Life Beyond Salmon Streams: Communities of Headwaters and Their Role in Drainage Networks

John S. Richardson
Wildlife Branch, British Columbia Ministry of Environment, Lands and Parks, and
Department of Forest Sciences, 2424 Main Mall, University of British Columbia, Vancouver, BC, V6T 1Z4, Canada
jrichard@interchg.ubc.ca

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.

Key words: cumulative effect, headwaters, productivity, riparian, stream.

Headwater streams serve important roles in drainage networks, including transport of water, sediment, and organic matter to lower reaches, in addition to providing a unique aquatic and riparian habitat. Since small streams make up much more than half of the total channel length in a watershed, the effects of land use can disturb the rates and quality of materials supplied to reaches downstream. These lower reaches are often habitat to fish and are thus given precedence for protection, rather than headwaters where other, lesser-known organisms are found.

Recent studies have demonstrated the critical role of organic matter input in supporting the productive capacity of streams (Richardson 1991, Wallace et al. 1997). Many species depend critically upon the energy provided by organic matter, by the habitat it creates, or both (Richardson 1991, 1992). Species diversity is, in part, a function of the productivity of a system. Forest harvest and other forms of riparian clearing obviously lead to severe reductions in organic matter inputs and shifts in community structure, but changes in communities can also be caused by changes in temperature patterns, algal growth, or hydrology. Exclusion of litter inputs or removal of leaf packs results in dramatic declines in diversity and productivity throughout stream food webs (Wallace et al. 1997, L. Rowe and J. Richardson unpubl. data). All of these studies point to the link between organic matter and the productivity base of the stream's food web, and to the importance of maintaining inputs of organic matter from riparian forests.

Small headwater streams are common, but their function in drainage networks and as habitat for organisms not associated with larger streams is poorly known. One of the main roles for riparian protection along larger streams is the supply of large woody debris, which may contribute habitat for some juvenile salmonids (Murphy and Koski 1989). We have little idea of the requirements for protection of headwater streams and whether changes in the tributaries may affect the downstream reaches that are provided with riparian reserves. Advances in the past decade make it possible to begin the task of evaluating the role of small streams in our watersheds.

In this paper I will discuss 3 themes related to the importance of headwaters for watersheds and for fish-bearing reaches downstream. First, organic matter supplied from the riparian zone is a critical and limited resource that forms the basis of most riverine food webs. This resource is supplied to downstream reaches from its input points, which are predominantly within headwaters. Second, headwaters and their riparian areas (including intermittent streams) provide habitat for many organisms of conservation concern, many of which we know very little about. Third, the issue of cumulative effects of changes to watersheds has been, and continues to be, difficult to address; however, this is a topic that needs to be studied.

STUDY AREA AND METHODS

The small streams studied by my students and I have included streams in the University of British Columbia (UBC) Malcolm Knapp Research Forest, the Chilliwack River valley, throughout the coastal western hemlock biogeoclimatic zone, and in the Horsefly Forest District.

RESULTS

Organic Matter

Small streams may get more than 95% of the energy that fuels their food webs from organic matter (leaves, needles, branches) that falls into the stream channel from the riparian area. The input of this organic matter, or detritus, can limit the productive capacity of some streams (Cummins et al. 1989, Richardson 1993). Estimates of organic matter inputs, decomposition rates, and standing crops (Richardson 1992) lead to the conclusion that small streams lose 70–94% of their inputs of particulate organic matter (POM; >0.45µm) to downstream reaches. In more recent studies (P. Kiffney and J. Richardson unpubl. data) we have estimated POM outputs of small, second-growth streams to be 0.76 ± 0.17 kg/m of stream channel (ash-free dry weight ± 1 s.e.).

We used a series of simple calculations based on input rates of organic matter (approx 270 $g/m^2/yr$) and stream channel areas (bankfull width X stream channel length ÷ 2 for the taper of the channel area). These particulate inputs were multiplied by a conservative estimate of lateral inputs (blow-in or wash-in from above the floodplain area) of 25%. Total inputs were discounted by 15% for losses due to leaching of soluble organics. Comparing our estimates of inputs and outputs would indicate that outputs are 4.79 (± 0.53) times that of the inputs. There are clearly mechanisms of the input-output process that we have yet to understand, but these numbers show that outputs are large and contribute substantially to downstream reaches.

Biodiversity

In British Columbia more than 75% of terrestrial vertebrates are closely associated with riparian areas (Morgan and Lashmar 1993). Headwater riparian areas may be unique in that they typically have a closed canopy with some different structural features than those found along larger streams with broad floodplains or openings in the canopy. Among the species found primarily in small streams are our 2 stream amphibians, the Pacific giant salamander (*Dicamptodon tenebrosus*) and the tailed frog (*Ascaphus truei*). Both these species are most commonly found in streams smaller than about 5 m bankfull width within British Columbia (Richardson and Neill 1995, 1998). Another vertebrate group found primarily along small streams are the water shrews.

The invertebrate faunas of streams and riparian areas are poorly known for any area of British Columbia, but we know enough to be able to point to groups of species that are uniquely associated with headwaters. There are several families of aquatic insects that are primarily associates of small, steep streams, including the mountain midges (Deuterophlebiidae) and net-winged midges (Blephariceridae). Two caddisflies of the genus *Eocosmoecus* have only been reported from about 6 sites each in British Columbia, and barely a handful of sites elsewhere in the Pacific Northwest (Wiggins and Richardson 1989).

The smallest of stream channels tend to have intermittent flow through late summer in British Columbia (unless spring-fed) and yet support a limited fauna of aquatic invertebrates. We do not yet know if there are species unique to these intermittent headwaters, but it is clear that some species reach their highest densities there and that they are by no means biological deserts (Muchow and Richardson 2000).

Cumulative Effects

Small changes in the biological and physical environment of headwaters may be incremental, leading to cumulative changes downstream. The magnitudes and directions of some of these changes are currently under study (Shrimpton et al. 2000, J. Richardson and P. Kiffney unpubl. data). It is clear that the effects of land use change the rates, timing, and variances of various processes, so it is not a simple matter to add and scale-up small changes to predict consequences downstream.

DISCUSSION

Small headwater streams play an important but unquantified role in the functioning of watersheds. The effects of changes in headwaters as a result of land use may be small and cumulative, but there have been few studies that have addressed any of the biological links between parts of a watershed at this scale. The uncertainty about management needs of headwater ecosystems and their role in maintaining healthy downstream environments is in part a consequence of the focus on fish habitat as the primary goal of riparian protection in western North America. While other objectives for riparian management have been articulated, the effectiveness of current guidelines have yet to be evaluated for goals other than protecting fish habitat. Some of the effects of not considering headwater protection include changes to subsidies of organic matter to downstream reaches, loss of a unique habitat, and small, incremental changes to downstream habitats.

Organic Matter

Stream ecosystems are intimately tied to the landscape through which they flow, and the streamside, or riparian, habitat is critical to the conservation of streams. The many influences of riparian areas on streams include supply of structural materials (large woody debris), inputs of organic matter, and shading. Over the past 2 decades the importance of organic matter inputs from riparian vegetation has been emphasized by many authors (Hynes 1975, Cummins et al. 1989). The 2 primary sources of biologically available energy in streams are primary production (algae and vascular plants) and detritus (organic materials from vegetation surrounding the stream). In many small, forested streams more than 80% of the energy base of the food web comes from organic inputs. Recent studies have demonstrated the critical role of organic matter input to maintenance of the productive capacity of streams (Richardson 1991, Wallace et al. 1997).

Given that small streams receive the highest loading of organic matter of any channels in a watershed, and given the high number of small channels, this represents a large supply of energy to downstream reaches. Although our calculation that the export of organic matter to downstream reaches from headwaters exceeds 4 times the inputs cannot be correct, it underlines 2 basic facts. First, we still do not understand all aspects of the dynamics of organic matter in small streams. And second, clearly there is an enormous energy subsidy to downstream environments from the inputs of riparian vegetation in headwaters.

Biodiversity

Many organisms are dependent upon headwater streams and their riparian habitat. I have used aquatic insects and stream amphibians as examples, but there are many other species dependent upon the maintenance of aquatic and adjacent riparian habitat for the persistence of their populations. In 1 of the only studies published to date on Pacific Northwest intermittent streams, many species of aquatic and semi-aquatic insects were found in these Oregon headwaters and nowhere else in the watershed, including many new species (Dieterich 1992, Dieterich and Anderson 1995). Many of these species are probably not rare or at risk; it's just that we have put very little collective effort into looking at these habitats.

In British Columbia, estimates show that the highest biodiversity of vertebrates and vascular plants is associated with riparian areas, more so than with any other component of the surrounding landscape (Morgan and Lashmar 1993). In British Columbia, about 75% of the species listed as being vulnerable to human activities are riparian zone associates. Many of the birds and bats that frequent riparian areas do so because of the supply of adult aquatic insects near the stream. Consideration of these organisms depends on a broader perspective on watershed management and riparian protection.

Buffer strips have been shown to be effective in preserving the biodiversity and productivity of streams in California (Newbold et al. 1980). In that study, streams lacking reserve strips had fewer species and high densities only of opportunistic species, to the detriment of the rest of the fauna, another aspect to biological diversity. There have been few studies of the need for riparian vegetation by the adult stages of aquatic insects, but some observations suggest that insects gather around tall trees for mating aggregations, and there is no indication of what effects removal of trees may have. Loss of headwater habitats may create problems for dispersal and eventual recovery of populations restricted to small streams and their riparian areas. We do not yet know the requirements for the conservation of many of these organisms at any spatial scale.

Cumulative Effects

A consideration that we are only just beginning to address is the problem of cumulative effects. While small streams may, by themselves, be a common and small habitat, it is likely that the downstream effects of disturbing large numbers of small channels add up. These cumulative effects are likely to be manifest as changes to process rates, as well as their temporal and spatial variation. These effects may include loss or altered timing of organic matter inputs, alteration of temperature regimes, changes in peak-flow hydrology, and alteration of sediment supply and routing. Lack of riparian vegetation around these small streams is reported to result in warmer temperatures downstream, higher rates of sediment transport, and rapid depletion of organic matter by export (Hartman and Scrivener 1990). These effects may be magnified downstream by the degree to which a watershed has been converted from natural vegetation. We have yet to design appropriate studies on the scale necessary to detect such cumulative effects against the large natural variation in downstream environments.

Many critical elements of the stream and streamside ecosystem may be maintained by the provision of buffer strips of riparian forest. However, these reserves are only applied to larger streams with fish populations, to the possible neglect of headwater channels. The estimates for buffer widths are obtained by measuring the sources of woody debris in streams and their point of origin (Murphy and Koski 1989), and have resulted in a generally applied buffer strip width of 30 m. Whether these reserve strips will fulfil any or all of the objectives of stream and riparian conservation is uncertain and the subject of several ongoing studies. One such study is currently underway at UBC's Malcolm Knapp Research Forest to test the effectiveness of current and alternative riparian reserve guidelines for the maintenance of stream and riparian ecosystems (J. Richardson unpubl. data). The collective wisdom of fisheries biologists and stream ecologists supports the protection of streamside areas as an important aspect of protection for fish stocks, water quality, and other biodiversity objectives. Nevertheless, guidelines for riparian protection remain largely untested. Testing of current guidelines and development of creative alternatives to those guidelines are required before we can offer the flexibility in riparian management desired by both industry and conservation interests.

MANAGEMENT IMPLICATIONS

There are many questions about the role of headwater channels in maintaining the function of watersheds and providing services for downstream environments. There may be adequate protection for small streams in protected areas, but there is a high degree of uncertainty. Beyond harvesting, there are other forest practices that may pose risks for headwater streams and may propagate downstream, for instance application of brush control (mechanical or chemical) and requirements for green-up in adjacent blocks. The seral stage distribution of riparian forest within a watershed may result in sufficient numbers of streams in the right spatial configuration to conserve the headwater stream ecosystem, but we have yet to even frame the appropriate question to test this. It will be unlikely that it is necessary to put reserves around every small stream, but we should make sure we know what the consequences are of not doing so. Watershed restoration and other conservation measures can only work if we take a watershed perspective. The high degree of uncertainty demands research into the role of these small channels in terms of cumulative effects, habitat loss, effects on dispersal, and downstream effects

ACKNOWLEDGEMENTS

This research was supported by Forest Renewal British Columbia and the University of British Columbia. I appreciate the assistance of many people with the work that underlies the ideas presented here.

LITERATURE CITED

Cummins, K. W., M. A. Wilzbach, D. M. Gates, J. B. Taliaferri, and W. B. Perry. 1989. Shredders and riparian vegetation. BioScience 39:24–30.

Dieterich, M. 1992. Insect community composition and physico-chemical processes in summer-dry stream of western Oregon. Ph.D. dissertation, Oregon State University, Corvallis,OR.

_____, and N. H. Anderson. 1995. Life cycles and food habits of mayflies and stoneflies from temporary streams in western Oregon. Freshwater Biol. 34:47–60.

Hartman, G. F., and J. C. Scrivener. 1990. Impacts of forestry practices on a coastal stream ecosystem, Carnation Creek, British Columbia. Can. Bull. Fish. and Aquatic Sci. 223.

Hynes, H. B. 1975. The stream and its valley. Verh. Int. verein. Limnol. 19:1–15.

Morgan, K. H., and M. A. Lashmar, eds. 1993. Riparian habitat management and research: proceedings of workshop, Kamloops, B.C., 4–5 May, 1993. Fraser River Action Plan, Environment Canada, Delta, BC.

Muchow C. L., and J. S. Richardson. 2000. Unexplored diversity: macroinvertebrates in coastal British Columbia headwater streams. Pp. 503–506 *in* L. M. Darling, ed. Proc. Conf. Biology and Management of Species and Habitats at Risk, Kamloops, BC, 15-19 Feb. 1999. Vol. Two. B.C. Minist. Environ., Lands and Parks, Victoria, BC, and Univ. College of the Cariboo, Kamloops, BC. 520pp.

Murphy, M. L., and K. V. Koski. 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. North Amer. J. Fish. Manage. 9:427–436.

Newbold, J. D., D. C. Erman, and K. B Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. Can. J. Fish. and Aquatic Sci. 37:1076–1085.

Richardson, J. S. 1991. Seasonal food limitation of detritivores in a montane stream: an experimental test. Ecology 72:873–887.

_____. 1992. Coarse particulate detritus dynamics in small, montane streams of southwestern British Columbia. Can. J. Fish. and Aquatic Sci. 49:337–346.

_____. 1993. Limits to productivity in streams: evidence from studies of macroinvertebrates. Pp. 9–15 *in* R. J. Gibson, and R. E. Cutting. eds. Production of juvenile Atlantic salmon, *Salmo salar*, in natural waters. Canadian Special Publication of Fisheries and Aquatic Sciences 118.

_____, and W. E. Neill. 1995. Distribution patterns of two montane stream amphibians and the effects of forest harvest: the Pacific giant salamander and tailed frog in southwestern British Columbia. Habitat Conservation Fund, Resour. Inventory Comm., and Skagit Valley Authority, B.C. Minist. Environ., Victoria, BC. Unpubl. rep.

_____, and _____. 1998. Headwater amphibians and forestry in British Columbia: Pacific giant salamanders and tailed frogs. Northwest Sci. (Spec. Issue) 72:122–123.

Shrimpton, J. M., J. F. Bourgeois, J. T. Quigley, and D. M. Blouw. 2000. Removal of the riparian zone during forest harvesting increases stream temperature: are the effects cumulative downstream? Pp. 531–535 *in* L. M. Darling, ed. Proc. Conf. Biology and Management of Species and Habitats at Risk, Kamloops, BC, 15-19 Feb. 1999. Vol. Two. B.C. Minist. Environ., Lands and Parks, Victoria, BC, and Univ. College of the Cariboo, Kamloops, BC. 520pp.

Wallace, J. B., S. L. Eggert, J. L. Meyer, and J. R. Webster. 1997. Multiple trophic levels of a forest stream linked to terrestrial litter inputs. Science 277:102–104.

Wiggins, G. B., and J. S. Richardson. 1989. Biosystematics of *Eocosmoecus*, a new nearctic caddisfly genus (Trichoptera: Limnephilidae, Dicosmoecinae). J. North Amer. Benthol. Soc. 8:355–369.