Chapter 7—Small bugs with big impacts: Ecosystem and watershed-level responses to the MPB epidemic

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Introduction

Mountain pine beetle (MPB) outbreaks have the potential for prolonged impacts on the delivery of clean water from infested subalpine watersheds throughout the West. Sixty-five percent of the West's water supply originates on forested land (Brown and others 2008), much of which has been affected by an unprecedented MPB epidemic over the past decade. Some lodgepole pine stands in Colorado have lost more than 70 percent of their basal area following the MPB epidemic (Collins and others 2012). The death of pine trees leads to increased availability of light, water, and nutrients for residual overstory trees and understory vegetation; it can also result in increased water and nutrient runoff.

The MPB epidemic may have a large influence on the energy and water balance of subalpine ecosystems. Water balance in the subalpine zone is modeled as the volume of water stored along with a series of water inputs and outputs from the system. The storage component includes ground water, soil moisture and snow pack. Inputs consist of precipitation in the form of rain and snow, and outputs include sublimation from the snowpack surface and from snow intercepted by tree canopies, evaporation from snow-covered and snow-free surfaces, and transpiration from trees and other vegetation during the growing season. Intercepted snow sublimates at a faster rate than snow on the ground due to its greater surface area and exposure to incoming solar radiation and heat transfer from the air. Water that is not lost to sublimation, evaporation, or transpiration is available for stream flow (Fig. 7.1).

Energy and water balances change throughout the year in subalpine forests. During winter, the net energy balance is negative, allowing snow to accumulate through the cold season. The energy balance becomes positive during spring, and this excess energy is used to warm and subsequently melt snowpack. The soil moisture deficit from the previous growing season is replenished as snowmelt moves into the soil. Ground water levels rise, and eventually stream flow increases relative to base flow levels during the winter. Trees also begin to transpire as temperatures warm, transferring soil moisture to the atmosphere.

Landscape-scale MPB epidemics have the potential to cause large changes in water balance in these subalpine watersheds. Snow is the dominant precipitation input in the subalpine zone where the MPB is most active, and snowmelt accounts for the vast majority of water available for runoff, agricultural, and municipal uses. After logging operations, decreased snow interception by tree

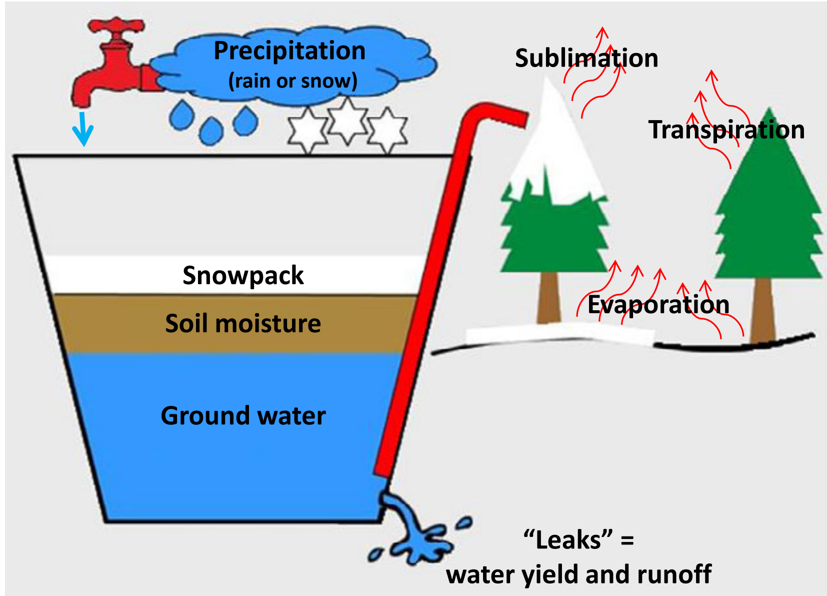

Figure 7.1. The water balance of an ecosystem is conceptualized as faucets, buckets, straws, and leaks. The faucet represents inputs of water from precipitation; the buckets represent pools of water in the ecosystem (i.e., snowpack, soil moisture, and ground water). Water moves out of the system through sublimation, evaporation, and transpiration (represented as a straw), and it leaves the system as water yield and runoff (represented as a leak in the bucket) (figure by Kelly Elder, USDA Forest Service).

canopies leads to increased snowpack accumulation (Woods and others 2004; Troendle and King 1985).

Similarly, the magnitude and timing of post-beetle snowmelt will be affected by the changes in the tree canopy, even though the forest overstory will deteriorate more slowly following a beetle attack than following tree harvesting. The net effect of the changing snowpack accumulation and water and nutrient use in beetle-killed forests varies depending on environmental conditions, tree species composition, the density of the forest understory, and management decisions. At the same time, these impacts are occurring against the backdrop of climate change, which is already impacting seasonal stream flows. Rood and others (2008) compared hydrographs from the early 1900s and early 2000s, and they found that many rivers across the West are experiencing higher winter flows, earlier spring run-off and peak flows, and reduced flows in the summer and early autumn. We have yet to see how these alterations might interact with watershed-scale impacts of the MPB epidemic.

In this webinar, we presented research on MPB-induced changes in energy and water balances, tree physiology, and nutrient cycling. These processes influence stream flow and nutrient and sediment export from affected watersheds.

Research findings

Research finding #1: Blue stain fungi associated with the beetles are primarily responsible for tree deaths during MPB outbreaks.

MPBs disrupt two basic life-sustaining processes in trees they infest. Adult beetles consume phloem tissue when building egg galleries and developing larvae consume phloem for food until maturity. Phloem feeding by adult and larval beetles contributes to some amount of phloem girdling, disrupting the transport of carbohydrates from the canopy to other tissues within the tree.

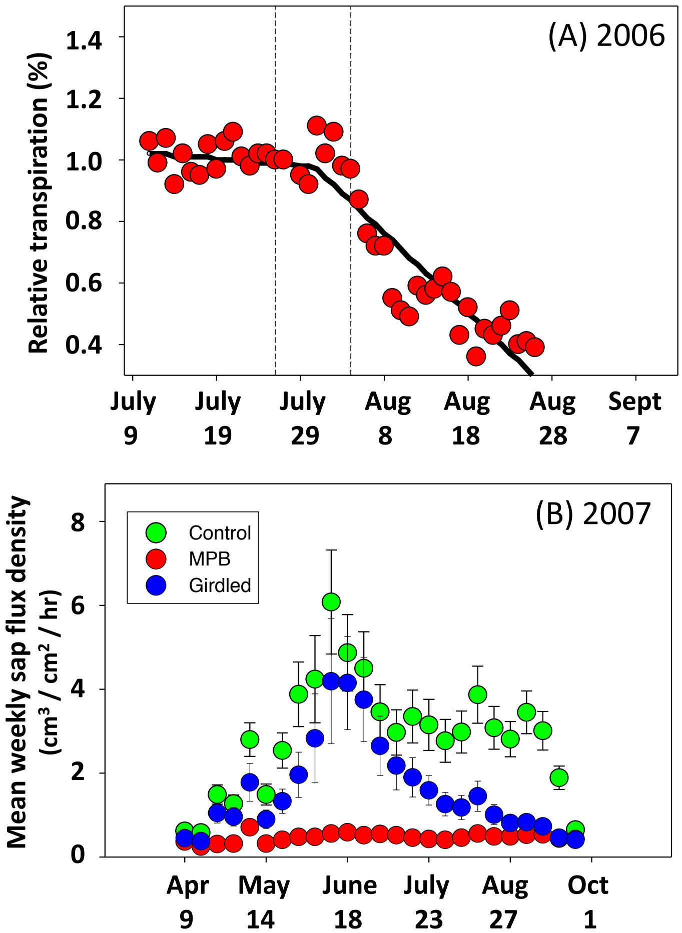

Figure 7.2. Relative rates of transpiration for beetle-attacked trees compared to control trees before and following MPB infestation (A), and mean sap flux density in the growing season following MPB infestation for beetle-attacked, girdled, and control trees (B). Error bars represent the variation between trees (figure modified from Hubbard and others 2013).

MPBs also carry a diversity of pathogenic spores from several genera of fungi (Yamaoka and others 1995; Kim and others 2008). Fungal spores carried into trees by MPBs germinate and spread fungal hyphae into tree tissue responsible for conducting water (*i.e.,* xylem in the sapwood). These fungi essentially block water transport from the soil to the canopy (Ballard and others 1984).

Studies at the Fraser Experimental Forest suggest that fungal infection of the xylem tissue is the primary cause of tree mortality. Fungal infections cause a rapid decrease in tree transpiration following a successful MPB attack. Tree water use can slow measurably ten days following a MPB attack, decline to 50 percent by the end of the summer, and essentially reach zero by the beginning of the next growing season (Fig. 7.2). Mechanically girdling trees without fungal infection resulted in slower transpiration rates during the first growing season, but transpiration rates of these trees were similar to control trees during the following summer. This experiment demonstrates that fungal infections, not phloem consumption by beetles, are primarily responsible for tree deaths during MPB outbreaks (Hubbard and others 2013).

Research finding #2: Tree mortality caused by the MPB epidemic substantially alters energy and water balances in subalpine forests.

Forest cover is a critical driver of water balance in subalpine environments. MPB outbreaks cause changes to water and energy balance as trees transition from live canopies to dead foliage (*i.e.,* red stage), and finally to losing all of their needles (*i.e.,* gray stage).

Management Implications	
	• Soil water availability and stream flow can increase during the red stage as transpiration of dead and dying trees declines. • Greater increases in soil water availability and stream flow are possible during the gray stage as less snow is intercepted by needle-less tree canopies. • Removal of hazard trees can decrease canopy interception, thereby enhancing snowpack accumulation in forests impacted by the MPB. However, removing large groups of trees can decrease snow accumulation due to wind scour.

Transpiration declines between the green and red stages. The introduction of blue stain fungi by MPBs causes pine needles to discolor and turn red as transpiration declines. Transpiration ceases altogether by the beginning of the first post-infection growing season (Hubbard and others 2013). Water previously removed by transpiration is then available for soil recharge, residual vegetation transpiration and/or stream flow.

Changes in watershed-level transpiration rates depend on the amount of MPB-induced tree mortality (which in turn depends on the original species composition and management history). Total basal area was reduced by 25 percent in managed mixed-species subalpine watersheds at Fraser Experimental Forest, whereas basal area losses averaged 40 percent in unmanaged stands (Fig. 7.3). These changes in basal area resulted in proportional changes in overstory transpiration rates. Transpiration in two managed watersheds was reduced by 20 and 29 percent, but transpiration in two unmanaged watersheds was reduced by 41 and 45 percent (Rob Hubbard, USDA Forest Service, *unpublished data*).

Interception does not change significantly between the green and red stages. Dead needles may intercept as much snow as living needles. However, interception begins to decline as trees transition into the gray stage, shedding their

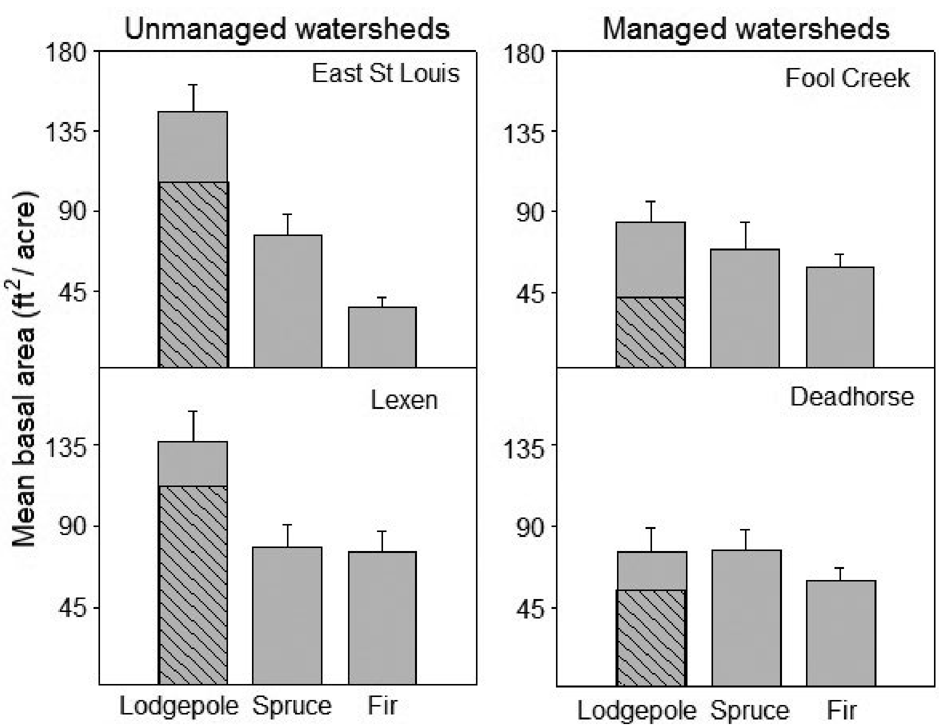

Figure 7.3. MPB-induced mortality of lodgepole pine trees (hatched bars) in unmanaged and managed watersheds at the Fraser Experimental Forest. Error bars represent the variation between subplots plots in each watershed (Chuck Rhoades, Rob Hubbard, and Kelly Elder, USDA Forest Service, unpublished data).

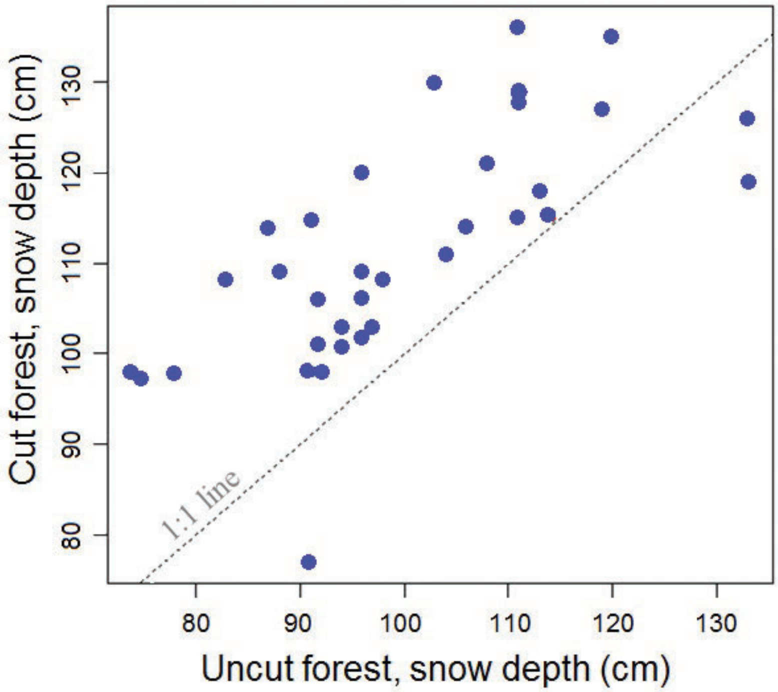

Figure 7.4. Snow depth for transects located in uncut versus harvested MPB-affected lodgepole stands. Study plots were located on the Fraser Experimental Forest, Colorado State Forest, Routt National Forest, and Medicine Bow National Forest in Colorado. The mean differences in snow depth are similar to differences observed in clear cuts versus unharvested areas impacted by the MPB (Kelly Elder, USDA Forest Service, unpublished data).

needles over a period of 1 to 5 years. Once all needles have been shed from the tree, interception is significantly lower, but it will not be zero until a tree topples to the ground anywhere from 1 to 15 years following MPB attack (Mitchell and Preisler 1998).

Less interception by tree canopies can translate into greater snowpack accumulation (Woods and others 2004). Preliminary results from the Fraser Experimental Forest suggest that snow and rain throughfall increase when a larger portion of the overstory is killed by the MPB. Snow accumulation (*i.e.,* depth, density, and water equivalent) are significantly higher in gray-stage forests that experience harvesting relative to uncut stands (Fig. 7.4). However, several harvested stands had lower snow depths. This is potentially from high wind scour due to plot location and/or the large size of the harvest units. Differences in silvicultural treatments could have also affected snowpack accumulation, with greater accumulation resulting from even thinning versus group-retention thinning (Woods and others 2004).

Research finding #3: Changes in the water balance of subalpine forests are likely different after tree harvesting than after mortality from the MPB epidemic.

Researchers and water managers have experimented with tree removal to increase stream flow for more than a hundred years. For example, researchers removed 50 percent of the forested basal area from the Fool Creek watershed in the Fraser Experimental Forest and observed a 40 percent increase in stream flow relative to an untreated watershed (Troendle and King, 1985). Over a 50-year period following basal area reduction, the average increase in stream flow was 29 percent (Kelly Elder and Laurie Porth, USDA Forest Service, *unpublished data*).

Management Implications

- Increases in water yields following the MPB epidemic are less substantial than increases resulting from clear-cutting operations. This is due to a more gradual decline in transpiration and interception rates and the greater abundance of live, residual vegetation in MPB affected forests.
- Advance regeneration and newly established vegetation utilize much of the soil water made available after the death of overstory trees, dampening increases in stream flow after the MPB epidemic.
- Retaining slash in post-epidemic forests (*e.g.,* lop and scatter) can increase snow accumulation by reducing wind scour. This potentially leads to greater water yields during the spring melt.

Changes in peak flow and overall runoff in the Fool Creek watershed were driven by reduced losses from interception and transpiration, as well as increased snow deposition into harvested strips. A recent analysis of yearly stream flows from Fool Creek estimates that hydrologic recovery would have occurred approximately 60 years following harvest had no further disturbance altered the system (Kelly Elder and Laurie Porth, USDA Forest Service, *unpublished data*).

It is not known if these studies are appropriate analogs for the impact of tree mortality from the MPB and subsequent tree harvesting. Studies that have examined impacts of MPB outbreaks on stream flow are relatively rare. Stream flows from infested watersheds will likely have a very different response over time due to differences in the energy and water balance of harvested versus beetle-killed forests.

Increases in stream flow are often lower following beetle-induced tree mortality than after tree harvesting. Between 1939 and 1946 a large spruce beetle outbreak killed approximately 20 percent of the basal area within the White River watershed in northwestern Colorado. During the 25-year period after the spruce beetle infestation, the average increase in water yield was 15 percent, and the largest increase occurred 15 years after the outbreak (Love 1955; Bethlahmy 1974). During the current MPB epidemic, stream flow was not different between a watershed infested by the MPB in 2003 and one not infested until 2008 (Fig. 7.5). These watersheds were decent analogs of each other, with a strong correlation in streamflow patterns prior to the MPB epidemic (Kelly Elder and Laurie Porth, USDA Forest Service, *unpublished data*).

Paired watershed studies are of little use in detecting long-term changes in stream flow induced by the MPB epidemic. This is because most basins with lodgepole pine across the Rocky Mountain West have been significantly impacted by MPBs. Instead, researchers are detecting changes in downstream flows by comparing annual precipitation patterns and discharge from beetle-impacted basins.

Why might the magnitude of water yield increase be lower following beetle-inducted tree mortality than after tree harvesting? Different rates of tree removal and different amounts of remaining live vegetation are primary factors explaining this pattern.

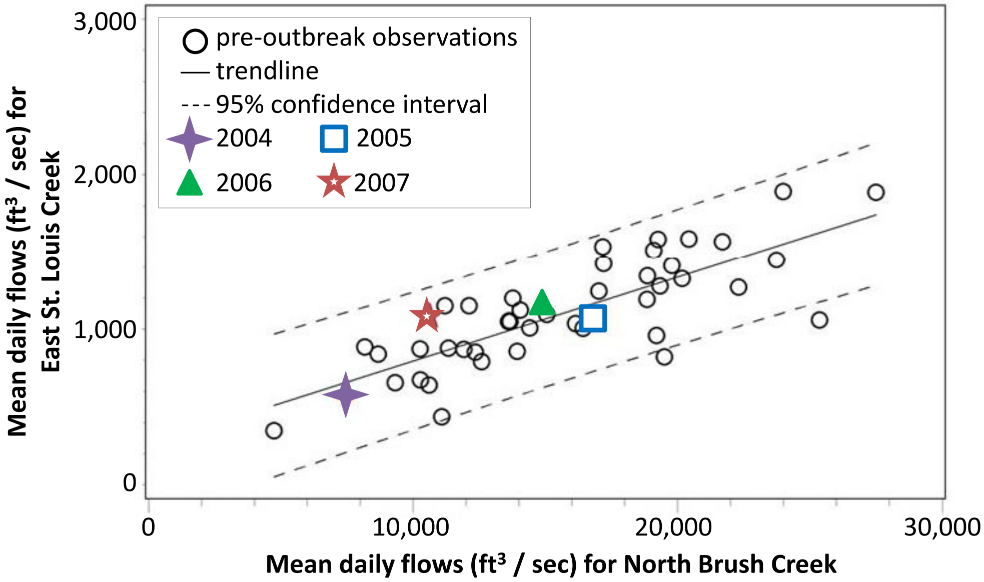

Figure 7.5. Mean daily flows from unaffected North Brush Creek watershed in southern Wyoming versus MPB-affected East St. Louis basin on the Fraser Experimental Forest, Colorado. Black circles represent pre-beetle altered flows and other icons represent post-beetle impacted flows. The solid regression line show the pre-beetle fit between the basin flows (data prior to 2003) and the dashed line show the 95 percent confidence interval. This data suggests that as of 2007, flows were still behaving as expected from an unaltered hydrologic regime (Kelly Elder and Laurie Porth, USDA Forest Service, unpublished data).

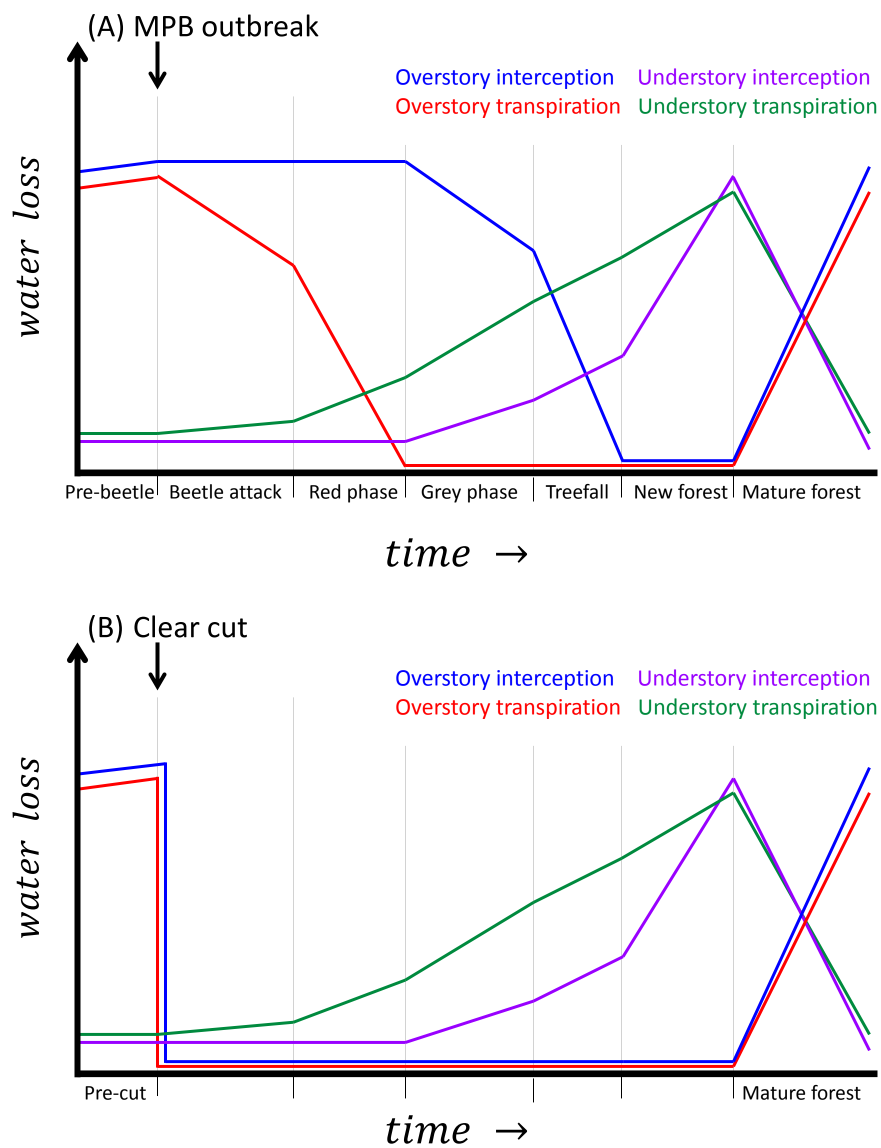

Figure 7.6. Changes in water loss in MPB-impacted mature forests (A) versus clear cut mature forests (B) (figure by Kelly Elder, USDA Forest Service).

Hydrologic recovery is generally slower following harvesting, resulting in a greater and more prolonged increase in stream flow (Fig. 7.6). Harvesting results in immediate removal of trees, resulting in immediate reductions in water losses from overstory interception and transpiration. In contrast, trees killed by MPBs shed their canopies slowly and remain part of the ecosystem for many decades, resulting in slower declines in interception and transpiration.

The amount of remaining live, vegetation also differs between a harvested and beetle-impacted watershed. MPBs only attack mature lodgepole pine trees in subalpine forests, leaving other overstory species and understory vegetation unaffected. This residual vegetation can quickly respond to increased water availability, reducing the amount of water contributing to stream flow. In contrast, harvest operations can remove all of the overstory trees and leave behind a much smaller amount of residual vegetation., However, harvesting can also increase surface roughness and lead to greater snow accumulation, especially when slash is left on-site.

Research finding #4: The MPB epidemic has had little effect on nitrogen losses from impacted watersheds.

Management Implications

- The MPB epidemic has marginally increased stream nitrate concentrations, but the changes do not pose threats to water quality.
- Protecting tree regeneration and enhancing establishment of new vegetation can help mitigate nitrogen losses from forest soils to streams.

Wildfire and logging often result in elevated nitrogen in stream water caused by changes in nutrient demand and nutrient cycling. The biogeochemical consequences of insect outbreaks are more uncertain. Overstory mortality resulting from MPB outbreaks results in lower stand-level demands for nutrients and waters. Several studies have similarly shown that soil resources increase under dead and dying trees. Clow and others (2011) observed greater soil moisture and nitrogen availability under recently-attacked and gray-stage trees in Grand County, CO (Fig. 7.7). This increase was potentially due to lower plant uptake, slower soil nitrogen turnover, and increased litter inputs.

Greater instantaneous soil nitrogen is apparent under beetle-killed trees, but there is little evidence that much of this nitrogen enters stream water. At Fraser Experimental Forest, nitrogen export in stream water following the MPB epidemic was less than 10 percent of observed seasonal variation (Fig. 7.8), and concentrations are well below EPA thresholds for water quality (120 parts per billion [ppb] for total nitrogen and 14 ppb for nitrate). Other studies across Colorado show similarly low nitrogen export from watersheds affected by the MPB epidemic (Rhoades and others 2013).

Why are stream nitrogen responses to the MPB epidemic so small? One reason might be increased nitrogen uptake by residual, live vegetation: at Fraser Experimental Forest, average foliage nitrogen content has increased from 0.8 to 1.3 percent in live pine trees located near beetle-killed trees (Hubbard and

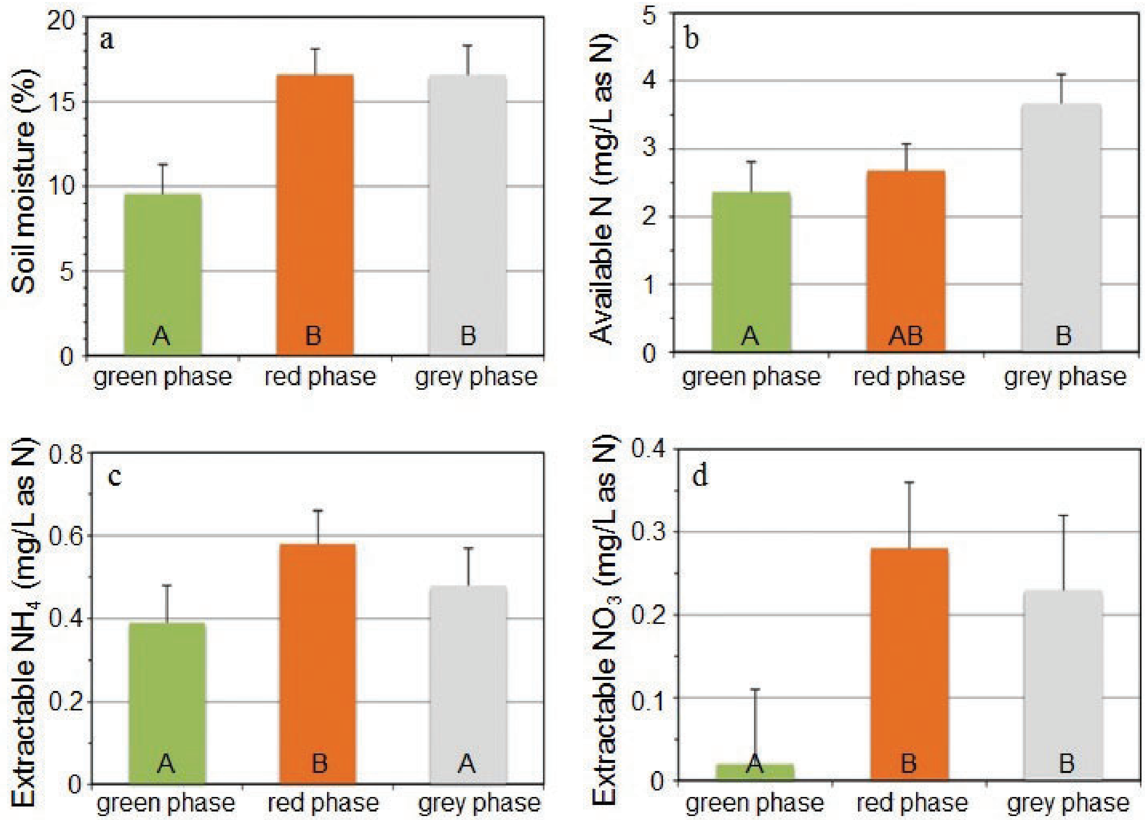

Figure 7.7. Means and standard deviations of soil (a) moisture, (b) available nitrogen, (c) extractable ammonium (NH4+), and (d) extractable nitrate (NO3-) in soils collected under live, red-stage, and gray-stage trees. Different letters indicate that the distributions were significantly different at $p < 0.1$ (figure from Clow and others 2011).

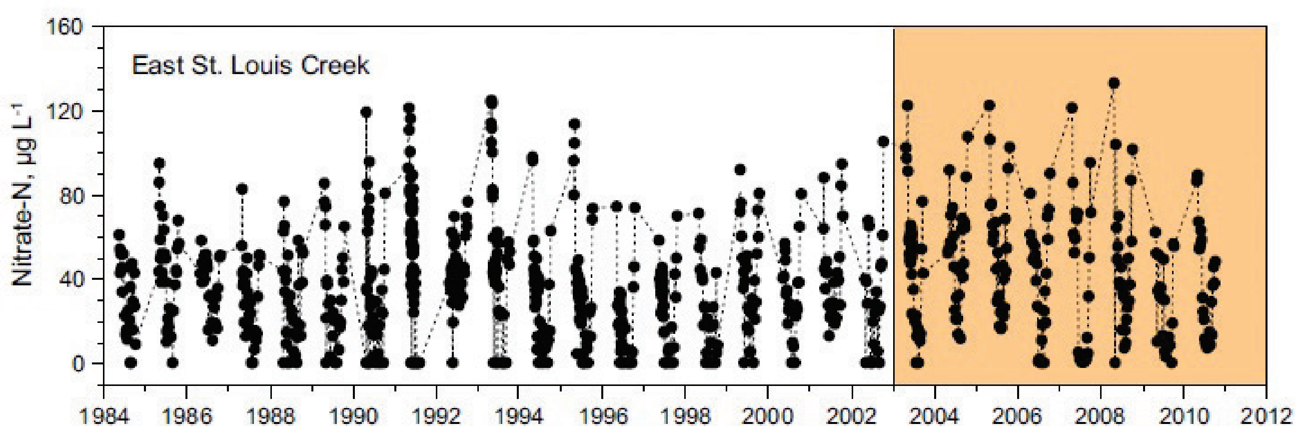

Figure 7.8. Nitrate (NO_3^-) concentrations in East St. Louis Creek on the Fraser Experimental Forest, CO, before extensive MPB kill of trees and during years of beetle kill (shaded area). Annual variation in nitrate concentrations dwarfs potential impacts of the MPB epidemic on water quality (figure from Rhodes and others 2013).

others 2013). More than 25 percent of trees sampled from four watersheds at Fraser showed increased growth in response to beetle-induced mortality of nearby trees. Likewise, seedlings are colonizing beetle-impacted areas across northern Colorado, and advance regeneration trees are growing faster than previous years in response to increased resource availability (Collins and others 2011).

Remaining Questions & Knowledge Gaps

- How will the magnitude and timing of changes in water quality and quantity vary over time as forests recover from the MPB epidemic? Are these responses similar or different for watersheds in other parts of the beetle-killed landscape?
- To what degree does beetle-induced tree mortality change snow accumulation and retention over time?
- How will water and nutrient uptake by residual live vegetation change as forests recover from the MPB epidemic?
- What impact will future disturbances (*e.g.,* forests insects and diseases, wildfires, and management activities) have on watershed processes in areas impacted by the current MPB epidemic?
- What are the implications of salvage harvesting in riparian areas for wildlife habitat, soil water holding capacity, stream temperatures, etc.?

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Meet the chapter presenters and authors

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