Responses of Amphibians to Fire Disturbance in Pacific Northwest Forests: a Review

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Abstract.—In western North America, major wildfires often now result in stand-replacement events and natural resources losses for many decades post-burn. Fire severity has been exacerbated by past fire suppression that has allowed large fuel load accumulations. To reduce woody debris and restore the ecological integrity of western forests, prescribed burning is increasingly used as a regional management tool. However, we do not understand the effects of either wildfire or prescribed fires on amphibians in stream, riparian and terrestrial habitats in western forests. Terrestrial amphibians, macroinvertebrates and other animals are surface active during periods of rainfall or high moisture. Wildland fire usually starts in the hot, dry summers typical of these more arid Western and Mediterranean climates and may have less effect on resident biota than prescribed fires often conducted during the late fall to spring rainy season, when there is sufficient moisture to prevent crown fires. Still, intense wildfires may result in increased erosion and sediment or changes in soil chemistry impacting downstream aquatic environments. To our knowledge, no published reports exist on effects of fire on the aquatic herpetofauna of the Pacific Northwest. Research efforts now underway include new studies of wildland fires in Oregon and Idaho on aquatic amphibians, and studies on the effects of prescribed fire on terrestrial salamanders and associated forests in the Klamath Province along the Oregon-California border. These will help evaluate the cumulative effects of fuels reduction on amphibian population and habitat structure, and provide guidelines to better manage for wildlife species characteristic of western forests. In the Pacific Northwest, investigations of fire effects on wildlife are severely lacking relative to the vast acreage, economic value, and biodiversity of its forest ecosystems. Given the increasing prominence of wildfire and prescribed burning in many western forest systems, we suggest more resources will be devoted to such research endeavors, and that they include other sensitive groups of wildlife such as mollusks.

Fire is a natural, recurring disturbance in forested ecosystems of western North America, but it has been aggressively suppressed for >50 years. Although fire prevention was implemented to protect forest resources, these efforts have resulted in greatly increased fuel levels and, in turn, increased risk of catastrophic fires (Pyne 1982, Agee 1988, Henjum et al. 1994). Catastrophic fires are generally defined as stand-replacing fires that burn at spatial scales and intensities atypical to the historic fire regime. For example, forested environments with long fire return intervals (300-600+ years) are subject to large-scale stand replacing fires because fuel loadings are typically high (Morrison and Swanson 1990). Of greater importance might be how past forest management activities such as clearcutting and thinning and associated forest fragmentation affects the resulting forest structure and the fire mosaic when they do burn. In contrast, forests with historically short fire return intervals (20-40 years) were characterized by reduced fuel loads where stand replacing fires were less common. Fire suppression is hypothesized to have the greatest affect on forests with short (i.e., <50 year) fire return intervals.

Resource managers now recognize the importance of fire for maintaining healthy forests, yet often face conflicting priorities when pursuing multiple resource management objectives. Prescribed burning, prescribed wildland fire (e.g., allowing natural fires to burn within specified parameters), and other fuels management practices are being introduced into the landscape to reduce fuel loadings, but little is known about their effects on the biota of the forests that are being restored or altered (Potter and Kessell 1980). For example, we lack information on the quantity and quality of the resulting downed woody debris that comprises the critical habitat for many species of resident wildlife. Current standards and guidelines of the Northwest Forest Plan require Federal land managers to promote retention of dead-and-down wood as wildlife habitat yet reduce high fuel loads through prescribed burning or other fuels reduction practices (USDA/USDI 1994).

Further, we lack information on both the short- and long-term suitability of the post-burn habitat for resident and migratory wildlife. Fuels management will alter the structure and composition of existing fire-suppressed systems. Large wood plays a vital role in ecosystem processes such as nutrient and water cycling (Harmon et al. 1986, Franklin and Spies 1991). It provides a moist, thermally stable habitat for many species of wildlife both large and small (Maser and Trappe 1984, Carey and Johnson 1995, Bull et al. 1997). We lack basic information on the response of large woody debris to burning and the suitability of fire-scarred woody debris for wildlife.

In Pacific Northwest forests, terrestrial salamanders are strongly associated with structural elements of the forest

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floor such as woody debris, moss, and surface/subsurface rock (Bury and Corn 1988, Corn and Bury1990, Welsh and Lind 1995). Stream amphibians also are dependent on the structural components of stream substrate including in-channel large woody debris (Corn and Bury 1989). However, almost nothing is known about the responses of amphibians and their habitats to fire and fuels management practices in the West (DeMaynadier and Hunter 1995, Welsh and Droege 2001). Only a few unpublished studies exist on the effects of fire on pond-breeding amphibians in western forests exist (Askey and Peterson 1993). These limited data sets indicate no significant differences in amphibian occurrence in ponds located in burned versus unburned forests.

There are some recent studies on the effects of prescribed fire on herpetofauna in the eastern U.S. (Russell et al. 1999, Ford et al. 1999), where fire frequency has been reduced and the season of burn changed from mostly growing-season to dormant-season in Southeastern pine forests (Means and Campbell 1980, Robbins and Myers 1992). Widespread public and agency concerns over large fires are now driving policy-level decisions to integrate fire and other fuel reduction strategies into management of ecosystems.

Our goal is to review and compare the effects of fire and fuel reduction management on Pacific Northwest amphibians and their associated habitats, especially downed woody material. We will attempt to summarize: (1) what we know generally from a few available studies, and (2) what information is needed.

Stream Amphibians

There are three families (10 species) of amphibians endemic to the rocky, cool-water streams in the mountainous regions of the Pacific Northwest. Many of these species are of conservation concern due to declining populations (Bury 1994, Smith et al. 1998). Therefore, understanding fire effects on stream amphibians and their habitats will be of utmost importance in future management practices in Northwest forests. Some stream amphibians such as the giant salamander (*Dicamptodon* spp.) may respond positively to increased stream productivity (increased periphyton or algae growth) for a few years after forest opening from timber harvest (Murphy and Hall 1981) and presumably fire. Stream amphibians also are sensitive to changes in debris flow, elevated temperature, water chemistry, and sedimentation that often occur post-disturbance (Bury 1988, Gamradt and Kats 1997, Kerby and Kats 1998, Welsh and Ollivier 1998). For example, the tailed frogs (*Ascaphus* spp.) are among the least tolerant of the anurans to elevated temperature and will die quickly when exposed to water temperatures at or near 29.6°C (deVlaming and Bury 1970). In contrast, giant salamanders tend to have broader tolerance to temperature and siltation than other stream amphibians (Bury 1988).

Although direct mortality of aquatic and wetland-associated life stages of amphibians may be low where wet areas and riparian zones provide refugia from fire (Vogl 1973), terrestrial life stages in nearby uplands may experience much higher mortality associated with the direct and indirect effects of fire that alter prey availability or change shelter and microclimate (Lyon et al. 1978, 2000; Russell et al. 1999). Further, physical and biological changes in adjacent uplands may influence the survival and well-being of biota in riparian zones through downslope effects on hydrology and water chemistry in streams (Minshall 1989).

Some research on large, stand-replacing wildfires on lotic biota suggests that fire ultimately benefits aquatic invertebrates and fishes, even those species that are negatively affected by the disturbance immediately after the fire (Roby and Azuma 1995, Minshall et al. 1997, Rieman et al. 1997). For example, Lyon et al. (1978) suggested that some aquatic invertebrates may decline immediately after a fire, then increase to levels above pre-fire conditions as a response to increased stream productivity. Large fires can have long-term effects on streams by: (1) reducing invertebrate diversity for a decade or longer (Roby and Azuma 1995); (2) changes in peak discharge, stream channel morphology, large woody debris inputs, and sediment loadings; and (3) elevated temperature and altered water chemistry (Richards and Minshall, 1992; Minshall et al. 1997). Also, the effects of fire on stream biota may be more pronounced in headwater streams than in mid-order or larger streams (Roby and Azuma 1995, Minshall et al. 1989, Minshall et al. 1997).

Although there is little empirical evidence of how fire impacts stream amphibians, we can glean some information from the Old-growth Wildlife Habitat Program in the Pacific Northwest (Ruggerio et al. 1991), which compared biota across chronosequences of forest categorized into young, mature, and old-growth stands. Because almost all of these stands were naturally regenerated from wildfires, the younger stands were most recently burned. Thus, fire-sensitive wildlife populations would be expected to be different in younger stands compared to older, mature stands that had a longer time since disturbance.

Spies (1991) estimated the age of trees across the chronosequence of stands in the Oregon Coast Range (Table 1) and reported that the young and mature stands were not the equivalent of intensively-managed plantations resulting from harvest. For example, there often were large amounts of downed woody debris in young natural stands, resulting from input of fallen trees that were fire killed. There was less wood volume in mature stands and then large accumulations again in old-growth. Managed stands tended to have low

Table 1.—Estimated ages of trees in stands in the Oregon Coast Range (from Spies 1991).

Stand type	Young	Mature	Old-growth
Mean age	55	100	315
Range	30-79	84-120	130-525

amounts of downed wood once slash rotted or was burned on site. Clearcut stands lack large trees and, in turn, recruitment of large downed woody material on the forest floor.

Bury et al. (1991a) found no significant difference among stream amphibians across natural young, mature, and old-growth stands in three Northwest biogeographic provinces (Table 2). However, Corn and Bury (1989) reported that the density and biomass of four species of stream-associated amphibians were significantly greater (2-7X) in uncut forest (natural regeneration) than in streams in clearcut stands sampled 14-40 yr post harvest. Although there were few young natural stands (n = 3), the abundance of amphibians was similar to streams found in mature and old-growth stands (Table 3), but had markedly greater numbers compared to streams running through clearcut stands. This evidence suggests that wildland fire had little effect on stream amphibians or amphibians recovered rapidly in postburn conditions, but clearcut logging was detrimental and had long lasting effects. However, further study is needed on this topic, especially with more replicates of study streams.

Studies on prescribed and wildland fire effects on stream-breeding amphibians in the Northwest are currently underway. In Idaho, we (Pilliod and P. S. Corn) have initiated a 3-year study comparing Rocky Mountain tailed frog (*Ascaphus montanus*) populations in streams running through both burned and unburned forests. In conjunction with this retrospective study, we are conducting an experimental prescribed fire study in the South Fork Salmon sub-basin where Rocky Mountain tailed frog and Idaho Giant salamander (*Dicamptodon aterrimus*) populations will be monitored in six streams for 3 years pre- and 2 years post-burn. Similar research will start in Oregon in 2002 by one of us (Bury).

Riparian Habitats

Riparian zones adjacent to streams are important habitats for Pacific Northwest amphibians (Bury 1988). Most of the endemic stream amphibians of the region inhabit the waters and adjacent cool, vegetated banks. Riparian vegetation serves to shade and cool stream temperatures, and protect the rocky substrate from siltation from upslope disturbance. Stream amphibians like tailed frogs (*Ascaphus truei*) often move into the riparian zone after transformation (T. Wahbe, pers. comm.), where conditions are relatively cool and moist year-round compared to hotter, drier upslope areas.

In forested stands west of the Cascade crest, riparian areas associated with permanent streams are not scheduled for prescribed burning (T. Atzet and J. Lint, pers. comm.). These Federal lands have been protected as riparian reserves under the Northwest Forest Plan (NWFP). The Aquatic Conservation Strategy of the NWFP provides riparian reserves of 1-2 tree heights away from all permanent streams. In 1997, an unpublished NWFP report on "Riparian Reserve Evaluation of Techniques and Censuses: Federal Guide for Watershed Analysis" suggested that management activities in riparian areas are feasible, including fuels reduction. Introduction of prescribed fire into riparian areas appears to be only allowable on an experimental basis for research or pilot studies at this time. However, prescribed fire likely will occur near riparian zones and there may be an influence from these adjacent, upslope areas.

Fire suppression in riparian areas for long periods will create fuel build-ups that may eventually lead to unnaturally severe fire in riparian zones, especially in the more productive sites at lower elevations. Further, disruption of the natural fire regime likely will result in changes in riparian forest structure and composition. This may include increased amounts of input of woody debris into streams that, in turn, influence channel processes and habitat availability for stream or streamside amphibians.

Terrestrial Habitats

To our knowledge, there are no studies addressing the effects of fires on terrestrial amphibians in the Pacific Northwest. However, we can again glean useful information from the Old-growth Wildlife Habitat Program (Ruggerio et al. 1991). Bury et al. (1991b) summarized results for 130 stands in the chronosequence from three Provinces (OR Cascades, OR Coast Range, WA Cascades). Each stand was sampled in the fall for one month of pitfall trapping (1,080 trap-nights/stand), and most were sampled twice (1983 and 1984). This intensive effort showed that there were no significant differences in catch of 6 of 8 common species of amphibians along the chronosequence with young stands did not differing from mature or old-growth. The Northwestern salamander (*Ambystoma gracile*) was more common in old-growth whereas red-backed salamanders (*Plethodon vehiculum*) were more frequent in young stands than in other types. However, both of these species may be influenced by factors other than stand age. The Northwestern salamander is a migratory species that travels overland and location of breeding ponds may greatly influence its local abundance. The red-backed salamander requires rocky substrate and this may have influenced its distribution. Overall, the

Table 2.—Distribution of 79 streams by stand category and natural regenerated or harvested state.

	Natural Regeneration			Clearcut Harvest
	Young	Mature	Old-growth	
Washington Cascades	6	6	6	0
Oregon Cascade	6	6	6	0
Oregon Coast Range	3	10	10	20

Table 3.—Stream-associated amphibians taken from three categories of forest stands in the Oregon Coast Range. Results are mean numbers caught/10 m (most were headwaters about 1 m wide).

Species	Old-growth and Mature (n = 20)	Young Natural (n = 3)	Young Harvest (n = 20)
Tailed frog, *Ascaphus truei*	9.8	8.3	3.5
Torrent salamander, *Rhyacotriton variegatus*	3.1	1.7	0.4
Pacific giant sal., *Dicamptodon tenebrosus*	23.4	34.3	4.6
Dunn's salamander, *Plethodon dunni*	4.6	3.0	1.4

resident amphibians were either little influenced by fire or had recovered since burning 3-5 decades earlier.

Using pitfall trapping in the Oregon Coast Range, Corn and Bury (1991) found no marked differences in numbers of the five most common amphibians across the chronosequence of natural regenerated stands (from earlier fires): young, 40-75 yrs old (n = 8 stands); mature, 80-120 (n = 10); and old-growth, 150-450 (n = 27). They also sampled 5 clearcut harvested stands (< 10 yrs post harvest) and overall abundance did not differ much from results in natural stands (young to old-growth) except that tailed frogs and torrent salamander (*Rhyacotriton* spp.) were absent. Both groups appear associated with streams and both are highly sensitive to logging.

Employing time-constrained searches of downed woody debris, Corn and Bury (1989) found a correlation between ensatina (*Ensatina eschscholtzi*) and clouded salamander (*Aneides ferreus*) numbers and stand amounts of downed wood. Loss of large wood input was hypothesized to be a limiting factor for several species of terrestrial plethodontids in Northwestern coniferous forests.

In northern California, Welsh and Lind (1991) reported that more species and numbers of individuals of amphibians, especially terrestrial salamanders, were in older forests compared to younger stands. These also were in the naturally regenerated chronosequence. These authors and others (Bury 1983, 1994; Smith et al. 1999; Welsh and Droege 2001) suggest that timber harvest has negative effects on several species of terrestrial salamanders in western coniferous forests. Similarly, there appear to be reduced numbers of salamanders in logged stands in deciduous and mixed forests in the eastern U.S. (Pough et al. 1987, Petranka et al. 1993, deMaynadier and Hunter 1995). Timber harvest, especially clearcutting, opens up forest canopies and leads to desiccation. Removal of trees reduces input of large chunks of woody debris into the forest ecosystem.

Further, harvested areas oftern are often subjected to secondary site preparation or other pre-commercial treatments such as burning, herbicide spraying and thinning to enhance new tree growth. Although we know little about how such multiple stressors work in concert, timber harvest (especially clearcutting) and associated silvicultural practices appear detrimental to terrestrial amphibian populations (De Maydanier and Hunter 1995, Welsh and Droege 2001).

To address how fire influences forest wildlife, we (Bury and Major) are involved with a study of fire effects on terrestrial amphibians in the Klamath Province (southern Oregon and northern California). Key objectives are to:

(1) Compare structural components of the forest floor and their use by terrestrial herpetofauna in burned and unburned sites;

(2) Determine the vulnerability of the structural components used by herpetofauna; and

(3) Evaluate habitat quality by relating diversity and abundance of herpetofauna to available forest floor structure.

Our study has two designs: retrospective (wildland fire) and experimental (prescribed fire with pre- and post-treatment). Retrospective work will describe forest floor structure in burned and adjacent unburned sites in recent (< 10 yr) wildland fires. We will conduct time-constrained terrestrial surveys at the paired sites to compare species richness and relative abundance of herpetofauna, and to characterize the use of the structural components by amphibians.

Our preliminary results from one large wildland fire in the North Umpqua River Basin in Oregon in 1996 indicate that there was no negative effect from this fire on terrestrial herpetofauna. We found more individuals in the burned than unburned comparison areas using 3 paired plots. However, much more cover was available in the unburned stands, so catch per cover object is somewhat less in the burned forest. Lack of response by the resident terrestrial amphibians may be related to occurrence of this wildland fire in summer during normally dry, hot conditions when terrestrial species of amphibians are deep underground. However, lack of information regarding pre-wildfire conditions (i.e., fuel loadings, cover availability, and associated amphibian detection rates) limits our inference capabilities. We have no data on possible long-term effects.

Unlike most wildland fires, prescribed burning activities often coincide with seasonal surface activity periods of terrestrial salamanders in the spring and fall. We (Major and Bury) are currently examining the effects of prescribed fire on herpetofauna in late seral coniferous and mixed-coniferous forests in the Klamath Province. Specifically, we are examining pre- and post-burn population-level responses of terrestrial salamanders across a series of prescribed fires. We also will compare structural components of the forest floor such as fire fuels and salamander habitat. Finally, we hope to explore the effectiveness of modeling population-level responses of terrestrial salamanders to changes in forest floor "habitats" through the use of predictive fuels consumption and fire effects modeling. Field sampling began in Summer 2001 with project completion expected in 2003.

Discussion

The lack of information on the effects of fire on fish and wildlife is a major impediment to developing ecologically sound fire management policies (McMahon and deCalesta 1990). Recent reviews of the effects of fire on amphibian communities uncovered relatively few studies, although most of the work reviewed had occurred in Southeastern pine plantations (Russell et al. 1999). Most aquatic studies have focused on stand-replacement burns and few have included an experimental component, such as prescribed burns (Major and Bury 2000). Further, many recent studies have examined population descriptors such as species presence or relative abundance, whereas more specific information on population change and measures of productivity may be needed to understanding cause-and-effect relationships of fire in the Pacific Northwest.

Although recent directives promote fuels reduction, we lack information on the quality of resulting postburn habitats or how resident wildlife species respond to fire-induced changes in availability of the altered structural elements (e.g., less forest duff, fewer cover objects). Reduction in quantity of fuels, downed woody debris, also could have a profound effect on the habitat needs of wildlife and associated biological integrity that federal land management is charged to conserve. Overall, scientific studies on fire effects on wildlife and associated habitats are just starting in the Pacific Northwest. The current studies will provide some information for evaluating the effects of fire and forest management practices on several amphibian species in stream, riparian, and terrestrial situations.

We believe there is a need for more investigations that relate fuels management to habitat quality for resident terrestrial herpetofauna for several reasons. Many terrestrial amphibians are sensitive to habitat change because they have moist, permeable skin and restricted home ranges. Most terrestrial amphibians and some reptiles also require large woody debris as nesting habitat or cover objects (Welsh and Droege 2001). Thus, herpetofauna are well suited as resident wildlife to measure responses to habitat changes.

There is a need to assess prescribed fires inside riparian reserves and adjacent slopes. For example, unburned riparian areas likely buffer the stream from the effects of fire immediately after the burn, but streams may have a delayed response until spring runoff carries sediment and nutrients into the stream during periods of peak discharge. On longer time scales, excluding burning in riparian areas may result in increased riparian forest and amounts of instream woody debris dynamics. This may increase amount of woody debris and pose greater fire risk in riparian areas, especially during drought periods. Amphibians may still respond to upland burning, because juveniles and adults of stream amphibians move into adjacent woods at the onset of fall rains and fire-associated mortality of terrestrial phases of these species may occur in prescribed fire periods.

The few studies of fire effects on streams to date have been conducted within single drainages or fire complexes and have been focused on stand-replacing wildfires. No published studies exist that address the relative effects of stand-replacing and prescribed fire at broad spatial scales. There is need for studies that combine an ongoing prescribed fire study with post-fire investigations of stream response to widespread wildland fires. These will provide opportunities to characterize the effects of fire treatments and severity on aquatic and riparian habitats.

We need integrated regional and national programs that better link wildlife habitat components into fuels inventories and fire effects models. Although inventory techniques are designed to collect information on structural components pertinent to fuels management goals, this information is of limited use in evaluating "habitat use" by wildlife. Further, a habitat/fuels approach would prove biologically useful in developing effective monitoring protocols and providing baseline information to elucidate working hypotheses on fire effects and ecological responses across different spatial scales. In the western U.S., much work has focused on inventorying volume and tonnage of downed woody fuels (Koski and Fischer 1979, Brown et. al. 1982). However, these studies address only a subset of structural components and do not provide information on fire-mediated changes in quantity, type, size, and physical characteristics of downed wood, which affects wildlife habitat quality (Bull et. al. 1997). Fire effects models (Peterson and Ryan 1986, Ryan and Reinhardt 1988, Keane et al. 1994) incorporate a wider range of fuel types and more precise description of post-burn conditions; however, they are limited in their utility to describe habitat quality across the range of structural legacy in northwest forests. Furthermore, these models only examine immediate post-fire changes and are based on modeling structural components influenced by past suppression.

Clearly, we should increase numbers and integration of projects that: 1) Determine what type and amount of surface and ground structure are required by resident wildlife, 2) Evaluate direct and indirect effects of fuels management on structural components important to resident wildlife, and 3) Predict the short- and long-term effects of fuels management on legacy components in forests and associated quantity and quality of habitat for resident wildlife. There is a rich literature and growing understanding of habitat requirements of forest wildlife, in part related to major efforts generated by the Northwest Forest Plan and other agency mandates. A future goal is to tie this information to fuels inventory models and integration of disciplines. Lastly, we need to recognize the vast acreage and diversity of forests in western North America, Geographically dispersed studies will be required to better define how wildland and prescribed fires affect wildlife across a broad spectrum of environmental conditions.

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