 g m^{-2} (March). Total annual litter fall was 426 g dry weight, which corresponds to 1.2 g m^{-2} d^{-1} . Flowers, fruits and seeds contributed 37 g m^{-2}, woody debris, 122 g m^{-2}, and leaves 267 g m^{-2} to this total. Leaf fall from native trees, which accounted for approximately 57% of total litter input (244 g m^{-2} a^{-1}), was significantly higher in summer than in winter. The summer peak in leaf fall recorded is far smaller and more protracted than the autumnal peak recorded for many Northern Hemisphere streams. Monthly total standing stocks of CPOM ranged from 14 g dry weight m^{-2} in January to 69 g m^{-2} in August, and a mean total CPOM standing stock at 41 g m^{-2} mth^{-1} was estimated. This comprised 18 g m^{-2} mth^{-1} soft litter, and 23 g m^{-2} mth^{-1} hard litter. CPOM standing stocks showed no seasonal trends, and with the exception of two species, standing stocks of endemic leaf species reflected their contributions to the total litter fall. Contrary to earlier reports for streams in the Fynbos Biome, Window Stream has CPOM standing stocks well within the ranges reported for low-order streams worldwide.

240. Stewart, G. H. and L. E. Burrows. 1994. Coarse woody debris in old-growth temperate beech (Nothofagus) forest of New Zealand. Canadian Journal of Forest Research 24: 1989-1996.

The volume, biomass, and carbon and nitrogen content of coarse woody debris were measured on three 1-ha reference plots in old-growth *Nothofagus fusca* (Hook. f.) *Oerst.* - *Nothofagus menziesii* (Hook. f.) Oerst. forest on the South Island of New Zealand. Two decay sequences for logs and one for standing dead trees (snags) were recognised from two-way indicator species analysis (TWINSPAN) of up to 30 variables related to physical characteristics and structural integrity. Wood volume (up to 800 m^3 /ha) and biomass were high (up to 300 Mg/ha), and the inside-out decay sequence from heartwood to sapwood was unusual compared with that of other temperate hardwood forests. Coarse woody debris represented significant carbon and nitrogen pools, with ca. 150 Mg/ha and 370 kg/ha, respectively, in one stand. The coarse woody debris component of these broad-leaved evergreen hardwood forests was much higher than that reported for other temperate hardwood forests and approaches that of many northern hemisphere conifer forests. The large coarse woody debris pools are discussed in relation to live stand biomass, natural disturbances and tree mortality, and decomposition processes.

241. Stohlgren, T. J. 1988. Litter dynamics in two Sierran mixed conifer forests: I. Litterfall and decomposition rates. Canadian Journal of Forest Research 18: 1127-1135.

Litterfall was measured for 4 years and leaf litter decomposition rates were studied for 3.6 years in two mixed conifer forests (giant sequoia - fir and fir-pine) in the southern Sierra Nevada of California. The giant sequoia - fir forest (GS site) was dominated by giant sequoia (*Sequoiadendron giganteum* (Lindl.)Buchh.), white fir (*Abies concolor* Lindl. & Gord.), and sugar pine (*Pinus lambertiana* Dougl.). The fir-pine forest (FP site) was dominated by white fir, sugar pine, and incense cedar (*Calocedrus decurrens* (Torr.) Florin). Litterfall, including large woody debris < 15.2 cm in diameter, at the GS site averaged 6364 kg/ha/year compared with 4355 kg/ha/year at the FP site. Compared with other temperate coniferous forests, annual variability in litterfall (as computed by the ratio of the annual maximum/minimum litterfall) was extremely high for the GS site (5.8:1) and moderately high for the FP site (3.4:1). In the GS site, leaf litter decomposition after 3.6 years was slowest for giant sequoia (28.2% mass loss), followed by sugar pine (34.3%) and white fir (45.1%). In the FP site, mass loss was slowest for sugar pine (40.0%), followed by white fir (45.1%), while incense cedar showed the greatest mass loss (56.9%) after 3.6 years. High litterfall rates of large woody debris (i.e., 2.5-15.2 cm diameter) and slow rates of leaf litter decomposition in the giant sequoia - fir forest type may result in higher litter accumulation rates than in the fir-pine type. Leaf litter times to 95% decay for the GS and FP sites were 30 and 27 years, respectively, if the initial 0.7-year period (a short period of rapid mass decay) was ignored in the calculation. A mass balance approach for total litterfall (< 15.2 cm diameter) decomposition yielded lower decay constants than did the litterbag study and therefore longer times to 95% decay (57 years of the GS site and 62 years for the FP site).

242. Stone, J. N., A. MacKinnon, J. V. Parminter, and K. P. Lertzman. 1998. Coarse woody debris decomposition documented over 65 years on southern Vancouver Island. Canadian Journal of Forest Research 28: 788-793.

In 1929-1930, Stig Schenstrom and J.D. Curtis established an experiment to study thinning dynamics of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) on southern Vancouver Island, British Columbia. As a subcomponent of the experiment, the coarse woody debris (CWD) from the previous stand were mapped and the decay condition classified on five permanent plots. These scaled drawings and classifications were updated in 1945-1947 and 1995-1996. This unique 65-year period of CWD observation confirms that observations of CWD volume loss on Vancouver Island are similar to elsewhere in the Pacific Northwest. The simple exponential decay rate constant was 0.022/year based on volume of primarily Douglas-fir on the five plots. The decay rate constant by large-end diameter was 0.067/year for logs less than or equal to 20 cm, 0.056 > year^{-1} for 21-40 cm, 0.021/year for 41-80 cm, and 0.012/year for logs > 80 cm.

243. Sullivan, K., T. E. Lisle, C. A. Dollof, G. E. Grant, and L. M. Reid. 1987. Stream channels: the link between forests and fishes. In Streamside Management: Forestry and Fishery Interactions. E. O. Salo and T. W. Cundy (Eds). Seattle, Washington, University of Washington, Institute of Forest Resources: 39-97.

The hydraulic characteristics of flow though channels are an important component of fish habitat. Salmonids have evolved in stream systems in which water velocity and flow depth vary spatially within the watershed and temporally on a daily, seasonal, and annual basis. Flow requirement vary during different phases of the freshwater life cycle of salmonids: free passage is necessary during migration of adults; clean and stable gravel beds ensure successful incubation of eggs; and adequate velocity and depth of flow provide space for summer creating and overwintering. The life cycles of salmonid species have adapted to the temporal variations in flow conditions by timing the phases of the life cycle to take advantage of the season discharge characteristics. Spatial variability enhances species diversity by creating a variety of habitats within stream reaches; these are partitioned among individual species and age groups have different tolerances for velocity, depth, and cover conditions.

Channel morphology is determined largely by sediment and water input to the channels, and is formed during storm events when flow is great enough to transport the coarse sediments lining the channel bed. The resulting channel shape consists of a sequence of recognizable units known as riffles, pools, and boulder cascades. Water flowing down the stream is forced continually to adjust its velocity and depth in response to the changing channel shape: flow in shallow and fast in riffles, and slow and deep in pools. Large obstruction such as woody debris, boulders, and bedrock outcrops alter channel width, increasing the variation in velocity and depth in the vicinity of the obstruction and anchoring the position of pools. Discharge also varies through time creating additional variation of hydraulic conditions.

Forest management can affect channel morphology by changing the amount of sediment or water contributed to the streams, thus disrupting the balance of sediment input and removal. Excessive input of coarse sediments from landslides can smooth the channel gradient by filling pools. Removing large woody debris from channels reduces sediment storage and eliminated the local hydraulic variability associated with the obstruction. Loss of habitat diversity by either mechanism may reduce or change the fish species found in a stream reach. If the changes result in decreased space, population may also decrease. Strategies to minimize the effects of land management on channel morphology and fish habitat should include practices that minimize increases in coarse sediment input, and that preserve the morphologic complexity of the channel.

244. Sundbaum, K. and I. Naslund. 1998. Effects of woody debris on the growth and behaviour of Brown trout in experimental stream channels. Canadian Journal of Zoology 76: 56-61.

We examined the effects of woody debris on the growth and behaviour of brown trout (*Salmo trutta*) in experimental stream channels. Two types of habitat were used in the study: a complex habitat created by placing woody debris on a gravel bed and a uniform habitat consisting of a gravel bed only. The experiment was run both outdoors with wild fish that fed on natural invertebrate drift and indoors with hatchery fish that were fed artificial food. In both treatments most of the fish lost mass. In all trials, however, the fish in the woody debris channel lost less mass than the fish in the control channel. Study of the fishes' behaviour revealed less swimming activity, less aggression, and less feeding activity in the woody debris channel than in the control channel. The results of this study indicate that the presence of woody debris decreases intraspecific competition through visual isolation, allowing fish to reduce aggressive interactions and energy expenditure.

245. Swanson, F. J., G. W. Lienkaemper, and J. R. Sedell. 1976. History, physical effects, and management implications of large organic debris in western Oregon streams. USDA Forest Service, General Technical Report, PNW-56.

Large organic debris has historically been an important element in small mountain streams of the Pacific Northwest. The debris serves to slow the movement of water and inorganic and fine organic matter though the channel. Debris may remain in the channel for decades or longer, and tends to stabilize some sections of a streambed and streambanks while destabilizing other areas. The combination of clearcutting and the complete removal of large debris in a channel may deprive a stream of this natural feature of streams for a century or longer. The consequences are likely to be downcutting and "channelization" of the stream, accelerated transport of fine organic and inorganic sediment, and a possible decrease in biological productivity of the stream ecosystem. Therefore, stream debris management during logging operation should include leaving undisturbed the natural, stable organic debris in the channel.
The principal factors controlling the concentration, stability, and functions of stream debris are the history and condition of the surrounding timber stand, flushing history of the channel, stability and abundance of bedload material, steepness of the channel and adjacent hillslopes, and slope stability in the drainage. Because of this complexity, each stream presents a unique situation which should be inspected in the field and considered on an individual basis before a debris management decision is made.

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

Large organic debris in streams controls the distribution of aquatic habitat, the routing of sediment through streams systems, and the stability of streambed and banks. Management activities directly alter debris loading by addition or removal of material and indirectly by increasing the probability of debris torrents and removing standing streamside trees. We propose that by this combination of factors the character of small and intermediate-sized streams in steep forested terrain of the Pacific Northwest is being substantially altered by forest practices.

247. Swanson, F. J. and J. F. Franklin. 1992. New forestry principles from ecosystem analysis of Pacific Northwest forests. Ecological Applications 2: 262-274.

Forest management practices on Federal lands in the Pacific Northwest of the United States have been the center of intense controversy. Conflicting value systems, new information, and new perspectives have fueled the debate over the balance between timber production and preservation of natural ecosystems. In this paper we consider examples from three aspects of forest management: (1) management of forest stands, (2) management of the patchwork of forest stands at the landscape scale, and (3) management of streams and riparian networks. In each of these cases we examine: management practices and perspectives of the recent past, findings from ecosystem research that are leading to change in those practices, resulting changes in management practices, and future research directions. We also suggest a path for future change, including systems for managing in the face of uncertainty. Results of research in natural and managed forest and stream ecosystems have been pivotal in reassessment and redesign of management practices to provide a broader range of management options for society to consider. Results of studies of natural disturbance processes and their effects are used as reference points for management systems intending to sustain biological diversity and ecosystem productivity. Stand management practices, for example, are being modified to retain some live trees and greater amounts of dead woody debris, both standing and down, in areas that would instead be clear-cut under intensive plantation forestry practices. The motivations of these modified practices are to sustain biological diversity, including key wildlife species, and to maintain soil productivity. Models of alternative forest-cutting patterns at a landscape scale are being used to examine their effects on ecosystem structure and function. One result of this analysis has been to shift from the previous system of dispersing cutting units to a system involving greater aggregation of units using designs to provide for species preferring forest interior habitat as well as species favoring edge and early seral habitats. As a results of ecosystem research, the management of stream and riparian networks can now be based on understanding of forest-stream interactions and designed within a drainage-basin context. Overall, emphasis in research and management seems to be in early stages of shifting from featured species-e.g., Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and Northern Spotted Owl (*Strix occidentalis* caurina)-to ecosystems, and from the scale of forest stands to landscapes and the entire region. In addition to the contribution of ecosystem research to redesign of management techniques, ecosystem scientist also have roles in the social processes for determining the future course of management of natural resources. An important medium for scientist participation is establishment of adaptive management programs, in which management activities are conducted as experiments to test hypotheses and to develop information needed for future natural resource management.

248. Swift, L. W., Jr., K. J. Elliott, R. D. Ottmar, and R. E. Vihnanek. 1993. Site preparation burning to improve southern Appalachian pine-hardwood stands: Fire characteristics and soil erosion, moisture, and temperature. Canadian Journal of Forest Research 23: 2242-2254.

Three southern Appalachian stands with sparse and unproductive pine-hardwood overstories and dense *Kalmia latifolia* L. understories were treated to restore productivity and diversity on steep slopes. An adaptation of the fell and bum practice was applied in summer and fall 1990. About one-half of the woody fuels were consumed at each site. A range of fire intensities was observed. Flame temperatures approached 800 degree C, but the heat pulse into the forest floor only reached 60 degree C at 5 cm. Humus and charred leaf litter remained on most of the surface after burning. Evidence of soil erosion was spotty and related to points of local soil disturbance. No soil left the sites. At the end of the first growing season, 23% of the burned surfaces were covered by growing plants and 62% by residual forest floor and woody debris. Felling and burning reduced evapotranspiration so that soil in the treated areas remained moister than under adjacent uncut stands. Opening the sites increased soil temperatures 2 to 5 degree C at 10 cm during the first 16 months after treatment.

249. Tally, T. 1980. The Effects of Geology and Large Organic Debris on Stream Channel Morphology and Process for Streams Flowing Through Old Growth Redwood Forests in Northwestern California. Doctor of Philosophy. University of California, Santa Barbara, Santa Barbara, CA, 273 pages.

Large organic debris and the distribution of rock types along streams flowing through old-growth redwood forests significantly influence channel form and fluvial processes in small to intermediate size streams. Both rock type and large organic debris are important in the development of the long-profile, while large organic debris is especially significant in producing a diversity of channel morphology and sediment sites.
Specific climatic conditions of northwestern California help to support the unique and complex redwood forest ecosystem, dominated by the coast redwood tree (*Sequoia sempervirens).* As some of the earth's most heavily timbered hectared, the coastal redwood forest produces some of the tallest, largest, and oldest trees on earth. The large size and longevity of the redwood trees has a profound effect on the quality and quantity of large organic debris accumulations found instream channels draining redwood forests. The size of individual large organic debris ranges from 10 cm to 5.0 meters in diameter, and may exist in the stream channels for over two centuries.
Debris loading and distribution depend upon a variety of interrelated variables and processes, including: rock type, channel slope, hillslope angle, tree density, landsliding, floodplain formation, and hydraulic variables. Debris loading is generally inversely proportional to upstream drainage basin area and directly proportional to the tree density of redwoods proximal to the channel. Debris loading in the studied stream varies for 12-268 kilograms of large organic debris per square meter of active stream channel. Distribution of debris along the channel is more important than debris loading in determining the magnitude of debris contribution to the control of channel morphology. Debris accumulations range from small and simple, single piece accumulations to large and complex accumulations up to 100 m long and containing several large trunks. Debris accumulations are classified according to how they affect channel morphology. Process and morphologic effects of debris accumulations include: pool formation; control of sediment storage and distribution; influence on stream bank stability; size, shape, width and complexity of channel pattern; distribution of stream power along the channel; and

the character of the longitudinal profile. Sixty percent of the length of the stream channel of Little Lost Man Creek is directly influenced by organic debris.
The distribution of resistant rock types along the channel of Little Lost Man Creek produces a convex profile. The slope of the profile at various scales is adjusted to rock type and large organic debris spacing, loading, accumulation type. For Little Lost Man Creek organic debris controls 42 percent of the drop in elevation along the channel, and in combination with boulder debris, 58 percent of the drop. Seventy-eight percent of all the pools along the profile are related to accumulation of large organic debris. Pool depths are a function of rock type, as well as local channel slope, with pool depths being directly proportional to channel slope and to the percentage of massive sandstone underlying the channel.
Debris-related sediment storage sites cover 40 percent of the active stream channel along Little Lost Man Creek and help to buffer the movement of sediment along the channel. It is estimated that these sediment storage sites along Little Lost Man Creek contain 200 years of mean annual bedload discharge and that available storage space could hold another 100 years of bedload discharge.
It is concluded that large organic debris is an important part of the natural fluvial system in redwood forests and that proper management of hillslope and riparian, as well as stream, environments is necessary for the adequate protection of both the physical characteristics of the stream environment.

250. Tarzwell, C. M. 1937. Experimental evidence on the value of trout stream improvement in Michigan. Transactions of the American Fisheries Society 66: 177-187.

Although much stream improvement work has been accomplished and numerous papers have been written dealing with the methods of improvement, the evaluation of the results obtained had received little attention. Little or no experimental work had been done with the exception of that carried on in Michigan by the Institute for Fisheries Research. It is believed that more consideration should be given to a study of the permanence and the utility of the various types of structures used for improvement work and to the physical and biological changes which they produce in a stream.
While engaged, since the summer of 1930, in the development of methods for the improvement of trout streams, the writer had endeavored to appraise each device and to evaluate its effect on environmental conditions. Many structures were installed primarily for experimental research. The rechecking and evaluation of the various types of stream improvement devices formed the principal art of the investigations carried on in 1931.

251. Taylor, C. M., M. R. Winston, and W. J. Matthews. 1993. Fish species-environment and abundance relationships in a Great Plains river system. Ecography 16: 16-23.

Fish assemblages in the upper Red River system of southwestern Oklahoma (USA) were predictable along measured environmental gradients. Conductivity was the most important variable predicting structure of fish assemblages, followed by stream size, alkalinity, woody debris, and water clarity, Classification of abundance data identified four groups each of species and sites. Species groups were separated on a habitat template, indicating similar environmental responses within groups. However, site groups showed considerable overlap on the template. Correlations among species' environmental preferences were significantly associated with correlations of species' abundances. Likewise, site correlations on the basis of measured environmental variables and on the basis of species' abundances were significantly similar. We tested abundance and distribution data for agreement with the hierarchical model of Kolasa. Several testable predictions of the model described our data well: specialist species outnumbered

generalist species and were less abundant, on average, than generalist species. Average abundance of species was highly correlated with their ecological ranges and species were clumped along both ecological range and abundance axes.

252. Thevenet, A., A. Citterio, and H. Piegay. 1998. A new methodology for the assessment of large woody debris accumulations on highly modified rivers (example of two French piedmont rivers). Regulated Rivers: Research and Management 14: 467-483.

Methodologies that have been developed to quantify large woody debris (LWD) have been largely tested and adapted for mountain streams of the Pacific Northwest, characterised by a very high density of LWD, composed of large pieces of wood. In French rivers, LWD studies have focused on larger systems presenting low density and discrete distributions of LWD accumulations, where existing methods could not readily be used. We thus propose an easy-to-use method to quantify LWD within such systems. After defining three representative types of LWD, the volume is obtained by representing each LWD accumulation by a simple geometric form in order to measure its height, width and length. A model is then built for the different accumulation types to estimate wood mass from the measured volume. Since the measured volume is a combination of air and wood, we quantified the proportion of air, which is, respectively, equal to 18, 90 and 93% for trunks, wood jams and shrubs. To understand variability in wood mass, we evaluated the influence of different factors on wood density (defined as the ratio between mass and volume). The main factor was found to be the water absorption capacity of the wood, whereas a lesser factor was the degree of wood decay. Most wood pieces were found to increase their mass by an average of 100% and more after only 24 h in contact with water. Moreover, the observed levels of water loss and water absorption during the first 24 h of removal or exposure to water imply major short-term variations in wood mass, which may have significant consequences for wood transport during flooding. (C) 1998 John Wiley & Sons, Ltd.

253. Thevenet, A. and B. Statzner. 1999. Linking fluvial fish community to physical habitat in large woody debris: sampling effort, accuracy and precision. Archiv Fur Hydrobiologie 145: 21.

Large woody debris (LWD) in running waters provides complex and important habitat for fish communities. Quantifying the structure of LWD should improve the understanding of habitat choice of fish as well as fish habitat management. Therefore, we evaluated the efficiency of techniques to describe physical habitat and fluvial fish community characteristics that are required to quantify fish-habitat relationships for LWD. An open electrofishing technique for 15 minutes with two electrodes captured more than 70 % of the fish through a single removal in a 50 m^2 zone. On average only 3.4 % of the fish escaped from the zone during electrofishing. Mean conditions and variability of physical LWD habitat in a sampled zone could be accurately and precisely described with 10 (water depth, current velocity, mineral bottom substrate size) or 20 (LWD variables) point measurements. Partial Least Square (PLS) regressions showed the potential of the LWD sampling procedure to relate fish community characteristics to physical habitat. Fish abundance was significantly related to current velocity, water depth and mineral substrate size, which are traditionally used in studies of fish-habitat relationships. In addition, depending on the species, abundances were significantly related to various LWD variables that characterised density, location, shelter function and structural diversity of LWD.

254. Tillma, J. S., C. S. Guy, and C. S. Mammoliti. 1998. Relations among habitat and population characteristics of spotted bass in Kansas streams. North American Journal of Fisheries Management 18: 886-893.

Spotted bass *Micropterus punctulatus* are popular sport fish in streams and reservoirs throughout the southeastern United States. Despite their popularity, there is a paucity of information on population characteristics and habitat requirements of spotted bass in streams. The purpose of this study was to document the factors that influence spotted bass populations in Kansas streams. Study sites were selected throughout the native range of spotted bass in Kansas. Spotted bass were sampled by electrofishing, and 31 habitat variables were measured at 16 study sites. Linear regression analyses (single and multiple) were used to determine relationships between habitat variables and spotted bass density (number/ha), biomass (kg/ha), catch per effort (CPE; number per minute of electrofishing), relative weight (Wr), and growth. Variability in density of spotted bass 180 mm or longer was best explained by rootwad area (m^2/ha). However, variability in biomass and CPE of spotted bass 180 mm or longer was best explained by rootwads and undercut bank area (m^2/ha). Relative weight was negatively correlated with density and CPE. Mean back-calculated length at age 3 was positively correlated with Wr. These data indicate that habitat, such as woody debris and undercut banks, influences spotted bass density and biomass in Kansas streams.

255. Trimble, S. W. 1997. Stream channel erosion and change resulting from riparian forests. Geology 25: 467-469.

Forested stream banks, compared to grassed ones, can destabilize stream channels by promoting erosion. Four reaches on Coon Creek, Wisconsin, each with long-term grassed and forested subreaches were examined. Grassed reaches were narrower and had smaller channels (bankfull cross sections) than forested reaches, suggesting that grassed channel reaches stored about 2100 to 8800 m^3 more sediment per kilometre than forested reaches. Available evidence suggests that conversion of riparian forests to grass would allow storage of sediment along channels, possibly decreasing downstream sediment yields. These findings are important as many grassed riparian corridors are rapidly reverting to forest because of economic conditions and governmental policies.

256. Triska, F. J. and K. Cromack. 1980. The role of wood debris in forests and streams. Forests: Fresh Perspectives from Ecosystem Analysis, Corvallis, Oregon: 171-190. Oregon State University Press.

In the Pacific Northwest, old-growth forests and their associated streams contain large quantities of coarse wood debris. To date, such debris has been considered an impediment to reforestation and stream quality. Consequently, it has been virtually ignored in ecological studies, partly because man's need for wood fiber has resulted in the removal of debris from forests throughout the world but also because the extended period necessary for wood to decay makes it difficult to study nutrient recycling from such a process. In this paper, we shall attempt to correct that omission by exploring how wood debris is utilized in forest and stream ecosystems.

Such an exploration is timely in view of the diminishing amount of pristine forest. In the Pacific Northwest, the greatest accumulation of wood debris occurs from natural mortality and blowdown in such forests. Now that forests are being cut every 80 years instead of standing 250 to 500 years (the interval between natural catastrophic fires), it is crucial that we determine the role of wood debris in pristine habitats and then incorporate that knowledge into existing management strategies for our forests and watersheds.

Our exploration will begin with determining the amounts of wood debris in various forest and stream ecosystems and its rates of accumulation in each. We shall then examine how debris modifies existing habitats and creates new ones. Next, we shall determine how rapidly coarse wood debris breaks down into its component elements and how its carbon and other elements are recycled. Finally, we shall discuss what implications these data have for the managers of forested watersheds in the Pacific Northwest.

257. Trotter, E. H. 1990. Woody debris, forest-stream succession, and catchment geomorphology. Journal of the North American Benthological Society 9: 141-156.

The retention potential of forest headwater streams is strongly influenced by forest succession through the input and transport of different amounts and types of wood and the interaction of woody debris with drainage basin geomorphology during forest succession. To evaluate experimentally the effects of changing amounts of wood on the retention potential of streams, ten log dams were added to a 50-m reach on two second-order streams, Aspen 1 and Aspen 2. Both streams lacked woody debris and flowed through a successional aspen forest in the southern Rocky Mountains. All wood > 5 cm in diameter was removed from a 50-m reach of a third stream, Conifer, previously choked with wood in an adjacent climax conifer forest. Although both aspen streams were in the same forest type, Aspen 1 appeared to be at an earlier successional stage than Aspen 2. It flooded more frequently, had more erosion in its upper drainage basin, and had an unstable channel compared with Aspen 2. Within each stream, reaches with wood stored twice the organic matter of reaches without wood. Sides of streams stored more than centers (Aspen 1 = 6 .times., Aspen 2 = 2 .times., Conifer = 3.5 .times.). Conifer contained 3.5 times and Aspen 2 contained 2 times more stored organic matter than Aspen 1. Average water velocities were lower in reaches with wood than in reaches without wood in Aspen 2 and Conifer, but not in Aspen 1. Velocities decreased and width and depth increased in both aspen reaches with wood. Velocities increased and width and depth decreased in the conifer reach without wood. Dye-measured transit time revealed the greatest difference between Conifer reaches and the smallest differences between Aspen 1 reaches. Experimental releases of uniformly shaped "woodchips" and spray-painted leaves showed that Aspen 1 was least retentive and Conifer was most retentive, but the greatest difference in retention of particles was between the Aspen 1 reaches. When wood is added, streams retain and store organic matter directly by holding back organic matter and indirectly by increasing the physical heterogeneity of the channel and deflecting water movement into eddies and backwaters. Finally, the effects of woody debris vary with channel stability supporting the concept of linkage between stream succession and the geomorphic processes occurring within each catchment as a whole.

258. Tschaplinski, P. J. and G. F. Hartman. 1983. Winter distribution of juvenile coho slamon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. Canadian Journal of Fisheries and Aquatic Sciences 40: 452-461.

Numbers of juvenile coho salmon (*Oncorhynchus kisutch*) in streams are reduced substantially in winter compared to those that occur in summer. Most of this reduction occurs early in autumn with the onset of the first seasonal freshets. Stream sections containing adequate winter habitat in the form of deep pools, log jams, and undercut banks with tree roots and debris lost fewer fish during freshets and maintained higher numbers of coho in winter than sections without these habitat characteristics. These features provide shelter and reduce stream velocities. Microhabitats occupied by coho juveniles in winter after logging were unchanged from those described before logging--all microhabitat were characterized by low water velocities (0.3 m/s). Up to 48% of the coho population inhabiting stream sections with adequate shelter remained there by midwinter (Jan. 3). This percentage was typical of stream sections where at least some trees remained after logging. Streamside trees stabilized the banks and prevented their collapse. In contrast, two of three study sections that had been clear-cut logged had unstable banks which collapsed during winter freshets. Almost no coho populations remained in these sections in winter. Many coho emigrate from the main stream to seek the shelter of low-velocity tributaries and valley soughs concurrent with the decline of coho populations in Carnation Creek during autumn and early winter. This seasonal shift in distribution reverses in the spring when large numbers of coho reenter the main stream. Fish overwintering in these sites have a high apparent survival rate. Before logging a 4-yr mean of 169 ± 44 coho entered one tributary (a slough called 750-m site) in autumn. Of these numbers entering, 72.2% came out in spring. During and after logging, an annual mean of 288 coho entered the same site. The apparent survival rate during and after logging was 67.4 %, essentially unchanged from the prelogging value. Logging has neither reduced the numbers of coho juveniles that enter such sites in autumn to overwinter, nor reduced the numbers leaving these sites to reenter Carnation Creek in spring.

259. Turner, D. P., G. J. Koerper, M. E. Harmon, and J. J. Lee. 1995. A carbon budget for forests of the conterminous United States. Ecological Applications 5: 421-436.

The potential need for national-level comparisons of greenhouse gas emissions, and the desirability of understanding terrestrial sources and sinks of carbon, has prompted interest in quantifying national forest carbon budgets. In this study, we link a forest inventory database, a set of stand-level carbon budgets, and information on harvest levels in order to estimate the current pools and flux of carbon in forests of the conterminous United States. The forest inventory specifies the region, forest type, age class, productivity class, management intensity, and ownership of all timberland. The stand-level carbon budgets are based on growth and yield tables, in combination with additional information on carbon in soils, the forest floor, woody debris, and the understory. Total carbon in forests of the conterminous U.S. is estimated at 36.7 Pg, with half of that in the soil compartment. Tree carbon represents 33% of the total, followed by woody debris (10%), the forest floor (6%), and the understory (1%). The carbon uptake associated with net annual growth is 331 Tg, however, much of that is balanced by harvest-related mortality (266 Tg) and decomposition of woody debris. The forest land base at the national level is accumulating 79 Tg/yr, with the largest carbon gain in the Northeast region. The similarity in the magnitude of the biologically driven flux and the harvest-related flux indicates the importance of employing an age-class-based inventory, and of including

effects associated with forest harvest and harvest residue, when modeling national carbon budgets in the temperate zone.

260. Tyrrell, L. E. and T. R. Crow. 1994. Dynamics of dead wood in old-growth hemlock-hardwood forests of northern Wisconsin and northern Michigan. Canadian Journal of Forest Research 24: 1672-1683.

We studied the dynamics of coarse woody debris (logs and snags) in old-growth forests by estimating rates of tree mortality, snag change, and log decay in hemlock-hardwood stands located in northern Wisconsin and northern Michigan. To estimate mortality and snag changes, we recensused live trees and dead snags in permanent plots in 15 stands. We also recorded recent mortality along transects, and noted category of mortality (standing death, breakage, or uprooting) for gap-maker trees and logs in 25 stands. Decay rates were estimated from a simple exponential model of wood density from log sections against the age of the wood since tree death, and from ages of trees growing on decaying "nurse" logs. From data obtained in permanent plots, annual tree mortality averaged 0.9% original basal area, 0.9% original live tree density, and 4.8 trees/ha. Of the three categories of tree mortality, standing death accounted for 62% of all mortality, while breakage represented 25%, and uprooting, 13%. Based on origin of logs, species composition affected category of mortality. Eastern hemlock (*Tsuga canadensis* (L.) Carr.) was significantly more prone to uprooting while yellow birch (*Betula alleghaniensis* Britton) and paper birch (*Betula papyrifera* Marsh.) were less prone to uprooting than expected if independence of species and categories of mortality were assumed (chi^2 216.5, df = 14, $p < 0.001$). Changes in snags (fragmentation to shorter snags or collapse at the base) occurred for < 7% of the original snags annually. Fragmentation occurred for 2.1 snags/ (ha times year), and collapse for 1.3 snags/(ha times year). We estimated that it takes nearly 200 years for hemlock logs to lose structural integrity and become partially incorporated into the soil. At > 350 years, the two oldest hemlock-hardwood stands had accumulated volumes of logs > 65 m^3/ha distributed among all decay classes, and appeared to be at a dead wood equilibrium in which rates of log production from mortality balance rates of wood loss by decay.

261. Tyrrell, L. E. and T. R. Crow. 1994. Structural characteristics of old-growth hemlock-hardwood forests in relation to age. Ecology (Tempe) 75: 370-386.

We characterized the structure of 25 old-growth hemlock-hardwood forests in northern Wisconsin and adjacent Michigan in order to examine our working hypotheses that differences in their structure are related to stand age (i.e., stage of development) and that changes in stand structure continue after old-growth status is achieved. Estimates of stand age, i.e., age of oldest tree cored, based on 10 cores taken from hemlocks of a range of diameters in each stand, ranged from 177 to 374. By investigating the patterns of live tree structure, coarse woody debris (CWD), tip-up mounds, and canopy gaps in relation to stand age, we were able to infer changes that occur during stand development. Along the gradient of old-growth stand development, some changes in structural features, including total volume of CWD, snag (standing dead tree) basal area, and total area and average size of canopy gaps were continuous, linear increases over time. In contrast, changes in live tree and snag density, density of large trees, volume of well-decayed hemlock logs, and diameter-age relationships occurred after a threshold stand age of 275-300 yr was reached. Area and density of tip-up mounds and density of large seedlings and saplings were not correlated with stand age. Old-growth hemlock-hardwood stands at the upper end of the age continuum (> 275-300 yr) have accumulated both gradual and threshold structural changes, acquiring most of the following characteristics: (1) a strong correlation between age and diameter of trees, (2) low densities of live trees distributed

across all size classes, (3) trees > 70 cm dbh (diameter at breast height), (4) dead wood > 120-150 m^3/ha, with logs > 80 m^3/ha, (5) hemlock logs present in all decay classes, and (6) canopy gaps occupying > 10% of the stand, with the average gap size > 50 m^2, some gaps > 200 m^2, and no more than 30% of the gaps < 10 m^2. The two oldest stands may be at or near equilibrium, where maximum volumes of CWD are maintained through a balance of tree growth and mortality, and wood decay; and oldest tree age approaches 400+ yr, the maximum longevity typical for hemlock.

262. Urabe, H. and S. Nakano. 1998. Contribution of woody debris to trout habitat modification in small streams in secondary deciduous forest, northern Japan. Ecological Research 13: 335-345.

Field studies to examine the influence of woody debris on rainbow trout (*Oncorhynchus mykiss*) abundance through habitat modification were conducted in two small streams, the Horonai and Uenae streams, running through secondary deciduous forest in south-western Hokkaido, northern Japan. Reach-based woody debris volume (total woody debris volume per 100 m^2 of study reach) was significantly correlated with the total basal area of riparian stands along the margins of the Horonai stream, but no significant relationship was evident between them for the Uenae stream. This inconsistency between the streams was considered to be a result of the difference in stream size (width, depth and discharge). Woody debris was the principal agent for pool formation, although it had a far smaller volume than that found in streams draining old-growth coniferous forest in North America, where most of the previous studies have been carried out. Untransported debris pieces of larger volume more effectively contributed to pool formation than smaller transported pieces. The volume of individual debris scour pools was positively correlated with the volume of woody debris associated with each. Similarly, reach-based pool volume increased with total woody debris volume, but the relationship was less clear in the Uenae stream, having more abundant transported woody debris than the Horonai stream. The biomass of rainbow trout in individual pools, which were regarded as the most preferred habitat type for stream salmonids, was correlated with pool volume. A positive relationship also existed between reach-based standing crop and pool volume. These results revealed that secondary deciduous forest, like old-growth coniferous forest, plays an important role in enhancing the carrying capacity for rainbow trout by supplying woody debris which promoted preferred habitat formation.

263. Van Sickle, J. and S. V. Gregory. 1990. Modeling inputs of large woody debris to streams from falling trees. Canadian Journal of Forest Research 20: 1593-1601.

A probabilistic model predicts means and variances of the total number and volume of large woody debris pieces falling into a stream reach per unit time. The estimates of debris input are based on the density (trees/area), tree size distribution, and tree-fall probability of the riparian stand adjacent to the reach. Distributions of volume, length, and orientation of delivered debris pieces are also predicted. The model is applied to an old-growth coniferous stand in Oregon's Cascade Mountains. Observed debris inputs from the riparian stand exceeded the inputs predicted from tree mortality rates typical of similar nonriparian stands. Debris pieces observed in the stream were generally shorter, with less volume per piece, than those predicted by the model, probably because of bole breakage during tree fall. As a second application, predicted debris inputs from riparian management zones of various widths are compared with the input expected from an unharvested stand.

264. Vose, J. M., W. T. Swank, B. D. Clinton, J. D. Knoepp, and L. W. Swift. 1999. Using stand replacement fires to restore southern Appalachian pine-hardwood ecosystems: Effects on mass, carbon, and nutrient pools. Forest Ecology and Management 114: 215-226.

Pine-hardwood ecosystems in the southern Appalachians are in serious decline due to fire exclusion and insect infestations. Fire has been advanced as a tool to restore these ecosystems, yet there are few studies evaluating overall ecosystem effects. Our objectives were to evaluate the effects of stand restoration burning on forest floor nitrogen (N) and carbon (C) pools, and soil and stream chemistry. We measured changes in forest floor (coarse woody debris, small wood, litter, and humus) mass, N, and C; changes in soil chemistry (calcium (Ca), potassium (K), magnesium (Mg), cation exchange capacity (CEC), pH, C, and N); and changes in stream nitrate (NO_3). Results showed that significant reductions in mass, N, and C occurred only for litter and small wood on the ridge, where N losses were 52.9 kg ha^1 for litter and small wood combined. No significant effects were observed on the mid- or lower slope of the treatment watershed. Losses on the ridge are considerably lower than losses which occur with alternative burning treatments used in the region, such as the fell and burn treatment. Soil and stream chemistry showed no response to burning. Spatial heterogeneity in fire intensity (combustion temperatures ranged from < 52 - >800degree C) and severity associated with stand replacement burning results in a mosaic of fire effects and considerably less consumption and subsequent nutrient losses.

265. Wallace, J. B. and A. C. Benke. 1984. Quantification of wood habitat in subtropical coastal plain streams. Canadian Journal of Fisheries and Aquatic Sciences 41: 1643-1652.

To assess the importance of woody debris in 2 relatively unaltered coastal plain streams in the southeastern USA, a line intersect technique, developed by foresters, was used to estimate volume, mass, surface area and spatial distribution. The ash-free dry mass of in-channel woody material was 6.5 kg/m^2 of stream channel bottom in the 6th-order Ogeechee River and 5.0 kg/m^2 in the 4th-order Black Creek. Most wood is located near the erosional bank in these meandering streams. These wood mass estimates are much higher than expected for middle-order streams and are similar to those from several small headwater streams in other regions. Due to their very low slopes (< 0.02%), these streams appear to have insufficient stream power to move large woody material. Snag, or woody, habitat is the major stable substrate in these sandy-bottomed streams and is a site of high invertebrate diversity and productivity. In-channel snag surface area per square meter of channel bottom was 0.249-0.433 m^2 in the Ogeechee and 0.191-0.379 m^2 in Black Creek, depending on the hydrograph stage. With invertebrate biomass of 6.6 g dry mass/m^2 of snag surface, this results in an invertebrate biomass of a least 1.88 g/m^2 of channel bottom. Wood is also important to fishes, providing a rich source of invertebrate food, habitat and cover. In addition to its obvious biological role, wood enhances the ability of a stream to process and conserve nutrient and energy inputs and has a major influence on the hydrodynamic behavior of the river. The quantification of wood habitat seems mandatory to assess past or potential impacts of snag removal on ecosystem processes in low-gradient streams.

266. Wallace, J. B., J. R. Webster, and J. L. Meyer. 1995. Influence of log additions on physical and biotic characteristics of a mountain stream. Canadian Journal of Fisheries and Aquatic Sciences 52: 2120-2137.

Three pairs of cobble riffle study sites were established in a second-order stream in North Carolina and logs added to the downstream riffle at each site. At log addition transects, stream depth increased, current velocity decreased, cobble substratum was covered by sand and silt, and both coarse and fine particulate organic matter increased dramatically. Log additions had less dramatic effects on uptake lengths of ammonium, nitrate, and phosphate, but they had immediate and significant impacts on invertebrate community structure: abundances and biomass of scrapers and filterers decreased; collectors and predators increased; overall shredder biomass did not change, but biomass of trichopteran and dipteran shredders increased, while that of most plecopteran shredders decreased; and plecopteran predators also decreased despite greater abundances of potential prey. These observations suggest that physiological and morphobehavioral constraints preclude many animals from tracking resources among patches when patches display very different abiotic conditions. Secondary production of scrapers and filterers decreased, whereas that of collectors and predators increased. The shifts in functional group abundances, biomass, and production between reference and debris-dam transects, which differed considerably from those previously reported for low-gradient, sandy-bottom streams, accentuate the importance of localized abiotic factors in structuring invertebrate communities within patches.

267. 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 µm FPOM < 1 mm) was investigated in a coniferous forest stream ecosystem in western Oregon [USA]. The amount of wetted surface area of both large (> 10 cm) and fine woody debris (1-10 cm) was 0.018 and 0.069 m^2/m^2 stream bed, respectively, during summer base flow. These values increase to 0.062 and 0.195 m^2/m^2 stream bed during winter flows. 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. Examination of FPOM samples with scanning electron microscopy revealed an abundance of wood-derived particles. Erosion rates of wood surfaces ranged between 0.5 and 11 mm/yr depending on decay state of the log. Using conservative estimates of processing rates, woody debris could be a source for approximately 90 $g/m^2/yr$ of FPOM, but with slightly a less conservative estimate, wood processing could easily generate several times the FPOM that is contributed by leaf and needle litter.

268. Ward, J. V., K. Tockner, P. J. Edwards, J. Kollmann, G. Bretschko, A. M. Gurnell, G. E. Petts, and B. Rossaro. 1999. A reference river system for the Alps: The 'Fiume Tagliamento'. Regulated Rivers: Research and Management 15: 53-75.

A major deterrent to a full understanding of the ecological ramifications of river regulation at the catchment scale is a lack of fundamental knowledge of structural and functional attributes of morphologically intact river systems. For example, both the River Continuum and the Serial Discontinuity Concepts, in their original formulations, had the implicit assumption of a stable, single-thread channel from headwaters to the sea. The Flume Tagliamento traverses a course of 172 km from its headwaters in the Italian Alps to the Adriatic Sea. No high dams impede the river's passage as it flows through the characteristic sequence of constrained, braided, and meandering reaches. The Tagliamento, the only large morphologically intact Alpine river remaining in Europe, provides insight into the natural dynamics and complexity that must have characterized Alpine rivers in the pristine state. The Tagliamento has a flashy pluvio-nival regime (mean Q = 109 m^3/s, with flood flows up to 4000 m^3/s). Thousands of newly-uprooted trees were strewn across the active bed and floodplain along the river's course following a major flood in the autumn of 1996. The active floodplain is up to 2 km wide and contains a riparian vegetation mosaic encompassing a range of successional stages. Up to II individual channels per cross section occur in the braided middle reaches. Islands are a prominent feature of the riverine landscape and island dynamics are postulated to play a key role in determining pattern and process across scales. Future studies will examine the roles of island dynamics and large woody debris in structuring biodiversity patterns of aquatic biota and successional trajectories of riparian vegetation. The high levels of spatiotemporal heterogeneity exhibited by the Flume Tagliamento provide a valuable perspective for regulated river ecologists and those engaged in conservation and restoration. Copyright (C) 1999 John Wiley & Sons, Ltd.

269. Wei, X., J. P. Kimmins, K. Peel, and O. Steen. 1997. Mass and nutrients in woody debris in harvested and wildfire-killed lodgepole pine forests in the central interior of British Columbia. Canadian Journal of Forest Research 27: 148-155.

Mass and nutrients in woody debris, including coarse (greater than or equal to 5 cm) and fine (< 2.5 cm) woody debris, and wood decomposition rates were studied in harvested and wildfire-killed lodgepole pine forests (*Pinus contorta* ssp. latifolia Engelm. ex S. Wats.) in the central interior of British Columbia. There were significant differences in the mass of aboveground coarse woody debris and total woody debris between harvested and wildfire-killed sites. However, there were no significant differences in these two variables between stem-only harvested and whole-tree harvested sites. Whole-tree harvesting removed more N and P (about 2-fold) than stem-only harvesting. Belowground woody debris may be nutritionally important for stands growing on low-fertility sites because of its important contribution to the total woody debris and relatively high asymbiotic nitrogen fixation rates. Because of differences in size and position, coarse woody debris on the harvested sites decays more rapidly and persists for less time than that on the fire-killed sites. The nutrient removals caused by harvesting were within the estimated range of nutrient removals caused by wildfire.

270. Wei, X. and J. P. Kimmins. 1998. Asymbiotic nitrogen fixation in harvested and wildfire-killed lodgepole pine forests in the central interior of British Columbia. Forest Ecology and Management 10: 343-353.

Rates of asymbiotic nitrogen fixation in woody debris, forest floor and mineral soils were investigated in stem-only harvested and wildfire-killed lodgepole pine (*Pinus contorta* ssp. latifolia Engelm. ex S. Wats.) stands in the central interior of British Columbia using an acetylene reduction assay. The long-term contribution of those nitrogen fixation processes to site nitrogen economy was estimated by mass loadings, associated nitrogen fixation rates and decomposition models. Asymbiotic nitrogen fixation activity was detected in all the woody and litter substrates examined. There were significant differences in nitrogenase activities between substrates. The highest activity (16.10 ± 75 nm C_2H_4/g/day) occurred in the below-ground woody debris (dead roots), followed in order by stumps, advanced or medium decay stems, litter, humus, early decay stems and, the lowest (0.07 ±0.03 nm C_2H_4/g/day), mineral soil. Because of its relatively high rate of nitrogen fixation, below-ground woody debris is thought to have an important, but largely unrecognized, ecological role in the long-term site productivity of lodgepole pine forests. Moisture was the most important factor affecting the asymbiotic nitrogen fixation activity in woody debris in the study area. Asymbiotic nitrogen fixation in the above-ground woody debris was greater on the wildfire-killed sites than on the harvested sites due to much higher woody debris loadings and longer persistence on the former sites. The dynamics and role of asymbiotic nitrogen fixation over pine stand development were presented and discussed. Replacement of nitrogen removals from disturbance by asymbiotic nitrogen fixation would take 180 years for both stem-only and wildfire-killed sites. However, this could be shortened while considering other sources of nitrogen fixation in the study area such as nitrogen-fixing shrub, *Sheperdia canadensis* (L.) Nutt and mycorrhizae. Management implications of asymbiotic nitrogen fixation were also discussed.

271. Wells, R. W. and J. A. Trofymow. 1998. Coarse woody debris in the coastal forests of southern Vancouver Island. Northwest Science 72: 23-24.

In this extended abstract, we present results from a study of coarse woody debris in forests of coastal British Columbia. We examined trends of CWD abundance across chronosequence plots established by the Canadian Forest Service, on the drier east side (CWHxm subzone) and the wetter west side (CWHvm subzone) of southern Vancouver Island. Overall, total biomass of CWD on the east side was substantially (and significantly) lower than on the west side. Mean total biomass, across the chronosequences, ranged from 17 Mg/ha to 38 Mg/ha (55m^3/ha to 149 m^3/ha) on the east side and 65 Mg/ha to 191 Mg/ha (307 m^3/ha to 636 m^3/ha) on the west side.

272. Wilzbach, M. A. 1988. How tight is the linkage between trees and trout? California Riparian Systems Conference, University of California, Davis: 250-255. USDA Forest Service.

This paper explores the tightness of the linkage between stream dwelling salmonids and riparian vegetation. Comparison of original distributions of salmonid species with that of vegetation types shows that distribution within a given salmonid species is not limited to a specific vegetation type, and that difference salmonid species co-occur within a given vegetation type. Examination of reported differences in trout production among streams appear to be related to differences in riparian setting only indirectly and insofar as these reflect differences in prey availability and, to a lesser extent, differences in habitat features. Variability in trout production estimates are minimized when comparison are

species specific and normalized for temperature differences among streams. Within a riparian vegetation type, the relationship between trout production and sucessional age of the streamside vegetation is often inverse.

273. Wohl, E., S. Madsen, and L. MacDonald. 1997. Characteristics of log and clast bed-steps in step-pool streams of northwestern Montana, USA. Geomorphology 20: 1-10.

The role of log and clast steps was studied in 53 step-pool reaches in 32 streams in northwestern Montana. In each reach, 20 consecutive steps were sampled. Drainage areas ranged from 0.5 to 11.5 km^2. Mean step spacing was found to be proportional to channel gradient, width of the bankfull channel, and drainage area; mean step height was proportional to the width of the channel. No significant difference exists between clast and log steps with regard to step spacing and step height. This suggested either that (1) woody debris is mobile in even the smallest channels in the study area, or (2) channel flows arrange clast steps around immobile woody debris. Calculations of theoretical entrainment and transport of sediment suggest that the coarse clasts forming steps are capable of being entrained at bankfull discharge in most channels. The presence of immobile log steps (composed of living roots) in the upstream reaches, an increase in the percentage of log steps with gradient, and a decrease in this percentage with the width of the bankfull channel and drainage area, imply that woody debris is mobile primarily in the downstream reaches. Calculations of flow resistance suggest that most steps serve to maximize flow resistance. These results support the second hypothesis, that the height and spacing of clast steps are adjusted around immobile log steps to maintain consistent step characteristics.

274. Wood-Smith, R. D. and J. M. Buffington. 1996. Multivariate geomorphic analysis of forest streams: Implications for assessment of land use impacts on channel condition. Earth Surface Processes and Landforms 21: 377-393.

Multivariate statistical analyses of geomorphic variables from 23 forest stream reaches in southeast Alaska result in successful discrimination between pristine streams and those disturbed by land management, specifically timber harvesting and associated road building. Results of discriminant function analysis indicate that a three-variable model discriminates 10 disturbed from 13 undisturbed reaches with 90 per cent and 92 per cent correct classification respectively. These variables are the total number of pools per reach, the ratio of mean residual pool depth to mean bankfull depth, and the ratio of critical shear stress of the median surface grain size to bankfull shear stress. The last variable can be dropped without a decrease in rate of correct classification; however, the resulting two-variable model may be less robust. Analysis of the distribution of channel units, including pool types, can also be used to discriminate disturbed from undisturbed reaches and is particularly useful for assessment of aquatic habitat condition. However, channel unit classification and inventory can be subject to considerable error and observer bias. Abundance of pool-related large woody debris is highly correlated with pool frequency and is an important factor determining channel morphology. Results of this study yield a much needed, objective, geomorphic discrimination of pristine and disturbed channel conditions, providing a reference standard for channel assessment and restoration efforts.

275. Young, W. J. 1991. Flume study of the hydraulic effects of large woody debris in lowland rivers. Regulated Rivers: Research and Management 6: 203-212.

As a 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 that were 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 loss of faunal habitat, and possible geomorphic instability. The results of these experiments indicate that 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.

276. Young, M. K. 1994. Movement and characteristics of stream-borne coarse woody debris in adjacent burned and undisturbed watersheds in Wyoming. Canadian Journal of Forest Research 24: 1933-1938.

Following fire, changes in streamflow and bank stability in burned watersheds can mobilize coarse woody debris. In 1990 and 1991, I measured characteristics of coarse woody debris and standing riparian trees and snags in Jones Creek, a watershed burned in 1988, and in Crow Creek, an unburned watershed. The mean diameter of riparian trees along Jones Creek was less than that of trees along Crow Creek, but the coarse woody debris in Jones Creek was greater in mean diameter. Tagged debris in Jones Creek was three times as likely to move, and moved over four times as far as such debris in Crow Creek. In Jones Creek, the probability of movement was higher for tagged pieces that were in contact with the stream surface. Larger pieces tended to be more stable in both streams. It appears that increased flows and decreased bank stability following fire increased the transport of coarse woody debris in the burned watershed. Overall, debris transport in Rocky Mountain streams may be of greater significance than previously recognized.

277. Young, M. K. 1995. Telemetry-determined diurnal positions of Brown Trout (*Salmo trutta*) in 2 south-central Wyoming streams. American Midland Naturalist 133: 264-273.

Positions of 51 adult brown trout in tyro streams were monitored to evaluate habitat use from mid-June to early December 1991 using radio telemetry. Nearly all brown trout occupied more than one location during the study. Brown trout tended to occupy habitats in deep water near the bank and close to cover. In Douglas Creek, habitat and cover influenced by beaver activity were used in excess of their abundance, whereas in South French Creek, sites with coarse woody debris were used disproportionately. Measures of water velocity did not consistently distinguish used from available habitats, and the importance of water velocity may have been overshadowed by selection for overhead cover.

278. Young, M. K. 1996. Summer movements and habitat use by Colorado River cutthroat trout (Oncorhynchus clarki pleuriticus) in small, montane streams. Canadian Journal of Fisheries and Aquatic Sciences 53: 1403-1408.

Radio telemetry was used to assess the mobility of, and habitat use by, 29 adult Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*) in the North Fork Little Snake River drainage in south-central Wyoming from 27 May to 27 August 1992. Median home range (233 m) and median total movement (332 m) were larger than expected for cutthroat trout in small streams, and all but two fish used more than one primary habitat type during the study. Median weekly movement and the number of primary habitat units used generally declined as summer progressed. Of the available habitats, those used by Colorado River cutthroat trout tended to consist of deeper water in pools, especially pools formed by large woody debris. Fish were significantly farther from stream banks and not significantly closer to cover than would be expected by chance. These patterns of mobility and habitat use may be influenced by the connectivity and productivity of the study streams.

279. Zimmerman, J. K., W. M. Pulliam, D. J. Lodge, V. Quinones-Orfila, N. Fetcher, S. Guzman-Grajales, J. A. Parrotta, C. E. Asbury, L. R. Walker, and R. B. Waide. 1995. Nitrogen immobilization by decomposing woody debris and the recovery of tropical wet forest from hurricane damage. Oikos 72: 314-322.

Following damage caused by Hurricane Hugo (September 1989) we monitored inorganic nitrogen availability in soil twice in 1990, leaf area index in 1991 and 1993, and litter production from 1990 through 1992 in subtropical wet forest of eastern Puerto Rico. Experimental removal of litter and woody debris generated by the hurricane (plus any standing stocks present before the hurricane) increased soil nitrogen availability and above-ground productivity by as much as 40% compared to unmanipulated control plots. These increases were similar to those created by quarterly fertilization with inorganic nutrients. Approximately 85% of hurricane-generated debris was woody debris > 5 cm diameter. Thus, it appeared that woody debris stimulated nutrient immobilization, resulting in depression of soil nitrogen availability and productivity in control plots. This was further suggested by simulations of an ecosystem model (CENTURY) calibrated for our site that indicated that only the large wood component of hurricane-generated debris was of sufficiently low quality and of great enough mass to cause the observed effects on productivity. The model predicted that nutrient immobilization by decaying wood should suppress net primary productivity for 13 yr and total live biomass for almost 30 yr following the hurricane. Our findings emphasize in forest ecosystems through its effects on the activity of decomp osers. We suggest that the manner in which woody debris regulates ecosystem function in different forests is significantly affected by disturbance regime.