Extrapolating the Effects of Post-Wind Throw Salvage Logging on Native, Terrestrial Salamander Populations

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1. Abstract

Terrestrial salamanders are an integral component of forest ecosystems, for they play an important role in leaf litter trophic interactions, soil nutrient dynamics, and are a forest indicator species. Due to their physiological constraints, terrestrial salamanders prefer to inhabit environments that are dark, cool, and moist. Salvage logging removes large portions of the tree canopy, coarse woody debris, and leaf litter, which in turn lead to higher air and soil temperatures as well as decreased soil moisture. The change in these essential abiotic factors is potentially harmful to salamanders, leading to desiccation, death, or migration from previously habitable areas. The effects of clear-cut logging on terrestrial salamanders have been extensively researched; however, there is only one study to date that has analyzed the effects of salvage logging on terrestrial salamanders. More research on this subject needs to be conducted to determine the extent of the impact of salvage logging on terrestrial salamanders, so that regulations can be put in place to protect them. This literature review extrapolates the potential effects of salvage logging on terrestrial salamander populations from studies of clear-cut logging to generate reasonable hypotheses about salvage logging's potential effects, demonstrating the critical need for research on this topic.

2. Introduction

Ecosystem disturbances in forests, both natural and anthropogenic, can result in critical environmental changes that have a direct effect on local inhabitants. Eastern deciduous forests are subject to a multitude of natural disturbances that could potentially impact native faunal and floral species including fire, flooding, insect outbreaks and wind storms (hereafter wind throw). Wind throw results in tree fall, which in turn, leads to an increased light-gap in the tree canopy, increased nutrient availability in the forest floor, increased downed wood in the form of coarse and fine woody debris, and uprooting creating pit-and-mound topography (Bennett and Adams 2004, Bottero et al. 2013, Bouget and Duelli 2004, Covington 1981, Grialou et al. 2000). Anthropogenic stressors, namely differential logging practices, can also disturb forest ecosystems. Covington (1981) found that during the first fifteen years following a clear-cutting, the forest floor, i.e. organic matter, declined over 50%. Covington (1981) attributed this decline to the lower leaf and wood litter fall and more rapid decay rate resulting from higher temperature, moisture content, and nutrient levels in the forest floor. Moreover, Chen et al. (1993) found that in clear-cut plots air and soil temperature and wind velocity increased compared to intact forests, while air and soil moisture decreased.

These variable factors of physiognomy, topography, and microclimate are instrumental for the habitats of native fauna, and changes in such could result in decreased survival, reproduction, and inhabitance. Clearly, each of these individual disturbances has an impact, but natural disturbances can also be coupled with an anthropogenic disturbance, such as salvage logging, which refers to the removal of downed and standing trees, as well as other biological material after a natural disaster (Homyack and Haas 2009). It has become important to determine the synergistic effects of multiple, sequential natural and anthropogenic disturbances on a single ecosystem. Native species may have the adaptability to withstand one large natural disturbance, but adding a second, anthropogenic disturbance further decreases the availability of abiotic components, such as tree density and amount of coarse woody debris (Waldron et al. 2013). This could potentially lead to the habitat requirements of local species reaching lethal or suboptimal levels, decreasing or extripating their populations.

In relation to other taxonomic groups, amphibians are the most threatened by current logging practices. Amphibians have been on the decline throughout the world (Stuart et al. 2004). Ignoring their disappearance is detrimental as they fill key roles in the forest ecosystem. Specifically, in eastern deciduous forests, salamanders are largely abundant and play a key role in the stability of the ecosystem. Plethodontid salamanders influence population dynamics and have been found to have both positive and negative effects of various invertebrate densities, including several taxa of leaf litter mesofauna (Best and Welsh Jr. 2014, Walton 2013). This is in part because salamanders are a keystone predator that serves as a control over species diversity and abundance. Morin (1995) determined that the presence of salamanders in a habitat influences the species composition and density of its prey, for a lack of salamanders increases interspecific competition between prey animals. However, the extent of the impact on prey species can vary due to prey selection and prey switching, which depends on the availability of preferable prey in an ecosystem (Walton 2013). Salamanders can also increase the presence of different leaf litter arthropod species, such as Collembolans, by regulating the existence of their predators (Rooney et al. 2000). Population dynamics in a forest ecosystem can be affected by territorial behavior of salamanders, as well, leading to interspecific competition for resource space and food resources (Hairston 1980, Walton 2013).

Terrestrial salamanders also have an impact on soil dynamics within inhabited forest ecosystems. Wyman (1998) found that while decreasing invertebrate populations through predation, Northern red-backed salamanders also indirectly reduced the rate of decomposition between 11 and 17% by consuming leaf fragmenters (e.g. Coleoptera and Diptera larvae). By reducing the number of large larval shredders and mircrofloral grazers, leaf litter retention increases, which in turn, leads to significantly greater carbon capture within the soil (Best and Welsh 2014). Salamanders' use of burrowing systems also makes them an instrumental asset in soil dynamics, as burrowing facilitates the translocation of nutrients, fungi, and other microorganisms to subsurface plant food systems, deposition of excretory nutrients and organic matter for use by bacteria and fungi, and increased dispersal of gases through the soil (Davic and Welsh 2004). Salamander migration can also serve as a means of dispersal for other organisms, for metamorphic Ambystoma salamanders disperse fairy shrimp (*Branchinectac oloradensis*) eggs between forest pools by feeding on female fairy shrimp in one pool and defecating intact eggs in another (Bohonak and Whiteman 1999).

In addition to their roles ecologically, salamanders are also an important tool for assessing environmental stress, for amphibians are good bioindicators due to their permeable skin and eggs that readily absorb substances from the environment, making them tightly linked to the microclimate and successional processes that also influence other difficult to study organisms (Blaustein 1994). Ecosystem processes, such as moisture cycling, food-web dynamics, and succession affect salamander populations, much like they impact other elements of forest biodiversity. However, the variability in response of plethodontid salamanders to environmental changes is much lower than those of other species, and this consistency in response gives them an advantage as a measurement of long-term forest health (Welsh and Droege 2001).

Storfer (2003) suggested four future research directions necessary to help stave off the amphibian decline, and applying these to maintain salamander populations and their ecological role. One of his suggestions was performing multi-factorial studies, i.e. researching how two or more different stressors could potentially affect amphibian populations. Using this approach, we need to consider the impact of salvage logging on native salamander populations and their ability to adapt to the environmental changes. Logging practices alone, when more intense than single-tree selection, have a significantly greater impact on salamander abundance than a natural disturbance (Hocking et al. 2013).

To date, only one study has been conducted pertaining to the effects of log salvaging operations after a major wind disturbance on amphibian communities. This study occurred for only 2 years and found no difference in abundance of salamanders on salvaged logged versus unlogged sites (Greenberg 2001). However, it may require a longer period of study to collect enough data to provide statistically significant results. Moreover, the consequences of logging practices on amphibian species can be long lasting, thus more long-term studies are needed to collect data that is more reflective of the lasting impact (Homyack and Haas 2009). Therefore, more research is needed on this topic to gain a more thorough understanding of the consequences of multiple disturbances on native salamander populations.

As such, the purpose of this literature review is to extrapolate the effects of salvage logging after wind throw on native, terrestrial salamander populations. The review will be contrasting commercial logging and salvage logging and their effect on forest ecosystems, examining impacts of salvage logging imposed on other animal taxa, determining the effects of commercial logging on salamander habitat requirements, and concluding with future research possibilities.

3. Commercial Logging vs. Salvage Logging

With the paucity of research specifically focused on herpetofaunal response to salvage logging, studies on commercial, clear-cut logging will largely be used to extrapolate the potential effects of salvage operations on herpetofauna. Commercial clear-cut logging is the most closely related, widely researched form of logging operation that could provide comparable results. Commercial clear-cut logging, as defined by Homyack and Haas (2009), refers to partial overstory removal without regard to future values and unmerchantable trees left on site. Salvage logging refers to the harvesting of both downed and standing trees and other biological material from areas after a natural or anthropogenic disturbance to recover from or prevent what would otherwise be an economic loss (Lindenmayer and Noss 2006, Waldron et al. 2013). Since salvage logging follows the path of natural disturbance, it is heterogeneous, more extensive, and has higher logging rates than commercial logging (Radeloff et al. 2000). Much like commercial logging, however, salvage logging can have a highly variable impact and depends on the nature of many attributes of the environment and logging practice, including the ecosystem, ecological processes, elements of the biota in question, the intensity of logging (frequency, spatial pattern, etc.), and the preceding natural disturbance (Lindenmayer and Noss 2006).

Salvage logging reduces the abundance of structural legacies, such as large logs, and increases habitat homogeneity (D'Amato et al. 2011, Waldron et al. 2013). Specifically, Waldron et al. 2013 found that post-wind throw salvage logging decreased downed coarse woody debris and snags with a more uniform distribution among decay classes. Salvage logging also contributes to biotic homogenization by preventing the increase in species richness that would naturally occur after a canopy-opening natural disturbance (Brewer et al. 2012, Cannon and Brewer 2013).

Bottero et al. (2013) found that different natural disturbances preceding salvage logging lead to different patterns of regeneration. It is imperative to establish a thorough knowledge of salvage logging, researching not only salvage logging in general, but each disturbance type, thereby minimizing the use of extrapolation. Research pertaining to post-fire salvage logging is much more abundant than the few studies done on post-wind throw logging.

4. Impacts of Salvage Logging Imposed on Other Animal Taxa

Past research has studied the effects of salvage logging on many species native to forest ecosystems, such as birds, insects, and some mammals. The effect on birds is the most widely studied consequence due to the obvious nature in which logging can affect them. Saab et al. (2008) found that nest-site location for most bird species located in the forests of the western United States are consistently associated with high snag densities and large diameters. Rost et al. (2012) found that salvage logging negatively impacts snag-associated species in different habitat types, as in both the Mediterranean Basin and the Rocky Mountains, snag-associated bird species decreased in both abundance and species richness post-salvage logging. Post-wind throw salvage logging can vastly change the species composition of birds, shifting from dominance by canopy-foraging species to brush-foraging species, in addition to the overall decrease in species diversity, density, and richness (Lain et al. 2008).

Similarly, the abundance of forest-associated beetle species decreased after a salvage logging event, while open-habitat or disturbance-associated species increased, altering the species composition of the landscape (Cobb et al. 2010, Koivula and Spence 2006). Cobb et al. (2010) found that differences in beetle species composition among undisturbed, burned, logged, and salvage logged plots correlated with differences in the quantity and quality of coarse woody debris.

Salvage logging often reduces the number of standing trees with hollows, which in turn, reduces the availability of habitat for cavity-dwelling species, thus having negative consequences for native cavity-dwelling species (Lindermeyer and Ough 2006). Hebblewhite et al. (2009) studied the effect of salvage logging on the trophic relationship between wolves and ungulate species, finding that ungulates often avoided post-logging areas, regardless of an increase in forage biomass, due to an increase in the population of wolves.

The effect of salvaging logging on insectivorous bats showed that open-habitat foragers benefited from logging, while there was little effect on closed-habitat foragers, making them a poor indicator of the negative impact salvage logging can have on native species (Mehr et al. 2012).

This is by no means an exhaustive account of the research to date; however, it provides an overview of the research done on the faunal groups. Although a considerable amount of conducted research has been on other native forest species, amphibians have only received attention in one study to date (Greenburg 2001). Considering the ecological importance of amphibians in forest ecosystems and the negative impact salvage logging has had on many other forest-dwelling species, research efforts need to direct attention to the impact of salvage logging on salamanders to understand fully the impacts this anthropogenic disturbance can have.

5. How Can Salvage Logging Affect Terrestrial Salamanders?

Many studies have confirmed that clear-cut logging practices lead to a decrease in terrestrial salamander abundance, diversity, and richness (Ash 1996, Grialou et al. 2000, Homyack and Haas 2009, Petranka et al. 1993, Raymond and Hardy 1991, Hocking et al. 2013). Altering the vegetative structure of a forest ecosystem can alter the key microclimate variables that affect a salamander's survival. Clear-cut logging decreases percent canopy cover and reduces decayed coarse woody debris and leaf litter, which leads to more extreme temperatures and less cover, which may result in mortality or loss of habitat (Grialou et al. 2000). Pentranka et al. (1993) found that in US Forest Service lands in western North Carolina, 75-80% of salamanders in mature stands are lost following clear-cutting, which is an average of 13.7 million salamanders, or 0.34% of the population, annually; although a seemingly small percentage, these effects could be detrimental due to the long recovery time of salamander populations. Declines in salamander populations occur not only in clear cuts but also in surrounding forests (Hocking et al. 2013) and lead to skewed spatial distributions and populations (Raymond and Hardy 1991).

Homyack and Haas (2009) found that sivicultural treatments that disturb the canopy have long-term negative effects on the abundance of salamanders. *Plethodon cinereus* of all life stages required approximately 60 years to return to pre-disturbance levels in a central Appalachian hardwood forest. In a salvage-logged forest, further canopy removal would occur after a wind storm, which alone can decrease the canopy by over 90% (Lain et al. 2008). Other Plethodontid salamanders, including Del Norte salamanders, are associated with closed, multi-story canopies that provide a cool, moist microclimate and are of much lower abundance in managed stands (Dupuis et al. 1995, Hartwell and Lind 1995, Pough et al. 1987). The decrease in abundance of terrestrial Plethodontid salamanders in areas without dense canopy cover is due to physiological constraints, as they depend on cutaneous respiration, which makes them susceptible to water loss at the high temperatures and low moisture associated with an open canopy (Feder 1983, Peterman and Semlitsch 2013).

This risk of water loss can also explain the loss of salamanders in environments that lack significant amounts of coarse woody debris, as clear-cut plots do (Butts and McComb 2000, Dupuis et al. 1995, Grover 1998). Cover objects serve as a salamander's moist retreat from dry conditions, lowering their risk of desiccation (Feder 1983). Salamanders are more abundant in areas with higher densities of coarse woody debris (Burger 1935, Owens et al. 2008). However, the necessity of coarse woody debris as a habitat component has been refuted (see Davis et al. 2010). During the first few years following clear-cutting, there is an extremely low input of woody litter to the forest floor (Covington 1981). Waldron et al. (2013) found that the amount of coarse woody debris nearly halved following salvage logging, as well as decreasing snag and the density of standing trees.

A salamander's movement and foraging efficiency are closely related to a high density of coarse woody debris, as cover is necessary to maintain the moist, cool environments necessary for survival during travel (Grover 1998). An increase in temperature from clear-cut harvesting can have metabolic costs for plethodontids, forcing them to face trade-offs, exchanging foraging and reproductive energy for basic maintenance costs (Homyack et al. 2011). Johnston and Frid (2002) found that the increased surface and soil temperatures after harvesting restricted the movements of terrestrial Pacific giant salamanders, limiting time for foraging and migration, and forcing them to become dependent on precipitation for movement. Keen (1984) found that the duration of *Desmognathus fuscus* activity is directly related to substrate moisture, and they ingest more prey when active, thus moisture and temperature associated with coarse woody debris affect foraging efficiency (1979). Plethodontid salamanders choose habitats with more moisture and face higher mortality rates when subjected to dry conditions (Jaeger 1971).

Likewise, loose leaf litter can provide a habitat in which salamanders can burrow to protect themselves from the heat and dryness of the day (Feder 1983, Heatwole 1960). Pough et al. 1987 found that the depth of leaf litter was the best predictor of aboveground salamander activity. Dupuis et al. (1995) also found that salamander distribution was directly associated with the amount of soil moisture. Not only do salamanders benefit from moist, loose soil as a means of aboveground protection but salamanders also burrow down into the soil on extremely warm or dry days (Taub 1961).

The negative impacts of commercial clear-cut logging clearly stem from logging attributes that also apply to salvage logging, thus there is a very high potential for similar consequences. Specifically, salvage logging after wind throw will further open the canopy, remove the fallen coarse woody debris, and lower the depth of leaf litter. As such, temperatures will rise and moisture will drop to extremes that are unlivable for ectothermic poikilotherms, like terrestrial salamanders. It is likely that salvage logging could alter the environment enough to make it unsuitable for the native salamander populations, causing death, migration, or inefficient foraging and reproduction.

6. Conclusions and Future Directions

This literature review has compiled the results of a wide range of studies on logging practices and salamanders as a means of extrapolating the impacts of post-wind throw salvage logging on native terrestrial salamander populations. Considering how similar the extent of standing tree, coarse woody debris, and woody litter removal are between clear-cut logging and salvage logging practices, we conclude that salvage logging would have equally negative impacts on salamanders, if not worse due to it being a second disturbance. Such extensive removal of natural cover objects considerably increases the temperature and dryness of the environment, and doing this after a natural disturbance could intensify the effects or undo any potential positive outcomes from wind-throw, such as an increase in coarse woody debris. In turn, salvage logging could increase salamander mortality rates and force those who survive to face higher energy costs and/or migrate, extirpating local populations.

To elucidate the impact of salvage logging on salamander populations, research conducted on the subject should be considered by land managers when determining their logging practices. Researchers should focus their studies on determining threshold levels of environmental attributes needed to maintain salamander populations in local ecosystems, so that logging practices do not remove an excessive amount of resources. Logging regulations need to recognize the importance of maintaining native salamander populations due to the necessity of their ecological role in forest ecosystems and their usefulness as an indicator species.

A means of maintaining salamander populations with logging practices must be formulated, since the economic consequences of natural disasters, outlawing salvage logging entirely may be an unreasonable request. The most effective means of recreating a stable environment for salamanders is requiring the reincorporation of coarse woody debris into the environment post-logging, providing shelter from the heat of the day. Setting a minimum requirement, determined by researchers, would provide a means of maintaining a cool, moist atmosphere for salamanders while retaining economic benefits of logging practices.

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