Responses of Aquatic and Streamside Amphibians to Timber Harvest: A Review*

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Abstract

Stream-dwelling amphibians, which can be the dominant vertebrates of small streams in forests of the Pacific Northwest, are prototypic riparian organisms. Larvae of several species are totally aquatic, while adults use the terrestrial streamside (riparian) habitat to varying degrees. Impacts of timber harvest vary among species, physical habitats, and regions of the Pacific Northwest. Populations of giant salamanders (*Dicamptodon*) increased following clear-cutting in the Oregon Cascades, while in the Oregon Coast Range, the long-term effects of logging were negative and severe for all species. Timber harvest is less disruptive in high-gradient streams and in streams where there is uncut timber remaining upstream. Buffer strips adjacent to headwater and small streams can provide shade and reduce sedimentation from logging activities. Critical needs exist to define the ecological requirements of amphibians in headwaters, assess the effects of logging on amphibians in different regions and under varying climatic regimes, and determine what sizes of buffer strips or uncut patches are most effective and cost-efficient for protecting stream amphibians.

Introduction

Amphibians are important components of aquatic and riparian habitats associated with headwater (first- and second-order) and larger streams in forests of the Pacific Northwest. Amphibians play several ecological roles. Giant salamanders (*Dicamptodon*) replace salmonid fishes as the primary vertebrate predator in headwater streams (Murphy and Hall 1981). Tailed frog (*Ascaphus truei*) larvae are primary consumers feeding mainly on diatoms growing on rock surfaces, whereas adult frogs are secondary consumers feeding mainly on insects (Nussbaum et al. 1983). Amphibians may, at least occasionally, be preyed on by large trout (Carlander 1969, Wydoski and Whitney 1979). Amphibians transfer energy across the aquatic-terrestrial boundary. It is not widely appreciated that amphibians can reach high levels of abundance and that they can occupy a significant place in energy pathways. Olympic salamanders (*Rhyacotriton olympicus*) reached densities of from 12.9 to 41.2 per m^2 at two sites in Oregon (Nussbaum and Tait 1977). Burton and Likens (1975) estimated that biomass of all terrestrial and aquatic salamanders in a New Hampshire forest was twice that of breeding birds and equal to the biomass of small mammals.

There is a growing body of information about the effects of timber harvest on salmonid fishes (e.g., Meehan et al. 1977; Bisson and Sedell 1984; Everest et al. 1985; Salo and Cundy 1987). Three recent studies have examined the influence of timber harvest on salmonids and amphibians (Murphy and Hall 1981; Murphy et al. 1981; Hawkins et al. 1983). However, they report only numbers and biomass of the Pacific giant salamander (*D. ensatus*), which they found to be common in both uncut and logged habitats. Other

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*Peer – reviewed contribution

species of aquatic amphibians were rarely taken and not included in the data analyses, perhaps due to their low numbers in logged sites or to inappropriate sampling techniques (electroshocking). Several equivocal or anecdotal observations suggest that logging has negative impacts on aquatic amphibians (Noble and Putnam 1931, Metter 1964, Bury 1968, 1983, Nussbaum et al. 1983).

Stream-dwelling amphibians have received little attention because they have little or no commercial value, they are most abundant in first- and second-order headwater streams that frequently do not support salmonids, and they occupy both aquatic and terrestrial habitats. Salmonids are commercially very valuable, and the higher-order streams that are their principal habitat have received considerable attention. Organisms like amphibians that occupy habitats at interfaces between ecological disciplines (aquatic and terrestrial ecology) are often overlooked (Swanson et al. 1982).

Small stream channels are recognized as important to downstream fish habitat and water quality (Waring 1976, Swanson and Lienkaemper 1978, Rice et al. 1979, Everest et al. 1985). Land managers, however, place less emphasis on protecting the integrity of these small waters than on protecting that of streams with salmonid habitat (Anderson 1985, Gibbons 1985, Swank 1985, Vanderheyden 1985). Knowledge of the responses of small vertebrates to logging is important to land managers, who must manage forest lands for wildlife as well as wood production (Cutler 1980, Brown and Curtis 1985). Thus, the impacts of management activities on headwaters and their resident faunas merit greater attention.

This paper (1) reviews current evidence on the occurrence and abundance of amphibians in streams flowing through logged and uncut forests in the Pacific Northwest; (2) briefly discusses the major physical features of streams that are changed by logging and the reasons why these may affect amphibian populations; (3) examines how management of forests may affect amphibians over short-term and long-term periods; and (4) suggests alternatives for sustaining aquatic amphibians and their habitats in managed forests in the Pacific Northwest.

Aquatic and Streamside Amphibians

Several endemic amphibians occur in the cool, wet habitats of the Pacific Northwest (Nussbaum et al. 1983, Bury 1988). Four groups of species are characteristic of headwaters and small streams in the region (Figure 1; Table 1): the tailed frog (*Ascaphus truei*), Olympic salamander (*Rhyacotriton olympicus*), giant salamanders (*Dicamptodon* spp.), and lungless salamanders (*Plethodon* spp.).

Tailed Frog

Eggs and tadpoles of this species require cool, flowing waters (Metter 1964, Bury 1968, de Vlaming and Bury 1970, Brown 1975, Nussbaum et al. 1983). The length of the larval period is reported to be 2-3 years (Metter 1967), and thus this species is dependent on permanent water. Adults may not breed until 7-8 years of age (Daugherty and Sheldon 1982).

Tailed frogs in interior areas occur in disjunct populations (isolated in streams with favorable conditions) and dispersal between populations is rare (Metter 1967, Daughtery and Sheldon 1982). Our recent research (Bury et al., in prep.) indicates that at least some juveniles and adults disperse overland in western Oregon and Washington, perhaps because of the increased precipitation, longer periods of rainfall, and greater moisture in the dense forest canopy of areas closer to the ocean.

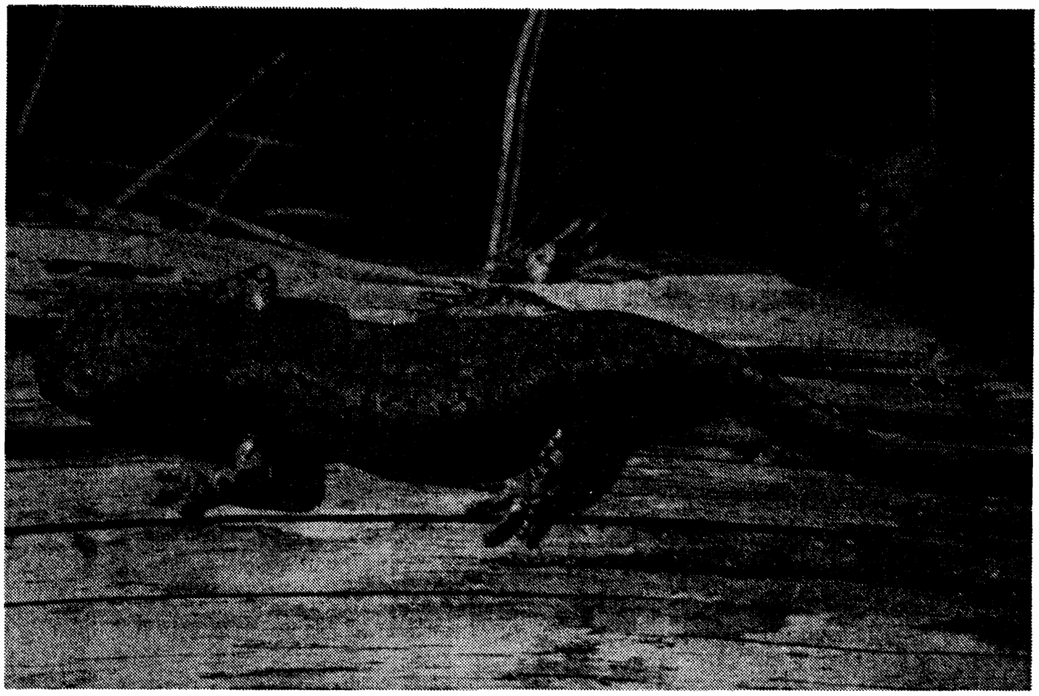

Figure 1. Stream-dwelling amphibians common in undisturbed headwater streams in the Oregon Coast Range (maximum total lengths of adults from Nussbaum et al. 1983): (a) tailed frog (*Ascaphus truei*, 50 mm), (b) Pacific giant salamander (*Dicamptodon ensatus*, 340 mm).

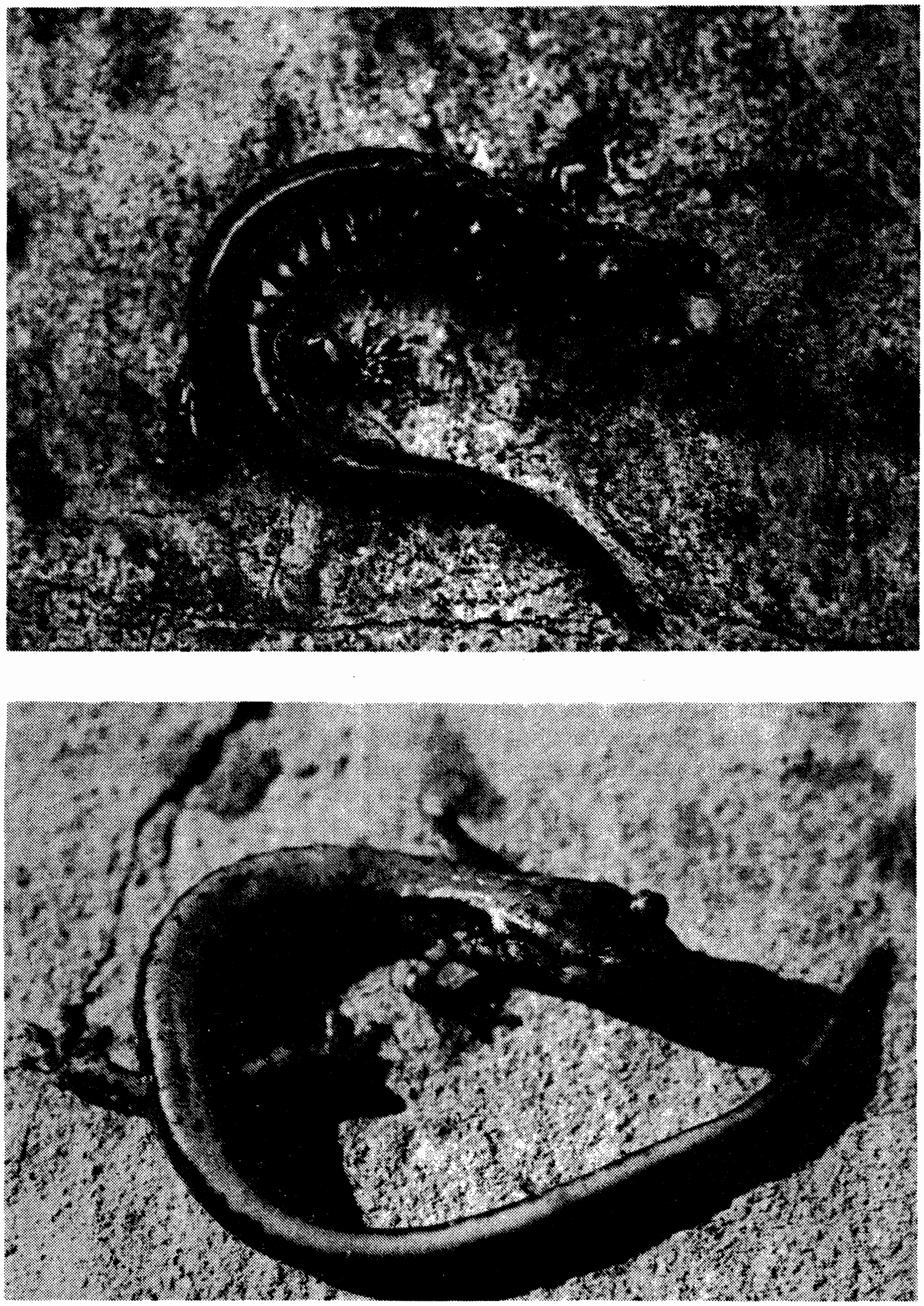

Figure 1. (continued): (c) Olympic salamander (*Rhyacotriton olympicus*, 56 mm), (d) Dunn's salamander (*Plethodon dunni*, 154 mm).

Table 1. Four species from the Oregon Coast Range represent spatial separation of stream-dwelling amphibians in Pacific Northwest waters. Asterisks represent relative use of each microhabitat, based on no use (blank) to total dependency (****).

		Microhabitat		
Species	Life stage	Aquatic	Streamside	Upland
Tailed frog	Larvae	****		
Ascaphus truei	Juv-Ad	**	*	*
Olympic salamander	Larvae	****		
Rhyacotriton olympicus	Juv-Ad	**	**	
Pacific giant salamander	Larvae	****		
Dicamptodon ensatus	Juv-Ad	**	*	*
Dunn's salamander	Juv-Ad	*	**	*
Plethodon dunni				

Olympic Salamander

This small salamander is restricted to the splash zone and shallow water of seeps, waterfalls, and creeks (Table 1). Eggs and larvae require cool waters, and both juveniles and adults rarely venture farther than 1 m from water (Nussbaum and Tait 1977, Nussbaum et al. 1983). This species is restricted to forests west of the Cascades. Recent work suggests that populations in the Olympic peninsula and Coast Range of Washington and northern Oregon, the Coast Range of southern Oregon and northern California, and the Oregon Cascades may represent three distinct species (Good et al. 1987).

Giant Salamanders

These large salamanders (up to 350 mm long) inhabit creeks and streams throughout forested areas of the Pacific Northwest. Temperature requirements are broader than those of either tailed frogs or Olympic salamanders, and giant salamanders are found in a wider range of habitats. Again, eggs and larvae occur in water, but juveniles and adults may be found on land.

The Pacific giant salamander (*D. ensatus*) occurs from northern California to southern British Columbia. Cope's giant salamander (*D. copei*) is a smaller species occurring almost exclusively in waters from extreme northern Oregon to the Olympic peninsula (Nussbaum 1970). The Rocky Mountain giant salamander (*D. aterrimus*) occurs in the Blue Mountains of eastern Oregon and Washington, northern Idaho, and western Montana (Daugherty et al. 1983).

Lungless Salamanders

These medium-sized salamanders occur in rock rubble or talus, most often along creeks and streams (Table 1). They may occur in association with the Olympic salamander (Nussbaum et al. 1983). Eggs presumably are deposited under rocks on land, but only one nest has been found. Juveniles and adults may be at water's edge, and they will jump into the water to avoid capture.

Dunn's salamander (*P. dunni*) occurs in extreme northwestern California, west of the crest of the Cascades in Oregon, and in the southwest corner of Washington. Van Dyke's salamander (*P. vandykei*) sometimes is found in similar habitats in western Washington. Less is known about this species than about Dunn's salamander.

Short-Term Effects of Logging

The initial impact of logging results from changes in the inputs of energy into the stream. Clear-cutting increases insolation and raises stream temperatures (Hall and Lantz 1969, Brown and Krygier 1970, Hartman et al. 1984, Beschta et al. 1987), thereby increasing microbial respiration, primary production, invertebrate consumers, and populations of invertebrate and vertebrate predators (Murphy and Hall 1981, Murphy et al. 1981, Hawkins et al. 1982, 1983, Bisson and Sedell 1984, Scrivener and Andersen 1984). These effects are temporary, lasting only until the canopy is reestablished. For example, stream shading is rapid and may reach 50 percent in less than 5 years and near prelogging levels after 10 years in the Oregon Coast Range (Andrus and Froehlich 1988).

Increases in water temperature following clear-cutting can be significant. Mean July temperature of Needle Branch, a second-order Coast Range stream, increased from 14°C to 22°C following clear-cutting of the entire drainage; the maximum temperature was 30°C (Brown and Krygier 1970). The effects of increased temperature were apparently not severe for salmonids (Hawkins et al. 1983, Scrivener and Andersen 1984), except for catastrophic mortality related to slash burning (Hall and Lantz 1969). Freshwater salmonids have wide thermal tolerances and the ability to seek out the cool-water areas that are present even in streams in clear-cuts (Bilby 1984a, Beschta et al. 1987). However, Hartman et al. (1984) caution that seemingly small natural or logging-related changes in stream temperature regimes have had important effects on the life history of young salmon, particularly earlier emergence of fry.

Pacific giant salamanders apparently react to clear-cutting in a manner similar to salmonids. This species typically is more abundant in streams traversing recent clear-cuts than in densely forested stands (Murphy and Hall 1981, Murphy et al. 1981, Hawkins et al. 1983), probably because of enhanced populations of invertebrate prey. However, this effect is not universal. Larval salamanders are dependent on crevices in the substrate for cover (Bury 1988, Corn and Bury, in prep.). In low-gradient streams, fine sediments accumulate and may eliminate the crevice habitat (Murphy and Hall 1981). Hall et al. (1978) observed that in streams with gradients less than 6 percent, biomass of Pacific giant salamanders was greater in streams in old-growth forests compared to reaches in clear-cuts.

The immediate effects of clear-cutting on other species of aquatic and riparian amphibians have been little studied. Aspects of the biology of these species and some of the results of our study of long-term effects of logging (Corn and Bury, in prep.) suggest that the short-term effects are largely negative.

Tailed frogs are likely to be affected by the increased water temperature in streams in clear-cuts. Tailed frog tadpoles are less mobile than salmonids and have low temperature preferences. Tadpoles from northern California selected water temperatures of about 10°C in the laboratory, and tadpoles acclimated to 5°C had a critical thermal maximum (lethal limit) of 29°C (de Vlaming and Bury 1970). Embryos have even narrower thermal tolerances. Brown (1975) found that normal development of tailed frog embryos occurred only below 19°C.

Food sources may be altered by increased insolation of the stream after clear-cutting. Larval frogs (tadpoles) are filter feeders, relying almost exclusively on diatoms that they scrape off rocks (Altig and Brodie 1972, Nussbaum et al. 1983). Beschta et al. (1987) suggest that increased sunlight and/or stream temperatures resulted in blooms of filamentous green algae and a shift in the species composition of the periphyton away from diatoms. The scraper guild of aquatic invertebrates also feeds on the thin layer of aufwuchs (algae, bacteria, detritus, and diatoms) that cover rocks in streams. Hawkins et al. (1983) observed reduced densities of these species in riffles of unshaded versus shaded stream reaches. Dense growths of green algae in unshaded streams may interfere with access to the rock surfaces and thus to the primary food of tailed frog tadpoles.

Populations of Olympic salamanders probably respond to increased sedimentation and water temperature. Our research in the Oregon Coast Range suggests that this species and the Pacific giant salamander react to the accumulation of fine sediments in similar fashions (Corn and Bury, in prep.). Olympic salamanders also have narrow, low temperature tolerances (Nussbaum et al. 1983). They may be eliminated or stressed by increased water temperatures.

Long-Term Effects of Logging

The second impact of logging is alteration of the stream habitat, which is long-term. Ultimately, introduction of new pieces of downed wood into the streambed is reduced (Swanson and Lienkaemper 1978, Sedell and Swanson 1984, Bryant 1985), and fine sediments accumulate, especially in low-gradient streams (Murphy et al. 1981, Hawkins et al. 1983). Sediments may be increased directly from logging practices (Hartman et al. 1987) or from road construction (Adams and Beschta 1980). The presence of sedimentary rock in a watershed is also an important determinant of the amount of sedimentation (Duncan and Ward 1985).

Habitat alterations generally have negative impacts on the stream fauna, and the effects may persist for decades (Meehan et al. 1977, Scrivener and Andersen 1984). The bloom of productivity following clear-cutting is short-lived, and once shade is reestablished over a stream, invertebrate, salmonid, and salamander populations decline (Murphy et al. 1981, Hawkins et al. 1982, 1983). Habitat alteration becomes much more important in determining amphibian populations over the long term.

Case Study: Oregon Coast Range

The most extensive study of the long-term effects of logging on amphibians is our survey of headwater streams in the Coast Range of Oregon. The following discussion summarizes our results (Corn and Bury, in prep.). We censused amphibians in 10-m reaches of 23 streams in uncut forests ranging in age from 60 years to about 500 years (control streams) and in 20 streams in logged stands with reestablished canopies. Logging occurred from 14 to 40 years prior to our surveys. There were marked differences in the occurrence, density, and biomass of amphibians between control streams and streams in logged sites. All four species (tailed frogs, Pacific giant salamanders, Olympic salamanders, and Dunn's salamanders) occurred significantly more often in the control streams than in the streams in logged stands. Considering all four species together, there was greater species richness in control streams. Three or four species were present in 21 control streams (91 percent), but only five streams in logged stands (25 percent) contained that many species. Four streams in logged stands (20 percent) had none of the species present.

Tailed frogs, Olympic salamanders, and Pacific giant salamanders reached significantly greater densities in unlogged than in logged streams (Figure 2), and all four species had significantly greater biomass in control than in logged streams.

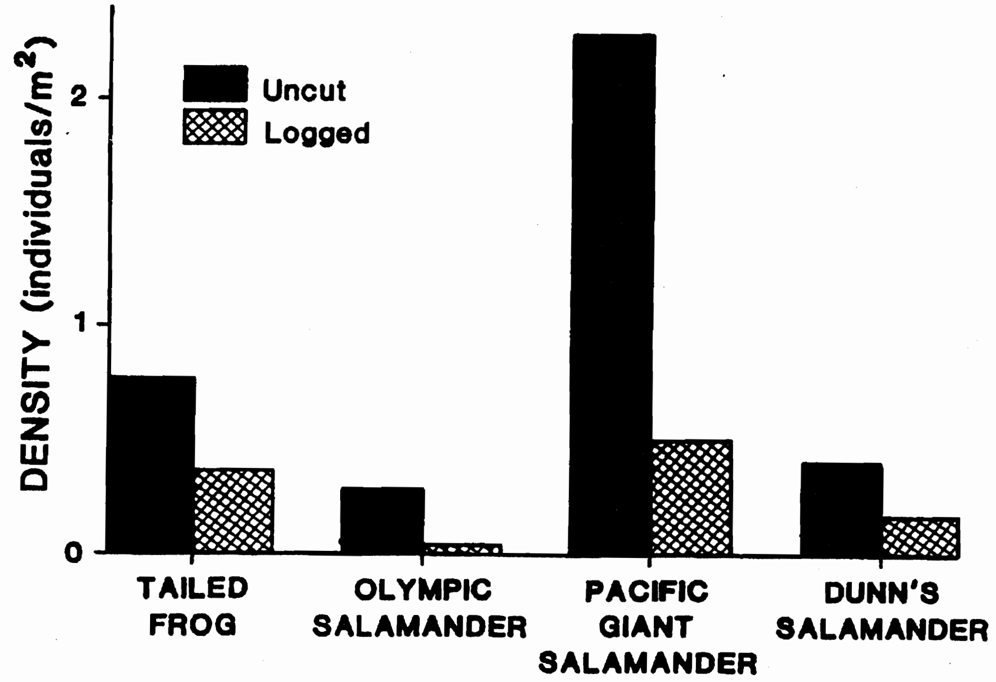

Figure 2. Density estimates of amphibians present in 23 streams in uncut forests and 20 streams in logged stands. Data were collected in 1984 and 1985 in the Oregon Coast Range (Corn and Bury, in prep.).

We measured physical characteristics of each stream. Streams in logged stands had slightly greater canopy cover than control streams, but there were no differences between stream types in the size of the drainage, water temperature, stream width or depth, stream gradient, or the proportion of the stream composed of pool habitat. However, we did observe differences in substrate composition. We determined the dominant substrate visually at ten points in each stream. Fine sediments were significantly more abundant in streams in logged stands, whereas control streams had a higher percentage of cobbles and boulders. The increase in fine sediments was probably due to logging practices because there were no road crossings upstream from the sample reach in any of the streams in logged stands.

In control streams, densities of tailed frogs, Pacific giant salamanders, and Olympic salamanders were unrelated to stream gradient. In streams in logged stands, however, there were positive relationships between density and gradient for both Pacific giant and Olympic salamanders. The Olympic salamander was absent from all logged sites with low gradients (less than 11 percent). We interpret this result to mean that increased sedimentation from logging is a persistent effect in low-gradient streams that severely reduces microhabitats for salamanders. Sediments are flushed from high-gradient streams, and substrate crevices are maintained. Densities of tailed frogs in streams in logged stands were unrelated to gradient. It is possible that the long-term reduction in tailed frog abundance is due to local extinction immediately following clear-cutting and limited recolonization of streams after shading is reestablished.

Our study also suggests that the presence of uncut timber upstream influences the presence of aquatic amphibians in logged areas. Uncut areas upstream may mitigate logging impacts by reducing temperatures or sedimentation, and they are likely sources of animals for recolonization. Tailed frogs and Dunn's salamanders were present more often in streams in logged stands when there was some uncut timber upstream in the drainage. Pacific giant salamanders were present in equal frequencies in streams with and without uncut timber upstream. Olympic salamanders occurred in only three streams in logged stands, so the presence of uncut areas upstream does not appear to have a significant effect on this species.

Occurrence of species was not related to age of the logged stand (a comparison between stands under and over 25 years old). However, most of our sites had canopies over the streams; we did not sample sites in open clear-cut forests. There may be increases in abundance of some species after the canopy returns, but we did not find indications that amphibian populations improve as second-growth forests approach rotation age.

An Integrated Model

We have attempted to interpret the results of the studies discussed above and describe the abundance of aquatic amphibians in streams in second growth for the first 50 years after clear-cutting (Figure 3). These initial models are necessarily somewhat crude. Some of the curves are based on real data, whereas others represent our best guess of how amphibian abundance responds to regrowth of the forest. Figure 3a illustrates changes in key physical features of the stream: canopy cover and accumulation of fine sediments in high and low gradients. Canopy cover is reestablished in about 10 years, and sediments are flushed from high-gradient streams but retained in low-gradient streams. Sediments are also dependent on channel morphology and watershed geology (Adams and Beschta 1980, Duncan and Ward 1985); these complications are ignored in this simple model. Figures 3b through 3d plot abundance of the three aquatic species. We did not include Dunn's salamander. This species declined in streams in logged stands, but the factors involved are obscure.

Tailed Frog (Figure 3b)

The immediate reaction of this species to clear-cutting is variable. Extinction may occur, but there are probably regional differences. Populations in the Cascades of Oregon and Washington and on the Olympic peninsula should have a higher probability of surviving clear-cutting, although abundance will be reduced. Populations in the Coast Range of Oregon and northern California most likely go extinct. We did not find relationships of abundance to stand age or stream gradient in the Oregon Coast Range, but it is possible such relationships occur elsewhere.

Pacific Giant Salamander (Figure 3c)

The response of Pacific giant salamander populations is dependent on stream gradient. In high-gradient streams, abundance increases after the canopy is removed, but the opposite occurs in low-gradient streams. Abundance remains depressed for several decades in low-gradient streams, but extinction of populations is probably a rare event.

Olympic Salamander (Figure 3d)

Most populations of Olympic salamanders probably go extinct following clear-cutting. Recolonization is rare and is greater in high-gradient streams.

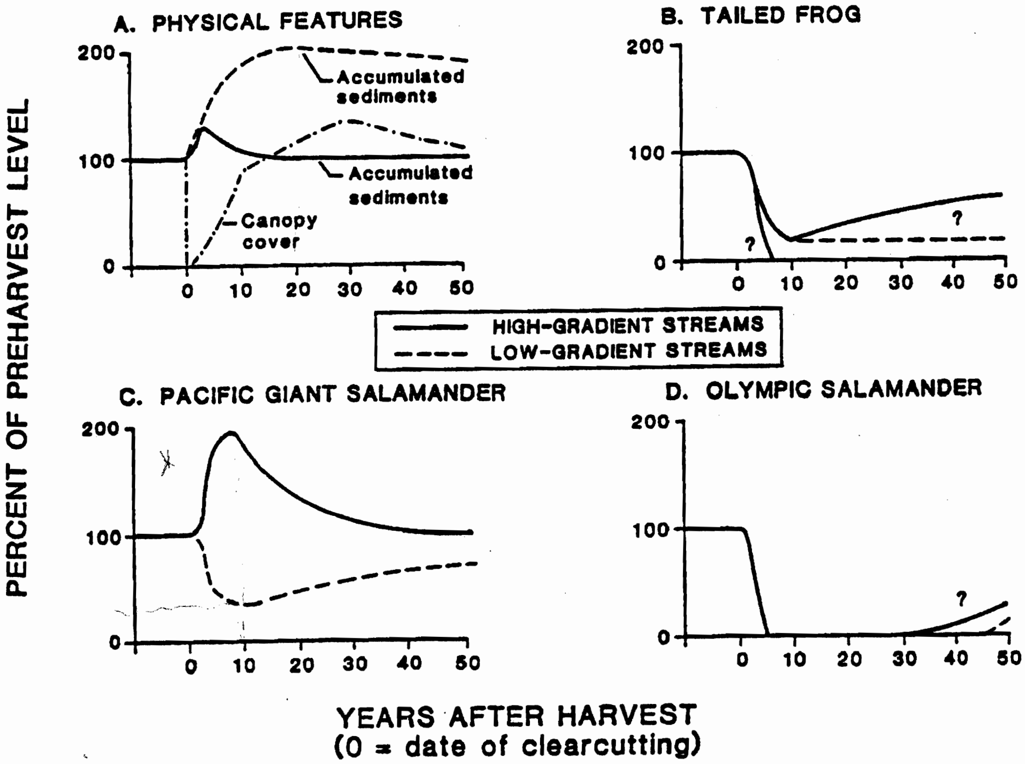

Figure 3. Conceptual models of changes in habitat (a) and abundance of aquatic amphibians (b-d) in headwater streams following clear-cutting of the surrounding forest. Responses of habitats and species may depend on stream gradient (solid lines = gradients >10%, dashed lines = gradients <10%). Preharvest values (100%) are in unmanaged (old-growth) forests. Tailed frogs (b) may be driven to extinction in some streams but not others after logging. Olympic salamanders (d) may recover earlier in high-gradient streams.

Management Recommendations

Improve Techniques

Most prior work on the effects of logging on stream amphibians in the Pacific Northwest used electroshocking (Murphy and Hall 1981, Hawkins et al. 1983), reflecting a fisheries orientation. We have employed hand collecting in headwaters, which yields 2 to 4 species in high numbers (Bury and Corn, in press). There is a need to compare the effectiveness of these two techniques for sampling aquatic amphibians in Northwestern streams. We need to better quantify through new methodology what are the immediate effects of clear-cutting on each species, as well as to define species' habitat preferences and environmental tolerances, particularly for Olympic salamanders.

Vulnerability of Populations

The results of this review and of our field endeavors (Bury 1988, Corn and Bury, in prep.) are important to the management of forested areas in the Pacific Northwest for several reasons. We have shown that there are negative impacts on amphibian populations due to current logging practices. However, management agencies and conservation groups seem most concerned about knowing whether logging endangers the survival of any species on a drainage-wide or regional basis. Our present knowledge suggests that each species of aquatic and streamside amphibian has a different life history and reaction to logging. Our data suggest that at least two species, tailed frogs and Olympic salamanders, may be at risk in intensively managed forests in the Oregon Coast Range and, perhaps, elsewhere.

Olympic salamanders are rarely present in logged streams. Tailed frogs were more common, but were rare in drainages that had been completely logged. Adult tailed frogs do not move long distances and they show a strong tendency to breed in the natal stream (Metter 1964, Daugherty and Sheldon 1982). Movements of Olympic salamanders are less well known, but it is unlikely that they wander far from the aquatic habitat. Both tailed frogs and Olympic salamanders probably occur as isolated, discrete populations, particularly in drier forests and in heavily managed lands. If these species are extirpated from a drainage, recolonization may require many years, even if stream habitats improve more quickly following logging.

Populations of Pacific giant salamanders were present in a majority of logged streams, but in reduced numbers. Dunn's salamanders were also reduced in logged areas, but this species and the Pacific giant salamander inhabit a wide variety of habitats (Nussbaum and Clothier 1973, Nussbaum et al. 1983). Populations of these species are less likely to be eliminated by timber harvest than are those of Olympic salamanders and tailed frogs.

Regional Differences

Hall et al. (1978) state that it is important to have an extensive approach and a wide perspective when assessing the effects of logging. They found consistent differences in the responses of cutthroat trout to logging between the Coast Range and Cascades in Oregon. Geomorphology of areas also differs. For example, Murphy et al. (1981) reported that streams in the Cascades are sediment-poor compared to those near more erosive soils in coastal Oregon and coastal California. Similarly, we think that logging may be less stressful to aquatic amphibians in the Cascades of Washington and Oregon than in the Coast Range of Oregon and northern California, due to hotter, drier conditions in the latter areas. However, we can neither prove nor negate this contention without further field work. There are also genetic differences among populations (Good et al. 1987) that potentially could produce varying responses by the animals to environmental parameters, e.g., temperature tolerances.

Because there has been so little research on the effects of timber harvest on amphibians in the Pacific Northwest, there is an almost unlimited choice of projects for comparative research. We suggest that comparisons be made not only between different regions but also between climatic regimes within regions. We recommend that stream management practices be backed by specific research for each sensitive species (e.g., tailed frogs, Olympic salamanders) in each area of concern.

Headwaters

Although clear-cutting may have immediate and severe effects on amphibians (Bury 1983), the open canopy is transitory. With about 10 years needed to reestablish the canopy in the Oregon Coast Range, only 17 percent of the forest would be in the open canopy stage at any time in forests with 60-year rotation ages. Because intensively managed forests will contain little or no old growth, survival of amphibian populations in areas of timber harvest may depend on species' abilities to reinvade and reproduce in streams in second-growth forests. In this scenario, careful planning will be needed to avoid local extirpation of aquatic animals.

The first step is to determine which amphibian species are present in small streams traversing timber sales. We suggest that headwater channels in timber sales be surveyed and, if tailed frogs or Olympic salamanders are present, these be afforded some protection. Cutting plans should be developed that maintain continual shade over the stream and, perhaps more importantly, reduce the amount of sediment entering the stream.

Buffer Strips or Uncut Patches

Buffer strips have been shown to be effective at protecting stream biota and habitat, by maintaining shade and reducing sedimentation (Newbold et al. 1980, Murphy et al. 1986, Beschta et al. 1987, Hartman et al. 1987). Buffer strips are employed to protect fish habitat on larger streams, but they also should be required along headwaters. Buffer strips protect some terrestrial habitat, which is important for adult and juvenile amphibians. For example, adult tailed frogs cannot tolerate high temperatures and high rates of evaporative water loss (Claussen 1973a,b). However, there are costs to buffer strips, and they are not trivial (Dykstra and Froehlich 1976). Headwater channels in the Pacific Northwest have poorly developed or no riparian areas (Swanson et al. 1982, Bury 1988), and large volumes of merchantable timber are often next to streams. The cost per acre of buffer strips in coastal Oregon is higher on small streams than on large streams (Andrus and Froehlich 1988). Poorly designed buffer strips are also somewhat prone to failure by blowdown (Steinblums et al. 1984).

We suggest that there may be techniques available that can reduce the costs of buffer strips while protecting amphibian populations and the headwater habitats. Retention of deciduous vegetation and small trees (or cull) may be one inexpensive way to preserve shade. For example, there may be appreciable canopy provided by big-leaf maple, alder, and unmerchantable conifers at sale sites. If marketable timber were felled away from the stream (which is often the case), the deciduous trees would be mostly left intact and there would be less logging debris to clean up.

Because amphibians have small home ranges, a relatively small, high-quality riparian area may house a viable population. What we are suggesting is that the entire length of a stream may not need to be protected to ensure survival of amphibian populations. Rather, a clump or discontinuous clumps of trees might be left along small streams. Our results from the Oregon Coast Range indicate that some species will reinvade disturbed reaches if there are protected waters present in the same drainage (Corn and Bury, in prep.).

High-priority topics for future research should include life history information (viable population sizes) on tailed frogs and Olympic salamanders and information on the effectiveness of different types and sizes of buffer strips or discontinuous patches in protecting amphibian populations. Is it more effective to protect wildlife with small-width buffer strips, discontinuous habitat patches, or both? This information is critical for management.

Coarse Woody Debris (CWD)

There are important functions of CWD as sediment traps and sources of nutrients and cover in temperate forests and streams (Franklin et al. 1981, Maser and Trappe 1984, Sedell and Swanson 1984, Wilford 1984, Harmon et al. 1986). We presume that removal of CWD from streams would be disruptive to amphibian communities.

Earlier logging activities tended to use stream beds for slash piles, adding appreciable amounts of large and small woody debris. Current management practices favor extensive stream cleanup. Sometimes almost all debris is removed (Swanson and Lienkaemper 1978). Triska et al. (1982) state:

> Under current land-use practices, we are effectively channeling our mountain streams and managing land to keep them so.... If the stream does not retain organic material and maintain a diversity of physical habitats then, biologically, it may be unable to process organic matter from the adjacent forest and large, functional and structural components in the stream ecosystem could disappear.

It has recently been recognized that excessive removal of CWD has detrimental effects on stream biota and their habitats (Bilby 1984b, Bisson and Sedell 1984, Lestelle and Cederholm 1984, Elliot 1986). In the intensive treatments of the Carnation Creek study in British Columbia, large CWD was broken up or removed from the stream channel. This resulted in increased erosion of the streambank, increases in pea gravel and fine sediments, and decreases in numbers of coho salmon (Hartman et al. 1987).

We recommend that natural CWD be retained in steams during logging cleanup; the large debris normally is partially buried or decayed and should be left in place. Cull or broken trees that fall across streams (e.g., over the water) or adjacent to the water may provide beneficial effects by serving as sources of nutrients over several decades, retaining sediment, and providing habitat diversity. Studies are needed on the relationship of such CWD and animal life in Pacific Northwest streams.

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