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Occupancy of Stream-Associated Amphibians within the Interstate 90 Snoqualmie Pass Corridor

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OCCUPANCY OF STREAM-ASSOCIATED AMPHIBIANS WITHIN THE

INTERSTATE 90 SNOQUALMIE PASS CORRIDOR

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by

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ABSTRACT

OCCUPANCY OF STREAM-ASSOCIATED AMPHIBIANS WITHIN THE

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Detection of stream-associated amphibians in visual encounter surveys is challenging due to their cryptic nature; however, occupancy models were developed to deal with these detectability problems and provide estimates of occupancy that can also be related to site characteristics. Highway crossing risks and habitat isolation were mitigated for in recent construction of wildlife underpasses, where creeks cross Interstate 90 east of Snoqualmie Pass in Washington State. The effects of these restored underpasses on stream-associated amphibians were evaluated across 8 creeks, some with and some without restored underpasses, by comparing modeled occupancy of 3 amphibian species in stream habitat upstream, under, and downstream of Interstate 90. The amphibians modeled in this study are Coastal Giant Salamander (*Dicamptodon tenebrosus*), Cascades Frog (*Rana cascadae*), and Coastal Tailed Frog (*Ascaphus truei*). Multiple visual encounter surveys were conducted in the 8 creeks over two years during July-September. Over all surveys, *D. tenebrosus*, *R. cascadae*, and *A. truei* had detection probabilities of 0.66, 0.51, and 0.39/survey, respectively. Average occupancy probabilities were similar among these 3 species: 0.54/survey for *D. tenebrosus*, 0.55/survey for *R. cascadae*, and 0.52/survey for *A. truei*. Creek section occupancy model estimates support the use of underpass-culverts by all three amphibians in this study. Although highway underpass renovation occurred fairly recently, *R. cascadae* and *D. tenebrosus* are already being found within newly completed underpasses with rock substrate that matches the surrounding habitat. Recommended features that should be incorporated into future crossing structures to enhance connectivity between amphibian populations in the I- 90 Snoqualmie Pass East Project include (1) incorporating rock substrate that mimics surrounding stream habitat as much as possible, (2) planting native vegetation that will eventually provide canopy cover, and (3) manipulating the creek's overall slope or gradient as little as possible, as this will retain vital pools and small waterfalls.

Key words: Coastal Giant Salamander, *Dicamptodon tenebrosus*, Cascades Frog, *Rana cascadae*, Coastal Tailed Frog, *Ascaphus truei*, occupancy model, road ecology, culverts, Snoqualmie Pass, Washington

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Amphibians

During the last few decades, amphibians worldwide have experienced significant population declines, including extirpation of species. One third of global amphibian species are considered to be in jeopardy (Stuart et al. 2004). The average annual amphibian occupancy probability in ponds and similar habitats in the United States declined by 3.7 % from 2002 to 2011 (Adams et al. 2013). Occupancy of amphibian species on the International Union for Conservation of Nature's (IUCN) red-list declined at an even higher rate of 11.6% per year (Adams et al. 2013). Anthropogenic factors have been implicated in these declines, which include habitat loss and degradation, introduction of exotic and invasive species, pollution primarily from agricultural runoff, and unsustainable use (Gibbons et al. 2000). Disease and global climate change are also threats to amphibian survival (Gibbons and Stangel 1999; Klesecker et al. 2001). Amphibians are considered especially susceptible to contaminants and changes to their habitat conditions (Cauble and Wagner 2005). As terrestrial ectotherms, they are sensitive to changes in environmental temperatures and as semi-aquatic animals their permeable skin allows for gas exchange, rather than being solely reliant on internal lungs for respiration. This skin permeability can make amphibians particularly vulnerable to harmful chemicals introduced into the environment (Gibbons and Stangel 1999;

Cauble and Wagner 2005). The amphibian chytrid fungus has been implicated in multiple local population extinctions in Central America and Australia (Stuart et al. 2004). Many cases of amphibian mortality in North America have also been attributed to this chytrid fungus, as well as to other infectious diseases and water molds (Chestnut et al. 2014). Ultraviolet B radiation (UVB) is a growing concern for amphibians especially as the ozone layer in the atmosphere continues to be depleted. Amphibian eggs and hatchlings are fully aquatic and exposure to UVB radiation has been shown to have harmful effects on these life history stages (Gibbons et al. 2000; Kiesecker et al. 2001).

Amphibians' susceptibility to environmental changes has made them important indicator species of habitat health and quality and ecosystem integrity (Welsh and Ollivier 1998). This can be especially useful in areas that have been disturbed, and subsequently restored to more natural conditions, such as the creek habitats described in this study (Welsh and Hodgson 2008).

Road Impacts and Mitigation

Habitat loss and degradation is closely tied to the ecological impact of roads. The direct effect of roads that cross natural habitat is largely due to mortality caused by collision with vehicles during migration events, or mortality due to road construction (Jochimsen et al. 2004). This can be especially damaging to amphibian populations that migrate to and from wetland breeding sites (Ashley and Robinson 1996; Semlitsch 2000; Andrew et al. 2008; Glista et al. 2008). Forman and Alexander (1998) estimate that one million vertebrates are killed on roads every day in the United States alone. It is likely that of all vertebrate groups, amphibians are predominantly impacted by road-related mortality (Glista et al. 2008). Highest amphibian mortality rates are found at roadways in the vicinity of wetlands and ponds (Forman and Alexander 1998; Aresco 2003).

The indirect effects of roads are harder to determine. Dr. Richard Forman coined the term "road-effect zone" as the area affected by roadways on species, soil, and water (Forman and Alexander 1998). The reported width of this road-effect zone varies in distance and is under much debate, but studies show it can extend outward 100 m to 800 m on either side of a vehicle corridor (Forman and Alexander 1998; Andrews et al. 2008). Forman (2000) estimated that the public road system ecologically affects about one-fifth of the land area in the United States. The Pacific Northwest and Appalachian Mountains are both regions with high risks of habitat fragmentation within densely forested areas, due to the high road densities typical of highways and interstates (Riitters and Wickham 2003). Indirect road effects include both abiotic and biotic systems. The presence of roads can alter the physical environment, such as light, noise, temperature, sedimentation, density and moisture content of soil, dust, chemical influx due to road maintenance and land use by humans (Andrew et al. 2008; Trombulak and Frissell 2000).

These abiotic road effects can alter to the biotic ecosystem by: introduction and spread of exotic species, changes to reproductive success (e.g., spread of diseases), and changes in animal behaviors (e.g., road avoidance) (Reh and Seitz 1990). Roadways often become barriers to population connectivity and gene flow because many species are either unwilling or unable to cross major roads (Reh and Seitz 1990). These barriers lead to habitat fragmentation and population isolation (Andrews 1990). The isolation of a population limits the genetic exchange between populations and as a result, leads to reduced genetic diversity. Populations with low genetic diversity are more susceptible to inbreeding and to outside threats and stressors prevalent in the road-affect zone (Andrews et al. 2008).

There are a number of mitigation methods that attempt to minimize the effect of roads on ecological systems. The most effective of these is to perform an ecological evaluation before construction planning to avoid critical habitats and natural wildlife corridors (Clevenger et al. 2002). Seasonal road closures or installation of animal crossing signs during predicted wildlife migration periods have also been effective (Seigel 1986). For preexisting roads that cannot be seasonally closed, road crossing structures may mitigate the impacts of habitat fragmentation. There are multiple forms these structures can take, such as tunnels, culverts, wildlife underpasses, expanded bridges, viaducts, and wildlife overpasses. Culverts, wildlife underpasses, and expanded bridges can be used in areas where hydrology is a concern. Open-bottom passages allow for natural streambed substrate to be retained or replicated to encourage animal use and provide transitional habitat for amphibians and other stream-dwelling species (Glista et al. 2009).

It has been found that differences in culvert dimensions, road width, type and variety of vegetation, and culvert overhang height can influence the intensity of wildlife use (Yanes et al. 1995). Expanded bridges and viaducts are useful for larger fauna. Wildlife overpasses are designed to allow animals to cross above traffic, mostly for large mammals, but the presence of natural vegetation on these structures can give a variety of species an intermediate habitat. Many of these structures include additional fencing or walls along the road that serve to guide animals to these crossing structures and avoid individual random crossing attempts (Glista et al. 2009).

Occupancy Modeling

Occupancy modeling is a method to determine abundance for species with detection probabilities of less than one (MacKenzie et al. 2002). Traditional presence/absence surveys often underestimate the population size and range of cryptic species, such as amphibians. Failure to find a cryptic species' does not prove that the species is absent. Using multiple survey events at the same site and the probability of failing to detect a species multiple times, occupancy modeling attempts to lessen the uncertainty inherent in traditional visual encounter surveys (MacKenzie et al. 2006). The output of this model gives an occupancy probability estimate, a species detection probability estimate, and any covariates that influence the occupancy and detection estimates. A detection probability is the probability that a species will be encountered in a study site given that the species does inhabit that site (MacKenzie et al. 2006). This detection probability is determined using data from repeated surveys of the same sites (MacKenzie and Royle 2005). This allows for the resolution of false absences. In this model, occupancy is defined as the probability that a random survey site is occupied by a species regardless of whether or not its presence was actually detected (MacKenzie et al. 2006). This analytical method is still quite new to the scientific community and was first proposed by MacKenzie (2002). While this model was created with pond/wetland amphibians in mind it has been used for a variety of species and habitats (MacKenzie et al. 2006; Groff et al. 2016). Other researchers have also used this model to determine species' occupancy and detection in stream and riverine habitats (Kroll et al. 2008; Anlauf-Dunn et al. 2014).

Unlike a General Linear Model, occupancy models use two types of covariates, detection and occupancy (MacKenzie et al. 2006). Detection covariates influence how effective surveys are at detecting the focal species, given that the species is in fact present. Occupancy covariates are factors that may influence the probability of a species occupying a specific site at any particular time. For example, different surveyors or different habitat complexities will affect how often a species is detected, but it will not affect whether or not the species is present at the survey site. Most occupancy covariates can also be used as detection covariates. Heavy canopy cover can affect a surveyor's ability to find the focal species while also affecting the occupancy of that animal, depending on its habitat preferences. Another unique feature of occupancy modeling is the ability to use the same covariate simultaneously for both detection and occupancy. As occupancy models are typically used for species that are often underrepresented in field surveys, these detection covariates can help mitigate the detectability problem by giving a probability estimate of how likely one is to detect a particular species, given that the species is present (MacKenzie et al. 2006).

Amphibian Use of Interstate 90 Snoqualmie Pass East Underpasses

The Washington State Department of Transportation has constructed a number of enhanced wildlife underpasses where creeks cross under Interstate 90 to the east of Snoqualmie Pass in order to restore connectivity among amphibian and other vertebrate populations (WSDOT 2017). The purpose of the present study was to assess the impact of these new crossing structures on amphibian populations. Determining the species detectability, occupancy probabilities, and habitat correlations of stream-associated amphibians using the new habitat opened up by these crossing structures, both underneath and downstream of Interstate 90 in the vicinity of Snoqualmie Pass, were the principal objectives of this study.

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CHAPTER II

JOURNAL ARTICLE

OCCUPANCY OF STREAM-ASSOCIATED AMPHIBIANS WITHIN THE INTERSTATE 90 SNOQUALMIE PASS CORRIDOR

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ABSTRACT-- Detection of stream-associated amphibians in visual encounter surveys is challenging due to their cryptic nature; however, occupancy models were developed to deal with these detectability problems and provide estimates of occupancy that can also be related to site characteristics. Highway crossing risks and habitat isolation were mitigated for in recent construction of wildlife underpasses, where creeks cross Interstate 90 east of Snoqualmie Pass in Washington State. The effects of these restored underpasses on stream-associated amphibians were evaluated across 8 creeks, some with and some without restored underpasses, by comparing modeled occupancy of 3 amphibian species in stream habitat upstream, under, and downstream of Interstate 90. The amphibians modeled in this study are Coastal Giant Salamander (*Dicamptodon tenebrosus*), Cascades Frog (*Rana cascadae*), and Coastal Tailed Frog (*Ascaphus truei*). Multiple visual encounter surveys were conducted in the 8 creeks over two years during July-September. Over all surveys, *D. tenebrosus*, *R.*

cascadae, and *A. truei* had detection probabilities of 0.66, 0.51, and 0.39/survey, respectively. Average occupancy probabilities were similar among these 3 species: 0.54/survey for *D. tenebrosus*, 0.55/survey for *R. cascadae*, and 0.52/survey for *A. truei*. Creek section occupancy model estimates support the use of underpass-culverts by all three amphibians in this study. Although highway underpass renovation occurred fairly recently, *R. cascadae* and *D. tenebrosus* are already being found within newly completed underpasses with rock substrate that matches the surrounding habitat. Recommended features that should be incorporated into future crossing structures to enhance connectivity between amphibian populations in the I- 90 Snoqualmie Pass East Project include (1) incorporating rock substrate that mimics surrounding stream habitat as much as possible, (2) planting native vegetation that will eventually provide canopy cover, and (3) manipulating the creek's overall slope or gradient as little as possible, as this will retain vital pools and small waterfalls.

Key words: Coastal Giant Salamander, *Dicamptodon tenebrosus*, Cascades Frog, *Rana cascadae*, Coastal Tailed Frog, *Ascaphus truei*, occupancy model, road ecology, culverts, Snoqualmie Pass

Introduction

The impact of roads on surrounding ecosystems is an evolving area of study, and whereas direct road mortality due to vehicle encounters or road construction has obvious impacts on animal populations (Jochimsen and others 2004), the indirect effects may be just as harmful (Forman and Alexander 1998; Andrews and others 2008). In the United States alone, one million vertebrates are reportedly killed on roads every day (Forman and Alexander 1998). Glista and others (2008) report that of all vertebrate groups, amphibians may be the most vulnerable to road mortality because they regularly migrate to and from wetland habitats during pre- or post-breeding migrations (Ashley and Robinson 1996; Semlitsch 2000; Andrew and others 2008). Not surprisingly, the highest amphibian road mortality rates are commonly found at roadways near wetlands and ponds (Forman and Alexander 1998; Aresco 2003).

The indirect effects of roads on ecosystems are more complex. It has been estimated that about one-fifth of the land area in the United States is ecologically affected by the public road system (Forman 2000). There are a number of indirect road effects including: changes in animal behaviors (for example, altered home ranges and movement patterns) and reproductive success (for example, noise pollution drowning out frog breeding calls), as well as changes in the physical environment such as changes in thermal conditions, levels of noise and light, soil moisture content and density, dust accumulation, patterns of surface-water run-off, increased sedimentation, and an influx of pollutants and invasive species (Andrew and others 2008). The area affected by the synergistic impact of these factors has been broadly termed the “road-effect zone” (Forman 2000). Some studies have shown that this road-effect zone can extend outward for 100 m on either side of a vehicle corridor (Forman and Alexander 1998). Additional stressors related to roads include alterations in the chemical environment due to road maintenance and use, as well as changes in anthropogenic land use adjacent to highways (Trombulak and Frissell 2000). Roads often lead to habitat fragmentation and isolation (Andrews 1990), and become barriers to population connectivity and gene flow because many species are either unwilling or unable to cross major highways (Reh and Seitz 1990). The subsequent fragmentation of populations may lead to reduced genetic fitness as a result of limited genetic exchange between populations. Smaller gene pools may also lead to populations that are more susceptible to inbreeding and outside threats and stressors, such as those mentioned above (Andrews and others 2008).

Highway structures such as tunnels, culverts, expanded bridges, viaducts, and wildlife under and overpasses can be constructed in order to mitigate and minimize the effect of roads on ecological systems (Glista and others 2009). However, the most effective mitigation measure is to perform an ecological evaluation prior to construction planning, to avoid critical habitats and natural wildlife corridors (Clevenger and others 2002). Wildlife underpasses, expanded bridges, and culverts can be used for amphibians and other stream-dwelling species. Culverts with open-bottom passages are preferred so that natural streambed substrate can be retained or replicated to encourage animal use and provide transitional habitat (Glista and others 2009). Differences in culvert dimensions, road width, type and variety of vegetation, and culvert overhang height can influence the frequency of wildlife use of these road-spanning structures (Yanes and others 1995).

As an integral part of the expansion of Interstate 90 (I-90) as it crosses the Cascade Mountains to the east of Snoqualmie Pass in Washington State, a number of new enhanced crossing structures (one extended bridge, one wildlife overpass, and a number of wildlife underpasses) are being added to aid connectivity among wildlife populations (WSDOT 2017a). These structures have been designed to mimic the natural habitat and are integrated into the major highway expansion design.

The present study examines the impact of the new crossing structures in the I-90 Snoqualmie Pass East corridor on local populations of the most common amphibian species by comparing amphibian usage between streams with restored crossing underpass habitat and streams with un-restored culverts. Typical visual encounter surveys (VES) of amphibians often suffer from low sampling accuracy and imperfect detection that may bias the resulting presence-absence estimates (Heyer and others 1994). However, applying occupancy estimation and modeling can overcome difficulties associated with this inherent low detectability (MacKenzie and others 2002). Occupancy models were first used for pond and wetland species, including amphibians. This methodology has been utilized by a number of amphibian researchers since its development (Adams and others 2013, Groff and others 2017). Occupancy modeling utilizes multiple survey events at the same site to estimate a species level of detection probability and a site occupancy probability, as well as determination of physical or environmental covariates that influence occupancy and detection (MacKenzie and others 2006). These models take into account that the failure to detect a cryptic species' presence does not prove the absence of that species (Bailey and Adams 2005).

In the present study, we survey for the detection-non-detection of amphibian species in stream habitat upstream, under, and downstream of both restored and un-restored underpasses in the I-90 Snoqualmie Pass East corridor. We also determine (1) the occupancy probability of amphibian species utilizing these highway crossing structures, (2) whether these occupancy probabilities differ between species and survey sites, and (3) what covariates may influence those occupancy probabilities. Adding detection and occupancy covariates to the models allow us to determine possible habitat or environmental features influencing species' occupancy. We predict that habitat features found to be influential to amphibian occupancy will be useful as guidance in current and new crossing structure design. Occupancy modeling survey designs suggest two or three surveys for each sampling unit should be sufficient (MacKenzie and Royle 2005); however, additional visits are often needed for cryptic species, such as amphibians (Thoms and others 1997).

Methods

Study Area

Interstate 90 is an East-West multi-lane highway that crosses the Cascade Mountain Range through the Okanogan-Wenatchee National Forest in Washington State. This highway crosses the Cascade Mountains at Snoqualmie Pass, where stream habitat that was formerly separated by the highway and by narrow bridges and culverts has been reconnected by a number of wildlife underpasses (WSDOT 2017a). Our study area consisted of 8 creeks, which had a mixture of restored and un-restored underpasses, east of the summit of Snoqualmie Pass: Gold Creek, Rocky Run, Wolfe Creek, Price Creek, Noble Creek, Swamp Creek, Cedar Creek, and the control creek, Mosquito Creek (Fig. 1).

Visual Encounter Surveys

Five creeks (Gold Creek, Rocky Run, Wolfe Creek, Price Creek, and Noble Creek) were surveyed at four creek sections: (1) a 30 m stream reach directly upstream of the highway, (2) the accessible section underneath the highway, (3) a 30 m stream reach directly downstream of the highway, and (4) a designated 30 m reference reach at a location at least 300 m upstream of I-90. Two creeks (Swamp Creek and Cedar Creek) could only be surveyed in a single section, a 30 m reach directly downstream of I-90, as other sections of these two creeks were on private land and were inaccessible. These 7 creeks are a mix of restored crossing structure sites and un-restored sites (Fig. 1). The control creek (Mosquito Creek), which is at least 2 kilometers away from the highway and does not pass under I-90, was surveyed at a single 30 m section. Each creek was surveyed multiple times between July and September in 2015 (4 to 11 surveys per creek) and 2016 (2 to 5 surveys per creek). The number of surveys conducted per site each year varied and were dependent on site accessibility. Two sites on Noble Creek and 3 on Price Creek that were surveyed in 2015 were inaccessible in 2016 due to

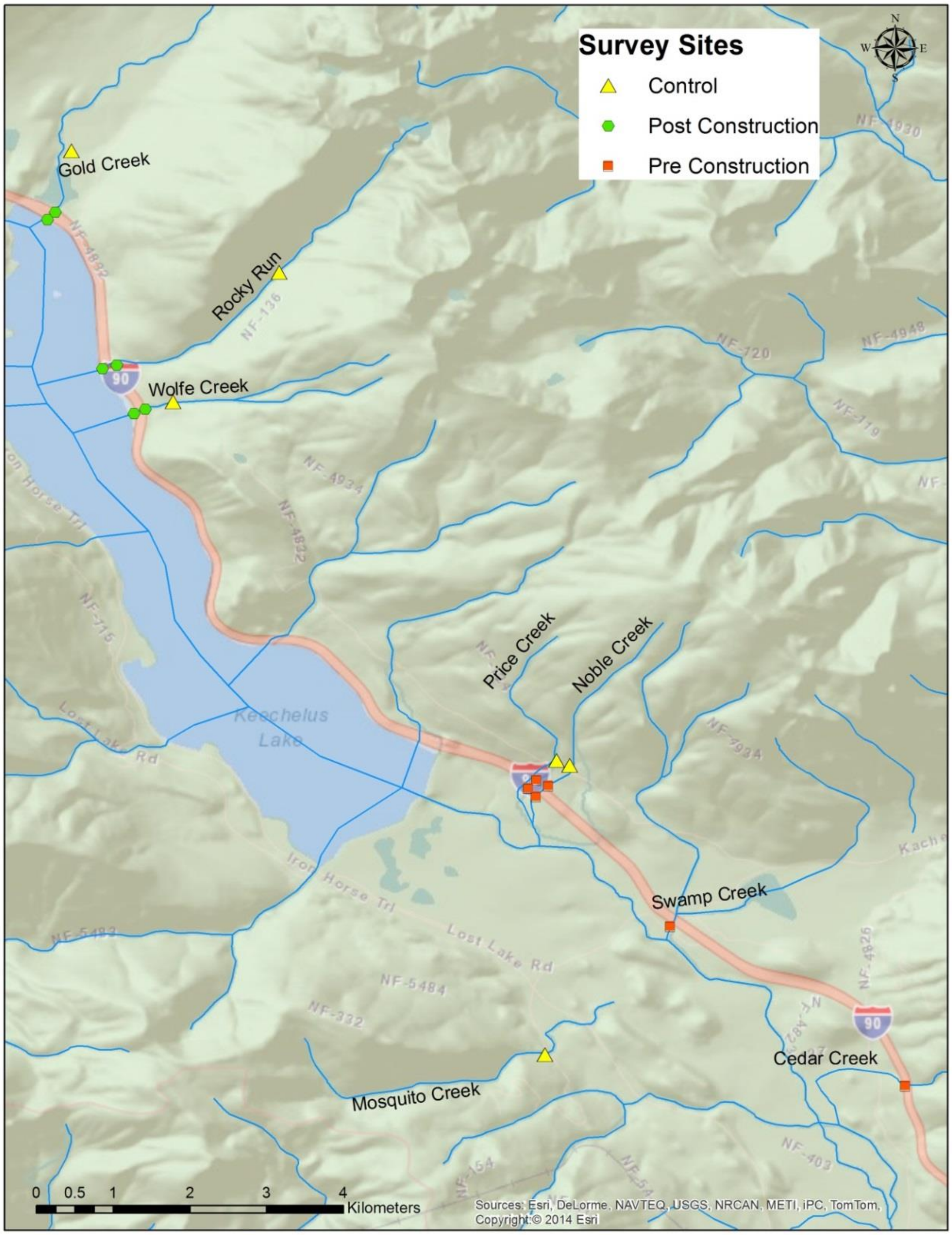

Figure 1. Amphibian survey sites near Snoqualmie Pass, WA, USA. Yellow triangles indicate reference reaches as well as the control creek (Mosquito Creek) without highway influence. Green circles indicate survey sites with restored wildlife underpasses. Orange squares indicate survey sites with unrestored culverts-underpasses that had not been replaced at the time of this study, 2015-2016.

construction of a new underpass and nearby overpass. A VES "soft-touch" technique was used for surveying all locations (Heyer and others 1994). This soft-touch technique involves lifting rocks that can be moved with little disturbance and searching the nearby vegetation. Data collected included enumeration of individuals of each species found.

Potential Visual Encounter Survey Error

Causes of potential error in VES of amphibians include (1) reduced detection probability as habitat complexity increases; (2) variable detection skill of individual surveyors; (3) variable detection related to differences in time of day, stream flow, and weather conditions; and (4) inherent variations in detectability of different species (Heyer and others 1994, Olson and others 1997, Bailey and Adams 2005). Although many of these sources of survey error are impossible to avoid, we provided similar training to all surveyors involved in this study and conducted most surveys under similar light levels and weather conditions. Nevertheless, our enumeration of the 3 amphibian species in the creeks in our study area should be considered as rough indicators of detection-non-detection and not as exact population abundance. However, our application of occupancy modeling should minimize some of the potential errors inherent in VES.

Microhabitat Conditions

A suite of 15 occupancy and 6 detection variables were evaluated as covariates during detection and creek occupancy model selection (Table 1). These included standard variables such as creek, survey year, and stream segment (upstream, under, downstream, or reference section). A number of microhabitat characterizations, specific to each stream section, were evaluated as covariates, including stream type, elevation, distance from highway, dominant rock, stream gradient, percent canopy cover, and so forth (see Table 1 for complete list). We determined elevation using a handheld GPS device. Percent canopy cover for each creek was calculated using average densitometer readings from two locations in each 30 m section. We measured percent slope in the field using a clinometer. Visual estimates were used to determine the dominant rock size and percent channel substrate composition by boulder (20 cm-100 cm diameter), cobble (5 cm-19 cm), and gravel (<5 cm). 'Highway distance' was measured using a GIS map. The 'I-90 Adjacent' covariate separated creek sections that abutted the highway from the reference sections. Air and water temperature covariates were also recorded at the start of each survey. Precise definitions of each of the evaluated covariate variables are presented in Table 1. The "Type" covariant was a personal categorical classification system for stream characteristics. These characteristics included the presence of pools, falls, and runs. For the purposes of this study: a "pool" is classified as an area of calm water in deeper depressions along the stream bed, a "run" is an area of smoothly flowing water along a flat stream bed, and a "fall" is a small waterfall where the creek bed is interrupted by boulders or steeper slopes. Each creek section was characterized by at least one of these type descriptors, and often by a combination of the three descriptors. These creeks fell into four different categories: run, run-pool, run-pool-fall, or pool-fall (Table 1).

Table 1. All microhabitat measurements recorded during surveys and used during model selection to evaluate *Dicamptodon tenebrosus*, *Rana cascadae*, and *Ascaphus truei* detection and occupancy in 8 creeks in the vicinity of Snoqualmie Pass, Washington, USA, 2015-2016.

Covariate	Description
Occupancy Variable	
Location	Creek surveyed
Year	2015 or 2016 survey season
Section	Upstream, under, downstream, or reference section relative to I-90
Elevation	Elevation of creek section surveyed (m)
Cover	Percent canopy cover
Slope	Averaged percent incline of creek section
Type	Presence of creek characteristics: pools, falls, and runs
Dominant Rock	Class of dominant rock size: boulder, cobble, and gravel
Boulder	Percent boulder coverage (20–100 cm)
Cobble	Percent cobble coverage (5–19 cm)
Gravel	Percent gravel coverage (<5 cm)
Highway Distance	Distance to Interstate 90 (m)
I-90 Adjacent	Creek section adjacent to I-90 or non-adjacent
Air Temperature	Air temperature (°C)
Water Temperature	Water temperature (°C)
Detection Variable	
Julian Date	Calendar date of survey
Location	Creek surveyed
Year	2015 or 2016 survey season
Section	Upstream, under, downstream, or reference section relative to I-90
Cover	Percent canopy cover
Highway Distance	Distance to I-90 (m)

Occupancy Modeling and Statistical Analysis

Results of repeated VES of the 3 amphibian species at all sites were selected as model inputs to estimate the occupancy and detection probabilities. The R Program package “unmarked” was used to create and compare the detection and occupancy models and estimates (Fiske and Chandler 2011). All numerical variables were standardized to account for the variety of microhabitat measurement units. Two different models were used for each species. The first model contained only location and section as covariates with all other parameters held constant. This model was used to determine the individual creek and creek section occupancy estimates that were used to evaluate species' occupancy between sites with restored underpasses and those without restored underpasses. The second model for each species included the covariates determined to be significant to that particular species' detection and occupancy. These models were identified as the most accurate using Akaike's Information Criterion (AIC). Some correlated covariates, such as creek section, elevation, and distance from the highway, as well as the three substrate sizes, were analyzed independently. For each species, we considered the relevance and the AIC values of each of these correlated covariates separately, to determine which covariate would be useful and which ones would be discarded.

Results

Species Variation

Six different amphibian species, listed in order of abundance, were encountered during the course of these surveys: Coastal Giant Salamander (*Dicamptodon tenebrosus*), Cascades Frog (*Rana cascadae*), Coastal Tailed Frog (*Ascaphus truei*), Western Toad (*Anaxyrus boreas,* formerly known as *Bufo boreas*), Pacific Chorus Frog

(*Pseudacris regilla*, formerly known as *Hyla regilla*), and Rough-Skinned Newt (*Taricha granulosa*) (Fig 2). *Anaxyrus boreas*, *P. regilla*, and *T. granulosa* were rarely encountered and are not normal inhabitants of the creeks in our study area and will not be discussed further in this report.

Dicamptodon tenebrosus were found in 63% of creeks surveyed, with a mean estimated occupancy across sites of 0.55 (s = 0.47) in 2015 and 0.53 (s = 0.47) in 2016, and with an overall mean detection probability of 0.66 (s = 0.18). *Rana cascadae* were found in 88% of creeks with an occupancy probability of 0.65 (s = 0.42) in 2015 and 0.46 (s =0.42) in 2016, and with a detection probability of 0.51 (s = 0.03). *Ascaphus truei* were found in 75% creeks with occupancy estimates of 0.61 (s = 0.44) in 2015 and 0.44 (s = 0.49) in 2016, and with a detection probability estimate of 0.39 (s = 0.18). Table 2 shows the raw survey counts for each species separated by location and year.

General occupancy models were used to determine the section-specific occupancy estimates for each year, which were then used to determine standard deviations (Figs. 3a, 4a, 5a). Over all, the reference sections of these creeks had the highest probability of *D. tenebrosus* occupancy at around 84% (Fig. 3a). The I-90 adjacent creek sections had around 50% probability of *D. tenebrosus* occupancy. The *R. cascadae* model suggests that both the downstream sections and the reference sections tend to have a higher occupancy probability (around 67%) than the upstream and under sections (Fig. 4a). *Ascaphus truei* exhibited a trend of around 80% occupancy probability in the reference sections of these creeks; however, the average I-90 adjacent sections had much lower probabilities of *A. truei* occupancy of around 30% (Fig. 5a).

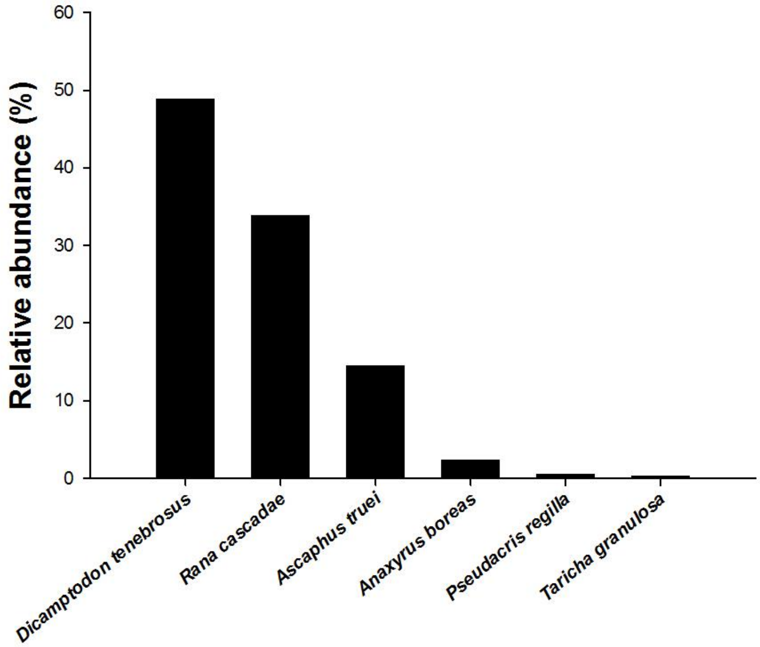

Figure 2. Percent relative abundance for 6 amphibian species encountered in or around 8 surveyed creeks in the proximity of Snoqualmie Pass, Washington, USA, 2015-2016.

Table 2. Overall survey counts for the studied amphibian species separated by species, location and survey year found in 8 creeks in the vicinity of Snoqualmie Pass, Washington, USA.

Location	*Dicamptodon tenebrosus*		*Rana cascadae*		*Ascaphus truei*	
	2015	2016	2015	2016	2015	2016
Gold Creek	0	0	6	1	0	0
Rocky Run	38	11	0	1	5	3
Wolfe Creek	53	34	3	0	4	7
Price Creek[a]	62	10	18	3	5	0
Noble Creek[a]	13	6	9	4	4	3
Swamp Creek	0	0	21	21	0	0
Cedar Creek	0	0	17	40	15	21
Mosquito Creek	8	2	19	1	2	1
Yearly totals	174	63	93	71	35	35

[a]Three survey sites on Price Creek and 2 on Noble Creek that were surveyed in 2015 were inaccessible in 2016 due to construction activity.

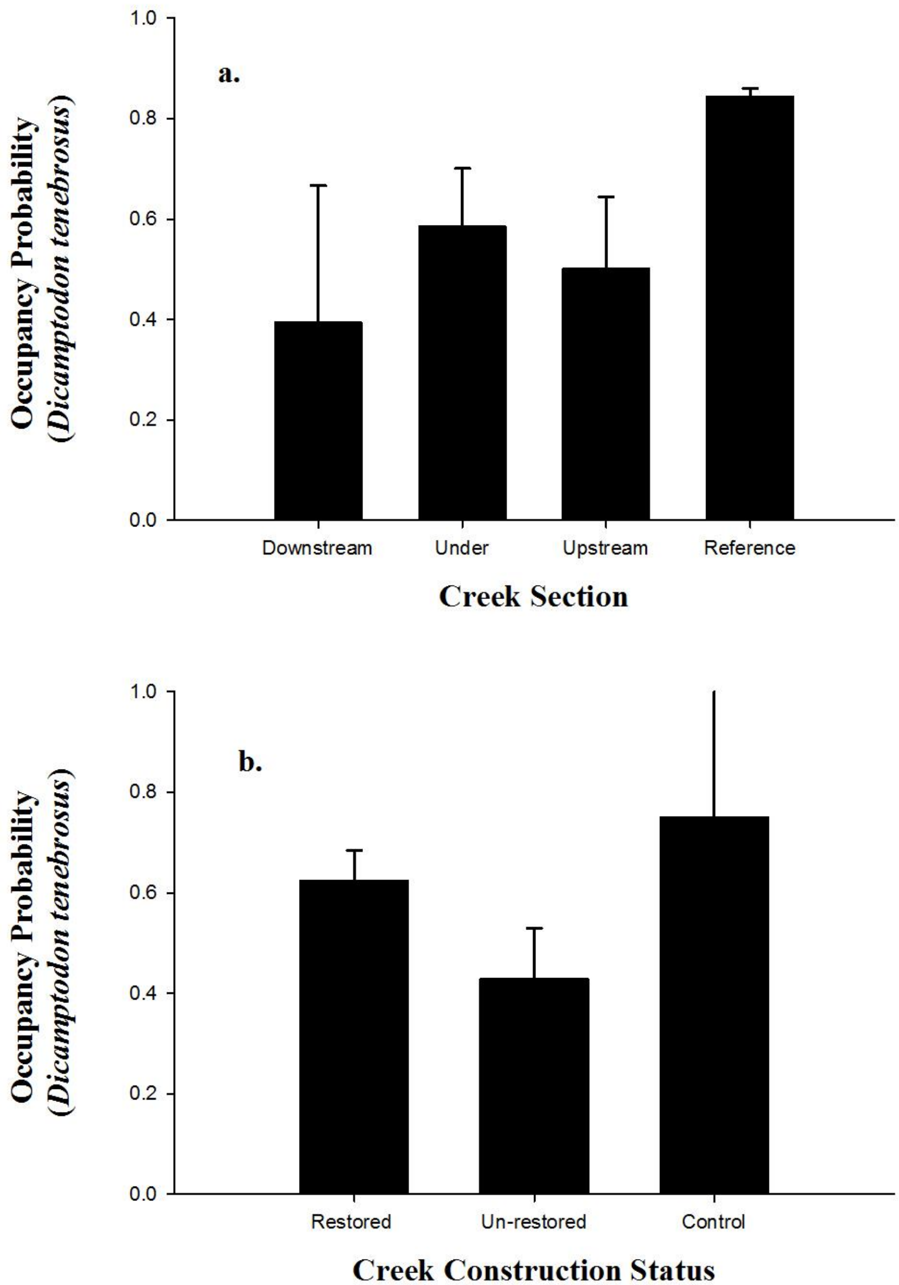

Figure 3. Occupancy estimate results from the general occupancy models using combined survey data from 2015 and 2016 for *Dicamptodon tenebrosus,* in the vicinity of Snoqualmie Pass, Washington, USA. Figure 3a shows the mean (± SD) occupancy probability estimates of creek sections based on their relationship to Interstate 90. Figure 3b shows the mean (± SD) occupancy estimates of creeks based on the construction status of their wildlife underpasses.

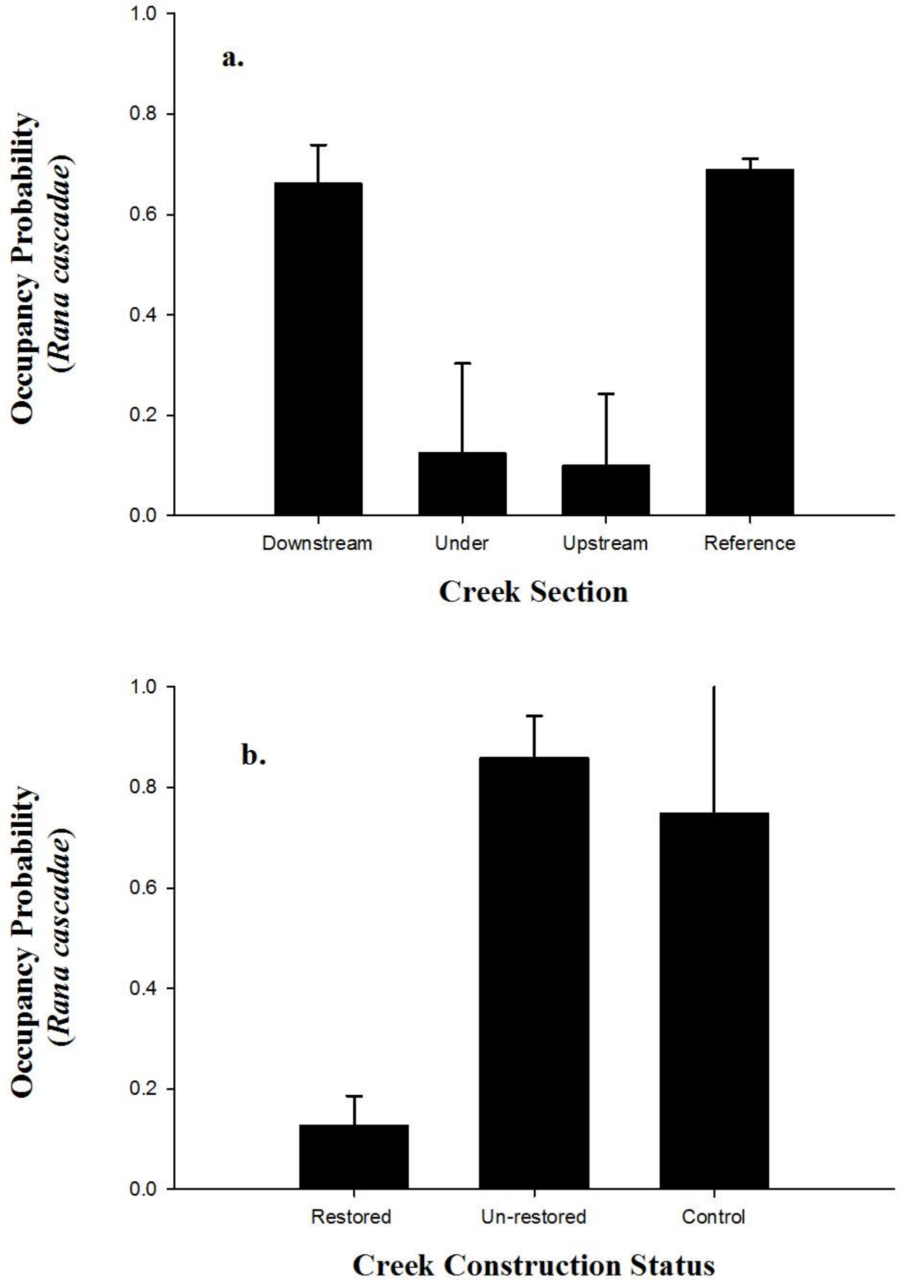

Figure 4. Occupancy estimate results from the general occupancy models using combined survey data from 2015 and 2016 for *Rana cascadae,* in the vicinity of Snoqualmie Pass, Washington, USA. Figure 4a shows the mean (± SD) occupancy probability estimates of creek sections based on their relationship to Interstate 90. Figure 4b shows the mean (± SD) occupancy estimates of creeks based on the construction status of their wildlife underpasses.

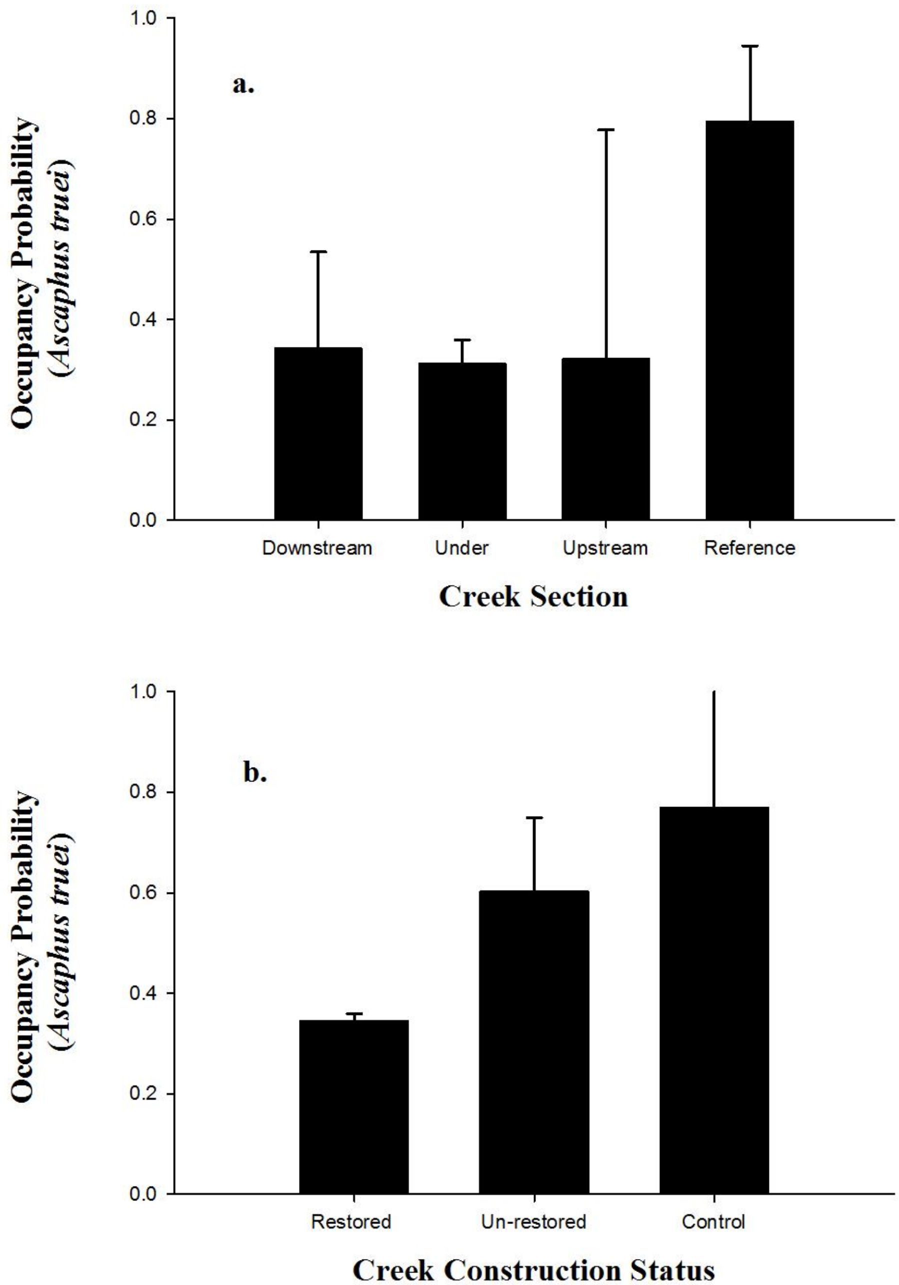

Figure 5. Occupancy estimate results from the general occupancy models using combined survey data from 2015 and 2016 for *Ascaphus truei,* in the vicinity of Snoqualmie Pass, Washington, USA. Figure 5a shows the mean (± SD) occupancy probability estimates of creek sections based on their relationship to Interstate 90. Figure 5b shows the mean (± SD) occupancy estimates of creeks based on the construction status of their wildlife underpasses.

Restored vs. Unrestored Comparisons

The creek-specific estimates were categorized by the construction status of their wildlife underpasses: restored (Gold Creek, Rocky Run, and Wolfe Creek), un-restored (Price, Noble, Swamp and Cedar Creeks), and the control (Mosquito Creek), which does not intersect with the interstate and is thus in the most natural condition (Figs. 3b, 4b, 5b). The standard deviations for the restored and un-restored sites were based on the range of occupancy probabilities between creeks in the same category, rather than by year. The standard deviations for the control creek were based on yearly variation. The standard deviations of these estimates are too large to draw specific conclusions; however, *Dicamptodon tenebrosus* occupancy probabilities tended to be highest in the control creek (Fig. 3b). The *R. cascadae* model indicated that this species had higher occupancy probabilities at un-restored sites than at restored sites (Fig. 4b). Occupancy probability for *R. cascadae* at the restored sites was only 8%. *Ascaphus truei* occupancy probabilities were about 34% in restored creeks, 60% in un-restored creeks, and 77% in the control creek (Fig. 5b).

Habitat Features

Significant habitat features preferable to each species were found using high-ranked occupancy models based on AIC values (Table 3). All models used have lower AICs than their corresponding null model, where all covariates remain constant. The *D. tenebrosus* model found the survey date to be an influential detection covariate (Table 3). The corresponding *D. tenebrosus* occupancy covariates are: creek type, gravel coverage, and highway distance. The detection probability for this species was lowest at the beginning of the survey season and highest at the end of the season. Occupancy probabilities of *D. tenebrosus* were highest at run-pool-fall and pool-fall characterized creeks (Rocky Run and Wolfe, Price, and Noble creeks), rather than creeks with a run or run-pool structure. The percentage of gravel substrate in a creek was inversely related to occupancy probability, whereas distance relative to I-90 was directly related to *D. tenebrosus* occupancy.

Table 3. The best supported occupancy models based on AIC values for *Dicamptodon tenebrosus*, *Rana cascadae*, and *Ascaphus truei*. The detection and occupancy covariates determined to be significant factors in the detection and occupancy probabilities of common amphibians found 8 creeks in the vicinity of Snoqualmie Pass, Washington, USA, 2015-2016.

Model Species	Detection covariate(s)	Occupancy covariate(s)
D. tenebrosus	Julian date	Type + Gravel Coverage + Highway Distance
R. cascadae	Location	Section + Type + Canopy Cover + Slope
A. truei	Julian date	Canopy Cover + Gravel Coverage + Elevation

The model selected for *R. cascadae* has location as its detection variable (Table 3), indicating that each creek has individual characteristics making it easier or more difficult to detect presence of *R. cascadae*, such as overgrown riparian zone, volume of water, interstitial spaces, and so forth. The occupancy covariates for *R. cascadae* are creek section, type, canopy cover, and slope (Table 3). This model indicated that occupancy probability for *R. cascadae* was highest in the downstream sections, followed by the reference section, then the upstream section, and finally the under the highway section, which registered the lowest probability of occupancy. According to this model, *R. cascadae* is more likely to be found in creeks characterized by runs or run-pool-falls (Gold, Swamp, Cedar, and Mosquito creeks) rather than creeks with run-pools or pool-falls. *R. cascadae* occupancy is positively associated with percent canopy cover and negatively associated with slope.

The *A. truei* model found the survey date to be influential to the detection probability (Table 3). As with *D. tenebrosus*, this model also indicated increased detection probabilities as the survey season advanced. This model included canopy cover, percentage of gravel coverage, and elevation to be significant to *A. truei* occupancy (Table 3). *A. truei* occupancy is positively associated with percent canopy cover, percentage of gravel substrate, and elevation.

Within and Between Creek Variation

The general microhabitat variations within and between creeks are seen in Table 4. The microhabitat substrate variations are seen in Table 5. Within creek variations were largest between the reference reach and the three adjacent I-90 reaches (downstream, under, and upstream). Gold Creek was characterized by a cobble substrate (Table 5) and long flat runs interspersed with small side pools and no riparian vegetation for cover (Table 4). Gold Creek's reference reach was similar in substrate but contained no side pools and some canopy cover provided by tall shrubs.

Table 4. General habitat features evaluated by occupancy models, separated by creek and section (30 m upstream of the highway, under the highway, 30 m downstream of the highway, and reference reach). Variation in some covariates indicates yearly changes within 8 creeks in the vicinity of Snoqualmie Pass, Washington, USA, 2015-2016.

Creek	Section	Elevation (m)	Canopy Cover (%)	Slope (%)	Type	Distance from I-90 (m)
Gold[a]	Upstream	757	0	2-6	run-pool	0
	Under	757	100	2-5	run-pool	0
	Downstream	757	0	2-3	run-pool	0
	Reference	766	20-32	4	run	907
Rocky[a]	Upstream	768	38	30-36	pool-fall	0
	Under	760	100	22	pool-fall	0
	Downstream	760	6-12	15-18	pool-fall	0
	Reference	1079	71	9-13	run-pool	1600
Wolfe[a]	Upstream	772	64-97	32-50	pool-fall	0
	Under	765	100	19	pool-fall	0
	Downstream	760	0	18-21	pool-fall	0
	Reference	950	83-94	58-73	pool-fall	524
Price[b]	Upstream	785	90	22	pool-fall	0
	Under	760	100	2	run	0
	Downstream	744	93	9	run-pool	0
	Reference	833	93-97	26-27	pool-fall	332
Noble[b]	Upstream	788	85	22	run-pool	0
	Downstream	776	92	9	run-pool	0
	Reference	840	86-95	24-36	run-pool-fall	370
Swamp[b]	Downstream	717	68-85	2-4	run-pool	0
Cedar[b]	Downstream	760	76-98	18-33	run-pool	0
Mosquito[c]	Control	800	84-92	13	run-pool-fall	3800

[a] Creek with restored highway underpass.
[b] Creek with un-restored highway underpass.
[c] Control creek, does not cross I-90.

Table 5. Creek substrate features evaluated by occupancy models, separated by creek and section (30 m upstream of the highway, under the highway, 30 m downstream of the highway, and reference reach). Variation in some covariates indicate yearly changes within 8 creeks in the vicinity of Snoqualmie Pass, Washington, USA, 2015-2016.

Creek	Section	Dominant Rock	Boulder (%)	Cobble (%)	Gravel (%)
Gold[a]	Upstream	cobble	10	60	30
	Under	cobble	10	60	30
	Downstream	cobble	10	60	30
	Reference	cobble	5	85	10
Rocky[a]	Upstream	boulder	90	9	1
	Under	boulder	90	4-5	5
	Downstream	boulder	90	9	1
	Reference	cobble	40	55	5
Wolfe[a]	Upstream	boulder	50	30	20
	Under	boulder	50	30	20
	Downstream	boulder	50	30	20
	Reference	boulder	80	10	10
Price[b]	Upstream	boulder	55	25	20
	Under	concrete	0	0	0
	Downstream	cobble	5	40	55
	Reference	boulder	75	20	5
Noble[b]	Upstream	boulder	60	15	25
	Downstream	cobble	5	55	40
	Reference	cobble	45	50	5
Swamp[b]	Downstream	cobble	0	90	10
Cedar[b]	Downstream	cobble	5	75	20
Mosquito[c]	Control	cobble	10	70	20

[a] Creek with restored highway underpass.
[b] Creek with un-restored highway underpass.
[c] Control creek, does not cross I-90.

Rocky Run's I-90 adjacent sections had an average slope of 24% and were characterized by pools and small falls (Table 4) with boulders being the dominant rock size (Table 5). Rocky Run's reference section also contained boulders; however, cobble was more prevalent. This reference section also had more canopy cover, a shallower slope, and was characterized as run-pool (Table 4). The Wolfe Creek I-90 adjacent sections had a similar slope, creek type, and rock substrate to Rocky Run due to their proximity. Wolfe Creek's reference section had more canopy cover and the steepest slope of all surveyed sites (Table 4).

The reference sections for Price Creek and Noble Creek are only about 160 m apart; however, these creeks were noticeably different. On average, Noble Creek had a water temperature at least 2^{o}C cooler than Price Creek. Price Creek's upstream and reference sections were more similar to each other than either the under or downstream sections despite the 300 m between those sections. Price Creek's under section was a large concrete box culvert about 2 m in height with a concrete bottom, and its downstream section had a lower gradient than the upstream and reference sections (Table 4). Noble Creek was similar to Price Creek in regard to its slope pattern, with its steepest to shallowest sections being, in order: the reference section, upstream section, under section, and downstream section. The reference section of Noble Creek contained runs interspersed with pools and falls (Table 4). Swamp and Cedar creeks only had one surveyed section each and were both characterized by runs and pools with cobble substrates (Table 5). Both of these creeks were downstream from I-90 and flowed out of concrete box culverts. Their main difference was in slope; unlike Cedar

Creek, Swamp Creek was very flat with slow moving, almost stagnant water (Table 4). The ledge of Cedar Creek's box culvert was 0.5 m above the streambed. The control creek, Mosquito Creek, had short runs with pools and small falls (Table 4) and a cobble substrate (Table 5).

Yearly Variation

Four to 11 surveys per creek were conducted in 2015 and 2 to 5 surveys per creek in 2016. This change does not affect the model estimates because occupancy modeling was created to address these kinds of survey variations and only 2 surveys to each site is required. The number of creek reaches surveyed also changed from 2015 to 2016. The culverts of Price Creek and Noble Creek were under construction for the I-90 wildlife overpass and access to the previously studied upstream, under, and downstream reaches of these two creeks were restricted and as such these reaches were not surveyed in 2016.

The Snoqualmie Pass snowfall yearly total was larger in the winter of 2015 than it had been in the 2 years previous (WSDOT 2017). Three creeks (Rocky Run, Wolfe Creek, and Cedar Creek) showed evidence of creek-bed erosion and channelization. Rocky Run in particular, experienced large volumes of snow pack run-off in the spring before the 2016 survey season that washed away large amounts of loose riparian soil and new vegetation. Yearly variation also accounted for a few changes in percent canopy cover and percent slope between survey seasons. These changes can be seen in Table 4 as ranges in canopy cover and slope. In this instance, wider ranges signify more extreme changes between the survey years. For canopy cover this can mean either normal vegetative growth or disturbance in the riparian zone, such as fallen trees and channelization. Changes in slope can signify normal shifts in the water channel's path or disturbance of the substrate itself due to increased channelization or shifting substrate. Wolfe Creek and Cedar Creek exhibited the largest changes in percent canopy cover and percent slope between seasons. Wolfe Creek's upstream canopy cover dropped 33% and its slope decreased by 18%, likely due to riparian zone erosion and channelization (Table 4). Cedar Creek's canopy cover increased 22% and its slope decreased 15% between seasons. Gold Creek's reference section exhibited a change of 12% in canopy cover, likely caused by the presence of beavers in 2016 which vastly altered the riparian landscape and decreased overall canopy cover (Table 4).

For the most part, yearly species' counts show fewer individuals found in 2016 than 2015 due to fewer surveys being conducted (Table 2). The decrease in Price Creek and Noble Creek counts coincides with the decrease in number of creek sections surveyed (Table 2). The *A. truei* counts increased the second season despite the lower number of total surveys.

Discussion

Detection and Occupancy Estimates

Dicamptodon tenebrosus had the highest detection probabilities of the 3 amphibian species in our study area at a rate of 0.66/survey. In many cases *D. tenebrosus* individuals were typically found in the same general locations week after week. Next most likely to be detected was *R. cascadae* with a probability of detection of 0.51/survey, and lastly was *A. truei*, the most cryptic amphibian in our study, with a detection probability of only 0.39/survey.

The average occupancy probabilities showed a different pattern: with *R. cascadae* having the highest occupancy probability of 0.55, then *D. tenebrosus* with a 0.54 probability, and lastly *A. truei* with an occupancy estimate of 0.53. A number of factors may have led to occupancy estimates for all three amphibians being higher in 2015 than in 2016. Firstly, the number of surveys per creek decreased from 4 to 11 in 2015, to 2 to 5 per creek in 2016. This change should not overly affect the estimates, as occupancy modeling does not require an equal number of surveys for each site or season unlike general linear models. Secondly, the number of creek reaches surveyed also changed from year to year, because both the Price Creek and Noble Creek culverts were under construction for the I-90 wildlife overpass in 2016 and the downstream, under, and upstream sections of these two creeks were inaccessible. Thirdly, many of these creeks suffered substantial creek-bed disturbance due to the higher than normal snowfall during the 2015 to 2016 winter season at Snoqualmie Pass (WSDOT 2017b).

The recently restored creeks experienced creek-bed erosion and channelization, while the relatively untouched reference sections above the highway showed little or no disturbance between 2015 and 2016 (Table 4 and 5). However, it was noted that a number of riparian zone trees had fallen into the control creek (Mosquito Creek) between survey seasons. Unlike the decrease in occupancy probabilities, detection probabilities increased from 2015 to 2016, as well as a detection increase within each survey season, for *D. tenebrosus* and *A. truei* (Table 3). Both *D. tenebrosus* and *A. truei* were typically found submerged. As water levels decreased throughout the survey seasons, density of aquatic species increased which led to higher detection rates.

Creek section occupancy model estimates indicate the use of restored underpass habitat by all three amphibians in this study (Fig. 3, 4, and 5). Although highway underpass renovation occurred fairly recently, *R. cascadae* and *D. tenebrosus* are already being found regularly within newly completed underpasses with rock substrate that matches the surrounding habitat. The creek-bound *D. tenebrosus* is unlikely to move upstream in the un-restored underpass sites (Price, Noble, Swamp, and Cedar creeks) due to the presence of either metal or concrete culverts without streambed substrate. At the time of this study, 3 of the 4 un-restored crossing sites had box culverts with outlet overhangs ≥0.10 m, which are considered to be complete barriers to some aquatic salamanders (Anderson and others 2014). Natural vegetation has been planted in the riparian zone of 2 of the 3 currently restored creeks. This mitigation method may eventually result in increased canopy cover that could encourage more amphibian movement and higher site occupancy.

Habitat Features

The *D. tenebrosus* occupancy estimates selected creek type, gravel substrate, and distance from highway to be influential covariates (Table 3). These data suggest that this species prefers creeks containing small waterfalls and pools. A possible explanation is the increased oxygen content typically found in more turbulent creeks (Welsh and Ollivier 1998). The percentages of gravel, cobble, and boulder substrate in creek-beds are correlated. As such, the inverse relationship between percent of gravel substrate and *D. tenebrosus* occupancy could indicate that *D. tenebrosus* prefer larger substrate sizes in stream-beds. Cobble and boulder substrate can provide cover from predators and the interstitial spaces underneath and between rocks, where eggs clusters can be protected (Jones and others 2005). Despite individuals being found near and under the highway, in general, *D. tenebrosus* occupancy increased the farther away the creek sections were from I-90. Most habitat association studies are more focused on stand age, basin order, or creek lithology, none of which are relevant to this study due to the proximity of survey sites (Dudaniec and Richardson 2012, Kroll and others 2008, Wilkins and Peterson 2000). All of our habitat features are on a stream-reach scale. However, our results do support some of the findings in other *D. tenebrosus* studies. Wilkins and Peterson (2000) propose a positive association between pool frequency and species abundance and suggest that a “step-pool bed morphology” may be favored, which is similar to our pool-fall creek type. Dudaniec and Richardson (2012) found that relative abundance increased with percentage of boulders within streams, which indicates a preference for larger substrates rather than gravel sized substrate. Our results differed in that elevation and stream gradient (slope) were found to be relevant to species abundance whereas our model discarded these covariates (Dudaniec and Richardson 2012).

The *R. cascadae* occupancy model had a detection variable of creek (Table 3). This is likely due to each creek having differing habitat complexities that make detecting amphibians inconsistent between creeks. *R. cascadae* is not often found in the water but rather occupies the surrounding riparian zone or large dry rocks in the creek. The *R. cascadae* occupancy covariates are creek section, creek type, percent canopy cover, and degree of slope. *Rana cascadae* had the highest occupancy probabilities in the downstream and reference reaches. Although high occupancy probabilities in the reference reach is a commonality between these species, usage of the downstream reach is not. This could be due to a combination of factors. Firstly, the creeks that showed the largest *R. cascadae* detection probabilities, Swamp Creek and Cedar Creek, had inaccessible under, upstream and reference sections, and could not be surveyed. Only the downstream reaches of these 2 creeks could be surveyed, which may account for some of the downstream section bias in occupancy probabilities. Secondly, both Swamp and Cedar Creeks are either fed by wetlands or have wetlands nearby. Unlike *A. truei* and *D. tenebrosus*, which both reproduce in streams, *R. cascadae* reproduce in ponds or wetlands and experience metamorphosis after 1-3 months, compared to *A. truei,* which has a larval period of 1 to 6 years depending on elevation and the *D. tenebrosus,* which has a larval period of 18 to 24 months (Jones and others 2005). Both of these wetland-fed creeks contain juvenile *R. cascadae* that are dispersing away from breeding sites. This may account for the heightened occupancy probabilities in the downstream section of these creeks.

The creek types with higher *R. cascadae* occupancies are run and run-pool-fall. The presence of runs is evidently a positive factor in *R. cascadae* occupancy. Percent canopy cover is also positively associated with this species' occupancy (Table 3). Canopy cover blocks direct sunlight, which likely keeps *R. cascadae* from drying out too quickly. *R. cascadae* also seems to prefer a lower degree of slope in the single digits (i.e. low gradient). Unfortunately, *R. cascadae* are not included in many habitat association papers and those that do are focused on wetlands and sub-alpine lake habitats rather than mountain streams and have no relevant habitat features for comparison (Cole and North 2014).

The *A. truei* model gave occupancy covariates of canopy cover, percent gravel substrate, and creek elevation as occupancy factors (Table 3). Dense canopy cover is a significant habitat association for both *A. truei* and *R. cascadae*. However, *A. truei* and *D. tenebrosus* occupancies have opposite relationships to percent gravel in creek-beds. *A. truei* occurs where there is more gravel, 20-25% of creek-bed substrate, whereas *D. tenebrosus* occurs where there is ≤10% gravel. During surveys, a number of partially metamorphosed *A. truei* individuals, were found amongst gravel substrate. These gravel beds may be an important microhabitat in *A. truei* growth following the tadpole stage. Although elevation is also a covariate influencing *A. truei* occupancy, this species is known to be found from sea level to 1600 m (Jones and others 2005) and the elevation range of our study sites is 717 m to 1080 m (Table 4). It is possible that this apparent elevation preference is related to general highway avoidance by *A. truei* and is driven by the fact that the reference creek sections, as well as the control creek, are at higher elevations than the creek sections that are adjacent to I-90.

Similar to the *D. tenebrosus* studies, most *A. truei* habitat-association research has focused on stand age, basin order, or creek lithology (Hayes 2006, Kroll and others 2008, Wilkins and Peterson 2000). Kroll and others (2008) found stream gradient to be a factor in occupancy, whereas our study did not. Wilkins and Peterson (2000) did not find any preference in relation to canopy cover, although they did find a preference for higher elevation. However, all of their study sites were below 500 m, whereas all of our sites were above 700 m.

Any future occupancy studies in this area may consider adding presence and extent of algal blooms and fine sediment, both of which were observed downstream of the restored and un-restored underpasses. These factors may be particularly important for *D. tenebrosus*, which exhibits reduced survival in the presence of road-related stream sedimentation (Honeycutt and others 2016). Large woody debris in and around creek channels have been associated with *D. tenebrosus* abundance and may be another useful future covariate to study (Wilkins and Peterson 2000).

Management Implications

Although long-term monitoring will be necessary to fully evaluate the effectiveness of the restored crossing structures toward reconnecting amphibian populations on either side of I-90, results of the present study allow us to make several preliminary recommendations that may enhance population reconnection. Habitat features that should be incorporated into future crossing structures in the I-90 Snoqualmie Pass East Project area depend on the creek in question and the species that inhabit it. For *D. tenebrosus* inhabited creeks, creek-bed substrate should have a higher proportion of cobbles and boulders than gravel. Gravel should be limited to below 10% of the total substrate because we found that *D. tenebrosus* occupancy was negatively associated with gravel coverage. New crossing structures should attempt to provide pools and small waterfalls in the transitional habitat underneath the Interstate, as we determined that this species preferred pool-fall and run-pool-fall characterized creeks.

For *R. cascadae* inhabited creeks, we suggest planting native vegetation that will eventually provide canopy cover and terrestrial refuges as *R. cascadae* prefers creeks with more canopy cover. Creeks with a naturally low gradient should retain their overall slope to allow for creek runs because this species prefers gradients less than 15% as well as run and run-pool-fall characterized creeks. Special attention should be paid to creeks near wetlands as these may be important dispersal corridors for juvenile *R. cascadae.*

New crossing structures for *Ascaphus truei* inhabited creeks should also include native vegetation that will eventually provide canopy cover as it is positively associated with this species' occupancy probabilities. We found that gravel coverage was positively associated with occupancy. As such, we suggest that creek-bed substrate should have gravel coverage of 20-25% in the transitional habitat underneath the highway to encourage usage by larval *A. truei,* as well as adult individuals. Due to the opposing preferences for creek gradient, type and percent gravel substrate found in the different amphibian species in this study, we emphasis the need for variation in these habitat features, especially in creeks occupied by more than one amphibian species such as those characterized by run-pool-falls. It is hoped that incorporating these habitat features will aid in increasing connectivity between amphibian populations on either side of I-90 and in other similar highway projects. These new open-bottomed crossing structures are already in use by the 3 amphibian species discussed here and we believe occupancy of these sites will only increase in the coming years.

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CHAPTER III

CONCLUSION

These are my suggestions for future students who plan to survey in the Washington State Snoqualmie Pass area. Don’t plan to get any work done the first time you visit your survey sites. Simply finding those sites and familiarizing yourself with them can be quite time consuming. Don’t necessarily trust creek locations on the maps you have, especially if you are surveying Price and Noble Creeks. A lot of changes have occurred since many of those maps where printed and the creeks’ supposed location may no longer be the reality. However, those maps are very useful in locating and identifying forestry roads. Always be able to pinpoint your current location on a map: there are many side roads and it is easy to get lost. Cellular phone reception is unavailable more often than not, especially further away from Interstate 90, so hard copy maps are necessary. It is a good idea to take GPS points of your survey sites and record the path you took to get there so that you can find those site again later. It can take a few trips to become familiar with the forestry roads. It might also be helpful to find a campsite before you start surveying. Surveying events often go longer than expected and searching for a campsite in the dark can be frustrating. I would caution anyone surveying at night to do so with a partner. If your sites require a hike to get to, I would discourage students from conducting night surveys because it can be very easy to get lost at night. One possibility is hiking into and camping near your survey site.

However, if you have multiple survey sites this may be too time consuming.

My stream-associated amphibian survey methodology was to first start downstream and work your way upstream so that any fine sediment and silt dislodged during surveying does not obscure your view. Lift any light rocks and cobbles straight up as gently as possible to avoid sending up a cloud of silt. Don't simply tilt the rock to one side as this may injury any animal hiding underneath it. Be sure to check the undersides of the rocks as well, that's where Tailed Frog tadpoles will be attached. Be gentle in replacing rocks to their original location. Always have a net and a few plastic bags on hand for captured amphibians. The net's handle can be used to flush salamanders out from underneath large boulders. Gently sift gravel through your net to search for juvenile Tailed Frogs. Rainy nights are the best times to find terrestrial Coastal Giant Salamanders. Aquatic Coastal Giant Salamanders are also nocturnal; however, I chose not to survey at night, as my survey sites required some steep climbs that would not be safe in the dark. Do not expect to find Cascades Frogs on rainy days, they are typically found near creeks on sunny days when they are taking refuge from the heat. If you are surveying Cascades Frogs, plan to finish your surveys before September. In my experience, this species is one of the first to leave the creeks for their overwintering locations. Do not expect to start your amphibian creek surveys before June because the water levels will likely be too high for creek surveys.

For students planning to use occupancy modeling in their project, I suggest researching both the modeling program "PRESENCE" as well as the occupancy modeling R Program package "unmarked" developed by Fiske and Chandler (2011). Program

PRESENCE was originally developed by the creator of this modeling method, Darryl MacKenzie. The decision to use either of these free software programs is largely a matter of preference. I was more familiar with R Program, so I chose to use the “unmarked” package. There are many online tutorials and explanations of both of these methods; however, I found it extremely helpful to get advice from someone with experience in occupancy modeling in particular. These two programs require two different data configurations which makes conversion between them difficult. Choose a program and data configuration to use early in your project to avoid later backtracking.

I would discourage using occupancy modeling as an additional analysis for preexisting data from projects using more common statistical models, such as a General Linear Model. Occupancy modeling generally requires planning and strategizing before any surveying takes place. Trying to fit preexisting data into an occupancy modeling format can be very overwhelming and at times impossible. For those whose goal is to use occupancy modeling, I would suggest planning to visit each of your survey locations four to five times if possible. Different numbers of surveys at each location is allowed in this modeling method; however, the model may automatically discard a location or two if it does not have an acceptable amount of data. I would highly suggest doing a literature review of any occupancy modeling with a similar focus to yours before any surveying takes place. This can help you decide what covariates you want to measure and plan how to take those measurements in advance. Take your occupancy covariate measurements as early in your surveying season as possible, unforeseen events may occur to make those sites unavailable later in the year. For occupancy modeling, one year of survey data will be sufficient. If you have properly prepared before you start surveying, I would not recommend more than one seasons' worth of data. The variation between years may unnecessarily complicate your results. My second year of survey data did not bring anything new to my final results. If I had the opportunity to repeat this research, I would have only surveyed for one season and I would have added woody debris measurements to my suite of covariates.