POND-BREEDING AMPHIBIAN ASSEMBLAGES OF THE PUMICE PLAIN AT MOUNT ST. HELENS- THIRTY-THREE YEARS POST-ERUPTION

by

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ABSTRACT

Amphibian responses to intense volcanic disturbance have not been widely studied. Yet given the global distribution of volcanoes, their frequency of eruptions, and associated areal extent of disturbance, it is important to understand how amphibians are affected by volcanism. The 1980 eruption of Mount St. Helens in Washington State (USA) provides an outstanding opportunity to assess amphibian response to a range of volcanic disturbance types. Reported here is a case study conducted on the Pumice Plain, an area intensely disturbed by a number of volcanic forces that destroyed all pre-eruption life and set the stage for evaluating amphibian community assembly in the context of primary succession. Amphibians were monitored at 25 study sites that included four habitats (pond, lake, wallow, and seep) during summer 2013. Two survey methods were employed (aquatic funnel trap and visual encounter) at each survey site to obtain information on species presence and reproduction. Biophysical habitat characteristics were measured including study site area, elevation, water depth, sediment type, percent cover of vegetation, dissolved oxygen, conductivity, pH, and temperature. Results showed that five amphibian species were present on the Pumice Plain: *Rana cascadae, Rana aurora, Pseudacris regilla*, *Anaxyrus boreas*, and *Ambystoma gracile.* *R. cascadae* was encountered at 76% of the survey sites, while *P. regilla* was encountered at 72% of the sites surveyed. *A. boreas* and *A. gracile* were found only in the pond and lake habitats, occupying 20% of all sites surveyed. *R. aurora* is the least frequently encountered species on the Pumice Plain, and present at only 12% of all survey sites. *A. boreas* and *P. regilla* are the most abundant species on the Pumice Plain, with the majority of the captures being at the pond habitat. In regards to richness, the ponds contain the most species, with all five species present. Thirty-three years post-eruption, the Pumice Plain supports a diverse assemblage of pond-breeding amphibians. These pond-breeders demonstrated resiliency to intense volcanic disturbance. *R. cascadae* and *P. regilla* appear to be the most resilient of the species studied based on their broad distribution across the study sites.

Keywords: Mount St. Helens, 1980 eruption, Pumice Plain, amphibians, amphibian assemblages, pond-breeders, succession, disturbance, volcanic eruption.

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INTRODUCTION

Mount St. Helens (MSH) has been, and continues to be, an ideal area to study how life recolonizes after catastrophic natural disturbance. Many researchers have come to the volcano to study effects of the eruption on various species; in particular, how they react to their changing environment and interact with other species within their community (Dale et al., 2005). Species response to the eruption has ranged widely depending on the location distance and direction from the vent, timing of the event, type and intensity of the volcanic disturbance, severity, and the adaptability of the species effected. MSH is an extremely dynamic landscape that offers important insights about geophysical forces and ecological responses to major disturbances. The study of amphibians is of high ecological importance, as they are declining worldwide, and are sensitive to environmental change (Stuart et al., 2004; Wake, 1995). How these species respond to environmental disturbance allows us to obtain valuable information on patterns of both resistance and resiliency of individual species, and the process of community assembly- and Mount St. Helens is a natural laboratory for investigation.

May 18th, 1980: Mount St. Helens Erupts

Prior to the main 1980 eruption, MSH experienced numerous small earthquakes, steam explosions, and rapid magmatic growth that resulted in a protruding bulge 450’ outward on the north flank of the volcano. This growth weakened the edifice, and eventually fractured and collapsed as the 1980 debris avalanche (Swanson and Major, 2005). The debris avalanche triggered superheated water and gas from inside the mountain to be released as a massive pyroclastic density current. This laterally-directed blast moved at about 90 m/s catching up with the debris avalanche and deposited volcanic material on ~600 km^2 of land (Sparks, Moore & Rice, 1986). The hot gas, steam, ash, and fragments were also ejected vertically from the volcano, in a massive mushroom cloud which was carried northeast on the prevailing wind and eventually settled on the land. Within ~20 km of the vent, the blast surge obliterated forests in its path, scorching all vegetation, and depositing 2 km^3 of debris (Moore & Sisson, 1981). Pyroclastic flows began about noon and continued for five hours, depositing a total accumulation of up to 40 m, with individual flows ranging from .25-40 m thick (Criswell, 1986). The tree removal and pyroclastic flow zones, created an area called the Pumice Plain, which is a relatively flat barren area, with boulders and cobbles of dacite pumice and other rock types that lie embedded within a matrix of gravel and sand.

Amphibian Declines

Scientists first became alarmed about amphibian populations world-wide when the concern of multiple herpetologists began surfacing at the First World Congress of Herpetology in 1989. Accounts were subsequently backed up by research, as of 2004, it was estimated that 32.5% of amphibian species were globally threatened (Stuart et al., 2004). Over the last thirty years, scientists have learned that there are multiple, interacting reasons for declines. Reasons for extinction are many including climate change, increased ultraviolet radiation, habitat loss, disease pathogens, environmental contaminants, introduced species, and overexploitation. Most scientists agree that underlying causes for declines are extremely complex, interconnected, and multi-faceted, and the origin is mostly anthropogenic (Blaustein & Kiesecker, 2002; Stuart et al., 2004). Although many declines are caused by human activities, natural disturbances are known to have caused declines in some species (Blaustein et al., 1998; Shriever, Ramspott, Crother & Fontenot, 2009; Hossack & Pilliod, 2011). For example, hurricanes, fire, and volcanic eruptions have caused amphibian declines, but these factors are rarely studied, and little is known about amphibian resiliency to these types of disturbances.

Amphibian Sensitivity to Environmental Change

Amphibians are known to be sensitive to environmental change (Rowe et al., 2003; Halliday, 2007; Hopkins, 2007). Two characteristics make amphibians particularly sensitive to their surrounding environment: their complex life cycle and their physiology. Most amphibians, including all Anuran (frog and toad) taxa have bi-phasic life histories that typically include a terrestrial adult stage and an aquatic larval stage. Since they require two distinct habitats during their life, poor conditions in either make them susceptible to declines or extirpations. Disturbances that cause the quality or availability of habitat, including abiotic or biotic features, can cause severe population changes (Dunson et al., 1992). In addition, Anuran tadpoles are herbivores, while caudate (salamanders) larvae are carnivores, with all amphibian adults being carnivorous. This complex trophic aspect of their ecology requires amphibians to utilize different environments, allowing for many environmental variables like prey availability, and biophysical conditions like habitat quality (water quality, water levels, photoperiod, and cover) which can make amphibians vulnerable when fluctuations in these conditions arise.

Amphibian’s thin, permeable skin, used for gas and water exchange, makes them susceptible to dehydration and uptake of pollutants. Highly permeable skin restricts most amphibians to moist environments and is crucial to their survival.

Natural Disturbances

Natural disturbances are often important in maintaining ecological diversity in ecosystems (Waltz & Covington, 2004). Wildfire, debris flows, volcanic eruptions, and flooding may drive change within populations and ecosystem function. These events, whether small-scale or catastrophic, may force individuals to seek new habitable environments through dispersal. As such, disturbances can be critical to maintaining long-term balance and diversity (Pickett & White, 1985; White & Jentsch, 2001). However, not all amphibians will benefit from disturbance. Species-specific response to disturbance is highly dependent on habitat type, timing of the event, scale of destruction, and how well the species has coevolved with the disturbance. Some species like *Anaxyrus boreas* (Western toad) benefit from disturbance, like wildfire, as it creates suitable early seral habitat and provides increased connectivity of habitat patches. Other species like *Ascaphus truei* (Coastal tailed frog) have not been as resilient to disturbances and environmental changes. These different responses to disturbance across taxa, make management strategies complex. More research efforts are needed, to fully understand how these species respond to disturbances.

Wildfires have become more frequent and severe in the western United States, and this has implications for amphibians and their conservation as temperatures warm, and seasonal and climactic variations change (Hossack & Pilliod, 2011; Westerling et al., 2006). Changes in temperature and moisture levels will surely challenge amphibian populations after wildfire events (Hossack & Pilliod, 2011). Amphibians will likely be affected, as moisture content decreases, when large woody debris or leaf litter is removed by burning (Whitfield et al., 2007). Studies conducted by Hossack & Corn (2007) in Glacier National Park were done after a 2001 wildfire burned mixed forest canopy and 42 aquatic test sites that had been previously monitored for amphibians. They found fire had no effect on the occupancy of breeding sites with two species, *Ambystoma macrodactylum* (Long-toed salamander) and *Rana luteiventris* (Oregon Spotted frog). One amphibian species, *A. boreas* benefited from fire by colonizing new wetlands that they hadn't previously used for breeding (Hossack & Corn, 2007).

However, not all species benefit or are immune to the effects of fire. Negative effects of wildfire on some species include mudslides, loss of vegetation, and consequently an increase in UV-B radiation when cover is reduced. Removal of vegetation by fire could also affect amphibian egg laying habitat, as amphibians typically lay eggs attached to vegetation. When vegetation is removed, an increase in UV-B can create sublethal effects, which, when combined with other stressors, adversely affect amphibians. Blaustein et al. (1998) demonstrated that Pacific Northwest Anurans exposed to UV-B decreased hatching success, whereas species shielded from UV-B exposure had a greater hatching success. This was particularly true for Pacific Northwest Anurans, although was not true for *Pseudacris regilla* (Pacific tree frog), which has a higher tolerance of UV-B than other species (Blaustein et al., 1998).

Similar to fire, severe weather events can stress populations of amphibians. Hurricanes have increased drastically since the 1870's with ~50% increase in the number of hurricanes that have occurred (NOAA, National Hurricane Data Archive). Whether these hurricanes cause problems to amphibian populations is largely unknown and few studies have been documented. Although there is no doubt that immediate mortalities exist following some hurricanes, either by impact or habitat alteration, species are able to rebound quickly in some habitats, whereas others are not.

Shriever, Ramspott, Crother & Fontenot (2009) studied the effects of Hurricanes Ivan, Katrina, and Rita in southeastern Louisiana (from 2000-2004 and 2005-2006) and found that herpetofuana overall were harmed by surge overwash. Studies were conducted in levee, herbaceous marsh, and forested swamp, and they found that abundance and richness decreased overall after each storm (Shriever et al., 2009). However, adaptation and resilience to brackish water may differ between species, and may be dependent on cycling of water and recharge abilities of each ecosystem.

Amphibian Research at Mount St. Helens

Amphibian populations at MSH have received considerable attention by scientists for the past 33 years with the aim of documenting initial and long-term responses to the eruption.

Historically, 15 amphibian species occupied the lakes, streams, and forests of the blast area (Karlstrom, 1986; Crisafulli et al., 2005b). Previous research has led to an appreciable body of information on survivorship, colonization, population dynamics, gene flow, and habitat associations. Most amphibian species rebounded or recolonized defaunated sites quickly after the 1980 eruption. Many species, like the Western toad (*Anaxyrus boreas)* and the Pacific tree frog *(Pseudacris regilla)*, may have been protected under snow, ice, or soil, due to the timing of the eruption (MacMahon and Anderson, 1985). These species moved into adjacent areas and colonized only one to two years after the eruption (Karlstrom, 1986).

Karlstrom (1986) conducted research at the Elk Rock Ponds along the North Fork of the Toutle River, in the Debris Avalanche zone. Six surveys were conducted at these ponds, during the summer of 1985. Three species were observed: *P. regilla, A. boreas,* and *R. cascadae*. *P. regilla* was the most frequently encountered species, followed by *R. cascadae*, with only one *A. boreas* observed during his study. Of the 22 ponds surveyed, 17 contained Anurans present and breeding (Karlstrom, 1986). Emerging patterns for breeding preferences (egg-laying) was noted, with *P. regilla* preferring emergent vegetation, *A. boreas* preferring shallow pond margins, and *R. cascadae* preferring quiet ponds near mountain meadows (Karlstrom, 1986). Egg masses of these three species were observed in at least some of the 22 ponds at Elk Rock, with *P. regilla* and *A. boreas* spawning in more ponds than *R. cascadae*. Post-eruption reproductive potential for these three species in the Debris Avalanche zone was evident due to the large amounts of *A. boreas* larvae and metamorphs that were observed, but survival potential may have been limited, as only one adult was observed during the study (Karlstrom, 1986). As of 1985, avian and reptilian predators appeared few or absent; food may have been a limiting factor, and may be the potential reasons for the low number of adult amphibians present and returning to breed (Karlstrom, 1986).

Crisafulli et al. (2005b) conducted studies on amphibian populations in four habitats, including ponds and lakes, streams, seeps, and uplands. Two study areas were investigated: One site (75 km²) was the debris-avalanche deposit and pyroclastic-flow zone (DAPF), and included the Pumice Plain, where no species survived. A second study site (480 km²) was sampled in the blowdown and scorch zones (BDSC zone). Trees were either leveled by the lateral blast or singed and left in a standing dead position, and amphibians survived. Surveys were conducted for 20 years, from 1980-2000, but not all sites were sampled continuously, and sample efforts were not uniform through the time period. Data were grouped by year, 1980-1985 represented species survival and colonization; and 1995-2000 represented colonization and persistence. The 1980 eruption created 130 new ponds and lakes in the DAPF zone (Crisafulli et al., 2005b). Newly formed ponds on the Debris Avalanche zone were of diverse type, including ephemeral and perennial ponds that developed over time to contain a wide variety of plants, and species rich communities that hosted a variety of wildlife by 2005 (Crisafulli et al., 2005a). Six species were found in ponds and lakes in the DAPF zone during the course of this study, including the Pacific Treefrog (*Pseudacris regilla*), Northern Red-legged frog (*Rana aurora*), Cascades frog (*Rana cascadae*), Western toad (*Anaxyrus boreas*), Northwestern salamander, (*Ambystoma gracile*), and the Rough-skinned newt (*Taricha granulosa*). The authors suggested that the amphibians invading these newly created ponds were derived from source populations in the lesser disturbed blowdown zone some 3-7 km away. The Western toad and the Pacific tree frog were established in the Debris Avalanche zone only three years after the eruption, and the Northern Red-legged frog and Cascades frog established two to four years later. The Northwestern salamander and the Rough-skinned newt colonized much later, nine and ten years post eruption, respectfully (Crisafulli et al., 2005b). All of these species were observed from 1989-2000, with the exception of the Cascades frog.

Amphibians associated with stream, seep, and terrestrial habitats were not found on the Pumice Plain, part of the DAPF zone as all of these areas were obliterated after the eruption and species associated with these habitats had failed to establish populations (Crisafulli et al., 2005b). These study sites began showing signs of recovery, with some stream systems beginning to clear, starting in 1995. Absence of species was thought to be caused by poor habitat conditions including: high concentrations of sediment; lack of cobble substrates, riparian zones, vegetation, and woody debris; an increase in temperature (due to lack of shade), and lack of cool, moist microclimates; or poor dispersal capabilities (Crisafulli et al. 2005b).

Another study at MSH conducted by Spear et al. (2012) examined the genetic structure of source Coastal tailed frog populations and its recolonization and gene flow in four zones created by the eruption: debris avalanche/pyroclastic flow zone (DAPF zone), blowdown/scorch zone (BDSC zone), tephra fall zone (intact forest with 10-20 cm of pumice and ash), and undisturbed forest. The BDSC zone had two distinct management strategies which were further divided into two zones, with one area (part of MSH National Volcanic Monument) left to recover naturally, while another area was intensely managed; with salvage logging, slash treatment, and tree planting. Results of this study suggest that gene flow from an outside source population has been high across the suite of study sites, and no significant differences existed for allelic diversity and inbreeding between disturbed and non-disturbed sites (Spear et al., 2012). This study used landscape genetic analysis to identify distinct variables that promote or inhibit gene flow in coastal tailed frogs. Model comparisons using Akaike information criterion (AIC) suggested that there was a positive relationship of frost free period with least cost path (traveling along stream and forest corridors), a negative relationship with slope, suggesting that increased slope will yield an increase in gene flow, and that in the BDSC unmanaged test area that contained biological legacies, amphibians did not travel in least cost path. This suggests that unmanaged sites, with sufficient large woody debris that provide cover, suitable microsites and microclimates may allow amphibians to take alternate and unpredicted paths when migrating. According to other studies, coastal tailed frogs are not known for crossing long distances, but this study suggests that these amphibians found paths of connectivity through a relatively hostile environment to increase gene flow with amphibian survivors (Spear et al., 2012).

Bakkegard (2008) conducted research on gene flow and colonization of *A. gracile* and *T. granulosa*. She investigated three study areas including the same new ponds studied by Crisafulli et al. 2005b that lacked surviving amphibian, lakes in the blowdown zone with surviving species, and undisturbed reference lakes, and found that *T. granulosa* and *A. gracile* did not have distinct population structures, that exhibit panmictic populations. Bakkegard (2008) concluded that there was no evidence of founder or bottleneck effects, and her data supports that study sites were colonized by a large number of survivors from adjacent areas, new immigrants, or both. There was no loss of genetic diversity, which suggests that both *A. gracile* and *T. granulosa* will travel longer distances and are ready colonizers of disturbed landscapes (Bakkegard, 2008).

Unlike *A. gracile* and *T. granulosa*, *Ascapheus truei* typically has low dispersal capabilities (depending on habitat) and is a cold, stream-dwelling species, sensitive to environmental changes (temperature and substrate), and habitat alteration. Hawkins et al. (1988) investigated *A. truei* in Clearwater Creek close to Mount St. Helens for three consecutive summers (1885-1987). They compared habitat types and densities of tadpoles in non-forest (areas devastated by the eruption), headwater forest, and forested areas. Their data reaffirms that *A. truei* is found in colder, faster moving water (more animals found in water 61-80 cm/s), with course substrates, little embeddedness, and substrates typically ~10-30 cm. The densities of tadpoles were highest in streams that flowed through lower reaches where the forest had been killed by the lateral blast, and upper reaches supporting intact forests. They believed this configuration of habitat created abundant food sources (algae) for larvae, and suitable upland forest habitat for adults. Temperature was not a factor in overall densities of tadpoles, as no adverse effects were observed in open areas, but water temperatures were up to 20° C in open reaches, and this is approaching the tolerance limit for this species (Hawkins et al., 1988). Understanding how cold-dwelling stream amphibians respond to devegetated and embedded stream channels help us understand the effects of habitat alterations, whether natural (volcanic eruptions) or anthropogenic (logging).

Succession at Mount St. Helens

Ecological responses to the geophysical disturbances that occurred during the eruption, varied. Volcanic disturbance processes altered forests, meadows, streams, ponds, and lakes (Dale et al., 2005). Physical changes to aquatic systems included changes to water depth, area, substrate content, and the ability to establish plant growth (Dale et al., 2005).

It is highly unlikely that any amphibians persisted on the Pumice Plain posteruption; as they would not have been able to survive the high temperatures (300° C to 600° C) or the large amount of debris deposited (10 m to 195 m) (Swanson & Major, 2005).

Amphibians are likely to be sensitive to environmental change, and as their habitats are altered, whether from anthropogenic change (climate change, disease, habitat alteration) or natural disturbances (volcanic eruption), understanding how these species respond is critical to their long-term persistence and well-being. The justification for this research project is to understand amphibian community assembly on the Pumice Plain, an area undergoing primary succession. Further, it will provide a 33 year baseline data benchmark for future research.

Finally, this case study at MSH contributes more broadly to our understanding on how amphibians respond to environmental changes and catastrophic events.

The focus question for this research is: What are the patterns of amphibian community assembly on the Pumice Plain and how do patterns of assembly vary across habitat types. To understand habitat types, I investigated how biophysical elements vary across habitats and their influence on habitat preference.

METHODS

Climate and Vegetation

My study area has a wet, mild, maritime climate. Most precipitation falls as rain or snow between October and May with a total annual accumulation of about 2,250 mm. At ~1,050 m elevation our site is in a heavy snow zone, but because of the absence of tree canopy, which was destroyed by the eruption, snow pack is typically shallow (e.g., <30cm) and ephemeral, coming and going many times each winter. The area has a pronounced summer drought, where rainfall is often little or even absent for several weeks, or longer. Average annual temperature is about 5.6˚C, average July temperature is about 15˚C, and average January temperature is about -2.0˚C (Franklin and Dyrness, 1988). High amounts of precipitation and spring snow melt causes high water levels in streams, seeps, ponds, and lakes. Streams remain highly dynamic with annual shifts in channel, scour and deposition following freshets. This is most pronounced on the Pumice Plain where major stream alterations are commonplace because of unconsolidated and highly erodible substrates.

Thirty-three years post-eruption, the Pumice Plain is a highly diverse environment, containing numerous patchily distributed habitats suitable for amphibian persistence and reproduction that are embedded within a comparatively barren and inhospitable landscape. A diverse assemblage of grassland forb species form the dominant upland vegetation communities, with woody shrubs present at low densities. Plant succession has proceeded rapidly in areas with ample summer moisture levels and support dense thickets of deciduous shrubs, primarily willow (*Salix sitchensis)*, slide alder (*Alnus crispa*), and cottonwood (*Populas trichocarpa*), providing shade and cover for species like amphibians, small mammals, and birds. This is particularly true in the numerous seeps and springs along many of the braided stream channels that run south-north and drain into Spirit Lake.

Some other understory plants include: big huckleberry, vine maple, pearly everlasting, fireweed, Indian paintbrush, lupine, and various grasses. In 1998, 18 years post-eruption, 150 species of vascular plants inhabited primary succession areas of the debris avalanche zone; and vegetation cover went from zero in 1980 to as high as 70% in some areas by 2000 (Dale et al., 2005).

Amphibian Species of the Pumice Plain

Today, six species of amphibians, Western toad (*Anaxyrus boreas*), Pacific Treefrog (*Pseudacris regilla*), Rough-skinned newt (*Taricha granulosa*), Northwestern salamander (*Ambystoma gracile*), Northern Red-legged frog (*Rana aurora*), and Cascades frog (*Rana cascadae*) have been found on the Pumice Plain. All six species are pond and lake breeders, where adults travel to ponds to breed in the winter months. Females deposit a gelatinous mass, fertilized by the males during amplexus, which is a form of psuedocopulation in which the male anurans embrace the females, and eggs are shed into the water and fertilized. Typically these egg masses are attached to aquatic vegetation, rocks, and large woody debris in the littoral zone of ephemeral or perennial wetlands. These eggs develop quickly, and metamorphose (anurans and newts) within 2-4 months. The Northwestern salamander completes metamorphosis in about 15 months, unless it remains neotenic, where adults retain juvenile characteristics like gills, but are sexually mature. Shortly after egg laying, adults disperse, followed shortly after by juvenile amphibians.

Study Site Location and Descriptions

Study sites are located on the Pumice Plain, a 15 km^2 area north and west of the volcano (Figure 1). I identified four structurally distinct habitats on the Pumice Plain: wallow, seep, pond, and lake. Twenty-five study sites were selected within these four habitat zones. Study sites were spread across the Pumice Plain (Figure 2). Study site selection was based on the presence of suitable amphibian habitat (i.e. aquatic areas), and the ability to survey the area adequately (C. Crisafulli, personal communication, 2013).

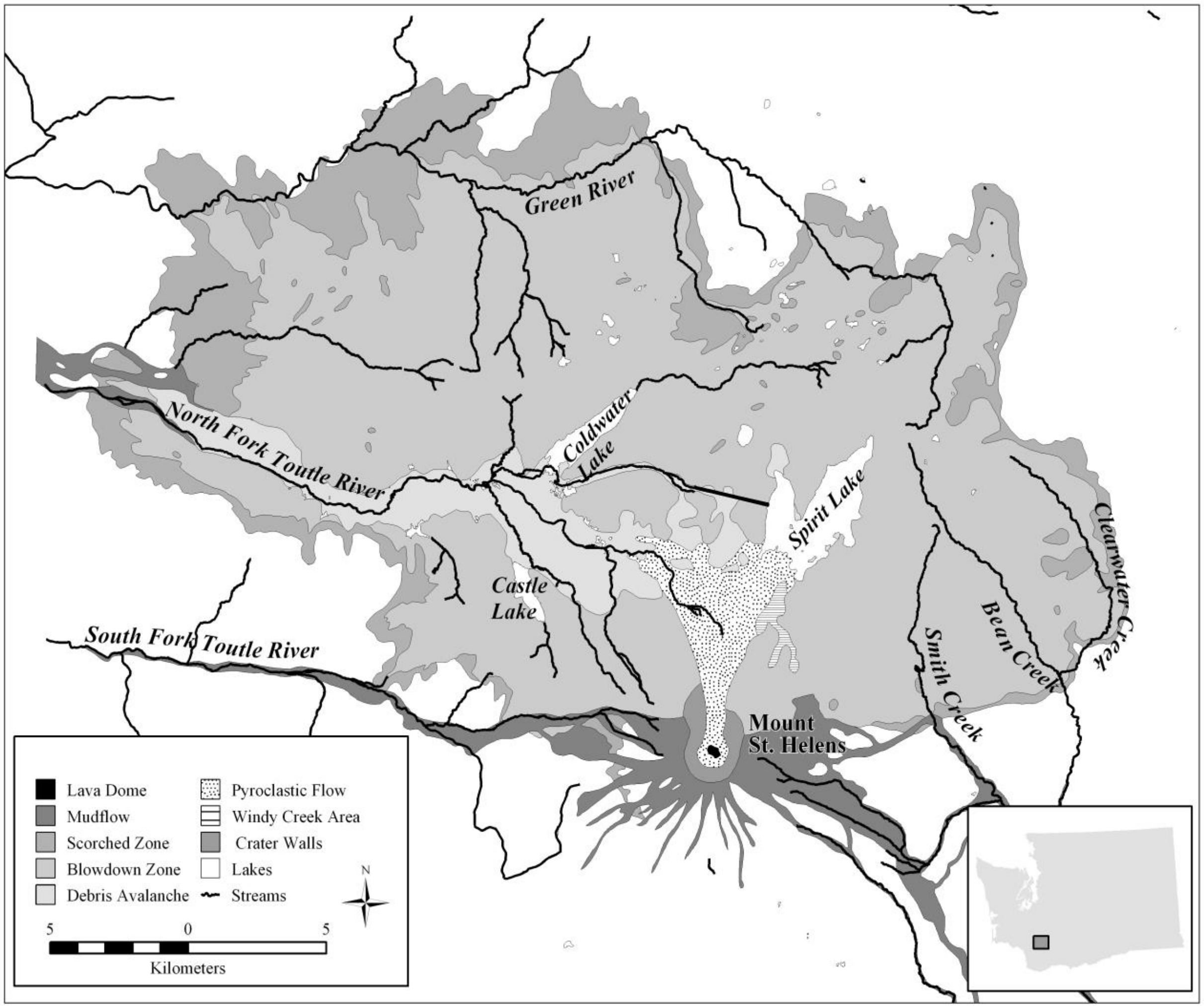

Figure 1. Base Location Map: Mount St. Helens National Volcanic Monument, situated in SW Washington. Orientation of the Pumice Plain in relation to other environmental & geologic zones.

All three ponds present on the Pumice Plain were sampled. A portion of Spirit Lake (three sample sites) were selected in Duck Bay, a long narrow bay in the southeast portion of the lake. Of the 16 Wallows located on the Pumice Plain, 14 were adequate for amphibian sampling. Of the numerous seeps present on the Pumice Plain, five were selected for sampling- for logistical purposes (good trail access). Additional seeps not surveyed were at greater distances, over rugged terrain, or densely covered by *Salix sitchensis* (willow) that would have prevented accurate visual estimates of amphibian abundances.

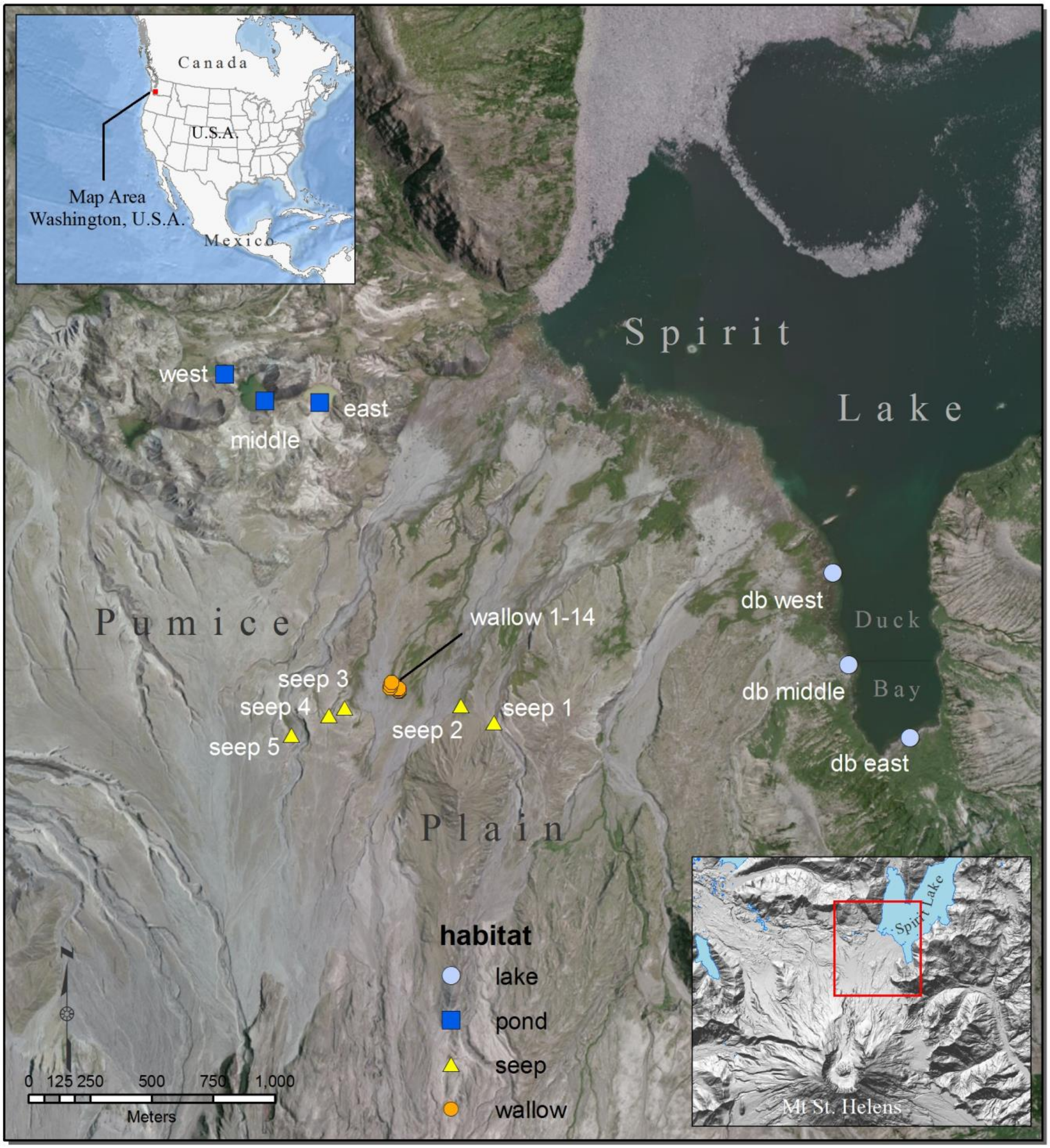

Figure 2. The 25 study site locations grouped by habitat (lake, pond, seep, and wallow) on the Pumice Plain.

All sample sites were measured for area, length, width, elevation, and spatial location (i.e., GPS coordinates) *(Appendix A).* In addition, at each study site, data was gathered for vegetation, dominant substrate, water depth, temperature, pH conductivity, and dissolved oxygen. Water quality testing was done on August 21st, 2013, at each study site, with the YSI Multi-Parameter Water Quality Monitor, Model 650 MDS.

Wallow Study Sites (Wallows 1-14)

Wallow study sites were centrally located along the Pumice Plain- west of Seep 2, and between Geothermal Creek, and Geothermal West (Figure 2). Wallows were formed by elk excavations in marshy-seep areas, creating shallow depressions. These depressions fill with water, forming small permanent ponds that are used by amphibians for breeding in spring, and for foraging habitat in summer. Wallows are fed from groundwater sources that maintain cool temperatures throughout the summer. Substrates in the wallow habitat consisted of sand (0.5-2 mm) and small gravel (3-10 mm.) Water temperature ranged from 7.3-13.8°C at Wallow sites 1-14. Wallow sites 1-9 were warmer than the others, ranging from 10.6-11.57°C. Wallows ranged in depth from 12-28 cm, with an average depth of 22.1 cm. PH at the 14 wallow sites were very similar, ranging from 6.18 to 6.87. Conductivity (micro Siemens per centimeter) ranged from 135 to 169 indicating relatively low dissolved ion concentrations. Dissolved oxygen ranged from 1.37 mg/L to 4.91 mg/L, a 3.54 mg/L difference.

Vegetation at the wallow habitat was homogenous due to the close proximity of each study site and the dominance of Sitka Willow (*Salix sitchensis*) and similar perennial herbs and grasses (Figure 3). Vegetation abundance (% cover) at wallows consisted of *Salix sitchensis* (60 %), *Carex sp.* (15 %), *Racomitrium canescens* (10 %), *Juncus sp*. (8 %), and *Trifolium repens* (7 %). No aquatic vegetation was found, although a significant amount of detritus was found in each wallow due to the large amount of decayed forb and grass species present at this site.

Figure 3. Vegetation by habitat type are A- Lake habitats, B-Wallow habitats, C-Pond habitats, and D-Seeps. A -Duck Bay East, B –Wallow 3 & 4, C-Pond East, and D-Seep 3.

Seep Study Sites (Seeps 1-5)

Seeps are located at slope inflection points where ground-water surfaces and gently flows in small channels or by laminar flow through sedge and moss dominated plant communities. At incised seep locations, water often runs down the channel wall, creating moist environments that host a multitude of forbs, grasses, bryophytes, and fern-like species. Five seep sites were chosen, that were distributed across the Pumice Plain (Figure 2). Study sites ranged from 436.6 m² to 4830.0 m².

Eighty percent of seep habitats contained fine gravel sediment (Seep 1-4), while only 20% consisted of large gravel (Seep 5). There was considerable variation in temperature across the five seep study sites, 7.38˚-15.45˚-C. Seeps 2 through Seep 5 were similar in water quality parameters. Seep one had the lowest temperature, highest conductivity, DO, and pH, when compared to the other seep sites (conductivity 367 μs/cm, DO 7.47 mg/L, pH 7.61). The seep study sites were shallow; depth ranged from 7-20 cm.

The two dominant plant species at the seep study sites were *Salix sitchensis* and *Racomitrium canescens.* *Alnus crispa* was the subdominant shrub species, found only at Seep 2 & 3, and ranged from 5% -25% cover. The two graminoid species, *Carex sp*. and *Juncus sp.* were found singularly or together at all seep sites and ranged from 4% cover to 25% cover. The two forb species that were encountered at the seep study sites were *Epilobium sp.* and *Castilleja minuata* with less than 5% cover at each site. No aquatic plant species were found at the seep study sites.

Ponds (Pond East, Middle, and West)

All three ponds present on the Pumice Plain were included in this study, and were located on the western edge of the study area (near the eastern edge of the Debris Avalanche deposit) in close proximity to one another and situated among the "hummocks" (Figure 2). Pond size varied and ranged from 720.0-14,102.0 m^2, with Pond East and Middle being the largest and deepest of the three ponds sampled. Pond Middle and Pond West are in close proximity, and during winter months when precipitation is high, combine to act as one integral pond system. Pond habitat study sites contained fine sediment (< 0.5 mm), a clay-like substrate. Pond temperatures were high, relative to other habitats on the Pumice Plain. In addition, substantial water loss occurred at the three ponds over the five weeks of data collection.

Temperatures at the pond sites were warm and varied substantially (19.46 - 27.54°C). Dissolved oxygen and pH readings were high, with pH ranging from 8.0 to 10.04. Dissolved oxygen was high, compared to other habitats sampled. Dissolved oxygen ranged from 8.49 mg/L to 10.22 mg/L. Conductivity readings were substantially higher than any other habitat on the Pumice Plain with readings in the 450-495 µs/cm for Pond West and Pond Middle. These readings suggest water high in calcium, sodium, chloride, and/or magnesium.

The riparian zone around the ponds was moderately developed resulting in percent coverage values form 60 to 80% coverage. The dominant species at all ponds was *Salix sitchensis*, with 50-70% cover, and *Juncus sp.* with 5% cover at all sites. Aquatic vegetation was present at all ponds with *Juncus sp.* comprising >15% cover in the shallow littoral zone, at all sites; and *Potomagetan natans* (Narrow Leaf Pond Weed) found only in Pond Middle, with 40 % cover, in deeper water ranging from 1.0-1.5 meters.

Lake Habitat (Duck Bay-East, Middle, and West)

Spirit Lake, situated north of the Pumice Plain and west of Windy Ridge, is the central drainage for seeps and stream systems running north-south along the Pumice Plain. The lake is large, 11.4 km², with an average depth of 36 m. The lake contains a large tree mat left over from the 1980 eruption, which continually changes position around the lake due to fluctuating wind patterns. The three study sites at Spirit Lake are located in Duck Bay, which is a long narrow segment of the lake stretching off to the southeast (Figure 2). The lake perimeter consists of narrow small sandy beaches, intermittent with dense patches of *Salix sp*. and stranded logs. Sample areas ranged from 688-720 m². Traps were placed outward to a depth of ~1 meter, typically attached to logs. VES was only done at Duck Bay East because of time constraints.

Duck Bay, at Spirit Lake, contained fine (<5 mm) particle substrates at each sample location. Water quality data was taken only at Duck Bay West (DB-West), where the temperature was warm (19.46° C). Duck Bay's pH was higher compared to most Pumice Plain habitats, with a reading of 8.0. Dissolved oxygen reading was 8.49, levels that support amphibians and the introduced rainbow trout species, *Oncorhynchus mykiss*. Conductivity was typical of the water sources on the Pumice Plain (139 µs/cm).

Duck Bay Middle (DB-Middle) contained only 5% cover of *Salix sitchensis*, with 95% bare ground. Presence of the aquatic forb, *Ranunculus aquatilis* was low, with only a 5% cover over a 688 m^2 area. Only a few logs were present in the littoral zone of this study site. Contrary to the other study sites at Spirit Lake, Duck Bay East (DB-East) had an extensively vegetated riparian zone, with *Salix sitchensis* being the only species present at 75% cover. Two aquatic species were found in low abundance, *Potomagetan natans* (Large leaf pond weed) at 7% cover, and *Ranunculus aquatilis* with <2% cover. Like Duck Bay West, this site contained a higher amount of large woody debris in the littoral zones.

Sampling Methods

Ideas for inventory were gathered from past studies on amphibians (Crisafulli, 1997; Crisafulli et al., 2005b), and I used similar methodologies for sampling, including aquatic funnel traps, dip nets, and visual observations of plant and amphibian species on land, according to the research procedures *(Appendix B).* Four distinct habitats (wallow, seep, pond, and lake) were inventoried, and Global Positioning System coordinates were obtained for each study site. Surveys began July 15th and continued through August 18th, with two phases for the amphibian inventory data: Visual Encounter Surveys (VES) and Aquatic Funnel Trap Surveys (AFT), with procedures used by scientists at MSH and discussed in *Sampling Amphibians in Lentic Habitats* (Crisafulli, C., 1997). Amphibian sampling was conducted twice at each selected site for each type of sampling, VES & AFT (for a total of four sample sessions per site) for a more accurate account of amphibian presence, with the exception of Duck Bay West and Middle, which VES was not conducted at those two sites.

Aquatic funnel traps are mesh, collapsible traps that have been extremely useful for biologists in capturing amphibian species. Funnel traps used in this study are from Memphis Net and Twine Company, with dimensions of 10” X 10” X 17” (Model RN10). They prove to be an ideal method for capturing larval, and breeding adult amphibians, in ponds, lake and wallow habitats. Aquatic funnel traps were placed in the littoral zone, at varying depths and vegetation zones, relatively equally spaced around the pond or lake perimeter. Traps were clearly marked with the trap number, and attached to vegetation, and trap locations did not change between the sample periods. Traps were set for a 24-hour period, and then retrieved and captured animals processed. Captured amphibians were identified to species, tallied, measured, and immediately released. In the wallows, one trap per wallow was placed in the deepest section, although some wallows (e.g., Wallow 8) were not deep enough to place a trap. Some seasonal drawdown of water occurred during the sample season, and for AFT sample session 2, one more wallow (Wallow 5) was too shallow to sample.

Seep habitats were not sampled using aquatic funnel traps because they were too shallow.

Aquatic funnel traps were placed at depths ranging from 90-110 cm at all three study sites at Duck Bay. Spirit Lake was sampled on consecutive days, August 15th and 16th.

Aquatic funnel trapping was performed at Pond East, Middle, and West on July 18th and again on August 1st, 2013. Sixteen traps were put into the shallow littoral zone of each pond during AFT session 1. Sample efforts were reduced for Pond Middle and West for AFT session 2, due to the decrease in water depth. Funnel trapping at the wallow habitat is as follows: session 1 was conducted on July 24th -25th, 2013, and trapping session 2 was conducted on August 7th - 8th, 2013.

Five seeps were inventoried west of Willow Springs to Camp Creek on the westward region of the Pumice Plain. Time allocated to each seep depended on the area (size), ease of travel due to the riparian zone complexity, and the amount of amphibians being captured. Since seep habitats were too shallow, VES were done twice at each sample site to compare species encountered to AFT data for wallows, pond and lake habitats. VES methods were kept consistent between all seep sites. Juvenile and subadults were lumped into a single category of "subadults" for VES seep data. In addition, during VES survey 2, Seep 5 experienced some retreat in the seep distance (20 m), due to the shallowness of this section. This area was surveyed, but there was no water in the area.

VES surveys were done in all riparian zones, shore zones, and shallow littoral zones with an intermediate approach to looking at all or nearly all vegetation. Visual surveys continued into the littoral zone looking for tadpole, larvae, juvenile, subadult, and adult amphibians, as well as using dip nets for sweeping larval frogs and salamander species. As amphibian species were retrieved, they were put into a bucket for identification. Amphibians were spotted, captured using nets or placed into a plastic bag for measuring and identifying (Figure 4). Measurements like total length (TL) and snout-to-vent (SVL) of species were recorded in millimeters for all species except tadpoles (Figure 4). Juvenile SVL were not recorded at every test site, due to the unusually high amounts of *Anaxyrus boreas*, *Rana cascadae*, and *Pseudacris regilla* that were encountered in high numbers at Spirit Lake East, Pond Middle, and Pond West.

Figure 4. Snout-to-Vent lengths were recorded for all juvenile, sub-adult, and adult frogs and salamanders.

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When using dip-nets, a side-to-side sweeping motion was used along the littoral zone of the pond or lake study sites at five meter intervals. Captured amphibians were placed in a bucket and counted, measured, and recorded for species, sex, and life-stage.

Vegetation surveys were done in conjunction with VES. Most common plants were identified and recorded based on percent ocular cover estimations of the riparian zone out to two meters from the water's edge, and again for aquatic vegetation within the pond system or lake survey area (any vegetation within the littoral zone). Bare ground (plant absence) was also recorded. Plants were identified to either species, or in some cases genus-level, and vegetation lifeform was recorded for each species (shrub, grass, forb, bryophyte, and fern and relatives).

Dominant substrates were determined in all habitat areas. Some examples of possible substrates include: fines (<0.5 mm), sand (0.5-2 mm), small gravel (3-10 mm), and large gravel (11-100 mm), muck, and coarse detritus. Depth, length, and width were measured at all sites; and at seep locations, depth and width were measured at regular intervals.

Statistical Analysis

Analysis was done for species richness using the habitats as independent variables, with survey one and survey two data ran separately. We also examined larval captures per trap night, (trial one only) for all species combined *(P. regilla, R. cascadae, A. boreas, and A. gracile*), and individual species found at lake, wallow, and pond habitats, which didn't include seep habitats due to their shallowness at the time of the surveys. Of the twenty five test sites observed, 19 were sampled with aquatic funnel traps and used to determine these capture rates. We examined larval abundances of each species encountered in the larval stage and neotenic varieties in the aquatic funnel traps for trapping session one only, as by AFT session 2, most *P. regilla, R. cascadae, and A. boreas* had metamorphosed.

Larval abundances and richness were also compared to biophysical parameters like area, depth, conductivity and dissolved oxygen. Univariate and multivariate analysis was conducted to see how these types of covariates positively or negatively affect amphibian captures.

Total captures were also determined, using AFT methods, and averaged by the number of survey sites. Ponds contained three sites (East, Middle, and West), wallows contained 14 sites, but Wallow 8 was removed from the data, as it was too shallow to survey with AFT methods, so N=13 prospectively. The lake habitat contained three survey sites all located in Duck Bay of Spirit Lake.

For all analyses where our predictor variables were categorical (habitat types) and our dependent variables were continuous, we used generalized linear models (ANOVA) for associated analyses. We arcsine transformed all proportion data, and specified a Poisson distribution and log link for analyses where the dependent variable was narrowly bounded (Zar, 2009).

This analysis was done to test for differences in physical characteristics of habitats and how relevant they were with richness. This was done by using all available data, and was broken down by VES and AFT trap session 1 and 2. Larval abundances were determined by the amount of amphibians per trap, per trap night in pond, lake and wallow sites. Area and richness was determined using all available data, including VES and AFT data. Univariate and multivariate analysis was done using a regression summary with individual species being the dependent variable.

For data regarding breeding and presence, we summarized these trap data sets by species and life stage. Tadpoles of similar Gosner stages, (e.g.-amphibians in early-late metamorphosis), were lumped into a single category of "tadpole" (Gosner, 1960). Breeding refers to captures of tadpoles or larvae, and implies presence. Presence refers to amphibian species in the juvenile to adult life stages that were captured in traps or seen during VES sampling trials.

For biophysical data: z MAX depth, conductivity, dissolved oxygen, riparian vegetation, and aquatic vegetation were analyzed using straight ANOVA methods, treating area as one continuous variable.

RESULTS

Amphibian Presence on the Pumice Plain

Amphibians were observed in the four habitats (wallow, pond, lake, and seep) sampled on the Pumice Plain (Table 1). *R. cascadae* and *P. regilla* were the most common species encountered across the 25 study sites (Table 2).

Table 1

Amphibians present in habitats sampled on the Pumice Plain at Mount St. Helens during summer 2013

Order	Family	Scientific Name	Common Name
Anura	Hylidae	*Pseudacris regilla*	Pacific Treefrog
	Ranidae	*Rana cascadae*	Cascades frog
		R. aurora	Northern Red-legged frog
	Bufonidae	*Anaxyrus boreas*	Western toad
Caudata	Ambystomatidae	*Ambystoma gracile*	Northwestern salamander

R. cascadae and P. regilla were encountered at 76% and 72% of the survey sites, respectively. *A. boreas* and *A. gracile* were observed in 20% of all sites study sites. *R. aurora* is the least frequently encountered species on the Pumice Plain, present at only 12% of all study sites.

Amphibian Occupancy and Breeding by Habitat

Amphibians were observed breeding in 64% of the 25 survey sites. The prevalence of breeding at the study sites was: *P. regilla* in 64%, *R. cascadae* 44%, *A. gracile* 20%, *A. boreas* 16%, and *R. aurora* was not found breeding in any survey sites. *P. regilla* was encountered breeding at 50% of the wallows, while *R. cascadae* was present at 64% and breeding at 29% of the wallows. In 29% of the wallows, no species were encountered by either survey method.

No other amphibian species were found present or breeding at the wallow sites.

Table 2

Amphibian breeding versus presence at wallow, seep, pond and lake habitats. Breeding and presence are represented under each species as B (Breeding=tadpole or larvae), or P (Presence=juvenile or adult) amphibians encountered at each survey site

Habitat	Site	AMGR	ANBO	PSRE	RACA	RAAU
Wallow	W-1	—	—	B	P	—
	W-2	—	—	B	—	—
	W-3	—	—	—	P	—
	W-4	—	—	B	B	—
	W-5	—	—	B	B	—
	W-6	—	—	B	B	—
	W-7	—	—	B	B	—
	W-9	—	—	—	P	—
	W-10	—	—	B	P	—
	W-12	—	—	—	P	—
Seep	S-1	—	—	B	P	—
	S-2	—	—	B	B	—
	S-3	—	—	P	P	—
	S-4	—	—	P	P	—
	S-5	—	—	B	B	P
Pond	East	B	P	B	B	P
	Middle	B	B	B	B	P

	West	—	B	B	B	—
Lake	DB-East	B	B	B	B	—
	DB- Middle	B	—	B	—	—
	DB-West	B	B	B	B	—

P. regilla was found breeding at 60% of the seeps. *Rana cascadae* was also found present at all seep sites, but breeding at only 40% of the seeps. One individual *R. aurora*, a subadult, was found at Seep 5, which was located, the farthest west on the Pumice Plain, in close proximity to the transition zone between the pyroclastic zone and the debris avalanche zone. *A. gracile* and *A. boreas* were not found breeding at the seep survey sites.

Five amphibian species were present at pond sites. The complete assemblage (five species) were present at 67% of the pond sites. *P. regilla* and *R. cascadae* were present & breeding at 100% of the three pond sites. *Anaxyrus boreas* was present at all sample sites, but breeding occurred at two of the three ponds. Recently metamorphosed toadlets were observed at the water's edge and riparian zones of these two ponds. *A. gracile*, was found present and breeding at Pond East and Middle, but was not found at Pond West.

Rana aurora was present at Pond East and Pond Middle, but with very few numbers, making it the least abundant species at the pond study sites.

Four of the five species of amphibians known to occur on the Pumice Plain were encountered at the Spirit Lake study sites. *P. regilla* and *A. gracile* were present and breeding at 100% of the sample sites. *A. gracile* was represented by aquatic forms, including neotenes, juveniles, and hatchlings. *A. boreas* and *R. cascadae* were both observed at Duck Bay East and West, but were not encountered at Duck Bay Middle study site.

At Spirit Lake, all four species encountered were breeding at Duck Bay East and West, while 50% were breeding at Duck Bay Middle.

P. regilla and *R. cascadae* solely occupied the wallow and seep habitats. *R. cascadae* and *P. regilla* were present at all seep sites, compared to 50% presence at Wallows 1-14. *A. gracile* was found only at pond and lake habitats, and *R. aurora* was found present only at pond and seep habitats. The only two species consistently found across all habitats were *P. regilla* and *R. cascadae*.

Amphibian Richness

The lake and pond habitats had the highest species richness values of the four habitats sampled (Wald x^2 (3) =18.7, P=0.000032, Figure 5). In survey one; the ponds were richest in species with a mean value of 2.83 (N=6) compared to other habitats. Lakes averaged 2.25 species (N=4), then seeps with 1.8 species (N=5), with wallows having the lowest value (.75 species) of all habitats (N=28). Survey two yielded slightly more species for three of the four habitats (Wald x^2 (3) = 30.7, $p<0.0001$), Figure 6). Lakes were richest with mean value of 3.25 species (N=4).

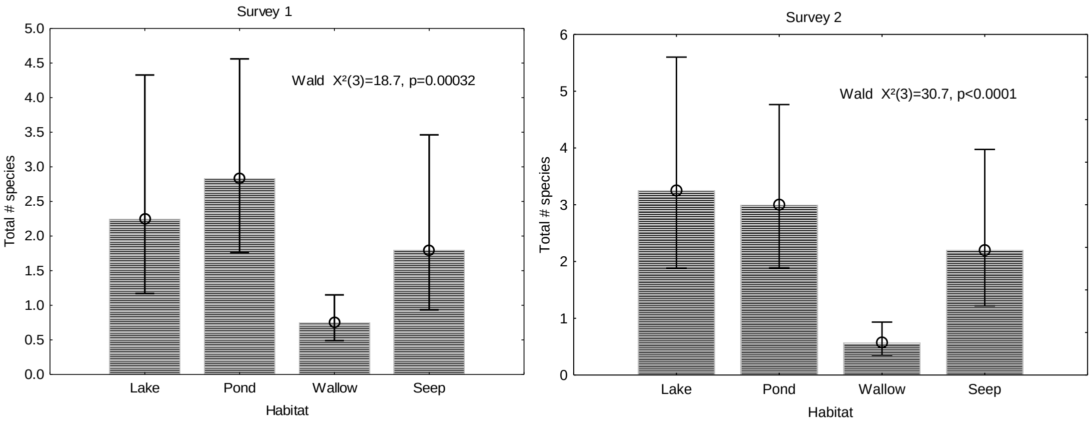

Figure 5 & 6. Species richness, using all survey methods, among habitat sites. Survey one (left), survey two (right).

Ponds followed with 3.0 species (N=6), then seeps with 2.2 species (N=5). Wallows remain the least rich habitat (mean=.57; N=28). Significant differences in richness only existed between the wallows and the lake and pond habitats.

Larval Captures-Comparisons among Habitats

Ponds had the highest abundance values, with total mean (68.21) captures per trap/trap night, greater than three times the average of lakes (Mean=18.23), and almost nine times (Mean=7.62) the captures of wallow sites (Wald x^2 (2)=337.64, $p<0.001$, Figure 7). The ponds had a total of 3, 274 captures (N=3), followed by lake habitat with 711 captures (N=3), with wallows having the least captures (99 captures, N=13) (*Appendix F*).

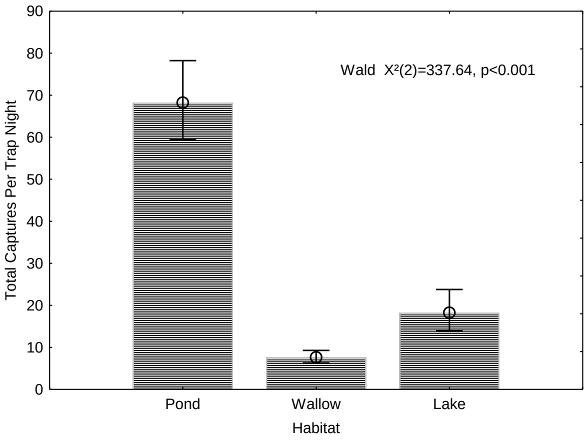

Figure 7. Total amphibian mean captures per trap/trap night in pond, wallow, and lake habitats.

Lakes contained a mean of 237 total captures per survey site, while wallows only containing an average of 7.62 amphibians per wallow. Amphibian species abundance varied by habitat. *A. boreas* was the most abundant species on the Pumice Plain, and *P. regilla* a distant second (Figures 8-12). *R. cascadae* and *A. gracile* were the least abundant species encountered among the habitat sites. The ponds yielded the greatest number of *A. boreas* with a total of 2,650 captures across the three ponds (Mean=883.33) (Wald $x^2(1)$ =1670, $p<0.0001$,

Figure 8). Spirit Lake had significantly less captures, with 700 (Mean=233.33) *A. boreas* among the three survey sites, and wallows contained no *A. boreas* in the larval stage.

P. regilla was well represented in the three pond sites (588 captures, Mean=196), when compared to other habitats (Wald $x^2(2)$ =940, $p<0.001$, Figure 9). *P. regilla* was encountered in the wallows (mean=11.23; 146 total captures), and in the three lake study sites (mean=2.67; 8 captures). *R. cascadae* and *A. gracile* were less abundant, with less than six mean larval or neotenes captures combined at each survey site. *R. cascadae* was slightly more abundant than *A. gracile*, with a mean of 5.33 captures at each pond, 2.0 at each wallow, and 0.33 at each lake survey site (Wald $x^2(2)$ =24.3, p=0.00001, Figure 10).

A. gracile was more abundant in the larval stage than in the neotenic life form. Only 20 larvae/neotenes were captured at the ponds (Larvae Mean=4, Neotene Mean=2.67). *A. gracile* abundance in the larval and neotenic lifeform at lake habitats was only 0.33 (Wald $x^2(1)$ =7.7, p=0.0055, Figure 11; Wald $x^2(1)$ =5.5, p=0.019, Figure 12).

Richness and Area

For the wallow sites, there was a positive relationship between area and species richness (Wald $x^2(2)$ =17.5, p=0.00016, Figure 13). Similarly, there was a positive relationship between sample site area and species richness in the pond habitats (Wald x^2 (2) =11222, p=0.0001, Figure 14). When combining pond and wallow habitats, which are effectively very small ponds, it clearly shows a correlation between area and richness, with larger sites hosting a richer and more diverse number of species (Wald $x^2(4)$=72885, $p<0.0001$, Figure 15).

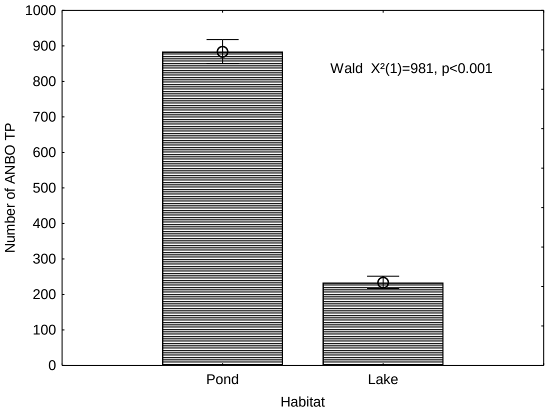

Figure 8

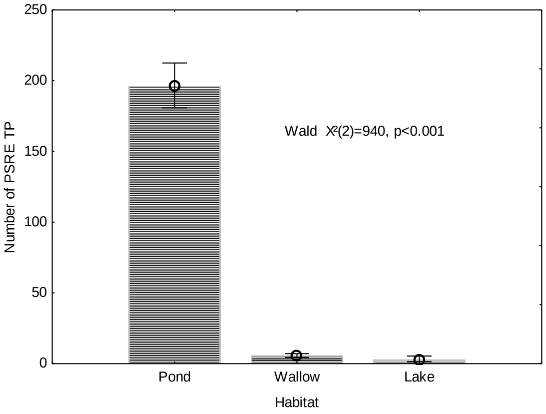

Figure 9

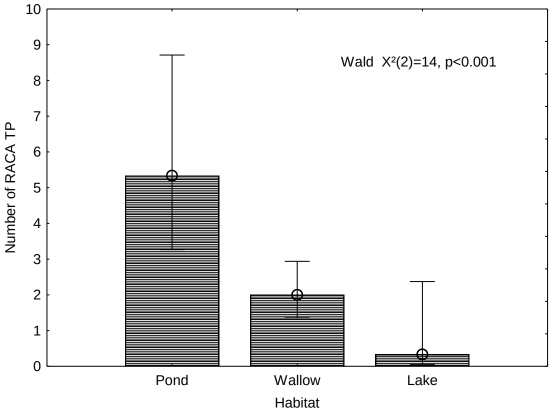

Figure 10

Figures 8-12. Mean abundance values of *A. boreas (Fig. 8), P. regilla (Fig. 9), R. cascadae (Fig. 10), A. gracile* larvae (*Fig. 11*), *A. gracile* neotenes (*Fig. 12*); captured by habitat. Survey one data.

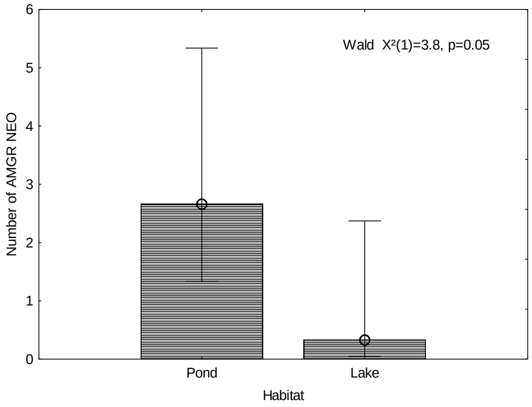

Figure 11

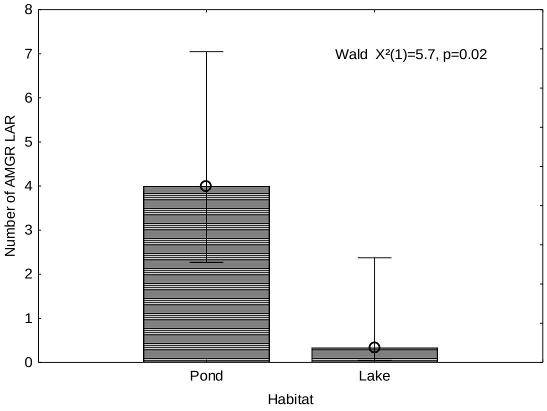

Figure 12

Seeps did not show a correlation between species richness and area, as some smaller sites contained more species than larger sites (VES survey 2, Mean area=510.5 m²) (Wald x²(2) =2069, p<0.0001, Figure 16).

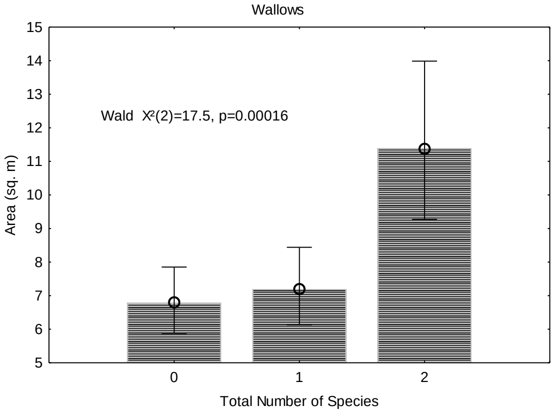

Figure 13

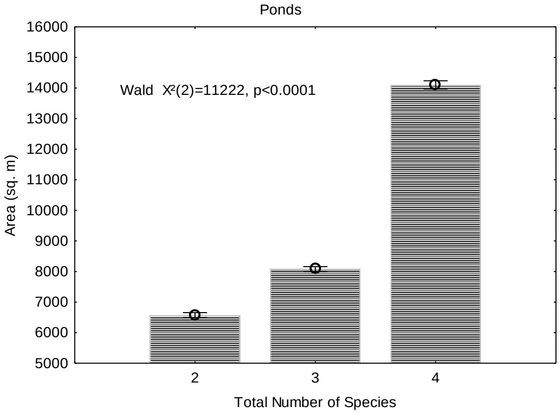

Figure 14

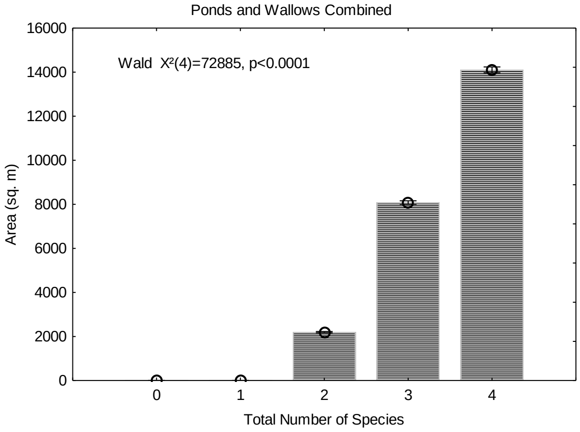

Figure 15

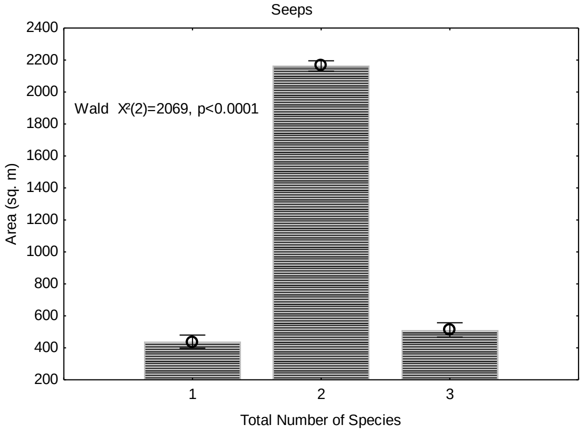

Figure 16

Figures 13-16. Richness of amphibian species by habitat type. Richness at pond (*Fig. 13*), wallow (*Fig. 14*), pond and wallow (*Fig. 15*), and seep habitats (*Fig. 16*) in relation to study site area (m²).

Fish and Fishless Habitats (Pond and Lake)

When comparing ponds (fishless) and lake (containing fish) habitats, there were far more amphibian captures in habitats without fish, more than three times the amount of larvae present in Spirit Lake (Wald $x^2(1)=75$, $p<0.0001$, Figure 17).

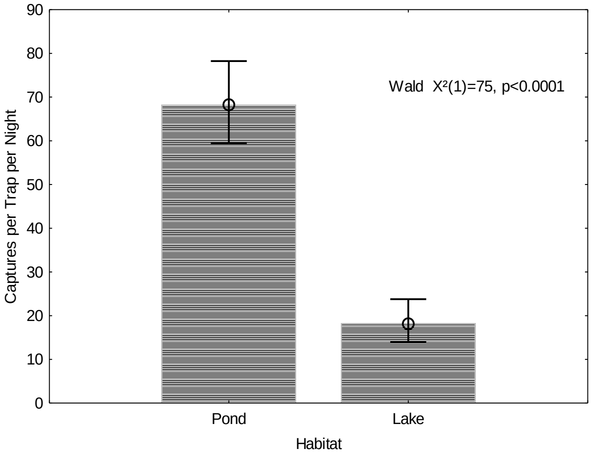

Figure 17. Comparison between fish (Spirit Lake) and fishless (pond) habitats.

Biophysical Variables among Habitats

These biophysical habitats variables varied among and within the habitat types. The pond habitat had the greatest area (Figure 18), maximum depth (Figure 19), conductivity (Figure 20*)*, dissolved oxygen (Figure 21), riparian vegetation (Figure 22), and aquatic vegetation (Figure 23). Wallows were small and shallow and contained low dissolved oxygen levels. Wallows and seeps contained high amounts of riparian vegetation.

Riparian vegetation cover and complexity was high at the wallow and seep habitats yielding a richer plant community. Whereas, the pond and lake habitat had greater amounts of aquatic vegetation than seeps and wallows.

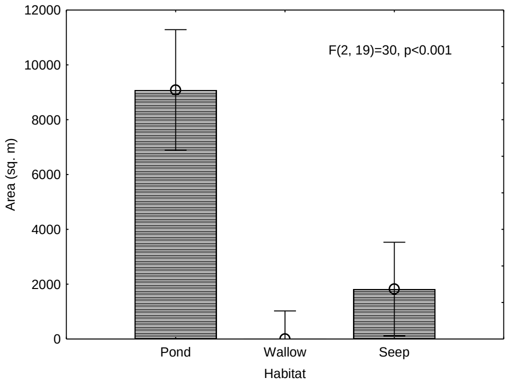

Figure 18

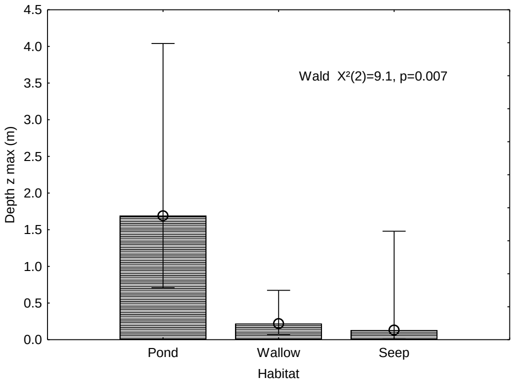

Figure 19

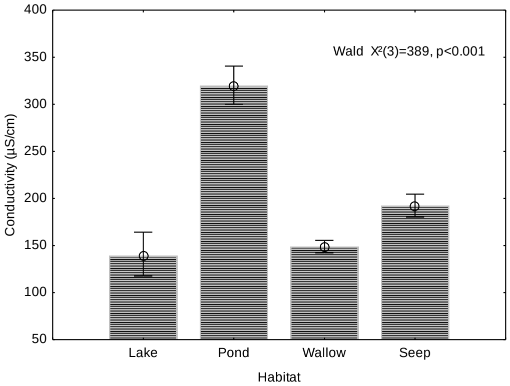

Figure 20

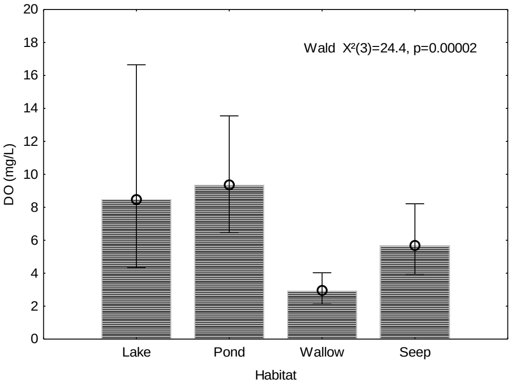

Figure 21

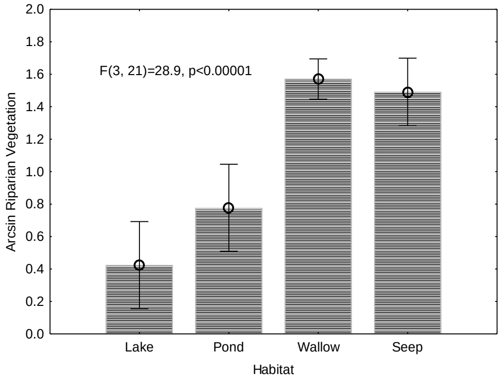

Figure 22

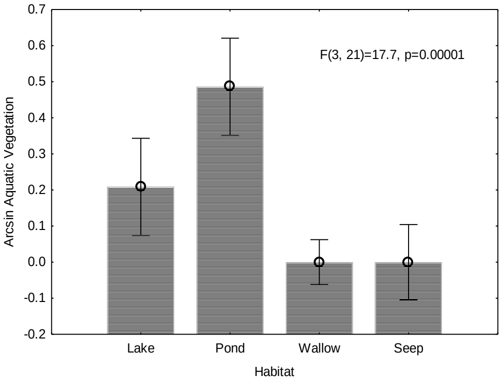

Figure 23

Figures 18-21. Biophysical data compared between lake, pond, wallow, and seep habitat sites. Area (*Fig. 18*), z max depth (*Fig. 19*), conductivity (*Fig. 20*), dissolved oxygen (*Fig. 21*), riparian vegetation (*Fig. 22*), and aquatic vegetation (*Fig. 23*).

Some of these biophysical habitat features were significantly correlated to the number of larval captures. Although *P. regilla* and *R. cascadae* didn’t show a significant relationship between captures and area, depth, conductivity and dissolved oxygen, *A. boreas* and *A. gracile* showed some relationships between the Univariate variables tested. Area (m^2), conductivity ($\mu S/cm$), and % DO saturation were the strongest predictors in determining number of captures. Whereas, *A. gracile* (neotenes and larvae), area, conductivity, % DO saturation, and depth were predictors for determining abundance values.

A Univariate analysis for *A. boreas*, revealed r^2 values for conductivity and dissolved oxygen that explained 45% of the variation predicting this species’ capture rates ($p=0.0030$). These abiotic factors were even more important in determining capture rates for *A. gracile*, with area, depth, conductivity, and DO all being significant predictors. Area appears to be the single most important variable explaining 91% of the variation in predicting capture rates ($p=0.00000$), 74% variation with depth ($p=0.00001$), and 43% for dissolved oxygen ($p=0.0042$).

Multivariate analysis was performed to determine if biophysical variables were predictors for species abundances. For *A. boreas*, there was a negative relationship between site area and larval captures; and positive relationship between DO and conductivity variables and larval captures ($p<.0002$). *A. gracile* had a positive relationship between captures and area. However, *A. gracile* had a negative relationship with DO and conductivity ($p<.0002$).

DISCUSSION

Amphibian Presence & Distribution

Amphibians present on the Pumice Plain during the summer 2013 were *P. regilla, R. cascadae, R. aurora, A. boreas,* and *A. gracile*. These species had been previously documented within the adjacent Debris Avalanche zone, and also at Spirit Lake, and *P. regilla* was known to occur at the two ponds on the western edge Pumice Plain (Karlstrom, 1994; Crisafulli et al., 2005b; Bakkegard, 2008). However there had never been a comprehensive survey for amphibians across habitats (ponds, lake, wallow, and seep) on the Pumice Plain prior to this study. *P. Regilla* and *R. cascadae* were widely distributed across the different habitats on the Pumice Plain, suggesting a generalist strategy. *P. regilla* was observed at several intensely disturbed locations at Mount St. Helens only one year post-eruption, and it is evident, that this species colonizes quickly (i.e., high dispersal capacity) and is highly adaptable to a wide range of environmental conditions (Karlstrom, 1986; Crisafulli et al., 2005b). Both *P. regilla* and *R. cascadae,* were found to tolerate low dissolved oxygen levels which are present at the Wallows (range= 1.37-4.91 mg/L). Most amphibians in lab experiments are stressed when dissolved oxygen levels are below 4 mg/L, but some Anurans can tolerate very low levels (Sparling, 2009). In addition, some species can acclimate to low levels of dissolved oxygen over time (Sparling, 2009). Perhaps *P. regilla* and *R. cascadae* have acclimated, and since they are quick to metamorphose (2-4 months depending on temperature), can tolerate low oxygen levels for a short duration. *R. cascadae* and *P. regilla* have been documented moving up to 3.7 km away from breeding and source populations, and some Pacific tree frogs were observed up to 10 km away, found in the volcano's crater (Crisafulli et al., 2005b). The ability to be highly mobile and adaptable to changing biophysical conditions are likely important characteristics leading to their successful establishment on the Pumice Plain.

A. boreas prefers ponds and lakes for breeding, as these areas have less riparian vegetation, and shallow areas with warm temperatures that are suitable conditions for egg-laying and rapid larval development. The ponds and Spirit Lake had warmer temperatures than seeps and wallows, and *A. boreas* was only observed in these two habitats. *A. boreas* is also highly mobile and individuals marked at Mount St. Helens have been observed up to 5.7 km away from breeding areas (Crisafulli et al., 2005b). Estimation counts were conducted during VES surveys, >10 million recently metamorphosed toads were observed at two of the study ponds. These individuals disperse from the warm shallow waters of the ponds and lakes to other areas. After dispersal from their natural waters across the Pumice Plain, *A. boreas* metamorphs may travel several kilometers within a few weeks, usually following stream courses (Charlie Crisafulli, personal communication, 2013).

One curiosity is the absence of *Taricha granulosa* (Rough-skinned newt), which had been previously observed at Spirit Lake and in the riparian zone of streams on the Pumice Plain (Crisafulli et al., 2005b). *T. granulosa* was not encountered during my study. According to MacMahon and Andersen (1985), *T. granulosa* survived and bred in the blast zone, and bred in more areas than any other amphibian species present post-eruption. *T. granulosa* is highly adaptable and mobile, and it is interesting that this species wasn't encountered in this study; all habitats would be acceptable as this species can tolerate a wide range of conditions (Karlstrom, 1986). Increased sampling may have increased the likelihood of detection of this species.

Another species not encountered in my study is *Ambystoma macrodactylum* (Long-toed salamander). This species was historically present before the 1980 eruption, but during post-eruption investigations has been found in two locations in the blast area (Crisafulli et al., 2005b). The most likely reasons for why this species was not detected during my study are lack of source populations within a reasonable distance.

Breeding versus Presence

The ponds and Spirit Lake conveyed a different story than the other habitats sampled, with all five species of amphibians present at the pond habitat, and four of the five species present at Spirit Lake. The percentage of breeding amphibians at the ponds was slightly lower than Spirit Lake, due to the presence of *R. aurora* at the ponds, with no evidence of breeding detected (i.e. no captured tadpoles).

It is evident from this study that ponds serves as critical breeding habitat for all four amphibian species. The varied habitat conditions (e.g., vegetation, temperature, high dissolved oxygen and conductivity), all served as important biophysical parameters. *A. gracile* was not found breeding in Pond West, which was shallow (117 cm max depth) and likely either dries up by late summer and/or freezes through in the winter, thus preventing successful establishment of this species. *R. aurora* was not found breeding in any survey location, although adult male and female animals were observed, and a breeding population could appear in the future.

Amphibian Richness

Lake and ponds had the highest species richness values. Spirit Lake and the three ponds provide warm shallows preferred by *A. boreas, P. regilla, R. cascadae, R. aurora,* and deeper sections what would be preferred by *A. gracile* (Stebbins 1951; Karlstrom 1962). There is also sufficient aquatic vegetation used by P. regilla and A. gracile during ovipositioning. Lakes had four species present, but each in low numbers, except for *A. boreas*. The wallows and seeps contained only two species, as it doesn't have the depth *A. gracile,* or area that *A. boreas* prefers.

Larval Abundances

A. boreas is the most abundant species on the Pumice Plain, with more than 4,000 individuals captured (AFT 1 & 2) at the ponds and millions observed during the pond visual surveys, followed by more than 700 captured in Spirit Lake. Pond West and Duck Bay East contained the majority of the *A. boreas* individuals. *A. boreas* congregated to the east side of Duck Bay, where the combination of logs and the shallow perimeter provided a warm protected environment. The shallow depth and high temperatures created favorable conditions in the lake and pond habitats for *A. boreas* during the breeding season (Karlstrom, 1996). The high numbers encountered could be due to the fact that this species was one of the first colonizers of the Pumice Plain after the eruption, and it's been found to remain stable in ponds after disturbances like fire (Hossack & Corn, 2007; Hossack & Pilliod, 2011). *A. boreas* favors the change in increase light after trees are removed. The 1980 eruption removed virtually all vegetation, much like the results of forest fire. These species have been shown to colonize ponds that had not been utilized before (Hossack & Corn, 2007; Hossack & Pilliod, 2011), thus disturbance has allowed for this species to flourish in the past 33 years at MSH. The high numbers of *A. boreas* in Spirit Lake, compared to low overall numbers for other amphibian species, could be due to the fact that toads contain toxins which deter fish predation.

A. gracile experienced low capture rates at all lake and pond sites. One possible reason for low abundance values in Spirit Lake is due to the non-native species, *Oncorhynchus mykiss*. Fish may cause amphibian declines as they can compete, consume, carry disease, and harm native amphibians (Drost & Fellers, 1994; Kiesecker, 2003; Kiesecker, Blaustein, & Miller, 2001b). Amphibian species are sensitive to alien predators, as most native species do not have evolutionary history to adapt and function in the presence of non-native species (Kats

& Ferrer, 2003). This lack of adaption to invasive species typically leads to declines. Many field surveys have shown negative correlations between alien predators and native amphibian populations, including *P. regilla*, many *Rana sp., Litoria sp., Ambystoma macrodactylum,* and *Taricha torosa* (Mathews et al., 2001; Knapp & Mathews, 2000; Jennings & Hayes, 1985; Gillespie, 2001, Funk & Dunlap, 1999; and Gamradt and Kats, 1986). Non-native's like trout and bullfrogs consume native amphibians at all life-stages, and cause an increase in predatory stress. Fish *(Oncorhynchus spp.*) cause many other negative effects including reduced activity, decreased survivorship, and reduced metamorph size (Kiesecker & Blaustein 1997, 1998; Gillespie, 2001). Studies done in Yosemite National Park document a decrease in the Mountain yellow-legged frog, once non-native trout are introduced (Knapp & Matthews, 2000). Subsequently, in another study, an increase in the Mountain yellow-legged frog was observed after non-native fish were removed (Knapp, Boiano & Vredenburg, 2007).

Other studies have shown that predation by *O. mykiss* decreased populations of *A. gracile* and showed a decrease in larval size and survivorship, and habitat use alteration (Tyler et al., 1998).

Research done by Slater (1955) documented the presence of *A. gracile* in Spirit Lake, pre-eruption and Crisafulli (unpublished data) found this species in that lake in 1983. Crisafulli et al. (2005b) found that *A. gracile* wasn't established in the Debris Avalanche zone until nine years post-eruption, presumably due its low dispersal capabilities.

Wallows were relatively abundant, and Wallow 6 was the most productive during both trapping sessions, yielding 55% of the total captures for the wallows. Depth, size, and temperature could have been a factor, as it had the greatest area and depth of the wallows, with a depth of 38 cm, and with a median temperature of 10.53° C, as water temperatures ranged from 7.3-13.18 °C in all wallows.

Based on the data collected from the small sections of seep habitat, thousands of amphibians utilize these seeps as a whole, with *P. regilla* and *R. cascadae* utilizing this habitat exclusively during July and August. It is highly likely that *A. boreas* juveniles and subadults disperse to these areas in the latter months. From VES surveys, Seep two is the most productive of the seeps with over 100 tadpoles captured on 16-July-2013.

Rana aurora was once the dominant Anuran species on the Pumice Plain, post eruption (C. Crisafulli, personal communication, 2013). It is possible that competition by *R. cascadae* has displaced *R. aurora's* distribution west into the Debris Avalanche zone, where hundreds of ponds were created after the eruption. This area contains a robust population of *R. aurora* (Crisafulli et al. 2005b). Studies conducted in 1999-2000 by Crisafulli and others (2005b) found *R. aurora* present in˜85 of the 117 (73%) ponds surveyed in the Debris Avalanche zone (Marietta complex). In terms of breeding, *R. aurora* was found actively breeding in 40 of the 117 ponds (34%).

Biophysical Data and its Effect on Amphibian Preference

Some substantial differences and similarities existed among sites within each habitat type, and also between habitat types and this were true for all variables (size, depth, substrate, water quality, and vegetation). Similarities existed between Spirit Lake and the ponds, both having fine sediment substrates, higher water temperatures, pH and DO, compared to seep and wallow habitats. Similarities existed for conductivity at all sites, with most readings between 130-185 µs/cm, with the exception of Seep 1, Pond Middle, and Pond West, which were considerable higher (367-495 µs/cm). Wallows and seeps had small gravel and sand substrates. Wallows had the coolest water temperatures, with seeps slightly higher in average temperatures.

Conductivity (µS/cm)

According to Klaver, Peterson, and Tatla (2013) high levels of conductivity positively corresponded to high levels of occupancy for the boreal toad (*Anaxyrus boreas*). The results of their study are similar to other findings conducted by Peterson et al. (1991), in which they found no *A. boreas* in areas with low conductivity, and a large amount of breeding sites that were associated with high conductivity ponds. This is also observed on the Pumice Plain, where high abundances of *A. boreas* were found breeding in ponds with high conductivity (range=475-495); Pond Middle and West). In contrast, at Pond East, *A. boreas* was not observed breeding (absence of tadpoles) and the conductivity reading was 10µS/cm, the lowest reading on the Pumice Plain.

In other research, conductivity was positively related to low abundances of amphibians contracting virulent pathogens. Conductivity is important in osmoregulation and larval development. Higher levels of conductivity may strengthen amphibian populations and allow them to cope with other anthropogenic stresses, like disease.

Dissolved Oxygen (mg/L)

Dissolved oxygen levels are important to amphibians' physiological processes. Optimal levels for amphibians are greater than 4 mg/L for most amphibians, though there are exceptions (Sparling, 2009). The pond habitat was saturated with oxygen, with readings ranging from 7.82-10.22 mg/L. Spirit Lake also had a higher reading than other sites on the

Pumice Plain with 8.49 mg/L. This could be a factor for *A. boreas* as it has been found to prefer highly oxygenated environments (Savage, 1952). In contrast, the wallows were anoxic (with 7 of the 14 wallows < 3 mg/L) compared with other sites and habitats. Some amphibian species (*P. regilla and R. cascadae*) seem to tolerate this type of habitat, which could explain why they use all habitats on the Pumice Plain.

PH values

All sites sampled were in the range (pH 4-8) of amphibian tolerance, except for Pond Middle and West (Warner and Dunson, 1998). Pond Middle and West were slightly elevated above this range of tolerance (pH 9-10). These higher pH values could be due to the higher amounts of aquatic vegetation in these two ponds or the mineral content in the substrate. Time of day could have effected these values, as the act of photosynthesis causes an increase in pH.

Temperature and Vegetation

The ponds appeared to lack ground water influence during the summer drought months and had very little topographic or vegetative cover to block sunlight, resulting in warm water temperatures. Considerable evaporation occurred in the ponds, which lack outlet channels, over the six weeks of surveys, and this reduction in water depth and area coupled with increased solar gain undoubtedly were factors contributing to higher temperatures. Larval amphibians prefer warm shallow waters, and these conditions were observed in pond and lake study sites. *A. boreas* was present in significantly high numbers, and it is clear that the warm shallows are important in this species reproductive strategy, as they can escape predators in fish inhabited lakes, and metamorphose quickly. Boulders and cobbles along the riparian zone provide shelter, where vegetation is sparse, and I observed many *A. boreas* metamorphs finding shelter beneath these rocks. It seems that large amounts of riparian vegetation are not imperative for this species.

P. regilla and *R. cascadae* disperse from other areas on the Pumice Plain, as metamorphs and utilize the seep and wallow habitats as they provide cooler waters, adequate food, and cover for developing amphibians. These sites had greater plant abundances and amount of species at all study sites for perennial forbs and grasses, compared to pond and lake habitats.

Depth

The deepest habitat was the ponds and Spirit Lake, which also contained shallow breeding grounds for ovipostion. This variation in depth makes it favorable for lentic breeding amphibians. Shallower habitats, like the seeps and wallows were almost entirely occupied by *P. regilla* and *R. cascadae. R. aurora* and *A. gracile* were present only in these deeper habitats.

Summary

In summary, how species respond to catastrophic disturbances is not widely studied. Overall, amphibians have been resilient to the 1980 eruption of Mount St. Helens, with rapid colonization by *A. boreas, P. regilla,* and *R. cascadae.* All of these species survived the eruption in adjacent areas, as they would have been protected under snow and ice (Crisafulli et al., 2005b), although is it assumed that no amphibian species would have been able to withstand the amount of debris deposited and the high temperatures of the eruption on the Pumice Plain itself. These amphibian species were present only three years post-eruption (early immigrants), with some visual sightings only 1-2 years post-eruption. The combination of high vagility and fecundity, coupled with suitable habitat genesis were likely the most important factors underlying this rapid response. *A. boreas* was not as widespread as *P. regilla* or *R. cascadae*, but this species has amazing reproductive capabilities, with millions of tadpoles and metamorphs observed during my study. The pond habitat provides warm, shallow water, food availability, cover; and lack of predators that enable these large populations to persist. Garter snakes, (*Thamnophis spp*.) were only observed four times while conducting surveys at the pond habitats. Amphibians on the Pumice Plain will likely persist at high abundances until forest cover reduces food supply by altering light regimes and overall productivity, or predators or pathogens cause populations to fall.

Some species that previously had colonized post-eruption have shifted their distribution and or may have lost their fragile foothold. *Taricha granulosa* and *Rana aurora* were once present in high numbers on the Pumice Plain after the eruption, whereas now they are hardly present or altogether absent. Another historical species that was present pre-eruption is the Long-toed salamander (*Ambystoma macrodactylum*), which was also not observed during this study. This species could be a potential colonizer in the future.

Species compositions will likely change on the Pumice Plain, as the habitat continues to evolve during the course of succession. Thirty-three years post eruption; many habitats exist that have conditions favorable to amphibian persistence. Understanding amphibian habitats and conditions, as well as how amphibians adapt to natural and anthropogenic disturbances could provide possible changes in management strategies for these species following catastrophic events.

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APPENDICES

APPENDIX A

MOUNT ST. HELENS AMPHIBIAN MONITORING PROJECT

AQUATIC FUNNEL TRAPPING & VISUAL SURVEYING PROTOCOLS

Mount St. Helens Amphibian Project-
Aquatic Funnel Trapping & Visual Surveying Protocol

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Overview/Inventory

A combination of sampling techniques will be used to monitor amphibians in the Pumice Plain region of Mt. St. Helens National Volcanic Monument. The goal of this study is to determine the presence and distribution of amphibian populations as well document the vegetative habitats, and determine which habitats are used for breeding amphibians. Techniques will vary depending on habitat, including size and depth. Five different habitats will be assessed including seeps, streams, ponds, wallows, and a portion of Spirit Lake. Aquatic funnel traps will be used to sample amphibians in pond/lake ecosystems and visual encounters will be used at all habitats. Traps will be placed in a variety of habitat types defined by water depth and vegetation. Each pond will be sampled using 16 or more collapsible minnow traps (Memphis Net and Twine Co. Model RN10) for two consecutive days every week from approximately mid-July through mid-August. Traps will be checked each morning and captured animals will be processed in accordance with the Funnel Trapping Code Form and recorded on the Funnel Trapping Data form.

Habitat Types

Seeps -Can be defined as an area where a freshwater spring emerges from the ground and keeps the area moist and wet. These areas tend to be slow moving water or still water habitats. Visual surveys and dip-net surveys will used.

Wallows- These areas were created by elk, and resemble small potholes, that later filled with water. These areas are marshy wetland type habitats. Visual surveys and dip-net surveys will be used.

Streams- Streams surveyed will be faster moving streams with low to high gradient riffles that will flow into Spirit Lake. Visual surveys and dip-net surveys will be used.

Ponds/Lakes- These are defined as deeper water habitats where a combination of visual surveys, dip-net surveys, and aquatic funnel trapping will be used.

Surveys

Visual Surveys/Dip-net Surveys- Will be conducted at all test site habitats. When conducting Visual Encounter Surveys (VES), three survey zones will be observed: waterline, shallow littoral zone, and the shore zone including any riparian vegetation. The waterline is the physical line where the waterline meets land. The shallow littoral zone is any are that is safely wadable out from the shoreline (typically less than 1 meter deep). The shore zone is approximately 3 meters outward from the pond, and includes any vegetation or logs. When surveying a pond or lake habitat, the waterline should be surveyed first, then the littoral zone, and finish with the shore zone. Dip-nets may be used in the littoral zone and used in a sweeping motion back and forth at 5 meter intervals, making sure to sweep down 2-3 cm into the bottom of the pond substrate. Look thoroughly through the sediment in the net, making sure not to miss any amphibians. When surveying a homogenous habitat like a seep, a zigzagging motion should be walked slowly looking for amphibian species. When counting numerous tadpoles like Bufo boreas (Western Toad), estimate numbers by counting in 100's or 1000's.

Aquatic Funnel Trapping- Sixteen or more traps will be installed within the shallow littoral zone of each pond. Traps will be distributed around the perimeter of the pond in water depths between 20 and 60 cm and in each of the vegetation types present. Areas with no vegetation and too shallow of depth will not be represented as trap station areas. Stations will be marked with pin flags or flagging that has the trap number clearly written with Sharpie pen. Traps will be placed next to station markers or flagging with care to ensure that the trap is positioned flat on the pond bottom and that the entrance holes are below the water surface. Make sure all zippers are closed and each trap is checked for holes after each trapping session, so repairs can be made. Flagging should be tied to each trap string with the trap number clearly written on it. Traps should be set out in the morning of first day of trapping and checked the next day, preferably in the morning or early afternoon, if possible.

Checking Traps—Traps should checked in numerical order, starting with the lowest numbered trap and working up until finished with all traps. One crew member should carefully approach the trap station, lift the trap from the water, and bring the trap back to the shoreline to process the contents with the other crew members. Crews should have two buckets and several smaller containers with lids to place animals into during processing. Fill buckets with water and place all captured animals into a bucket. Have reference materials (species accounts and keys) on hand and begin identifying and measuring animals, and recording information on the data form according to the Code Sheet. **When recording data make sure the recorder repeats the data back to the processor for accuracy.**

As animals are processed place them into the **second bucket**. If an animal cannot be identified by the crew it should be retained in a sample container with lid and placed in shade until others examine and determine the animal's identity. Once all animals and macro invertebrates are processed, inspect traps for broken zippers, tears in netting, and unraveled stitching in corners. Move onto next trap. When your crew has finished trapping, go over trap check-off list to ensure that no traps were missed. Double check to make sure the data pages are finished and complete.

APPENDIX B

MSH FUNNEL TRAPPING CODE SHEET

MSH AMPHIBIAN FUNNEL TRAPPING DATA FORM
CODE SHEET 2013

Listed below are instructions for completing data entry on the **Amphibian Funnel Trapping Data Form** and the accompanied **Continuation Form.**

1. TRAP NUMBER: Record the number assigned to the trap being checked.

2. SPECIES: Use four letter code of Latin binomial: the first two letters of the genus and the first two letters of the specific name. For example: Ambystoma gracile would be recorded as "**AMGR**". If no species are found write **"NSF"** under species column.

Species	Scientific Name	Code
Northwestern salamander	*Ambystoma gracile*	AMGR
Rough-skinned newt	*Taricha granulosa*	TAGR
Northern red-legged frog	*Rana aurora*	RAAU
Pacific tree frog	*Pseudacris regilla*	PSRE
Cascade Frog	*Rana cascadae*	RACA
Western toad	*Anaxyrus boreas*	ANBO

3. SEX: When possible indicate the gender of each individual captured as follows: **"M" =** male, **"F" =**female, or **"U"** = unknown.

4. LIFE STAGE: Categories will vary among species, but will include: **"AD" =** adult, **"SUB"=**sub adult, **"JUV" =** juvenile, **"LAR" =** larvae for salamanders and newts, **"NEO"** =neotenic varieties, **"TP" =** tadpole for frogs and toads. **"HATCH"**=hatchling, and **"TRANS"=**transformer. Note, **AD, SUB,** and **JUV** are metamorphosed individuals that vary by age. AD are sexual mature, SUB are larger than JUV and not sexually mature, and JUV are recently metamorphosed froglets/toadlets/salamanders.

5. NUMBER CAPTURED:	Record the number of animals captured. For metamorphosed frogs and toads and for larval, neotenic, subadult, and adult salamanders you will record one. For tadpoles record the total number for each species captured in trap.
6. TOTAL LENGTH (TL):	Measured in millimeters (mm) on the ventral surface from the tip of the snout to the tip of the tail. Record length measurements for all individuals captured, except tadpoles.
7. SNOUT TO VENT (SVL):	Measure in millimeters (mm) on the ventral surface from the tip of the snout to the cloaca. Record the snout to vent length (SVL) on all larval and adult salamanders and newts.
8. MACROINVERTEBRATES:	See the macro invertebrate data form. Record the number of each species per trap. Use the keys and ID books to determine species (by common name).
9. COMMENTS:	Use space to make any remarks regarding the captures or the condition of the trap.

APPENDIX C

HABITAT LOCATION: GPS, ELEVATION, AND SURVEY TYPE

Habitat Location: GPS, Elevation, and Survey Type

Habitat Type	Site	WGS84 UTM Zone 10T		Elevation (m)	Survey Type & Number of Surveys	
		Northing	Easting		AFT	VES
Wallow	W-1	563836	5121840	1097.6	2	2
	W-2	563833	5121843	1097.6	2	2
	W-3	563828	5121846	1097.3	2	2
	W-4	563830	5121847	1092.7	2	2
	W-5	563827	5121850	1097.0	2	2
	W-6	563837	5121849	1095.8	2	2
	W-7	563815	5121843	1097.3	2	2
	W-8	563814	5121851	1099.7	0	2
	W-9	563815	5121861	1097.0	2	2
	W-10	563819	5121850	1095.8	2	2
	W-11	563822	5121864	1093.3	2	2
	W-12	563802	5121854	1097.3	2	2
	W-13	563803	5121862	1101.5	2	2
	W-14	563805	5121867	1096.4	2	2
Seep	S-1	564228	5121700	1091.5	0	2
	S-2	564083	5121785	1093.6	0	2
	S-3	563636	5121692	1101.9	0	2
	S-4	563550	5121741	1107.9	0	2
	S-5	563382	5121702	1111.0	0	2
Pond	East	563461	5123034	1062.5	2	2
	Middle	563277	5123088	1054.6	2	2
	West	563128	5123118	1054.0	2	2
Lake	DB-East	565919	5121654	1046.7	2	2
	DB-Middle	565684	5121851	1051.3	2	0
	DB-West	565588	5122127	1037.5	2	0

APPENDIX D

HABITAT DESCRIPTIONS BY SURVEY SITE

Habitat Description by Study Site

Habitat descriptions by amphibian study site on the Pumice Plain, at Mount St. Helens National Volcanic Monument. Substrate categories are as follows: F (Fines <0.5 mm), S (Sand, 0.5-2 mm), SG (Small Gravel, 3-10 mm), and LG (Large Gravel, 11-100 mm.) Water quality data was collected on August 21st, 2013, using YSI multi-parameter water quality monitor, Model 650 MDS. Dash represents no data collected at that site.

Habitat	Site	Area Sampled (m^2)	Depth (cm)	Substrate	Temp (℃)	pH	Conductivity (µS/cm)	DO (mg/L)	DO % Saturation
Wallow	W-1	4.0	16	SG	10.56	6.30	151	2.21	19.8
	W-2	3.7	18	SG	10.6	6.31	161	1.53	13.8
	W-3	3.5	15	SG	11.57	6.59	169	1.37	12.6
	W-4	9.4	24	SG	10.29	6.49	147	3.15	28.1
	W-5	1.2	12.5	SG	13.18	6.18	166	3.08	29.4
	W-6	21.0	38	S	10.65	6.28	150	2.89	26.0
	W-7	3.7	22.5	S	10.7	6.63	149	1.58	14.3
	W-8	4.6	12	S	-	-	-	-	-
	W-9	23.1	24	S	10.73	6.77	151	3.69	33.2
	W-10	8.2	21	SG	8.96	6.79	141	2.54	22.0
	W-11	9.0	35	S	7.83	6.58	139	4.91	41.4
	W-12	3.7	21	S	8.18	6.87	138	2.15	18.4
	W-13	2.3	22	S	7.3	6.73	136	4.43	36.5
	W-14	8.6	28	SG	7.52	6.75	135	4.57	38.1
Seep	S-1	4830.0	12.7	SG	7.38	7.61	367	7.47	62.3
	S-2	1870.5	20	SG	13.62	6.29	136	5.25	50.8
	S-3	1477.1	8	SG	13.28	6.57	132	5.52	52.9
	S-4	436.6	7	SG	15.45	6.89	140	6.13	61.4
	S-5	510.5	20	LG	12.25	6.77	185	4.05	37.8
Pond	East	9074.0	160	F	21.78	7.02	10	7.82	89.3
	Middle	14,102.0	230	F	22.19	10.04	495	10.02	115.1
	West	4,075.0	117	F	27.54	9.56	475	10.22	129.7
Lake	DB-East	710.0	100	F	-	-	-	-	-
	DB-Middle	688.0	90	F	-	-	-	-	-
	DB-West	720.0	110	F	19.46	8	139	8.49	92.4

APPENDIX E

VEGETATION DATA: SPECIES AND PERCENT COVER

Species, Lifeform and Percent Cover by Study Site

Species Prensence and percent cover of vegetation at each amphibian study site. Riparian and aquatic vegetation lifeform codes are F (Forb), G (Grass), S (Shrub), FN (Fern and fern allies), and B (Bryophyte). Dash represents no species found.

		Riparian Vegetation			Aquatic Vegetation		
Habitat	Name	Taxa	Lifeform	% Cover	Taxa	Lifeform	% Cover
Wallow	W1-W14	*Salix sitchensis*	S	60	—	—	—
		Carex sp.	G	15	—	—	—
		Racomitrium canescens	B	10	—	—	—
		Juncus sp.	G	8	—	—	—
		Trifolium repens	F	7	—	—	—
Seep	S-1	*Racomitrium canescens*	B	40	—	—	—
		Salix sitchensis	S	25	—	—	—
		Juncus sp.	G	10	—	—	—
		Carex sp.	G	5	—	—	—
		Epilobium sp.	F	5	—	—	—
Seep	S-2	*Racomitrium canescens*	B	50	—	—	—
		Salix sitchensis	S	25	—	—	—
		Alnus crispa	T	25	—	—	—
		Equisetem arvense	FN	15	—	—	—
		Juncus sp.	G	10	—	—	—
Seep	S-3	*Salix sitchensis*	S	60	—	—	—
		Racomitrium canescens	B	30	—	—	—
		Alnus crispa	S	5	—	—	—
		Carex sp.	G	4	—	—	—
		Castilleja sp.	F	1	—	—	—
Seep	S-4	*Salix sitchensis*	S	50	—	—	—
		Racomitrium canescens	B	30	—	—	—
		Juncus sp.	G	10	—	—	—
		Carex sp.	G	5	—	—	—
		Equisetem arvense	FN	5	—	—	—
Seep	S-5	*Salix sitchensis*	S	50	—	—	—
		Racomitrium canescens	B	20	—	—	—
		Carex sp.	G	15	—	—	—
		Juncus sp.	G	10	—	—	—
		Epilobium sp.	F	5	—	—	—
Pond	East	*Salix sitchensis*	S	60	*Juncus sp.*	G	5
		Juncus sp.	G	5	—	—	—
Pond	Middle	*Salix sitchensis*	S	50	*Potomagetan natans*	F	40
		Juncus sp.	G	5	*Juncus sp.*	G	5
		Equisetum arvense	FN	5	*Elodea canadensis*	F	10
Pond	West	*Salix sitchensis*	S	70	*Juncus sp.*	G	15
		Juncus sp.	G	5	—	—	—
		Equisetum arvense	FN	5	—	—	—
Lake	DB-East	*Salix sitchensis*	S	75	*Potomagetan natans*	F	7
		—	—	—	*Ranunculus aquatilis*	F	2
Lake	DB-Middle	*Salix sitchensis*	S	5	*Ranunculus aquatilis*	F	5
Lake	DB-West	—	—	—	—	—	—

APPENDIX F

LARVAL CAPTURES PER TRAP NIGHT BY HABITAT AND STUDY SITE

Amphibian Larval Captures by Habitat and Study Site

			AFT Trapping Session 1						AFT Trapping Session 2					
			PSRE	RACA	ANBO	AMGR		Total	PSRE	RACA	ANBO	AMGR		Total
Habitat	Site	Statistic	TP	TP	TP	LAR	NEO	Captures	TP	TP	TP	LAR	NEO	Captures
Pond	East	TOTAL	49	0	0	7	3	59	15	0	0	1	5	21
		MEAN	3.06	0	0	0.44	0.12	3.69	0.94	0	0	0.06	0.31	1.31
		ST DEV	4.07	0	0	0.63	0.54	3.84	1.95	0	0	0.25	0.87	1.96
		RANGE	0-13	0	0	0-2	0-2	1-13	0-7	0	0	0-1	0-2	0-7
	Middle	TOTAL	44	4	147	5	5	205	13	1	23	2	5	44
		MEAN	2.75	0.25	9.19	0.31	0.31	12.81	0.87	0.13	1.50	0.13	0.33	2.75
		ST DEV	2.62	0.77	25.63	0.48	0.70	26.41	0.90	0.00	9.87	0.00	0.50	4.98
		RANGE	0-9	0-3	0-104	0-1	0-2	1-110	0-3	0-1	0-19	0-1	0-2	0-20
	West	TOTAL	495	12	2503	0	0	3010	177	1	1533	0	0	1711
		MEAN	30.94	0.75	294.47	0	0	188.13	19.70	0.11	170.33	0	0	190.11
		ST DEV	17.21	0.93	138.18	0	0	140.32	7.83	9.45	143.24	0	0	148.20
		RANGE	10-74	0-3	6-509	0	0	16-526	9-35	0-1	8-439	0	0	17-458
Wallow	W-1	TOTAL	11	0	0	0	0	11	4	0	0	0	0	4
	W-2	–	7	0	0	0	0	7	11	0	0	0	0	11
	W-3	–	0	0	0	0	0	0	0	0	0	0	0	0
	W-4	–	1	4	0	0	0	5	0	1	0	0	0	1
	W-5	–	7	0	0	0	0	7	–	–	0	0	0	–
	W-6	–	33	22	0	0	0	55	12	16	0	0	0	28
	W-7	–	14	0	0	0	0	14	7	0	0	0	0	7
	W-9	–	0	0	0	0	0	0	0	0	0	0	0	0
	W-10	–	0	0	0	0	0	0	3	0	0	0	0	3
	W-11	–	0	0	0	0	0	0	0	0	0	0	0	0
	W-12	–	0	0	0	0	0	0	0	0	0	0	0	0
	W-13	–	0	0	0	0	0	0	0	0	0	0	0	0
	W-14	–	0	0	0	0	0	0	0	0	0	0	0	0
	W1-W14	TOTAL	73	26	0	0	0	99	37	17	0	0	0	54
		MEAN	5.61	2.00	0	0	0	7.62	3.08	1.42	0	0	0	4.50
		ST DEV	9.55	6.11	0	0	0	28.37	4.52	6.40	0	0	0	8.19
		RANGE	0-33	0-22	0	0	0	0-55	0-12	0-16	0	0	0	0-28
Lake	DB-East	TOTAL	6	1	700	1	1	709	4	1	1426	3	1	1435
		MEAN	0.46	0.07	53.85	0.07	0.07	54.54	0.31	0.08	109.70	0.23	0.08	110.38
		ST DEV	0.45	0.00	402.41	0.00	0.00	193.94	0.58	0.00	820.70	0.00	0.00	396.20
		RANGE	0-2	0-1	0-698	0-1	0-1	0-700	0-1	0-1	0-1423	0-3	0-1	0-1429
	DB-Middle	TOTAL	1	0	0	0	0	1	1	0	0	1	0	2
		MEAN	0.08	0.00	0.00	0.00	0.00	0.08	0.08	0.00	0.00	0.08	0.00	0.15
		ST DEV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
		RANGE	0-1	0	0	0	0	0-1	0-1	0	0	0-1	0	0-1
	DB-West	TOTAL	1	0	0	0	0	1	1	2	3	2	0	8
		MEAN	0.08	0.00	0.00	0.00	0.00	0.08	0.08	0.15	0.23	0.15	0.00	0.62
		ST DEV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	1.18	0.00	1.45
		RANGE	0-1	0	0	0	0	0-1	0-1	0-2	0-2	0-1	0	0-5