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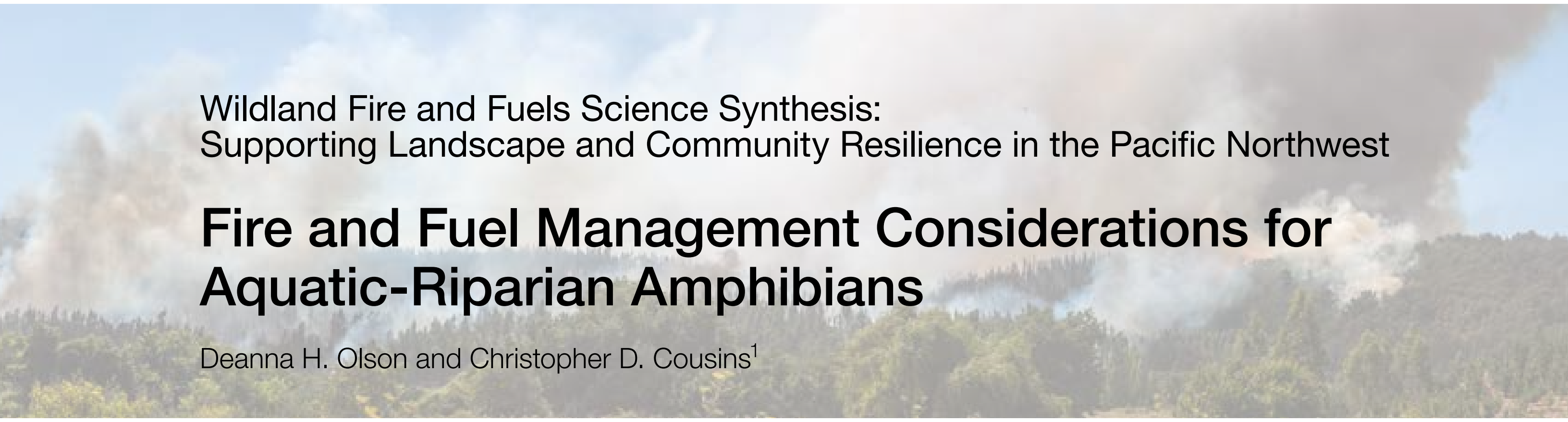

Wildland Fire and Fuels Science Synthesis:
Supporting Landscape and Community Resilience in the Pacific Northwest

Fire and Fuel Management Considerations for Aquatic-Riparian Amphibians

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Introduction

Amphibians are the most threatened vertebrate class, with 41 percent of species at risk of extinction globally (Luedtke et al. 2023). The forests of the Pacific Northwest of North America have a remarkably unique amphibian fauna, but land development, timber harvest, and wildfire have changed these forests over the past 200 years (Davis et al. 2017), elevating concerns for many forest-associated amphibians. Here, we focus on aquatic- and riparian-associated amphibian species in these forests that may be at additional risk from fire and fuel management (for terrestrial amphibians, see Brown 2026 [in this series]).

Purpose

This synthesis identifies at-risk amphibians tied to aquatic-riparian habitats in Pacific Northwest forests for fire-management considerations. We synthesize amphibian ecology and fire- and forest-management effects to provide guidance for sustainability of these amphibians during prefire fuel management, active wildfire management, and postfire management activities.

Ecology and Conservation

We list 20 amphibian taxa as key aquatic-associated amphibians in the coniferous forests of the U.S. Pacific Northwest that are distinguished by breeding habitats (table 1) (Blaustein et al. 1995, see also Olson et al. 2007a). Obligate stream breeders include three iconic Northwestern amphibian groups with ancient lineages, strong old-forest associations, and viability concerns (table 1). These amphibian groups are (1) the most primitive frogs on Earth (tailed frogs [*Ascaphus* spp.]); (2) the largest salamanders on Earth that venture into uplands (Pacific giant salamanders [*Dicamptodon* spp.]); and (3) headwater-stream specialist salamanders (torrent salamanders [*Rhyacotriton* spp.]) (fig. 1A) (Thurman et al. 2022). In contrast, pond-breeding amphibians, such as the Cascades frog (*Rana cascadae*) (fig. 1C) and northern red-legged frog (*R. aurora*), require still waters of ponds, lakes, or streams for egg deposition and larval recruitment. Additionally, the Dunn's salamander (*Plethodon dunni*) is a streambank and riparian forest dwelling species (Kluber et al. 2008, Olson and Weaver 2007), and the Van Dyke's salamander (*Plethodon vandykei*) (fig. 1B) is associated with seeps along forested streambanks or isolated in upland forests (Olson and Crisafulli 2014).

Following larval metamorphosis, most aquatic-breeding amphibians disperse to uplands for terrestrial life functions: foraging, seeking daytime microhabitat refugia from predators or adverse climate conditions, and dispersal. Cool, moist microhabitats in uplands are used by aquatic breeders, as well as moisture-associated terrestrial salamanders, such as the Klamath black salamander (*Aneides klamathensis*) (Nauman and Olson 2004). The

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Table 1—General habitat types by life stage of aquatic-associated amphibian species found in older forests of the Pacific Northwest (Washington, Oregon, northwestern California) with viability risk assessment and state sensitive species status

Species	Habitat type by life stage[a]			Viability risk assessment[b]		State sensitive species[c]
	Ponds and lakes	Streams	Riparian	T	L and R	
Caudates						
***Dicamptodon* spp.** **Giant salamanders[d]**	**—**	**L, P, M**	**M**	**Med-H**	**H**	**WA, OR, CA**
***Rhyacotriton* spp.** **Torrent salamanders[e]**	**—**	**L, M**	**M**	**Med-H**	**H**	**WA, OR, CA**
Ambystoma gracile Northwestern salamander	L, P, M	L*, P, M	M	Med-H	Med	—
A. macrodactylum Long-toed salamander	L, M	—	M	—	—	—
A. tigrinum Tiger salamander[f]	L, P, M	—	M	—	—	WA, OR
Batrachoseps attenuatus California slender salamander	—	—	M	—	—	OR
Plethodon dunni **Dunn's salamander**	**—**	**—**	**M**	**Med**	**Mod**	**WA**
P. vandykei **Van Dyke's salamander**	**—**	**Seeps**	**M**	**Med-H**	**H**	**WA**
Taricha granulosa Rough-skinned newt	L, P, M	L*, M	M	Med	Med	—
Anurans						
Anaxyrus boreas Western toad	L, M	L*, M	M	—	—	WA
A. woodhousii Woodhouse's toad	L, M	L*, M	M	—	—	—
***Ascaphus* spp.** **Tailed frogs[g]**	**—**	**L, M**	**M**	**Med-H**	**Mod**	**WA, OR, CA**
Pseudacris regilla Pacific treefrog	L, M	L*, M	M	—	—	—
Rana aurora **Northern red-legged frog**	**L, M**	**L*, M**	**M**	**—**	**Mod**	**WA, OR, CA**
R. boylii Foothill yellow-legged frog	—	L*, M	M	—	—	OR, CA
R. cascadae **Cascades frog**	**L, M**	**L*, M**	**M**	**—**	**Mod**	**WA, OR, CA**
R. luteiventris Columbia spotted frog	L, M	L*, M	M	—	—	WA, OR
R. pretiosa Oregon spotted frog	L, M	L*, M	M	—	—	WA, OR
Lithobates pipiens Northern leopard frog	L, M	L*, M	M	—	—	WA, OR, CA
Spea intermontana Great Basin spadefoot	L, M	L*, M	M	—	—	WA, OR

Bold font indicates the seven taxa that have a modeled forest variability risk and state sensitive species ranking.

— = not applicable.

[a] L = larva, L* = eggs and larvae can occur in nonflowing parts of streams, P = paedomorphs, M = metamorphs (from Blaustein et al. 1995).

[b] Summary of viability risk assessments (Med = medium risk, H = high risk, Med-H = medium to high risk, Mod = moderately high risk) in Pacific Northwest forests within the range of the northern spotted owl (*Strix occidentalis caurina*) conducted by Thomas et al. (1993) (T) and Lehmkuhl and Ruggiero (1991) (L and R).

[c] States with Sensitive Species Status within our geographic scope: WA = Washington, OR = Oregon, CA = California.

[d] *Dicamptodon copei* is sensitive in Washington and Oregon. *Dicamptodon ensatus* is sensitive in California. *Dicamptodon aterrimus* is sensitive in Montana, which is outside the geographic scope of this summary.

[e] All four *Rhyacotriton* spp. are sensitive species in the states where each occurs.

[f] Taxonomy of the *A. tigrinum* complex includes six subspecies which are elevated to full species by some sources (Lannoo and Phillips 2005). In the eastern Cascades and Columbia Plateau, there are disjunct occurrences of the western or blotched tiger salamander, *A. t. mavortium*.

[g] *Ascaphus montanus* is sensitive in Washington and Oregon, *Ascaphus truei* is sensitive in Washington, Oregon, and California.

Figure 1—Example aquatic-riparian amphibians of the U.S. Pacific Northwest that are state-listed sensitive species and have been evaluated to be at moderate to high risk in regional viability assessments of fauna associated with western moist coniferous forests (table 1): (A) Cascades torrent salamander (*Rhyacotriton cascadae*), a stream-breeder (Crisafulli 2005); (B) Van Dyke's salamander (*Plethodon vandykei*), a seep and riparian associate (Jones and Crisafulli 2005); and (C) Cascades frog (*Rana cascadae*), a pond breeder (Olson 2005). Photos by C.D. Cousins.

basic ecology of aquatic-riparian amphibians connects them to other biota through the food web and their other key ecological functions (see "Ecosystem Services").

We identify seven aquatic-riparian amphibian taxa with sustainability concerns that merit closer consideration for fire-management activities. To identify these seven taxa, we merged results of two past assessments of amphibian viability concerns from altered forest conditions and current conservation status ranks (table 1). First, nine aquatic-riparian taxa were considered highly associated with older moist coniferous forest conditions; two species-viability assessments ranked these nine taxa as having medium-to-high risk of reduced viability because of changes in old-forest conditions (table 1) (Lehmkuhl and Ruggiero 1991, Thomas et al. 1993). It may be especially important to consider these nine taxa during fire-management activities that could alter the cool, moist forest habitat conditions that they need for survival, but those with sensitive status are especially high priorities for sustainability management in regional moist coniferous forests. However, only seven of these nine taxa have been assessed to be rare or at risk to long-term sustainability by federal or state governments. We use these combined assessments of forest-habitat concerns and federal or state at-risk status to identify seven priority species here.

Federal and state species conservation-status ranks can be used to identify rare species and other concerns that are potentially related to declining populations (e.g., torrent salamanders) (Howell and Maggiulli 2011). Fifteen aquatic-riparian-associated amphibians in Northwestern forests (table 1) have state sensitive-species ranks: vulnerable [S3], imperiled [S2], or critically imperiled [S1] (NatureServe 2024). Together, 7 of 20 aquatic-riparian amphibian taxa (table 1: bold) have **both** state sensitive status and modeled viability concerns in regional moist coniferous forests, highlighting dual priorities for amphibian considerations during fire management. These dual priority amphibian taxa are the giant and torrent salamander species complexes, Van Dyke's and Dunn's salamanders, tailed frogs, and northern red-legged and Cascades frogs. Actions that can reduce the loss, degradation, and fragmentation of aquatic-riparian forest habitats for these seven amphibian taxa during fire-management activities are especially important. Other species or populations could be elevated for fire-management concerns on a case-by-case basis.

Ecosystem Services

Aquatic-riparian amphibians play key ecological roles in the larger forest ecosystem. Stream and pond breeders sequester aquatic nutrient and energy subsidies as larvae grow, and they transport these to uplands when they metamorphose into terrestrial life forms. In turn, growth of amphibians in uplands results in sequestration of terrestrial nutrients and energy that are deposited back to aquatic habitats upon breeding and egg deposition (Baxter et al. 2005). Also, because some amphibians prey upon invertebrates that are decomposers, such as those with a leaf-litter diet, their predation may effectively forestall litter breakdown and carbon release to the atmosphere (Best and Welsh 2014). Therefore, these amphibians may have a role in reducing greenhouse gas emissions.

Food-web linkages of amphibians are complex—amphibians are centrally located in trophic networks functioning as both prey and predators and affecting direct and indirect interactions across several trophic levels. These effects can add stability to old-forest ecosystems because some Northwest aquatic amphibian species are relatively long-lived with long-term predatory effects (e.g., Dunn's salamander [*Plethodon dunni*], Cascades frog [*Rana cascadae*], western toad [*Anaxyrus boreas*]) (Reinke et al. 2022). This means their loss from the system could disrupt trophic linkages that contribute to current levels of ecological resilience. In this regard, stream amphibians of Pacific Northwest forests have been considered indicators of ecosystem stress (Welsh and Ollivier 1998).

Effects of Wildland Fire and Fire Management on Aquatic-Riparian Amphibians

There are few fire effects studies addressing aquatic-riparian amphibians. In this section, we note chief concerns, list research gaps (see "Research Gaps"), and summarize research efforts to date. Two chief concerns are (1) loss of overstory forest-canopy closure that contributes to shading and cool, moist microhabitats used by aquatic- and riparian-associated amphibians, and (2) ground disturbances leading to loss of physical habitat structures (e.g., large down wood) and substrate interstices that provide cool, moist refugia. For example, soil compression from large equipment used in prefire fuel reduction, fire-line establishment, and postfire salvage operations could reduce subsurface forest refugia by compressing interstitial spaces that amphibians use for vertical migration; soil compression could also result in direct mortality of amphibians.

In high-topography landscapes, the likelihood of postfire erosion and debris flows are particularly concerning because of sluicing, sedimentation, or embeddedness of aquatic-riparian habitats (e.g., Burnett and Miller 2007, Cover et al. 2010). Stream peak flows may increase in the wet seasons following riparian and upland forest fires or timber harvests because there is less forest vegetation to intercept water from snowmelt or rain. Consequently, streams could be vulnerable to scour and sedimentation, with potential adverse effects on instream amphibians (see also Welsh and Ollivier 1998). Because critical rearing habitat is in coarse substrates, instream eggs and larvae may be highly susceptible to fine-substrate deposition from postfire erosion. In some locations, obligate stream breeders have multiyear larval life stages (e.g., it may take up to 4 years for tailed frog larvae to metamorphose to adult forms), so a single sedimentation/sluicing event could eliminate up to 4 years of recruitment for a local population. Site-scale losses in recruitment can lead to genetic bottlenecks (low genetic variation), which would slow recovery if gene flow among sites or watersheds is affected (e.g., Cope's giant salamander [*Dicamptodon copei*]) (Steele et al. 2009).

These effects are most relevant for at-risk aquatic-riparian amphibians in forest areas that are either identified as being at high risk of wildfire or projected to be affected by high-severity wildfire. Such areas are often priorities for prefire management activities to reduce fuels and may coincide with portions of these amphibians' ranges that have already burned and could be a priority for postfire management as well. Hossack and Pilliod (2011) reported that >9 percent of the southern torrent salamander (*Rhyacotriton variegatus*) range and almost 24 percent of the Rocky Mountain tailed frog (*Ascaphus montanus*) range had burned since 1987; these proportions likely have increased because of fires since that report. In the ranges of the at-risk aquatic-riparian amphibians that we have identified (table 1), reducing soil compression during postfire salvage operations and accelerating forest restoration may be warranted. Monitoring amphibians in areas with restoration activities could help inform adaptive management for future restoration activities.

Postfire assessments are lacking for most Pacific Northwest amphibian species. However, in Montana, Hossack et al. (2006) reported postfire effects of reduced abundance and an altered age-class structure for Rocky Mountain tailed frogs, with higher losses of larvae in their first year. Yet in Idaho, Dunham et al. (2007) reported no postfire difference in larval patch occupancy of these frogs. These discordant results between studies could be explained by differential wildfire severity and refugia availability. Other positive, negative, and neutral effects of fires were summarized for a variety of aquatic amphibians by Hossack and Pilliod (2011). These results again supported the context-dependence of wildfire severity and fire-management disturbance effects on amphibian habitats, while also supporting the higher risks posed to small, isolated, or already stressed populations. Future studies on streams several years postfire could elucidate the long-term persistence or resolution of negative effects, a significant data gap.

We note two additional research gaps that stand out for regional aquatic- and riparian-associated amphibians relative to wildland fire-management effects. First, the potential effects of prescribed fire on at-risk aquatic-riparian amphibians are unstudied in this region. When prescribed burns occur in moist or cool times of the year to avoid fire escape, the timing could coincide with periods when these animals are more surface active in upland forests, suggesting a risk for upland life stages. Focusing prescribed burns on sun-exposed upland forest areas away from cool, moist riparian or hill-shaded

Research Gaps

Research on the following questions could help inform management strategies for aquatic-riparian amphibians:

- How much area within ranges of aquatic-riparian amphibian species has been burned by recent wildfires?
- Are there priority areas for postfire assessments or restoration management for aquatic-riparian amphibians?
- What are the effects of wildfire on these taxa immediately postfire and several years later, considering lag-time effects from their complex life history, their occurrences in different aquatic or terrestrial habitats, and their longevity?
- How does postfire restoration management affect these species?
- How well do aquatic-riparian amphibians disperse between sites to enable recolonization of fire-affected populations?
- What landscape-scale attributes affect gene flow (i.e., dispersal across watersheds)?
- How well do the habitats of at-risk aquatic-riparian amphibians align with fire refugia?
- Can mapping of fire risks and fire refugia contribute to prioritization of wildfire management activities to sustain amphibian breeding, foraging, overwintering, or dispersal habitats?

areas might help reduce potential adverse effects on this amphibian assemblage.

Second, there are research gaps regarding long-term effects from wildfire and fire-management activities for Pacific Northwest aquatic-riparian amphibians. For example, there could be few immediate effects on instream or pond life stages, but a local decline might be observed later, suggesting adults in burnt uplands may have been affected such that subsequent years' breeding activity and juvenile recruitment were reduced (see Pianka 1970, Pilliod et al. 2003). Relatively long-lived organisms, such as the at-risk fauna highlighted here, some of which may live 10 to 20 years (e.g., Jones et al. 2005, Reinke et al. 2022), may have complex life histories that facilitate local persistence despite episodic disturbances to their aquatic or upland habitats and life stages. For example, a reserve of several annual cohorts of aquatic young may persist if upland adults do not survive a wildfire, and over time the local population could be restored as those younger age classes mature. Alternatively, if a stream were to be sluiced by a debris flow, several cohorts of upland adults may survive to breed in subsequent years, reinitiating the early life stages within a local population. In this way, these taxa may have life history traits that afford adaptive capacity for ecological resilience (Thurman et al. 2020), some having traits that support their ability to persist in place (i.e., longevity and complex life history with life forms in water and on land) or shift in space (i.e., longevity and dispersal ability for recolonization of extirpated sites). These concepts warrant research to better understand resilience and risk of these species to increasing frequencies or severities of wildfire and other forest disturbances over time.

We are beginning to understand that some amphibian species are broad dispersers, and others are not, as results of landscape genetics studies increase our understanding of dispersal patterns. For example, Cope's giant salamander, one of our at-risk taxa, is thought to be mostly restricted to streams with limited upland habitat use and overland-dispersal potential (Steele et al. 2009). For fire management, this species' life history would support actions to retain populations within streams and riparian areas of occupied subdrainages within a larger watershed. Its congener, the more widely distributed coastal giant salamander (*D. tenebrosus*), was shown to often have similar genetic signatures among adjacent small drainages separated by headwater ridgelines but showed some limitations in landscape-scale gene flow (i.e., dispersal) in the Oregon Coast Range. The coastal giant salamanders appeared to be still "chasing glacial retreat" as there was reduced genetic variation among the northern populations that were sampled (Auteri et al. 2022). Retaining both local populations and upland forest dispersal habitat, including stream-riparian areas and corridors across watershed ridgelines, at both local and landscape scales may be warranted for species that have limited dispersal and landscape-scale gene flow.

Identifying fire refugia could inform the design of restoration pathways for broader overland aquatic-amphibian dispersal across watersheds (fig. 2). Several efforts have supported aquatic-riparian areas functioning as fire refugia in Northwestern forests (e.g., Krawchuk et al. 2023, n.d. [in this series]; Lesmeister et al. 2025, 2026 [in this series]), and streamside forested areas have been considered amphibian refugia for which at-risk terrestrial salamander conservation strategies have been designed (Cuenca and Jones 2023, Olson et al. 2007b). Although design elements of over-ridge dispersal pathways between watersheds to link aquatic amphibian populations has been developed conceptually (Olson and Burnett 2013, Olson and Kluber 2014), additional analyses with landscape fire risk patterns are warranted. Yet, landscape genetic analyses of a couple of aquatic amphibians have contributed to corridor-design considerations. Torrent salamander landscape-scale gene flow (dispersal) was positively associated with forest cover and negatively associated with roads (Emel et al. 2019). Similarly, tailed frog postdisturbance recolonization pathways appeared to follow forest habitats (Spear and Storfer 2008) with a negative effect from postdisturbance salvage that reduced down wood (Spear et al. 2012). Given these findings, identifying remnant patches of upland forest that remain after fire could inform management of amphibian connectivity pathways during forest restoration. Effectiveness monitoring and adaptive management of established corridors could improve the efficacy of future habitat connectivity designs across landscapes.

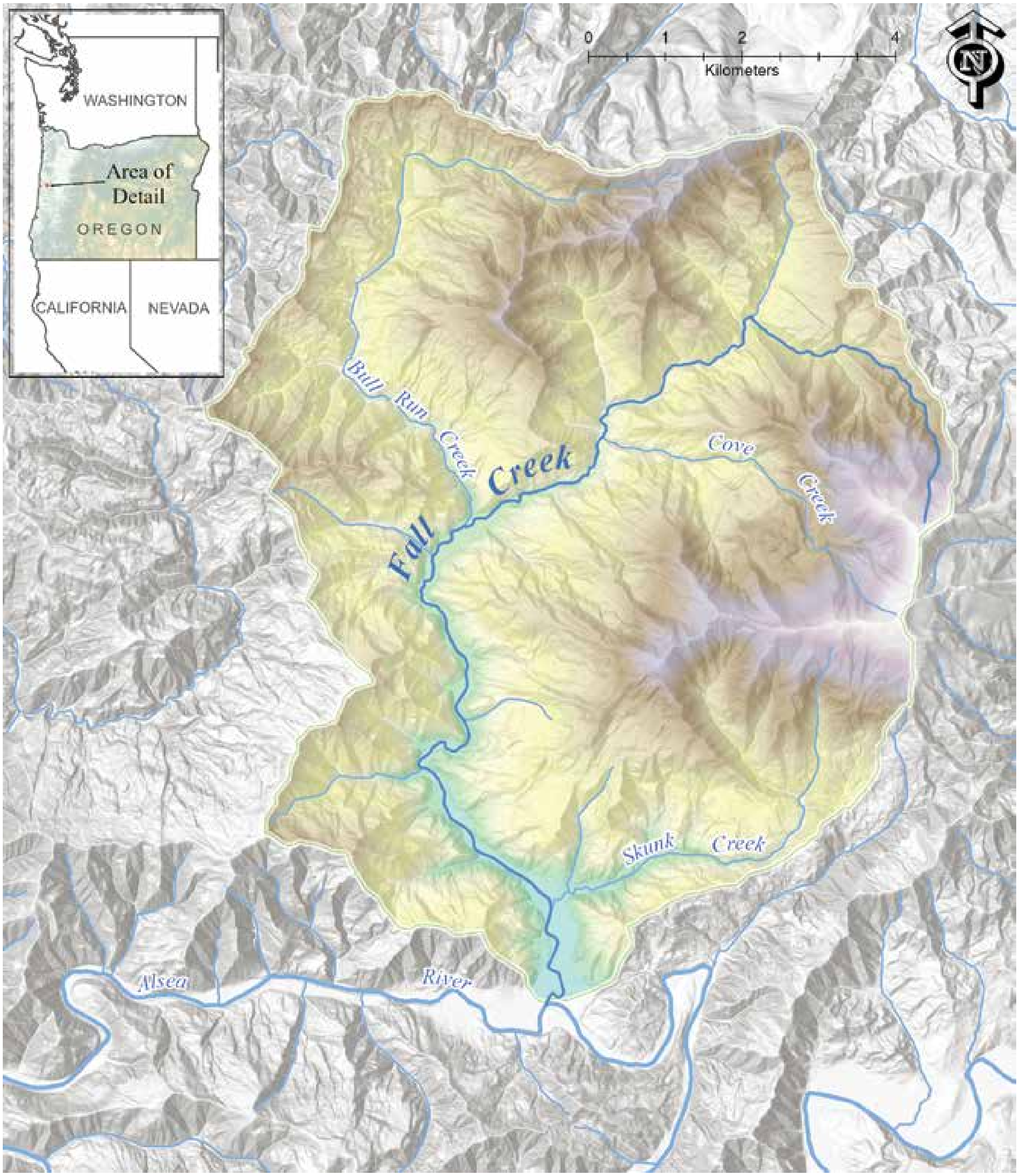

Figure 2—The Fall Creek watershed in the Oregon Coast Range is a 6th-field watershed (hydrologic unit code [HUC] 12) composed of moist, coniferous forest. The watershed perimeter is a boundary area to consider for fire management, including forestalling the risk of adjacent fire encroachment. Inside the watershed perimeter, smaller creek drainages similarly have ridgeline boundaries that could be used for fire management to remove disturbances from sensitive aquatic-riparian habitats critical to amphibian life functions. Watershed boundaries also are areas to retain or restore forest cover to aid over-ridge dispersal of amphibians (Emel et al. 2019).

In addition, these over-ridge, dispersal-habitat patterns raise concerns for managing forest microhabitats with fire-management guidance along amphibian population connectivity corridors at watershed ridgeline boundaries (fig. 2). At these boundaries, establishing fire lines and roads and removal of forest habitats and down wood could later present barriers to low-mobility amphibian dispersal and result in population fragmentation. Consequently, postfire restoration of contiguous forest structures on the ground (e.g., logs, which retain cool, moist microhabitats) (Kluber et al. 2009) between watersheds may warrant consideration to support amphibian dispersal habitat, which may aid gene flow and retention of genetic variation among populations (Olson and Burnett 2013). In conservation biology, increasing habitat fragmentation may lead to a population extinction vortex because increasing population isolation may result in reduced genetic variation over time as well as a higher likelihood of extinction (Gilpin and Soulé 1986). Management for retention of interconnected habitats and populations at landscape scales could counter this risk.

Wildfire and Fuel Management Mitigations

We propose two spatial scales of protection to help sustain aquatic-riparian amphibians in the face of wildfire management activities. First, establishing firelines and roads, backburns, fire-retardant drops, and postfire salvage activities at or near large watershed ridgeline boundaries (e.g., fig. 2) would separate many direct disturbance effects from sensitive aquatic-riparian amphibians and their breeding habitats. Such management also could proactively select efficient locations for postfire restoration of between-watershed dispersal habitat for at-risk amphibians of concern in the area. Second, within large watersheds and smaller subdrainages, keeping both wildfire and fire-management activities outside of pond- and streamside riparian buffers (fig. 3) would protect multiple life stages of aquatic-riparian amphibian species: eggs, larvae, juveniles, and breeding adults.

Guidance from the federal Northwest Forest Plan's Aquatic Conservation Strategy considers interim riparian reserves along (1) nonfish-bearing perennial streams measuring **one site-potential tree height** (one-tree buffer, 300-ft minimum width on each side of the stream) and (2) fish-bearing perennial streams (where aquatic amphibians also may occur) extending **two site-potential tree heights** (two-tree buffer, 600-ft minimum width on each side of streams; the wider buffers shown schematically in fig. 3A) (Reeves et al. 2018, USDA and USDI 1994). Also, riparian reserves have been implemented during forest management activities in debris flow-prone areas to retain slope stability. Landslide potential is another factor to consider for riparian buffer placement during fire-management activities (e.g., prefire thinning, fire protection, postfire salvage), as downslope erosion into stream-riparian areas could adversely affect at-risk amphibians and other sensitive ecosystem components. Riparian buffer protection along nonfish-bearing intermittent streams in headwaters is an additional consideration because some taxa, such as the at-risk torrent salamanders, are highly associated with these areas (Olson and Weaver 2007).

As established under the Aquatic Conservation Strategy, upon completion of watershed analyses, interim riparian reserves could be changed, or restoration activities could be permitted within riparian reserves. To date, limited riparian reserve-width changes or restorations have been conducted based on four factors: (1) uncertain reference conditions to anchor restoration aims, (2) concerns for microclimate conditions or down-wood recruitment limitations for fish habitat, (3) concerns for rare and little-known species, and (4) trust issues among forest stakeholders (Reeves et al. 2018). Relative to factor (3), riparian reserves may benefit the following seven stream- and riparian-associated amphibians within the Northwest Forest Plan area: coastal tailed frog (*Ascaphus truei*), Cascades torrent salamander (*Rhyacotriton cascadae*), Columbia torrent salamander (*R. kezeri*), southern torrent salamander, Cope's giant salamander, Van Dyke's salamander, and Klamath black salamander (Olson and Burnett 2013, USDA and USDI 1997). Overall, one- and two-tree streamside riparian buffers of the Aquatic Conservation Strategy apply to lands administering the Northwest Forest Plan for restricted prefire, during-fire, and postfire ground- and stream-disturbing activities. Within these areas, water removal from small streams and use of large equipment that can compress substrates warrant case-by-case consideration for seven at-risk amphibian taxa of focus here.

Additionally, many studies have addressed the effects of other streamside management zones on amphibians

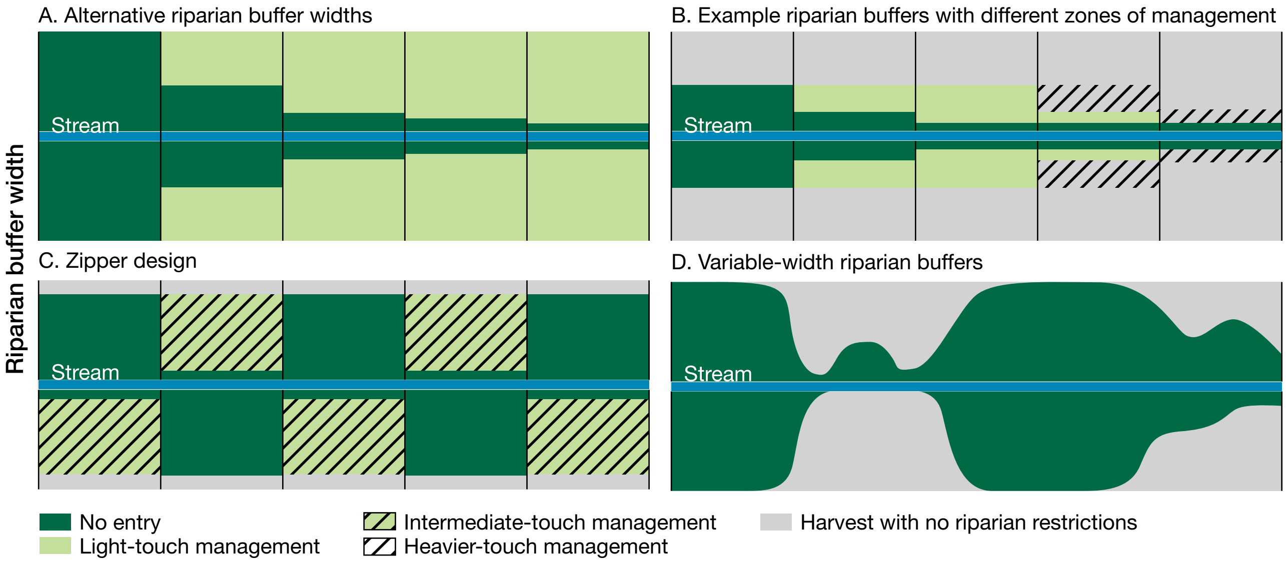

Figure 3—Going beyond best management practices for amphibian-species protections in U.S. Pacific Northwest coniferous forests might include alternating near-stream riparian buffer configurations (from Olson et al. 2022) with upland prefire and postfire management activities. Alternative riparian buffer widths might include: (A) no-entry buffers of different widths with upland harvest; (B) example riparian buffers with different zones of management; (C) zipper design that alternates intensities of near-stream management, where shaded sections with diagonal lines may be light- or heavy-touch management; and (D) variable-width riparian buffers that could address site-specific conditions, such as steep, erosion-prone slopes; hill-shaded areas with cool, moist microclimates; and seeps or swales.

in Pacific Northwest forests (see Olson and Ares 2022). Such studies may inform efficacy of adaptive management **within** one- and two-tree buffers for prefire fuel reduction and postfire risk- or wood-management on a site-by-site basis (e.g., alternative buffers with upland thinning) (see "Riparian Buffers for Prefire and Postfire Restoration Management"). Olson et al. (2022) conceptualized various designs, including near-stream zones for no entry and outer zones for light- to heavy-touch streamside riparian-buffer management (e.g., forest thinning) as "beyond best management practices" for aquatic ecosystems (fig. 3) (Olson et al. 2022). Yet, until site-scale risk analyses are available, minimum buffer widths of 50 to 300 ft for no-entry areas might reduce adverse forest disturbance effects on aquatic-riparian amphibians (Olson and Ares 2022). Monitoring such implementation could provide further information to assess the sustainability of sensitive amphibian taxa at site-to-drainage scales and could inform adaptive management of riparian management policies.

Furthermore, although shading by forest overstory can affect microclimate refugia in forests that are important for ground-dwelling amphibians associated with cool, moist habitats, other factors interact with overstory for site-level effects on microclimates. The "stream effect" (Anderson et al. 2007, Olson et al. 2007a, Rykken et al. 2007) refers to the cool, moist microclimate gradient from cold-water streams of the Pacific Northwest that radiates into forested uplands to various distances dependent upon site conditions. A microclimate-gradient inflection point in riparian forests occurred 50 ft from streams; beyond 50 ft, cool, moist microclimates abated more readily with increased distance from streams in intact forests (Anderson et al. 2007). Although edge effects from upland forestry activities may affect this near-stream microclimate gradient (e.g., Anderson et al. 2007), Rykken et al. (2007) independently reported that a 98-ft streamside buffer retained the riparian microclimate gradient in their study of upland timber harvest. A 50-ft distance-from-streams has relevance for aquatic-riparian amphibians and their habitat components in three other ways: (1) it matches the riparian habitat area used by semiaquatic Dunn's salamanders (Kluber et al. 2008); (2) it protects the riparian zone containing most amphibians and amphibian movements (Olson and Kluber 2014); and (3) it ensures that the primary source of instream down wood in small streams is protected (Burton et al. 2016). Together, these results support a 50-ft riparian width to retain many aquatic-riparian amphibian habitats and life functions in addition to the near-stream elevated, cool, moist conditions. Such a buffer could be considered a

Riparian Buffers for Prefire and Postfire Restoration Management

The *Density Management and Riparian Buffer Study of Western Oregon* (Cissel et al. 2006) provides insights for fire restoration management within streamside riparian reserves of the Northwest Forest Plan. The aquatic vertebrates and habitats study component examined vertebrate responses in small headwater streams to streamside buffer widths, including the one- and two-tree buffers of the Northwest Forest Plan and two narrower buffers (20 ft and a minimum of 50 ft), with upland thinning of secondary forests from about 200–300 trees per acre to 80 trees per acre. Olson et al. (2014) reported adverse effects on animals at the time-step of 10 years after the upland thinning treatments, when a negative treatment effect on streambank Dunn's salamander (*Plethodon dunni*) was detected within the narrowest buffer treatment (20 ft). This study went on to conduct a second thinning of the upland forest to 35 trees per acre with the three narrower stream buffers (20 ft, 50-ft minimum width, one-tree buffer), and after 1 year, Olson and Burton (2014) reported a lower density of torrent salamanders (*Rhyacotriton* sp.) in streams with the narrowest buffer treatment (20 ft). At 5 years after the second thinning, Olson and Ares (2022) reported lower densities of sculpins (Cottidae spp.), coastal giant salamander (*Dicamptodon tenebrosus*), and torrent salamanders in streams with the two narrower buffers (20 ft and a minimum of 50 ft). With lag-time effects evident from the first and second harvest, Olson and Ares (2022) considered the benefits of mixed-width, no-entry streamside buffer implementation during upland forest restoration activities to hedge uncertainties in effects on sensitive aquatic biota. However, the more persistent negative effect of the 20-ft buffer suggested that narrower buffers were a more certain risk, whereas the 50-ft, no-entry buffer and larger buffers may reduce effects of upland restoration actions.

no-entry zone within wider riparian reserves or could be implemented along intermittent streams in headwaters where torrent salamanders occur (Olson and Ares 2022). Nevertheless, there is heterogeneity of stream habitat conditions and animal assemblages in Northwestern forests (Penaluna et al. 2017), and it may be important to match no-entry riparian buffer designs to site-specific conditions and to consider fire risk and severity on a case-by-case basis (fig. 3). For example, where avoidance of riparian buffers could be prudent for prefire and postfire management, during-fire management decisions might override buffer-width or no-entry guidance as tradeoffs are weighed to safeguard forest ecosystem values.

Hill shading and elevation in montane watersheds also alter forest microclimates (Suzuki et al. 2008) and may be useful at the site-scale for identification of upland amphibian refugia that interact with fire and fire-management effects. For example, hill-shaded, cooler microclimate conditions could serve as natural climate refugia for amphibians and locations of lower fire severity (e.g., Krawchuk et al. 2023, n.d. [in this series]). Therefore, aspects of hillslopes and positions relative to streams could inform fire-management decisions. These might include directing increased fuel management toward warmer, drier, exposed slopes and decreasing management activities on cool, moist, shaded slopes. Cuenca and Jones (2023) used hillslope aspect and position relative to streams to guide fuel reduction in terrestrial amphibian habitats in the Klamath National Forest, California. For example, in areas that were not designated as wildland-urban interface where forest habitat patches were ≥0.25 ac, on **north- and east-facing slopes** (with more hill shading), guidance was to retain 60–100 percent (averaging ≥70 percent) overstory canopy closure on the **lower two-thirds** of the hillslope (areas with more cool, moist riparian conditions), compared to 40–100 percent retention (averaging ≥60 percent when feasible) on the **upper one-third** of the hillslope (warmer, drier areas). On the more exposed **south- and west-facing aspects**, 40–100 percent (averaging ≥60 percent when feasible) overstory canopy cover was to be retained on the **lower two-thirds** of hillslopes, and ≥30 percent cover on the **upper one-third**.

Similar to this California guidance (Cuenca and Jones 2023), maintaining >70 percent canopy cover on 80 percent of a site with ≥40 percent canopy closure on the remaining 20 percent of the site, was the guideline used in the fire-management recommendations for terrestrial amphibian populations in the Siskiyou Mountains in Oregon (Clayton et al. 2009). Such fuel-reduction guidance may be relevant within ranges of both at-risk aquatic amphibians with upland dispersal as adults (table 1) and terrestrial salamanders. Additional restrictions for upland amphibian habitats addressed understory burning, hand piling, and firelines, and included seasonal restrictions on fire-management activities, pushing them outside of cool, moist spring and fall seasons when amphibian surface activities are at their peak (Clayton et al. 2009, Cuenca and Jones 2023, Olson et al. 2007b). Aquatic-breeding amphibians can have migratory seasons to and from breeding waters and across forest uplands for between-site dispersal (e.g., during spring and fall rains). Restricting ground disturbance for prefire fuel reduction or postfire salvage operations to warmer, drier conditions at seasonal boundaries, before or after ground-soaking wet seasons, could minimize direct effects on surface-dwelling amphibians.

Distance to the Pacific Ocean affects marine influence as a microclimate moderator that can interact with the likely distribution of forest stand conditions and aquatic-associated amphibians. This gradient of marine influence with distance from the ocean also can affect wildfire frequency and severity and the efficacy of fire-management actions. In drier inland landscapes, amphibians may be more restricted to cool, moist microhabitats, so reduced fuel management within such refugia may be particularly effective at sustaining amphibians. For example, in inland drier forests of northwestern California, Klamath black salamanders were often seen in streambank areas (Nauman and Olson 2004), whereas, in areas nearer the Pacific Ocean with maritime climate influence, they are considered terrestrial salamanders occurring in more general forested uplands. Retention of near-stream buffers with upland thinning for partial

Key Takeaways

Wildfire risk to amphibians can be addressed by management activities before, during, and after fires, with set-asides for aquatic-riparian amphibian protection and delineation of areas for active management. Management options include the following:

- Protect seeps, streams, ponds and lakes, and lower hillslope riparian forests near water to provide cool, moist habitats where aquatic amphibian densities are highest because of the co-occurrence of all life stages: eggs, larvae, juveniles, and adults.
- Prevent entry into standing or flowing water, and water removal, and restrict use of heavy equipment and other ground-disturbing activities before, during, and after fires.
- Apply practices such as one and two site-potential, tree-height riparian reserves as stipulated in the U.S. federal Northwest Forest Plan.
- Manage riparian reserves, including outer zones, for ladder fuel removal and tipping of larger trees toward streams to aid development of down-wood habitats, while reducing overstory tree density in highly stocked stands.
- Reduce ground disturbances on hill-shaded slopes so forests upslope of riparian buffers with hill shading retain moist refugia used by amphibians for foraging, overwintering, and dispersal life functions.
- Use watershed boundaries to retain or restore forest cover to aid over-ridge dispersal of amphibians. Specific fire-management activities could occur at watershed boundary ridgelines, upper hillslope positions, and sun-exposed aspects, e.g., (1) prefire, reduce fuels from dense secondary forest stands by forest thinning; (2) during fire, apply fire retardants, backburning, and fireline construction; and (3) postfire, conduct salvage activities where landslide potential affecting streams is low.

canopy cover and overhead shading would likely aid this species during prefire management in drier inland forests where fire risk also is higher.

Chemical applications, such as fire retardants during active wildfires or ignition fuels used to initiate prescribed fires, are a potential risk to amphibians because of their highly permeable skin and possible adverse reaction to toxic chemicals. Avoidance of aquatic-riparian habitats and nearby riparian buffers used by at-risk amphibians during fire-retardant and prescribed fire fuel applications would be optimum. Application at upland watershed boundaries would move exposure away from many aquatic-riparian amphibians.

Lastly, fire-management activities, including water draws and drops during active wildfire management may pose additional risks to amphibians. Draws from small bodies of water can change habitat suitability at those draw sites, whereas water draws from larger lakes and streams may reduce that risk. Water drops during fire management may also transport aquatic invasive species (National Wildfire Coordinating Group 2017). These include aquatic predators, such as nonnative crayfish and fishes and disease-causing pathogens. For example, the presence of the invasive amphibian chytrid fungus *Batrachochytrium dendrobatidis* (*Bd*) in North America (O'Hanlon et al. 2018) and the disease it causes in susceptible amphibians, chytridiomycosis, has led to watershed mapping of *Bd* occurrences in the United States to inform water-drop decisions during wildfire management (Olson et al. 2013, 2021a). Although *Bd* is considered endemic to the United States today, there are genetic variants with different levels of virulence, which are not well mapped. Keeping *Bd* and other nonnative pathogens and predators out of watersheds where they are not known to occur would be a safeguard for native aquatic communities; fire managers could adopt biosecurity measures, such as the disinfection of field gear, large equipment, and water transported between watersheds (Gray et al. 2017, Julian et al. 2020, Olson et al. 2021b).

Metric Equivalents

When you know:	Multiply by:	To find:
Feet (ft)	0.305	Meters
Acres (ac)	0.405	Hectares
Trees per acre	2.47	Trees per hectare

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