

Applying Four Principles of Headwater System Aquatic Biology to Forest Management

Robert J. Danehy and Sherri L. Johnson

Abstract

Headwater systems, including the channel and the adjacent riparian forest, are a dominant landscape feature in forested watersheds, draining most of the watershed area, and comprising the majority of channel length in drainage networks. Being at the upper extent of watersheds, these systems are smaller and steeper than large streams, and create microhabitats that support diverse instream communities distinct from those in larger streams. Forest management can disturb headwater streams through changes in physical structure, sediment, light, and riparian detrital inputs. Locally, the extent of the buffer surrounding the system mediates disturbance intensity and responses. At broader scales, the effect of the shifting mosaic of stand ages across a landscape is less well-described. In addition, as watersheds are periodically harvested, long-term impacts of repeated canopy removal are unclear. We synthesize recent research from western Oregon and Washington focused on forest effects on headwater stream ecology. We draw on over twenty published manuscripts from Pacific Northwest (PNW) research, as well as seminal work from beyond the PNW. Findings of these studies are examined in light of four principles for managing forest near streams: *system* (the stream and riparian area as a system); *flow* (sources and duration); *disturbance* (types and frequency); and *topography* (elevation, gradient, and aspect). The interaction between local influences and landscape drivers varies among headwater systems. Nevertheless, the underlying influences on headwater system ecology are repeatedly demonstrated in recent work. Consideration of these principles in planning ongoing forest management activities can promote the stewardship of headwater systems.

Keywords: Headwater, headwater systems, flow regime, disturbance, landscape, biodiversity.

Introduction

Research focused on the aquatic biology of headwater streams has increased as ecologists recognize the importance of these ecosystems (Lowe and Likens 2005). The research stems from an interest in better understanding linkages between forest and streams, as well as headwaters and downstream processes and functions. Recent policy questions and concerns about the role of headwater systems within stream networks

(Adams 2007; Leibowitz et al. 2008) have also increased interest in understanding these ecosystems.

There is also a growing recognition that headwater streams are critical components of ecosystems and landscapes (Gomi et al. 2002; Wipfli et al. 2007). They comprise the majority of stream length and drain the majority of watershed area (Leopold 1964). Given their small areal extent taken individually, the stream

Robert J. Danehy is forest watershed program manager at National Council for Air and Stream Improvement, 720 SE 4th St. Corvallis, OR 97333; bdanehy@ncasi.org; **Sherri L. Johnson** is a research ecologist for the USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331; sherrijohnson@fs.fed.us

and associated riparian areas which comprise the headwater system can blend into the dominant vegetation of a landscape, making them less obvious. Nonetheless, the cumulative extent of their influence, together with a clearer appreciation of the role of these systems across larger spatial scales, is increasingly acknowledged (Meyer and Wallace 2001; Richardson and Danehy 2007).

Given that small streams drain watersheds and therefore link landscapes, how they are managed has important consequences. Best management practices (BMPs) for forest management vary according to ownership. In Oregon, these range from wide buffers on federal lands, to smaller buffers on state lands, to all merchantable timber allowed to be harvested near small, non-fishbearing streams on private lands (Adams 2007). These differences in riparian management are linked to the objectives of the landowner and the goals of the BMPs. Additionally, in the PNW, headwater system BMPs were developed with consideration for their potential impact on water quality and fish populations downstream (Adams 2007). For federal buffers, the default is two site-potential trees (90 m) on each side of fishbearing streams, and narrower buffers on non-fishbearing streams (30–45 m): these can be modified with adequate justification. On private forests, BMPs are less conservative, taking into consideration the socioeconomic objective that sufficient harvestable land is available to support the economic needs of logging businesses, and thereby local communities (Adams 2007).

A major difference in riparian protection for headwater streams between federal and private lands stems from Endangered Species Act (ESA) requirements. The federal forests in the region are required to be managed in ways that directly promote recovery of ESA-listed species, including conservative assumptions about riparian conditions to protect fish and wildlife habitats (Reeves et al. 2006). Although take of anadromous fish or wildlife listed under ESA is to be avoided on private lands, riparian

protection requirements on those lands are primarily intended to meet water quality criteria under the Clean Water Act (Adams 2007).

Definitions of headwater systems vary, although the upstream end of fish distribution as the lower bound is a convenient construct (Fransen et al. 2006; Moore and Bull 2004). As streams shrink to a size, a flow, or both that limits fish habitation, there are often associated changes in biotic communities (Olson and Weaver 2007). Community composition and ecological processes in these upper reaches are therefore driven by diverse interactions, both biotic (i.e., lack of fish) and abiotic (small and steep, with less stream flow) (Richardson and Danehy 2007).

Vertebrates other than fish use headwater systems, but few are fully aquatic. There can be robust amphibian populations with communities of one to as many as twelve species in western Oregon streams (Olson and Weaver 2007). The stream is a source of water and foraging habitats for most terrestrial wildlife, creating areas that are biologically rich and active (Anthony et al. 1987, 1996; Meyer et al. 2007; Moldenke and ver Linden 2007; Richardson et al. 2005a; Rykken et al. 2007a; Wilk et al. 2010). Within the aquatic portion of the headwater system, there are rich aquatic communities of macroinvertebrates and periphyton (Danehy et al. 2007; Dieterich and Anderson 2000; Herlihy et al. 2005). The composition of those communities and the abundance of taxa within those communities are determined by a suite of factors that we summarize as four principles.

We review research on headwater streams primarily from forested landscapes west of the Cascade divide in the Pacific Northwest, but include selected relevant studies from small fishbearing streams, even though these are not generally considered headwaters. We group these studies by four principles of headwater system aquatic biology to assist land managers in their understanding of the implications of management and types of impacts one might expect.

Four Principles

1. System—Riparian conditions matter. Forest-stream interactions are dominated by riparian conditions. Tight aquatic-terrestrial interactions occur for small streams. Generally, riparian detrital inputs (allochthonous) greatly exceed production from instream plants and primary producers (autochthonous production) (fig. 1).

The river continuum concept (Vannote et al. 1980) describes the types of interactions between instream aquatic biology and riparian influences as changes occur with stream size. Important drivers of aquatic biology are direct insolation and allochthonous inputs that respectively increase and decrease with stream size. Much prior research and policy focused on wadeable streams with fish, but more recent efforts have highlighted the ecology of headwater systems. Richardson and Danehy (2007), in a synthesis of the underlying factors of the ecology of headwater systems, describe how small size creates a tight coupling with the surrounding environment, how the lack of fish can change the structure of faunal communities, and how periodic low flows are common in small streams.

The links between the flowing stream and the surrounding riparian forest are influenced by the condition of the riparian forests. Concerns over timber harvest up to the edge of the streams have led to buffer requirements across the PNW, although the size and efficacy of those buffers have been an ongoing debate (Adams 2007; Dent et al. 2008; Groom et al. 2011). Whereas fishbearing streams are all buffered to a range of requirements, and the smallest streams in some jurisdictions have small buffers, on private lands in Oregon, forest practices allow the removal of all merchantable timber along fishless streams. This typically results in a riparian area dominated by shrubs and hardwood trees such as alder (*Alnus* spp.). Consequently, headwater systems have the potential to be altered more dramatically than downstream systems. These impacts have been



Figure 1—Examples of headwater systems in the Oregon Coast Range. Riparian vegetation is tightly woven to the stream, with the stream channel fully covered in upper image. (Photos by R. Danehy.)

investigated by multiple researchers and are discussed in a recent body of literature.

More than thirty years ago, Murphy and Hall (1981) and Hawkins et al. (1982) examined effects of clearcut logging on stream communities in the Cascades, and found a suite of changes including increases in algae, aquatic insects, and salamander and fish biomass where the surrounding area has been clearcut. Those studies have more recently been corroborated by a set of studies in both the Coast Range and Cascades ecoregions of Oregon. A series of research efforts published over the last decade addresses timber harvest impacts on headwater systems (Banks et al. 2007; Cole et al. 2003; Danehy et al. 2007; Frady et al. 2007; Herlihy et al. 2005; Moldenke and ver Linden 2007; Romero et al. 2005; Rykken

et al. 2007a). The research provides us with substantial information concerning the influence of changes in riparian forests on headwater biota, particularly invertebrates. While targeting forest management, those efforts also contribute to our broader understanding of headwater systems.

The results of the recent research provide substantial information on responses of headwater stream biota and their habitats following forest management and changes in riparian condition. After logging near headwaters, many researchers have noted major changes in instream physical features (Johnson and Jones 2000; Moore and Wondzell 2005). Total macroinvertebrate density and shifts in composition have been strongly correlated with the instream changes (Cole et al. 2003; Banks et al. 2007; Danehy et al. 2007). Banks et al. (2007) found that abundance and richness of emerging aquatic insects are slightly higher in clearcut reaches. Moldenke and ver Linden (2007) found more biomass and density of the insect orders Ephemeroptera, Plecoptera, and Trichoptera (EPTs) and all feeding groups except scrapers at clearcut sites. Danehy et al. (2007) examined macroinvertebrates in clearcut, thinned, and forested stands. They found no detectable differences between thinned and forested. However, clearcut sites had higher macroinvertebrate abundance, more Chironomidae taxa, and higher biomass. Over time and with riparian regeneration, these differences were less apparent. Frady et al. (2007) compared streams through second-growth forests and old-growth sites and found no clear differences in macroinvertebrate assemblages between treatments. However, where alder had re-established in the riparian areas, they collected higher densities of shredders than in conifer-dominated reaches.

Herlihy et al. (2005) found that substrate condition and topographic features are the most important indicators of aquatic insect community composition across three western Oregon ecoregions. However, when viewed at larger spatial scales and across ecoregions,

they concluded that logging was not a major driver in shaping western Oregon headwater macroinvertebrate communities; rather, the greatest variation in forested stream communities was due to substrate size, stream gradient, and altitude. Moldenke and ver Linden (2007) also found that elevation was a stronger determinant than riparian condition for insect communities.

In addition to research conducted on the role buffers have on forested headwater biota, there has been work that evaluates the links between the stream and riparian areas. This research reinforces the importance of viewing them as ecosystems with frequent exchange of energy. One area of research that was particularly insightful is the work that documents reciprocal subsidies (Nakano et al. 1999; Baxter et al. 2005) from the stream to the riparian areas. It had long been recognized that allochthonous inputs from areas outside the stream are important to instream biology. Moving upstream the ratio of allochthonous to autochthonous contribution of energy changes, which is a central tenet of the river continuum concept (Vannote et al. 1980). Starting in the 1990s, the role of marine-derived nutrients from salmon was documented by Cederholm et al. (1999) and Bilby et al. (2001); these insights reinforced the importance of salmon to forested ecosystems, particularly in the Pacific Northwest. At about the same time, in Japan, Nakano et al. (1999) and Nakano and Murakami (2001) developed a comprehensive understanding of reciprocal subsidies from the stream to the riparian forest. That research documented the importance of insects emerging from the stream for the diets of a suite of riparian predators, particularly birds and bats, and has been continued by Baxter et al. (2005). In a third-order stream, Farrand (2004) also observed that insect emergence was a major subsidy of energy to the riparian area, with only a small portion of adult aquatic insects returning to the stream. Gomi et al. (2002) and Moldenke and ver Linden (2007) documented that in fishless streams, invertebrates were a vector of energy leaving the

stream and subsidizing the riparian zone. This science of reciprocal subsidies documents a cycle of energy flow from outside the stream into the stream and from within the stream to adjacent terrestrial ecosystems.

In terms of regulatory guidelines, headwater systems have been valued for their importance in supporting fish habitat downstream rather than as important biological communities unto themselves. The connection between upstream and downstream systems includes the export of heat, food in the form of drifting invertebrates, organic material, substrates, and large wood (Alexander et al. 2007; Binkley et al. 2010; Danehy et al. 2011a; Gomi et al. 2002; Hassan et al. 2005; Moore et al. 2005a; Piccolo and Wipfli 2002; Richardson 1992; Richardson et al. 2005b; Wipfli and Gregovich 2002). Those subsidies were in the form of cold, clean water to create appropriate thermal habitat for fish (Danehy et al. 2005; Dent et al. 2008; Johnson 2004), organic matter that is processed and used by fish prey (invertebrates) (Kiffney and Richardson 2010; Richardson et al. 2005a; Wipfli and Gregovich 2002), and nutrients to fuel autochthonous production (Compton et al. 2003; Ashkenas et al. 2004).

2. Flow—Presence and duration of flow are a primary driver of aquatic biota composition and abundance. In addition, non-flowing wet channels or those with hyporheic flows provide important habitats for amphibians and some insects. Springs can support aquatic communities close to ridgelines (fig. 2).

The duration of flow is a critical feature in headwater systems, as these streams may be perennial, spatially intermittent, seasonally intermittent, or ephemeral. Headwater biota often have adaptations to annual, pervasive low flow events. The adaptations to low flow vary with organisms, as recently elucidated by Walters (2011). These traits of taxa (i.e., desiccation resistance, crawling rate, armoring, size at maturity, rheophily, and habit) (Poff et al. 2006)

can help us understand why some taxa survive better than others.

The source and type of flow for a headwater stream varies widely. In a central Coast Range study, all the streams had a spring source which resulted in flows continuing into late summer (Danehy et al. 2007). The sources of these streams were on average 250 m from the ridgeline. Other researchers (for example, Banks et al. 2007) found that the upper portions of headwater sites were intermittent. Yet insects continued to emerge from the streambed even as the stream dried.

The duration and magnitude of flow have strong influences on the flora and fauna of the systems. Yamamuro (2009) observed different communities and indicator taxa in runoff-



Figure 2—Headwater streams start in the upper reaches of watersheds and increase in flow volume as channels join. Throughout the year, flow can be continuous, spatially intermittent, or seasonal. B. A headwater stream arises from a small spring. (Photos by R. Danehy.)

dominated streams versus spring-fed streams in the upper McKenzie River basin. *Yoraperla* spp., a Plecopteran which was found in all streams, showed shifts in timing of life-history events, with more cohorts present in the spring-fed streams. In other perennial spring-fed headwater channels, Danehy and Bilby (2009) found clear seasonal differences in both macroinvertebrate and periphyton assemblages. The macroinvertebrate assemblage in springtime was richer, more abundant, and had higher biomass. They also found that the periphyton community was dominated by diatoms, particularly *Achnanthes lanceolata*, with greater richness of diatoms at sites with higher base flow. These differences in flow conditions are manifested across landscapes and undoubtedly contribute to biological diversity of headwater systems and forests.

Flow intermittency may be particularly important in supporting biological diversity in headwater systems. Banks et al. (2007) found that community patterns vary by season and flow duration more than flow type, which may be due to subsurface flow being present in the intermittent channels. Others, including Dieterich and Anderson (2000), Delucchi (1989) and Delucchi and Peckarsky (1989) observed substantial differences in aquatic insect communities in perennial streams versus those that go dry in the summer. Dieterich and Anderson (2000) captured more species from temporary streams (>125) than from permanent streams (100). Progar and Moldenke (2002) also noted differences in composition between temporary or intermittent streams compared to perennial streams, and found higher densities and biomass of insects from temporary streams during periods of flow. During wet seasons, these intermittent streams can be important habitats and attract species more typical of larger streams. These results suggest that insect life cycles are synchronized with annual changes in flow, but are still susceptible to changes in the timing and duration of base flow. Given what we have learned about these communities at base flow,

research suggests that headwater systems could be among the first ecosystems affected should climate change create drier conditions (Mote and Salathe 2010).

3. Disturbance—Various disturbance processes affect headwater systems, including forest harvest, debris flows, and fire. These infrequent events shape the channel structure and biotic assemblages of headwater systems (fig. 3).

Disturbance is a natural part of the functioning of headwater systems. A variety of disturbances influence streams, and many headwater species are well-adapted or quickly recover following these episodic events. Debris flows are a well-



Figure 3—Various types of disturbance periodically reshape headwater systems. A. A stream flowing through a burned eastside forest. B. This stream channel was scoured down to bedrock by a debris flow. (Photos by S. Johnson.)

recognized disturbance to Pacific Northwest streams, particularly after extreme rainfall (Turner et al. 2010; Robison et al. 1999). In the Coast Range, May and Gresswell (2003) estimated that the mean recurrence interval of debris flows was between 97 and 357 years. Snyder (2000) suggested that in portions of the Cascade Range, return intervals of debris flows could be more frequent. Debris flow occurrences can be associated with forest management, including roads and harvest (Snyder 2000; May 2002; Swanson and Dyrness 1975; Turner et al. 2010). Fire is a less-frequent disturbance type for western Oregon (Agee 1993; Cissel et al. 1999), but when severe fires do occur, they can fundamentally change the composition and trophic organization of headwater streams. The intensity of fire, ranging from small, localized ground fires to large, canopy-replacing fires, has differing consequences for forest-stream interactions. Similar to debris flows, anthropogenic influences involving fire suppression can alter fire regimes and severity (Franklin et al. 2002; Moser and Wade 2005). Despite the potential for local and larger-scale impacts and influence by anthropogenic actions, disturbances in Pacific Northwest ecosystems are natural processes that create habitat diversity.

We also know that after disturbances, stream community recovery begins rapidly; the magnitude and intensity of disturbance influences the period of recovery (Anderson 1992; Minshall 2003). In controlled-fire experiments in eastern Washington, Mellon et al. (2008), using a suite of sampling methods (benthic, emergent, and drift sampling), found higher macroinvertebrate densities but lower diversity at burned sites. Instream communities at burned sites were dominated by chironomids. In the Yellowstone fires of 1988, Minshall et al. (2003) found similar results. After ten years, differences between reference and burned sites were still evident in headwater streams, suggesting that fire impacts decrease with increasing stream size (Minshall et al. 2003).

There have been fewer studies comparing stream communities before and after debris flows. After a debris flow in the Cascades, Lamberti et al. (1991) found that fish recolonize within a year of the event and at densities similar to pre-disturbance levels. For macroinvertebrates, Anderson (1992) and Kobayashi et al. (2010) observed rapid recovery, but major shifts in functional feeding groups after disturbance. In a longer-term study, Danehy et al. (2011b) found community differences in both periphyton and macroinvertebrates eight years after the debris flows, and predicted that those differences would remain until a full riparian canopy develops (20 or more years). Many have suggested that debris flow disturbances are essential components of creation and maintenance of fish habitat downstream (Benda et al. 2005; Bigelow et al. 2007; Burnett and Miller 2007; Reeves et al. 1995, 2003). Wood recruitment to downstream fishbearing reaches by the transport of trees from headwaters to mainstem reaches during floods and debris flows creates habitats for fish and other biota (Reeves 2003).

Floods and drought also disturb headwater systems. Floods can rearrange instream habitat and affect biota as well as disturb adjacent riparian areas (Johnson et al. 2000). Although perceived to be a major risk, actual washout of organisms by high flows is often minimal. After a high-intensity flood in a fishbearing stream, Swanson et al. (1998) observed few changes to resident fish and amphibians. Droughts can also be extreme events that influence instream biota. Classifying droughts as a disturbance depends on the timing, duration, or magnitude (Richardson and Danehy 2007). Droughts need to be distinguished from annual low flows, because low flows and flow-duration lengths are integral components of headwater system ecology.

4. Topography—Topographic differences, (e.g., gradient, aspect, elevation) contribute to biotic diversity. Different taxa occur across elevational gradients. As streams

steepen, substrate coarsens and channels narrow, altering available habitats for macroinvertebrates and vertebrates, and opportunities for algal colonization (fig. 4).

Topography of headwater streams and their location in the watershed influences habitat availability, species composition, and life histories (Vannote et al. 1980; Montgomery 1999). Topography and geomorphology also strongly shape riparian vegetative composition as well as water availability, disturbance regimes (see previous section), and stream temperature characteristics (Johnson 2004). Development rate of instream organisms is linked with temperature (Li et al. 2011; Ward and Stanford 1982), which correlates with elevation and aspect. Headwater systems, with all other variables being similar, can show differing insect community compositions across elevations. Frady et al. (2007) found 70 percent overlap and 30 percent difference in macroinvertebrate assemblages in old-growth streams of similar size but at different elevations. Moldenke and ver Linden (2007) suggested that differences in macroinvertebrate community composition due to elevation were more important than silvicultural treatments. In a study of 169 randomly selected sites across western Oregon, Herlihy et al. (2005) found that topographic features of catchment slope, channel slope, and elevation are correlates of multiple environmental variables and useful in predicting macroinvertebrate diversity.

Headwater stream geomorphology in the mountains of the Pacific Northwest is often dominated by step-riffle or step-pool morphology (Jackson et al. 2002; Benda et al. 2005; Danehy et al. 2007). The distance between steps increases as gradient decreases (Bryant et al. 2007). In highly complex systems, the steps are created by small wood or exposed boulders that influence flow paths and modify the rate of flow, particularly at low flows (Kasahara and Wondzell 2003). Danehy et al. (2007) found that time of travel ranges from 0.4 to 3.4 m·min⁻¹ in Coast

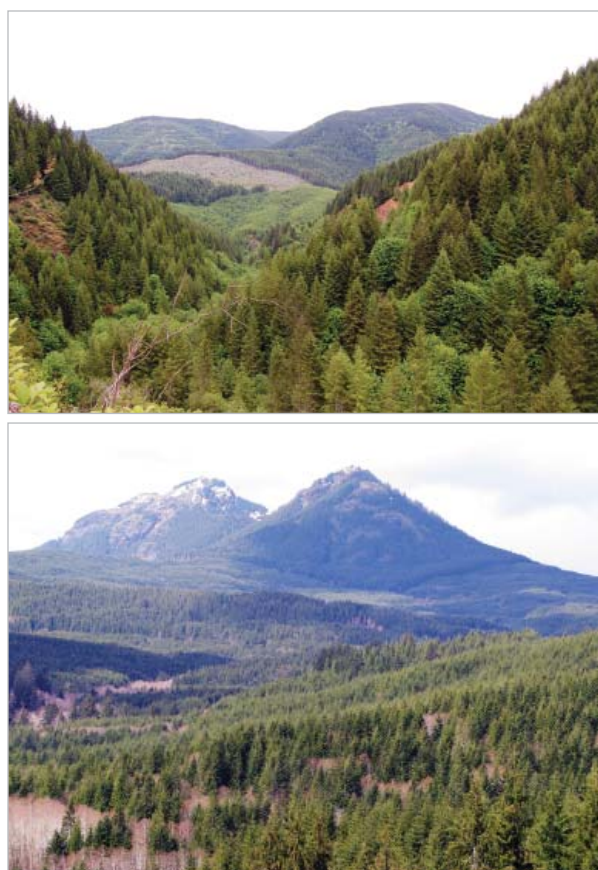


Figure 4—Across landscapes, topography provides a range of elevations, aspects, and gradients, creating a range of conditions for aquatic and riparian flora and fauna. (Photos by R. Danehy.)

Range headwater streams. At higher flows, the retentive features also serve to reduce the export of sediment and large wood. Benda et al. (2004) hypothesized that headwater streams serve as reservoirs or storage areas and transport little via episodic transport. However, Gomi et al. (2005), in their review of research on suspended sediment, concluded that small streams could transport tons of sediment annually, particularly immediately after a disturbance such as road construction.

The zone of influence of a headwater stream can be identified by the changes in microclimate with distance from the stream. In Coast Range streams, two studies found that the zone of influence was narrow, with topography having a large influence on the climatic gradients (Anderson et al. 2007; Rykken et al. 2007b). In studies of buffer

treatments, the strongest gradients have been observed to occur within the first 10 m away from the stream (Anderson et al. 2007). Headwater valleys are often narrow, allowing topographic shade to augment riparian-derived shading. Topographic shading and sun exposure differs in east-to-west versus north-south aspect streams (Anderson et al. 2007; Moore et al. 2005b). While seemingly obvious, these differences do affect air and stream temperatures and insolation and therefore headwater system biota.

Management Implications

Given the tight linkages between headwater streams and their surrounding forests, forest management has the potential to influence instream communities. A reduction in riparian buffers will lead to increased insolation, which can lead to more primary production, and possibly more food for consumers and predators. However, there are also potential trade-offs when managing or making a change to one portion of a complex ecosystem. Increased insolation raises water temperatures (Johnson 2004; Moore et al. 2005a), which can increase growth rates for some taxa but can also negatively influence other taxa and processes. Changes in species composition following forest management have been observed, as well as increased biomass and richness in algae, insects, and salamanders (Banks et al. 2007; Clapcott and Barmuta 2010; Danehy et al. 2007; Moldenke and ver Linden 2007). Evaluating trade-offs and selecting management strategies that benefit one group or taxon but negatively influence others is a challenging process for managers, researchers, and policy makers.

Headwater streams and adjacent riparian areas are generally viewed by ecologists as important habitats with unique species and valuable ecosystem functions. Others may look to headwater systems for the services they provide to downstream fish and humans, or view them from a broad landscape perspective with limited individual value. When managing

headwaters, it is important to consider the trade-offs among differing management activities. We know that following disturbance that removes riparian forests, headwater ecosystem processes and aquatic biota will be affected for a few years until some shading returns. Changes in resource availability (energy, nutrients, detritus inputs) also occur with disturbances. The extent and severity of a management activity or disturbance across a landscape will influence diversity and recolonization rates.

The scientific consensus is mixed on how far downstream management effects are propagated. The recruitment of large wood to create and maintain fish habitat is an example of an important connection between headwaters and downstream (Reeves et al. 1995, 2003). The processes controlling other links between headwaters and downstream continue to be examined. There are a range of findings on upstream-downstream links, including how far potential food items drift (Danehy et al. 2011a; Wipfli et al. 2007), or sediment is transported (Gomi et al. 2005; Benda et al. 2005) or thermal impacts extend (Danehy et al. 2005; Johnson 2004; Moore et al. 2005b). There is a clear need for more comprehensive study of downstream responses to upstream disturbances. Rigorous monitoring as well as new watershed studies throughout Oregon and Washington will help develop our understanding of the mechanisms and trade-offs involved in forest management along headwater streams.

Summary

Headwater streams and riparian systems are ubiquitous and diverse landscape features. The natural diversity of communities in headwaters has been further altered by a legacy of prior forest management approaches coupled with natural disturbances. Each of the four principles—*system*, *flow*, *disturbance*, and *topography*—influences that diversity. Some research suggest that aquatic production in headwater streams increases after

harvest for selected taxa, these results need to be viewed cautiously, as long-term and landscape-scale effects are not well understood. To date, there have been no long-term assessments or thorough systematic evaluations of effects of disturbances or forest management on full biological diversity or on responses across multiple trophic levels in PNW headwater systems.

However, we have learned much from previous research: 1. Riparian buffer designs affect the biology of headwater systems; 2. The nature of the flow regime is a major influence on the magnitude, distribution, and diversity of aquatic biology of a headwater system; 3. Disturbance history needs to be included in evaluations of possible future conditions; and 4. Location in a landscape matters and provides essential context—steep, perennial, high-elevation streams will have very different biological potential than systems that differ in those characteristics. These four principles provide a framework and context for responses to management activities around headwater streams.

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