Section 9

RIPARIAN AREA FUNCTION & MANAGEMENT IN HEADWATERS & SMALL STREAMS

An annotated bibliography

Compiled for the Region II Forest Resources and Practices Science and Technical Committee

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SUMMARY

While the effect of riparian management practices on larger streams and their biota have been researched extensively in the last 30 years, very little is known about the physical, chemical and biological linkages between headwaters and higher order streams in drainage networks (Richardson 2000). This annotated bibliography is an attempt at compiling recent literature that extends our knowledge on the ecological function of headwaters and other types of small streams in drainage networks, how riparian management practices might affect these small streams, and, in turn, affect the larger streams further downstream in the drainage network.

There are four major features of small headwater streams that could have implications for anadromous and high value resident fish species in these and higher order streams. Headwaters, even those that do not contain fishes, are potentially important sources of sediments, water, nutrients, and organic matter to downstream areas that do contain fish (Gomi et al. 2002).

Sediments. Disruption of the riparian zone of headwaters and small streams, either through natural events and/or riparian management, can facilitate release of fine and larger sediments downstream to fish bearing waters (Naiman et al. 2000). Soil moisture and windthrow play a role in these changes. Loss of riparian shade can exacerbate loss of soil moisture through a decrease in relative humidity, leading to an increase in the amount of fine sediment released downstream during flooding (Naiman et al. 2000). Increases in windthrow can increase the availability of fine sediments from exposed root wads (Kelsey 1996). An increase in erosion can increase the rate of channel incision which may increase the amount of drying of soils and decrease root biomass leading to further erosion (Toledo and Kauffman 2001). An increase or decrease in the rate of natural disturbance of small streams can alter the rate of sediment delivery, causing changes in the rate of change to downstream channel morphology (Naiman et al. 2000; Gomi et al. 2002). Riparian buffers were effective at maintaining pre-logging particle size distributions and channel habitat distributions in first and second order streams (Jackson et

al. 2001).

Water. Disruption of the riparian zone can increase variability in the flow regime (higher peak flows and lower base flows) that can alter delivery of sediments, water, nutrients and organic matter to from small headwater streams to downstream areas (e.g., Archer and Newson 2001). Water temperature may also become more variable (higher summer highs and lower winter lows; see Amaranthus et al. 1989 and Chen et al. 1998), potentially shifting the timing of significant life history events of fishes and macroinvertebrates (spawning, hatching, smoltification; see Chen et al. 1998, Macdonald et al. 2003, Moring 1975). However, stream temperature changes can be moderated by tributaries or lakes (Mellina et al. 2002).

Nutrients. Disruption of the riparian zone can change the moisture content of surrounding soils, potentially changing the delivery rates of sediments and necessary nutrients (Toledo and Kaufmann 2001). Increased sunlight can switch streams from primarily allochthonous-based to autochthonous-based production (many references including Bilby and Bisson 1992 and Hetrick et al. 1998). Changes in the source of production can alter macroinvertebrate communities although densities of the resultant communities may be the same or higher than pre-disturbance conditions (Cole et al. 2003, Price et al. 2003, Paradise et al. 2002, Sponseller et al. 2001).

Organic Matter. Disruption of the riparian zone can alter the amount and timing of litter fall and large woody debris (LWD) delivery to downstream areas (e.g., Bilby and Bisson 1992, Bragg 2000, Piccolo and Wipfli 2002, Young et al. 1999). Litter fall and LWD processed in headwater areas can contribute substantial organic matter inputs to downstream fish bearing areas (Wipfli and Gregovich 2002). Riparian buffer design and management are well founded for assuring a source of LWD to streams, but there was no consistent relationship between buffer width and the amount of leaf litter provided to a stream (Grady 2001).

Although there have been recent studies implicating riparian management actions in changes to fish (Fitzgerald et al. 1997, Hetrick et al. 1998 and Young et al. 1999) and amphibian populations (Corn and Bury 1989, Dupuis and Steventon 1999, Willson and Dorcas 2003, Wilkins and Peterson 2002), there remains a lack of studies on the cumulative effects of riparian management activities on small headwater streams, the linkages between these headwaters and higher order streams (Sidle et al. 2000), and their biota (Richardson 2000). Nonetheless, there are several good overviews of the importance of riparian area management on small streams (see Gomi et al. 2002, Young 2000, Naiman et al. 2000, Richardson 2000, Raphael et al. 2002, and Bisson et al. 2002.) that should be considered when developing management prescriptions for these types of streams.

References were primarily determined from online databases available to Alaska state government (http://www.library.state.ak.us/index/index.html). Databases used in the search were: Fish and Fisheries Worldwide, Arctic and Antarctic Regions, Wildlife and Ecology Studies Worldwide, Water Resources Abstracts, BasicBIOSIS, Aquatic Science and Technology Abstracts, and GEOBASE. References were also sought from the Stream Riparian Bibliography housed at the University of Washington (http://riparian.cfr.washington.edu/). The compiled reference list is also available electronically as a Procite 5 database. When possible and available, PDF files of articles were also compiled; these references are noted with an asterisk following the citation.

REFERENCES

Amaranthus, M., Jubas, H., and Arthur, D. 1989. Stream shading, summer streamflow and maximum water temperature following intense wildfire in headwater streams. USDA Forest Service, General Technical Report PSW-109 75-78.

Adjacent headwater streams were monitored for postfire shade, summer streamflow and maximum water temperature following the 40,000 ha Silver Complex fire in southern Oregon. Average postfire shade (30 percent) for the three streams was considerably less than prefire shade (est.>90 percent). Dramatic increases in direct solar radiation resulted in large but variable increase in maximum water temperature. Increase was greatest in Stream C where temperature increased 10.0oC. Stream B increased 6.2oC. Stream A increased 3.3oC. Variation in maximum water temperature increase was strongly correlated to summer streamflow (r2 = 0.98) and percent total streamside shade (r2 = 0.80). The greatest maximum water temperature increase was associated with lowest summer streamflow and total postfire shade. Shade from dead vegetation provided the most shade averaged for all three streams. Shade from dead vegetation was more than three times greater than shade from topography and two times greater than shade from live vegetation. Considerable loss of live vegetation and large but variable increases in maximum water temperature can accompany intense wildfire in headwater streams. Review of the Silver Fire Complex indicates, however, that less than 5 percent of the headwater streams burned in this summer.

Archer, D. and Newson, M. 2001. The use of indices of flow variability in assessing the hydrological and instream habitat impacts of upland afforestation and drainage. Journal of Hydrology 268: 244-258.

Although the impact of plantation forestry and ground-preparation drainage on headwater runoff response has been widely studied, there are remaining uncertainties concerning the time scale of changes, scale effects of Catchment size and impacts on flow variability. Flow variability, along with changes in sediment loads and water quality, is likely to be a defining element of the overall instream habitat quality of headwater catchments. In this paper a method is described for the characterization of flow variability using 15-min data on the 1.5 km2 Coalburn catchment, from 1967 to 1998, over a period of change from natural moorland to closed canopy coniferous forest. The method is based on annual number, and average and total duration of pulses above selected threshold flows but decouples the effects of variable annual rainfall. The number of pulses increased from pre- to post-drainage but pulse number has declined steadily and pulse duration increased with forest growth-the catchment has become more, then less 'flashy'. The method provides a comprehensive, continuous and quantitative picture of changes in hydrological regime that is relevant to current assessments of instream physical habitat and 'environmentally acceptable flows'. It is possible that low invertebrate numbers and low levels of fish recruitment in the Coalburn channel may be in part attributable to changes in flow regime. (c) 2002 Elsevier Science B.V. All rights reserved.

Bilby, R.E. and Bisson, P.A. 1992. Allochthonous versus autochthonous organic matter contributions to the trophic support of fish populations in clear-cut and old-growth forested streams. Canadian Journal of Fisheries & Aquatic Sciences 49: 540-551.

Annual organic matter inputs and production of stocked coho salmon *Oncorhynchus kisutch*, coastal cutthroat trout *O. clarki clarki*, and shorthead sculpin *Cottus confusus* from spring through early autumn were monitored in two headwater tributaries of the Deschutes River, Washington. One site was bordered by old-growth coniferous forest; the other was an area clear-cut without buffer strips 7 yr before the study. Allochthonous organic matter (terrestrial origin) dominated inputs to the old-growth site and contributed c300 g/m-2yr-1, while autochthonous organic matter totaled 100 g/m-2yr-1. In the clear-cut site, autochthonous inputs contributed 175 g/m-2yr-1, but allochthonous inputs contributed only 60 g/m-2yr-1 owing to loss of riparian vegetation. Although combined allochthonous and autochthonous inputs were almost twofold greater in the old-growth site, fish production was greater in the clear-cut site. Production of coho salmon and shorthead sculpin during early summer was largely responsible for differences between sites. Fish populations appeared to depend upon food derived from autotrophic pathways during spring and summer in the presence or absence of forest canopy. -from Authors. Bilby, R.E. and Fransen, B.R. 1992. Effect of habitat enhancement and canopy removal on the fish community of a headwater stream. Ann. Meeting, Northwest Science Association, Bellingham, WA (USA) 24-28 Mar 1992.

The riparian trees along a 2km section of stream in western Oregon were logged in 1985, in violation of forest practice regulations. As part of the judgment against the landowner, wood was placed in the channel to improve habitat in 1988. Fish populations and habitat have been monitored since 1986 at 3 sites: the enhanced area, an non-enhanced reach without a canopy and a non-enhanced reach with a canopy. Pool area increased 20% as a result of the wood addition at the enhanced site. Pool area during summer also increased at the site with the canopy due to beaver activity. Speckled dace (*Rhinichthys osculus*) have exhibited the greatest response, increasing in numbers at all 3 sites, with greatest gains in the enhanced reach. Salmonid density at all three sites also has increased since 1988. Age 0+ steelhead *(Oncorhynchus mykiss)* exhibit an inverse relationship between density and growth. "

Bisson, P.A., Raphael, M.G., Foster, A.D., and Jones, L.L.C. 2002. Influence of site and landscape features on vertebrate assemblages in small streams. General Technical Reports of the US Department of Agriculture, Forest Service PNW-GTR-563 : 61-72.*

The relative influence of site- and landscape-level habitat features on fishes and stream-dwelling amphibians was evaluated at 62 headwater streams on the Olympic Peninsula in Washington state. Watershed areas at the study sites ranged from 16 to 2,817 ha (average 265 ha) and the catchments had varied geologic, land use, and natural disturbance histories. Site-level features included stream habitat type, channel substrate, and riparian forest condition. Landscape-level features included forest age, drainage characteristics, elevation, road density, and landslide frequency. There were important differences in habitat associations among species within the two major headwater vertebrate groups (fishes and amphibians) as well as between the two groups themselves. In general, fishes were more strongly influenced by in-stream habitat

parameters than by riparian or watershed variables. Stream-dwelling amphibians, however, were influenced by riparian and watershed features and were less affected by in-stream habitats. Thus, fishes may be the best overall indicators of site-scale stream conditions; amphibians seem to be more sensitive indicators of landscape-scale riparian and upland features. Preliminary comparison of the information value of different landscape-level variables (their importance to stream-dwelling vertebrates relative to the cost of obtaining them) showed that certain variables had much greater utility for landscape-scale assessments than others.

Bonin, H.L., Griffiths, R.P., and Caldwell, B.A. 2000. Nutrient and microbiological characteristics of fine benthic organic matter in mountain streams. Journal of the North American Benthological Society 19: 235-249.

Fine benthic organic matter (FBOM) was collected over a 10-mo period from 14 1st-order streams in the Cascade Mountains of western Oregon to investigate 1) relationships between FBOM substrate quality and microbial activity, 2) links between organic matter sources and FBOM substrate quality, and 3) how FBOM is influenced by riparian vegetation, elevation, and season. Streams drained forests in 3 successional age classes: old-growth forest dominated by Douglas-fir *(Pseudotsuga menziesii)* and western hemlock *(Tsuga heterophylla)*, and young regenerating stands, either 10 y old with a large riparian herbaceous component, or 30 y old and surrounded by deciduous trees such as red alder *(Alnus rubra)*. Seasonal trends showed a major autumn depression in carbon:nitrogen ratios (C:N) and an increase in microbial activities, a likely result of increased leaf inputs after an early fall storm. Decreases in C:N, total C, total N, and organic P were correlated with reciprocal increases in respiration, ß-glucosidase and phosphatase activities, and acetylene reduction, all of which are relative indicators of microbial activity. Lower C:N and higher denitrification potentials, respiration rates, ß-glucosidase and phosphatase activities, and mineralizable N were observed in young stands compared to old growth, suggesting higher quality FBOM and faster decomposition rates in young stands. An exception to this trend was acetylene reduction, which was greater in FBOM from old-growth streams. Significantly lower C:N at high elevations (1220-1280 m) versus low elevations (580-800 m) suggested the presence of more herbaceous vegetation and alder in high-elevation riparian zones. Lower total N and total C, and elevated denitrification potentials, acetylene reduction, respiration rates, and phosphatase activity at low elevations (580-800 m) suggested greater decomposition rates at low elevations. Organic P was 3.6 and 2.2 mg P/g organic matter at high and low elevations, respectively, a significant difference probably resulting from the young geologic age of parent material at high elevations. Data from this study suggest a potential link, mediated by shifts in FBOM, between headwater forest management and dynamics of stream food webs.

Bragg, D.C. 2000. Simulating catastrophic and individualistic large woody debris recruitment for a small riparian system. Ecology 81: 1383-1394.

Surprisingly little research has been done to partition the contribution of catastrophic disturbance from that of small-scale individualistic mortality events on riparian large woody debris (LWD) recruitment. This study compared the impact of both processes on recruitment through

simulation of several catastrophic disturbances (a spruce beetle outbreak, a moderately intense fire, and a clearcut) and undisturbed (individualistic mortality only) old growth for a small headwater stream in the Intermountain West of the United States. All scenarios progressed through a two-stage process, with the Forest Vegetation Simulator growth and yield model controlling forest dynamics and a postprocessor (CWD, version 1.2) predicting riparian LWD recruitment. Projections indicate that individualistic only conditions delivered 2.5 m3 LWD·100 m reach-1·10-yr·cycle-1; while the spruce beetle-, fire-, and clearcut-affected stands averaged 2.9, 3,2, and 1.5 m3 LWD·100 m reach-1·cycle-1, respectively. Stands impacted by natural catastrophic disturbance significantly ($P < 0.05$) increased cumulative (300 yr) LWD recruitment over the individualistic-only scenario, whereas clear-cutting significantly decreased total delivery. In-stream LWD loads, relatively stable in undisturbed riparian zones, fluctuated sharply under catastrophic disturbance. Peak channel loads associated with natural perturbation occurred 30 yr after the event while debris volumes under clear-cutting immediately declined. The post-event recruitment and in-stream LWD stocks of all disturbance scenarios eventually fell below undisturbed conditions, requiring decades to recover historical volumes. Catastrophic disturbances induced such steep oscillations in riparian LWD load that the systems experiencing frequent large-scale perturbations never achieved a long-term steady state, as some have postulated. Because of the inflation in cumulative LWD delivery, it may prove advantageous to encourage (or imitate) some catastrophic disturbance in forests along streams noticeably depauperate of LWD.

Bramblett, R.G., M.D. Bryant, B.E. Wright, and R.G. White. 2002. Seasonal use of small tributary and main-stem habitats by juvenile steelhead, coho salmon, and Dolly Varden in a southeastern Alaska drainage basin. Transactions of the American Fisheries Society 131:498-506.*

The movement of juvenile salmonids between small tributaries and main-stem habitats in southeast Alaska watersheds is poorly understood. We observed movements of steelhead *Oncorhynchus mykiss*, coho salmon *O. kisutch*, and Dolly Varden *Salvelinus malma* between mainstem and tributary habitats at weirs located on tributaries in the Staney Creek watershed in southeast Alaska. We used seasonal relative abundance (catch per unit effort) in eight main-stem reaches and eight tributaries to corroborate observed movement in the two streams with weirs. We observed juvenile steelhead and coho salmon moving through the weirs into tributaries during the fall as flows increased and temperatures decreased. The relative abundance of steelhead was greater in main-stem sites than in tributaries during the summer, whereas during spring and fall relative abundance in the tributaries was similar to that in the main stem. Juvenile coho salmon were abundant in tributaries during all seasons. The relative abundance of Dolly Varden was greater in the tributaries than in the main-stem during all seasons. These results underscore the significance of links between main-stem habitats and small tributaries for production of juvenile salmonids.

Brookshire, E.N.J. and Dwire, K.A. 2003. Controls on patterns of coarse organic particle retention in headwater streams. Journal of the North American Benthological Society 22: 17-34.

Organic matter retention is an integral ecosystem process affecting C and nutrient dynamics and biota in streams. Influences of discharge (Q), reach-scale channel form, and riparian vegetation on coarse particulate organic matter (CPOM) retention were analyzed in 2 headwater streams in northeastern Oregon. *Ginkgo biloba* leaves were released in coniferous forest reaches and downstream floodplain meadow reaches during spring high flow and summer baseflow. Transitional reaches were also analyzed during summer baseflow. Paper strips, simulating sedge blade retention, were released in meadow reaches during high flow. Mean transport distances (Sp) were calculated as the inverse of the longitudinal loss rate (k) of leaves in transport. The metrics Sp, width-specific discharge (Qw = Q/stream width), and the mass transfer coefficient (vdep = Qw/Sp) were used to investigate retention. Values of Sp (0.9-97 m) were 2 to 11 times longer during high flow than baseflow. Mean Sp in forest reaches (29.3 m) was significantly shorter than in meadow reaches (68.9 m) during high flow but not during baseflow. Standardizing k for the scaling effects of Q by analyzing the relationship between Qw and Sp, in which the slope equaled the inverse of mean vdep of all Ginkgo releases, indicated times when vdep was higher or lower than predicted by Q. Values of Sp were driven largely by Q, yet most experiments in which values of vdep exceeded those predicted by Qw occurred during high flow. Values of vdep (0.3-32 mm/s) across experiments were generally inversely related to Sp but did not differ between forest and meadow reaches during high flow. Unlike meadow reaches, mean vdep in forest reaches was higher during high flow (5.2 mm/s) than baseflow (1.1 mm/s). Values of vdep were positively related to large wood volume and negatively related to the extent of floodplain inundation during high flow. Yet, in the meadow reach that had lower relative channel constraint, paper strips were transported farther onto the floodplain as Q rose, resulting in long-term (~1.5 mo) retention. Despite downstream increases in Q, there were no differences in mean baseflow Sp or vdep among reaches in either stream, indicating some longitudinal compensation in retention. Alternating associations between retention metrics and structural elements of the stream channels between flow periods suggests dynamic reach-scale hydrologic-retention thresholds in response to changes in Q. Analysis of vdep across experiments indicated that channel morphology, stream wood, and riparian vegetation are major controls on CPOM retention.

Chen, Y.D., McCutcheon, S.C., Norton, D.J., and Nutter, W.L. 1998. Stream temperature simulation of forested riparian areas: II. Model application. Journal of Environmental Engineering - ASCE 124: 316-328.

The SHADE-HSPF modeling system described in a companion paper has been tested and applied to the Upper Grande Ronde (UGR) watershed in northeast Oregon. Sensitivities of stream temperature to the heat balance parameters in Hydrologic Simulation Program-FORTRAN (HSPF) and the riparian shading parameters in SHADE were analyzed for stream temperature calibration. Solar radiation factors (SRF), as well as diurnal, seasonal, and longitudinal variations, were evaluated to verify the accuracy and reliability of SHADE computations. Simulated maximum values of stream temperature, on which the riparian

restoration forecasts are based, are accurate to 2.6-3.0 ºC compared with 8-10 ºC exceedences over stream temperature goals for salmon habitat restoration under the present riparian vegetation conditions. Hourly simulations have approximately the same accuracy and precision. Stream temperature regimes were simulated for different hydroclimatic conditions and hypothetical restoration scenarios of riparian vegetation. Regardless of natural weather cycles, the restoration of riparian vegetation is needed along many headwater streams to significantly alleviate the lethal and sublethal stream temperatures currently associated with salmon habitat in the UGR basin.

Cheng, J.D., Lin, L.L., and Lu, H.S. 2002. Influences of forests on water flows from headwater watersheds in Taiwan. Forest Ecology and Management 165: 11-28.

Forests cover 59% of Taiwan island where disastrous floods, landslides and debris flows occur often due to heavy typhoon-season rainstorms, steep terrain, fragile geologic formations and frequent earthquakes. This study evaluated the hydrologic influences of forests on Taiwan's headwaters watersheds and supports the century-old policy of designating protection forests for streamflow regulation and soil conservation. Despite rainfall intensity that often exceeds 100 mm/h overland flow rarely occurs on Taiwan's permeable forest soils. High evapotranspiration totaling 800-1200 mm annually contributes to reduced streamflows. In Taiwan forests reduce stream sedimentation from landslides by enhancing slope stability with roots and protect water quality by minimizing stream temperature fluctuation, regulating nutrient concentration and filtering contaminants. Floods in Taiwan are mainly caused by heavy rainstorms exceeding 250 mm and are not significantly affected by the currently low level of annual forest removal. Rapid urbanization of some forested watersheds may cause increased peak flows and decreased low flows due to significantly reduced soil infiltration capacities. Forests' influences are minimal on landslides, debris flows or floods caused by extreme natural events such as the 7.3 Richter-scale earthquake in September 1999 or the rainstorms exceeding 1000 mm during Typhoon Herb in August 1996.

Clarke, K.D. and Scruton, D.A. 1997. Use of the Wesche method to evaluate fine-sediment dynamics in small boreal headwater streams. North American Journal of Fisheries Management 17: 188-193.*

Fine-sediment infiltration was monitored by the Wesche sediment method in the Copper Lake watershed, Newfoundland, Canada, from June 1990 October 1994 as part of a multidisciplinary forest harvesting buffer zone research project. Initial study in Copper Lake has focused on evaluating the ability of this method to measure sediment dynamics in small boreal forest streams and in developing methods for data analyses and interpretation. The Wesche method discerned expected differences in sediment yield among sites due to logging-road construction and seasonal trends. Stream reaches impacted by bridge construction and culvert installation had significantly higher sediment accumulation than streams not affected by road construction. The Wesche method was a relatively simple and inexpensive way to compare fine sediment yield in streams with similar hydrologic regimes and was easily used in remote locations. Due to the nonparametric nature of the data collected with this method, randomization techniques were used

to develop 95% confidence intervals around the mean. Use of these statistics allowed a significance level to be used in comparisons between stream reaches, an approach easily understood by the multidisciplinary audience interested in fishery-forestry research and management.

Cole, M.B., Russell, K.R., and Mabee, T.J. 2003. Relation of headwater macroinvertebrate communities to in-stream and adjacent stand characteristics in managed second-growth forests of the Oregon Coast Range mountains. Canadian Journal of Forest Research 33: 1433-1443.

Although headwater streams constitute a significant portion of stream length within watersheds, their aquatic fauna, contributions to regional biodiversity, and responses to forest management have been understudied. Macroinvertebrate communities, physical habitat, and water chemistry were sampled from 40 headwater streams in managed forests in the Oregon Coast Range mountains. We characterized functional and structural attributes of macroinvertebrate communities in relation to physical, chemical, and biological gradients. Substrate composition, specific conductance, and riparian forest age showed the strongest correlations with resultant ordination patterns in macroinvertebrate community composition. Among individual metrics of community structure and composition, total macroinvertebrate density and dominance by three taxa showed the strongest correlations with forest age. No community measures were related to densities of torrent salamanders *(Rhyacotriton kezeri)* or crayfish *(Pacifastacus leniusculus)*, suggesting these potential predators had little influence on overall macroinvertebrate community structure. Rare taxa were sampled from several reaches, including *Rhyacophila* probably *viquaea* for which little information is available, and an *Eobrachycentrus* species, previously known to occur only in the Cascade mountains. Headwater streams within these managed forests of northwestern Oregon appear to be taxa rich, continue to support taxa limited to headwater streams, and harbor taxa about which little is known.

Connolly, P.J. and Hall, J.D. 1999. Biomass of coastal cutthroat trout in unlogged and previously clear-cut basins in the central coast range of Oregon. Transactions of the American Fisheries Society 128: 890-899.*

Populations of coastal cutthroat trout *Oncorhynchus clarki clarki* were sampled in 16 Oregon headwater streams during 1991-1993. These streams were above upstream migration barriers and distributed among basins that had been logged 20-30 and 40-60 years ago and basins that had not been logged but had burned 125-150 years ago. The objective of our study was to characterize the populations and habitats of age-1 or older cutthroat trout within these three forest management types. Streams within unlogged basins had relatively low levels and a small range of trout biomass (g/m2). Streams in basins logged 40-60 years ago supported low levels but an intermediate range of trout biomass. Streams in basins logged 20-30 years ago supported the widest range of biomass, including the lowest and highest biomasses among all streams sampled. The variable that best explained the variation of trout biomass among all 16 streams was the amount of large woody debris (LWD). All streams were heavily shaded during at least part of the year by mostly closed tree canopies. Deciduous trees were more prominent in canopies over

streams in logged basins, while conifers were more prominent in the stream canopies of unlogged basins. Our results suggest that trout production in basins extensively clear-cut 20-60 years ago may generally decrease or remain low over the next 50 or more years because of decreasing loads of remnant LWD, persistent low recruitment potential for new LWD, and persistent heavy shading by conifers. These logged basins are not likely to show an increase in trout biomass over the next 50 years unless reset by favorable natural disturbances or by habitat restoration efforts.

Cooper, A.B. 1990. Nitrate depletion in the riparian zone and stream channel of a small headwater catchment. Hydrobiologia 202: 13-26.

A mass balance procedure was used to determine rates of nitrate depletion in the riparian zone and stream channel of a small New Zealand headwater stream. In all 12 surveys the majority of nitrate loss (56-100%) occurred in riparian organic soils, despite these soils occupying only 12% of the stream's border. This disproportionate role of the organic soils in depleting nitrate was due to two factors. Firstly, they were located at the base of hollows and consequently a disproportionately high percentage (37-81%) of the groundwater flowed through them in its passage to the stream. Secondly, they were anoxic and high in both denitrifying enzyme concentration and available carbon. Direct estimates of in situ denitrification rate for organic soils near the upslope edge (338 mg N/m2/h) were much higher than average values estimated for the organic soils as a whole (0.3-2.1 mg N/m2/h) and suggested that areas of these soils were limited in their denitrification activity by the supply of nitrate. The capacity of these soils to regulate nitrate flux was therefore under-utilized. The majority of stream channel nitrate depletion was apparently due to plant uptake, with estimates of the in situ denitrification rate of stream sediments being less than 15% of the stream channel nitrate depletion rate estimated by mass balance. This study has shown that catchment hydrology can interact in a variety of ways with the biological processes responsible for nitrate depletion in riparian and stream ecosystems thereby having a strong influence on nitrate flux. This reinforces the view that those seeking to understand the functioning of these ecosystems need to consider hydrological phenomena.

Corn, P.S. and Bury, R.B. 1989. Logging in western Oregon: responses of headwater habitats and stream amphibians. Forest Ecology and Management 29: 39-57.

Occurrence and abundance of four species of aquatic amphibians were compared between 23 streams flowing through uncut forests and 20 streams flowing through forests logged between 14 and 40 years prior to the study. Species richness was highest in streams in uncut forests. Eleven streams in uncut forests contained all four species, and only two streams had fewer than three species present. Eleven streams in logged stands had one or no species present, and only one contained all four species. Density and biomass of all four species were significantly greater (2-7X) in streams in uncut forests. Physical comparisons between types of streams were similar, except that streams in logged stands had generally smaller substrata, resulting from increased sedimentation. Densities of Pacific giant salamanders *(Dicamptodon ensatus)* and Olympic salamanders *(Rhyacotriton olympicus)* were positively correlated with stream gradient in logged stands, but not in uncut forests, suggesting that the

disruptive effects of increased sedimentation are greatest in low-gradient streams. Tailed frogs *(Ascaphus truei)* and Dunn's salamanders *(Plethodon dunni)* occurred more often in streams in logged stands when uncut timber was present upstream, but neither density nor biomass of any species were related to either presence of uncut timber upstream or years since logging. Logging upstream from uncut forests also had no effect on the presence, density or biomass of any species. Tailed frogs and Olympic salamanders may be extirpated from headwaters traversing clearcuts; these streams should be afforded some protection in plans for managed forests.

Dupuis, L. and Steventon, D. 1999. Riparian management and the tailed frog in northern coastal forests. Forest Ecology and Management 124: 35-43.

Although the importance of aquatic environments and adjacent riparian habitats for fish has been recognized by forest managers, headwater creeks have received little attention. The tailed frog, *Ascaphus truei*, inhabits permanent headwaters, and several U.S. studies suggest that its populations decline following clear-cut logging practices. In British Columbia, this species is considered to be at risk because little is known of its abundance, distribution patterns in the landscape, and habitat needs. We characterized nine logged, buffered and old-growth creeks in each of six watersheds (n=54). Tadpole densities were obtained by area-constrained searches. Despite large natural variation in population size, densities decreased with increasing levels of fine sediment (<64 mm diameter), rubble, detritus and wood, and increased with bank width. The parameters that were correlated with lower tadpole densities were found at higher levels in clear-cut creeks than in creeks of other stand types. Tadpole densities were significantly lower in logged streams than in buffered and old-growth creeks; thus, forested buffers along streams appear to maintain natural channel conditions. To prevent direct physical damage and sedimentation of channel beds, we suggest that buffers be retained along permanent headwater creeks. Creeks that display characteristics favoring higher tadpole densities, such as those that have coarse, stable substrates, should have management priority over less favorable creeks. Measures should also be taken to minimize fine sediment inputs from roads and stream crossings.

Elliott, S. 2000. The impact of riparian disturbance on physiochemical characteristics of seston. M.S.thesis, University of Washington, Seattle.

Suspended particulate matter (seston) plays an important role in the trophic ecology of forested streams. Forest management in and along the riparian corridor alters existing levels of allochthonous and autochthonous contributions to the lotic system, ultimately changing various physicochemical characteristics of seston. This thesis is divided into two chapters, the first providing a subject background on seston dynamics and the second detailing the results of my study of physicochemical parameters of seston at summer baseflow. In this study, my objectives were to describe the effects of riparian condition on physicochemical parameters of seston at summer baseflow, to assess the utility of seston analysis as an indicator of riparian recovery, and to develop a conceptual model of baseflow seston dynamics following logging disturbance in the riparian corridor. To achieve this, I sampled seston at summer baseflow from 19 streams on the

Olympic Peninsula of Washington state. The riparian condition of each stream was characterized by harvest history and other parameters to determine the successional condition of the canopy. I analyzed total seston concentration, percent organic matter, chlorophyll-a concentration, and the carbon to nitrogen (C:N) ratio at baseflow discharge, to determine trends related to riparian condition. Seston was visually characterized using the scanning electron microscope (SEM). Consistent with other studies, summer baseflow seston concentrations and percent of organic matter were not correlated with any single or combination of riparian factors, consistent with other studies. Chlorophyll-a concentrations were generally low (<1.0 µg Chl-a·Lą), and were found to be correlated with canopy closure ($p<0.01$, $r_{ر} = 0.45$), particularly when streams of 1st and 2nd order were considered alone ($p<0.01$, $r_{ر} = 0.64$). C:N ratios ranged from 7.6 to 25.6, with average values at coniferous sites significantly higher than those at alder-dominated deciduous sites ($p<0.01$, ANOVA) or at sites with no appreciable riparian cover ($p<0.02$, ANOVA). Visually, diatoms were a significant proportion of the total seston at each riparian cover type (range = 47-66% of the number of particles), although significantly higher concentrations of diatoms were found in sites lacking cover. Wood particles were not well-represented (range 2-4% of seston particles) and concentrations did not vary among site cover types nor by any other potentially related parameter. Visual characterization of seston using the Shannon-Wiener diversity index (H') for each site, revealed a greater diversity of particles (by type and size) in the mature coniferous sites ($p<0.01$, ANOVA). Physicochemical parameters of seston at summer baseflow, specifically those which are directly influenced by riparian characteristics, could prove valuable as a tool for assessing riparian integrity.

Fiebig D.M, Lock M.A, and Neal C. 1990. Soil water in the riparian zone as a source of carbon for a headwater stream. Journal of Hydrology 116: 217-237.

Conflicting views on the potential importance of soil water as a source of dissolved organic carbon (DOC) in headwater streams are addressed by comparing organic chemistries of soil waters in the riparian zone with an adjacent stream at an upland site in mid-Wales during one year. DOC, which as a whole is relatively refractory, was contrasted with the labile dissolved free amino acids (DFAAs). It is concluded that the riparian zone can contribute substantial amounts of DOC to a stream ecosystem, and that the streambed must be a key area of chemical reactivity where much of this material is initially processed.

Fitzgerald, D.G., Kott, E., Lanno, R.P., and Dixon, D.G. 1997. A quarter century of change in the fish communities of three small streams modified by anthropogenic activities. Journal of Aquatic Ecosystem Stress and Recovery 6: 111-127.

Anthropogenic modification of small stream habitats in southern Ontario has occurred with little concern for indigenous, non-game fish communities. The combined effects of urbanization, impoundment, and agriculture on the fish communities of three small streams, from headwaters to near-confluence locations, were evaluated by comparing current fish community structure to historical records (species lists) collected over the last quarter century. Comparisons using cluster analysis showed that spatial and temporal shifts in fish community composition did not occur immediately after stream modifications but took up to 10 years. Replacement of common

species by formerly rare or absent species was evident in two streams subjected to urbanization and impoundment; stream sections subjected to primarily agriculture land use demonstrated minimal change during this study period. Urban zones and sections downstream of impoundments were dominated by species tolerant of controlled flows, siltation, channelization, homogenous spawning substrates, and elevated temperatures. Barrier-free headwater and agriculture zones with abundant riparian vegetation supported communities that were intolerant of controlled flows, dependent on lower summer water temperatures, and require high dissolved oxygen levels. Greater understanding of the causative forces shaping fish communities can be used to facilitate integration of greater biological realism into any future conservation or restoration programs in anthropogenically-modified streams.

Forsey, E.S. and Baggs, E.M. 2001. Winter activity of mammals in riparian zones and adjacent forests prior to and following clear-cutting at Copper Lake, Newfoundland, Canada. Forest Ecology and Management 145: 163-171.

A study of winter tracks carried out to determine mammal usage of boreal habitats in response to clear-cutting on three headwater streams. Species considered were the endangered Newfoundland marten *(Martes americana atrata)*, short-tailed weasel *(Mustela erminea)*, red fox *(Vulpes vulpes)*, red squirrel *(Tamiasciurus hudsonicus)*, and the snowshoe hare *(Lepus americanus)*. Track abundances were significantly ($p<0.05$) higher in the forest interior than in riparian habitats. A shift in activity on the transects was noted following prescribed cutting. Tracks were more abundant along transects within riparian buffers than along those within clear-cut/open areas. A significant change in activity (displacement) of the pine marten was recorded. The results suggested that for environmentally sensitive species, i.e., American marten, small disturbances or alterations in habitat caused immediate and significant effects.

France, R.L. 1998. Density-weighted δ13C analysis of detritivory and algivory in littoral macroinvertebrate communities of boreal headwater lakes. Annales Zoologici Fennici 35: 187-193.

Investigations of the incorporation of terrestrial detritus into aquatic macroinvertebrates through δ13C analysis are becoming frequent for streams and wetlands, but comparatively little information exists for forest-fringed oligotrophic lakes. Although the most accurate assessment of community patterns in carbon dependency will be made through an organism density-weighted analysis of δ13C, this has never previously been undertaken for any freshwater system. Littoral macroinvertebrates (predominantly amphipods, ephemeropterans and dipterans, as well as odonates and trichopterans) from boreal lakes in northwestern Ontario, Canada displayed ranges of 6‰ to 9‰ in δ13C, all centered about -26‰. The closer agreement between the density-weighted δ13C distribution for these macroinvertebrates to tree rather than epilithon values, suggests that these organisms may be relying more substantially upon allochthonous detritivory than upon autochthonous algivory for energy sustenance. This finding therefore challenges the precept in some timber management guidelines that dismisses riparian trees as an important energy source for lake foodwebs.

Fuchs, S.A., Hinch, S.G., and Mellina E. 2003. Effects of streamside logging on stream macroinvertebrate communities and habitat in the sub-boreal forests of British Columbia, Canada. Canadian Journal of Forest Research 33: 1408-1415.

Much of the future timber supply in the Northern Hemisphere will come from boreal and sub-boreal forests, yet there has been little investigation of how aquatic communities in these regions would be affected by logging. We conducted an empirical, comparative study to investigate the effects of streamside clear-cut logging on benthic macroinvertebrates, algal standing stock, and in-stream physical and chemical habitats in the sub-boreal central interior region of British Columbia. We found that streams that flowed through old-growth forests (sites termed "not logged") did not differ from streams flowing through older logged forests (where the riparian zones were harvested 20–25 years before our sampling; sites termed "older logged") with respect to macroinvertebrate total density or biomass, feeding guild density or biomass, and chlorophyll a biomass. However, streams flowing through newly logged forests (where the riparian zones were harvested within 5 years of our sampling; sites termed "recently logged") had nearly twice the macroinvertebrate biomass as those in not logged or older logged sites and higher chlorophyll a biomass. There were no differences among the three stream categories in regard to structural aspects of the physical habitat (e.g., substrate composition, large organic debris density, dimensions of pools and riffles). Streamside logging in sub-boreal forests appears to enhance primary and secondary production, but this phenomenon may only be evident for the first two decades following logging.

Gill, R. E. 1996. Sediment delivery to headwater stream channels following road construction and timber harvest in the Blue Mountains, Oregon. Interagency Committee on Water Data. Proceedings of the Sixth Federal Interagency Sedimentation Conference. Vol. 2, X38-X45. US, US Government.

The objectives of this study were: 1) to determine the amount and rate of sediment delivery to ephemeral (first and second order) stream channels following road construction and logging, and 2) to evaluate the WWSED sediment yield predictions.

Gomi, T., Bryant, M.B., Sidle, R.C., and Woodsmith, R.D. 2003. Characteristics of channel steps and reach morphology in headwater streams, southeast Alaska. Geomorphology 51: 225-242.

The effect of timber harvesting and mass movement on channel steps and reach morphology was examined in 16 headwater streams of SE Alaska. Channel steps formed by woody debris and boulders are significant channel units in headwater streams. Numbers, intervals, and heights of steps did not differ among management and disturbance regimes. A negative exponential relationship between channel gradient and mean length of step intervals was observed in the fluvial reaches (<0.25 unit gradient) of recent landslide and old-growth channels. No such relationship was found in upper reaches (≥0.25 gradient) where colluvial processes dominated. Woody debris and sediment recruitment from regenerating riparian stands may have obscured any strong relationship between step geometry and channel gradient in young alder, young

conifer, and recent clear-cut channels. Channel reaches are described as pool-riffles, step-pools, step-steps, cascades, rapids, and bedrock. Geometry of channel steps principally characterized channel reach types. We infer that fluvial processes dominated in pool-riffle and step-pool reaches, while colluvial processes dominated in bedrock reaches. Step-step, rapids, and cascade reaches occurred in channels dominated by both fluvial processes and colluvial processes. Step-step reaches were transitional from cascades (upstream) to step-pool reaches (downstream). Woody debris recruited from riparian corridors and logging activities formed steps and then sequentially might modify channel reach types from step-pools to step-steps. Scour, runout, and deposition of sediment and woody debris from landslides and debris flows modified the distribution of reach types (bedrock, cascade, and step-pool) and the structure of steps within reaches.

Gomi T, Sidle R.C, Bryant M.D, and Woodsmith R.D. 2001. The characteristics of woody debris and sediment distribution in headwater streams, southeastern Alaska. Canadian Journal of Forest Research 31: 1386-1399.

Large woody debris (LWD), fine woody debris (FWD), fine organic debris (FOD), and sediment deposition were measured in 15 steep headwater streams with five management and disturbance regimes. Clear-cut channels logged in 1995 contained large accumulations of logging residue that initially provided sites for sediment storage. Half of the LWD in clear-cut channels was recruited during and immediately after logging. Woody debris from logging activities remains in young growth conifer channels 37 years after logging. Numbers of LWD in clear-cut and young conifer channels were significantly higher than in old-growth channels, although numbers of FWD pieces were not significantly different because of higher recruitment from old-growth stands. Channels that experienced recent (1979 and (or) 1993) and earlier (1961 and (or) 1979) scour and runout of landslides and debris flows contained less LWD and FWD, although large volumes of LWD and FWD were found in deposition zones. The volumes of sediment stored in young alder and recent landslide channels were higher than in the other channels. Because of the recruitment of LWD and FWD from young alder stands, the ratio of sediment stored behind woody debris to total sediment volume was higher in young alder channels compared with recent landslide channels. Numbers of LWD and FWD pieces in all streams were significantly correlated with the volumes of sediment stored behind woody debris. Timber harvesting and soil mass movement influence the recruitment, distribution, and accumulation of woody debris in headwater streams; this modifies sediment storage and transport in headwater channels.
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Gomi, T., Sidle, R.C., and Richardson, J.S. 2002. Understanding processes and downstream linkages of headwater systems. BioScience 52: 905-916.*

Headwater systems, the areas from which water originates within a channel network, are characterized by interactions among hydrologic, geomorphic, and biological processes that vary from hillslopes to stream channels and from terrestrial to aquatic environments (Hack and Goodlett 1960). Although hydrologic, geomorphic, and biological processes in headwater systems have been studied for the last 50 years and much knowledge related to these systems is available (Hack and Goodlett 1960, Hewlett and Hibbert 1967, Likens et al. 1977), the roles of

headwater streams within the watershed and the linkages from headwater to downstream systems are poorly understood. Headwater systems are critical areas for nutrient dynamics and habitat for macroinvertebrates, fish, and amphibians within watersheds (Meyer and Wallace 2001). Because of their geographical isolation, headwater systems also support genetically isolated species; thus, they support an important component of biodiversity in watersheds. For instance, new and endangered species are often found in headwater streams because such streams are relatively unexplored (Dieterich and Anderson 2000). Therefore, understanding the spatial and temporal variations of hydrologic, geomorphic, and biological processes in headwater systems is the key to comprehending the diversity and heterogeneity of riparian and riverine ecosystems. Headwater systems are also important for understanding and protecting downstream ecosystems, because they are intimately linked. However, because headwater streams are small and numerous, the roles of headwater systems are typically underestimated and inadequately managed compared with larger downstream systems. Furthermore, management practices for protecting and restoring headwaters are different from those for larger systems, because headwater systems have greater drainage density and different land use types and intensities. Consequently, for the roles and downstream linkages of headwater systems to be understood, inherent differences between processes in headwater systems and larger watersheds need to be recognized in both conceptual and field studies. Therefore, our objectives for this article are to review characteristics of and differences in processes between headwaters and larger watershed systems; we also demonstrate spatial and temporal variations of hydrologic, geomorphic, and biological processes in headwater systems and the linkages of headwaters to downstream systems.

Grady, J. 2001. Effects of buffer width on organic matter input to headwater streams in the western Cascade Mountains of Washington State. M.S. thesis, University of Washington, Seattle.

Large-scale forest clear-cutting is often no longer considered an acceptable forest management strategy, and more environmentally focused forestry practices are being developed and implemented. As alternative forest management techniques and strategies are developed and tested, it is essential that environmental studies are conducted at the same time to ensure that the alternative practices are in fact providing significant environmental protection. The primary emphasis of this study was to determine the effects of forest harvesting on litterfall delivery to the stream channel. Responses in streams of watersheds harvested at varying degrees of disturbance were compared to nearby undisturbed streams. From September 1999 to October 2000 litterfall was collected every 2 to 4 weeks when road access was snow-free to the sites. With the knowledge of forest characteristics litterfall inputs between similar riparian forests were compared to assess the capability of buffers to simulate natural litterfall delivery to the stream channel. No clear statistical relationship could be determined by which litterfall amounts were related to buffer widths.

Haack, S.K., Burton, T., and Ulrich, K. 1988. Effects of whole-tree harvest on epilithic bacterial populations in headwater streams. Microbial Ecology (1988): 165-181.

Bacteria attached to rock and glass surfaces were studied in streams draining a whole-tree harvested watershed (WTH) and a nonharvested (CONTROL) watershed in the Hubbard Brook Experimental Forest, New Hampshire, U.S.A. Seasonal trends in numbers of cells/cm2, mean cell volume, cell size-frequency distribution, and bacterial biomass were determined using 4'6-diamidino-2-phenylindole (DAPI) epifluorescent microscopy and scanning electron microscopy (SEM); the response of these parameters to decreased pH and increased nitrate concentration in the WTH stream was assessed via controlled manipulation of stream water chemistry in artificial channels placed in the CONTROL stream. Bacterial distribution varied significantly between the two streams and seasonally within each stream in apparent response to differential availability of dissolved organic carbon from algae and autumn-shed leaves. Decreased pH similar to that in the WTH stream had a significant effect on cell numbers, mean cell volume, and biomass in the CONTROL stream. Decreased pH accounted for some aspects of the altered bacterial distributions observed in the WTH stream. Nitrate at concentrations similar to those in the WTH stream had no effect on bacterial distribution in the CONTROL stream suggesting that headwater stream epilithic bacteria were carbon limited.

Hagar, J.C., Williams, C.E., Moriarity, W.J., Walters, G.L., and Hill, L. 1999. Influence of riparian buffer width on bird assemblages in Western Oregon. Journal of Wildlife Management 63: 484-496.

The goals of current management practices in riparian areas in the Pacific Northwest include protecting and maintaining habitat for terrestrial wildlife. However, little is known about the use of riparian buffers by terrestrial wildlife, particularly how buffer width may affect abundance and species composition of wildlife communities. In this study, I compared bird assemblages in logged and unlogged riparian areas along headwater streams and assessed the relations between bird abundance and riparian buffer width. The abundances of 4 species of forest-associated birds that were more abundant in unlogged than in logged headwater riparian stands (Pacific-slope flycatcher *[Empidonax difficilis]*, brown creeper *[Certhia americana]*, chestnut-backed chickadee *[Poecile rufescens]*, winter wren *[Troglodytes troglodytes])* increased with increasing width of riparian buffers. However, 4 other species that also were more abundant in unlogged than logged riparian stands (Hammond's flycatcher *[Empidonax hammondii]*, golden-crowned kinglet *[Regulus satrapa]*, varied thrush *[Ixoreus naevius]*, hermit warbler *[Dendroica occidentalis]*) were rarely observed in even the widest buffers sampled (40-70 m on 1 side of the stream). Although riparian buffers along headwater streams are not expected to support all bird species found in unlogged riparian areas, they are likely to provide the most benefit for forest-associated bird species if they are >40 m wide, and density of large trees within buffers is not reduced by harvesting.

Hammer, R. G. 1989. Forest headwaters riparian road construction and timber harvest guidelines to control sediment. Woessner, W. W. and Potts, D. F. Proceedings of the symposium on headwaters hydrology. 127-131. Bethesda, MD, American Water Resources Association.

Two major principles to control forest headwaters sediment are to minimize sediment from road construction and to maintain woody debris stream structures such as log steps which store sediment. Guidelines for road construction in riparian areas include slash filter windrows at the toe of road fill slopes. Studies indicate that slash filter windrows trap 75 percent or more of road sediment at low cost. Guidelines for timber harvest in riparian areas include provision for large woody debris recruitment to headwater streams. Forest headwater stream channels are dependent upon woody materials to form log steps which store sediment, dissipate stream energy, and provide fish habitat.

Hetrick, N.J., Brusven, M.A., Bjornn, T.C., Keith, R.M., and Meehan, W.R. 1998. Effects of canopy removal on invertebrates and diet of juvenile coho salmon in a small stream in Southeast Alaska. Transactions of the American Fisheries Society 127: 876-888.*

We assessed changes in availability and consumption of invertebrates by juvenile coho salmon *Oncorhynchus kisutch* in a small stream in southeast Alaska where patches of dense second growth riparian vegetation bordering the stream had been removed. Benthic invertebrate populations were assessed during summer 1988 and 1989 with a Hess sampler. Aerial invertebrates were sampled during summer 1989 with wire-mesh sticky traps hung just above the water surface and with floating clear-plastic pan traps. Invertebrate drift was assessed during summer 1989 with nets placed at the downstream end of closed- and open-canopy stream sections. Diets of age-0 and age-1 coho salmon were sampled by flushing stomach contents of fish collected from closed- and open-canopy stream sections. Abundance and biomass of benthic invertebrates were larger in open- than in closed-canopy stream sections and were primarily dipterans, ephemeropterans, and plecopterans. More insects were caught on sticky traps in open than in closed sections on two of four dates sampled, and composition of the catch was primarily dipterans (74% in both closed- and open-canopy sections). Catch rates of invertebrates in the pan traps were significantly higher in closed than in open sections on 12 July and were greater in open than in closed sections on 11 August. No significant canopy effect was detected with regard to dry weight of insects captured in pan traps. Composition of the pan-trap catches was primarily dipterans in both closed and open sections (65% and 72%). Abundance of invertebrates in the drift was significantly higher in closed sections than in open sections on two of four dates sampled; dry weight of invertebrate drift did not differ significantly between canopy types. Dry weight of stomach contents of age-0 and age-1 coho salmon was greater for fish sampled in closed- than open-canopy sections on one of four dates sampled; no significant canopy effect was detected for the other three dates sampled. Aerial insects were more abundant in drift and in diets of age-0 and age-1 coho salmon in closed- than in open-canopy sections. Diet of age-0 coho salmon in both closed and open sections and diet of age-1 fish in closed sections overlapped significantly with composition of the drift. Diet of age-1 coho salmon in open sections, however, did not overlap significantly with drift, an indication of selectivity in feeding behavior. Based on higher abundance of aerial invertebrates above the water surface and increased standing crop of

benthic invertebrates that we observed in open- versus closed canopy sections of Eleven Creek, it appears that canopy removal has the potential to increase the carrying capacity of juvenile coho salmon in streams where populations are food limited.

Hetrick, N.J., Brusven, M.A., Bjornn, T.C., and Meehan, W.R. 1998. Changes in solar input, water temperature, periphyton accumulation, and allochthonous input and storage after canopy removal along two small salmon streams in Southeast Alaska. Transactions of the American Fisheries Society 127: 859-875.*

Changes in solar radiation, water temperature, periphyton accumulation, and allochthonous inputs and storage were measured after we removed patches of deciduous, second-growth riparian vegetation bordering two small streams in southeast Alaska that produce coho salmon *Oncorhynchus kisutch*. Solar radiation and leaf litter input were measured at the water surface at random locations dispersed through six alternating closed- and open-canopy stream sections. Water temperature, periphyton, and stored organic samples were collected near the downstream end of each section. Solar radiation intensity was measured with digital daylight integrators and pyronometers, periphyton biomass and chlorophyll a were measured on red clay tile substrates, allochthonous input was measured with leaf litter baskets, and benthic organic matter was measured with a Hess sampler. Average intensity of solar radiation that reached the water surface of open canopy sections was significantly higher than in closed-canopy sections of two streams measured during daylight hours in summer 1988 and of one stream measured day and night in summer 1989. Average daily water temperature was similar in the two canopy types in summer 1988, but was higher in open- than in closed-canopy sections in 1989. Accumulation of periphyton biomass was significantly higher in open- than in closed-canopy sections of the two streams studied in the summer of 1988 and of the one stream sampled in 1989. Accrual of periphyton biomass on tiles placed in the stream for 30-d colonization periods during the summer months of 1989 was also significantly higher in the open than closed sections. Accumulation of chlorophyll a was significantly higher in the open- than in closed-canopy sections of the two streams in 1988 but did not differ significantly between canopy types in 1989. Thirty-day accrual of chlorophyll a was greater in open- than in closed-canopy sections of the one stream studied in 1989. Allochthonous input to the streams decreased after canopy removal, but the amount of organic material stored in the substrate did not differ significantly between open- and closed-canopy sections. Weather was predominantly overcast and rainy in summer 1988 and mostly sunny with infrequent rain in 1989. We speculate that advective heat transfer and high stream discharge from frequent rains moderated the effect of canopy removal and increased solar radiation on water temperatures in open-canopy stream sections in 1988. In 1989, solar radiation was a significant factor in regulating water temperature, especially when streamflows were low. Using a model, we predicted that water temperatures would change little in a 160-m open-canopy reach of Eleven Creek during any weather condition when flows were high. With low flows, however, stream temperatures in open sections of Eleven Creek were predicted to exceed the optimum for growth of juvenile coho salmon in about 20 m during clear sunny weather and in about 50 m when cloudy and overcast.

Jackson, C.R., Sturm, C.A., and Ward, J.M. 2001. Timber harvest impacts on small headwater stream channels in the coast ranges of Washington. Journal of the American Water Resources Association 37: 1533-1549.

We evaluated changes in channel habitat distributions, particle-size distributions of bed material, and stream temperatures in a total of 15 first- or second-order streams within and nearby four planned commercial timber harvest units prior to and following timber harvest. Four of the 15 stream basins were not harvested, and these streams served as references. Three streams were cut with unthinned riparian buffers; one was cut with a partial buffer; one was cut with a buffer of non-merchantable trees; and the remaining six basins were clearcut to the channel edge. In the clearcut streams, logging debris covered or buried 98 percent of the channel length to an average depth of 0.94 meters. The slash trapped time sediment in the channel by inhibiting fluvial transport, and the average percentage of times increased from 12 percent to 44 percent. The trees along buffered streams served as a fence to keep out logging debris during the first summer following timber harvest. Particle size distributions and habitat distributions in the buffered and reference streams were largely unchanged from the pre-harvest to post-harvest surveys. The debris that buried the clearcut streams effectively shaded most of these streams and protected them from temperature increases. These surveys have documented immediate channel changes due to timber harvest, but channel conditions will evolve over time as the slash decays and becomes redistributed and as new vegetation develops on the channel margins.

Kawaguchi, Y. and Nakano, S. 2001. Contribution of terrestrial invertebrates to the annual resource budget for salmonids in forest and grassland reaches of a headwater stream. Freshwater Biology 46: 303-316.*

1. The annual input, contribution to the diet of salmonids, and quantitative input of terrestrial invertebrates to four reaches with contrasting forest (n = 2) and grassland riparian vegetation (n = 2) were compared in a Japanese headwater stream.
2. The annual input of terrestrial invertebrates falling into the forest reaches (mean ± 1 SE = 8.7 x 103 ± 0.3 x 103 mg m-2year-1) was 1.7 times greater than that in the grassland reaches (5.1 x 103 ± 0.8 x 103 mg m-2year-1), with clear seasonality in the daily input of invertebrates in both vegetation types. The daily input, however, differed between the vegetation types only in summer, when it rose to a maximum in both vegetation types.
3. Fish biomass also differed among the seasons in both vegetation types, being less in the grassland reaches. The contribution of terrestrial invertebrates to the salmonid diet in the forest and grassland reaches was 11 and 7% in spring, 68 and 77% in summer, 48 and 33% in autumn, and 1 and 1% in winter, respectively. The prey consumption rate of fish, which was similar between the vegetation types, increased with stream temperature and was highest in summer. Terrestrial invertebrates supported 49% (mean ± 1 SE = 5.3 x 103 ± 0.4 x 103 mg m-2year-1) of the annual, total prey consumption (10.9 x 103 ± 1.7 x 103mg m-2year-1) by salmonids in the forest and 53% (2.0 x 103 ± 0.3 x 103 mg m-2year-1) (3.8 x 103 ± 0.6 x 103 mg m-2year-1) in the grassland reaches.
4. Salmonids were estimated to consume 51 and 35% of the annual total (falling plus drift) input of terrestrial invertebrates in the forest and grassland reaches, respectively. The input of terrestrial invertebrates by drift, however, was almost equal to the output in both vegetation

types, suggesting that the reach-based, in-stream retention of terrestrial invertebrates almost balanced these falling in.
5. Difference in the riparian vegetation, which caused spatial heterogeneity in the input of terrestrial invertebrates, could play an important role in determining the local distribution of salmonids.

Keith, R.M., Bjornn, T.C., Meehan, W.R., Hetrick, N.J., and Brusven, M.A. 1998. Response of juvenile salmonids to riparian and instream cover modifications in small streams flowing through second-growth forests of Southeast Alaska. Transactions of the American Fisheries Society 127: 889-907.*

We manipulated the canopy of second-growth red alder *Alnus rubra* and instream cover to assess the effects on abundance of juvenile salmonids in small streams of Prince of Wales Island, southeast Alaska, in 1988 and 1989. Sections of red alder canopy were removed to compare responses of salmonids to open- and closed-canopy sections. At the start of the study, all potential instream cover was removed from the study pools. Alder brush bundles were then placed in half the pools to test the response of juvenile salmonids to the addition of instream cover. Abundance of age-0 coho salmon *Oncorhynchus kisutch* decreased in both open- and closed-canopy sections during both summers, but abundance decreased at a higher rate in closed-canopy sections. More age-0 Dolly Varden *Salvelinus malma* were found in open-canopy sections than in closed-canopy during both summers. Numbers of age-1 and older coho salmon and Dolly Varden were relatively constant during both summers, and there was no significant difference in abundance detected between open- and closed-canopy sections. Abundance of age-0 coho salmon decreased in pools with and without additional instream cover during both summers. Abundance of age-1 and older coho salmon and age-0 Dolly Varden did not differ significantly in pools with or without added cover during either summer. Abundance of age-1 and older Dolly Varden was higher in pools with added instream cover than in pools without cover during both summers. Age-0 coho salmon decreased in abundance throughout the summer in both years. Emigration was measured in 1989 and accounted for most of the decrease in abundance. Age-0 coho salmon emigrants were significantly smaller than age-0 coho salmon that remained in the stream.

Kelsey, K.A. 1996. Responses of Headwater Stream Amphibians to Forest Practices in Western Washington (*Ascaphus Truei, Dicamptodon Tenebrosus*). Ph.D. thesis, University of Washington, Seattle.

Differences in *Ascaphus truei* (tailed frog) and *Dicamptodon tenebrosus* (Pacific giant salamander) populations were examined to detect possible effects of clear-cut logging and identify important habitat features influencing their distributions in small, western Washington Cascade streams. Streams surveyed were upstream of fish-bearing regions where amphibian population densities were high and areas were not necessarily protected by buffer strips of standing trees. Long-term responses were investigated by comparing density (#/m2) of *A. truei* and *D. tenebrosus* populations in streams in forests that had never been logged (unmanaged forests) to streams in forests that had been logged (managed forests). Short-term responses were

investigated by comparing density and biomass (g/m2) of larvae and adults in unharvested controls with treatment sites harvested within 18 months. Overall results showed greater negative impact on the density of *A. truei* larvae than on *D. tenebrosus* larvae. To compare populations between unmanaged and managed forests, I combined two data sets for which streams were surveyed using identical methods but nearly a decade apart. Eighteen unmanaged forest streams were surveyed in 1984 and 23 managed forest streams were surveyed in 1992 and 1993. The coefficient of variation between streams was greater in managed forest (166%) than in unmanaged forests (124%) for *A. truei* density but greater in unmanaged forests (194%) than managed forests (103%) for *D. tenebrosus*. Density and biomass of both species were similar between unmanaged and managed forests. Greater variability in *A. truei* density in managed forest streams suggests that this species is more vulnerable than *D. tenebrosus* to habitat changes following timber harvest. Ten managed forest streams were surveyed in each of three years from 1992 to 1994 to detect differences in pre- and post-logging abundance. Control streams showed greater densities of *A. truei* second-year tadpoles and greater biomass of *D. tenebrosus* larvae than streams that were clearcut with variable-width buffer strips remaining. Volumes of down wood in stream channels were lower in treatment streams and could be related to decreases in salamander larval biomass. Results support previous conclusions that *A. truei* tadpoles are more vulnerable to habitat changes following clear-cut logging than larvae of *D. tenebrosus.* Stream habitat associations suggest that both species tend to be concentrated within specific, but not exclusive, areas of the stream, even though individuals can be found together in many areas. *Dicamptodon tenebrosus* larvae were found in greatest numbers in the lower sections, where wider channels allow more sunlight to penetrate, resulting in higher water temperature and primary production rates. *Ascaphus truei* tadpole densities were highest in streams with high volumes of down wood and low amounts of sediment. *Ascaphus truei* adults tended to congregate in the colder, smaller streams, closer to the stream's source than the larvae of either species. During the fall, adult male frogs with pronounced secondary sexual characteristics were frequently observed in these areas. Forest management practices must protect headwater stream habitat to provide breeding areas for *A. truei*. Leaving structures that reduce sediment inputs and provide long-term sources of down wood can help mitigate the impacts of logging on stream amphibians and stream habitat. Alternative configurations of tree buffers should be sought to reduce windthrow which also contributes to sediment inputs to the stream by uprooting trees and exposing areas of bare soil.

Kiffney P.M and Bull J.P. 2000. Factors controlling periphyton accrual during summer in headwater streams of southwestern British Columbia, Canada. Journal of Freshwater Ecology 15: 339-351.

In headwater coastal streams of southwestern British Columbia, previous research suggested that light limited periphyton growth and abundance of grazing invertebrates. Logging along a reach of stream allowed us to further examine the importance of light, as well as other abiotic factors, in regulating stream periphyton and grazers. We placed unglazed ceramic tiles in three watershed, two of which served as controls. In the third watershed, we placed tiles in one reach that was newly harvested, as well as in an upstream, forested reach. Tiles were placed in streams in late June and removed weekly over a six-week period for determination of periphyton chlorophyll a and ash-free dry mass. We also measured discharge, dissolved nitrate and

phosphate, and counted the number of invertebrate grazers on each removed tile weekly. Peak biomass, as chlorophyll a, was reached on day 29 with alga biomass at the logged site (19 µg m-2) seven to fourteen times higher than at the control sites. Stepwise, multiple linear regression suggested that light was the single best predictor explaining 64% of the variation in peak biomass of chlorophyll a. Although periphyton biomass on tiles was much higher in the clearcut reach, so was fine sediment. Inorganic mass entrapped in the periphyton mat was two to four times higher in the clearcut stream than at other sites. Grazer abundance was not related to periphyton biomass, but was negatively related to sediment levels. Our results are consistent with the hypothesis that grazer abundance was determined by sediment levels rather than alga biomass.

Kreutzweiser, D.P. and Capell, S.S. 2001. Fine sediment deposition in streams after selective forest harvesting without riparian buffers. Canadian Journal of Forest Research 31: 2134-2142.

Fine sediment accumulation was measured in streams in low-order forest watersheds across a gradient of selective harvesting with no protective riparian buffers. Comparisons were made among sites in selection-cut (40% canopy removal), shelterwood-cut (50% canopy removal), diameter limit cut (about 85% canopy removal), and undisturbed tolerant hardwood catchments. These were further compared with a headwater stream catchment not harvested but affected by logging road activities. The greatest increases in fine inorganic sediment occurred at the road-improvement site with mean bedload estimates more than 4000 times higher than pre-manipulation values. Sediment bedload was still significantly elevated 2 years after the road-improvement activities. Significant increases (up to 1900 times the pre-harvest average) in inorganic sediment also occurred at the highly disturbed diameter-limit site as a result of heavy ground disturbance and channeled flowpaths from skidder activity in riparian areas. Similar increases were detected at the selection-cut site but were attributable to secondary road construction in the runoff area. In the shelterwood harvest area, where logging roads were not a factor, no measurable increases in sediment deposition were detected. There was little indication that harvesting activities at any site affected the organic fraction or the particle size distribution of fine sediments. The results of this study suggest that riparian buffer zones may not be necessary for selective harvesting in hardwood forests at up to 50% removal, at least in terms of reducing sediment inputs.

Kreutzweiser, D.P. and Capell, S.S. 2003. Benthic microbial utilization of differential dissolved organic matter sources in a forest headwater stream. Canadian Journal of Forest Research 33: 1444-1451.

Streamside mesocosm experiments were conducted in a low-order forest watershed to directly examine responses by microbial communities on standardized substrates to different terrestrial and aquatic sources of dissolved organic matter (DOM). Community respiration (oxygen uptake), microbial density (colony-forming units on agar plates), leaf decomposition, and community metabolic profiles (metabolism patterns in sole carbon source utilization assays) were measured. Stream benthic microbial communities responded immediately and positively to

increases in terrestrially derived DOM. Respiration activity and density estimates increased significantly, but there was no significant change in community metabolic profile. Responses were greater to DOM extracted from upper soil horizons than from deeper soils. Community respiration and bacterial abundance also increased in response to an aquatic DOM source, but were accompanied by a significant change in community metabolic profiles. Results provide direct experimental evidence that benthic microbial communities of forest headwater streams are able to rapidly utilize terrestrial DOM.

Kurashige, Yoshimasa and Allison, Robert J. editor. 2002. Sources of river-suspended sediment after selective logging in a headwater basin.: Applied geomorphology; theory and practice. International Association of Geomorphologists. Publication 10: pp. 183-195; John Wiley & Sons, Chichester, United Kingdom; 21 refs. United Kingdom.

Liljaniemi P, Vuori K.-M, Ilyashuk B, and Luotonen H. 2002. Habitat characteristics and macroinvertebrate assemblages in boreal forest streams Relations to catchment silvicultural activities. Hydrobiologia 474: 239-251.

We compared the stream habitat characteristics and macroinvertebrate assemblages of boreal headwater streams in both the Finnish and the Russian parts of a single river basin, the Koitajoki Riven Over the last 50 years, the Finnish side of the catchment has been managed using modern forestry techniques, whereas Russian side has remained nearly unexploited and is near to its natural state. Differences in silvicultural activities were observed to contribute to differences in habitat structure. The channel habitats were in fairly natural state in the Russian reference streams, whereas the impacted Finnish sites were cleared and straightened. In comparison with the impacted channels, the abundance of coarse woody debris (CWD) was 10-100-fold higher in the reference streams. Implications on the forestry-induced deterioration of water quality were also observed. On the contrary, only small differences in macroinvertebrate assemblages were detected. Despite the lower amount of retentive structures (CWD), significantly higher relative abundance of shredders was observed in the forestry-impacted streams. Otherwise the zoobenthic communities were quite similar in the two subcatchments. We suggest that several mechanisms may explain this similarity: (1) community structure is controlled by naturally acidic conditions, (2) the adverse impacts of forestry on habitat structure and water quality of streams may be compensated by increased input of deciduous litter and organic compounds from drained, structurally young riparian forests and (3) macroinvertebrate species have flexible feeding habits and may thus readily adapt to changing conditions.

Macdonald, J.S., Beaudry, P.G., MacIsaac, E.A., and Herunter, H.E. 2003. The effects of forest harvesting and best management practices on streamflow and suspended sediment concentrations during snowmelt in headwater streams in sub-boreal forests of British Columbia, Canada. Canadian Journal of Forest Research 33: 1397-1407.

This paper examines suspended sediment concentration and stream discharge during freshet in three small sub-boreal forest streams (<1.5 m in width) in the central interior of British Columbia

for 1 year prior to (1996) and for 5 years following forest harvesting (1997–2001). Harvesting prescriptions in a 20-m strip beside one stream required complete removal of merchantable timber (>15 cm diameter at breast height (DBH) for pine and >20 cm for spruce), while all stems <30 cm DBH were retained beside a second stream. A third stream remained unharvested as a control. The two riparian treatments were prescribed to test the efficacy of current British Columbia legislation that allows for varying amounts of riparian retention as best management practices for the management of windthrow. Both treated watersheds were clear-cut harvested (approximately 55% removal) in January 1997, and in the following year, temporary access roads were deactivated, including two stream crossings in the low-retention watershed. An increase in peak snowmelt and total freshet discharge was first noted in the second spring following harvest in both treatments and remained above predicted in all subsequent years. Suspended sediment also increased during freshet following harvest but returned to levels at or below preharvest predictions within 3 years or less in the high-retention watershed.

Macdonald, J.S., MacIsaac, E.A., and Herunter, H.E. 2003. The effect of variable-retention riparian buffer zones on water temperatures in small headwater streams in sub-boreal forest ecosystems of British Columbia. Canadian Journal of Forest Research 33: 1371-1382.

Stream temperature impacts resulting from forest harvesting in riparian areas have been documented in a number of locations in North America. As part of the Stuart–Takla Fisheries–Forestry Interaction Project, we have investigated the influence of three variable-retention riparian harvesting prescriptions on temperatures in first-order streams in the interior sub-boreal forests of northern British Columbia. Prescriptions were designed to represent a range of possible harvesting options outlined by the Forest Practices Code of B.C., or associated best management practice guidelines. Five years after the completion of harvesting treatments, temperatures remained four to six degrees warmer, and diurnal temperature variation remained higher than in the control streams regardless of treatment. Initially, the high-retention treatment acted to mitigate the temperature effects of the harvesting, but 3 successive years of windthrow was antecedent to reduced canopy density and equivalent temperature impacts. We speculate that late autumn reversals in the impacts of forest harvesting also occur. Temperature impacts in this study remained within the tolerance limits of local biota. However, even modest temperature changes could alter insect production, egg incubation, fish rearing, migration timing, and susceptibility to disease, and the effects of large changes to daily temperature range are not well understood.

May, C.L. and Gresswell, R.E. 2003. Large wood recruitment and redistribution in headwater streams in the southern Oregon Coast Range, U.S.A. Canadian Journal of Forest Research 33: 1352-1362.

Large wood recruitment and redistribution mechanisms were investigated in a 3.9 km2 basin with an old-growth *Pseudotsuga menziesii (Mirb.)* Franco and *Tsuga heterophylla (Raf.)* Sarg. forest, located in the southern Coast Range of Oregon. Stream size and topographic setting strongly influenced processes that delivered wood to the channel network. In small colluvial

channels draining steep hillslopes, processes associated with slope instability dominated large wood recruitment. In the larger alluvial channel, windthrow was the dominant recruitment process from the local riparian area. Consequently, colluvial channels received wood from further upslope than the alluvial channel. Input and redistribution processes influenced piece location relative to the direction of flow and thus, affected the functional role of wood. Wood recruited directly from local hillslopes and riparian areas was typically positioned adjacent to the channel or spanned its full width, and trapped sediment and wood in transport. In contrast, wood that had been fluvially redistributed was commonly located in mid-channel positions and was associated with scouring of the streambed and banks. Debris flows were a unique mechanism for creating large accumulations of wood in small streams that lacked the capacity for abundant fluvial transport of wood, and for transporting wood that was longer than the bank-full width of the channel.

McDonnell, J. J., McGlynn, B. L., Kendall, K., Shanley, J., and Kendall, C. 1998. The role of near-stream riparian zones in the hydrology of steep upland catchments. Kovar, K., Tappeiner, U., Peters, N. E., and Craig, R. G. eds. Hydrology. Water Resources and Ecology in Headwaters , 173-180.

Surface and subsurface waters were monitored and sampled at various topographic positions in a 40.5-ha headwater catchment to test several hypotheses of runoff generation and stream chemical and isotopic evolution during snowmelt. Transmissivity feedback was observed on the hillslopes during the melt period. Groundwater levels and stream DOC were highly correlated with stream discharge. Hysteresis in the groundwater-streamflow relation suggests that localized water flux from the riparian areas controlled the rising limb and main peak response of the melt hydrograph, whilst hillslope drainage controlled the timing and volume of the falling limb. Lateral flow from upslope positions was detected in the riparian zone.

Meehan, W.R., Swanson, F.J., and Sedell, J.R. 1977. Influences of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply. Pacific Northwest Forest and Range Experiment Station, Corvallis, OR. Forestry Sciences Lab. 137-145.

The riparian zone has important influences on the total stream ecosystem including the habitat of salmonids. Shade and organic detritus from the riparian zone control the food base of the stream and large woody debris influences channel morphology. The effectiveness of a riparian zone in regulating input of light, dissolved nutrients and litterfall to the stream varies through time following wildfire, clearcutting or other disturbances. The influence and role of riparian vegetation will vary with stream order and position along the continuum from headwaters to mouth. Riparian zones are affected by livestock grazing, logging, and road construction.

Mellina E, Pearson G, Moore R.D, Hinch S.G, and Macdonald J.S. 2002. Stream temperature responses to clearcut logging in British Columbia The moderating influences of groundwater and headwater lakes. Canadian Journal of Fisheries and Aquatic Sciences 59: 1886-1900.*

Although the future timber supply in the northern hemisphere is expected to come from boreal and subboreal forests, little research has been conducted in these regions that examines the temperature responses of small, lake-headed streams to streamside timber harvesting. We examined the temperature patterns of two subboreal outlet streams in north-central British Columbia for 1 year before and 3 years after clearcut logging and found only modest changes (averaging 0.05–1.1°C) with respect to summer daily maximum and minimum temperatures, diurnal fluctuations, and stream cooling. A multistream comparative survey conducted in the same geographic region revealed that streams headed by small lakes or swamps tended to cool as they flowed downstream, and headwater streams warmed, regardless of whether or not timber harvesting took place. Stream cooling was attributed to a combination of warm outlet temperatures (promoted by the presence of the lakes) and cold groundwater inflows. A regression model revealed that summertime downstream warming or cooling in headwater and outlet streams could be predicted by upstream maximum summer temperatures and canopy cover. Lentic water bodies and groundwater inflows are important determinants of stream temperature patterns in subboreal forests and may subsequently moderate their responses to streamside harvesting.

Moore, R.D. and Richardson, J.S. 2003. Progress towards understanding the structure, function, and ecological significance of small stream channels and their riparian zones. Canadian Journal of Forest Research 33: 1349-1351.

Incomplete knowledge of the ecological functions of small streams and their riparian zones, particularly their roles in larger watershed and landscape contexts, contributes to confusion and debate about the levels of riparian vegetation retention required along small streams for the purpose of protecting aquatic ecosystems, riparian wildlife, and water quality. As a consequence, there are marked differences in riparian forestry practices and management among jurisdictions throughout North America. To aid in resolving these issues, a symposium on small streams and their riparian zones was held at The University of British Columbia from 19 to 21 February 2002, which brought together scientists, managers, and practitioners and provided a forum for the presentation and discussion of emerging research results. This special issue includes a selection of papers presented at that symposium as well as one solicited paper.

Moring, J.R. 1975. Alsea Watershed Study.: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part II – Changes in the environmental conditions. Oregon Department of Fish and Wildlife

Three small tributaries of the Alsea River, Oregon, were monitored during a 15 year study 1959-1973. One watershed (Needle Branch) was clearcut without buffer strips. The second (Deer Creek) was clearcut in patches with buffer strips. The third (Flynn Creek) was unlogged, and

served as a control. This portion covers the environmental results of the study, and outlines those components that were altered as a result of logging activities (road construction, yarding, felling). Water temperature maxima and ranges were significantly increased in Needle Branch by removal of riparian, protective vegetation during clearcutting. Maximum temperatures reached 26.1 degrees C near the mouth, and 29.5 degrees C at a point upstream in summer 1967. Temperatures increased 12.7 degrees C over the pre-logging average in June, and a 15.6 degree C maximum diurnal fluctuation was measured in 1967. Surface dissolved oxygen levels dropped to 2.5 mg/liter in the summer of logging, and intragravel levels decreased to a mean of 1.3 mg/liter the same summer. There was a pronounced decrease in intragravel dissolved oxygen during the first winter when salmonid eggs were developing in the gravel. Mean monthly streamflow increased by 26.9 percent in Needle Branch after logging. There was a 205.3 percent increase in suspended sediments in Needle Branch and a 53.5 percent increase in Deer Creek following road construction. Permeability of the gravel in Needle Branch was depressed from logging, and remained so during the post-logging years.

Moring, J.R. and Lantz, R.L. 1975. Alsea Watershed Study.: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part I – Biological Studies. Oregon Department of Fish and Wildlife

Three small tributaries of Drift Creek, tributary to the Alsea River, Oregon, were monitored during a 15-yr logging study 1959-1973. One watershed (Needle Branch) was clearcut without buffer strips. A second (Deer Creek) was clearcut in patches with buffer strips and the third (Flynn Creek) was unlogged, and served as a control. This report covers the biological results of the study, and outlines those components that were altered as a result of logging activities (road construction, yarding, felling). Cutthroat trout populations were severely depressed after logging in Needle Branch, and remained low during the eight-year post-logging period. The timing of downstream migration of cutthroat juveniles in the stream was altered for two years after debris clearance and slash burning in Needle Branch. Coho salmon were less affected by logging, but average lengths and weights and condition factors were low in juveniles in Needle Branch the summer after logging. Those fish that were fry and fingerlings in Needle Branch at the time of logging had lower fecundities when they returned as adults. Coho biomass and net production rates increased in the streams of the two logged watersheds following logging. The two youngest year classes of reticulate sculpins were almost completely destroyed by logging in Needle Branch and there was a decline in numbers of adult western brook lampreys in Needle Branch in post logging years. Additional biological data on fish populations are presented.

Mosley, M.P. 1980. The impact of forest road erosion in the Dart Valley, Nelson. New Zealand Journal of Forestry 25: 184-198.

A survey of erosion on a road system constructed in granitic terrain in Nelson for production forest development has been carried out. Rates of sediment input into the stream system in 1978-9 averaged 255 m3/km/y over the 25km road system, with a range from 14 m3/km/y for a 10 year old valley bottom road to 1270 m3/km/y for a 1 year old midslope road which had suffered a number of large culvert or fill slope failures. Total rates of erosion on the road systems were

three times greater, but much sediment is fed onto vegetated slopes beneath the roads, and stored there. Total sediment input into the stream system in 1978-9 was estimated as 12 000 t/y, in comparison with an estimated natural sediment yield from the catchment of 9600 t/y. Much of the sediment has been stored in headwater channels (which are, however, probably subject to periodic flushing by major storm events), deposited upon point bars above the low flow water level in the main river, or flushed out to sea in suspension. The impact of the road-derived sediment upon the Dart River is, therefore, probably limited.-Author.

Naiman, R.J., Bilby, R.E., and Bisson, P. 2000. Riparian ecology and management in the Pacific coastal rain forest. BioScience 50: 996-1011.*

The research effort focused on understanding the dynamics and managerial uses of riparian zones. “Riparius,” a Latin word meaning “belonging to the bank of a river,” refers to biotic communities living on the shores of streams, rivers, ponds, lakes, and some wetlands. Riparian zones strongly influence the organization, diversity, and dynamics of communities associated with aquatic ecosystems (Gregory et al. 1991, Décamps 1996). Riparian areas possess distinct ecological characteristics because of their interaction with the aquatic system. Thus, their boundaries can be delineated by changes in soil conditions, vegetation, and other factors that reflect this aquatic–terrestrial interaction (Naiman and Décamps 1990, 1997). Riparian zones vary widely in their physical characteristics, which are vividly expressed by an array of life history strategies and successional patterns. Consequently, these areas are among the biosphere’s most complex ecological systems and also among the most important for maintaining the vitality of the landscape and its rivers (Naiman and Décamps 1990, 1997). The variability of natural riparian zones reflects the inherent physical heterogeneity of the drainage network, the processes shaping stream channels, and the characteristics of the biotic community (Figure 1). In effect, riparian biota are the products of past and present interactions among biophysical factors. In turn, the biota themselves have strong, long-term influences on the geological structures and processes that shape them. The riparian forests of the Pacific Coastal Ecoregion (PCE) of North America are floristically and structurally its most diverse vegetation (Pollock 1998, Pollock et al. 1998), and their maintenance has become an integral component of watershed management strategies (Naiman and Bilby 1998). Since 1990, significant advances in understanding the structure and dynamics of riparian zones in the PCE have led to their being recognized as key components of land and water management. Many of the region’s management guidelines are based on these recent scientific advances as well as on the strong foundation of knowledge built by S.V. Gregory and his colleagues (Gregory et al. 1991). In this article, we summarize the scientific advances of the last decade in understanding the ecology of PCE riparian zones and show how this understanding directly contributes to better stream and watershed management.

Olson, D.H., Chan, S.S., and Thompson, C.R. 2002. Riparian buffers and thinning designs in western Oregon headwaters accomplish multiple resource objectives. General Technical Reports of the US Department of Agriculture, Forest Service GTR-563: 81-92.*

We are investigating headwater riparian and upland forest management to achieve multiple resource objectives, primarily accelerated development of old-growth habitat and rare species

management. For stands 40 to 50 yrs old, a control and three density management treatments are under study. Treatments include a mosaic of leave- and clearcut-islands within a matrix of thinning to various densities. Within this template, four no-entry riparian buffer zones also are under investigation. Companion studies utilize these two templates for biota and/or habitat characterizations; in particular, we are examining amphibians, mollusks, fishes, microclimate, and microsite. The balance of resource objectives was apparent during study implementation. For example, >100 species were evaluated by federal field units at the stand scale across 13 study sites, and many became conflicts to study implementation. The common methods of conflict resolution involved leaving unthinned areas, such as the study design elements of various sizes of riparian buffers and unthinned leave islands. The mosaic of stand-scale conditions resulting from such designs effectively addresses sustainability. This is a cooperative study between the U.S. Department of Interior, Bureau of Land Management, and the U.S. Department of Agriculture, Forest Service, with companion projects conducted by Oregon State University and U.S. Geological Survey partners.

Olson, D.H., Weaver, G.W., Ellenburg, L.L., Hansen, B., and Thompson, R. 2000. Stream vertebrates in managed headwater streams: habitat associations of assemblages and species. Northwestern Naturalist 81: 84-85.

A greater understanding of the ecology of headwater stream vertebrates in managed forest stands is needed for the refinement of forestry practices that manage for multiple resources, including species, habitats and socio-economic values. Pretreatment sampling for our Riparian Buffer Study in western Oregon has revealed distinct amphibian and fish assemblages corresponding to instream habitat gradients in headwaters. Habitat and faunal data were collected across 13 study basins and >140 headwater stream reaches; over 4,000 animals of 15 taxa have been sampled. Canonical correlations were calculated separately for instream species-assemblages, instream and bank fauna, and bank amphibians. Results identified several distinct species-assemblages, each with ranked habitat correlates. Assemblage patterns were more related to hydrological, topographic, and geomorphic habitat attributes (e.g. channel flow type and size, gradient) than fine scale microhabitat features (e.g. downed wood, substrate size). Generalized linear models (Poisson and logistic regression) of individual species-habitat relations were generated for seven taxa (trout spp., cottid spp., *Dicamptodon tenebrosus, Rhyacotriton variegatus, R. cascadae, Plethodon dunni, Ascaphus truei,* and *Taricha granulosa*). Results correspond to assemblage-associations. Our study shows the relatively restricted use of the uppermost nonfish-bearing stream channel by a unique amphibian assemblage dominated by torrent salamander species, currently a species of concern in the region. Our Riparian Buffer Study treatments are designed to advance the development of management approaches that have a high likelihood of persistence of such sensitive species within managed wetlands.

Paradise, C., Gage, M., and Spivak, A. 2002. Effects of land use on insect communities in headwater streams north of Charlotte, NC. Program of the 63rd Annual Meeting of the Association of Southeastern Biologists. 49(2), 174-175.

Increased development north of Charlotte, NC threatens habitat quality for aquatic life in streams by decreasing riparian buffers near streams and increasing the amount of runoff into streams. Sedimentation from erosion and poor construction practices is a principal source of stream pollution in developing areas. Our research focused on the relationship between benthic insects and stream condition as affected by surrounding land use. Because different insect families can tolerate varying levels of pollution, we were able to use the insects as indicators of stream and watershed health. We visited ten streams periodically from May 2001 to present, collected insect samples, conducted water chemistry tests, and assessed the physical habitat of the stream and its immediate surroundings. We used a Geographic Information System (GIS), aerial photographs, and digitized topographic maps to determine watershed boundaries and land use patterns within each watershed. The watersheds were categorized as undisturbed or disturbed based on land use and chemical and physical variables of the stream. Insect communities were consistently more diverse and abundant in streams draining undisturbed watersheds than in streams draining disturbed watersheds. Of all benthic samples taken at disturbed streams, only one stonefly of the family Perlidae was found. Stoneflies have a low tolerance to pollution, and they were found regularly in streams with undisturbed watersheds. These results imply a decrease in aquatic habitat quality in human-impacted watersheds and also suggest a need to protect those streams yet unaffected by development by imposing stricter riparian buffer regulations and erosion control practices.

Piccolo, J.J. and Wipfli, M.S. 2002. Does red alder *(Alnus rubra)* in upland riparian forests elevate macroinvertebrate and detritus export from headwater streams to downstream habitats in southeastern Alaska? Canadian Journal of Fisheries and Aquatic Sciences 59: 503-513.*

We assessed the influence of riparian forest canopy type on macroinvertebrate and detritus export from headwater streams to downstream habitats in the Tongass National Forest, southeastern Alaska. Twenty-four fishless headwater streams were sampled monthly, from April to August 1998, across four riparian canopy types: old growth, clearcut, young-growth alder, and young-growth conifer. Young-growth alder sites exported significantly greater count (mean = 9.4 individuals·m-3 water, standard error (SE) = 3.7) and biomass (mean = 3.1 mg dry mass·m-3 water, SE = 1.2) densities of macroinvertebrates than did young-growth conifer sites (mean = 2.7 individuals·m-3 water, SE = 0.4, and mean = 1.0 mg dry mass·m-3 water, SE = 0.2), enough prey to support up to four times more fish biomass if downstream habitat is suitable. We detected no significant differences in macroinvertebrate export between other canopy types or in detritus export among different canopy types. Roughly 70% of the invertebrates were aquatic; the rest were terrestrial or could not be identified. Although we do not recommend clearcutting as a means of generating red alder, maintaining an alder component in previously harvested stands may offset other potentially negative effects of timber harvest (such as sedimentation and loss of coarse woody debris) on downstream, salmonid-bearing food webs.

Price, K., Suski, A., McGarvie, J., Beasley, B., and Richardson, J.S. 2003. Communities of aquatic insects of old-growth and clearcut coastal headwater streams of varying flow persistence. Canadian Journal of Forest Research 33: 1416-1432.

Headwater streams, varying in flow persistence from ephemeral to intermittent to perennial, provide the tightest coupling between water and land, yet they often receive the least protection during forest management. We described communities of aquatic insects in perennial, intermittent, and ephemeral channels surrounded by old-growth forest and 4- to 8-year-old clearcuts in Clayoquot Sound, British Columbia, to determine whether temporary streams have unique aquatic communities and to examine the short-term impacts of harvesting. We measured flow persistence, stream size, canopy cover, organic detritus, and algal biomass in 19 streams. We sampled aquatic invertebrates with a combination of emergence cages and kicknet samples. Temporary and old-growth streams had more organic detritus and a higher abundance of shredders. Perennial and clearcut streams had a higher abundance of some algal grazers, but not higher algal biomass. Insect richness was similar in intermittent and perennial streams of each seral stage but lower in ephemeral streams. Intermittent streams contained four taxa not found in the other stream classes; perennial and ephemeral streams had none. Communities of aquatic insects differed between streams surrounded by clearcuts and old growth, and varied with continuity of flow.

Raphael, M. G., Bisson, P. A., Jones, L. L. C., and Foster, A. D. 2002. Effects of streamside forest management on the composition and abundance of stream and riparian fauna of the Olympic Peninsula. US Department of Agriculture, Forest Service No. GTR-563.*

We conducted a retrospective study of the influence of timber harvest on vertebrate assemblages in and adjacent to small streams on the Olympic Peninsula, Washington, 1996 to 1999. Sixty-two sites were selected, with adjacent sites representing old-growth conditions and five site conditions resulting from silvicultural treatments: young, mature, thinned mature, buffered old, and buffered mature sites. To determine site-level patterns of species composition and structure, we developed an integrated sampling design targeting specific vertebrate taxa along and perpendicular to the axis of the stream. We also characterized the vegetation and habitat characteristics of streams and streamside buffers. Instream and near-stream amphibians were the best indicators of stream and streamside habitat condition, probably because of their low mobility, tendency to reside in or return to specific locations, lengthy larval period, ability to populate beyond obstacles to movement, and narrow limits of environmental tolerance. Small buffers contributed to site structural diversity, but fish communities were highly variable and not strongly related to buffer width. Effects of forest management on headwater stream and riparian-associated vertebrates were often difficult to assess, probably because other factors such as local geomorphic features, weather patterns, long-term disturbance histories, and characteristics of surrounding landscapes obscured these patterns.

Richardson, J. S. 2000. Life beyond salmon streams: communities of headwaters and their role in drainage networks. L.M. Darling. Proceedings on Biology and Management of Species and Habitats at Risk, Kamloops BC, 15 - 19 Feb., 1999. Volume Two. Victoria, BC Canada, BC Ministry of the Environment, Land and Parks.*

The headwaters of our watersheds are important for a number of intrinsic reasons, as well as for their impact on maintenance of downstream environments. The emphasis of research and management in stream ecosystems has typically been on salmonid fish, to the neglect of other stream and riparian organisms. Headwaters are sources of a large proportion of the energy used to fuel river food webs via organic matter that enters headwaters in the form of leaf litter from riparian vegetation. Headwaters themselves harbor a number of poorly known species, some of which occur nowhere else. There are many species associated with these environments, especially invertebrates, for which we lack even the most basic of information. Finally, the cumulative effects of small, incremental alterations to headwater channels may have impacts on downstream environments, but we have yet to design studies that adequately address this issue.

Sauter, K.F. 1994. Explaining variation in Western Washington riparian management zone width on state and private lands. M.S. thesis, University of Washington, Seattle, Seattle, Washington.

The past ten years have seen a tremendous shift toward riparian management among land managers. In Washington state, forest managers watched riparian regulations spring to life in 1976 and continue to gain in prominence and complexity. These regulations have been implemented on a tapestry widely varied in the physical land forms they encompass, the landowners and managers who follow them, and these people's scientific literacy and attitudes toward the regulations. Given the complexity of both the regulations and the regulated, assessing the effectiveness of the regulations is a complicated job. However, before their effectiveness can be determined, it will be necessary to find out how the regulations are being followed, to what extent people are complying with the regulations and why, and where gaps in riparian literacy, if any, exist. This study begins this process of discovery by searching for explanations for some of the variation seen in riparian management zones. Riparian management zones (RMZs) are strips of standing forest left along streams to buffer them and their inhabitants from the effects of clearcutting and other timber harvesting practices. In their current form, western Washington RMZs have been required only since 1988. Between 1976 and 1988 the Washington Forest Practice(s) Rules and Regulations required "streamside management zones" which were intended to provide "stream bank integrity and temperature control" (Washington Forest Practices Board, 1976 and 1982). In order to accomplish this intent, regulations required 25-50 foot buffers, leaving "all nonmerchantable vegetation" and "sufficient merchantable timber, if any, necessary to retain 50 [to] 75 percent of the summer mid-day shade of the water surface" (Washington Forest Practices Board 1976). In 1988 the RMZ regulations were strengthened considerably, requiring up to 100 foot buffers (Washington Forest Practices Board, 1988). The change in regulations was a result of the Timber/Fish/Wildlife (TFW) Agreement reached in 1987 among representatives of the Washington state tribes, forest products industry, environment community and natural resource agencies. The agreement sought to resolve conflicts between these diverse groups by recognizing the common goal of preservation of natural resources and at the same

time the need for a viable timber industry. As the final report of the agreement states, "these needs are not mutually exclusive. They are compatible" (TFW Agreement 1987).

Sharpe, W.E. 1975. Timber management influences on aquatic ecosystems and recommendations for future research. Water Resources Bulletin 11: 546-550.

Recent watershed research indicates that many timber management practices have profound effects on the water quality of small headwater streams. These streams often support fisheries of high value. Current knowledge seems to indicate that a definite potential exists for a symbiotic relationship between timber and fisheries management. Maximum development of both resources is attainable only if further research efforts recognize the mutually benefiting aspects of these heretofore separate disciplines . Future research should carefully examine the complex interrelationships between small headwater aquatic ecosystems and the riparian forest environment.

Sidle, R.C., Fujieda, M., Shimizu, T., Tsuboyama, Y., Noguchi, S., and Hosoda, I. 2000. Stormflow generation in steep forested headwaters: A linked hydrogeomorphic paradigm. Hydrological Processes 14: 369-385.

Headwater catchments are sources of sediments, nutrients, and biota for larger streams, yet the hydrologic pathways that transport these materials remain unclear. Dynamics of stormflow generation related to landform attributes and antecedent rainfall were investigated in a steep forested headwater catchment at Hitachi Ohta Experimental Watershed, Japan. Such headwater catchments are deeply incised: the narrow riparian corridors have limited capacities to store and transmit water to streams. Storm runoff was monitored at several nested scales within the catchment: (1) 2·48 ha first-order drainage (FB); (2) incipient 0.84 ha first-order drainage (FA) comprised of two zero-order basins; (3) 0·25 ha zero-order basin (ZB); and (4) 45 m2 hillslope segment (HS), including subsurface matrix flow (MF) and preferential flow (PF). Results from applied tracer and staining tests as well as observations of piezometric, tensiometric, and subsurface temperature responses were also employed to elucidate hydrologic pathways during storms. During the driest conditions, water yield from FB was only 1%; runoff occurred as saturated overland flow from the small riparian zone and direct channel interception. For slightly wetter conditions, subsurface flow from the soil matrix augmented stormflow. As wetness increased, two significant non-linear hydrologic responses occurred: (1) threshold response in geomorphic hollows (zero-order basins) where runoff initiated after an accumulation of shallow groundwater; and (2) self-organization and expansion of preferential flow pathways, which facilitate subsurface drainage. Stormflow increases observed during periods of increasing antecedent wetness depend upon temporal and spatial linkages and the unique hydrologic behavior of three components: (1) narrow riparian corridors; (2) linear hillslopes; and (3) geomorphic hollows. These linkages form the basis for an emerging hydrogeomorphic concept of stormflow generation for steep forested headwaters. Knowledge of stormflow response is critical to the assessment of management practices in these headwater areas as well as the routing of water and materials to larger stream systems. Copyright (C) 2000 John Wiley and Sons, Ltd.

Smidt, S. and Oswood, M.W. 2002. Landscape patterns and stream reaches in the Alaskan taiga forest: Potential roles of permafrost in differentiating macroinvertebrate communities. Hydrobiologia 468: 95-105.

We investigated spatial variability in the community structure of stream macroinvertebrates at six reaches within Caribou-Poker Creeks Research Watershed in the Alaskan taiga forest. Stream reaches differed most notably in river continuum position (stream orders 1-4) and influence of permafrost. Permafrost may underlie much of an entire watershed or may be only locally present in valley bottoms. Permafrost distribution influences hydrology, water temperature, and riparian vegetation. We sampled benthic macroinvertebrates six times during the ice-free season between June 1995 and June 1996. Mean invertebrate abundance (range: 1,160-14,494 individuals • m-2) was significantly different among sites, the lower values occurring in stream reaches affected by the local presence of permafrost and the highest value in a headwater stream unaffected by permafrost. Taxonomic composition of the macroinvertebrate community also differed among reaches, with the quantity of watershed-level permafrost and stream size providing the strongest influences. This research highlights the importance of permafrost at two spatial scales (watershed and reach) for macroinvertebrate communities of headwater streams at high latitudes.

Sponseller, R.A., Benfield, E.F., and Valett, H.M. 2001. Relationships between land use, spatial scale and stream macroinvertebrate communities. Freshwater Biology 46: 1409-1424.*

1. The structure of lotic macroinvertebrate communities may be strongly influenced by land-use practices within catchments. However, the relative magnitude of influence on the benthos may depend upon the spatial arrangement of different land uses in the catchment.
2. We examined the influence of land-cover patterns on in-stream physico-chemical features and macroinvertebrate assemblages in nine southern Appalachian headwater basins characterized by a mixture of land-use practices. Using a geographical information system (GIS)/remote sensing approach, we quantified land-cover at five spatial scales; the entire catchment, the riparian corridor, and three riparian 'sub-corridors' extending 200, 1000 and 2000 m upstream of sampling reaches.
3. Stream water chemistry was generally related to features at the catchment scale. Conversely, stream temperature and substratum characteristics were strongly influenced by land-cover patterns at the riparian corridor and sub-corridor scales.
4. Macroinvertebrate assemblage structure was quantified using the slope of rank-abundance plots, and further described using diversity and evenness indices. Taxon richness ranged from 24 to 54 among sites, and the analysis of rank-abundance curves defined three distinct groups with high, medium and low diversity. In general, other macroinvertebrate indices were in accord with rank-abundance groups, with richness and evenness decreasing among sites with maximum stream temperature.
5. Macroinvertebrate indices were most closely related to land-cover patterns evaluated at the 200 m sub-corridor scale, suggesting that local, streamside development effectively alters assemblage structure.6. Results suggest that differences in macroinvertebrate assemblage structure can be explained by land-cover patterns when appropriate spatial scales are employed.

In addition, the influence of riparian forest patches on in-stream habitat features (e.g. the thermal regime) may be critical to the distribution of many taxa in headwater streams draining catchments with mixed land-use practices.

Steedman, R.J. 2000. Effects of experimental clearcut logging on water quality in three small boreal forest lake trout *(Salvelinus namaycush)* lakes. Canadian Journal of Fisheries and Aquatic Sciences 57: 92-96.*

Water quality was monitored in three 30-ha stratified headwater Precambrian Shield lakes for 5 years before and 3 years after moderate to extensive catchment deforestation. These lakes, which had water renewal times of about a decade, showed only minor changes in water quality by the third year after logging. Water quality response in a lake with moderate deforestation and intact shoreline forest was similar to that in two lakes with extensive upland and shoreline deforestation. By the second and third years after logging, May-September average volume-weighted concentrations of dissolved organic carbon, chlorophyll, total nitrogen, K+, Cl-, and Si had all increased, generally by about 10-40% over predisturbance levels, while Ca2+ and Mg2+ had declined by 10-25%. Dry weather the first year after logging was associated with temporary declines of 10-20% in dissolved organic carbon and chlorophyll.

Steedman, R.J. 2003. Littoral fish response to experimental logging around small boreal shield lakes. North American Journal of Fisheries Management 23: 392-403.*

Littoral minnow trap catch in three small (26-39-ha), dimictic, oligotrophic headwater lakes in northwestern Ontario, Canada, was monitored for years before and after moderate to extensive watershed and shoreline clear-cutting. An abundant and diverse littoral fish community, dominated by Cyprinidae, persisted in the study lakes 5 years after logging, suggesting that logging impacts were small, compensatory, or delayed. The species richness of the catch among lakes ranged from 6 to 10 species and was constant within lakes. Although catch and average fish size varied significantly over the 10-year study, changes were not clearly linked with logging impacts. In the postlogging period, total catch was 17% less in the moderately disturbed lake (45% of watershed logged, with shoreline buffer strips) and 2-27% less in the two intensively disturbed lakes (75% of watershed and 60% of shoreline logged) than in the prelogging period. However, total catch began to decline 1-2 years before the experimental logging treatments in all cases. A similar pattern of reduced catch was evident for most of the abundant littoral fish species individually, although each lake had at least one relatively uncommon species that increased in abundance during the postlogging period. Average fish size in the moderately disturbed lake was 1-7% smaller in the postlogging period. In the extensively disturbed lakes, average size of the most abundant species increased by 1%; other species showed various responses, ranging from an 11% increase to an 11% decrease. Removal of approximately 23,000 fish from two of the lakes in the last year of the study did not produce an immediate reduction in total catch.

Story, A.R., Moore, D., and Macdonald, J.S. 2003. Stream temperatures in two shaded reaches below cutblocks and logging roads: downstream cooling linked to subsurface hydrology. Canadian Journal of Forest Research 33: 1383-1396.

This study examined water temperature patterns and their physical controls for two small, clearing-heated streams in shaded reaches downstream of all forestry activity. Field observations were made during July–August 2000 in the central interior of British Columbia, Canada. For both reaches, downstream cooling of up to 4°C had been observed during daytime over distances of ~200 m. Radiative and convective exchanges of energy at heavily shaded sites on both reaches represented a net input of heat during most afternoons and therefore could not explain the observed cooling. In one stream, the greatest downstream cooling occurred when streamflow at the upstream site dropped below about 5 L·s-1. At those times, temperatures at the downstream site were controlled mainly by local inflow of groundwater, because the warmer water from upstream was lost by infiltration in the upper 150 m of the reach. Warming often occurred in the upper subreach, where cool groundwater did not interact with the channel. At the second stream, creek temperature patterns were comparatively stable. Energy balance estimates from one afternoon suggested that groundwater inflow caused about 40% of the ~3°C gross cooling effect in the daily maximum temperature, whereas bed heat conduction and hyporheic exchange caused about 60%.

Sutherland, G.D. 2002. Risk assessment for conservation under ecological uncertainty: A case study with a stream-dwelling amphibian in managed forests. Ph.D. thesis, University of British Columbia.

Quantifying risks of forest and habitat management options are often limited by uncertainties in habitat associations, life history and population trends for resident species. Using the tailed frog *Ascaphus truei*, a headwater stream-dependent amphibian, I: (1) developed hierarchical models of habitat relationships across this species' range in British Columbia; (2) examined plausible life history responses to habitat change, and (3) investigated population persistence outcomes within and among streams to uncertain effects of forest harvesting and disturbance scenarios. To develop habitat association relationships I used classification and regression trees (CART) together with simple and partial Mantel tests. Variables describing biophysical setting at meso- and micro-scales had a greater influence on occurrence and abundance of larval frogs than did adjacent forest practices, possibly because most sampling sites were in disturbed watersheds. Underlying geology was a consistently important determinant of occurrence patterns, with fine-scale stream structure more important in determining abundance. Using life stage-based population matrix models, I explored consequences of different life history strategies and ranges of habitat productivity and environmental variation on population persistence. Persistence is decreasingly sensitive to changes in growth rates, tadpole and adult survival, and fecundity. Populations also appear more sensitive to changes in survivorship of in-stream stages (eggs, hatchlings and tadpoles) than riparian stages (juveniles/adults). Clinal, elevational, and local reductions in habitat productivity (e.g., shorter growing seasons, reduced light penetration in mid-seral forests) appear as dominant factors mediating how local fluctuations in demographic rates determine risks of loss of small populations, even if environmental variation is relatively low. Using a spatially explicit metapopulation-landscape dynamics model, I explored six

plausible hypotheses linking habitat alterations to population dynamics in response to forest harvesting and disturbances. Risks to populations from disturbance depend strongly on assumptions about age at first reproduction. Incremental effects of forest harvesting on risks were small compared with those already incurred through stochastic events (floods, debris flows, climatic variation) or state of the landscape. Once extirpated, population recovery through dispersal appears unlikely. However, key uncertainties about the impacts of harvesting and forest succession on demographic rates render evaluation of alternative riparian protection systems difficult with present knowledge.

Swee May, T., Franklin, J.F., and Montgomery, D.R. 1997. Forest harvest patterns and landscape disturbance processes. Landscape Ecology 12: 349-363.

A physically-based model of the topographic influence on debris flow initiation and a rule-based model for wind damage were used to assess the influence of forest clearcutting patterns (i.e., location, size, shape and distribution of cut units) on the potential for landscape disturbance by these processes in Charley Creek watershed, Washington State, USA. Simulated clearcutting patterns consisted of 7, 9 or 26 ha square or rectangular harvest units distributed in either an aggregated or dispersed pattern under three stream-buffering scenarios. The slope-stability model predicted that potentially unstable ground is concentrated along steep headwater streams and inner-gorge side-slopes. Areas susceptible to wind damage were determined from the combination of slope, aspect, elevation, soil drainage and primary tree species. Among the variables examined here, the location of harvest units constitutes the most important factor influencing the potential for shallow landsliding. In contrast, the location, size, and shape of clearcuts and the interactions among these three factors significantly influenced the potential for wind damage. Minimal correspondence between areas predicted to be potentially unstable and areas susceptible to wind damage implies that harvest patterns designed to mitigate the potential for shallow landsliding may not necessarily reduce the potential for wind damage. Our results demonstrate that: (1) the location of timber harvesting is more important than the geometry of harvest activity in influencing shallow landsliding; (2) forest harvest patterns strongly influence the potential for disturbance processes; and (3) a single cutting pattern will often fail to meet all landscape management goals.

Toledo, Z.O. and Kauffman, J.B. 2001. Root biomass in relation to channel morphology of headwater streams. Journal of the American Water Resources Association 37: 1653-1663.

Intact riparian zones are the product of an incredibly complex multitude of linkages between the geomorphic, hydrologic, and biotic features of the ecosystem. Land-use activities that sever or alter these linkages result in ecosystem degradation. We examined the relationship between riparian vegetation and channel morphology by sampling species composition and herbaceous root biomass in incised (down-cut and widened) versus unincised (intact) sections of unconstrained reaches in three headwater streams in northeastern Oregon. Incision resulted in a compositional shift from wetland-obligate plant species to those adapted to drier environments. Root biomass was approximately two times greater in unincised sections than incised sections and decreased with depth more rapidly in incised sections than in unincised sections. Total root

biomass ranged from 2,153 g•m-2 to 4,759 g•m-2 in unincised sections and from 1,107 g•m-2 to 2,215 g•m-2 in incised sections. In unincised sections less than 50 percent of the total root biomass was found in the top 10 cm, with approximately 20 percent in successive 10-cm depth increments. In contrast, incised sections had greater than 60 percent of the total root biomass in the top 10 cm, approximately 15 percent in the 10 to 20 cm depth, less than 15 percent in the 20 to 30 cm depth, and less than 10 percent in the 30 to 40 cm depth. This distribution of root biomass suggests a positive feedback between vegetation and channel incision: as incision progresses, there is a loss of hydrologic connectivity, which causes a shift to a drier vegetation assemblage and decreased root structure, resulting in a reduced erosive resistance capacity in the lower zone of the streambank, thereby allowing further incision and widening.

Trayler, K.M. and Davis, J.A. 1998. Forestry impacts and the vertical distribution of stream invertebrates in south-western Australia. Freshwater Biology 40: 331-342.*

1. Vertical distributions of invertebrates (> 53 □m) were compared between two logged and two undisturbed headwater streams in south-western Australia. The abundance and composition of invertebrates from core samples (4 cm diameter, 30 cm depth) were determined at intervals of 0-1 cm, 1-5 cm, 5-15 cm and 15-30 cm.
2. In addition to examining the effects of clearfell logging, this study provides the first description of the interstitial communities of Australian sandy streams. The interstitial fauna of the undisturbed streams were concentrated in the upper 5 cm of the bed and were numerically dominated by nematodes, a characteristic more typical of marine and lentic habitats than lotic systems.
3. The invertebrate community structure was substantially altered in the logged streams, with fewer taxa collected than in undisturbed streams. Invertebrate densities in the logged and undisturbed streams did not differ in the upper 5 cm of the bed, but, below this, densities were significantly lower in the logged streams. Increased sedimentation did not appear to be responsible for the differences in community structure between logged and undisturbed streams.
4. The impact of clearfell logging to the extent shown here has not previously been demonstrated in south-western Australia. As a consequence it is strongly recommended that sampling of the benthic meiofauna is included in future biomonitoring protocols for the sandy streams of this region.

Wilkins, R.N. and Peterson, N.P. 2000. Factors related to amphibian occurrence and abundance in headwater streams draining second-growth Douglas-fir forests in southwestern Washington. Forest Ecology and Management 139: 79-91.

Forested headwaters of the US Pacific Northwest are an important habitat resource for a varied amphibian fauna. Factors related to occupancy and relative abundance for many of these species are poorly known, adding uncertainty to conservation decisions in managed forestlands. We sampled occurrence and abundance of amphibians in 40 perennial headwater streams traversing 50-65-year-old second-growth forests in the coast range of southwestern Washington. Streams were divided among basalt (n=18) and marine sediment (n=22) lithologies. Our samples resulted in collections of 1141 amphibians of six taxa - three stream-breeders and three woodland

salamanders. Stream-breeding taxa included larval and neotenic giant salamanders *(Dicamptodon spp.)*, Columbia torrent salamanders *(Rhyacotriton kezeri)* and larval tailed frogs *(Ascaphus truei)*. Pacific giant salamanders *(D. tenebrosus)* and/or Cope's giant salamanders *(D. copei)* occupied 95% of sampled streams, accounting for 57% of total amphibians collected. Streams traversing basalt lithology had almost twice the giant salamander abundance of marine sediment streams. Adjusting for lithology, giant salamanders increased in abundance with increasing pool frequencies in combination with increasing large woody debris (LWD) accumulations in adjacent riparian areas, and decreased with increasing accumulations of large (>60 cm diameter) woody debris in the channel. Torrent salamanders occupied 53% of sampled streams. The likelihood of habitat occupancy by torrent salamanders increased as channel gradient increased and basin area decreased. When adjusted for basin area, torrent salamander abundance increased as the proportion of the active channel with flowing water decreased, and at more northerly aspects. Larval tailed frogs larva were found in 13% of sampled streams, exclusively occupying basalt streams at elevations >300 m. At least one of the three species of woodland salamanders *(Plethodon spp.)* occupied habitats adjacent to 93% of sampled streams. Western red-backed salamanders *(P. vehiculum)* were most ubiquitous, occupying habitats adjacent to 85% of sampled streams. Dunn's salamanders *(P. dunni)* occupied habitats adjacent to 58% of sampled streams, likelihood of occurrence increasing with increasing gradient of the steepest sideslope. Van Dyke's salamanders *(P. vandykei)* occupied habitats adjacent to three streams, all of which traversed basalt lithologies on north-facing slopes. Our results suggest that habitat quality for headwater amphibians in this region is strongly influenced by landform characteristics, including basin lithology. These associations provide managers an opportunity to improve headwater amphibian conservation strategies by prioritizing stream segments with respect to their likely amphibian fauna.

Willson J.D and Dorcas M.E. 2003. Effects of habitat disturbance on stream salamanders Implications for buffer zones and watershed management. Conservation Biology 17: 763-771.*

With human populations increasing worldwide, habitat destruction and degradation are among the greatest threats facing wildlife. To minimize the impacts of development on aquatic habitats, numerous conservation measures have been implemented, including the use of riparian buffer zones along streams and rivers. We examined the effectiveness of current buffer-zone systems for management of small watersheds in conserving stream-dwelling salamander populations in 10 small streams (draining 40.5 ha) in the western Piedmont of North Carolina. We captured salamanders by means of funnel traps and systematic dipnetting and used a geographic information system to calculate the percentage of disturbed habitat within the watershed of each stream and within 10.7-, 30.5-, and 61.0-m buffer zones around each stream, upstream from our sampling locations. Although the relative abundance of salamanders was strongly inversely proportional to the percentage of disturbed habitat in the entire watersheds (R2 = 0.71 for *Desmognathus fuscus* and 0.48 for *Eurycea cirrigera*), we found little to no correlation between the relative abundance of salamanders and the percentage of disturbed habitat present within buffer zones (R2 = 0.06–0.27 for *D. fuscus* and 0.01–0.07 for *E. cirrigera*). Thus, conservation efforts aimed at preserving salamander populations in headwater streams must consider land use throughout entire watersheds, rather than just preserving small riparian buffer zones.

Wipfli, M.S. and Gregovich, D.P. 2002. Export of invertebrates and detritus from fishless headwater streams in southeastern Alaska Implications for downstream salmonid production. Freshwater Biology 47: 957-969.*

1. We examined the export of invertebrates (aquatic and terrestrial) and coarse organic detritus from forested headwaters to aquatic habitats downstream in the coastal mountains of southeast Alaska, U.S.A. Fifty-two small streams (mean discharge range: 1.2–3.6 L s-1), representing a geographic range throughout southeast Alaska, were sampled with 250-lm nets either seasonally (April, July, September) or every 2 weeks throughout the year. Samples were used to assess the potential subsidy of energy from fishless headwaters to downstream systems containing fish.
2. Invertebrates of aquatic and terrestrial origin were both captured, with aquatic taxa making up 65–92% of the total. Baetidae, Chironomidae and Ostracoda were most numerous of the aquatic taxa (34, 16 and 8%, respectively), although Coleoptera (mostly Amphizoidae) contributed the greatest biomass (30%). Mites (Acarina) were the most numerous terrestrial taxon, while terrestrial Coleoptera accounted for most of the terrestrial invertebrate biomass.
3. Invertebrates and detritus were exported from headwaters throughout the year, averaging 163 mg invertebrate dry mass stream-1 day-1 and 10.4 g detritus stream-1 day-1, respectively. The amount of export was highly variable among streams and seasons (5–6000 individuals stream-1 day-1 and <1–22 individuals m-3 water; <1–286 g detritus stream-1 day-1 and <0.1–1.7 g detritus m-3 water). Delivery of invertebrates from headwaters to habitats with fish was estimated at 0.44 g dry mass m-2 year-1. We estimate that every kilometre of salmonid-bearing stream could receive enough energy (prey and detritus) from fishless headwaters to support 100–2000 young-of-the-year (YOY) salmonids. These results illustrate that headwaters are source areas of aquatic and terrestrial invertebrates and detritus, linking upland ecosystems with habitats lower in the catchment.

Young, K.A. 2000. Riparian zone management in the Pacific Northwest: who's cutting what? Environmental Management 26: 131-144.*

In the Pacific Northwest (PNW) of North America, forestry practices during the last century have degraded the ecological linkages between riparian forests and streams. In an attempt to protect the integrity of lotic ecosystems and associated fisheries resources (primarily anadromous Pacific salmon, *Oncorhynchus sp*.), regional governments now restrict timber harvest in riparian forests. I summarize and assess the riparian zone management guidelines of the states of California, Oregon, and Washington (USA) and the province of British Columbia (Canada). Only Oregon and British Columbia protect fish-bearing streams with ‘‘no-harvest’’ zones, and only the wider (20–50 m) no-harvest zones for larger fish-bearing streams in British Columbia are likely to maintain near-natural linkages between riparian and stream ecosystems. All four jurisdictions protect most streams with ‘‘management zones’’ of variable width, in which timber harvest activities are restricted. All the management zone guidelines permit the harvest of the largest conifers from riparian forests and will, if applied over a series of timber harvest rotations (60–80 years), result in the continued removal of potential sources of large woody debris from the region’s watersheds. All four jurisdictions require additional protection for streams and

watersheds that are severely degraded or (in the United States) contain threatened or endangered species. The governments of the PNW have taken a ‘‘manage until degraded, then protect’’ approach to riparian forest management that is unlikely to maintain or restore the full suite of riparian-stream linkages necessary for lotic ecosystems to function naturally at the stream, watershed, basin, or regional scale.

Young, K.A., Hinch, S.G., and Northcote, T.G. 1999. Status of resident coastal cutthroat trout and their habitat twenty-five years after riparian logging. North American Journal of Fisheries Management 19: 901-911.*

In 1973 two sections of a small headwater stream containing allopatric nonanadromous coastal cutthroat trout *Oncorhynchus clarki* were subjected to two types of streamside logging: (1) clear-cut to the streambank with all existing wood and logging debris left in the channel and on adjacent hill slopes (section B; 4.2% gradient), and (2) clear-cut to the streambank with all logging debris and existing instream wood removed from the channel and adjacent hill slopes (section A; 0.8% gradient; termed scarified). A third upstream reference section was undisturbed (section C; 4.8% gradient). The hill slopes of both treatment sections were burned in 1974. Instream habitat (large woody debris and pool percentage), water temperature, and fish populations were assessed intermittently during the following 25 years. Instream habitat, water temperature, and trout density in section B were in all years similar to the upstream reference section, C. In section A, summer maximum stream temperatures reached 30°C immediately after logging but had moderated by 1975 and were similar to the reference section by 1983; the proportion of wetted area that was in pools was 14% in 1975, 33% in 1985, and 49% in 1997; trout density was low (0.05 fish/m2) after logging but had returned to the reference level (0.21 fish/m2) by 1983 and was double (0.49 fish/m2) the reference level in 1997. The recent increase in fish density in section A may have been influenced by instream habitat enhancement and riparian thinning conducted in 1985. Trout density in section A is presently similar to that found in a nearby low-gradient stream with an undisturbed riparian zone. Our results suggest that large pieces of wood that are left in and over small streams after logging, although a contravention of current logging regulations in British Columbia, may help protect resident trout populations following riparian logging.