NON-ALASKA REFERENCES

Canada

277) **Beaudry, P.G. 1989. Hydrology of the Skeena River floodplains I: Implications to herbicide use. In: Proceedings of Watershed '89: A Conference on the Stewardship of Soil, Air, and Water Resources, 21-23 March 1989, Juneau, Alaska. E.B. Alexander, Editor. USDA Forest Service, Alaska Region, R10-MB-77. Pages 165-171. (I)**

Author abstract: This study was initiated to provide information to silviculturists and concerned members of the public about the environmental characteristics of the Skeena River floodplains that affect the fate of forestry herbicides. This paper describes 1) the annual groundwater regime and its driving forces, 2) the stratigraphy of the deposits, 3) the physical characteristics of the soil, and 4) the climatic regime of both air and soil. Based on these data and the chemical and physical properties of certain herbicides, inferences are made about their probable fate in coastal alluvial environments. The period late July to early September is identified as the safest for the application of herbicides as the water table is low and consequently the chances of flooding are low. The surface deposits of fine silts and the rapid incorporation of organic matter into the soil should ensure low mobility of most herbicides.

278) **Beaudry, P.G., and A. Gottesfeld. 2001. Effects of forest-harvest rates on stream-channel changes in the central interior of British Columbia. In: Watershed Assessment in the Southern Interior of British Columbia. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. D.A.A. Toews and S. Chatwin, Editors. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 151-173. (A)**

Author abstract: The study investigates the relationship between the level of forest harvesting within 12 medium-sized watersheds and the change in stream-channel width over time. Stream-channel widths and sediment sources were measured from a chronosequence of rectified aerial photographs, dating back to the early 1960s. During the period between the mid 1960s and 1984 most of the study reaches evolved towards narrower channels. During the period between 1984 and the mid 1990s most of the watersheds experienced an increase in average channel width. No statistical relationship could be established between the level of forest harvest and the increase in channel width. Decadal variations in climate appeared to best explain the variability in the observed increases in stream-channel width during the late period.

279) **Berube, P. and F. Levesque. 1998. Effects of forestry clear-cutting on numbers and sizes of brook trout, *Salvelinus fontinalis* (Mitchill), in lakes of the Mastigouche Wildlife Reserve, Quebec. Canada Fisheries Management & Ecology. 5: 123-137. (K)**

Electronic abstract: Brook trout, *Salvelinus fontinalis* (Mitchill), angling data, collected between 1971 and 1991, were analysed before, during, and after logging operations for 20 lakes located within 200 m of a clear-cutting area and 16 reference lakes undisturbed by logging. The

mean weight of catches by anglers remained unchanged over the three periods, while catches per unit of effort (CPUE) and biomass per unit of effort (BPUE) decreased, respectively, by 18% and 22% after clear-cutting. These changes reflected a significant modification in population dynamics probably caused by logging operations. Results indicated that the negative impacts on aquatic fauna were felt more strongly on water bodies located in watersheds where deforestation was more severe; CPUE was inversely correlated with a cumulative cutting index (CI) developed from physiographic parameters. An increasing interannual trend of the spring-flood discharge in the order of 8% was noted. It was hypothesized that this increase might damage spawning and nursery habitats, hence affecting recruitment and offering a possible part of the explanation for the variations in fishing success. The cause-to-effect links and the mechanisms associated with changes affecting fish populations following deforestation remain to be clarified.

280) Bird, S.A. 2001. Streamside logging and riparian hazard assessment in step-pool streams. In: Watershed Assessment in the Southern Interior of British Columbia. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. D.A.A. Toews and S. Chatwin, Editors. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 134-142. (A, D, F)

Author abstract: A riparian assessment is usually completed as part of the Interior Watershed Assessment Procedure (IWAP). The riparian assessment focuses on the role of riparian vegetation and woody debris in maintaining channel stability and channel structure, and on how this role has been affected by logging. This paper evaluates the effectiveness of riparian assessment procedures in identifying channel disturbance in step-pool streams.

The procedure relies on the identification of indirect channel impacts from riparian logging. Indirect impacts include the loss of bank cohesion following decay of the riparian tree-root network, and the lack of large riparian trees available to the channel from overbank sources. The effects of indirect impacts may not be fully apparent in the channelfor several decades and not observed until the riparian area has partially recovered, and this may confound the assessment. Overview assessment procedures designed to identify channel impacts from streamside logging should focus on direct channel impacts. These tend to occur from operating machinery in or across the stream channel, operating machinery on top of banks, salvaging logs out of the active channel, and delivering logging debris to the channel from surrounding hillslopes or valley bottoms.

281) Bovis, M.J., and M. Jakob. 1999. The role of debris supply conditions in predicting debris flow activity. Earth Surface Processes and Landforms. 24: 1039-1054. (K)

Author abstract: Debris flow frequency and magnitude were determined for 33 basins in southwest British Columbia. Basins were first classified as either weathering-limited or transport-limited using a discriminant function based on debris-contributing area, an area-weighted terrain stability number, and drainage density. Multiple regression was used to predict magnitude, peak discharge, frequency and activity (frequency times magnitude) within each group of basins. Model performance was improved by stratifying the total sample of debris flow basins into weathering-and transport-limited groups. Explained variance increased by an average of 15 per cent in the transport-limited sample, indicating that sediment supply conditions in the more active basins are fundamental in predicting debris flow activity. An independent test of the

regression models with 11 basins yielded generally good results for debris flow magnitude and peak discharge. Prediction of debris flow frequency proved problematical in weathering-limited basins. The methods developed here provide estimates of debris flow attributes in basins for which few data on past events are available.

282) Brardinoni, F., M.A. Hassan, and H.O. Slaymaker. 2002. Complex mass wasting response of drainage basins to forest management in coastal British Columbia. Geomorphology. 49: 109-124. (K)

Author abstract: The impacts of logging activities on mass wasting were examined in five watersheds in the coastal mountains of British Columbia. Historical aerial photos were used to document mass wasting events, and their occurrence was related to logging activities in the study basins. Logged and forested areas were compared in terms of mass wasting magnitude and frequency, with reference to site characteristics. The recovery time of the landscape after logging was assessed. Bedrock type and basin physiography had no identifiable effect on mass wasting frequency and magnitude. Mass wasting failure was primarily controlled by slope gradient. Basin vulnerability increased, following clearcutting relative to forested areas, in that mass wasting was initiated on gentler slopes. The volume of sediment produced from logged slopes is of the same order as that from forested areas, which are steeper by as much as 10°. In both logged and forested areas, the size distribution of mass wasting events follows an exponential distribution. However, the variability in mass wasting size in forested areas is much higher than that obtained for logged areas. The recovery time after forest harvesting is over 20 years, which confirms published estimates based on vegetation reestablishment. Continuous disturbance of the basin, however, may extend the recovery time for the whole basin well beyond 20 years.

283) Buttle, J.M., I.F. Creed, and R.D. Moore. 2003. Advances in Canadian forest hydrology, 1999 – 2003. In: Quadrennial Report to the International Union of Geodesy and Geophysics and International Association of Hydrological Sciences. J.W. Pomeroy, Compiler. Canadian National Committee for the International Association of Hydrological Sciences (CNC-IAHS). Pages 5-19. (E, G, I)

Author abstract: Understanding the hydrological processes and properties of Canada's varied forest types is critical to sustaining their ecological, economic, social and cultural roles. This review examines recent progress in studying the hydrology of Canada's forest landscapes. Work in some areas, such as snow interception, accumulation and melt under forest cover, has led to modelling tools that can be readily applied for operational purposes. Our understanding in other areas, such as the link between runoff-generating processes in different forest landscapes and hydrochemical fluxes to receiving waters, is much more tentative. The 1999—2003 period saw considerable research activity examining the hydrological and biogeochemical response to natural and anthropogenic disturbance of forest landscapes, spurred by major funding initiatives at the provincial and federal levels. This work has provided valuable insight; however, application of the findings beyond the experimental site is often restricted by such issues as a limited consideration of the background variability of hydrological systems, incomplete appreciation of hydrological aspects at the experiment planning stage, and experimental design problems that often bedevil studies of basin response to disturbance. Overcoming these constraints will require, among other things, continued support for long-term hydroecological monitoring programs, the embedding of process measurement and modelling studies within these

programs, and greater responsiveness to the vagaries of policy directions related to Canada's forest resources. Progress in these and related areas will contribute greatly to the development of hydrological indicators of sustainable forest management in Canada.

284) Carignan, R., P. D'Arcy, and S. Lamontagne. 2000. Comparative impacts of fire and forest harvesting on water quality in Boreal Shield lakes. Canadian Journal of Fisheries and Aquatic Sciences. 57: 105-117. (H, I)

Electronic abstract: Water quality was monitored in Boreal Shield lakes for 3 years following their simultaneous impact by clearcut logging or wildfire. Seventeen similar undisturbed lakes served as references. Dissolved organic carbon (DOC) and the light attenuation coefficient (e_{PAR}) were up to threefold higher in cut lakes than in reference and burnt lakes. Compared with median values for reference lakes, cut and burnt lakes had higher concentrations of total phosphorus (TP) (two- to three-fold), total organic nitrogen (TON) (twofold), and K^+, Cl^-, and Ca^{2+} (up to sixfold). NO_3^- and SO_4^{2-} concentrations were up to 60- and 6-fold higher, respectively, in burnt lakes than in reference and cut lakes. In most cases, impacts were directly proportional to the area harvested or burnt divided by the lake's volume or area. These simple models correctly predicted the changes observed in three lakes harvested during the study. Some of the ob served effects occur on different time scales. Mobile ions released by fire (K^+, Cl^-, SO_4^{2-}, NO_3^-) or harvesting (K^+, Cl^-, some DOC) are rapidly flushed out of the watershed (50% decrease in 3 years). Other constituents or properties (TP, TON, DOC, e_{PAR}, Ca^{2+}, Mg^{2+}) show little change or are still increasing after 3 years and will take a longer time to reach normal levels.

285) Carver, M. 2001. Using indicators to assess hydrologic risk. In: Watershed Assessment in the Southern Interior of British Columbia. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. D.A.A. Toews and S. Chatwin, Editors. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 26-43. (K)

Author abstract: In British Columbia, forest managers employ indicators for evaluating hydrologic constraints. Although the Watershed Assessment Procedures provide the most visible example of this, broader administrative levels such as Land and Resource Management Plans and Timber Supply Reviews also make use of hydrologic indicators to support decisions. Unfortunately, the way indicators are used often does not take full advantage of current knowledge, nor does it always support transparent decision-making with scientific information clearly separated from social values. This paper reviews British Columbia's use of hydrologic indicators and provides practical options for improving the quality of hydrologic information provided to decision-makers.

In assessing forest-management options, decision-makers require clear expression of possible hydrologic outcomes. How these outcomes are best presented for consideration in decision-making is influenced by the spatial scale under consideration, data availability at this scale, data quality, analytic capabilities, and the current level of scientific knowledge. The literature demonstrates the prevalence of indicator and process models. The present version of the Watershed Assessment Procedure has moved away from a reliance on indicators to a greater focus on professional opinion based on limited field work. This shift may be suitable at the scale of specific watersheds, but it does not address broader management planning scales. The use of

Equivalent Clearcut Area as a single indicator of hydrologic impact continues to be evident in British Columbia at all management levels despite knowledge that Equivalent Clearcut Area can be only weakly linked to hydrologic impact.

A host of challenges is preventing the effective use of indicators in hydrologic assessment in British Columbia. The uncertainty and complexity associated with hydrologic linkage mechanisms present real challenges to the applied scientist when attempting to articulate potential hydrologic outcomes to decision-makers. Data availability/quality and computational power continue to be significant modeling issues. Evaluation of results and of the procedure itself have been lacking in British Columbia and yet form a cornerstone of effective adaptive management.

It is suggested that a preferred approach for supporting broad management decisions is a risk-assessment framework that provides a clear separation between scientific interpretation and value-based choices. A systematic evaluation of indicators linked to applied research would be required, along with standardized measures of hydrologic impact. It is concluded that until reliable process models can be developed and detailed data are available on a broad basis, indicators will continue to be an essential basis for making forest-management decisions.

286) Cheng, J.D. 1989. Streamflow changes after clear-cut logging of a pine beetle-infested watershed in southern British Columbia, Canada. Water Resources Research. 25: 449-456. (G)

Electronic abstract: The paired watershed technique was used to assess the streamflow changes of Camp Creek in interior British Columbia after clear-cut logging occurred over 30% of its 8400 ac. watershed. Existing hydrometric data for Camp Creek (beetle infested) and those of an adjacent control, Great Creek (not beetle infested), were analyzed for both the 1971-1976 prelogging and 1978-1983 postlogging periods. Postlogging Camp Creek streamflow changes are characterized by increases in annual and monthly water yields and annual peak flows, as well as earlier annual peak flow and half flow volume occurrence dates. The direction and magnitude of these postlogging streamflow increases are clear and consistent. The results are in good agreement with the findings of most previous studies conducted on watersheds that generally have been smaller than 2.5 km^2. This study provides strong evidence that changes in streamflow from large forested watersheds can be significant if a sizeable portion of its drainage is clear-cut.

287) Chew, L.C., and P.E. Ashmore. 2001. Channel adjustment and a test of rational regime theory in a proglacial braided stream. Geomorphology. 37: 43-63. (A)

Author abstract: The upstream reach of the Sunwapta River, Alberta, provides a useful quasi-experimental field case of channel adjustment in a proglacial stream. Historically, the formation of a proglacial lake deprived the river of its coarse sediment supply for several decades and lead to a dramatic decrease in braiding intensity close to the lake while braiding intensity increased further downstream. This response to the reduction of gravel input is consistent with previous experimental results. Subsequent construction activity and channelization close to the lake have contributed to the continuation of these temporal and spatial trends in channel pattern. The current state of adjustment of the river morphology can be explained, in the context of these historical changes, using rational regime equations. The study reach has no tributaries and bed material size decreases twofold along the reach while width and braiding intensity increase, yet

channel slope decreases by only 10%. The absence of any significant change in discharge downstream along the reach allows testing of regime equations under conditions in which discharge is held constant. The current downstream trends in slope and fluctuations in width are predicted reliably from rational regime equations, but not by the existing empirical hydraulic geometry relations. The rational equations incorporate the effect of grain size and slope on channel width and the effect of width and grain size on channel slope. The regime equations are successful even though they were devised for single channel gravel streams. The small (10%) decrease in slope along the reach, despite a halving of median grain size, is attributed to the counteracting (positive) effect on slope of the downstream increase in braiding intensity and width. The downstream increase in braiding intensity must be largely the result of decreasing grain size. This confirms the influence of grain size on channel pattern thresholds and demonstrates, using spatial transitions in channel pattern, that channel pattern predictions based on stream power alone are inadequate.

288) Church, M., and J.M. Ryder. 2001. Watershed processes in the southern interior of British Columbia: Background to land management. In: Watershed Assessment in the Southern Interior of British Columbia. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. D.A.A. Toews and S. Chatwin, Editors. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 1-16. (A, D, F, G, I)

Author abstract: The factors that govern morphology and processes along stream channels are the amount and timing of water delivery to the channel, the amount and calibre of sediment delivered, the gradient over which the channel flows, and conditions of bank vegetation and wood supply to the channel. A fundamental distinction must be recognized between low-order, headward drainage basins and larger, higher-order ones. Headward basins are the source of channeled streamflow and much of the sediment that moves through the drainage system. Trunk streams combine drainage from many headward channels. Headward channels are coupled to slopes that deliver sediment inputs directly; trunk streams are buffered from adjacent slopes by a valley flat. Headward channels are subject to episodic major disturbance, usually in the form of landsliding. Trunk channels experience the attenuated effect of disturbances at many places in the headwaters. Sediment delivery and onward transfer occur frequently in such channels. Exceptions occur. Headward channels sometimes are flat, and may drain extensive wetlands. Conversely, many valley streams are incised into and at least partially confined by high banks composed of Pleistocene sediments. Diagnosis of land surface conditions and actions to ensure soil and landscape stability should be focused upon hillside stability in headward drainage basins. Along valleys, the focus of attention must be the stream channel and riparian zone. Consequently, hydrological watershed assessment is an appropriate management tool in relatively small, upland drainage basins, but in larger drainage systems major management tool for uncoupled channels should be stream channel stability assessment.

289) Clague, J.J., R.J.W. Turner, and A.V. Reyes. 2003. Record of recent river channel instability, Cheakamus Valley, British Columbia. Geomorphology. 53: 317-332. (A, F)

Author abstract: Rivers flowing from glacier-clad Quaternary volcanoes in southwestern British Columbia have high sediment loads and anabranching and braided planforms. Their floodplains aggrade in response to recurrent large landslides on the volcanoes and to advance of glaciers during periods of climate cooling. In this paper, we document channel instability and aggradation during the last 200 years in lower Cheakamus River valley. Cheakamus River derives much of its flow and nearly all of its sediment from the Mount Garibaldi massif, which includes a number of volcanic centres dominated by Mount Garibaldi volcano. Stratigraphic analysis and radiocarbon and dendrochronological dating of recent floodplain sediments at North Vancouver Outdoor School in Cheakamus Valley show that Cheakamus River aggraded its floodplain about 1–2 m and buried a valley-floor forest in the early or mid 1800s. The aggradation was probably caused by a large (ca. $15–25\times10^6$ m^3) landslide from the flank of Mount Garibaldi, 15 km north of our study site, in 1855 or 1856. Examination of historical aerial photographs dating back to 1947 indicates that channel instability triggered by this event persisted until the river was dyked in the late 1950s. Our observations are consistent with data from many other mountain areas that suggest rivers with large, but highly variable sediment loads may rapidly aggrade their floodplains following a large spike in sediment supply. Channel instability may persist for decades to centuries after the triggering event.

290) Collins, B.D., D.R. Montgomery, and A.D. Haas. 2002. Historical changes in the distribution and functions of large wood in Puget Lowland rivers. Canadian Journal of Fisheries and Aquatic Sciences. 59: 66-76. (A, D)

Author abstract: We examined changes in wood abundance and functions in Puget Lowland rivers from the last ~150 years of land use by comparing field data from an 11-km-long protected reach of the Nisqually River with field data from the Snohomish and Stillaguamish rivers and with archival data from several Puget Lowland rivers. Current wood abundance is one to two orders of magnitude less than before European settlement in the Snohomish and Stillaguamish basins. Most importantly, wood jams are now rare because of a lack of very large wood that can function as key pieces and low rates of wood recruitment. These changes in wood abundance and size appear to have fundamentally changed the morphology, dynamics, and habitat abundance and characteristics of lowland rivers across scales from channel unit to valley bottom. Based on our field studies, rivers had substantially more and deeper pools historically. Archival data and field studies indicate that wood jams were integral to creating and maintaining a dynamic, anastomosing river pattern with numerous floodplain channels and abundant edge habitat and routed floodwaters and sediment onto floodplains. Establishing the condition of the riverine landscape before European settlement sets a reference against which to evaluate contemporary conditions and develop restoration objectives.

291) Commandeur, P.R., B.T. Guy, and H. Hamilton. 1996. The effects of woody debris on sediment fluxes in small coastal stream channels. Pacific Forestry Centre, Canadian Forest Service, Victoria, British Columbia, Information Report BC-X-367. 27pp. (B, D, I)

Author abstract: Two first-order streams located on the south coast of British Columbia were studied to determine the role of woody debris in controlling the routing and storage of sediment within high gradient channels in logged areas. The removal of logging slash from one of the two

channels resulted in a reduction in the trapping and storage of sediment compared to the control channel over a one-year period following logging. For the control, the steps created by the woody debris provided storage locations and reduced the transport of sediment, especially the larger sizes. About 37% of the sediment inputs were stored in the treated channel, whereas 66% of the sediment inputs were stored in the control channel. The remainder of the sediment inputs went through each channel. The sediment storage potential within the channels was limited, and in this study, the debris storage sites were filled in the first year following logging. Bedload (including some sediment transported in suspension but deposited within the weir/box) represented 30-35% of the total outputs for each channel. Over 90% of the bedload was finer than 2 mm for the control channel, whereas less than 40% consisted of particles finer than 2 mm for the treated channel. The role of woody debris in reducing stream sedimentation is briefly discussed.

292) Danylchuk, A.J., and W.M. Tonn. 2003. Natural disturbances on fish: Local and regional influences on winterkill of fathead minnows in boreal lakes. Transactions of the American Fisheries Society. 132: 289-298. (I)

Author abstract: We investigated the population dynamics of fathead minnow *Pimephales promelas* and the environmental factors of four small lakes in the boreal forest of Alberta, Canada, for 5 years to determine the influence of local and regional factors on the development of hypoxia and the occurrence of fish winterkill. Fathead minnow densities varied considerably among lakes and years, with dramatic (47–94%) year-to-year declines occurring when dissolved oxygen levels were extremely low in the intervening winter. Large declines (presumed winterkills) occurred after 25% of the "lake-winters," affecting three of four study lakes and 2 of 5 years. A fifth population in the same region, monitored for 15 years, displayed both a comparable frequency and temporal synchrony of large density decreases, suggesting that winterkill is a pervasive natural disturbance in small lakes of the Boreal Plains. In contrast to patterns displayed by larger fish species, smaller individuals in the fathead minnow populations were more strongly affected than larger individuals. Oxygen levels in a given lake and winter were related to (1) the collective interactions of productivity and depth of the lake, (2) the local and regional hydrogeology, and (3) the current and antecedent climate. As a result, the relative effects of these local and regional factors strongly influence the natural dynamics of fathead minnow populations in these lakes. Given that humans can alter many of the important factors, the natural incidence of winterkill could be augmented if human activities are poorly managed.

293) de Boer, D.H., M. Hassan, B. McVicar, and M. Stone. 2003. Recent (1999-2002) Canadian research on contemporary processes of river erosion and sedimentation, and river mechanics. In: Quadrennial Report to the International Union of Geodesy and Geophysics and International Association of Hydrological Sciences. J.W. Pomeroy, Compiler. Canadian National Committee for the International Association of Hydrological Sciences (CNC-IAHS). Pages 50-60. (A, F, I)

Author abstract: This review is part of the Canadian quadrennial report to the International Association of Hydrological Sciences (IAHS), and focuses on the science and management aspects of sediment dynamics in rivers and drainage basins published between 1999 and 2002. The themes of this review were selected to be of interest to the hydrological sciences in general,

and were chosen to represent a broad overview of the nature and directions of Canadian research in fluvial geomorphology, both in academia and in government and management. There is a large body of Canadian research that is aimed at elucidating the historical process record, for example through the use of lake sediments that reflect the erosional history of the contributing basin. This review, however, primarily concerns contemporary processes. The major themes of this review paper include sediment budgets and sediment yield; cohesive sediment transport; turbulent flow structure, sediment transport and bedforms; and bedload transport and channel morphology. These themes were selected because they have been the focus of substantial research in Canada.

Fluvial systems in Canada have a number of specific characteristics. First of all, Canada is a high latitude country, which means that, in most basins, the spring snowmelt is a dominant feature of the discharge and sediment transport regimes. Furthermore, in the northern part of the country, the presence of permafrost directly affects hydrological processes and is an important part of understanding fluvial processes and landforms. The northern location of Canada is also important from a historical perspective, since much of Canada was covered by ice during the Quaternary glaciations. As a result, the landscape in most of Canada is relatively young, and rivers are still actively adjusting to deglaciation, which only occurred during the late Pleistocene. The high latitude of the country also places it in that part of the world where CGMs generally indicate that the impact of global warming will be greatest in terms of temperature increase. Even though Canada is generally viewed as a relatively pristine country, its rivers are rarely unaffected by human activity. A multitude of dams has resulted in modifications of the annual discharge regime, and has led to changes in sediment storage and channel characteristics to a degree that is unknown, but likely substantial. Furthermore, in parts of Canada, human activity has led to a significant degradation of water and sediment quality—typically associated with urban, industrial and, sometimes, agricultural areas—and mobilization of large quantities of sediment within the drainage basin—typically caused by forestry and, sometimes, agriculture. Sediment quality and quantity in a stream directly affect the fish populations and, consequently, studies of the effect of human activity on fish habitat and behaviour form an important, practical part of fluvial geomorphology research in Canada.

Some of the characteristics of Canadian fluvial systems are reflected in the directions of research. Canadian research in fluvial geomorphology during the period of this review (1999-2002) continues in the same direction as earlier work summarized by Ashmore *et al.* (2000). There is a penchant for, and as a result, substantial progress has been made in, investigating the details of fluvial processes at relatively small scales. Examples of this emphasis are the investigations of floc structure, turbulence characteristics and bedload transport, which continue to form central themes in fluvial research in Canada. Translating the knowledge of small-scale, process-related research to an understanding of the behaviour of large-scale fluvial systems, however, continues to be a formidable challenge. Models play a prominent role in elucidating the link between small-scale processes and large-scale fluvial geomorphology, as they do in other fields such as climatology and oceanography. Canadian fluvial geomorphologists have recognized this role of models and, as a result, a number of papers describing models and modelling results have been published during the review period. It is to be expected that, in the future, the combination of detailed process measurements and models will gain importance in fluvial geomorphology in Canada, which will lead to an increased understanding of large-scale fluvial systems and strengthen the links between fundamental and applied research.

294) DeLong, S.C., S.A. Fall, and G.D. Sutherland. 2004. Estimating the impacts of harvest distribution on road-building and snag abundance. Canadian Journal of Forest Research. 34: 323-331. (K)

Author abstract: Various patterns of harvest in forests influence the length of road and number of stream crossings required. Snags are removed directly by harvesting, but they are also removed along road and opening edges to ensure worker safety. To assess the potential impacts of rate of harvest and pattern of harvest in an old-forest-dominated montane landscape, we developed a spatially explicit landscape dynamics model, which includes submodels for snag removal, harvesting activities, and access management. The model assesses the amount of new road construction and number of streams crossed by new roads, as well as changes in snag density and configuration across the landscape over a time horizon of several decades, in response to various harvesting patterns. We estimated that a dispersed 40-ha cutblock harvest pattern required about one-third more kilometres of new road over a 50-year period and removal of up to 70% more snags per hectare of harvest for safety purposes, compared with a harvest pattern based on natural-patch size distribution. Each 20% increase in stand-level retention resulted in a roughly equivalent increase in new road required. Up to eight times as many snags were removed per hectare of harvest for safety purposes at a stand-level retention of 70% than at a stand-level retention of 10%. The model appears to be an effective tool for determining the future impact of various harvest-pattern options on a number of important indicators of ecological impact.

295) Dhakal, A.S., and R.C. Sidle. 2003. Long-term modelling of landslides for different forest management practices. Earth Surface Processes and Landforms. 28: 853-868. (K)

Author abstract: Long-term effects of different forest management practices on landslide initiation and volume were analyzed using a physically based slope stability model. The watershed-based model calculates the effects of multiple harvesting entries on slope stability by accounting for the cumulative impacts of a prior vegetation removal on a more recent removal related to vegetation root strength and tree surcharge. Four sequential clearcuts and partial cuts with variable rotation lengths were simulated with or without leave areas and with or without understorey vegetation in a subwatershed of Carnation Creek, Vancouver Island, British Columbia. The combined infinite slope and distributed hydrologic models used to calculate safety factor revealed that most of the simulated landslides were clustered within a 5 to 17 year period after initial harvesting in cases where sufficient time (*c*. 50 years) lapsed prior to the next harvesting cycle. Partial cutting produced fewer landslides and reduced landslide volume by 1.4- to 1.6-fold compared to clearcutting. Approximately the same total landslide volume was produced when 100 per cent of the site was initially clearcut compared to harvesting 20 per cent of the area in successive 10 year intervals; a similar finding was obtained for partial cutting. Vegetation leave areas were effective in reducing landsliding by 2- to 3-fold. Retaining vigorous understorey vegetation also reduced landslide volume by 3.8- to 4.8-fold. The combined management strategies of partial cutting, increasing rotation length, provision of leave areas, and retention of viable understorey vegetation offer the best alternative for minimizing landslide occurrence in managed forests.

296) **France, R. 1997. Land water linkages: Influences of riparian deforestation on lake thermocline depth and possible consequences for cold stenotherms. Canadian Journal of Fisheries and Aquatic Sciences. 54: 1299-1305. (J)**

Author abstract: The purpose of the present study was to determine if riparian deforestation would expose lake surfaces to stronger winds and therefore bring about deepening of thermoclines and resulting habitat losses for cold stenotherms such as lake trout (*Salvelinus namaycush*). Removal of protective riparian trees through wind blowdown and two wildfires was found to triple the overwater windspeeds and produce thermocline deepening in two lakes at the Experimental Lakes Area. A survey of thermal stratification patterns in 63 northwestern Ontario lakes showed that lakes around which riparian trees had been removed a decade before through either clearcutting or by a wildfire were found to have thermocline depths over 2 m deeper per unit fetch length compared with lakes surrounded by mature forests. Riparian tree removal will therefore exacerbate hypolimnion habitat losses for cold stenotherms that have already been documented to be occurring as a result of lake acidification, eutrophication, and climate warming.

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

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

298) **Fuchs, S.A., S.G. Hinch, and E. Mellina. 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. (A, B, C, D)**

Author abstract: 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.

299) Gluns, D.R. 2001. Snowline pattern during the melt season: Evaluation of the H60 concept. In: Watershed Assessment in the Southern Interior of British Columbia. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. D.A.A. Toews and S. Chatwin, Editors. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 68-80. (G)

Author abstract: The H60 concept refers to the elevation of snowline when the upper 60% of a watershed is covered in snow. Timber harvesting in this "snow zone" is thought to have a greater influence on peak flows due to changes in snow accumulation and snowmelt when the forest canopy is removed. To account for this influence, the Interior Watershed Assessment Procedure provides a weighting mechanism for harvesting proposed in this zone. To test this principle, a 5-year study to look at snowlines and streamflow was undertaken. At the time of peak flow, on average, it was found that approximately 65% of a watershed was covered in snow. The H60 concept is valid for watersheds in the southern interior of British Columbia as a tool for evaluating forest-harvesting proposals.

300) Guthrie, R.H. 2002. The effects of logging on frequency and distribution of landslides in three watersheds on Vancouver Island, British Columbia. Geomorphology. 43: 273-292. (K)

Author abstract: Three hundred and sixty three landslides in three watersheds that totaled 382 km^2 were identified from air photographs, beginning at a date that preceded logging to the present. The three watersheds all lie on Vancouver Island; however, they have different precipitation regimes, topography, and amounts logged. Landslide areas in the watersheds varied in size from 200 m^2 to more than 1 ha. Nearly 80% of the landslides were debris slides; 15% were debris flows, and the remainder primarily rock falls. Following logging, the number of landslides increased substantially in all watersheds although the amount of increase was variable: approximately 11, 3, and 16 times in Macktush Creek, Artlish River, and Nahwitti River, respectively. Other analyses of changes in landslide density also produced highly variable results, with the number of landslides increasing between 2.4 and 24 times. Further, 2–12 times more landslides reached streams following logging activities. Densities for landslides impacting streams increased for the period of record from 1.5 to 10 times following logging activities. The

densities were substantially greater where only landslides that reached streams since development began in a watershed were considered. Roads had the greatest spatial impact in the watersheds (compared to their total area), with frequencies determined to have increased by 27, 12, and 94 times for Macktush, Artlish, and Nahwitti, respectively. The results highlight the relative impact of roads and their role in slope stability.

301) Guyette, R.P., and W.G. Cole. 1999. Age characteristics of coarse woody debris (*Pinus strobus*) in a lake littoral zone. Canadian Journal of Fisheries and Aquatic Sciences. 56: 496-505. (D)

Author abstract: Littoral coarse woody debris (CWD) is a persistent class of aquatic habitat that accumulates over many centuries and provides habitat for diverse floral and faunal communities. We used dendrochronological methods to analyze residence times and age-related characteristics of eastern white pine (*Pinus strobus*) CWD in the littoral zone of Swan Lake in Algonquin Provincial Park, Ontario. The mean calendar date of all the annual rings in CWD samples was 1551. Annual rings dated from calendar year 1893 to 982. The mean time from carbon assimilation in a live tree to carbon loss from littoral woody debris was 443 years. Outside ring dates of the woody debris were significantly correlated with the bole's maximum and minimum diameter ratio, mass, specific gravity, length, and submergence. Negative exponential functions described the temporal structure of the CWD mass and abundance. Accelerated inputs of woody debris resulted from late nineteenth century logging and a disturbance circa 1500. No mature eastern white pine have fallen into the lake over the last 100 years.

302) Hartman, G.F., J.C. Scrivener, and M.J. Miles. 1996. Impacts of logging in Carnation Creek, a high-energy coastal stream in British Columbia, and their implication for restoring fish habitat. Canadian Journal of Fisheries and Aquatic Sciences. 53 (Suppl. 1): 237-251. (A, B, F)

Author abstract: The land form, surficial geology, and hydrometeorology of the west coast of British Columbia cause streams in the region to be highly variable in flow and vulnerable to land-use disturbance. Carnation Creek, a small drainage in this region, was studied intensively for > 20 yr to examine the impacts of forest harvesting. Landslides and debris torrents modified steep slope tributaries and the mainstem of the creek. Bank erosion also altered the stream channel on the alluvial flood plain. These effects were additive in the system and reduced the quality of spawning and rearing habitat for juvenile salmonids. In streams like Carnation Creek, it is necessary to restore some stability to the hill slopes and gullies before attempting fish habitat improvements in the main channel. Salmonid production was limited by combinations of processes and conditions that were different for each species and life-history stage. Knowledge of the processes that limit fish production must be applied in habitat improvement work or the projects risk failure. Programs intended to restore natural function to systems or to improve habitat for fish must be planned, evaluated, and reported methodically if they are to succeed and provide information of use to future programs.

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

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

304) Hartman, G.F., L.B. Holtby, and J.C. Scrivener. 1984. Some effects of natural and logging-related winter stream temperature changes on the early life history of coho salmon (*Oncorhynchus kisutch*) in Carnation Creek, British Columbia. In: Fish and Wildlife Relationships in Old-Growth Forests. Proceedings of a symposium, 12-15 April 1982, Juneau, Alaska. W.R. Meehan, T.R. Merrell, Jr., and T.A. Hanley, Editors. Pages 141-149. (J)

Author abstract: Carnation Creek is a small rain-forest stream located on Barkley Sound, Vancouver Island, British Columbia. It is the site of a 15-year watershed study concerned with the impact of logging on anadromous and resident salmonids. This paper deals with some of the effects of natural and logging-induced stream temperature changes in winter on juvenile coho salmon. Extensive logging began in the winter of 1976-77 and continued until 1980-81, by which time 41% of the watershed had been clearcut. Stream temperatures in early winter from 1976-77 through 1980-81 were higher than they had been prior to logging. Temperature increases resulted from climatic amelioration, which began in 1976, and from the effects of logging. As a result of higher temperatures, coho salmon fry emerged earlier in the spring than they had prior to logging. Early emergent fish that did not move downstream during spring freshets began growing sooner. In 1981, the year of highest winter temperatures, fry emerged 47 days earlier than in the prelogging years and this, coupled with faster growth in late spring, led to the fish entering their first winter at a larger size. Consequently, survival through the winter was greater, leading to increased numbers and size of 1-year smolts and an increased proportion of 1-year versus 2-year smolts. Brief speculation is offered about processes that may have affected stream temperatures during winter.

305) Henderson, G.S., and D.A.A. Toews. 2001. Using sediment budgets to test the watershed assessment procedure in southeastern British Columbia. In: Watershed Assessment in the Southern Interior of British Columbia. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. D.A.A. Toews and S. Chatwin, Editors. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 189-208. (G, I)

Author abstract: In 1997 and 1998, the British Columbia Ministry of Forests tested the appropriateness of using the sediment-source technique described in the province's 1999 Interior Watershed Assessment Procedure (IWAP) to assess the input and output of sediment in 11 sub-watersheds in the Nelson Forest Region in southeastern British Columbia. Sediment input was estimated using the Rapid Road Erosion Technique Survey (RREST), a survey technique that

estimates quantities of sediment that erode from forestry roads and are transported into the stream system. Sediment output was calculated for the same sub-watersheds by measuring suspended sediment, turbidity, and streamflow, and these measurements were used to calculate sediment yield in nine of the 11 basins. Results show that, in these watersheds, forestry roads are a relatively small part of the annual sediment budget, and that natural sediment sources dominate the sediment regime. It is unlikely that rehabilitation of forestry roads would result in significant reductions in sediment yield when measured at the outlet of the basin.

306) Hogan, D. 2001. Stream channel assessment in the interior of British Columbia. In: Watershed Assessment in the Southern Interior of British Columbia. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. D.A.A. Toews and S. Chatwin, Editors. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 112-133. (A)

Author abstract: The Channel Assessment Procedure referred to in the Watershed Assessment Procedure was developed to provide an objective, repeatable method to assess stream-channel disturbance. It is based on field indicators of disturbance that were developed with an understanding of the naturally high variability of stream channels. The indicators relate to channel aggradation and degradation that can be linked to the primary hydrologic and geomorphic processes operating in a watershed. The channelassessment of Norns Creek is described to provide an illustration of the utility of the channel assessment as a component analysis within a watershed assessment. The channel assessment provides a detailed description of the channel reaches, including morphology, hillslope/channel coupling, and sediment transport and deposition sites. With the accompanying geo-referenced inventory of disturbance indicators, the experienced geomorphologist can then link watershed processes and channel conditions. This information is relevant to fish habitats and can form the basis for determining appropriate watershed restoration prescriptions.

307) Hogan, D.L. 1989. Channel response to mass wasting in the Queen Charlotte Islands, British Columbia: Temporal and spatial changes in stream morphology. In: Proceedings of Watershed '89: A Conference on the Stewardship of Soil, Air, and Water Resources, 21-23 March 1989, Juneau, Alaska. E.B. Alexander, Editor. USDA Forest Service, Alaska Region, R10-MB-77. Pages 125-142. (A)

Author abstract: A paired watershed study is being used to compare stream channels with various ages of mass wasting disturbance with similar channel types in undisturbed basins. In year 1 of a 4 year program (1988), approximately 27 km of stream channel were inventoried, including a wide range of stream sizes and debris torrent ages from 1 to 150 years. Morphological parameters of relevance to fish habitats were the focus of the field surveys. A case study is presented here.

A fundamental consequence of debris torrent inputs to stream channels is the establishment of sediment wedges associated with debris jams. Specific sedimentological, morphological and hydraulic changes occur upstream and downstream of the jams. The sediment wedges are of two basic types, vertical and lateral. The location, size and function of each type of jam controls morphology and their distribution along the water course influences the spatial adjustment of the channel. The integrity and longevity of the debris jams control the temporal response of the

channel. Initial results indicate that severe morphological alterations persist during the first decade following debris torrenting, but the channel begins to develop more normal characteristics during second and third decades. The morphological nature of stream channels 30 years after disturbance begins to resemble undisturbed channels.

308) Hogan, D.L., and D.J. Wilford. 1989. A sediment transfer hazard classification system: Linking erosion to fish habitat. In: Proceedings of Watershed '89: A Conference on the Stewardship of Soil, Air, and Water Resources, 21-23 March 1989, Juneau, Alaska. E.B. Alexander, Editor. USDA Forest Service, Alaska Region, R10-MB-77. Pages 143-155. (I)

Author abstract: A problem in watershed management is linking upslope erosion associated with forestry practices to downstream sedimentation of fish habitats. To overcome this problem, a sediment transfer hazard classification system was developed and applied to a northwestern British Columbia watershed. The system is based on geomorphic factors that influence sediment production, transport, and deposition. Data to describe these factors are obtained from air photographs, topographic maps, fish habitat inventories and interpretive terrain maps. The final product of the system is a sediment transfer hazard map that indicates where in a watershed sediment production and movement is a potential problem. This is an important tool for watershed and integrated resource managers because not all unstable or erodible sites pose a sedimentation hazard to fish. Knowing the hazards, managers can decide in an informed way where to restrict forest harvesting or focus limited dollars on special road construction and harvesting techniques. This paper describes the Sediment Transfer Hazard Classification System.

309) Johnston, N.T., E.A. MacIsaac, P.J. Tschaplinski, and K.J. Hall. 2004. Effects of the abundance of spawning sockeye salmon (*Oncorhynchus nerka*) on nutrients and algal biomass in forested streams. Canadian Journal of Fisheries and Aquatic Sciences. 61: 384-403. (C, D, E)

Author abstract: We used natural variation in sockeye salmon (*Oncorhynchus nerka*) spawner biomass among sites and years in three undisturbed, forested watersheds in interior British Columbia to test the hypotheses that salmon were a major source of particulate organic matter inputs to the streams and that carcass biomass determined stream-water nutrient concentrations and epilithic algal production. Sockeye carcasses were retained at the spawning sites, primarily (75–80%) by large woody debris (LWD) or pools formed by LWD. The abundance and distribution of sockeye salmon determined stream-water nutrient concentrations and epilithic chlorophyll *a* concentrations during late summer and early fall when most primary production occurred in the oligotrophic streams. Periphyton accrual rates were elevated at sites with high salmon biomass. Peak chlorophyll *a* concentration increased with increasing carcass biomass per unit discharge above a threshold value to reach maxima 10-fold greater than ambient levels. Epilithic algae were dominated by a few common, large diatom taxa. Salmon carcasses were the dominant source of particulate organic carbon in low gradient stream reaches. Nutrient budget modeling indicated that most of the salmon-origin nutrients were exported from the spawning streams or removed to the terrestrial ecosystem; diffuse impacts may extend over a much larger area than simply the sites used for spawning.

310) Jordan, P. 2001. Regional incidence of landslides. In: Watershed Assessment in the Southern Interior of British Columbia. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. D.A.A. Toews and S. Chatwin, Editors. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 237-247. (K)

Author abstract: A regional study was made of landslides in portions of the Arrow Forest District and the Kootenay Lake Forest District, which permits some preliminary conclusions to be made about the areal frequency of landslides, their causes, and their importance as sediment sources to streams. The study covered all or parts of 100 map sheets, totaling about one million hectares. Approximately 1700 landslides were inventoried by air-photo interpretation. A subset of about one-quarter of this study area, centered on the Slocan Valley, is discussed in this paper.

The data show that landslide frequencies are typically increased by roughly 10 times by forest development (depending on how one defines the land base for calculation of areal frequencies). The landslide frequency on private land is higher than on Crown land. About 95% of development-related landslides are due to roads or skid trails. On older roads, road-fill failures are apparently the most common cause. However, on newer roads, that most common cause is drainage concentration and diversion by roads. An important category of landslides occurs some distance below roads, below a culvert or a point of accidental drainage discharge. In many of these cases, the road itself is on gently sloping, low-hazard terrain, and the landslide occurs on steeper terrain below. This is known as the "gentle-over-steep" situation. The Forest Practices Code does little to reduce landslide hazard in this situation, because the need for professional engineering involvement in road design is triggered by the hazard at the road location, not below the road.

The terrain type most frequently involved in landslides, on an areal basis, is deep glaciofluvial or other stratified glacial deposits in valley bottoms. Otherwise, there are few generalizations that can be made about terrain factors contributing to landslide hazard, or about contributions of landslide sediment to streams. Landslides, like other geomorphic and hydrologic processes, tend to follow magnitude-frequency relations. Small landslides are most frequent, and often do not reach a stream. Large landslides are much less frequent, but often enter streams. In most watersheds, landslides are not a major component of the sediment budget, but in the rare cases where a large landslide occurs, it can dominate the sediment regime for 1 or several years.

311) Jordan, P. 2001. Sediment budgets in the Nelson Forest region. In: Watershed Assessment in the Southern Interior of British Columbia. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. D.A.A. Toews and S. Chatwin, Editors. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 174-188. (I)

Author abstract: We have ongoing sediment-budget studies in two parts of the Kootenays: at Redfish-Laird creeks in the West Arm Demonstration Forest, and at Gold Creek, one of the community watersheds of the City of Cranbrook. In addition, a number of watersheds have had monitoring programs that provide some sediment-budget information for 1 or more years.

The Redfish-Laird study began in 1993. Results show that April-September sediment yields for each year in Redfish Creek, which is developed with roads and logging, ranged from 25% greater than to double the yields for Laird Creek, the control. Most of the difference is probably

attributable to erosion from roads, and to a lesser extent, to road-related landslides that occurred before the study began. Road-maintenance activities can contribute significantly to sediment production. Contributions of sediment from cutblocks were insignificant.

The study in Gold Creek, which began in 1998, has so far shown much lower development-related sediment inputs to the creeks than in Redfish Creek. This is apparently due to a fundamental difference between the two areas in runoff generation mechanism. At Gold Creek, most of the snowmelt runoff from upland areas appears to enter fractured bedrock, and reach the creek through groundwater flow. This results in a low connectivity between sources of eroded sediment and the creek. In contrast, the hydrograph of Redfish Creek is dominated by surface runoff, and the sediment deliverability from roads to the creek is higher.

In 1997, we monitored suspended sediment production on 11 creeks used for community and domestic water supply. Watersheds underlain by granitic rocks tended to have the lowest average sediment yield; otherwise, there was little apparent relation between sediment yield and bedrock geology or extent of development. In general, sediment yield from most creeks used for water supply was quite low compared to typical yields elsewhere in British Columbia.

A sampling strategy of daily manual sampling during the spring freshet, and less frequent sampling for the rest of the year, has been found effective both for measuring total sediment yield and for monitoring water quality. Recording turbidity meters provide additional useful information.

312) Kelly, D.J., M.L. Bothwell, and D.W. Schindler. 2003. Effects of solar ultraviolet radiation on stream benthic communities: An intersite comparison. Ecology. 84: 2724-2740. (C, H)

Author abstract: The effects of solar ultraviolet radiation (UVR), both mid-ultraviolet (UVB; 280–320 nm) and near-ultraviolet (UVA; 320–400 nm), on benthic algal and invertebrate communities were compared in three reaches of a British Columbia coastal stream that differed in the degree of shading by riparian canopy (a full canopy, a partial canopy, and no canopy). At each of the three sites benthic communities were exposed to three different radiation treatments: photosynthetically active radiation alone (PAR; 400–700 nm), PAR+UVA, and PAR+UVA+UVB. Relative to the site with no canopy, UVR was 88% and 66% lower, and PAR was 83% and 49% lower at sites with full and partial canopy, respectively. Late summer increases in UVR to the streambed caused by declines in water level and dissolved organic carbon (DOC) were also lower at sites with high canopy.

Sites with less canopy shading had greater algal accrual, decreased biomass of total invertebrates, mayflies, and stoneflies, and reduced invertebrate community diversity compared to the heavily shaded reach of the stream. UVR produced taxon-specific community responses that varied across sites and increased with increasing UVR as summer progressed. At the full canopy site UVR had no impact, and the final (day 91) biomass and diversity of invertebrates was highest, and algal biomass lowest. Higher UVA radiation under reduced canopies inhibited algal accrual but had little effect on algal community composition. The biomass of several invertebrate taxa (e.g., *Dicosmoecus* spp., Limnephilidae) and community diversity were reduced by both UVA and UVB. Less sensitive taxa (e.g., *Paraleptophlebia* spp., Paraleptophlebidae) were inhibited only by the highest UVB levels in late summer when water transparency to UVR was greatest. Inhibition of grazers by UVR appeared to indirectly increase algal accrual, particularly at the partial canopy site.

Our results indicate that riparian shading may moderate UVR effects on benthic communities, mainly through impacts on invertebrates with indirect effects on algae. By reducing UVR exposure of streambeds, riparian canopies may be important for ameliorating UVR effects on shallow lotic systems, especially during late-summer, low-flow periods when DOC concentrations are reduced.

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

Author abstract: 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 preharvest 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.

314) Larkin, G.A., P.A. Slaney, P. Warburton, and A.S. Wilson. 1998. Suspended sediment and fish habitat sedimentation in central interior watersheds of British Columbia. Province of British Columbia, Ministry of Environment, Lands and Parks, and Ministry of Forests, Watershed Restoration Management Report No. 7. 31pp. (B, I)

Author abstract: Many watersheds in the central interior of British Columbia are designated for rehabilitation under the Watershed Restoration Program, which includes measures to control surface erosion. A study of suspended sediment and fish habitat sedimentation in several watersheds of the central interior, precursory to restoration activity, is described in this report. Suspended sediment concentrations measured during the spring snowmelt period indicated that sediment delivery to the nine streams surveyed was highly variable. Concentration profiles in some streams were indicative of chronic sources of sediment, but profiles in other streams were indicative of episodic sources of sediment. Severity-of-ill-effect values determined from the suspended sediment data were sufficiently high to indicate lethal and paralethal effects on the resident and migratory fish populations present in streams during the study period. Particularly severe impacts were predicted for eggs and developing larvae. High flow conditions in the spring of 1997 created considerable interference with the calibration and evaluation of sediment traps as

monitors for hillslope and/or stream bank restoration projects. Despite the problems, a positive relationship between sediment accumulation in the traps and suspended sediment loading was evident. The sediment traps are a robust technique and are recommended for selected use under moderate flow conditions, and where bedload movement is not dominant. The traps should become an integral part of monitoring the effectiveness of restoration projects involving erosion control, and will complement other evaluations of project success.

315) Macdonald, E., C.J. Burgess, G.J. Scrimgeour, S. Boutin, S. Reedy, and B. Kotak. 2004. Should riparian buffers be part of forest management based on emulation of natural disturbance? Forest Ecology and Management. 187: 185-196. (K)

Author abstract: Riparian communities (those near open water) have often been shown to display high structural and compositional diversity and they have been identified as potentially serving a keystone role in the landscape. Thus, they are the focus of specific management guidelines that attempt to protect terrestrial and aquatic ecosystems. We used a digital forest inventory database for a portion of the boreal mixed-wood forest in Alberta, Canada, to examine whether proximity to a lake affects forest composition, age, or configuration. Two analyses were employed: (1) forest composition (dominant canopy species, proportional composition of different species) and age (decade-of-origin) in bands of 50 m width and varying distance from small lakes were compared to forest in a similar spatial configuration but away from open water and (2) forest composition, dominant canopy species, age, and stand shape metrics were examined along transects emanating out from lakes in two regions, which varied in topography and dominant forest cover. We found no effect of distance from lake on forest age. The proportion of the landscape covered by forest of the predominant canopy species increased with distance from lake, but this was largely due to a corresponding decline in cover of non-forest vegetation rather than a change in forest canopy composition. At the spatial resolution of forest management planning, riparian forests in this region are of similar age and composition as those away from lakes. Since there is no natural analogue for riparian buffer strips around lakes, they may not be justified in the context of ecosystem management following the natural disturbance paradigm. Management of riparian forests should focus on meeting defined management and conservation objectives through, for example, protection of finer scale features of riparian zones and landscape-level planning for allocation of uncut forest.

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

Author abstract: 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.

317) Macdonald, J.S., P.G. Beaudry, E.A. MacIsaac, and H.E. Herunter. 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. (G, I)

Author abstract: 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.

318) Magnan, P., and I. St-Onge. 2000. Impact of logging and natural fires on fish communities of Canadian Shield lakes. Project Report 2000-36 written by the Sustainable Forest Management Network, University of Alberta, Edmonton. 22pp. (K)

Author abstract: The goal of this study was to determine if natural fires and logging have a significant impact on abundance, growth, and size structure of fish populations in 38 lakes of the Canadian Shield (Québec, Canada). The watersheds of 9 of these lakes underwent logging and 9 underwent natural fires while the 20 remaining lakes were used as references. No significant differences were found among the three lake groups in the catch per unit of effort of the most abundant species: white sucker (C*atostomus commersoni*), northern pike (*Esox lucius*), yellow perch (*Perca flavescens*), lake whitefish (*Coregonus clupeaformis*), fallfish (*Semotilus corporalis*), brook charr (*Salvelinus fontinalis*), walleye (*Stizostedion vitreum*), and burbot (*Lota lota*). No significant difference was found in the back-calculated length of yellow perch and white sucker, for which age determinations were made, among control, burned, and logged lakes.

However, we found that the proportion of small yellow perch and white sucker were significantly lower in populations of impacted lakes (burned and logged lakes pooled). The influence of logging and fires remained significant when a series of biotic and abiotic variables on watershed and lake characteristics were accounted for in multiple regression analyses. The lower proportion of small fish in impacted lakes could be due either to an increase in post-emergence mortality and (or) a shift of individuals to the pelagic zone.

319) Marcogliese, D.J., M. Ball, and M.W. Lankester. 2001. Potential impacts of clearcutting on parasites of minnows in small boreal lakes. Folia Parasitologica. 48: 269-274. (K)

Author abstract: Clearcutting and deforestation lead to increase erosion, increased water temperature, altered water chemistry, and modified watershed hydrology in aquatic systems. Effects on biological organisms have been documented for phytoplankton, zooplankton, benthos, and fish. In this study, parasites of the northern redbelly dace, Phoxinus eos (Cope), were examined from an experimental area consisting of headwater lakes and their watersheds in the boreal forest of Ontario, Canada prior to and after clearcutting around the lakes. Catchments of two lakes were heavily, and one lake partially, clearcut in 1996, and that of a fourth lakes was untouched. In 1993, three years prior to clearcutting, five taxa of parasites, including the monogeneans *Dactylogyrus* sp, and *Gyrodactylus* sp., metacercaria of the digenean *Clinostomum complanatum* (Rudolphi, 1819), and the nematode *Rhabdochona canadensis* Moravec et Arai, 1971 and the myxozoan *Mysobolus* sp, were founding or on northern redbelly dace. In 1998, two years after clearcutting, eight taxa werer found on northern redbelly dace, including all of the above pluse the digeneans *Allocreadium* sp. and *Ornithodiplostomum ptychocheilus* (Faurs, 1917) and the copepod *Ergasilus lizae* Kr?yer, 1863. Mean infracommunity species richness and the maximum number of species per fish were higher in the control and partially cut lakes than in the heavily logged lakes. Uninfected fish were found in the heavily cut lakes, but not in the other lakes. Thus, disturbance may reduce parasite infracommunity complexity. Among individual parasite species, *R. canadensis* was absent from the two most heavily clearcut lakes and abundant in the two other lakes in 1998. Clearcutting may have affected the abundance of certain invertebrates in these lakes, in particular the mayflies that serve as intermediate hosts for *R. canadensis*. The parasites *Allocreadium* sp., *O. ptychocheilus*, and *E. lizae* have not been previously reported in or on northern redbelly dace.

320) McEachern, G. 2003. Where land and waters meet: Understanding and protecting riparian areas in Canada's Forests. J.D. Gysbers and P.Lee, Editors; M. Carver, Contributor. Global Forest Watch Canada, Edmonton, Alberta. 39pp. (C, D, E, F, G, H, ,I, J)

Author abstract (Author Executive Summary): Global Forest Watch Canada has prepared this report in order to provide an overview of the current North American literature on the role and functions of riparian areas in Canada's forests, the impacts of disturbance (both natural and human-caused), and the mitigation of forestry impacts on riparian areas. The report also provides guidance on forest management practices that would improve the protection of riparian areas.

This report represents the most comprehensive review currently available about the state of our knowledge on this topic. It found that:

- Riparian areas can be negatively impacted by forest management activities;
- Improving forest management would substantially advance the protection of riparian areas and help to protect the ecological values they contain.

Riparian areas, those places where water meets land, sometimes dramatically and sometimes with great subtlety, are rich components of our forest systems. As with other transitional zones, riparian areas contain elements of two major ecological systems—in this case, the aquatic and the terrestrial. The combination of these ecological systems results in areas rich in diversity and site-specific character that provide critical ecological functions in Canada's forest ecosystems.

Riparian areas have always been affected by natural disturbances, from the changes wrought by fire or wind to the impact of beavers felling shoreline trees. Increasingly, they are also being affected by industrial activities, particularly logging. Industrial impacts can range from the very direct (e.g., building a road or bridge or logging directly within riparian zones) to the indirect (e.g., cutting in upland forests can change water yield and nutrient export).

This review concludes that further research and literature reviews of the impact of forestry on riparian areas need to be conducted. It also points to the need for greater sensitivity and scrutiny of forestry operations in or near riparian areas, including greater public and industry education about the values of riparian areas, audits of current management practices and increased consideration of the values of riparian areas during logging operations.

We hope this report will be useful both for increasing understanding of riparian areas and for providing specific ideas regarding the management of riparian areas.

321) Mellina, E., R.D. Moore, S.G. Hinch, J.S. Macdonald, and G. Pearson. 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. (J)

Author abstract: 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.

322) Michel, B. 1971. Winter regime of rivers and lakes. U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Cold Regions Science and Engineering Monograph III-B1a. 139pp. (K)

Author abstract: The monograph summarizes existing knowledge of river and lake ice surveys, heart balance on open water in winter, frazil, ice cover formation, ice breakup and ice control.

323) Millar, R.G. 2001. Riparian logging and channel stability. In: Watershed Assessment in the Southern Interior of British Columbia. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. D.A.A. Toews and S. Chatwin, Editors. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 143-150. (A, F)

Author abstract: Recently developed theory is used to derive a simple planform stability diagram. The stability diagram is based on the threshold between meandering and braiding rivers, and includes a friction angle parameter that can be used as a surrogate to quantify the stabilizing influence of riparian vegetation. The planform stability diagram can be used as a relatively simple screening tool to determine the sensitivity of a particular river or stream to riparian logging. The necessary parameters are channel slope (S), bankfull or mean annual discharge (Q), and the median bank grain diameter (D_{50}). Given that direct riparian logging is now forbidden under the Forest Practices Code, the stability diagram is probably most useful in assessing the current channel condition, and in the case of a wide and unstable channel, to assess whether direct riparian logging represents a significant factor in the current channel condition.

324) Moore, K. 1991. Partial cutting and helicopter yarding on environmentally sensitive floodplains in old-growth hemlock/spruce forests. FRDA Report 166. Issued under Canada-BC Forest Resource Development Agreement. A joint publication of Forestry Canada and the British Columbia Ministry of Forests. Co-published by B.C. Ministry of Forests, and Canada/BC Economic & Regional Development Agreement. 43pp. (K)

Author abstract (Author Summary): At Naden Harbour on the Queen Charlotte Islands, B.C., partial cutting and yarding with a Sikorsky S 64-E Sky-Crane helicopter has been used to remove old-growth Sitka spruce, western hemlock, and western red cedar from environmentally sensitive floodplain sites. Between 1986 and 1989, 67 500 m^3 of timber was logged from 141 ha in 14 partially cut blocks.

A retrospective study of the development of these partial cutting operations was conducted. Four case studies are presented to describe the type of floodplain sites on which partial cutting has been used. Various forestry concerns about partial cutting are reviewed, including the silvicultural implications, the damage to residual trees, blowdown following cutting, and the protection of important fish habitats. The procedures used to select appropriate sites, mark individual trees, and conduct falling, yarding, and postlogging clean-up are described.

The partial cutting and helicopter yarding at Naden Harbour has been successful in meeting the objectives of (1) harvesting a previously inaccessible volume of timber and (2) protecting environmentally sensitive fish habitats. The methods and procedures developed here for partial cutting and helicopter yarding may be appropriate on a variety of other sites in coastal British

Columbia where objectives such as protecting wildlife habitats, retaining aesthetic values, or maintaining the stability of steep slopes require or favour partial cutting over conventional clearcutting and cable yarding.

Most of the silvicultural concerns for partial cutting in old-growth coastal forests have been overcome at Naden Harbour. Most blocks are expected to be windfirm and will become fully stocked uneven-aged stands that will support another harvest before the normal rotation period. Procedures for improving the condition of the residual stand are identified in this report. As well, recommendations are made to ensure that the silvicultural objectives for the residual partially cut stand are set before tree marking and cutting begin.

325) Moore, R., T. Gomi, and A. Dhakal. 2003. Headwater stream temperature response to forest harvesting in coastal British Columbia: Influences of riparian buffer width, channel morphology and weather. AGU 2003 Fall Meeting, 8-13 December, San Francisco. Eos Transactions 84(46): Suppl. abstract H32D-03. (A, H, J)

Electronic abstract: Forest harvesting can influence stream temperature regimes, and the potentially deleterious impacts of higher temperatures on salmonids and other species have generated significant debate. One common approach to protecting streams is to leave a riparian buffer to provide shade. However, little information has been collected on the effectiveness of different buffer widths. We report the results of a 6-year field experiment to evaluate the effects of different riparian buffer widths on stream and riparian ecosystems, including stream temperature response, in headwater streams in coastal British Columbia. The experiment included 13 streams, with at least three being assigned to each of four treatments, including no harvesting (80 yr-old second growth conifer riparian forest), clear-cut harvesting with 10 m and 30 m riparian buffers, and clear-cut harvesting with no buffer. Regression analysis was used to calibrate the pre-harvest data for each treatment stream with one of the control streams, to provide a basis for estimating post-harvest treatment effects. Autoregressive and heteroskedastic errors were included in the regression model, because stream temperature exhibited serial correlation and the error variance increased with stream temperature. Temperature response was substantial in the clearcut treatments with no buffers, with maximum temperatures increasing by up to 8 degrees C. The magnitude of temperature response amongst the no-buffer treatments varied with channel morphology, particularly in relation to bank shading and stream depth. The treatment effect for daily maximum water temperature increased with decreasing flow and increasing maximum air temperature on the current day, and also exhibited significant autocorrelation, indicating that the sequence of daily weather conditions can influence the magnitude of temperature response.

326) Morse, B., and F. Hicks. 2003. Advances in river ice hydrology. In: Quadrennial Report to the International Union of Geodesy and Geophysics and International Association of Hydrological Sciences. J.W. Pomeroy, Compiler. Canadian National Committee for the International Association of Hydrological Sciences (CNC-IAHS). Pages 32-41. (A, F, G, I)

Author abstract: We identify three significant recent advances in the hydrology of river ice: (1) by bringing together disparate information, excellent review articles (Shen 2003; Prowse 2001a&b; Beltaos 2000) have noticeably advanced our appreciation of river ice hydrology.

Recently, there have also been two special journal issues on river ice (CJCE 2003 and HP 2002) and five conferences (CRIPE 1999, 2001 and 2003 and IAHR 2000 and 2002); (2) There has been the recognition that in order to advance, collaborate efforts are required (Prowse, 2001b) and Shen (2003) has specifically called for a collaborative research project; and (3) perhaps the greatest advance is the fact that there has been the birth of the discipline of the *hydrology* of river ice: The case has been made that river ice is too important to ignore when studying water quantity (Water Survey of Canada has launched a program to address this issue), water quality (temperature, dissolved oxygen, nutrients and pollutants), sediment transport and geomorphology (particularly as it relates to breakup), stream ecology (plants, food cycle, etc.) and fish habitat, behaviour and survival. There have also been significant advances in modelling (1-D public domain ice jam models are now available; the first public-domain 2-D model capable of simulating flows with an ice cover is now available and a commercial version of a complete 2-D ice-process model is being completed). The main need for further work is to: (1) interface geomorpological and habitat models with these river ice hydrodynamic models; (2) develop a complete package (database management, remote sensing, forecasting, intervention methodologies, etc.) to better intervene in ice jam induce flash floods (e.g. Badger Nfld, February 2003). We would add that, given the importance of winter navigation on the St. Lawrence River to the Canadian economy (approximately $2 billion annually), a durable and dependable solution to prevent ice jams downstream of Montreal is still required.

327) Mossop, B., and M.J. Bradford. 2004. Importance of large woody debris for juvenile chinook salmon habitat in small boreal forest streams in the upper Yukon River basin, Canada. Canadian Journal of Forest Research. 34: 1955-1966. (A, D)

Author abstract: The importance of large woody debris (LWD) in forested stream ecosystems is well documented. However, little is known about LWD in northern boreal forest streams. We investigated the abundance, characteristics, and function of LWD in 13 small tributary streams of the upper Yukon River basin, Yukon Territory, Canada. LWD abundance was similar to values reported from temperate regions, whereas LWD size and total volume were well below values for the Pacific Northwest. LWD formed 28% of the pools, which provide important habitat for juvenile chinook salmon (*Oncorhynchus tshawytscha* Walbaum). The median diameter of pool-forming pieces was 17 cm, and ring counts on fallen riparian trees indicated that pool-forming pieces were likely 70–200 years old when downed. Juvenile chinook salmon density was correlated with LWD abundance in our study reaches. We conclude that despite differences in climate and forest type, LWD in Yukon streams and LWD in temperate regions appear to perform a similar function in creating fish habitat. Resource managers should consider the relatively slow tree growth and thus potentially long recovery times following human disturbances in these watersheds.

328) Negishi, J.N., and J.S. Richardson. 2003. Responses of organic matter and macroinvertebrates to placements of boulder clusters in a small stream of southwestern British Columbia, Canada. Canadian Journal of Fisheries and Aquatic Sciences. 60: 247-258. (C)

Author abstract: Diversity and productivity of stream food webs are related to habitat heterogeneity and efficiency of energy retention. We tested the hypothesis that experimental

boulder placements in a second-order stream would increase diversity and abundance of macroinvertebrates by restoring detrital retention and habitat heterogeneity. Two relatively natural, upstream, reference reaches and a downstream treatment reach with a relatively straight channel and less woody debris were studied for 3 months before and 1.2 years after the placement of six boulder clusters in the treatment reach. Mean velocity and its coefficient of variation increased in the treatment reach (140 and 115%, respectively), whereas the reference reaches remained relatively unchanged after the placements. Enhanced particulate organic matter storage (550%) was accompanied by increased total macroinvertebrate abundance (280%) in the treatment reach, converging with those of the reference reaches almost 1 year after the treatment. Detritivorous taxa numerically dominated the macroinvertebrate community, the total densities of which were best predicted by the fine fraction of organic matter biomass at microhabitat scale. However, the effect of boulder clusters on taxonomic richness was negligible. Our findings suggest that boulder clusters can be used at least as a short-term means to restore macroinvertebrate productivity in detritus-based stream systems.

329) Nicholls, K.H., R.J. Steedman, and E.C. Carney. 2003. Changes in phytoplankton communities following logging in the drainage basins of three boreal forest lakes in northwestern Ontario (Canada), 1991–2000. Canadian Journal of Fisheries and Aquatic Sciences. 60: 43-54. (C)

Author abstract: The phytoplankton communities of three small boreal forest lakes (L26, L39, and L42) on Ontario's Precambrian Shield (Canada) were investigated over 10 years for possible effects of forest harvesting (logging) within their drainage basins (5 years before logging vs. 5 years after logging). During the postlogging period, higher biovolumes of several taxa were recorded, consistent with previously reported changes in nutrients, chlorophyll, light penetration, and mixing depth. Among the most dramatic changes were increases of 100 and 266% in Cyanophyceae in L39 and L42, respectively, 167% in Dinophyceae in L26, 51 and 130% in Chlorophyceae in L26 and L42, respectively, 182% in Bacillariophyceae in L26, and 53 and 73% in total phytoplankton in L26 and L42, respectively. Other effects associated with logging in the watersheds of these lakes included an increase in the numbers of taxa (in accordance with the intermediate disturbance hypothesis) and a decrease in interannual variability in phytoplankton community structure (in accordance with the ecosystem diversity–stability hypothesis). The less extensive logging of the L26 drainage basin and the maintenance of an unlogged shoreline buffer strip did not preclude apparent effects on phytoplankton comparable with some of those found in the other two lakes, where drainage basin logging was more extensive.

330) Outhet, D.N. 1974. Bank erosion in the southern Mackenzie River Delta, Northwest Territories, Canada. M.S. Thesis, University of Alberta, Edmonton. 89pp. (F, G, J)

Author abstract: Analysis of 2-week time lapse photography in the field and from the air, along with other data collected in the field, indicates that in the southern Mackenzie River Delta, the shape of an eroding bank is positively correlated with the erosion process and the rate and character of erosion. Poor correlations between bank erosion and the following factors indicate the complexity of erosion processes: current velocity; channel orientation to the wind; ice content of the bank sediment; vegetation; roots; water temperature; and ice during break-up.

Prediction of bank erosion cannot be made by measuring these factors. There are five different easily-distinguished bank shapes in the study area each with its own maximum and minimum erosion rates and manner of erosion. This information allows the short-term prediction of eroding bank behavior on the basis of bank shapes and the production of a map showing the erosion rate category into which each bank fits. This map may be used in the planning of construction in the area to avoid rapidly eroding banks such as those that may erode up to 30 m/yr.

331) Patoine A., B. Pinel-Alloul, and E.E. Prepas. 2002. Effects of catchment perturbations by logging and wildfires on zooplankton species richness and composition in Boreal Shield lakes. Freshwater Biology. 47: 1996-2014. (C, I)

Electronic abstract (Summary):
1. Forest logging and wildfires are important perturbations of the boreal forest, but their effects on lake biota remain largely unknown. Here, we test whether zooplankton species richness and species assemblages differed among three groups of lakes in Eastern Canada characterised by different catchment conditions: logged in 1995 (*n*=9); burnt in 1995 (*n*=9); unperturbed (*n*=20). Lakes were sampled in June, July and September 1 year after catchment perturbations.
2. Cumulative species richness in reference lakes averaged 46 (33–60) of which 63% were rotifers. Mean cumulative species richness and mean diversity in logged and burnt lakes did not differ from those in reference lakes.
3. Lake species assemblages were described by the density of 62 species (41 rotifers and 21 crustaceans). Among-group differences in species assemblages were not significant. Eighteen per cent of the total variability in species assemblages could be explained by 13 environmental factors, among which dissolved oxygen concentration and cyanobacteria biovolume were the most important. About 5% of species assemblage variability was attributed to covariation between environmental factors and time of sampling, while 4.1% was attributed to temporal variation.
4. Variations in zooplankton species richness and assemblages in Boreal Shield lakes are important, both among lakes and among sampling dates. They seem to depend on environmental factors unrelated to catchment-based perturbations, at least on the short-term of 1 year.

332) Patoine, A., B. Pinel-Alloul, and E.E. Prepas. 2002. Influence of catchment deforestation by logging and natural forest fires on crustacean community size structure in lakes of the eastern Boreal Canadian forest. Journal of Plankton Research. 24: 601-616. (C, E)

Electronic abstract: Logging and wildfires are important perturbation factors of the Canadian Boreal forest, but their effects on aquatic communities remain largely unknown. Here, we assess the ecological effects of logging and wildfires on aquatic communities, based on changes in crustacean zooplankton size spectra among logged, burnt and unperturbed lakes of the Canadian Precambrian Boreal Shield. A laboratory version of the Optical Particle Counter (OPC-1L) was used to establish the crustacean size spectra of zooplankton samples collected in 38 lakes characterized by different catchment conditions: logged in 1995 (nine 'logged' lakes); burnt in 1995 (nine 'burnt' lakes); left unperturbed over the past 70 years (20 reference lakes). Size spectra are characterized by crustacean biovolume in 22 size classes, from 200–300 µm equivalent spherical diameter (ESD) to 2300–2400 µm ESD. Size spectra in logged and burnt

lakes were on average shifted towards larger size classes relative to reference lakes, although the reference and burnt groups of lakes were the only pair statistically different from one another (at $\alpha = 5\%$). As a result, biovolume of crustacean organisms >1100 µm ESD in burnt lakes was on average higher by 366 and 388%, respectively, 1 and 2 years following catchment perturbations relative to reference lakes. Among a set of 15 water quality variables and 14 fish species density variables, potassium concentration and white sucker density were the most important environmental correlates of crustacean size structure.

333) Patoine, A., B. Pinel-Alloul, E.E. Prepas, and R. Carignan. 2000. Do logging and forest fires influence zooplankton biomass in Canadian Boreal Shield lakes? Canadian Journal of Fisheries and Aquatic Sciences. 57: 155-164. (C)

Electronic abstract: Zooplankton biomass was assessed in 20 reference lakes, nine logged-watershed lakes, and nine burned-watershed lakes during three summers following watershed disturbances by logging or wildfires. Biomass of cladocerans, calanoids, cyclopoids, and rotifers was quantified in the 38 lakes for the first year following disturbances. Limnoplankton biomass in four size fractions was quantified during 3 years following disturbances. One year after disturbances, burned-watershed lakes supported 59% more biomass of the rotifer size fraction of limnoplankton (100-200 µm) than reference lakes, while logged-watershed lakes supported 43% less of calanoid biomass. Two years after disturbances, differences in limnoplankton biomass between burned-watershed lakes and reference lakes were more pronounced than during the first year, while logged-watershed lakes supported levels of limnoplankton biomass no different from those of reference lakes. Three years after disturbances, no significant variations could be detected among the three groups of lakes for any of the limnoplankton size fractions. The proportion of watershed area impacted by logging activities was on average less than half the proportion impacted by wildfires. Nonetheless, both types of disturbances seemed to have opposite effects on the zooplankton biomass during the first year, and the effects did not extend beyond 2 years.

334) Pinel-Alloul, B., and A. Patoine. 2000. Comparative impact of natural fires and forest logging on zooplankton communities of boreal lakes. Project Report 2000-23 written by the Sustainable Forest Management Network, University of Alberta, Edmonton. 39pp. (C, E, I)

Author abstract: The goal of the research project was to determine if natural fires and forest logging have a significant impact on zooplankton biomass, biodiversity, species assemblages, and size spectra in lakes of the Canadian Boreal Shield. Wildfires and logging disturbances occurred in 1995. The research project was carried out from 1996 to 1998 in 38 lakes of the boreal forest in Québec: Twenty (20) lakes, undisturbed since 70 years, served as references; nine (9) lakes had 9-72% of their watershed logged and another 9 lakes had 50-100% of their watershed burnt. Three methodological approaches were used to determine zooplankton attributes: a) taxonomic analysis for zooplankton biomass, species richness and assemblages, b) analysis of size-fractionated limnoplankton ash-free dry weight, and c) determination of crustacean biovolume size spectra using an Optical Particle Counter (OPC). Our study reveals that natural fire and logging disturbances have different impacts on zooplankton community of boreal lakes. Natural fires increase zooplankton and limnoplankton biomass because of higher

inputs of mineral nutrients (nitrates and phosphorus) from burnt watersheds. Burnt lakes supported on average 53-64% more biomass of cyclopoids and rotifers (or 59% more biomass of limnoplankton 100-200 µm size fraction) than reference lakes the first 2 years after fire. In contrast, logging does not increase zooplankton biomass because of higher inputs of dissolved organic carbon from watershed which inhibit light transmission and biological production. Cut lakes supported on average 43% fewer biomass of calanoids than reference lakes during the first year after logging. The biomass of cladocerans and copepodite stages did not vary significantly among reference, cut and burnt lakes. The impacts of natural fire and logging on zooplankton biomass were more pronounced 2 years after disturbances. Impacts of wildfire and logging on zooplankton biodiversity and species assemblages, measured the first year following disturbances, are minor. Crustacean biovolumes in large size classes (1200-1500 µm) were higher in perturbed lakes, especially in burnt lakes. Zooplankton biomass and size spectra, as well as limnoplankton biomass are promising tools to monitor the effects of watershed disturbances by natural fire and logging on zooplankton communities in boreal lakes. However among-lake and seasonal changes in watershed and limnological characteristics are more important sources of variability in zooplankton biomass than watershed disturbances, and should be considered when assessing the environmental impacts of watershed disturbances on zooplankton in boreal lakes.

335) Price, K., and D. McLennan. 2002. North Coast LRMP background report: Hydroriparian ecosystems of the North Coast. Written for the North Coast LRMP, British Columbia. 80pp. (C, D, F, H, I, J)

Author abstract (Author Summary—First paragraph): This report provides background information on riparian ecosystems for the North Coast LRMP [North Coast Land and Resource Management Plan]. The report

- describes North Coast riparian ecosystems,
- reviews riparian ecological functions,
- presents riparian management policies for BC and neighbouring jurisdictions,
- lists potential strategic planning issues for consideration.

Literature is taken from the North Coast where possible. Where research is cited from areas outside the North Coast, the report describes the potential relevance of studies to North Coast ecosystems.

336) Price, K., A. Suski, J. McGarvie, B. Beasley, and J.S. Richardson. 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. (C, G)

Author abstract: 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.

337) **Rice, S., and M. Church. 1996. Bed material texture in low order streams on the Queen Charlotte Islands, British Columbia. Earth Surface Processes and Landforms. 21: 1-18. (D, I)**

Author abstract: Low order channels comprise a large proportion of the links of every drainage basin, and are often at the centre of land management concerns. They exhibit hydrological and geomorphological characteristics atypical of higher order links. This paper examines the nature and causes of variations in the bed material texture of two streams on the Queen Charlotte Islands, British Columbia. The extant, functional exponential model is found to be inadequate for explaining observed changes in grain size parameters with distance downstream. Recurrent disruption of sediment transport by large organic debris jams, and the sporadic contamination of the fluvial sediment population by colluvial inputs, preclude the development of longitudinal structure. Rather, grain size varies erratically over short distances. A stochastic model best describes the observed variations, and should be adopted as an alternative to the exponential model in low order links. Characteristic variances are controlled by the degree of hillslope-channel coupling, and the extent and characteristics of non-alluvial storage mechanisms.

338) **Rice, S.P., M.T. Greenwood, and C.B. Joyce. 2001. Tributaries, sediment sources, and the longitudinal organisation of macroinvertebrate fauna along river systems. Canadian Journal of Fisheries and Aquatic Sciences. 58: 824-840. (C, I)**

Author abstract: Tributary confluences are sites along a main channel where, because of the introduction of water and (or) sediment, the water volume, bed sediment character, and water quality of the mainstream can change abruptly. These shifts ensure that abiotic gradients seldom vary smoothly or continuously for distances of more than 10^0–10^2 km along any river system. The ways in which tributaries and related sediment recruitment points structure longitudinal changes in physical habitat are examined. Variables of importance to stream biota are affected and, in turn, it is suggested that the arrangement of tributaries and related features is an important control on the longitudinal organisation of macroinvertebrate benthos at moderate spatial scales. A new model is presented that stresses the importance of hydrological and sedimentological networks for organising lotic fauna. The link discontinuity concept emphasises the discontinuous nature of lotic ecosystem gradients, addresses the importance of tributaries in unregulated as well as regulated rivers, and extends, to its logical conclusion, the limited recognition of tributary influence in the river continuum concept. A case study from British Columbia, Canada, illustrates the general merit of the new model.

339) Richardson, J.S. 2000. Life beyond salmon streams: Communities of headwaters and their role in drainage networks. In: Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, 15-19 February 1999, Kamloops, British Columbia, Volume Two. L.M. Darling, Editor. B.C. Ministry of Environment, Lands, and Parks, Victoria, B.C. and University College of the Cariboo, Kamloops, B.C. Pages 473-476. (C)

Author abstract: 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 harbour 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.

340) Rosenfeld, J., M. Porter, and E. Parkinson. 2000. Habitat factors affecting the abundance and distribution of juvenile cutthroat trout (*Oncorhynchus clarki*) and coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences. 57: 766-774. (A, D)

Author abstract: The distribution, abundance, and habitat associations of juvenile anadromous coastal cutthroat trout (*Oncorhynchus clarki*) and coho salmon (*Oncorhynchus kisutch*) were evaluated using survey data from 119 sites in coastal British Columbia. Both cutthroat and coho occurred at their highest densities in very small streams (<5 m channel width), and bankfull channel width was the single best predictor of cutthroat presence (p=0.0001) and density (R^2 =0.55). Within a channel, densities of coho and larger (yearling and older) cutthroat parr were highest in pools, while densities of young-of-the-year cutthroat were significantly lower in pools and highest in shallower habitats. Abundance of larger cutthroat parr and pool habitat were positively correlated with large woody debris (LWD) within a subset of intermediate-gradient gravel-cobble streams, where pools appear to be limiting to larger cutthroat parr abundance. More than 50% of pools were formed by scour associated with LWD in streams ranging from 1.2 to 11 m channel width, and pools formed by LWD scour were on average 10% deeper than pools formed by other mechanisms. Disproportionate use of small streams by cutthroat indicates that protection of small stream habitat is important for long-term conservation of sea-run populations.

341) Scherer, R. 2001. Effects of changes in forest cover on streamflow: A literature review. In: Watershed Assessment in the Southern Interior of British Columbia. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. D.A.A. Toews and S. Chatwin, Editors. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 44-55. (G)

Author abstract: The Interior Watershed Assessment Procedure that is used in British Columbia relies heavily on the use of Equivalent Clearcut Area as a tool to estimate potential hydrologic impacts on forest development on peak flows. The purpose of this literature review was to summarize the results of numerous watershed experiments that have explored the relationship of changes in forest cover to changes in spring freshet peak flows, the timing of peak flows, water yield, and low flows. This review included only snowmelt-dominated watersheds that are situated within western Canada and the United States and that could be related to watersheds located within the central and southern interior of British Columbia. The review indicated highly variable changes in: peak flow (ranging from no change to 66% increase), peak-flow timing (ranging from no change to 18 days advancement), water yield (ranging from no change to 111% increase), and low flow (ranging from no change to 37% increase). Also, there was no consistent relationship between forest-cover removal and the above hydrologic variables.

342) Smith, D.G. 1976. Effect of vegetation on lateral migration of anastomosed channels of glaciers meltwater river. Geological Society of America Bulletin. 87: 857-860. (F)

Author abstract: A series of experiments were performed on bank materials of anastomosed channels in flood-plain silt deposits in the Alexandra Valley in Banff Park, Alberta, to determine the effect of vegetation roots on bank erodibility and lateral migration of channels. Underground roots from the dense growth of meadow grass and scrub willow provide the reinforcement of bank sediment and a riprap-like protection of channel banks from river erosion. Results from the experiments suggest that in cool environments with aggrading river conditions where overbank deposition of silt, clay, and fine sand dominate then valley fill, vegetation roots are able to rapidly accumulate and decay very slowly, thus affording protection to banks from erosion deeper party of the channels.

Experiments were performed with a specially designed erosion box, used as a means to stimulate natural erosion conditions and measure the influence of vegetation roots in reducing bank erosion. Results indicate that the bank sediments with 16 to 18 percent by volume of roots with a 5 –cm root-mat for bank protection, typical of the area, had 20,000 times more resistance to erosion than comparable bank sediment without vegetation. Assuming five severe erosion days per year, potential lateral channel migration would amount to 4.2 cm per year. Such resistance, due to vegetation, accounts for the remarkable stability of channels during the last 2,500 yr in the Alexandra Valley.

343) 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(S2): 92-96. (C, I)

Electronic abstract: 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

Ca^{2+} and Mg^{2+} 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.

344) Steedman, R.J., and R.S. Kushneriuk. 2000. Effects of experimental clearcut logging on thermal stratification, dissolved oxygen, and lake trout (*Salvelinus namaycush*) habitat volume in three small boreal forest lakes. Canadian Journal of Fisheries and Aquatic Sciences. 57: 82-91. (I, J)

Author abstract: Clearcut logging around three 30- to 40-ha dimictic northwestern Ontario lakes was associated with increases of 5% or less in midlake wind speed and no measurable changes in spring and fall circulation efficiency or duration of stratification. Water clarity, indexed as the depth at which photosynthetically active radiation was 1% of surface intensity, declined by 25% after 3 years. Late-summer thermoclines were about 1 m shallower in two lakes after logging, but it was not possible to exclude weather as a factor. None of the lakes showed significant declines in lake trout (*Salvelinus namaycush*) habitat volume. A forested shoreline buffer strip around one of the lakes prevented increases in midlake wind speed but did not prevent declines in water clarity and thermocline depth.

345) Steedman, R.J., R.S. Kushneriuk, and R.L. France. 2001. Littoral water temperature response to experimental shoreline logging around small boreal forest lakes. Canadian Journal of Fisheries and Aquatic Sciences. 58: 1638-1647. (J)

Author abstract: Shoreline logging did not significantly increase average littoral water temperatures in two small boreal forest lakes in northwestern Ontario, Canada. However, over the early summer monitoring period clearcut shorelines were associated with increases of 1–2°C in maximum littoral water temperature, and increases of 0.3–0.6°C in average diurnal temperature range, compared with undisturbed shorelines or shorelines with 30-m shoreline buffer strips. Comparison of simultaneous water temperatures at littoral locations with and without shoreline forest showed that increased temperatures were caused by daytime heating.

346) St-Onge, I., and P. Magnan. 2000. Impact of logging and natural fires on fish communities of Laurentian Shield lakes. Canadian Journal of Fisheries and Aquatic Sciences. 57(S2): 165-174. (K)

Electronic abstract: The goal of this study was to determine if natural fires and logging have a significant impact on abundance, growth, and size structure of fish populations in 38 lakes of the Laurentian Shield (Québec, Canada). The watersheds of nine of these lakes underwent logging and nine underwent natural fires, while the 20 remaining lakes were used as references. No significant differences were found among the three lake groups in the catch per unit of effort of the most abundant species: white sucker (*Catostomus commersoni*), northern pike (*Esox lucius*), yellow perch (*Perca flavescens*), lake whitefish (*Coregonus clupeaformis*), fallfish (*Semotilus corporalis*), brook trout (*Salvelinus fontinalis*), walleye (*Stizostedion vitreum*), and burbot (*Lota lota*). No significant difference was found among control, burned, and logged lakes in the back-calculated length of yellow perch, for which age determinations were made. However, we found that the proportions of small yellow perch and white sucker were significantly lower in populations of impacted lakes (burned and logged lakes pooled). The influence of logging and

fires remained significant when a series of biotic and abiotic variables on watershed and lake characteristics were accounted for in multiple regression analyses. The lower proportion of small fish in impacted lakes could be due to an increase in postemergence mortality or to a shift of individuals to the pelagic zone.

347) Story, A., R.D. Moore, and J.S. Macdonald. 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. (J)

Author abstract: 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 $L \cdot s^{-1}$. 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%.

348) Tonn, W.M., P.W. Langlois, E.E. Prepas, A.J. Danylchuk, and S.M. Boss. 2004. Winterkill cascade: Indirect effects of a natural disturbance on littoral macroinvertebrates in boreal lakes. Journal of the North American Benthological Society. 23: 237-250. (C)

Author abstract: Natural disturbances can provide insights into mechanisms organizing communities by perturbing systems at larger scales and more realistic intensities than can often be achieved otherwise. We took advantage of 2 winterkills of fish, a common disturbance of small lakes on the Boreal Plains of northern Alberta (Canada), to assess the effects of sudden, large reductions in fish densities on littoral macroinvertebrate assemblages. Winterkill nearly eliminated the native fish assemblages (dominated by northern pike, *Esox lucius*, and yellow perch, *Perca flavescens*) in the 2 lakes, whereas 2 nearby lakes with similar fish assemblages were unaffected and served as references. Environmental characteristics of both winterkill and reference lakes changed little from year to year. Uni- and multivariate analyses of macroinvertebrates revealed some inherent among-lake differences; however, strong and parallel changes in the invertebrate assemblages occurred only in the 2 winterkill lakes, congruent with the winterkills of fish. Decreases in fish biomass were generally accompanied by increases in macroinvertebrate density, particularly among taxa (e.g., amphipods, leeches, chironomids) commonly eaten by the native fish. As a result, analyses of matrix concordance and variance partitioning showed variation in macroinvertebrate assemblages was related to both temporal changes in fish density and environmental differences among lakes but that the fish and

environmental matrices were not strongly concordant. Our serendipitous study of community-level disturbance revealed that winterkill-induced reductions of fish densities can have strong, cascading effects on littoral macroinvertebrates in these boreal lakes.

349) Tonn, W.M., C.A. Paszkowski, G.J. Scrimgeour, P.K.M. Aku, M. Lange, E.E. Prepas, and K. Westcott. 2003. Effects of forest harvesting and fire on fish assemblages in boreal plains lakes: A reference condition approach. Transactions of the American Fisheries Society. 132: 514-523. (K)

Author abstract: To assess the impacts of forest harvesting and fires on lentic fish assemblages in the Boreal Plains ecoregion (Alberta, Canada), we applied a reference condition approach to 37 lakes in burned, logged, or undisturbed catchments. Fish assemblages in the reference lakes were classified into two types: those dominated by large-bodied piscivores and those dominated by small-bodied fishes. A discriminant function analysis with only two environmental descriptors (lake maximum depth and average slope of the catchment) could correctly predict assemblage type in 84% of reference lakes. Depth likely reflects the influence that winter oxygen concentrations have on fish assemblage type, whereas catchment slope is correlated with a variety of landscape-level features. Although potential effects of forest harvesting and fire can increase the susceptibility of lakes to winter hypoxia (via nutrient enrichment) and alter connectivity to the regional drainage network (via altered hydrology), fish assemblages in 93% of the disturbed lakes did not deviate from the discriminant function predictions, suggesting little, if any, assemblage-level effects of the disturbances over the 1–2-year time period of our study. Indeed, the level of disturbance in a catchment could explain less than 3% of the variation in assemblage structure, although a slight increase in the catches of white sucker *Catostomus commersoni* and a greater proportion of small individuals in white sucker populations may have reflected a modest enrichment effect in burned lakes. Current levels of landscape disturbance on the Boreal Plains appear to have minimal effects on lake fish assemblages but, because of the susceptibility of these lakes to winterkill, higher levels of terrestrial disturbance could prove detrimental.

350) Tripp, D.B., and V.A. Poulin. 1992. The effects of logging and mass wasting on juvenile salmonid populations in streams on the Queen Charlotte Islands. Land Management Report Number 80 written by Tripp Biological Consultants, Ltd., Nanaimo, British Columbia, and V.A. Poulin & Associates, Ltd., Vancouver, British Columbia. Written for the Fish/Forestry Interaction Program, Research Branch, B.C. Ministry of Forests, Victoria. 38pp. (A, B, D, F)

Author abstract (Author Summary): The effects of logging and mass wasting on juvenile coho salmon (*Oncorhynchus kisutch*), steelhead trout (*O. mykiss*, formerly *Salmo gairdneri*), and Dolly Varden char (*Salvelinus malma*) were assessed in streams on the Queen Charlotte Islands. Fish densities and habitat characteristics of 27-33 stream reaches were measured during summer and fall. Reaches sampled included undisturbed old-growth forest streams (unlogged), logged streams not directly affected by recent mass wasting (logged), and logged streams directly affected by recent debris torrents and slides (mass wasted). Overwinter survivals and smolt yields in three mass wasted and three non-mass wasted streams (all logged) were also estimated

in a downstream spring fish trapping program, after determining the number of fish present in each stream theprevious fall.

Logged reaches had less undercut bank cover than unlogged reaches, but did not differ significantly from unlogged areas in any other habitat variable measured. Mass wasted stream reaches, in contrast, had even less undercut bank cover, less large organic debris (LOD), fewer pools and glides, and more riffles. They also had shallower pools during summer, a smaller wetted stream width relative to rooted channel width, and less overwinter cover in the form of deep pools with undercut banks and abundant LOD.

With one exception, there was no relationship between summer and fall fish densities and any of the habitat parameters measured in this study. The exception was the depth of gravel scour overwinter, which appeared to determine the early summer abundance of coho fry in mass and non-mass wasted streams (all logged). Logged reaches had significantly higher coho fry densities than unlogged or mass wasted reaches in summer and fall. Fish in mass wasted reaches exhibited faster growth rates and attained larger sizes, as long as fry were not trapped in isolated pools when reaches ''dewatered''. In mass wasted streams, a combination of poor egg-to-fry survivals due to excess gravel scour, and poor juvenile overwinter survivals due to overwinter habitat loss, nullified any gains in production attributable to logging. It also nullified the high growth rates and large size achieved by fish in their first year in mass wasted streams. Juvenile overwinter survivals for all species were 2.1-3.5 times higher in non-mass wasted streams than in mass wasted streams; smolt yields were 1.5-3.3 times higher.

The overall impacts of mass wasting on juvenile fish, and coho salmon in particular, are serious enough to jeopardize the continued existence of self-sustaining populations in directly affected reaches until stream conditions improve. Four out of 11 mass wasted reaches in 1982 and 2 out of 3 mass wasted reaches in 1984 had effectively no coho fry. Impacts on Dolly Varden and steelhead trout did not appear as serious, though they too showed declines in overwinter survivals and smolt yields. Impacts on other species such as chum and pink salmon were not investigated, though presumably these species would be negatively stressed by increased gravel scour. Fish populations in otherwise normal (logged) reaches downstream of major mass wasting events may also be adversely affected by mass wasting upstream, but the problem requires further study.

351) Verschuren, J.P., and M. Bristol. 1974. Runoff from small watersheds and river bank erosion near Watson Lake, Y.T. Indian and Northern Affairs Publication No. QS-1585-OOO-EE-A1 written by the Department of Civil Engineering, University of Alberta. Written for the Arctic Land Use Research Program, Northern Natural Resources and Environment Branch, Department of Indian and Northern Affairs. 35pp. plus Appendices. (G, F)

Author abstract: This report describes the current research being conducted by the Department of Civil Engineering of the University of Alberta as part of the Arctic Land-Use Research Program. The objective of the program has been to conduct research into environmental problems resulting from land-use operations associated with resource development. This study has been conducted in the south-east Yukon, an area of the boreal forest within the region of discontinuous permafrost.

Hydrographs are presented for the entire period of record for eight study watersheds in the Watson Lake area, together with daily rainfall and mean daily temperatures. The hydrographs are

analysed and compared with those of two study watersheds situated in the foothills area of Alberta.

A comparison is made between the study watersheds and those of southern mountain areas by means of basin response factors calculated as the ratio of total 'quick' runoff to total precipitation measured over a monthly time period. The response factors are used to indicate which of the Watson Lake watersheds will be most susceptible to land-use changes.

Results of the 1973 erosion study at two sites on the Liard River are presented together with a preliminary interpretation of the data acquired to date, including an explanation of the erosion mechanism for deep rivers and the role played by bank vegetation. An erosion index has been formulated based on channel and flood plain characteristics to give an objective, quantitative measure of bank erosion potential.

An approach to further gauging of small streams in the North and to river bank erosion studies in general, is suggested.

352) Whitaker, A., Y. Alila, and D.A.A. Toews. 2001. Modelling of peak flow change using the DHSVM model. In: Watershed Assessment in the Southern Interior of British Columbia. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. D.A.A. Toews and S. Chatwin, Editors. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 94-111. (G)

Author abstract: The Distributed Hydrology Soil Vegetation Model (DHSVM) is a physically based model that uses a Digital Elevation Model (DEM) to stimulate the effect of topography on hydrologic processes. The influence of the forest canopy on the accumulation and melt of snowpack is simulated in an explicit and physically based approach. Model calibration was possible through the use of snow course surveys and snowline air-photo surveys in addition to stream discharge at Redfish Creek experimental watershed near Nelson, B.C., where extensive hourly data is available. The model appears to correctly simulate the influence of forest canopy on the snowpack, and simulated and observed hydrographs are well matched in both calibration and verification periods. Subsequently, 10 harvest scenarios, with varying levels of cutting in different elevation zones, were evaluated over the 5-year period of record (1992-1997). Redfish Creek basin (26km^2) is divided into four elevation zones based on the hypsometric curve. The three lower zones (770-1880 m) contain operable forest and make up 60% of the total basin area, while the high-elevation alpine zone (1880 - 2300 m) forms 40% of basin area. Results show that harvesting at progressively higher elevations (especially upper forest zone and alpine) causes progressively larger increases in peak flows. There is significant variability from year to year, indicating that the magnitude of peak-flow change depends on the unique weather conditions and seasonal melt pattern in a given year. Cutting in the lowest zone (H80-H100) has little or no effect on peak flow. In the middle forest zone (H60-H80), low-intensity cutting (7% of basin) has little effect, but consistent increases in peak flows are seen with high-intensity cutting (13% of basin). In the upper zone (above H60), low-intensity cutting increased peaks by 6.7-9.5%, while high-intensity cutting produced increases of 13.1-19.4%. A scenario with low-intensity cutting in all forest zones showed a significantly reduced impact on peak flows (except in 1997) even though a greater percentage of basin area (20%) was harvested. Peak-flow change is closely related to harvest elevation(s) and also to seasonal weather patterns in snow-dominated watersheds such as Redfish Creek.

353) Whitfield, P.H., and W.G. Whitley. 1986. Water quality-discharge relationships in the Yukon River basin, Canada. In: Proceedings of the Cold Regions Hydrology Symposium, University of Alaska, Fairbanks. D.L. Kane, Editor. American Water Resources Association Technical Publication Series TPS-86-1. American Water Resources Association, Bethesda, Maryland. Pages 149-156. (G, I)

Author abstract: Weekly and biweekly water quality samples were collected at ten sites throughout the Canadian portion of the Yukon River basin during 1982-1983. The relationships between the water quality variables and discharge are examined. Most of the relationships between the variables and discharge are either positive or negative and exhibit hysteresis, a few variables appear to be independent of discharge. A system of classification of the relationships, with potential causal mechanisms, is proposed.

354) Wilford, D.J. 1984. The sediment-storage function of large organic debris at the base of unstable slopes. In: Fish and Wildlife Relationships in Old-Growth Forests. Proceedings of a symposium, 12-15 April 1982, Juneau, Alaska. W.R. Meehan, T.R. Merrell, Jr., and T.A. Hanley, Editors. Pages 115-119. (I)

Author abstract: Large organic debris in old-growth forests provides important sediment-storage elements on hill slopes. As the old-growth trees fall or blow down across the slope, they form a series of cross-slope obstructions. Sediments and small organic debris from upslope mass movements are deposited behind these obstructions, forming a series of terraces which temporarily delay the delivery of sediments to stream channels. Documentation of this storage role of large organic debris is provided from an old-growth Sitka spruce-western hemlock forest site in the Queen Charlotte Islands of British Columbia.

355) Winkler, R.D. 2001. Forest influences on snow: Preliminary results on effects of regrowth. In: Watershed Assessment in the Southern Interior of British Columbia. Workshop proceedings, 9-10 March 2000, Penticton, British Columbia, Canada. D.A.A. Toews and S. Chatwin, Editors. British Columbia Ministry of Forests, Research Program, Victoria, Working Paper 57. Pages 56-67. (K)

Author abstract: In British Columbia, snow accumulation and snow melt dominate the hydrology of most interior watersheds. Both the amount of snow accumulation and the rate of melt vary with forest cover, and its removal and regrowth. For regulatory purposes, the complex relationships between forest cover, snowpack processes, and the risk of elevated spring flows are currently approximated by the single forest inventory variable, tree height. Field data from Mayson Lake and Upper Penticton Creek indicate that tree height alone explains little of the variability in snow accumulation or melt measured under various forest cover types relative to the open. Of the inventory variables measured, crown volume, length, and density explained the largest proportion of the variability in snow accumulation in the forest relative to the open, and the square root of basal area was the best predictor of melt. Work to develop a method of evaluating hydrologic recovery over a broader geographic area and range of forest cover types continues.

356) Woo, M.K., and P. Marsh. 2003. Snow, frozen soils and permafrost hydrology in Canada, 1999 – 2002. In: Quadrennial Report to the International Union of Geodesy and Geophysics and International Association of Hydrological Sciences. J.W. Pomeroy, Compiler. Canadian National Committee for the International Association of Hydrological Sciences (CNC-IAHS). Pages 27-31. (G)

Author abstract: This paper provides an overview of Canadian research on snow, frozen soils and permafrost hydrology for the period 1999-2002; the period between the 1999 IUGG meeting in Birmingham and the 2003 IUGG in Sapporo. During this period there were significant advances in both our understanding of the physical processes, and our ability to model these processes. This report assesses these advances.

357) Young, K.A., S.G. Hinch, and T.G. Northcote. 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. (A, D, J)

Author abstract: 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 reach 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/m^2) after logging but had returned to the reference level (0.21 fish/m^2) by 1983 and was double (0.49 fish/m^2) 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 an over small streams after logging although a contravention of current logging regulations in British Columbia, may help protect resident trout populations following riparian logging.