

# Effects of Habitat Fragmentation on Amphibians: What Do We Know and Where Do We Go From Here?

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## ABSTRACT

Numerous studies across North America indicate that clearcuts and second-growth stands are unsuitable habitat for amphibians compared to old-growth forests. As landscapes become increasingly fragmented, amphibian populations in remaining old-growth patches are isolated. Insularization leads to decreased genetic fitness within populations and may lead to local extirpations or extinctions of species. Because amphibians have low vagility, high philopatry, and are susceptible to desiccation, they may be particularly vulnerable to habitat fragmentation. I present a general overview of impacts of forest practices and habitat fragmentation on amphibian populations, highlighting key management issues: forest patch size, importance of wet areas, and connectivity. I draw examples from studies that have specifically investigated effects of habitat fragmentation, clearcutting, and habitat juxtaposition to address the following questions: 1) What do we know about the impacts of forest practices and habitat fragmentation on amphibian populations?; and 2) What information is needed for resource managers to conserve amphibian populations in British Columbia?

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**Key words:** amphibians, area effects, forestry, fragmentation, isolation, patch size.

## AMPHIBIANS AT RISK?

Concern over amphibian population declines will be one of the biological legacies of the past decade. Initially scientists debated the issue, charging that populations fluctuate naturally, and that long-term data were needed before any conclusions could be drawn (e.g., Pechmann et al. 1991). More recently, however, many researchers have come to agree that the phenomenon is indeed real (Wake 1998). In some locations (e.g., western North America), amphibians are at far greater risk of extinction than birds or mammals (B.C. Conservation Data Centre 1998, Doyle 1998).

Amphibian species and populations that were once wide-ranging and common have been lost, or have declined, in what appear to be pristine habitats (e.g., *Bufo boreas* populations in the Colorado Rockies; Carey 1993, Drost and Fellers 1996). It has been proposed that the declines may be indicative of large-scale environmental decay, and research into specific causes has begun to shift towards those which may result in generalized stress (Wake 1998). Many populations may be exposed to factors (i.e., stressors) that under normal conditions do not cause them to decline (i.e., they appear "healthy"). When additional stressors are added,

such as habitat alteration (e.g., forest harvesting), populations may be pushed past their tolerance limits. Further, the effects of stressors may be more pronounced in populations at the extremity of a species' range, making these populations more prone to extinction, but this has not been tested (Sjögren 1991b).

I suggest that all amphibian species in British Columbia may be at risk for the following reasons:

- The cause(s) of global declines in amphibian populations is not clear.
- The status of British Columbia amphibians is unknown (baseline data are lacking).
- Amphibians in the western United States are particularly vulnerable to extinction (Keister 1971), especially montane anurans (Drost and Fellers 1996).
- British Columbia amphibians may be particularly vulnerable to stress because many are at the northern limit of their range within the province (e.g., Pacific giant salamander [*Dicamptodon tenebrosus*] and Oregon spotted frog [*Rana pretiosa*]; the range of most of the Red-listed amphibian species in British Columbia is very limited; B.C. Conservation Data Centre 1998).
- Wide-spread habitat alteration is occurring throughout the province, with increased conversion of primary forest to second-growth stands, and greater isolation between remaining suitable habitat patches.

## EFFECTS OF FORESTRY ON AMPHIBIANS

Amphibians are ectothermic vertebrates capable of highly efficient energy conversion (Zug 1993). However, they must balance this energy efficiency with a physiological obligation to water. Many amphibian species lay their eggs in standing or running water, and all require moist environments for subcutaneous respiration (Zug 1993). Forests have moderate climatic conditions and structural attributes that provide amphibians with cover and moisture (e.g., downed wood). An example of this relationship can be found in the Pacific Northwest, where high amphibian species diversity and endemism is attributed to the combination of mountainous, forested areas and high rainfall (Keister 1971).

It has been demonstrated across North America that amphibian abundance is often lower in clearcuts and second-growth stands than in old-growth or mature forests due to changes in microclimate (e.g., Pough et al. 1987, Bury and Corn 1988, Petranka et al. 1994, Dupuis et al. 1995, Waldick 1997). However, it appears that not all species/populations are affected (e.g., Stelmock and Harestad 1979, Ward and Chapman 1995, Cole et al. 1997). It is difficult to know what the impacts of forest harvesting are on amphibians because most studies have been conducted within the past 15 years, which may be too soon to detect the long-term effects of habitat alteration (deMaynadier and Hunter 1995), and numerous logistical/design issues arise when attempting to compare studies (e.g., detectability of species within different habitat types). Reduced richness and abundance of amphibians in clearcuts and second-growth habitats at the stand level implies that these areas represent less suitable habitat types than old-growth forest, and that landscapes managed for forestry may increase isolation of populations, leading to genetic bottlenecks and/or local extirpation.

### LANDSCAPE-LEVEL EFFECTS OF

#### FORESTRY: HABITAT LOSS AND FRAGMENTATION

It is difficult to separate the effects of habitat loss from fragmentation (Fahrig 1997). A landscape becomes fragmented at different scales for different species depending upon whether the matrix environment poses a barrier to movement and dispersal. This results in either habitat loss or temporary/permanent habitat alteration. Amphibian populations may easily become isolated within a fragmented landscape because amphibians have low vagility, high philopatry, and often find the matrix environment inhospitable.

Amphibians may be particularly vulnerable to habitat fragmentation due to the spatial dynamics of their populations. Subpopulations of many species are philopatric to wet patches and upland forests. For this reason, some amphibian species live in metapopulations (e.g., many temperate aquatic-breeding species; Sjögren 1991a), likely in a variety

of forms (Harrison 1991). For example, some species may live in relatively extinction-resistant populations, where inter-patch dispersal is fairly high. Others may live in a source-sink situation, where subpopulations remain viable only through the immigration of dispersing juveniles from source areas (e.g., Gill 1978). Metapopulations of the latter sort may be particularly vulnerable to local extirpation in managed landscapes, due to the fact that the high surface to volume ratio of juvenile amphibians makes them especially susceptible to desiccation (Bellis 1962), and hence, potentially impacted more by the removal of forest cover than adults (deMaynadier and Hunter 1999).

The dynamics of source-sink populations are poorly understood for amphibians, but have serious implications for the conservation of breeding sites and the maintenance of connectivity among populations. Source sites may not be the same for each species, and they may shift through time. Small wetlands are valuable breeding habitat for many amphibians (Gibbs 1993), and they may act as stepping stones for maintaining connectivity among populations. However, small wetlands and streams are not afforded protection within British Columbia. In some areas, it is not economically viable to protect all wet areas, and the selection of sites has been based on wetland size and the presence of fish. However, wetland size has been identified as a poor indicator of habitat quality and species richness (Gill 1978; D. Bradford, U.S. Environmental Protection Agency, and J. Jaeger and B. Riddle, University of Nevada, pers. comm.).

## DO AMPHIBIANS RESPOND TO PATCH SIZE AND FRAGMENTATION?

Researchers have found that both amphibian abundance and species richness can be affected by forest area (Appendix 1). Hagar (1998) found that some amphibian species are area-sensitive in island archipelagos in Ontario, suggesting that the potential exists for some species to act as indicators of suitable reserve size and habitat fragmentation. In the most extensive long-term study addressing the effects of fragmentation on biodiversity, Tocher et al. (1997) found that amphibians did not respond to area effects as greatly as other taxonomic groups in tropical forest patches. In contrast, Rosenberg and Raphael (1986) found a greater stand-level response to fragmentation in amphibians than for birds or small mammals in California.

In other temperate studies, Dupuis and Bunnell (1999) found western redback salamanders (*Plethodon vehiculum*) responded to patch size in old-growth stands, but not in immature, second-growth stands. In Connecticut, Gibbs (1998b) found that some species were absent from a forest fragmentation gradient once forest canopy cover fell below 30–50%. Gibbs (1998c) also found that subpopulations of eastern redback salamanders (*Plethodon cinereus*) in a fragmented

landscape had greater genetic differentiation in locations where the forest had not been connected historically. Fragmentation may affect survivorship or reproductive success of amphibians (Wind 1996, Dupuis and Bunnell 1999).

#### MINIMUM PATCH SIZE

Nested assemblages, where a few common species tend to be omnipresent and rare species tend to occur only at richer sites, occur in naturally and anthropogenically fragmented environments (Hecnar and M'Closkey 1997). In Ontario, amphibian assemblages have been found to be highly nested (Hecnar and M'Closkey 1997), which, combined with their area-sensitivity, indicates that large reserves should support more species than small ones (Hagar 1998). Rosenberg and Raphael (1986) and Wind (1996) identified amphibian species that negatively responded to forest patches 10 ha. In a 20-ha fragment in Michigan, Ball (1999) estimated that 2 salamander species had a thriving population, while 2 other species were potentially vulnerable or declining. The size of the patch that can sustainably support a population will be influenced largely by the degree of insularity in the landscape. Rosenberg and Raphael (1986) estimated that forest patches <20 ha in size lacked the full complement of vertebrate species, and they recommended that isolated stands with >50% insularity should be no less than 50 ha.

#### INFLUENCE OF HABITAT

##### FEATURES AND LANDSCAPE CONFIGURATION

Many studies have found that amphibian responses to habitat fragmentation are influenced by the distribution of habitat features at the stand level (e.g., breeding sites; Appendix 1). The strong relationship between the distribution of amphibians and the patchy distribution of these habitat features may override area relations (Zimmerman and Bierregaard 1986). For example, Wind (1996) found that the existence of numerous wet areas in a 10-ha forest patch in Alberta appeared to mitigate area effects for wood frogs (*Rana sylvatica*) compared to drier 10-ha sites.

Just as the presence of wet areas will influence the distribution of aquatic-breeding species, the proximity to old-growth stands may affect terrestrial-breeding species within a multi-aged landscape. For example, Dupuis and Bunnell (1999) found that the density of western redback salamanders was lower only in managed stands that did not contain adjacent old-growth habitat, even though their patches were relatively large (i.e., >50 ha). In a study of 2 frog species in Ecuador, Marsh and Pearman (1997) found higher levels of abundance of both species in a large forest patch, but found that 1 species was affected by patch size while the other was affected by proximity to the large forest patch.

##### EDGE EFFECTS, ROADS, AND MOVEMENT PATTERNS

The impacts that edges have on amphibian populations are

unclear. Just as for other taxonomic groups, amphibian response to edge habitats is variable. For example, Rosenberg and Raphael (1986) found greater species richness in landscapes with increased edge in California. In the Amazon, species bred in artificial pools irrespective of proximity to edge (Gascon 1993), and increased species richness in forest patches was due to an influx of species that responded positively to increased edge habitat (i.e., habitat generalists; Tocher et al. 1997). D. Major (USDA Forest Service, pers. comm.) found evidence of a bimodal response in terrestrial amphibians to silvicultural edges in Oregon. He attributed the response to blowdowns (i.e., increased availability of downed wood along edges), which potentially ameliorated effects of microclimate change through increased cover and moist microsites. In contrast to this, studies conducted in the northeastern United States have found reduced abundance of amphibians along edges compared to forest interior (Gibbs 1998a), with effects extending 25–35 m into the forest (deMaynadier and Hunter 1998). Microclimate changes along silvicultural edges may extend 240 m into the forest interior (Chen et al. 1995). Amphibians may respond differently to microclimate conditions along edges depending upon their diel patterns and biological needs (e.g., nocturnal versus diurnal; Schlaepfer 1998).

Moderately fragmented landscapes may facilitate the movement of individuals of some species, through the creation of roads and other linear corridors, and open habitats (Pither and Taylor 1998). Gibbs (1998a) found that the relative permeability of forest-road edges was less for amphibians than either forest-interior (controls) or forest–open land edges, and deMaynadier and Hunter (2000) found reduced abundance of salamanders at road sites versus forested control sites. Nadorozny (1997) radio-tracked ranids in Nova Scotia, and found that individuals would remain in roadside ditches, and follow roadways, when they were encountered. They also moved more through open habitats than forested ones. Contrary to the hypothesis that species with high dispersal ability should be less area-sensitive (see review by Hagar 1998), increased movement/dispersal ability for amphibians may increase sensitivity to fragmentation (Gibbs 1998b, Hagar 1998). Increased movement may increase risks of predation (direct effects), and/or result in greater energy expenditure, stress, etc. (indirect effects). Landscape-level conservation strategies must take into consideration these filters and conduits to amphibian movement (Gibbs 1998a), and their impacts on natal dispersal (deMaynadier and Hunter 2000).

#### CONCLUSIONS AND RECOMMENDATIONS

I conducted a review of the current literature to determine whether amphibians are affected by various measures of habitat fragmentation (Appendix 1). Because relatively few

studies have addressed this issue for amphibians, and the scales and study designs differ, it is difficult to draw conclusions at this point. In addition, Rosenberg and Raphael (1986) point out that habitat fragmentation is a relatively new phenomena in the Pacific Northwest, where a threshold level of habitat loss and isolation may not have occurred yet (Fahrig 1997). The long-term effects (i.e., an equilibrium) may not be detectable at this point. Given this, some amphibian species have responded to patch size and edges. Based on our limited knowledge at this point, I make the following recommendations to resource managers and researchers regarding habitat fragmentation and amphibian populations in British Columbia.

#### RESOURCE MANAGERS

- Plan for harvest units that are >20 ha (larger with increased insularity), and/or keep patches close together and close to old-growth stands.
- Maintain reserves of old-growth and mature stands, large enough to contain a heterogeneous mixture of terrestrial (upland) and aquatic habitats, deciduous and coniferous stands (Cole et al. 1997). Reserves require a minimum additional 35-m buffer to reduce edge effects and maintain the amount of interior forest habitat, and isolated patches of old growth <20 ha should not be included in the overall tally of habitat preserved as old growth (Rosenberg and Raphael 1986).
- Plan harvest units and roads so that the proportion of edge habitat is minimized, avoid placing roads near potential breeding sites (Vos and Chardon 1998), and do not apply chemical treatments (e.g., CaCl<sub>2</sub>; see review by deMaynadier and Hunter 1995), especially during peak migration periods. Keep the number and width of roads to a minimum (deMaynadier and Hunter 2000).
- Identify key habitat attributes for amphibians, especially the location of wet patches. Plan harvest blocks in such a way as to leave wet patches in, or in close proximity to, old-growth and mature stands. Protect clusters of ponds (Sjögren 1991a), and ponds close to forest (Laan and Verboom 1990). Connect linear riparian areas to lentic and lotic systems, and upland forest (Dodd and Cade 1998).
- Harvested blocks should retain some large, live trees and snags to provide partial overstory shade to open clearcuts, and input of future sources of downed wood.

#### RESEARCHERS

- Design habitat suitability studies that include some measure of the "health" of amphibian populations, in addition to data collected on abundance and species richness. We need a clearer understanding of whether habitat is actually being lost (Fahrig 1997) or degraded to the point that amphibians in managed landscapes have reduced fitness

(i.e., are no longer successfully breeding).

- Sample the distribution of habitat characteristics within the study area and beyond, especially when comparing habitat types/treatments that affect the distribution (e.g., downed wood and wet patches) and movement patterns (e.g., roads/streambeds; Nadorozny 1997, Dodd and Cade 1998, Gibbs 1998a) of amphibians.
- We need a clearer understanding of the dynamics of dispersal patterns, and barriers to movement, in order to reduce insularity among populations.

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Appendix 1. Studies investigating measures of forest habitat fragmentation and amphibians.

Study Type	Location <sup>a</sup>	Objective(s)	Species	Design	Results/Conclusions	Source
Fragmentation	CT	Compared the population genetics of salamanders in fragmented and continuous forest	<i>Plethodon cinereus</i> (terrestrial-breeding salamander)	Forest patches within an urban/rural matrix	Genetic differentiation in fragmented population marginally greater than in continuous forest population; within subpopulations in fragmented landscape there was greater differentiation where forests were not connected historically.	Gibbs 1998c
Fragmentation	CT	Compared the distribution of woodland amphibians, with different life histories, along a spatially continuous gradient of forest fragmentation.	5 species (aquatic & terrestrial-breeding)	Forest fragmentation gradient, from heavily urban to rural environment	<i>P. cinereus</i> and <i>Pseudacris crucifer</i> found in suitable habitat along the gradient; <i>Rana sylvatica</i> / <i>Ambystoma maculatum</i> , and <i>Notophthalmus viridescens</i> were absent from portions of gradient with <30% and 50% forest canopy cover respectively. Traits of species with low tolerance to fragmentation were low density, population variability, and high mobility, coupled with restricted habitat needs.	Gibbs 1998b
Fragmentation	WA	Compared the richness and abundance of amphibians in stands of various sizes in relation to their surrounding landscape.	8 species (aquatic and terrestrial-breeding)	45 old-growth, mature, and young stands (ranging from 51-1689 ha), centred within 2025-ha managed landscapes	No relationship was found between species richness and stand size. The abundance of <i>P. vehiculum</i> (and <i>Taricha granulosa</i> ) was positively correlated with stand area. <i>P. vehiculum</i> may be packing into remaining stands. Stand-scale was more important than landscape variables. Elevation had a strong influence on distribution	Lehmkuhl et al. 1991
Area Effects	Brazil	Compared species richness of forest frogs in 1, 10, 100, and 500-ha reserves of primary forest	39 anuran species (aquatic and terrestrial-breeding)	Forest patches with clearcut / pasture / scrub matrix	Although a tight species-area relationship was found for forest frogs, the authors found greater explanatory power from the distribution of habitat features (i.e., breeding habitat) than area relations.	Zimmerman and Bierregaard 1986
Area Effects	Brazil	Compared richness, abundance, and breeding success within forest patches (100, 10, & 1 ha) and primary forest; pre and post-harvest data.	40 anuran species (aquatic and terrestrial-breeding)	Forest patches with clearcut / pasture / scrub matrix	The frog community appeared to less affected by habitat loss and fragmentation than other vertebrates; species richness was higher in patches, species response varied. Increased diversity was likely due to the influx of species which use the matrix habitat. Species presence was influenced by the distribution of breeding habitat and edges	Tocher et al. 1997

## Appendix 1. Continued.

Study Type	Location <sup>a</sup>	Objective(s)	Species	Design	Results/Conclusions	Source
Area Effects	AB	Compared the relative abundance of frogs found in forest patches (10 & 100 ha) and continuous forest; pre and post-harvest.	<i>Rana sylvatica</i> (aquatic-breeding frog)	Forest patches within a matrix of young clearcuts	The relative abundance of wood frogs was reduced, and average size of frogs increased, in 10-ha patches 2 years after harvesting compared to control sites. Wetness of the site appeared to influence amphibian abundance in small fragments.	Wind 1996
Area Effects	BC	Compared the abundance and richness of amphibians in old-growth and managed second-growth forest patches, with or without adjacent old growth.	<i>Plethodon vehiculum</i> (terrestrial-breeding salamander)	Forest patches within a clearcut matrix	The relative abundance of redbacks was greater in large old-growth stands, but not in mature second-growth stands. Managed stands contained more salamanders, (perhaps with greater survivorship), when old growth was adjacent.	Dupuis and Bunnell 1999
Area Effects	MI	Estimated absolute abundance of amphibians in a 19.7-ha forest fragment with a history of logging activity as they migrated to breeding ponds.	3 <i>Ambystoma</i> spp. and <i>Notophthalmus viridescens</i> (aquatic-breeding salamanders)	Farmland on 3 sides, and a road on the 4th	<i>A. laterale</i> complex and <i>Notophthalmus viridescens</i> populations appear to be thriving. <i>A. maculatum</i> has few females in the population, and may be vulnerable to extirpation. Few <i>A. tigrinum</i> were caught, and likely does not represent a viable population.	Ball 1999
Area Effects / Edge	CA	Compared species richness and relative abundance between stands with varying degrees of isolation, edge, and area on different scales (i.e., plot, stand, 1000-ha block).	6 species (aquatic and terrestrial-breeding)	Forest stands, fully or partially isolated by clearcuts, second growth, or hardwoods	Species richness was positively correlated with edge and degree of fragmentation. Responses to amount of edge, proximity to clearcut, and patch size varied among species. <i>Dicamptodon ensatus</i> and <i>Bufo boreas</i> were species thought to be most sensitive to fragmentation, with no tolerance for stands < 10 ha.	Rosenberg and Raphael 1986

## Appendix 1. Continued.

Study Type	Location <sup>a</sup>	Objective(s)	Species	Design	Results/Conclusions	Source
Area Effects / Edge	Ecuador	Compared the relative abundance of frogs within forest patches; at different distances from forest edge and within the matrix.	<i>Eleutherodactylus</i> <i>Chloronotus</i> , <i>E. Terpidonus</i> (terrestrial-breeding frogs)	Forest patches with pasture/low scrub matrix	The abundance of both species was greater in the large patch (200 ha) than small patches (0.25-5.3 ha). <i>E. chloronotus</i> was affected by patch size, whereas <i>E. terpidonus</i> was affected by distance to the large forest patch.	Marsh and Pearman 1997
Edge	Brazil	Compared the number of cohorts (i.e., signs of breeding) within plastic basins placed perpendicular to fragment edges (from inside forest, out to cleared area)	<i>Osteocephalus taurinus</i> , <i>Epipedobates femoralis</i> (aquatic-breeding frogs)	Edges of forest patches isolated by a matrix that was cleared for cattle grazing	For the two most abundant species, patterns of habitat use were independent of proximity to forest edge. <i>E. femoralis</i> used pools inside and outside forest at same frequency, however, <i>O. taurinus</i> did not breed outside primary forest.	Gascon 1993
Edge	CT	Compared an index of movement in relation to forest interior habitats, streambeds, edges and roads	6 species (aquatic and terrestrial-breeding)	Forest-road and forest-open land edges, and forest-interior controls	The capture rate of 3 species was influenced by forest borders; for all species, relative permeability of forest-road edges were much reduced compared to forest-interior and forest-open land edges.	Gibbs 1998a
Edge	ME	Compared the relative abundance of amphibians along silvicultural edges of different age classes	14 species (aquatic and terrestrial-breeding)	Edges of forest: 2- & 9- to 11-yr-old clearcuts, and forest: 5- & 25-yr-old pine plantations	Generally, salamanders were more sensitive than anurans, but habitat generalists and specialists were identified within each group. Depth of edge effects was estimated to be 25-35 m for management sensitive species (i.e., <i>P. cinereus</i> , <i>A. maculatum</i> , <i>A. laterale</i> , and <i>R. sylvatica</i> ).	deMaynadier and Hunter 1998
Edges of Forest Fragments	Costa Rica	Compared the relative abundance of frogs along forest-pasture edges	<i>Eleutherodactylus</i> frog species (terrestrial-breeding)	Cattle pasture-forest edges in primary forest fragments <25 ha	Nocturnal frog species were equally abundant along edges and interior forest, but one diurnal frog was less abundant along edges.	Schlaepfer 1998

<sup>a</sup> AB = Alberta, BC = British Columbia, CA = California, CT = Connecticut, ME = Maine, MI = Michigan, WA = Washington

