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Effects of Mountaintop Removal Mining on Population Dynamics of Stream Salamanders

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EFFECTS OF MOUNTAINTOP REMOVAL MINING ON POPULATION DYNAMICS OF STREAM SALAMANDERS

Thesis

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Forestry in the College of Agriculture, Food and Environment at the University of Kentucky

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2016

ABSTRACT OF THESIS

EFFECTS OF MOUNTAINTOP REMOVAL MINING ON POPULATION DYNAMICS OF STREAM SALAMANDERS

Mountaintop removal mining (MTR) is a notorious stressor of stream ecosystems in the Central Appalachians. Valley fills (VF) lead to reduced occupancy, abundance, and species richness of stream salamanders. Multiple factors may be responsible for these reductions, but specifically habitat fragmentation and degradation may reduce colonization rates and increase local extinction rates. From 2013-2015, repeated counts of salamanders were conducted in stream reaches impacted by MTR/VF and compared to counts in reference reaches to answer the question: do stream salamander population dynamics differ between stream reaches impacted by MTR/VF and reference stream reaches? I also investigated dynamics of stream habitat using measures relevant to stream salamander persistence. Accordingly, I examined number of cover objects, percent detritus, hydroperiod, and specific conductance. From the salamander capture data, colonization and survival probabilities were lower in MTR/VF reaches than reference reaches. MTR/VF reaches also had fewer cover objects, higher percent detritus, constant stream flow, and elevated specific conductance. Although specific conductance was increased in MTR/VF reaches, it was not strongly correlated with colonization and survival. I suggest reduced rates of colonization and survival in MTR/VF stream reaches are driven by inhibited dispersal and reduced individual survival due to degraded terrestrial and aquatic environments.

KEYWORDS: Appalachia, Kentucky, mountaintop removal, population dynamics, salamander

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July 12, 2016

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CHAPTER 1: INTRODUCTION

Species' distributions and abundances vary spatially and temporally, and the demographic processes responsible for this variation include colonization and extinction. Colonization, which quantifies the probability than an unoccupied area becomes occupied, is closely linked to movements of individuals (MacKenzie et al. 2003). Extinction (or conversely survival) highlights reductions in site occupancy across landscapes, that is, the probability that an occupied site becomes unoccupied over a time period (MacKenzie et al. 2003). Both colonization and extinction are indicative of population persistence; these vital rates can be greatly influenced by both abiotic (e.g., resource availability, Tilman 1993) and biotic conditions (e.g., competition, Comont et al. 2014). In particular, fragmented landscapes often have reduced colonization rates because they may be resistant to dispersal (Gamble et al. 2007), whereas stressors that deteriorate abiotic conditions can increase the probability of extinction (Schrott et al. 2005).

In Central Appalachia, mountaintop removal mining (MTR) represents the dominant form of land-cover change and has led to the deterioration of freshwater and terrestrial ecosystems (Bernhardt and Palmer 2011, Wickham et al. 2013). Mountaintop removal mining involves the extraction of shallow coal seams via removal of overlain geologic material (Palmer et al. 2010). Overburden material or spoil (i.e. unconsolidated rock) is often disposed into adjacent valleys, burying streams and forming valley fills (VF) (Palmer et al. 2010, Bernhardt and Palmer 2011). Unweathered rock in VFs alters downstream water chemistry (Lindberg et al. 2011, Bernhardt et al. 2012, Griffith et al. 2012). For example, elevated specific conductance in MTR/VF stream reaches, a result of high ion concentrations, is frequently above the Central Appalachian Ecoregion's aquatic benchmark of 300 μS/cm (Ecoregion 69; U.S. EPA 2011). MTR/VF landscapes also display altered hydrology (Griffith et al. 2012) due decreased infiltration and reduced evapotranspiration, which in turn increase discharge of MTR/VF streams (Messinger and Paybins 2003, Negley and Eshleman 2006). Peak flow is increased during large storm events compared to unmined streams (Messinger and Paybins 2003). Furthermore, MTR/VF streams often have stream flow in normally dry periods (Messinger and Paybins 2003). In addition to alterations to water quality and hydrology, MTR/VF landscapes contain widespread habitat fragmentation of the terrestrial environment (Wickham et al. 2013). Native vegetation is typically slow to recolonize the area, likely due to compaction required by the Surface Mining Control and Reclamation Act (Office of Surface Mining 1977) as well as thin topsoil and the prevalence of nonnative invasive plant species (Angel et al. 2005, Zipper et al. 2011).

Stream-breeding salamanders are common components of Central Appalachia, and populations tend to exhibit relatively stable occupancy due to high adult survival and moderately long life spans (2-10 years; Organ 1961, Danstedt 1975, Green 2003, Lowe 2003). Populations tend to have the highest densities in watersheds with undisturbed riparian zones (Willson and Dorcas 2003, Nowakowski and Maerz 2009). In disturbed areas, however, stream salamander populations often exhibit altered dynamics. For example, stream salamander populations have reduced occupancy after urbanization (Price et al. 2011). In preliminary studies within MTR/VF stream reaches, stream salamander populations have shown reduced occupancy, abundance, and species richness compared to reference streams (Wood and Williams 2013a, Muncy et al. 2014, Price et al. 2016). However, multi-year studies of stream salamander populations within MTR/VF stream reaches have yet to be published. Multiple years of data allow for estimations of population persistence that are not possible from single-year studies.

Using count data from three consecutive years, I estimated colonization and survival probabilities for five stream salamander species within MTR/VF stream reaches and reference stream reaches, and I examined habitat dynamics that may drive these processes. My objectives were to 1) determine if colonization and survival probabilities for stream salamander populations differ between site types (MTR/VF and reference stream reaches) and among species and life stages, and 2) differentiate relevant habitat conditions between site types that may influence these vital rates, with particular focus on specific conductance. For the first objective, I hypothesized that colonization and survival probabilities would be lower in MTR/VF stream reaches than reference stream reaches as a result of limited patch connectivity and hydrological changes. For the second objective, in relation to specific conductance, I hypothesized that because of altered hydrology, MTR/VF stream reaches would show consistently greater monthly and yearly specific conductance and more monthly and yearly fluctuation of specific conductance.

CHAPTER 2: METHODS

Location

I conducted salamander surveys in 23 intermittent, headwater streams in Breathitt and Knott Counties, southeastern Kentucky, USA (see Table 2.1, Figure 2.1). Streams were categorized by site type; those that had VF (n=11) were classified as MTR/VF, and the remainder (n=12) were considered reference. The MTR/VF streams were within the reclaimed Laurel Fork Surface Mine, active from the late 1990’s to early 2000’s and released from bond in November 2007. Dominant vegetation species on the landscape were autumn olive (*Elaeagnus umbellata*), sericea lespedeza (*Lespedeza cuneata*), tall fescue (*Schedonorus arundinaceus*), Virginia pine (*Pinus virginiana*), black locust (*Robinia pseudoacacia*), and white oak (*Quercus alba*) (Fritz et al. 2010). Reference streams were in the main block of Robinson Forest, a mixed mesophytic, second-growth forest located northeast of Laurel Fork Surface Mine. Prevalent vegetation in Robinson Forest included Eastern hemlock (*Tsuga canadensis*), white oak (*Quercus alba*), chestnut oak (*Q. prinus*), and tulip poplar (*Liriodendron tulipifera*) (Phillippi and Boebinger 1986). For more site details, see Muncy et al. (2014) and Price et al. (2016).

In 2013, Muncy et al. (2014) delineated 10-meter reaches within which to sample for salamanders. Ten meters was the desired stream length in order for salamander capture data to be comparable to other stream salamander studies in the eastern U.S. (e.g., Grant et al. 2009, Price et al. 2011). For MTR/VF streams, the reaches were located downstream of valley fills; locations of reference reaches were based on similarity to MTR/VF reach widths and depths. Due to variable microhabitat usage by stream salamander species (Petranka 2010), chosen stream reaches contained riffle, run, and pool microhabitats to promote detections of multiple salamander species.

Data Collection

Stream reaches were sampled three times per year from 2013-2015 (approximately monthly from April through June) at base flow during daylight hours. Active searches, consisting of overturning cover objects and sorting through detritus, were constrained to 0.5 man hours within the stream. I also conducted surveys in the riparian zone adjacent to streams; duration of these surveys was 0.25 man hours, and my efforts focused on searching under cover objects and detritus within 1 m from the wetted stream width. Captured individuals were counted and classified by species and life stage: larvae or adult (i.e. post-metamorphosis). I also recorded visually-detected salamanders that escaped capture during the sampling period. I released all individuals into the stream after recording data.

Before each sample, I documented multiple site-specific and visit-specific measures: water temperature (°C, using Max/Min Digital Thermometer©), air temperature (°C) and wind speed (mph, using Kestrel 2500 Pocket Weather Meter©), percent cloud, turbidity, average stream width (cm) and depth (cm) at 5-meter intervals, and date of last precipitation (from Monthly Climatological Summary at Kymesonet.org/historical_data.php). Once per year, habitat measurements at each stream reach were recorded, including substrate composition (using categories described in Jung et al. 2004) and number of cover objects (logs $\geq$8 cm and rocks $\geq$15 cm) within the stream reach. I collected 50 mL of water from the 10-meter transects in sterile, conical centrifuge tubes during each sampling event and monthly from July 2015-March 2016. Samples were taken to the Forestry Hydrology Lab (Department of Forestry at the University of Kentucky) to be analyzed for specific conductance using standard procedures (Greenberg et al. 1992).

To compare hydroperiod between site types, I arbitrarily selected six stream reaches of each site type in which to install Solinst LTC Levelogger Juniors (Model 3001, LTC F30/M10©), set to record stream level (i.e. height of water column), conductivity, and water temperature every 15 minutes. Leveloggers were placed inside of a PVC tube with holes to allow for water flow. The PVC tube was secured to rebar in the stream, and the logger was also tied to a nearby tree with rope. Unless the topography did not allow, I set up the Leveloggers upstream of the stream reaches where I sampled (see Appendix D for pictorial illustration of set-up). I also installed a single Solinst Barologger Edge (Model 3001, LT F5/M1.5©) at a weather station in each site type; these recorded barometric pressure (kPa) every 15 minutes, which was necessary so that Levelogger readings could be compensated for atmospheric barometric pressure. I uploaded Levelogger and Barologger data monthly and accumulated data from March 2015 through December 2015.

Habitat Analysis

To analyze habitat conditions between site types, I first investigated specific conductance from the water samples by running a mixed model (repeated measures ANOVA) using the proc mixed command in SAS (version 9.3) to compare site type-specific means and variation from 1) May 2013, May 2014, and May 2015, and 2) April

2015-March 2016. Assumptions of the model are normality, homogeneity, and independence (SAS Library 1997). For predictors, I used site type, year (for analysis 1, month for analysis 2), and an interaction term of site type and year (or month). The interaction term was included to test for dependence between predictors. I ran a similar mixed model to compare site type-specific means and variation for 1) percent detritus of stream substrate in 2013, 2014, and 2015, and 2) number of cover objects (logs ≥8 cm and rocks ≥15 cm) within the stream reaches in 2013, 2014, and 2015. For predictors, I used site type, year, and an interaction term of site type and year. For all models, protected LSD post-hoc t-tests were conducted on significant interactions (Full SAS code in Appendix C).

Hydroperiod is another aspect of habitat that I compared between site types and could specifically relate to salamander survival. Using Solinst's Levelogger 4.0.3 software©, I compensated Levelogger level readings with the Barologger atmospheric barometric pressure readings. I then calculated hydroperiod (percent of time water is present in the stream bed) using two methods, which each have limitations. First, I classified compensated level readings greater than zero as flowing water. However, since I discovered inaccuracies in some level readings, I also calculated hydroperiod using the Levelogger conductivity readings, classifying readings greater than zero as flowing water since conductivity is only recorded when the logger sensor is submersed. Both calculations were administered for the entire time that loggers were deployed (March to December 2015) as well as for the growing season (April 15 to October 15, 2015) for comparison since headwater streams tend to be intermittent (Datry et al. 2014). For all analyses, I calculated the mean hydroperiod and standard deviation for each site type.

Dynamic Modelling

I used dynamic occupancy modelling to evaluate my hypothesis regarding salamander population dynamics. Using a hierarchical framework, dynamic occupancy models take into account the actual versus realized states as well as spatio-temporal interactions (Royle and Kéry 2007). For this study, I used a hierarchical, dynamic occupancy model to examine species-specific initial occupancy, abundance, colonization, and survival. The model accounted for imperfect detection, a factor in detection surveys that, if ignored, could result in false negatives (i.e. an occupied site classified as unoccupied; Gu and Swihart 2004, Royle 2006, Mazerolle et al. 2007). Multiple visits (n=3) to every transect each year allowed for calculation of detection probabilities, providing estimations of the accuracy of the occupancy calculations. Populations at each stream reach were assumed to be independent and closed each year, entailing that no individuals entered or exited the stream reaches within yearly sampling replications (Dorazio et al. 2013).

I separated the salamander count data by life stage (i.e. larvae or adult) where possible for five stream salamander species. Due to few adult captures, I did not separate life stage for the spring salamander (*Gyrinophilus porphyriticus*) or the northern red salamander (*Pseudotriton ruber*). I had sufficient individuals to separate southern two-lined salamander (*Eurycea cirrigera*) adult and larvae. For the northern dusky salamander (*Desmognathus fuscus*) and seal salamander (*D. monticola*), I analyzed adults separately but combined larvae into a single "*Desmognathus* larvae" category due to larval identification complications (a solution also used in Price et al. 2016; see Appendix A for species-specific encounter matrices.)

In the model, occupancy (ψ) was considered a Bernoulli random variable (e.g., MacKenzie et al. 2003) that measures the probability that species *S* will occupy site *s*. Occupancy is denoted with a 1, whereas non-occupancy is 0. If site *s* was occupied in the first year, initial occupancy is, mathematically:

$$\psi_{S,s} = P(O_{S,s,1} = 1) \qquad \text{Eq. 1}$$

As seen in Equation 2, I investigated how site type and specific conductance affect occupancy. MTR/VF stream reaches have the $\mathrm{MTR_s}$ covariate equal to 1, and reference stream reaches have $\mathrm{MTR_s}$=0. Specific conductance was only analyzed for MTR/VF stream reaches; specific conductance in MTR/VF stream reaches was consistently elevated such that analysis with reference stream reaches would not provide beneficial information as to the potential effect on salamander occupancy parameters.

$$logit(\psi_{S,s}) = \beta_{S,0}^{(\psi)}(1 - MTR_s) + \beta_{S,1}^{(\psi)}MTR_s + \beta_{S,2}^{(\psi)}Conductance_{s,1} \qquad \text{Eq. 2}$$

Abundance given occupancy for species *S* at site *s* in year *y* ($A_{S,s,y}$) was modeled as a truncated Poisson distribution. Rate of abundance ($\lambda_{S,s,y}$) was modeled on a log scale with site type and specific conductance:

$$P\left(A_{S,s,y} = a \middle| O_{S,s,y} = 1\right) = \frac{e^{-\lambda_{S,s,y}}\lambda_{S,s,y}^{a}}{a!}\frac{e^{\lambda_{S,s,y}}}{(1-e^{\lambda_{S,s,y}}}, \ a = 1,2,3, \ldots \qquad \text{Eq. 3}$$

$$\log\left(\lambda_{S,s,y}\right) = \beta_{S,0}^{(\lambda)}(1 - MTR_s) + \beta_{S,1}^{(\lambda)}MTR_s + \beta_{S,2}^{(\lambda)}Conductance_{s,y} \qquad \text{Eq. 4}$$

Colonization (γ) is a measure indicating the probability that species *S* is present at site *s* in year *y +1* but did not occupy site *s* in year *y* (Eq. 5). Survival (Φ) is a measure indicating the probability that species *S* occupies site *s* in year *y +1* given that it occupied site *s* in year *y* (Eq. 6). Site type and specific conductance were also used as covariates for colonization and survival (as shown in Eq. 7 for survival):

$$\gamma_{S,s,y} = P(O_{S,s,y+1} = 1 | O_{S,s,y} = 0) \qquad \text{Eq. 5}$$

$$\phi_{S,s,y} = P(O_{S,s,y+1} = 1 | O_{S,s,y} = 1) \qquad \text{Eq. 6}$$

$$logit(\phi_{S,s,y}) = \beta_{S,0}^{(\phi)}(1 - MTR_s) + \beta_{S,1}^{(\phi)} MTR_s + \beta_{S,2}^{(\phi)} Conductance_{s,y+1} \qquad \text{Eq. 7}$$

The detection model indicates that individuals from species S occupying site s in year y were detected on visit v independently with probability ($p_{S,s,y,v}$). Given abundance, the number of detections ($Y_{S,s,y,v}$) follows a binomial distribution:

$$Y_{S,s,y,v} \sim Binomial\ (A_{S,s,y}, p_{S,s,y,v}) \qquad \text{Eq. 8}$$

Date of last precipitation (number of days since last precipitation event, *Precip*) and number of cover objects (*Cover*) were included in the model since they dictate salamander activity and thus may affect salamander detection (Orser and Shure 1975, Kleeberger 1985, Connette et al. 2011). These variables for each visit *v* were integrated into the model as covariates on the logistic scale:

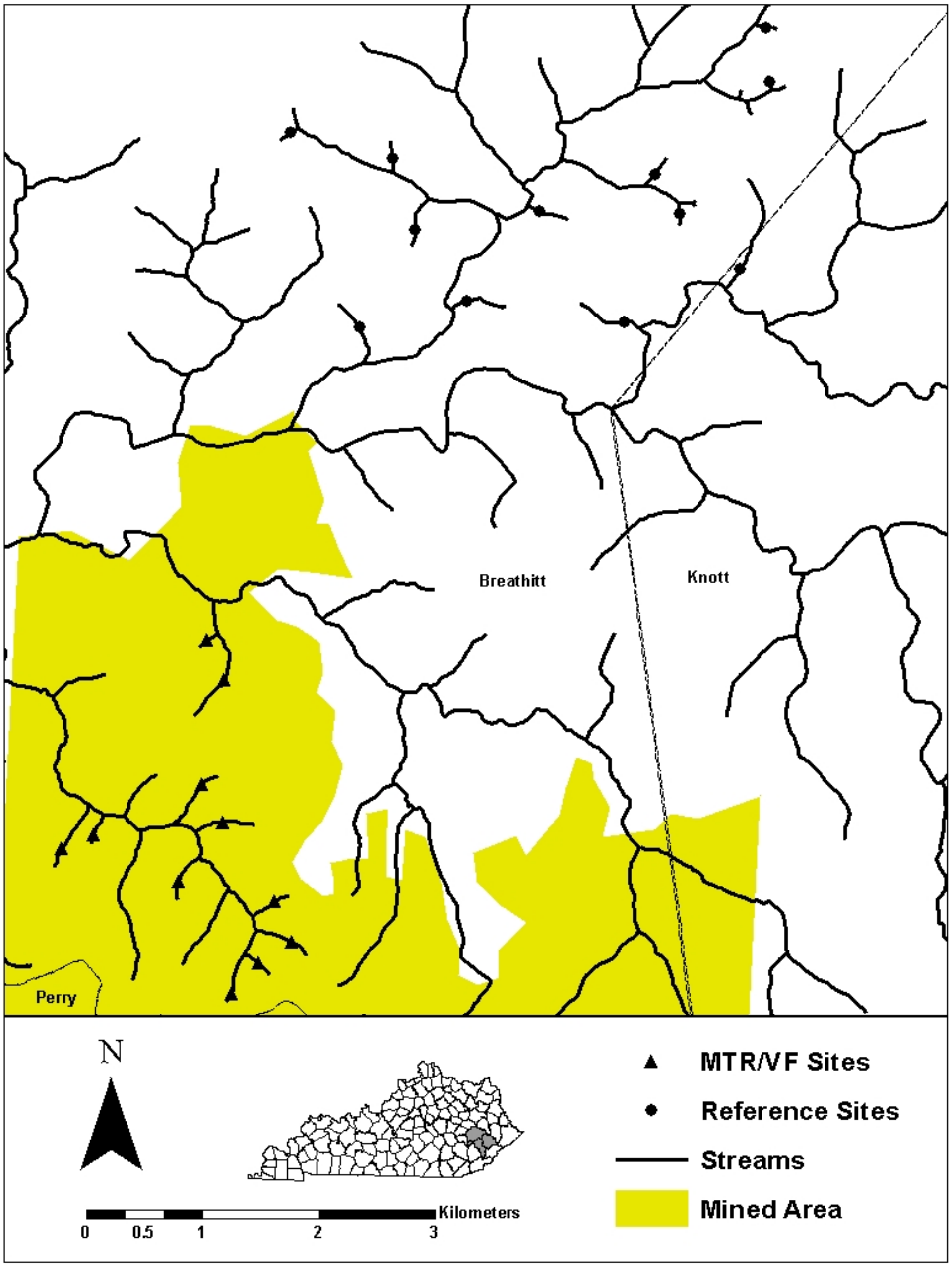
$$logit(p_{S,s,y,v}) = \beta_{S,0}^{(p)} + \beta_{S,1}^{(p)} + \beta_2^{(p)} Cover_{s,y} + \beta_2^{(p)} Precip_{s,y,v} \qquad \text{Eq. 9}$$

The model used a Bayesian framework, applying Markov chain Monte Carlo (MCMC) using the program JAGS in R (version 2.15.1©; R Development Core Team 2010; see Appendix B for full code). Non-informative priors were used, providing little information about the posterior distribution. For each parameter, I computed the mean and species-specific values for each site type, and I report the median and 95% credible intervals. I also calculated posterior distributions for each parameter (means and species-specific) with 95% credible intervals.

Table 2.1 Coordinates for Stream Reaches. Garmin eTrex 20© was used to obtain Northern and Western values. MTR/VF stream reaches are located below valley fills on the reclaimed Laurel Fork Surface Mine. Reference stream reaches are within Robinson Forest.

Stream Reach	Site Type	Northern	Western
Bee Branch Far	MTR/VF	37.43885	-83.17313
Bee Branch Near	MTR/VF	37.43753	-83.17129
Big Hollow	MTR/VF	37.42157	-83.1741
Hickory Log	MTR/VF	37.4238	-83.17381
Spice	MTR/VF	37.42444	-83.18521
Stillrock	MTR/VF	37.41773	-83.16781
Turkey	MTR/VF	37.42431	-83.18331
Unnamed White Oak Left	MTR/VF	37.41414	-83.16862
Unnamed White Oak Right	MTR/VF	37.41429	-83.16919
Wharton	MTR/VF	37.42519	-83.17512
White Oak	MTR/VF	37.41608	-83.16692
Boardinghouse	Reference	37.4619	-83.15867
Bucklick	Reference	37.46441	-83.13272
Cole's Fork A	Reference	37.46568	-83.1198
Falling Rock A	Reference	37.47327	-83.13432
Falling Rock B	Reference	37.47496	-83.13451
Field Branch A	Reference	37.47064	-83.15401
Goff	Reference	37.48154	-83.12122
Little Millseat A	Reference	37.47561	-83.15632
Little Millseat B	Reference	37.47805	-83.16625
Miller	Reference	37.4871	-83.12101
Mulberry	Reference	37.46517	-83.1496
Tome	Reference	37.47266	-83.14204

Figure 2.1 Site Map. Stream reaches for this study are located in Breathitt and Knott counties, Kentucky. MTR/VF stream reaches are located below valley fills on the reclaimed Laurel Fork Surface Mine. Reference stream reaches are within Robinson Forest. This map was published in Price et al. (2016).



CHAPTER 3: RESULTS

Habitat Dynamics

When comparing physical habitat of stream reaches from the two site types over three years, there was a significant interaction between site type and year for the three year comparison of percent detritus (F(2,42)=4.98, p=0.0115; Figure 3.1). This indicates that site type and year are not independent of each other, and thus each site type per year combination must be analyzed for differences. MTR/VF stream reaches had higher percent detritus than reference streams for every year but only significantly so in 2015 (p=0.0084; Figure 3.1). Number of cover objects did not have a significant interaction between site type and year (F(2,42)=0.46, p=0.6358; Figure 3.2). However, a greater number of cover objects were found within reference stream reaches in all three years compared to MTR/VF stream reaches (Figure 3.2).

Analysis of specific conductance of water samples from May 2013, 2014, and 2015 showed a significant interaction between site type and year (F(2,42)=24.04, p<0.0001; Figure 3.3). MTR/VF stream reaches had significantly greater mean specific conductance than reference stream reaches for all three years (p<0.0001; Figure 3.3; see Appendix E.01.1 for all p-values). Mean specific conductance of MTR/VF stream reaches also varied significantly among years (p<0.05), while mean specific conductance of reference stream reaches was statistically the same for all three years (p>0.05; Figure 3.3; see Appendix E.01.2 for all p-values). Similarly, for April 2015-March 2016 water samples, there was a significant interaction between site type and month (F(11,231)=11.70, p<0.0001; Figure 3.4). For every month, MTR/VF stream reaches had significantly greater mean specific conductance than reference stream reaches (p<0.0001;

Figure 3.4; see Appendix E.01.3 for all p-values). Reference specific conductance was not significantly different among months ($p>0.05$), but MTR/VF stream reaches demonstrated significant month-to-month variation ($p<0.05$; Figure 3.4; see Appendix E.01.4 for all p-values). Mean MTR/VF specific conductance ranged from 916.36 μS/cm (January 2016) to 1794.82 μS/cm (June 2015). In comparison, reference stream reaches had mean specific conductance below 60 μS/cm for all 12 months (Figure 3.4).

Hydroperiod highlighted further differences between MTR/VF and reference stream reaches (Table 3.1). Both level and conductivity calculations showed almost constant flow for MTR/VF stream reaches in both time spans. Conversely, reference stream reaches had flowing water less than 40% of the time spans. For the growing season, reference stream reaches had an average hydroperiod of 22.87 (±27.40 SD) using the levels calculation and 34.29 (±18.91 SD) using the conductivity calculation. Similar hydroperiods were calculated for reference sites from March through December 2015, with an average hydroperiod of 22.54 (±26.79 SD) using the levels calculation and 26.94 (±16.58 SD) using the conductivity calculation (See Appendix E.02 for site-specific calculations).

Salamander Dynamics

From the nine salamander sampling sessions in 2013 through 2015, a total of 2,303 individuals from the focal five species were detected. Of the 636 detected in 2013, only 76 were in MTR/VF stream reaches. Similarly, 52 of 817 and 98 of 850 salamanders were found in MTR/VF stream reaches for 2014 and 2015 respectively. *Eurycea cirrigera*, *D. fuscus*, and *D. monticola* were the most abundant species in both site types.

There was an increase in *D. fuscus* adult detections from 2013 to 2015 in reference stream reaches (61 in 2013 to 164 in 2015) but not as large of an increase in MTR/VF stream reaches (18 in 2013 to 30 in 2015). For MTR/VF stream reaches, there was a noticeable increase in number of *G. porphyriticus* each year (2 in 2013 to 12 in 2015). I detected very few *P. ruber* in either site type, with a maximum of 37 individuals (2015) in reference stream reaches and 5 individuals (2013) in MTR/VF stream reaches per year (See Appendix E.03 for species-specific counts for each year).

Neither number of cover objects (α = -0.08 (95% CI= -0.37 to 0.19)) nor last date of precipitation (α = 0.02 (95% CI= -0.17 to 0.22)) affected detection overall, with parameter differences close to zero and the 95% CI including zero (Figure 3.5). However, *D. monticola* adults (α = 0.32 (95% CI= 0.16 to 0.49)) and *E. cirrigera* adult (α = 0.19 (95% CI= -0.01 to 0.38)) were detected more frequently with more cover objects; all other species were detected less frequently with more cover objects (Figure 3.6). Detection of *D. fuscus* adults (α = 0.15 (95% CI= 0.05 to 0.25)) and *E. cirrigera* adults (α = 0.28 (95% CI= 0.12 to 0.45)) increased with more time between the last precipitation event and the date of capture (Figure 3.6).

Mean initial occupancy for all species and life stages was lower in MTR/VF stream reaches compared to reference stream reaches (Figure 3.7). The lowest initial occupancy estimate in the reference stream reaches was 0.63 (*P. ruber*), whereas the highest MTR/VF initial occupancy estimate was 0.48 (*D. fuscus* adults). Overall mean initial occupancy for MTR/VF stream reaches was 0.41 (95% CI= 0.23 to 0.60), compared to 0.91 (95% CI= 0.68 to 0.98) for reference stream reaches. Reference sites had an overall increase in initial occupancy (α = 2.64 (95% CI= 0.94 to 4.29); Figure

3.11). *Pseudotriton ruber* is the only species for which the effect on initial occupancy was not strong because the 95% confidence interval included zero (α = 1.19 (95% CI= -0.52 to 3.33); Figure 3.12). Increases in specific conductance were correlated with a decrease in initial occupancy (α = -0.68 (95% CI= -1.81 to 0.22); Figure 3.13), but the effect is not strong overall or for any life stage except *Desmognathus* larvae (α = -1.13 (95% CI= -3.85 to -0.09); Figure 3.14).

Mean abundance was lower for all species and life stages in MTR/VF stream reaches than reference stream reaches (Figure 3.8). The highest mean abundance in reference stream reaches was 11.61 ((95% CI= 8.48 to 18.46), *E. cirrigera* larvae), whereas the highest mean abundance in MTR/VF stream reaches was 1.21 ((95% CI= 0.85 to 1.80), *D. fuscus* adults*)*. All species at reference stream reaches had mean abundances greater than 4, but all mean abundances at MTR/VF stream reaches were less than 2. Reference sites had an overall increase in abundance (α = 1.37 (95% CI= 0.92 to 1.76); Figure 3.11), and the effect was strong overall and for every species (Figure 3.12). Increases in specific conductance were correlated with decreases in abundance (α = -0.19 (95% CI= -0.47 to 0.18); Figure 3.13), but the effect was weak overall. *Desmognathus fuscus* was the only species for which the effect was strong (α = -0.47 (95% CI= -0.75 to -0.19); Figure 3.14).

Mean colonization in MTR/VF stream reaches was lower than reference stream reaches for all species and life stage groups (Figure 3.9). In reference stream reaches, all species-specific mean colonization estimates were between 0.76 (95% CI= 0.42 to 0.97, *P. ruber*) and 0.88 (95% CI= 0.54 to 1.00, *D. fuscus* adults). Conversely, the highest estimated colonization probability for MTR/VF stream reaches was *D. fuscus* adults (0.27

(95% CI= 0.07 to 0.68)); the lowest was *D. monticola* adults (0.08 (95% CI= 0.00 to 0.26)). Overall mean colonization of MTR/VF stream reaches was 0.17 (95% CI= 0.06 to 0.40), compared to 0.82 (95% CI= 0.45 to 0.98) for reference stream reaches. Reference stream reaches were correlated with an increase in colonization (α = 3.16 (95% CI= 1.02 to 5.62); Figure 3.11). The effect of site type was strong overall and for all species except *G. porphyriticus* (α = 2.71 (95% CI= -1.83 to 7.39)) and *Desmognathus* larvae (α = 3.01 (95% CI= -1.43 to 7.71); Figure 3.12). Increases in specific conductance were correlated with a reduction in colonization (α = -0.33 (95% CI= -1.58 to 0.79); Figure 3.13), but the effect was weak overall and for all species (Figure 3.14).

Average survival in MTR/VF stream reaches was lower than reference stream reaches for all species and life stage groups (Figure 3.10). Within MTR/VF stream reaches, *E. cirrigera* adults had the highest survival (0.82 (95% CI= 0.52 to 1.00)), whereas *E. cirrigera* larvae had the lowest survival (0.52 (95% CI= 0.13 to 0.82)). All species and life stages in MTR/VF stream reaches had survival below 0.85, whereas the lowest survival for reference stream reaches was 0.90 (95% CI= 0.55 to 0.98, *P. ruber*). Overall mean survival in MTR/VF stream reaches was 0.71 (95% CI= 0.45 to 0.93), compared to 0.95 (95% CI= 0.82 to 0.99) in reference stream reaches. Reference sites were correlated with increases in survival, although the effect was weak (α = 1.99 (95% CI= -0.11 to 3.72); Figure 3.11). *Desmognathus fuscus* adults (α = 2.01 (95% CI= 0.10 to 3.84)), *D. monticola* adults (α = 2.69 (95% CI= 0.41 to 6.56)), and *E. cirrigera* larvae (α = 3.12 (95% CI= 1.12 to 5.77)) were the only species for which site type had a strong effect (Figure 3.12). Increases in specific conductance decreased survival (α = -0.01 (95%

CI= -1.25 to 1.01); Figure 3.13), although the effect was weak overall and for each species (Figure 3.14).

Table 3.1 Hydroperiod Calculations. Mean hydroperiod (the percent of time stream reaches have flowing water) was calculated for two time periods: March through December 2015, and the growing season (April 15 through October 15, 2015). Two methods were used to calculate mean hydroperiod for each time period: Levelogger compensated level greater than zero indicated flowing water (Levels), and Levelogger conductivity readings greater than zero indicated flowing water (Conductivity). MTR/VF stream reaches are located below valley fills on the reclaimed Laurel Fork Surface Mine. Reference stream reaches are within Robinson Forest. Units=percent of time with flowing water; SD= standard deviation.

Site Type	March-December				April 15-October 15			
	Levels		Conductivity		Levels		Conductivity	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
MTR/VF	100	0	97.33	4.88	100	0	96.83	7.40
Reference	22.54	26.79	26.94	16.58	22.87	27.40	34.29	18.91

Figure 3.1 Mean In-Stream Detritus. From a repeated measures ANOVA, the interaction of site type and year was statistically significant (F(2,42)=4.98, p=0.0115). Letters show statistical significance; columns that do not share a letter are statistically different (p<0.05; protected LSD post-hoc t-tests). Lowercase letters are used for comparing reference stream reaches; uppercase letters are used for MTR/VF stream reaches. The asterisk indicates statistical significance (p=0.0084) between site types within 2015. Error bars show 95% confidence intervals. MTR/VF stream reaches are located below valley fills on the reclaimed Laurel Fork Surface Mine. Reference stream reaches are within Robinson Forest.

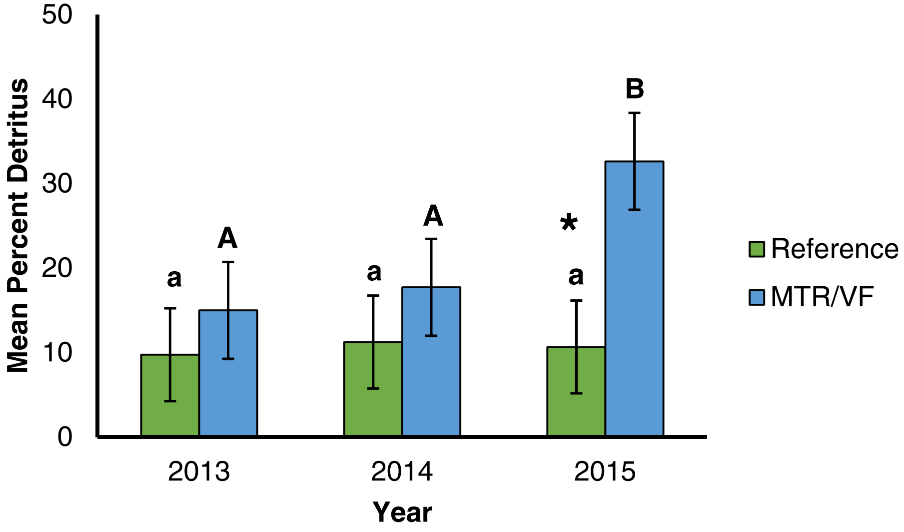


Figure 3.2 Mean Number of Cover Objects. From a repeated measures ANOVA, the interaction of site type and year was not statistically significant (F(2,42)=0.46, p=0.6358). Error bars show 95% confidence intervals. MTR/VF stream reaches are located below valley fills on the reclaimed Laurel Fork Surface Mine. Reference stream reaches are within Robinson Forest.

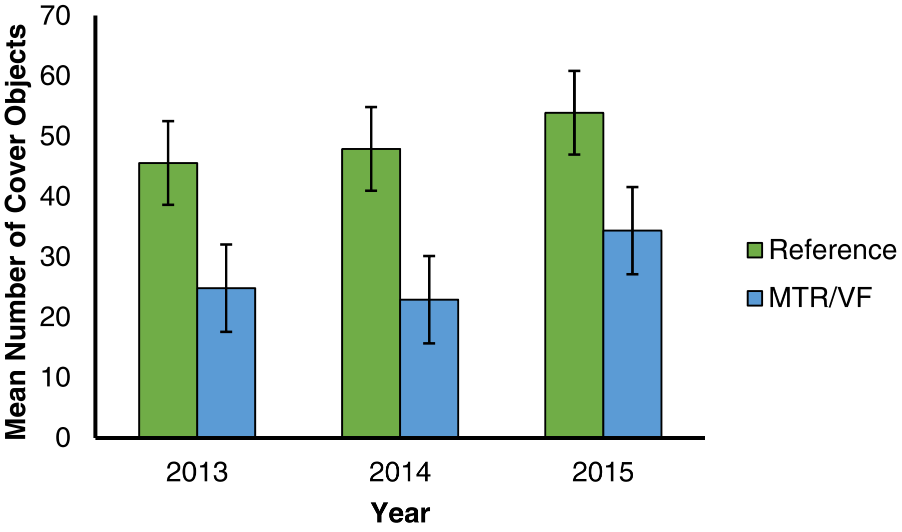


Figure 3.3 Comparison of Specific Conductance from May 2013-2015. Columns show mean specific conductance from grab samples in May 2013, May 2014, and May 2015. From a repeated measures ANOVA, the interaction of site type and year was statistically significant (F(2,42)=24.04, $p<0.0001$). Letters show statistical significance; columns that do not share a letter are statistically different ($p<0.05$; protected LSD post-hoc t-tests). Lowercase letters are used for comparing reference stream reaches; uppercase letters are used for MTR/VF stream reaches. Asterisks indicate statistical significance ($p<0.0001$) between site types within a single year. Error bars show 95% confidence intervals. MTR/VF stream reaches are located below valley fills on the reclaimed Laurel Fork Surface Mine. Reference stream reaches are within Robinson Forest.

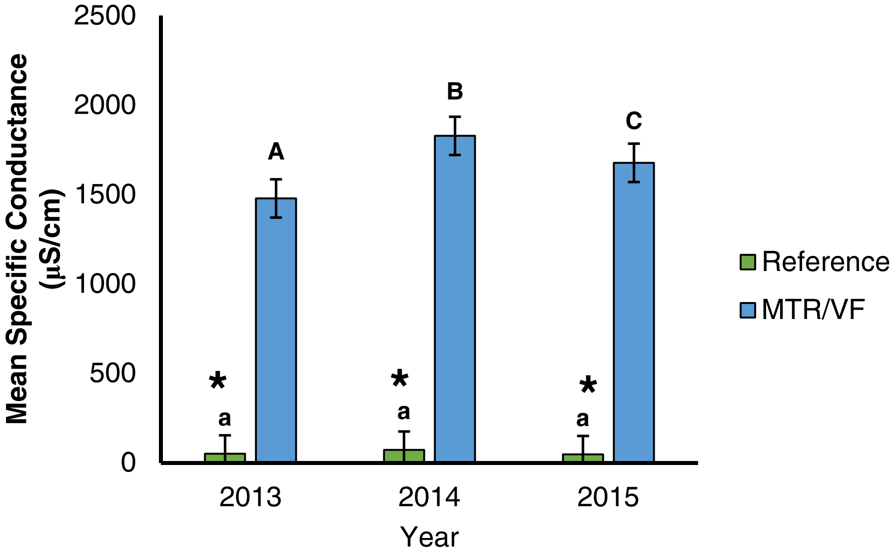


Figure 3.4 Monthly Mean Specific Conductance. Columns show mean specific conductance from monthly grab samples from April 2015-March 2016. From a repeated measures ANOVA, the interaction of site type and month was statistically significant ($F(11,231)=11.70$, $p<0.0001$). Reference specific conductance was not significantly different across months ($p>0.05$); however, specific conductance between site types was statistically significant ($p<0.0001$) for every month (protected LSD post-hoc t-tests). Asterisks indicate significant differences ($p<0.05$) in specific conductance of MTR/VF stream reaches between successive months. Error bars show 95% confidence intervals. MTR/VF stream reaches are located below valley fills on the reclaimed Laurel Fork Surface Mine. Reference stream reaches are within Robinson Forest.

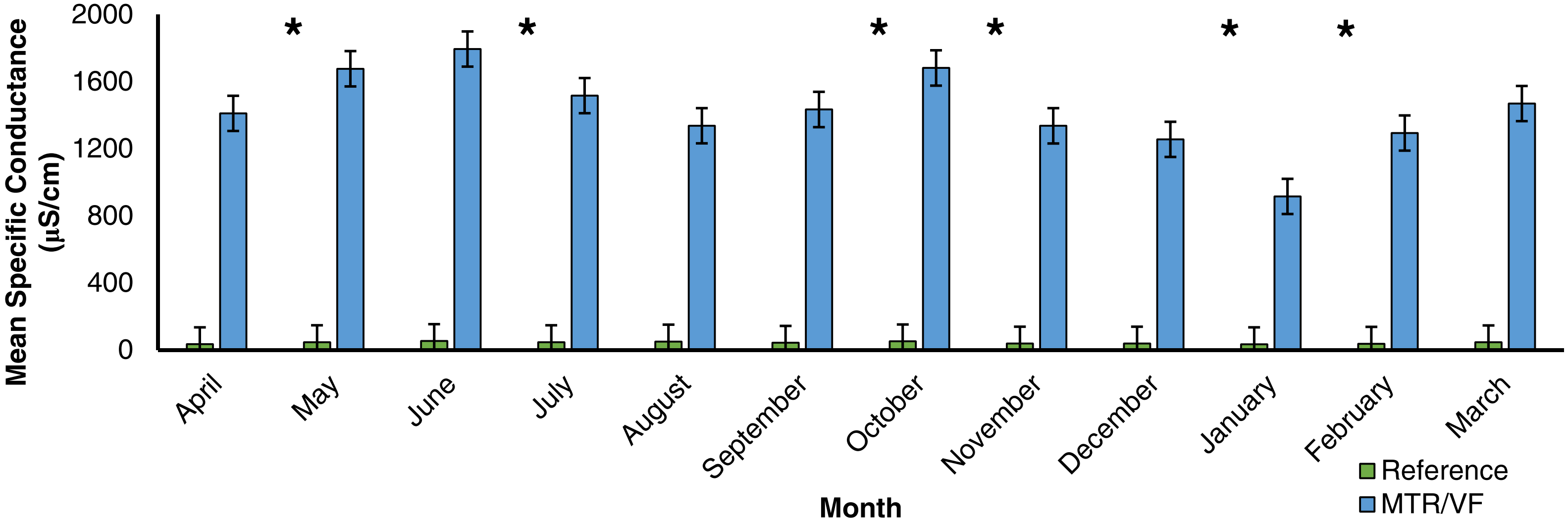


Figure 3.5 Posterior Distribution for Detection Covariates. This figure shows the mean effect of number of cover objects (logs ≥8 cm and rocks ≥15 cm) within 10-meter stream reaches and date of last precipitation (in relation to salamander sampling events) on salamander detection. Points are posterior means, and error bars show 95% credible intervals.

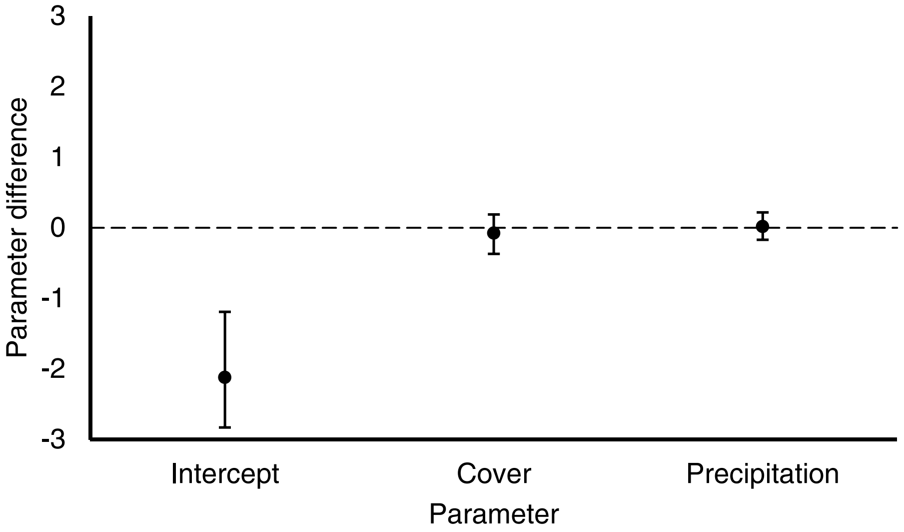


Figure 3.6 Species-Specific Posterior Distributions for Detection Covariates. These figures show the species-specific effects of number of cover objects (logs ≥8 cm and rocks ≥15 cm) within 10-meter stream reaches and date of last precipitation (in relation to salamander sampling events) on salamander detection. Points are posterior means, and error bars show 95% credible intervals. Groups are *Desmognathus fuscus* adults (DfA), *D. monticola* adults (DmA), *Eurycea cirrigera* adults (EcA), *Gyrinophilus porphyriticus* adults and larvae (Gp), *Pseudotriton ruber* adults and larvae (Pr), *E. cirrigera* larvae (EcL), and *Desmognathus* larvae (DuL).

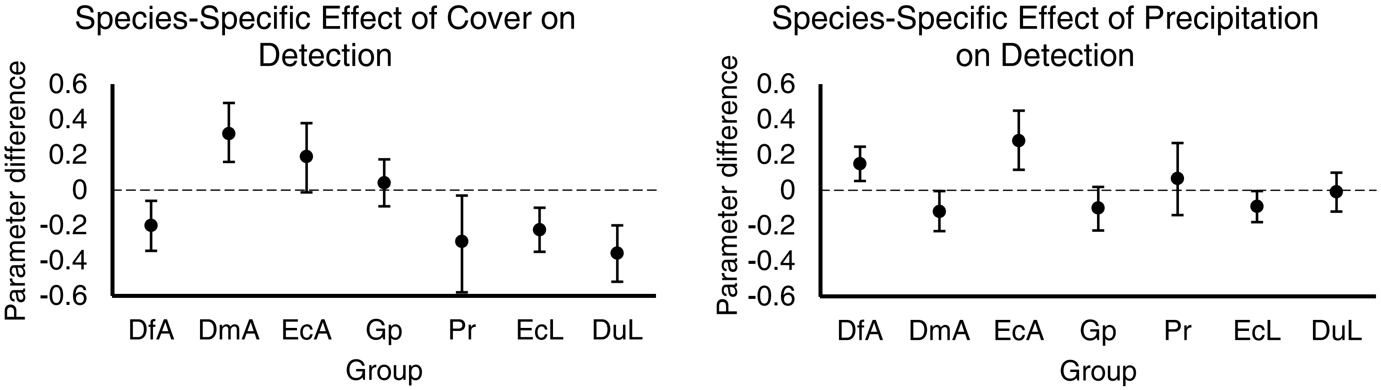


Figure 3.7 Stream Salamander Initial Occupancy Estimates. This figure shows species-specific and mean initial occupancy estimates in reclaimed mountaintop removal mining with valley fills (MTR/VF) and second-growth forest (reference) stream reaches. Columns represent average initial occupancy, and error bars show 95% credible intervals. Groups are denoted as *Desmognathus fuscus* adults (DfA), *D. monticola* adults (DmA), *Eurycea cirrigera* adults (EcA), *Gyrinophilus porphyriticus* adults and larvae (Gp), *Pseudotriton ruber* adults and larvae (Pr), *E. cirrigera* larvae (EcL), and *Desmognathus* larvae (DuL). MTR/VF stream reaches are located below valley fills on the reclaimed Laurel Fork Surface Mine. Reference stream reaches are within Robinson Forest.

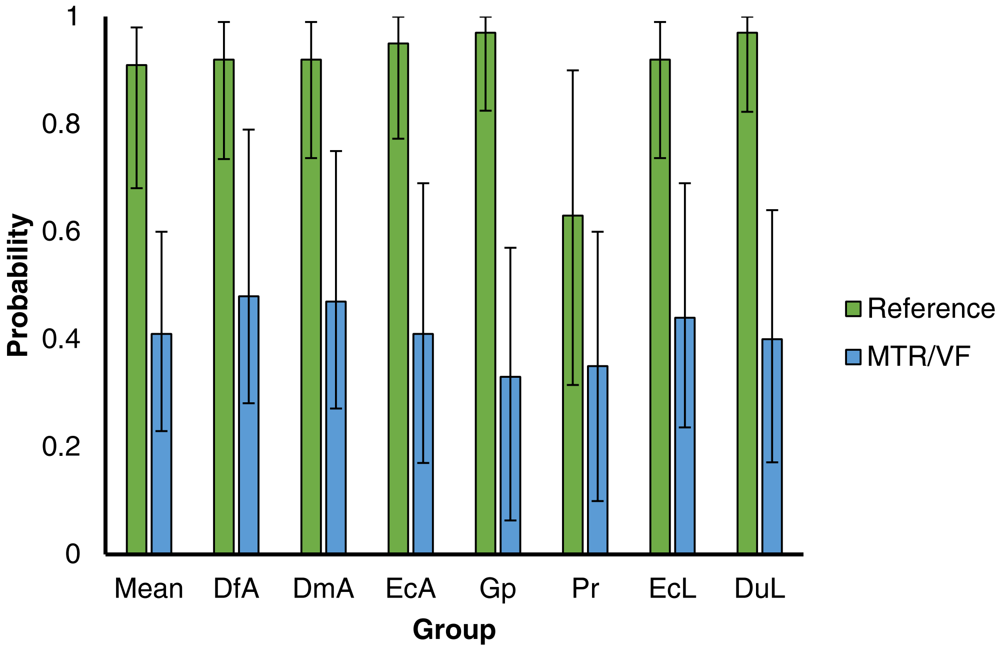


Figure 3.8 Stream Salamander Abundance Estimates. This figure shows species-specific abundance estimates, given occupancy, for reclaimed mountaintop removal mining with valley fills (MTR/VF) and second-growth forest (reference) stream reaches. Columns represent average abundance, and error bars show 95% credible intervals. Groups are *Desmognathus fuscus* adults (DfA), *D. monticola* adults (DmA), *Eurycea cirrigera* adults (EcA), *Gyrinophilus porphyriticus* adults and larvae (Gp), *Pseudotriton ruber* adults and larvae (Pr), *E. cirrigera* larvae (EcL), and *Desmognathus* larvae (DuL). MTR/VF stream reaches are located below valley fills on the reclaimed Laurel Fork Surface Mine. Reference stream reaches are within Robinson Forest.

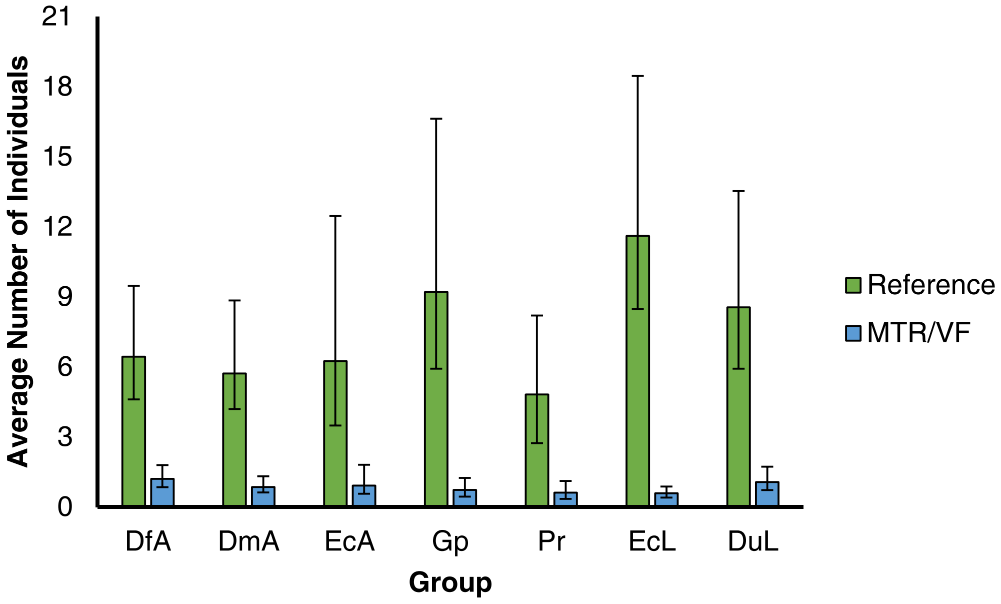


Figure 3.9 Stream Salamander Colonization Estimates. This figure shows species-specific and mean colonization estimates for reclaimed mountaintop removal mining with valley fills (MTR/VF) and second-growth forest (reference) stream reaches. Columns represent average colonization, and error bars show 95% credible intervals. Groups are *Desmognathus fuscus* adults (DfA), *D. monticola* adults (DmA), *Eurycea cirrigera* adults (EcA), *Gyrinophilus porphyriticus* adults and larvae (Gp), *Pseudotriton ruber* adults and larvae (Pr), *E. cirrigera* larvae (EcL), and *Desmognathus* larvae (DuL). MTR/VF stream reaches are located below valley fills on the reclaimed Laurel Fork Surface Mine. Reference stream reaches are within Robinson Forest.

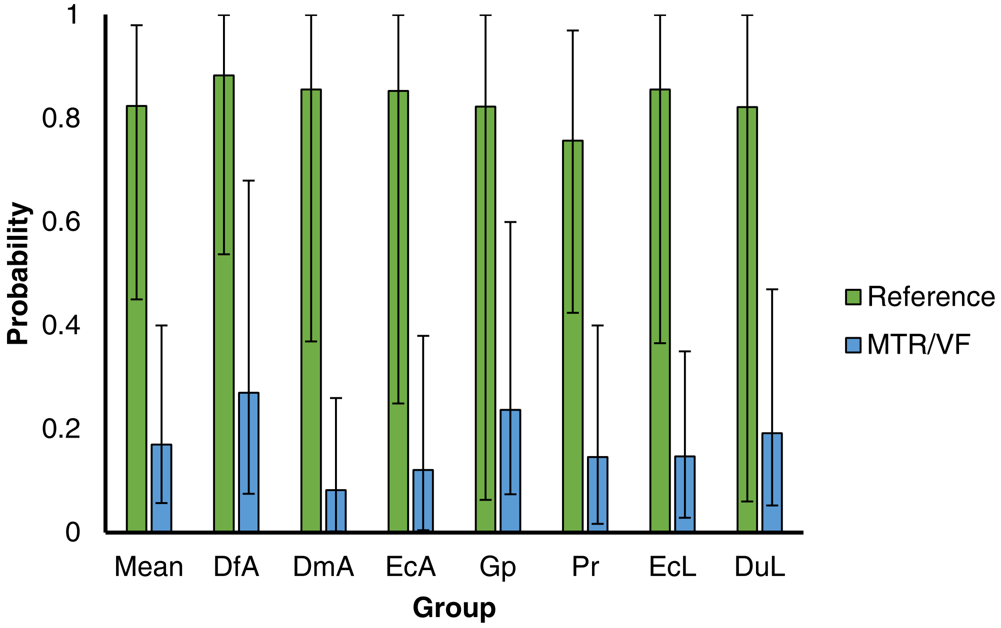


Figure 3.10 Stream Salamander Survival Estimates. This figure shows species-specific and mean survival estimates for reclaimed mountaintop removal mining with valley fills (MTR/VF) and second-growth forest (reference) stream reaches. Columns represent average survival, and error bars show 95% credible intervals. Groups are *Desmognathus fuscus* adults (DfA), *D. monticola* adults (DmA), *Eurycea cirrigera* adults (EcA), *Gyrinophilus porphyriticus* adults and larvae (Gp), *Pseudotriton ruber* adults and larvae (Pr), *E. cirrigera* larvae (EcL), and *Desmognathus* larvae (DuL). MTR/VF stream reaches are located below valley fills on the reclaimed Laurel Fork Surface Mine. Reference stream reaches are within Robinson Forest.

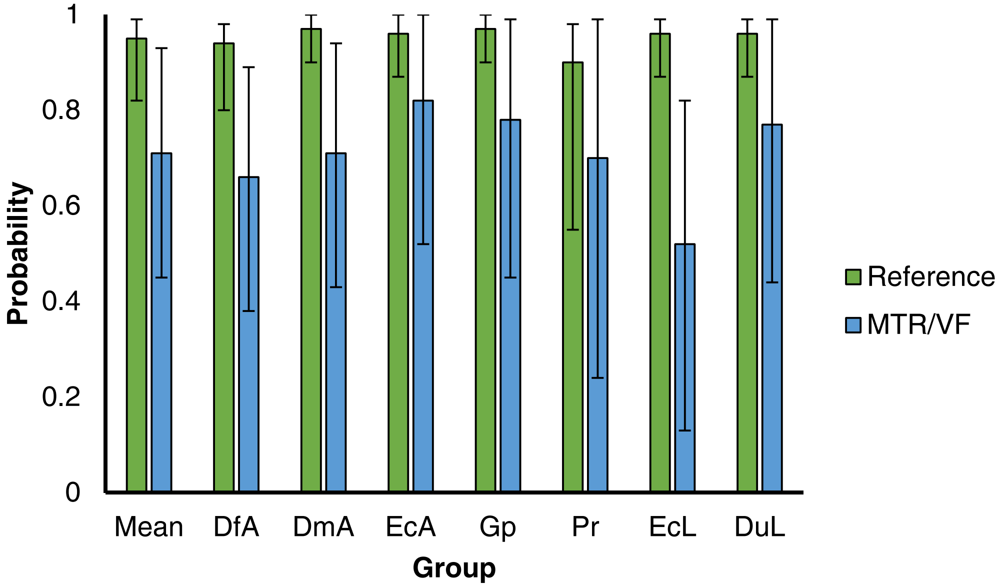


Figure 3.11 Posterior Distribution for Site Type. This figure shows the mean effect of site type (second-growth forest (reference) stream reaches vs. reclaimed mountaintop removal mining with valley fills (MTR/VF) stream reaches) on initial occupancy, abundance, colonization, and survival estimates. Points are posterior means, and error bars show 95% credible intervals. Positive values indicate higher parameter estimates in reference stream reaches than in MTR/VF stream reaches. MTR/VF stream reaches are located below valley fills on the reclaimed Laurel Fork Surface Mine. Reference stream reaches are within Robinson Forest.

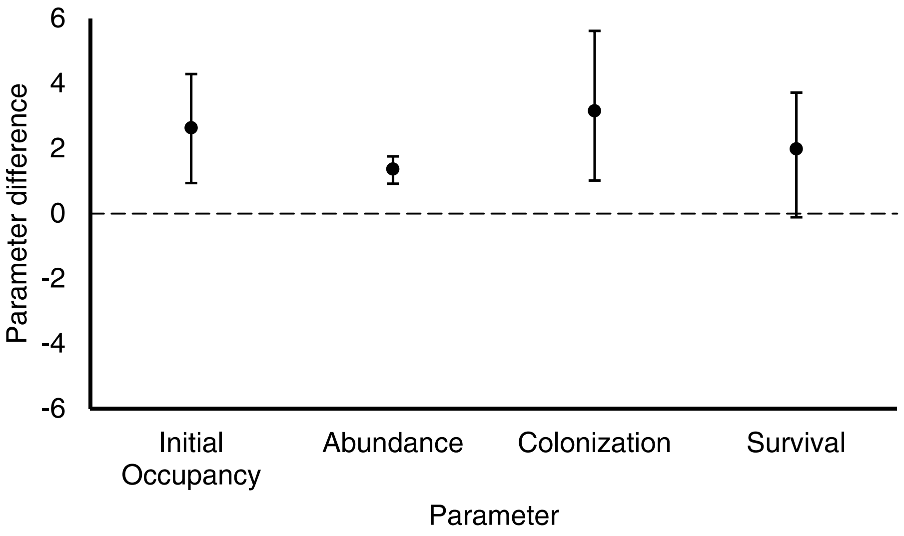


Figure 3.12 Species-Specific Posterior Distributions for Site Type. These figures show the species-specific effects of site type (second-growth forest (reference) stream reaches vs. reclaimed mountaintop removal mining with valley fills (MTR/VF) stream reaches) on occupancy dynamic estimates. Points are posterior means, and error bars show 95% credible intervals. Groups are *Desmognathus fuscus* adults (DfA), *D. monticola* adults (DmA), *Eurycea cirrigera* adults (EcA), *Gyrinophilus porphyriticus* adults and larvae (Gp), *Pseudotriton ruber* adults and larvae (Pr), *E. cirrigera* larvae (EcL), and *Desmognathus* larvae (DuL). MTR/VF stream reaches are located below valley fills on the reclaimed Laurel Fork Surface Mine. Reference stream reaches are within Robinson Forest.

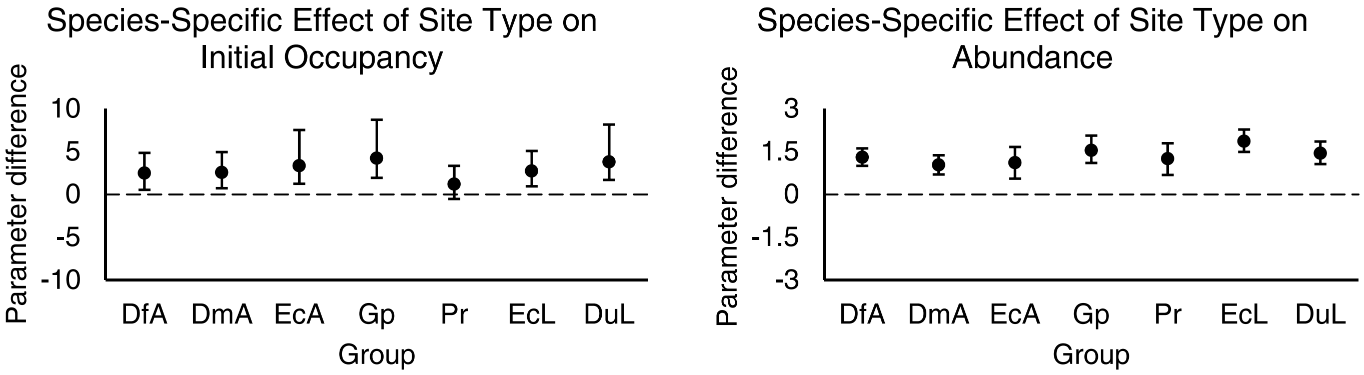


Figure 3.12 (continued).

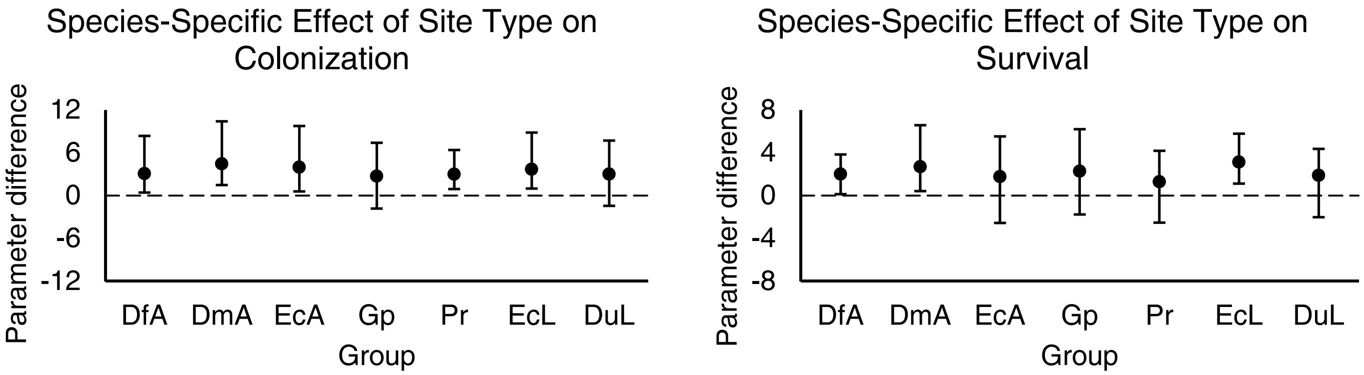


Figure 3.13 Posterior Distribution for Specific Conductance. This figure shows the mean effect of conductivity on initial occupancy, abundance, colonization, and survival estimates. Points are posterior means, and error bars show 95% credible intervals.

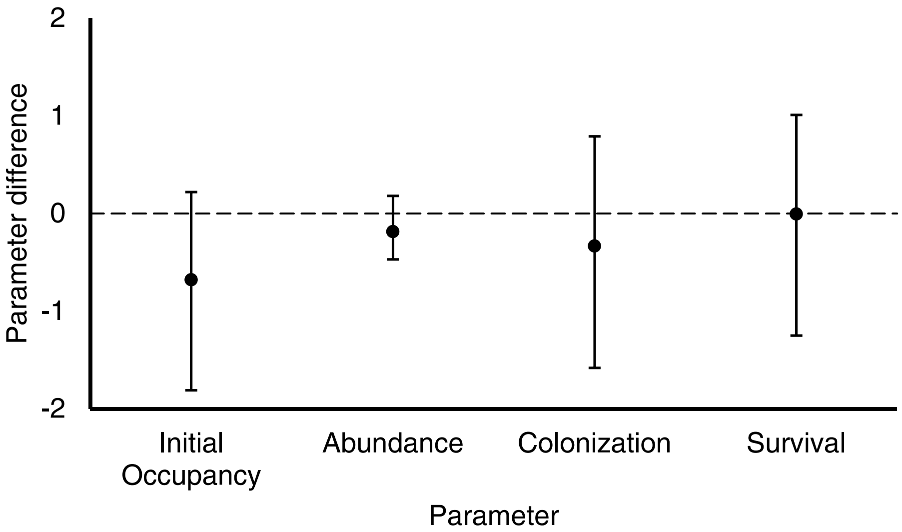
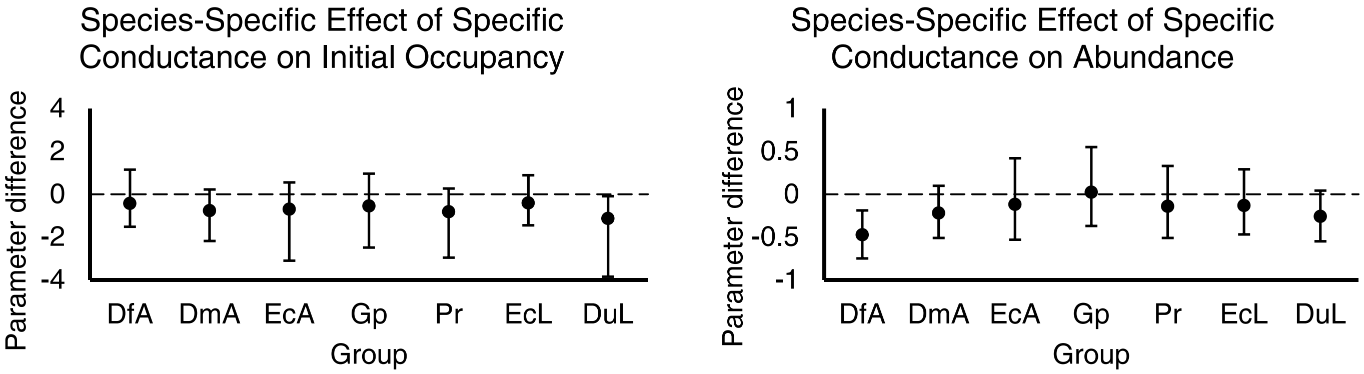
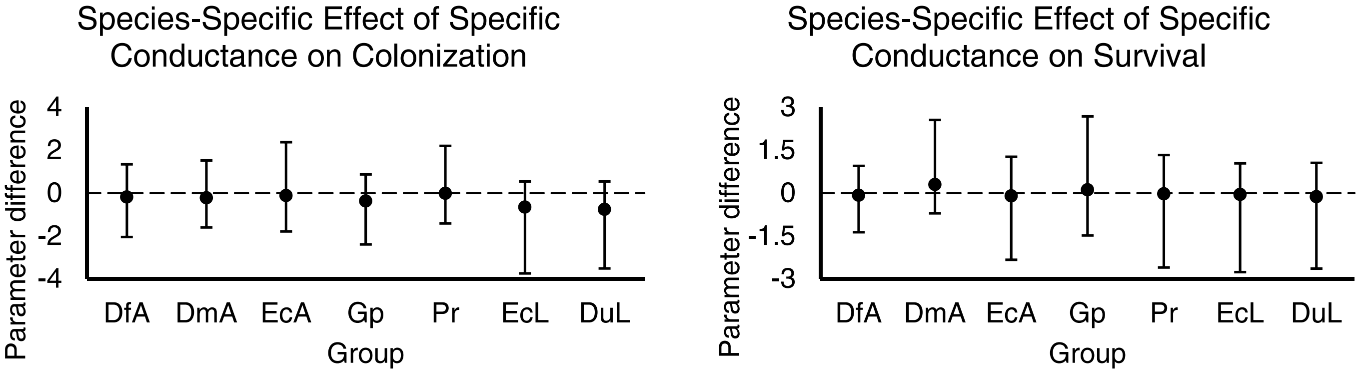


Figure 3.14 Species-Specific Posterior Distributions for Specific Conductance. These figures show the species-specific effects of conductivity on initial occupancy, abundance, colonization, and survival. Points are posterior means, and error bars show 95% credible intervals. Groups are *Desmognathus fuscus* adults (DfA), *D. monticola* adults (DmA), *Eurycea cirrigera* adults (EcA), *Gyrinophilus porphyriticus* adults and larvae (Gp), *Pseudotriton ruber* adults and larvae (Pr), *E. cirrigera* larvae (EcL), and *Desmognathus* larvae (DuL).


Species-Specific Effect of Specific Conductance on Initial Occupancy

Species-Specific Effect of Specific Conductance on Abundance

Figure 3.14 (continued).



CHAPTER 4: DISCUSSION

I found that over a three year period, stream salamander populations in MTR/VF stream reaches had reduced initial occupancy, abundance, colonization, and survival probabilities compared to reference stream reaches. Site type influenced the occupancy parameters, with MTR/VF occupancy parameters generally reduced, as evidenced by the posterior distributions. Although the effect of specific conductance on the occupancy parameters was unclear from my analyses, MTR/VF stream reaches always had elevated monthly and yearly specific conductance. MTR/VF stream reaches also had increased percentage of detritus and fewer cover objects than reference stream reaches. The perennial nature of the MTR/VF stream reaches is yet another alteration from typical intermittent Appalachian streams.

My data provide empirical evidence to Green (2003)'s claim that small stream-dwelling amphibians maintain stable populations. From reference stream reaches, I had a consistent number of salamander detections each year as well as high initial occupancy and abundance. This was expected, as stream salamanders have shown high occupancy in forested streams in previous studies (Price et al. 2011, Muncy et al. 2014). High colonization and survival estimates for reference stream reaches further reflect the stability of salamander populations in forested catchments. Even if local extinctions occur, my data suggest that recolonization rates are high and may allow for species recovery (Sjögren 1991, Hanski 1999).

Stream salamander populations in MTR/VF stream reaches, on the other hand, show altered population vital rates. In particular, the low colonization estimates could signify disruptions to dispersal in MTR/VF streams. For *D. fuscus* and *D. monticola*, juveniles are the dispersal agents, whereas adults are philopatric (Grant et al. 2010). Juveniles mostly use the terrestrial landscape to disperse (Grant et al. 2010); this out-of-network dispersal is advantageous compared to in-network since it requires less distance to access nearby reaches (Macneale et al. 2005) and reduces extinction risk by increasing connectivity among reaches (Hill et al. 2002). In Grant et al.'s study (2010), *D. fuscus* and *D. monticola* individuals had similar dispersal probabilities, likely due to comparable life histories. In my study, both species had reduced colonization probabilities in MTR/VF stream reaches compared to reference stream reaches, although *D. monticola* had a pronounced lower estimate in MTR/VF stream reaches compared to *D. fuscus*. This suggests that *Desmognathus* juveniles of both species may be having difficulties dispersing overland to other headwater stream reaches in the MTR/VF landscape.

Plethodontid salamanders have physiological limitations to dispersal, due to moisture and temperature requirements for respiration (Feder 1983), which may be exacerbated by reduced forest cover seen in the MTR/VF catchments (Reference 0.99 (95% CI= 0.99 to 1.00), MTR/VF 0.25 (95% CI=0.12 to 0.38); Muncy et al. 2014). Reduced canopy cover often increases temperature and decreases soil moisture (Chen et al. 1999), which likely prevent terrestrial salamander populations from obtaining pre-mining abundances on reclaimed MTR/VF land (Wood and Williams 2013b). Salamanders also have behavioral responses to changes in canopy cover, as dispersing Desmognathine salamanders avoid within-stream canopy gaps (Cecala et al. 2014). Dispersal limitations such as these could have contributed to low colonization of stream salamanders in MTR/VF stream reaches.

Conversely, reduced colonization in MTR/VF stream reaches may be a result of lack of local recruitment. In the MTR/VF stream reaches, all groups that included larvae (*E. cirrigera* larvae, *Desmognathus* larvae, *P. ruber*, and *G. porphyriticus*) had colonization below 0.25, indicating a less than 25% chance of recruitment. Even if a species was present in the stream below the stream reach and moved upstream to my sampling area (Lowe 2003, Lowe et al. 2008), there is little probability that larvae would be present the next year. On the other hand, larval salamanders had high probabilities (>0.75) of colonizing reference stream reaches where previously absent or undetected. Larvae in reference reaches, therefore, have much greater local recruitment compared to in MTR/VF reaches.

Individual survivorship may be reduced in MTR/VF stream reaches, leading to low population survival and potentially low colonization if dispersers are not able to persist. Impacts to the aquatic environment, as analyzed in this study, may be especially relevant to individual survival. *Eurycea cirrigera* larval abundance decreases at detritus concentrations greater than 11.40% (Miller et al. 2007), and the mean detritus concentration in MTR/VF stream reaches was at least 15% all three years of this study. Lower abundance suggests a reduction in survival, in this case likely due to inadequate prey base. Macroinvertebrates, the main food supply for stream salamanders, are the key organisms that reduce in-stream detritus amounts (Webster 1983), and the high percentage of detritus within MTR/VF stream reaches may indicate a lack of macroinvertebrate taxa. Additionally, detritus tends to dissolve slower in MTR/VF stream reaches and is strongly correlated with specific conductance (Fritz et al. 2010). Similarly, elevated levels of specific conductance are often correlated with low species richness and abundance of sensitive macroinvertebrates (Pond 2010, Pond 2012, Pond et al., 2014).

The altered hydrological regime likely has consequences for salamander persistence. While a few intermittent streams have been known to become perennial due to effluent discharge, the ecological effects of this transformation are unknown (Datry et al. 2014). In this study, the lowest survival estimate was for *E. cirrigera* larvae. *Eurycea,* particularly first-year larvae, are unable to combat drift downstream (Johnson and Goldberg 1975). As a result of increased runoff, *E. cirrigera* larvae may be washed away to farther downstream reaches (Barrett et al. 2010). Reduced infiltration from compaction and reduction of forest cover in catchments are known to increase runoff in MTR/VF stream reaches (Negley and Eshleman 2006). Yearly flow at MTR/VF stream reaches, as indicated by the hydroperiod calculations, suggests that these stream channels could be affected by increased peak water flow at any time in the year and inhibit larval *Eurycea* survival in particular.

Specific conductance did not have a strong correlation to colonization or survival, but the model analysis only considered the specific conductance variation within MTR/VF sites. Since mean specific conductance level in the MTR/VF stream reaches was consistently above the aquatic benchmark of 300 μS/cm in Central Appalachian Ecoregion (U.S. EPA 2011), individual survival may be so low as to not show any further effects due to specific conductance changes within MTR/VF stream reaches, even though known consequences of elevated specific conductance for amphibians include increased larval corticosterone levels and decreased survival (Karraker et al. 2008, Chambers 2011). Hitt and Chambers (2014) estimated a threshold specific conductance between 600 and 1000 µS/cm for fish in West Virginia. Regional headwater fish have conductivity thresholds of 343 µS/cm (for blackside dace) and 261 µS/cm (Kentucky arrow darter), above which few individuals are found (Hitt et al. 2016). Future studies should similarly calculate threshold values for stream salamanders in order to better understand the potential effects of specific conductance on individual survival.

From my data, it is evident that MTR/VF impacts not only the terrestrial and aquatic environments but also the persistence of stream salamanders on the landscape. If other MTR/VF stream reaches in the region are similar in habitat and water chemistry to my study stream reaches, stream salamander populations in MTR/VF stream reaches will decline unless steps are taken to ensure both structural and functional restoration of MTR/VF streams (Bernhardt and Palmer 2011). The Office of Surface Mining Reclamation and Enforcement recently proposed the Stream Protection Rule (2015), in compliance with the Clean Water Act (Environmental Protection Agency 1972) and SMCRA (Office of Surface Mining 1977), which may aid in future restoration processes. Recommended regulations in the proposed Rule include broader stream buffer zones and better overall protection and restoration of headwater streams (Office of Surface Mining Reclamation and Enforcement 2015). Future MTR/VF management needs to consider limitations to overland dispersal and protect upland habitat in addition to aquatic habitat (Miller et al. 2015). Implementation of these regulations, along with practices that help restore the vegetative structure of MTR/VF sites such as the Forestry Reclamation Approach (Angel et al. 2005), could reduce landscape resistance, repair hydrological regimes, and allow for improved salamander colonization and survival in MTR/VF stream reaches.

APPENDICES

APPENDIX A-MATRICES

A.01 Species-specific encounter matrices.

A.01.1 *D. fuscus* adult.

Site	MTR/VF	C1.1	C1.2	C1.3	C1.4	C2.1	C2.2	C2.3	C3.1	C3.2	C3.3
Boardinghouse	0	1	0	0	0	0	0	7	2	2	4
Bucklick	0	1	1	1	2	0	0	0	2	1	9
Cole's Fork A	0	0	0	2	1	5	3	5	0	5	15
Falling Rock A	0	5	7	4	5	6	8	3	3	7	1
Falling Rock B	0	0	0	0	0	3	1	2	4	3	1
Field Branch A	0	7	0	1	4	7	8	11	3	8	11
Goff	0	5	2	1	1	6	3	1	5	5	2
Little Millseat A	0	3	4	3	5	6	3	10	5	7	5
Little Millseat B	0	2	5	0	8	12	6	13	8	14	14
Miller	0	0	1	0	2	5	3	1	0	4	1
Mulberry	0	1	1	0	1	0	0	0	1	0	1
Tome	0	1	0	2	0	2	2	2	9	1	1
Bee Branch Far	1	1	0	0	0	1	0	1	0	3	0
Bee Branch Near	1	2	2	0	1	0	0	1	3	6	3
Big Hollow	1	0	0	0	0	0	0	0	0	0	0
Hickory Log	1	0	0	0	0	0	0	1	0	0	0
Spice	1	0	0	1	0	0	0	0	0	0	0
Stillrock	1	0	0	1	0	1	0	0	0	0	0
Turkey	1	0	0	0	0	0	0	0	1	1	1
Unnamed White Oak Left	1	1	3	4	2	3	2	3	0	0	0
Unnamed White Oak Right	1	0	0	0	0	0	0	0	6	1	5
Wharton	1	0	0	0	0	0	1	0	0	0	0
White Oak	1	0	0	3	4	1	1	1	0	0	0

A.01.2 *D. monticola* adult.

Site	MTR/VF	C1.1	C1.2	C1.3	C1.4	C2.1	C2.2	C2.3	C3.1	C3.2	C3.3
Boardinghouse	0	3	2	3	2	3	7	4	2	4	2
Bucklick	0	4	6	3	3	8	5	7	3	3	5
Cole's Fork A	0	1	4	2	0	11	1	5	3	5	8
Falling Rock A	0	1	0	0	0	2	1	0	0	0	1
Falling Rock B	0	6	4	4	1	13	8	12	2	2	6
Field Branch A	0	5	4	2	2	4	0	0	2	2	3
Goff	0	0	2	4	1	4	3	5	4	3	7
Little Millseat A	0	0	2	5	4	6	3	5	1	1	1
Little Millseat B	0	0	0	0	0	0	1	0	2	1	1
Miller	0	1	2	7	5	6	7	7	3	5	11
Mulberry	0	0	2	1	0	1	5	6	1	1	2
Tome	0	13	3	2	1	3	2	3	4	3	5
Bee Branch Far	1	0	0	2	1	0	1	0	1	1	2
Bee Branch Near	1	0	1	6	3	0	5	4	2	6	6
Big Hollow	1	0	0	0	0	0	0	0	0	0	0
Hickory Log	1	0	0	0	0	0	0	0	0	0	0
Spice	1	0	0	0	0	0	0	0	0	0	0
Stillrock	1	0	0	0	1	0	0	0	0	0	0
Turkey	1	0	0	0	1	0	0	0	0	0	0
Unnamed White Oak Left	1	3	0	0	0	0	0	0	0	0	0
Unnamed White Oak Right	1	0	0	0	0	0	0	0	0	0	0
Wharton	1	0	1	0	0	0	0	1	1	1	0
White Oak	1	0	0	0	0	0	0	0	0	0	0

A.01.3 *E. cirrigera* adult.

Site	MTR/VF	C1.1	C1.2	C1.3	C1.4	C2.1	C2.2	C2.3	C3.1	C3.2	C3.3
Boardinghouse	0	2	0	0	0	0	0	0	1	1	0
Bucklick	0	0	0	2	0	0	0	1	5	0	4
Cole's Fork A	0	2	0	0	0	0	0	2	0	0	1
Falling Rock A	0	4	1	2	0	0	1	0	1	0	0
Falling Rock B	0	3	2	0	0	4	1	1	2	4	1
Field Branch A	0	4	2	0	0	0	0	1	0	1	0
Goff	0	4	2	0	0	0	0	0	3	2	1
Little Millseat A	0	4	0	0	1	1	0	1	2	1	0
Little Millseat B	0	0	0	0	0	3	0	0	1	0	0
Miller	0	5	0	0	0	5	0	0	1	1	0
Mulberry	0	4	0	0	0	2	0	0	1	1	2
Tome	0	1	0	1	0	5	0	0	2	0	0
Bee Branch Far	1	0	1	0	0	1	0	0	0	0	0
Bee Branch Near	1	2	0	0	0	1	0	1	2	0	0
Big Hollow	1	0	0	0	0	0	0	0	0	0	0
Hickory Log	1	0	0	0	0	0	0	0	0	0	0
Spice	1	0	0	0	0	0	0	0	0	0	0
Stillrock	1	0	0	0	0	0	0	0	0	0	0
Turkey	1	1	0	0	0	0	0	1	0	1	0
Unnamed White Oak Left	1	0	0	0	0	0	0	0	0	0	0
Unnamed White Oak Right	1	0	0	0	0	0	0	0	0	0	0
Wharton	1	0	0	0	0	1	0	0	1	1	0
White Oak	1	0	0	0	0	0	0	0	0	0	0

A.01.4 *G. porphyriticus* adult and larvae.

Site	MTR/VF	C1.1	C1.2	C1.3	C1.4	C2.1	C2.2	C2.3	C3.1	C3.2	C3.3
Boardinghouse	0	2	1	6	2	4	3	4	1	5	4
Bucklick	0	2	5	5	0	1	6	2	0	4	7
Cole's Fork A	0	1	6	4	0	1	2	3	2	6	6
Falling Rock A	0	1	0	3	2	1	2	1	1	1	2
Falling Rock B	0	2	3	3	2	2	4	4	1	8	3
Field Branch A	0	4	1	2	7	3	2	4	4	2	1
Goff	0	1	0	1	0	0	1	1	4	4	3
Little Millseat A	0	0	1	0	2	0	1	3	1	1	1
Little Millseat B	0	1	1	0	0	0	2	1	2	5	5
Miller	0	0	1	3	10	1	6	8	0	5	6
Mulberry	0	0	2	4	3	4	1	0	0	3	3
Tome	0	1	2	7	2	3	3	1	0	3	1
Bee Branch Far	1	0	0	0	0	0	0	0	0	0	1
Bee Branch Near	1	0	0	2	0	1	0	0	0	0	0
Big Hollow	1	0	0	0	0	0	0	0	0	0	0
Hickory Log	1	0	0	0	0	1	1	1	0	1	0
Spice	1	0	0	0	0	0	0	0	0	0	0
Stillrock	1	0	0	0	0	0	0	0	0	0	0
Turkey	1	0	0	0	0	0	0	0	0	0	0
Unnamed White Oak Left	1	0	0	0	0	0	0	0	1	0	0
Unnamed White Oak Right	1	0	0	0	0	0	0	0	1	1	1
Wharton	1	0	0	0	0	0	0	0	0	0	0
White Oak	1	0	0	0	0	0	1	0	2	2	2

A.01.5 *P. ruber* adult and larvae.

Site	MTR/VF	C1.1	C1.2	C1.3	C1.4	C2.1	C2.2	C2.3	C3.1	C3.2	C3.3
Boardinghouse	0	4	0	2	1	1	6	3	0	1	4
Bucklick	0	0	0	0	0	1	0	2	3	1	0
Cole's Fork A	0	0	0	4	0	0	0	5	1	6	7
Falling Rock A	0	0	0	2	1	0	0	0	2	3	1
Falling Rock B	0	0	0	0	0	0	0	1	0	2	0
Field Branch A	0	1	2	0	1	1	2	8	0	1	0
Goff	0	0	0	0	0	1	0	1	0	0	0
Little Millseat A	0	0	3	0	0	0	0	0	0	4	0
Little Millseat B	0	0	0	0	0	0	0	0	0	1	0
Miller	0	1	0	0	0	0	0	0	1	0	0
Mulberry	0	0	0	0	0	0	0	0	0	0	1
Tome	0	0	0	0	0	0	0	0	0	0	0
Bee Branch Far	1	0	0	0	0	0	0	0	0	0	0
Bee Branch Near	1	0	1	0	0	0	0	1	0	0	0
Big Hollow	1	0	0	0	0	0	0	0	0	0	0
Hickory Log	1	0	0	0	0	0	0	0	1	0	3
Spice	1	0	0	0	0	0	0	0	0	0	0
Stillrock	1	0	0	0	0	0	0	0	0	0	0
Turkey	1	0	0	0	0	0	0	0	0	0	0
Unnamed White Oak Left	1	0	1	3	0	0	0	1	0	0	0
Unnamed White Oak Right	1	0	0	0	0	0	0	0	0	0	0
Wharton	1	0	0	0	0	0	0	0	0	0	0
White Oak	1	0	0	0	0	1	0	0	0	0	0

A.01.6 Combination *Desmognathus* larvae (*D. fuscus* and *D. monticola*).

Site	MTR/VF	C1.1	C1.2	C1.3	C1.4	C2.1	C2.2	C2.3	C3.1	C3.2	C3.3
Boardinghouse	0	1	8	7	2	1	3	0	9	3	1
Bucklick	0	4	2	14	0	3	5	0	6	2	0
Cole's Fork A	0	10	8	3	7	4	4	4	7	8	0
Falling Rock A	0	2	5	7	0	1	1	1	5	2	0
Falling Rock B	0	3	11	5	12	0	3	1	2	5	1
Field Branch A	0	7	6	3	8	1	5	0	6	5	0
Goff	0	0	0	0	2	0	0	1	2	0	0
Little Millseat A	0	2	3	0	2	1	6	1	0	1	4
Little Millseat B	0	8	5	9	0	2	2	0	2	3	0
Miller	0	2	2	3	3	0	4	2	2	0	0
Mulberry	0	1	3	0	4	1	1	2	3	2	0
Tome	0	0	1	0	3	3	1	3	0	0	0
Bee Branch Far	1	0	0	2	0	2	0	0	2	1	0
Bee Branch Near	1	3	2	0	2	0	1	0	0	0	0
Big Hollow	1	0	0	0	0	0	0	0	0	0	0
Hickory Log	1	0	0	0	0	0	0	0	0	0	0
Spice	1	0	0	0	0	0	0	0	0	0	0
Stillrock	1	0	0	0	0	0	0	0	0	0	0
Turkey	1	6	4	1	0	0	0	0	2	1	0
Unnamed White Oak Left	1	2	1	2	0	2	0	0	1	0	0
Unnamed White Oak Right	1	0	0	0	0	0	0	0	2	3	0
Wharton	1	0	0	0	0	0	0	0	1	0	0
White Oak	1	0	0	0	0	0	0	0	0	0	0

A.01.7 *E. cirrigera* larvae.

Site	MTR/VF	C1.1	C1.2	C1.3	C1.4	C2.1	C2.2	C2.3	C3.1	C3.2	C3.3
Boardinghouse	0	1	6	4	13	13	20	6	4	7	9
Bucklick	0	2	2	3	11	9	16	37	3	12	14
Cole's Fork A	0	0	0	1	0	3	1	4	2	6	0
Falling Rock A	0	8	7	7	36	5	11	15	6	6	10
Falling Rock B	0	1	1	2	9	4	10	5	7	8	8
Field Branch A	0	7	4	2	6	6	9	9	2	2	2
Goff	0	3	1	3	11	0	3	13	0	4	9
Little Millseat A	0	4	5	2	6	7	7	11	12	13	17
Little Millseat B	0	0	0	0	0	3	2	1	0	0	2
Miller	0	1	0	0	5	0	1	1	0	0	0
Mulberry	0	1	1	1	4	4	3	6	2	0	2
Tome	0	0	0	0	9	2	2	2	0	2	11
Bee Branch Far	1	0	0	0	0	0	0	0	1	0	1
Bee Branch Near	1	1	1	0	0	0	0	2	0	1	8
Big Hollow	1	0	0	0	0	0	0	0	0	0	0
Hickory Log	1	0	1	2	2	0	0	0	0	0	0
Spice	1	0	1	0	0	0	0	0	0	0	0
Stillrock	1	0	0	0	0	0	0	0	0	0	0
Turkey	1	0	0	0	0	0	0	4	0	0	0
Unnamed White Oak Left	1	1	0	0	0	0	0	0	0	0	0
Unnamed White Oak Right	1	0	0	0	0	0	0	0	0	0	0
Wharton	1	0	0	0	0	0	0	0	0	0	0
White Oak	1	1	1	0	0	0	0	0	0	0	0

A.02 Detection matrices.

A.02.1 Cover objects.

Site	MTR/VF	C1.1	C2.1	C3.1
Boardinghouse	0	28	25	15
Bucklick	0	49	57	37
Cole's Fork A	0	33	38	60
Falling Rock A	0	18	15	21
Falling Rock B	0	47	53	54
Field Branch A	0	40	40	24
Goff	0	75	78	119
Little Millseat A	0	34	42	50
Little Millseat B	0	36	36	22
Miller	0	61	66	134
Mulberry	0	73	68	69
Tome	0	53	57	42
Bee Branch Far	1	8	9	37
Bee Branch Near	1	43	47	75
Big Hollow	1	45	49	26
Hickory Log	1	5	4	6
Spice	1	6	2	6
Stillrock	1	29	27	46
Turkey	1	23	20	58
Unnamed White Oak Left	1	46	48	49
Unnamed White Oak Right	1	23	17	27
Wharton	1	21	19	37
White Oak	1	24	10	11

A.02.2 Date of last precipitation.

Site	MTR/VF	C1.1	C1.2	C1.3	C1.4	C2.1	C2.2	C2.3	C3.1	C3.2	C3.3
Boardinghouse	0	3	1	1	1	1	1	1	2	0	1
Bucklick	0	4	4	1	2	0	4	4	1	0	0
Cole's Fork A	0	4	4	2	2	0	4	4	1	0	0
Falling Rock A	0	2	1	1	1	1	1	0	0	3	0
Falling Rock B	0	2	1	1	1	1	1	0	0	3	0
Field Branch A	0	3	1	0	0	1	1	4	2	3	1
Goff	0	6	1	2	1	1	1	1	0	0	0
Little Millseat A	0	6	1	1	0	8	4	4	0	3	1
Little Millseat B	0	1	1	1	2	8	4	4	0	3	1
Miller	0	6	1	1	1	1	1	1	0	0	0
Mulberry	0	1	1	1	1	2	1	0	2	6	0
Tome	0	3	1	1	1	1	1	0	6	0	0
Bee Branch Far	1	2	1	2	1	2	1	1	1	0	0
Bee Branch Near	1	2	1	2	1	2	1	1	6	0	0
Big Hollow	1	1	1	0	1	1	2	4	0	0	1
Hickory Log	1	1	1	0	1	2	4	5	0	0	1
Spice	1	4	1	2	1	2	1	4	2	0	1
Stillrock	1	1	1	1	1	1	4	5	2	0	3
Turkey	1	4	1	0	1	2	1	4	2	0	1
Unnamed White Oak Left	1	4	1	1	1	1	4	5	2	0	3
Unnamed White Oak Right	1	4	1	1	1	1	4	5	2	0	3
Wharton	1	1	1	0	1	1	2	1	0	0	1
White Oak	1	4	1	1	1	1	4	5	2	0	3

If rained earlier in day prior to sampling: 0
If rained the day before sampling: 1
If rained two days before sampling: 2
Etc.

A.02.3 Specific conductance.

Site	MTR/VF	C1.1	C1.2	C1.3	C1.4	C2.1	C2.2	C2.3	C3.1	C3.2	C3.3
Boardinghouse	0		44.3	68.4	63.6	86.1	84.8	93.6	33	42.3	53.6
Bucklick	0	157.3	64.7	50.3	52.7	66.5	64.4	67.9	38.7	46.7	53.7
Cole's Fork A	0	54.1	67.5	72.8	66.8	64.5	97.8	114.8	42.6	63.2	101.5
Falling Rock A	0	99.4	36.9	44.2	48.8	46.2	52.1	54.5	34.3	41.7	45.1
Falling Rock B	0	46.6	36.5	47.8	51.7	47.4	58.8	68.4	35.4	47.4	48.3
Field Branch A	0	40.5	44.2	39.3	47	51.1	52.8	58.6	32.9	41.4	44.5
Goff	0	46.4	36.4	44.8	75.7	49	60.5	61.6	36.9	47.9	43.2
Little Millseat A	0	46.2	73.8	57.3	53.2	52.4	5.92	79.9	32.9	45.8	47.3
Little Millseat B	0	51.8	81.1	45.5	114.3	88.1	89.3	98.1	32.9	41.2	58.8
Miller	0	35.2	27.5	37.1	55.4	42.3	50.8	58.2	27.7	41.3	37.4
Mulberry	0	48.7	38.1	50	56.8	55.8	76.4	78	34	48.3	58.6
Tome	0	104	59.2	71.4	78.7	84.9	116.9	127.1	45.3	58.7	56.2
Bee Branch Far	1	1784	1467	1967	1550	1501	1724	1795	1287	1687	1657
Bee Branch Near	1		1425	1716	1793	1435	1562	1633	1408	1546	1491
Big Hollow	1	1561	1673	2240	2190	1694	1898	2010	1351	1682	1736
Hickory Log	1	1902	2020	2750	2710	2280	2480	2650	2090	2360	2460
Spice	1	2110	1880	2330	2210	1941	2080	2220	1786	1966	2130
Stillrock	1	1326	1545	2460	2430	2050	2430	2550	1750	2170	2690
Turkey	1	928	747	1129	1086		1075	1118	726	929	1040
Unnamed White Oak Left	1	1595	389	714	711	496	788	836	452	684	773
Unnamed White Oak Right	1	516	1530	1905	1872	1495	1771	1897	1279	1553	1623
Wharton	1	2320	2190	2530	2420	2250	2290	2400	1842	2070	2160
White Oak	1	1823	1394	2020	2050	1664	2010	2050	1553	1804	1967

APPENDIX B-MODEL CODE

B.01.1 General model code.

```
## Hierarchical dynamic occupancy model

## Notes:
##    S indexes species
##    s indexes site
##    y indexes year
##    v indexes visit

model{
  ##### Likelihood #####

  ##### Occupancy #####

  for(S in 1:nspecies){
    ## 1) Mean parameters

    for(mtr in 0:1){
      ## a) Initial occupancy
      eta.psi0[S,mtr+1] <- beta.occ[1,mtr+1,S]
      logit(psi0.pop[S,mtr+1]) <- eta.psi0[S,mtr+1]

      ## b) Colonization
      eta.gamma[S,mtr+1] <- beta.occ[2,mtr+1,S]
      logit(gamma.pop[S,mtr+1]) <- eta.gamma[S,mtr+1]

      ## c) Survival
      eta.phi[S,mtr+1] <- beta.occ[3,mtr+1,S]
      logit(phi.pop[S,mtr+1]) <- eta.phi[S,mtr+1]
    }

    ## 2) Site specific parameters
    for(s in 1:nsite){
      ## Initial occupancy
      logit(psi[S,s,1]) <- eta.psi0[S,MTR[s]+1] +
        beta.occ[1,3,S] * MTR[s] * Conductivity[s,1]

      Occupancy[S,s,1] ~ dbern(psi[S,s,1])

      ## Occupancy in subsequent years
      for(y in 2:nyear){
        ## Colonization
        logit(gamma[S,s,y-1]) <-  eta.gamma[S,MTR[s]+1] +
          beta.occ[2,3,S] * MTR[s] * Conductivity[s,y]

        ## Survival
        logit(phi[S,s,y-1]) <-  eta.phi[S,MTR[s]+1] +
          beta.occ[3,3,S] * MTR[s] * Conductivity[s,y]

        ## Occupancy
        psi[S,s,y] <- (1-Occupancy[S,s,y-1]) * gamma[S,s,y-1] +
          Occupancy[S,s,y-1] * phi[S,s,y-1]

        Occupancy[S,s,y] ~ dbern(psi[S,s,y])
      }
    }
  }

  ## Abundance given occupancy
  for(S in 1:nspecies){
    log(lambda.pop[S,1]) <- beta.abund[1,S]
    log(lambda.pop[S,2]) <- beta.abund[2,S]

    for(s in 1:nsite){
      for(y in 1:nyear){
```

```
            log(lambda[S,s,y]) <- beta.abund[1,S] * (1-MTR[s]) +
               beta.abund[2,S] * MTR[s] +
               beta.abund[3,S] * MTR[s] * Conductivity[s,y]

            Abundance.tmp[S,s,y] ~ dpois(lambda[S,s,y])T(1,)

            Abundance[S,s,y] <- Abundance.tmp[S,s,y]*Occupancy[S,s,y]
         }
      }
   }

   ## Detection
   for(S in 1:nspecies){
      for(s in 1:nsite){
         for(y in 1:nyear){
            for(v in 1:nvisit[y]){
               logit(p[S,s,y,v]) <- beta.det[1,S] +
                  beta.det[2,S] * CoverObjects[s,y] +
                  beta.det[3,S] * Precip[s,y,v]
            }
         }
      }
   }

   ## Observations
   for(i in 1:nobs){
      for(S in 1:nspecies){
         Y[i,S] ~ dbinom(p[S,Site[i],Year[i],Visit[i]],
                         Abundance[S,Site[i],Year[i]])
      }
   }

   ##### Priors #####

   ## Parameters for half-t priors on variance
   df <- 3
   tau <- .25

   ## Occupancy
   for(i in 1:3){ # 1=Initial, 2=Colonization, 3=Survival
      for(k in 1:3){ # 1=Intercept, 2=MTR, 3=Conductivity*MTR
         for(S in 1:nspecies){
            ## beta.occ[i,k,S] ~ dnorm(0,tau.beta.occ[i,k])
            xi.occ[i,k,S] ~ dnorm(0,tau.beta.occ[i,k])
            beta.occ[i,k,S] <- mu.beta.occ[i,k] + alpha.beta.occ[i,k] * xi.occ[i,k,S]
         }

         mu.beta.occ[i,k] ~ dnorm(0,.36)
         ## sigma.beta.occ[i,k] ~ dt(0,.25,3)T(0,)
         ## tau.beta.occ[i,k] <- pow(sigma.beta.occ[i,k],2)
         tau.beta.occ[i,k] ~ dgamma(df/2,df/2/tau)
         sigma.beta.occ[i,k] <- abs(alpha.beta.occ[i,k])/sqrt(tau.beta.occ[i,k])
         alpha.beta.occ[i,k] ~ dnorm(0,1)
      }
   }

   ## Abundance
   for(i in 1:3){
      for(S in 1:nspecies){
         ## beta.abund[i,S] ~ dnorm(0,tau.beta.abund[i])
         xi.abund[i,S] ~ dnorm(0,tau.beta.abund[i])
         beta.abund[i,S] <- mu.beta.abund[i] + alpha.beta.abund[i] * xi.abund[i,S]
      }

      mu.beta.abund[i] ~ dnorm(0,.001)
      ## sigma.beta.abund[i] ~ dt(0,.25,3)T(0,)
      ## tau.beta.abund[i] <- pow(sigma.beta.abund[i],2)
      tau.beta.abund[i] ~ dgamma(df/2,df/2/tau)
      sigma.beta.abund[i] <- abs(alpha.beta.abund[i])/sqrt(tau.beta.abund[i])
      alpha.beta.abund[i] ~ dnorm(0,1)
```

```
    }

    ## Detection
    for(i in 1:3){
        for(S in 1:nspecies){
            ## beta.det[i,S] ~ dnorm(0,tau.beta.det[i])
            xi.det[i,S] ~ dnorm(0,tau.beta.det[i])
            beta.det[i,S] <- mu.beta.det[i] + alpha.beta.det[i] * xi.det[i,S]
        }

        mu.beta.det[i] ~ dnorm(0,.36)
        ## sigma.beta.det[i] ~ dt(0,.25,3)T(0,)
        ## tau.beta.det[i] <- pow(sigma.beta.det[i],2)
        tau.beta.det[i] ~ dgamma(df/2,df/2/tau)
        sigma.beta.det[i] <- abs(alpha.beta.det[i])/sqrt(tau.beta.det[i])
        alpha.beta.det[i] ~ dnorm(0,1)
    }


    ##### Derived Values #####
    ## Percent occupancy
    for(S in 1:nspecies){
        for(s in 1:nsite){
            OccSum[S,s] <- sum(Occupancy[S,s,])
        }

        PercOcc[S,1] <- 100*inprod(OccSum[S,],(1-MTR[]))/(sum(1-MTR[])*nyear)
        PercOcc[S,2] <- 100*inprod(OccSum[S,],MTR[])/(sum(MTR[])*nyear)
    }

    ## Mean abundance given occupancy
    for(S in 1:nspecies){
        for(s in 1:nsite){
            AbundMean.tmp[S,s] <- mean(Abundance[S,s,])
        }

        AbundMean[S,1] <- inprod(AbundMean.tmp[S,],(1-MTR[]))/(sum(1-MTR[])*nyear)
        AbundMean[S,2] <- inprod(AbundMean.tmp[S,],MTR[])/(sum(MTR[])*nyear)
    }
}
```

B.01.2 Code for running model.

```
## ----setup, include=FALSE, cache=FALSE----------------------------------
## set global chunk options
opts_chunk$set(fig.align='center',
             fig.show='hold',
             dev="tikz",
             cache=FALSE,
             echo=FALSE,
             results="hide")
options(formatR.arrow=TRUE,width=90)

## ----prelim------------------------------------------------------------
## Load packages

library(knitr)
library(rjags)
library(coda)
library(xtable)
library(ggmcmc)
library(gridExtra)

## Load output file
load("~/Scratch/S_Price/Dynamic_Occupancy/coda.Rdata")

## Load data
load("../Data/Salamander Data 12.16.2015_formatted.Rdata")

## Remove PR
# Counts <- Counts[,-which(colnames(Counts)=="PR")]

## Set names
spnames <- colnames(Counts[,-(1:3)])

## Generate ggmcmc object
ggs.coda <- ggs(coda)

## Numerical summaries
summ <- summary(coda)

## Set table number
tab_num <- 1

## ----perc-occupancy,fig.height=7------------------------------------
## Percent Occupancy
ind <- grep("PercOcc",colnames(coda[[1]]))

coda_tmp <- mcmc.list(coda[[1]][,ind],coda[[2]][,ind])

names <- as.vector(t(outer(c("Control","MTR-VF"),spnames,paste,sep=" - ")))
colnames(coda_tmp[[1]]) <- colnames(coda_tmp[[2]]) <- names


X <- data.frame(Parameter=colnames(coda[[1]])[ind],
              x=length(ind):1)

f <- ggs_caterpillar(ggs.coda,"PercOcc",X=X)

f + geom_hline(yintercept=7.5) +
   labs(x="",y="") +
   scale_y_continuous(breaks=length(ind):1,labels=names)

tab <- f$data[order(f$data$x,decreasing=TRUE),1:6]
tab$Parameter <- as.vector(t(outer(c("Control","MTR-VF"),spnames,paste,sep=" - ")))
colnames(tab) <- c("Group","2.5%","5%","Median","95%","97.5%")

write.table(format(tab,nsmall=2,digits=2),file=paste0("Tables/",tab_num,"_percent_occupancy_summary.txt"),quote=FALSE,row.names=FALSE)
```

```
tab_num<- tab_num + 1

## ----mean-abund,fig.height=7---------------------------------------------
## Percent Occupancy
ind <- grep("AbundMean",colnames(coda[[1]]))

coda_tmp <- mcmc.list(coda[[1]][,ind],coda[[2]][,ind])

names <- as.vector(t(outer(c("Control","MTR-VF"),spnames,paste,sep=" - ")))
colnames(coda_tmp[[1]]) <- colnames(coda_tmp[[2]]) <- names


X <- data.frame(Parameter=colnames(coda[[1]])[ind],
                x=length(ind):1)

f <- ggs_caterpillar(ggs.coda,"AbundMean",X=X)

f + geom_hline(yintercept=7.5) +
   labs(x="",y="") +
   scale_y_continuous(breaks=length(ind):1,labels=names)

tab <- f$data[order(f$data$x,decreasing=TRUE),1:6]
tab$Parameter <- as.vector(t(outer(c("Control","MTR-VF"),spnames,paste,sep=" - ")))
colnames(tab) <- c("Group","2.5%","5%","Median","95%","97.5%")

write.table(format(tab,nsmall=2,digits=2),file=paste0("Tables/",tab_num,"_mean_abundance_summary.txt"),quote=FALSE,row.names=FALSE)
tab_num <- tab_num + 1



## ----mtr-overall,fig.height=2--------------------------------------------

## Overall effects of MTR-VF
coda_tmp <- as.mcmc.list(lapply(1:2,function(j){
   as.mcmc(cbind(sapply(1:3,function(k){
      coda[[j]][,paste0("mu.beta.occ[",k,",1]")] -
         coda[[j]][,paste0("mu.beta.occ[",k,",2]")]
   }),
   coda[[j]][,"mu.beta.abund[1]"] - coda[[j]][,"mu.beta.abund[2]"]))
}))

colnames(coda_tmp[[1]]) <- colnames(coda_tmp[[2]]) <- c(paste("Occ",c("Initial","Colonization","Survival"),sep="/"),"Abundance")

ggs_tmp <- ggs(coda_tmp)

(f <- ggs_caterpillar(ggs_tmp,X=data.frame(Parameter=colnames(coda_tmp[[1]]),x=4:1)) +
   geom_vline(x=0,lty=2) +
   scale_y_continuous(name="",labels=colnames(coda_tmp[[1]]),breaks=4:1) +
   scale_x_continuous(name="",limits=c(-5,5),oob=function(x,limits) pmax(pmin(x,limits[2]),limits[1])))

tab <- f$data[order(f$data$x,decreasing=TRUE),1:6]
colnames(tab) <- c("Group","2.5%","5%","Median","95%","97.5%")

write.table(format(tab,nsmall=2,digits=2),file=paste0("Tables/",tab_num,"_site_type_effects.txt"),quote=FALSE,row.names=FALSE)
tab_num <- tab_num + 1



## ----conductivity-overall,fig.height=2----------------------------------
## Overall effects of conductivity on occupancy and abundance, and detection effects
ind <- c(paste0("mu.beta.occ[",1:3,",3]"),
        "mu.beta.abund[3]")

coda_tmp <- as.mcmc.list(lapply(1:2,function(j){
   coda[[j]][,ind]
}))

colnames(coda_tmp[[1]]) <- colnames(coda_tmp[[2]]) <-
   c(paste("Occ",c("Initial","Colonization","Survival"),"Cond",sep="/"),
```

```
     "Abundance/Cond")

ggs_tmp <- ggs(coda_tmp)

(f <- ggs_caterpillar(ggs_tmp,X=data.frame(Parameter=colnames(coda_tmp[[1]]),x=4:1)) +
   geom_vline(x=0,lty=2) +
   scale_y_continuous(name="",labels=colnames(coda_tmp[[1]]),breaks=4:1) +
   scale_x_continuous(name="",limits=c(-5,5),oob=function(x,limits) pmax(pmin(x,limits[2]),limits[1])))

tab <- f$data[order(f$data$x,decreasing=TRUE),1:6]
colnames(tab) <- c("Group","2.5%","5%","Median","95%","97.5%")

write.table(format(tab,nsmall=2,digits=2),file=paste0("Tables/",tab_num,"_conductivity_effects.txt"),quote=FALSE,row.names=FAL
SE)
tab_num <- tab_num + 1


## ----detection-overall,fig.height=1.5------------------------------------
## Overall effects of conductivity on occupancy and abundance, and detection effects
ind <- paste0("mu.beta.det[",1:3,"]")

coda_tmp <- as.mcmc.list(lapply(1:2,function(j){
   coda[[j]][,ind]
}))

colnames(coda_tmp[[1]]) <- colnames(coda_tmp[[2]]) <-
   paste("Det",c("Intercept","Cover","Precip"),sep="/")

ggs_tmp <- ggs(coda_tmp)

(f <- ggs_caterpillar(ggs_tmp,X=data.frame(Parameter=colnames(coda_tmp[[1]]),x=3:1)) +
   geom_vline(x=0,lty=2) +
   scale_y_continuous(name="",labels=colnames(coda_tmp[[1]]),breaks=3:1) +
   scale_x_continuous(name="",limits=c(-5,5),oob=function(x,limits) pmax(pmin(x,limits[2]),limits[1])))

tab <- f$data[order(f$data$x,decreasing=TRUE),1:6]
colnames(tab) <- c("Group","2.5%","5%","Median","95%","97.5%")

write.table(format(tab,nsmall=2,digits=2),file=paste0("Tables/",tab_num,"_detection_parameters.txt"),quote=FALSE,row.names=FA
LSE)
tab_num <- tab_num + 1



## ----variances,fig.height=7.5--------------------------------------------
## Generate random half-t for comparison
jagged <- jags.model("test_half_t_bugs.R",data=list())
halft <- coda.samples(jagged,n.iter=10000,variable.names="x")

## Random effects variances

ind <- c(grep("sigma.beta.occ",colnames(coda[[1]]),value=TRUE),
        grep("sigma.beta.abund",colnames(coda[[1]]),value=TRUE),
        grep("sigma.beta.det",colnames(coda[[1]]),value=TRUE))

parnames <-
c(paste("Occ",as.vector(t(outer(c("Control","MTR","Conductivity"),c("Initial","Colonization","Survival"),paste,sep="/"))),sep="/"),
          paste("Abund",c("Control","MTR","Conductivity"),sep="/"),
          paste("Det",c("Intercept","Cover","Precip"),sep="/"))

coda_tmp <- as.mcmc.list(lapply(coda,function(mcmc){
   mcmc[,ind]
}))
colnames(coda_tmp[[1]]) <-  colnames(coda_tmp[[2]]) <- parnames

ggs_tmp <- ggs(coda_tmp)

(f <- ggs_caterpillar(ggs_tmp,X=data.frame(Parameter=parnames,x=15:1))+
   labs(x="",y="Parameter") +
   scale_y_continuous(breaks=15:1,labels=parnames) +
```

```
  geom_vline(x=quantile(halft[[1]],c(.5,.95,.975)),lty=c(2,3,3)))

tab <- f$data[order(f$data$x,decreasing=TRUE),1:6]
colnames(tab) <- c("Group","2.5%","5%","Median","95%","97.5%")

write.table(format(tab,nsmall=2,digits=2),file=paste0("Tables/",tab_num,"_variance_parameters.txt"),quote=FALSE,row.names=FAL
SE)
tab_num <- tab_num + 1



## ----mtr-species,fig.width=3,fig.height=2-------------------------------
for(S in 1:length(spnames)){
  ## Overall effects of MTR-VF
  coda_tmp <- as.mcmc.list(lapply(1:2,function(j){
    as.mcmc(cbind(sapply(1:3,function(k){
      coda[[j]][,paste0("beta.occ[",k,",1,",S,"]")] -
        coda[[j]][,paste0("beta.occ[",k,",2,",S,"]")]
    }),
    coda[[j]][,paste0("beta.abund[1,",S,"]")] -
    coda[[j]][,paste0("beta.abund[2,",S,"]")]
    ))
  }))

  colnames(coda_tmp[[1]]) <- colnames(coda_tmp[[2]]) <-
c(paste("Occ",c("Initial","Colonization","Survival"),sep="/"),"Abundance")

  ggs_tmp <- ggs(coda_tmp)

  print(f <- ggs_caterpillar(ggs_tmp,X=data.frame(Parameter=colnames(coda_tmp[[1]]),x=4:1)) +
     geom_vline(x=0,lty=2) + ggtitle(spnames[S]) +
     scale_y_continuous(name="",labels=colnames(coda_tmp[[1]]),breaks=4:1) +
     scale_x_continuous(name="",limits=c(-5,5),oob=function(x,limits) pmax(pmin(x,limits[2]),limits[1])))

  tab <- f$data[order(f$data$x,decreasing=TRUE),1:6]
  colnames(tab) <- c("Group","2.5%","5%","Median","95%","97.5%")


write.table(format(tab,nsmall=2,digits=2),file=paste0("Tables/",tab_num,"_site_type_effects_",spnames[S],".txt"),quote=FALSE,row.
names=FALSE)
}
tab_num <- tab_num + 1



## ----conductivity-species,fig.width=3,fig.height=2----------------------
for(S in 1:length(spnames)){
  ## Overall effects of conductivity on occupancy and abundance, and detection effects
  ind <- c(paste0("beta.occ[",1:3,",3,",S,"]"),
       paste0("beta.abund[3,",S,"]"))

  coda_tmp <- as.mcmc.list(lapply(1:2,function(j){
    coda[[j]][,ind]
  }))

  colnames(coda_tmp[[1]]) <- colnames(coda_tmp[[2]]) <-
    c(paste("Occ",c("Initial","Colonization","Survival"),"Cond",sep="/"),
     "Abundance/Cond")

  ggs_tmp <- ggs(coda_tmp)

  print(f <- ggs_caterpillar(ggs_tmp,X=data.frame(Parameter=colnames(coda_tmp[[1]]),x=4:1)) +
     geom_vline(x=0,lty=2) +
     ggtitle(spnames[S])+
     scale_y_continuous(name="",labels=colnames(coda_tmp[[1]]),breaks=4:1) +
     scale_x_continuous(name="",limits=c(-3,3),oob=function(x,limits) pmax(pmin(x,limits[2]),limits[1])))

  tab <- f$data[order(f$data$x,decreasing=TRUE),1:6]
  colnames(tab) <- c("Group","2.5%","5%","Median","95%","97.5%")
```

```
write.table(format(tab,nsmall=2,digits=2),file=paste0("Tables/",tab_num,"_conductivity_effects_",spnames[S],".txt"),quote=FALSE,r
ow.names=FALSE)
}
tab_num <- tab_num + 1



## ----detection-species,fig.width=3,fig.height=1.5------------------------
for(S in 1:length(spnames)){
  ## Overall effects of conductivity on occupancy and abundance, and detection effects
  ind <- paste0("beta.det[",1:3,",",S,"]")

  coda_tmp <- as.mcmc.list(lapply(1:2,function(j){
    coda[[j]][,ind]
  }))

  colnames(coda_tmp[[1]]) <- colnames(coda_tmp[[2]]) <-
    paste("Det",c("Intercept","Cover","Precip"),sep="/")

  ggs_tmp <- ggs(coda_tmp)

  print(g <- ggs_caterpillar(ggs_tmp,X=data.frame(Parameter=colnames(coda_tmp[[1]]),x=3:1)) +
      geom_vline(x=0,lty=2) +
      ggtitle(spnames[S])+
      scale_y_continuous(name="",labels=colnames(coda_tmp[[1]]),breaks=3:1) +
      scale_x_continuous(name="",limits=c(-3,3),oob=function(x,limits) pmax(pmin(x,limits[2]),limits[1])))

  tab <- f$data[order(f$data$x,decreasing=TRUE),1:6]
  colnames(tab) <- c("Group","2.5%","5%","Median","95%","97.5%")


write.table(format(tab,nsmall=2,digits=2),file=paste0("Tables/",tab_num,"_detection_parameters_",spnames[S],".txt"),quote=FALSE,
row.names=FALSE)
}
tab_num <- tab_num + 1


## ----initial-occ-table,results="asis"------------------------------------
ilogit <- function(x) exp(x)/(1 + exp(x))

index <- c("mu.beta.occ[1,1]",
           grep("^beta.occ\\[1,1",colnames(coda[[1]]),value=TRUE),
           "mu.beta.occ[1,2]",
           grep("^beta.occ\\[1,2",colnames(coda[[1]]),value=TRUE))

parnames <- c(outer(c("Mean",spnames),c("Control","Mined"),paste,sep=": "))

coda.psi0 <- as.mcmc.list(lapply(1:2,function(j){
  tmp <- ilogit(coda[[j]][,index])
  colnames(tmp) <- parnames
  tmp
}))

ggs.psi0 <- ggs(coda.psi0)

X <- data.frame(Parameter=colnames(coda.psi0[[1]]),
                x=16:1)

f <- ggs_caterpillar(ggs.psi0,X=X)

f + geom_hline(yintercept=8.5) +
  labs(x="",y="") +
  scale_y_continuous(breaks=16:1,
                     labels=X[,1])

tab <- f$data[order(f$data$x,decreasing=TRUE),1:6]
colnames(tab) <- c("Group","2.5%","5%","Median","95%","97.5%")
```

```
write.table(format(tab,nsmall=2,digits=2),file=paste0("Tables/",tab_num,"_initial_occupancy_summary.txt"),quote=FALSE,row.nam
es=FALSE)
tab_num <- tab_num + 1

## ----colonization-table,results="asis"-----------------------------------
index <- c("mu.beta.occ[2,1]",
        grep("^beta.occ\\[2,1",colnames(coda[[1]]),value=TRUE),
        "mu.beta.occ[2,2]",
        grep("^beta.occ\\[2,2",colnames(coda[[1]]),value=TRUE))

parnames <- c(outer(c("Mean",spnames),c("Control","Mined"),paste,sep=": "))

coda.gamma <- as.mcmc.list(lapply(1:2,function(j){
   tmp <- ilogit(coda[[j]][,index])
   colnames(tmp) <- parnames
   tmp
}))

ggs.gamma <- ggs(coda.gamma)

X <- data.frame(Parameter=colnames(coda.gamma[[1]]),
            x=16:1)

f <- ggs_caterpillar(ggs.gamma,X=X)

f + geom_hline(yintercept=8.5) +
   labs(x="",y="") +
   scale_y_continuous(breaks=16:1,
                  labels=X[,1])

tab <- f$data[order(f$data$x,decreasing=TRUE),1:6]
colnames(tab) <- c("Group","2.5%","5%","Median","95%","97.5%")

write.table(format(tab,nsmall=2,digits=2),file=paste0("Tables/",tab_num,"_colonization_summary.txt"),quote=FALSE,row.names=F
ALSE)
tab_num <- tab_num + 1

## ----survival-table,results="asis"----------------------------------------
index <- c("mu.beta.occ[3,1]",
        grep("^beta.occ\\[3,1",colnames(coda[[1]]),value=TRUE),
        "mu.beta.occ[3,2]",
        grep("^beta.occ\\[3,2",colnames(coda[[1]]),value=TRUE))

parnames <- c(outer(c("Mean",spnames),c("Control","Mined"),paste,sep=": "))

coda.phi <- as.mcmc.list(lapply(1:2,function(j){
   tmp <- ilogit(coda[[j]][,index])
   colnames(tmp) <- parnames
   tmp
}))

ggs.phi <- ggs(coda.phi)

X <- data.frame(Parameter=colnames(coda.phi[[1]]),
            x=16:1)

f <- ggs_caterpillar(ggs.phi,X=X)

f + geom_hline(yintercept=8.5) +
   labs(x="",y="") +
   scale_y_continuous(breaks=16:1,
                  labels=X[,1])

tab <- f$data[order(f$data$x,decreasing=TRUE),1:6]
colnames(tab) <- c("Group","2.5%","5%","Median","95%","97.5%")

write.table(format(tab,nsmall=2,digits=2),file=paste0("Tables/",tab_num,"_colonizatoin_summary.txt"),quote=FALSE,row.names=F
ALSE)
tab_num <- tab_num + 1
```

APPENDIX C-SAS CODE

C.01.1 SAS code percent detritus 2013-2015.

```
proc import datafile="E:\Habitat Data\Habitat Data SAS.xlsx"
out=habitat3yrs
dbms=xlsx
replace;
sheet="Sheet3";
getnames=yes;
run;

proc mixed data=habitat3yrs plots=residualpanel;
class site_type site year;
model Detritus=site_type year site_type*year /solution;
lsmeans site_type year site_type*year /pdiff;
repeated year /subject=site type=ar(1);
run;
```

C.01.2 SAS code number of cover objects 2013-2015.

```
proc import datafile="E:\Habitat Data\Habitat Data SAS.xlsx"
out=habitat3yrs
dbms=xlsx
replace;
sheet="Sheet3";
getnames=yes;
run;

proc mixed data=habitat3yrs plots=residualpanel;
class Site_type site year;
model Cover_Stream=site_type year site_type*year /solution;
lsmeans site_type year site_type*year /pdiff;
repeated year /subject=site type=ar(1);
run;
```

C.02.1 Spreadsheet imported into SAS for detritus and cover objects.

Site_type	Site	Year	Detritus	Cover_Stream
0	Boardinghouse	1	8	28
0	Bucklick	1	10	49
0	Cole's Fork A	1	17	33
0	Falling Rock A	1	0	18
0	Falling Rock B	1	20	47
0	Field Branch A	1	7	40
0	Goff	1	8	75
0	Little Millseat A	1	15	34
0	Little Millseat B	1	12	36
0	Miller	1	10	61
0	Mulberry	1	6	73

0	Tome	1	4	53
1	Bee Branch Far	1	5	8
1	Bee Branch Near	1	3	43
1	Big Hollow	1	10	45
1	Hickory Log	1	74	5
1	Spice	1	10	6
1	Stillrock	1	7	29
1	Turkey	1	5	23
1	Unnamed White Oak Left	1	20	46
1	Unnamed White Oak Right	1	5	23
1	Wharton	1	1	21
1	White Oak	1	25	24
0	Boardinghouse	2	8	25
0	Bucklick	2	10	57
0	Cole's Fork A	2	23	38
0	Falling Rock A	2	25	15
0	Falling Rock B	2	15	53
0	Field Branch A	2	10	40
0	Goff	2	5	78
0	Little Millseat A	2	15	42
0	Little Millseat B	2	5	36
0	Miller	2	10	66
0	Mulberry	2	7	68
0	Tome	2	2	57
1	Bee Branch Far	2	5	9
1	Bee Branch Near	2	5	47
1	Big Hollow	2	15	49
1	Hickory Log	2	80	4
1	Spice	2	15	2
1	Stillrock	2	10	27
1	Turkey	2	5	20
1	Unnamed White Oak Left	2	15	48
1	Unnamed White Oak Right	2	10	17
1	Wharton	2	5	19
1	White Oak	2	30	10
0	Boardinghouse	3	2	15
0	Bucklick	3	1	37
0	Cole's Fork A	3	40	60
0	Falling Rock A	3	4	21
0	Falling Rock B	3	25	54
0	Field Branch A	3	2	24

0	Goff	3	10	119
0	Little Millseat A	3	20	50
0	Little Millseat B	3	10	22
0	Miller	3	4	134
0	Mulberry	3	5	69
0	Tome	3	5	42
1	Bee Branch Far	3	40	37
1	Bee Branch Near	3	10	75
1	Big Hollow	3	20	26
1	Hickory Log	3	90	6
1	Spice	3	35	6
1	Stillrock	3	48	46
1	Turkey	3	9	58
1	Unnamed White Oak Left	3	20	49
1	Unnamed White Oak Right	3	1	27
1	Wharton	3	1	37
1	White Oak	3	85	11

C.03.1 SAS code specific conductance May 2013-2015.

```
/*Comparing water chemistry variables for May 2013-2015"*/
proc import datafile="E:\Water Data\Water Samples Forest Hydrology Lab\Water
quality SAS May.xlsx"
out=waterMay3yrs
dbms=xlsx
replace;
sheet="sheet1";
getnames=yes;
run;

title "Conductivity";
proc mixed data=waterMay3yrs plots=residualpanel;
class Site_type site year;
model Cond=site_type year site_type*year /solution;
lsmeans site_type year site_type*year /pdiff;
repeated year /subject=site type=ar(1);
run;
```

C.03.2 Spreadsheet imported into SAS for specific conductance May 2013-2015.

Site	Site_type	Year	Cond
Boardinghouse	0	2013	44.3
Bucklick	0	2013	64.7
Coles Fork A	0	2013	67.5
Falling Rock A	0	2013	36.9
Falling Rock B	0	2013	36.5
Field Branch A	0	2013	44.2
Goff	0	2013	36.4
Little Millseat A	0	2013	73.8
Little Millseat B	0	2013	81.1
Miller	0	2013	27.5
Mulberry	0	2013	38.1
Tome	0	2013	59.2
Bee Branch Far	1	2013	1467
Bee Branch Near	1	2013	1425
Big Hollow	1	2013	1673
Hickory Log	1	2013	2020
Spice	1	2013	1880
Stillrock	1	2013	1545
Turkey	1	2013	747
Unnamed White Oak Left	1	2013	389
Unnamed White Oak Right	1	2013	1530
Wharton	1	2013	2190
White Oak	1	2013	1394
Boardinghouse	0	2014	84.8
Bucklick	0	2014	64.4

Coles Fork A	0	2014	97.8
Falling Rock A	0	2014	52.1
Falling Rock B	0	2014	58.8
Field Branch A	0	2014	52.8
Goff	0	2014	60.5
Little Millseat A	0	2014	59.2
Little Millseat B	0	2014	89.3
Miller	0	2014	50.8
Mulberry	0	2014	76.4
Tome	0	2014	116.9
Bee Branch Far	1	2014	1724
Bee Branch Near	1	2014	1562
Big Hollow	1	2014	1898
Hickory Log	1	2014	2480
Spice	1	2014	2080
Stillrock	1	2014	2430
Turkey	1	2014	1075
Unnamed White Oak Left	1	2014	788
Unnamed White Oak Right	1	2014	1771
Wharton	1	2014	2290
White Oak	1	2014	2010
Boardinghouse	0	2015	42.3
Bucklick	0	2015	46.7
Coles Fork A	0	2015	63.2
Falling Rock A	0	2015	41.7
Falling Rock B	0	2015	47.4
Field Branch A	0	2015	41.4
Goff	0	2015	47.9
Little Millseat A	0	2015	45.8
Little Millseat B	0	2015	41.2
Miller	0	2015	41.3
Mulberry	0	2015	48.3
Tome	0	2015	58.7
Bee Branch Far	1	2015	1687
Bee Branch Near	1	2015	1546
Big Hollow	1	2015	1682
Hickory Log	1	2015	2360
Spice	1	2015	1966
Stillrock	1	2015	2170
Turkey	1	2015	929
Unnamed White Oak Left	1	2015	684

Unnamed White Oak Right	1	2015	1553
Wharton	1	2015	2070
White Oak	1	2015	1804

C.04.1 SAS code specific conductance monthly 2015.

```
/*Comparing water chemistry variables for April 2015-March 2016"*/
proc import datafile="E:\Water Data\Water Samples Forest Hydrology Lab\Water
quality SAS 2015.xlsx"
out=water2015
dbms=xlsx
replace;
sheet="Sheet2";
getnames=yes;
run;

title "Conductivity";
proc mixed data=water2015 plots=residualpanel;
class Site_type site month;
model Cond=site_type month site_type*month /solution;
lsmeans site_type month site_type*month /pdiff;
repeated month /subject=site type=ar(1);
run;
```

C.04.2 Spreadsheet imported into SAS for specific conductance monthly 2015.

Site	Site_type	Month	Cond
Boardinghouse	0	April	33
Bucklick	0	April	38.7
Coles Fork A	0	April	42.6
Falling Rock A	0	April	34.3
Falling Rock B	0	April	35.4
Field Branch A	0	April	32.9
Goff	0	April	36.9
Little Millseat A	0	April	32.9
Little Millseat B	0	April	32.9
Miller	0	April	27.7
Mulberry	0	April	34
Tome	0	April	45.3
Bee Branch Far	1	April	1287
Bee Branch Near	1	April	1408
Big Hollow	1	April	1351
Hickory Log	1	April	2090
Spice	1	April	1786
Stillrock	1	April	1750
Turkey	1	April	726
Unnamed White Oak Left	1	April	452
Unnamed White Oak Right	1	April	1279
Wharton	1	April	1842
White Oak	1	April	1553
Boardinghouse	0	May	42.3

Bucklick	0	May	46.7
Coles Fork A	0	May	63.2
Falling Rock A	0	May	41.7
Falling Rock B	0	May	47.4
Field Branch A	0	May	41.4
Goff	0	May	47.9
Little Millseat A	0	May	45.8
Little Millseat B	0	May	41.2
Miller	0	May	41.3
Mulberry	0	May	48.3
Tome	0	May	58.7
Bee Branch Far	1	May	1687
Bee Branch Near	1	May	1546
Big Hollow	1	May	1682
Hickory Log	1	May	2360
Spice	1	May	1966
Stillrock	1	May	2170
Turkey	1	May	929
Unnamed White Oak Left	1	May	684
Unnamed White Oak Right	1	May	1553
Wharton	1	May	2070
White Oak	1	May	1804
Boardinghouse	0	June	53.6
Bucklick	0	June	53.7
Coles Fork A	0	June	101.5
Falling Rock A	0	June	45.1
Falling Rock B	0	June	48.3
Field Branch A	0	June	44.5
Goff	0	June	43.2
Little Millseat A	0	June	47.3
Little Millseat B	0	June	58.8
Miller	0	June	37.4
Mulberry	0	June	58.6
Tome	0	June	56.2
Bee Branch Far	1	June	1675
Bee Branch Near	1	June	1491
Big Hollow	1	June	1734
Hickory Log	1	June	2460
Spice	1	June	2130
Stillrock	1	June	2690
Turkey	1	June	1040

Unnamed White Oak Left	1	June	773
Unnamed White Oak Right	1	June	1623
Wharton	1	June	2160
White Oak	1	June	1967
Boardinghouse	0	July	47.6
Bucklick	0	July	46.9
Coles Fork A	0	July	60.5
Falling Rock A	0	July	46.5
Falling Rock B	0	July	47.8
Field Branch A	0	July	40.4
Goff	0	July	48.2
Little Millseat A	0	July	46.8
Little Millseat B	0	July	45.3
Miller	0	July	36.7
Mulberry	0	July	51.1
Tome	0	July	49.8
Bee Branch Far	1	July	1397
Bee Branch Near	1	July	1298
Big Hollow	1	July	1636
Hickory Log	1	July	2480
Spice	1	July	1933
Stillrock	1	July	1803
Turkey	1	July	867
Unnamed White Oak Left	1	July	441
Unnamed White Oak Right	1	July	1315
Wharton	1	July	2030
White Oak	1	July	1491
Boardinghouse	0	August	54.9
Bucklick	0	August	48.5
Coles Fork A	0	August	65.9
Falling Rock A	0	August	50.8
Falling Rock B	0	August	48.5
Field Branch A	0	August	42.3
Goff	0	August	47.8
Little Millseat A	0	August	56
Little Millseat B	0	August	46
Miller	0	August	43.4
Mulberry	0	August	53.5
Tome	0	August	52.4
Bee Branch Far	1	August	1005
Bee Branch Near	1	August	1008

Big Hollow	1	August	1539
Hickory Log	1	August	2460
Spice	1	August	1732
Stillrock	1	August	1759
Turkey	1	August	81.4
Unnamed White Oak Left	1	August	471
Unnamed White Oak Right	1	August	1423
Wharton	1	August	1916
White Oak	1	August	1321
Boardinghouse	0	September	40.8
Bucklick	0	September	39.5
Coles Fork A	0	September	65.7
Falling Rock A	0	September	34.2
Falling Rock B	0	September	43.7
Field Branch A	0	September	41.6
Goff	0	September	37.5
Little Millseat A	0	September	39.9
Little Millseat B	0	September	34.9
Miller	0	September	34.4
Mulberry	0	September	53.7
Tome	0	September	59.8
Bee Branch Far	1	September	1276
Bee Branch Near	1	September	1196
Big Hollow	1	September	1376
Hickory Log	1	September	2030
Spice	1	September	1756
Stillrock	1	September	1974
Turkey	1	September	884
Unnamed White Oak Left	1	September	628
Unnamed White Oak Right	1	September	1327
Wharton	1	September	1764
White Oak	1	September	1569
Boardinghouse	0	October	45.9
Bucklick	0	October	53.1
Coles Fork A	0	October	69.4
Falling Rock A	0	October	45.4
Falling Rock B	0	October	51.6
Field Branch A	0	October	47.5
Goff	0	October	47.4
Little Millseat A	0	October	54.7
Little Millseat B	0	October	42

Miller	0	October	43.1
Mulberry	0	October	65.5
Tome	0	October	61.5
Bee Branch Far	1	October	1538
Bee Branch Near	1	October	1447
Big Hollow	1	October	1654
Hickory Log	1	October	2430
Spice	1	October	2020
Stillrock	1	October	2230
Turkey	1	October	1041
Unnamed White Oak Left	1	October	719
Unnamed White Oak Right	1	October	1558
Wharton	1	October	2070
White Oak	1	October	1797
Boardinghouse	0	November	36.6
Bucklick	0	November	34.9
Coles Fork A	0	November	54.1
Falling Rock A	0	November	33.6
Falling Rock B	0	November	38.3
Field Branch A	0	November	35.7
Goff	0	November	35.5
Little Millseat A	0	November	43.7
Little Millseat B	0	November	33.6
Miller	0	November	30.2
Mulberry	0	November	48.7
Tome	0	November	43.5
Bee Branch Far	1	November	1166
Bee Branch Near	1	November	1075
Big Hollow	1	November	1309
Hickory Log	1	November	1999
Spice	1	November	1632
Stillrock	1	November	1772
Turkey	1	November	849
Unnamed White Oak Left	1	November	655
Unnamed White Oak Right	1	November	1237
Wharton	1	November	1649
White Oak	1	November	1367
Boardinghouse	0	December	39.8
Bucklick	0	December	40
Coles Fork A	0	December	49
Falling Rock A	0	December	39

Falling Rock B	0	December	39
Field Branch A	0	December	33.2
Goff	0	December	37.3
Little Millseat A	0	December	38
Little Millseat B	0	December	36.9
Miller	0	December	28
Mulberry	0	December	43.1
Tome	0	December	43.2
Bee Branch Far	1	December	1014
Bee Branch Near	1	December	981
Big Hollow	1	December	1292
Hickory Log	1	December	2090
Spice	1	December	1476
Stillrock	1	December	1464
Turkey	1	December	665
Unnamed White Oak Left	1	December	352
Unnamed White Oak Right	1	December	1346
Wharton	1	December	1825
White Oak	1	December	1314
Boardinghouse	0	January	34.6
Bucklick	0	January	38.5
Coles Fork A	0	January	45.6
Falling Rock A	0	January	34.9
Falling Rock B	0	January	36.2
Field Branch A	0	January	32.6
Goff	0	January	37.5
Little Millseat A	0	January	35
Little Millseat B	0	January	34.1
Miller	0	January	26.4
Mulberry	0	January	37.8
Tome	0	January	25.7
Bee Branch Far	1	January	263
Bee Branch Near	1	January	1073
Big Hollow	1	January	1469
Hickory Log	1	January	1211
Spice	1	January	629
Stillrock	1	January	185
Turkey	1	January	512
Unnamed White Oak Left	1	January	249
Unnamed White Oak Right	1	January	1273
Wharton	1	January	1826

White Oak	1	January	1390
Boardinghouse	0	February	37.7
Bucklick	0	February	41.4
Coles Fork A	0	February	42.7
Falling Rock A	0	February	37.1
Falling Rock B	0	February	37.8
Field Branch A	0	February	33.1
Goff	0	February	37.9
Little Millseat A	0	February	37.6
Little Millseat B	0	February	36.8
Miller	0	February	27.9
Mulberry	0	February	37.3
Tome	0	February	41.1
Bee Branch Far	1	February	1255
Bee Branch Near	1	February	1167
Big Hollow	1	February	1458
Hickory Log	1	February	1795
Spice	1	February	1676
Stillrock	1	February	1340
Turkey	1	February	653
Unnamed White Oak Left	1	February	334
Unnamed White Oak Right	1	February	1266
Wharton	1	February	2010
White Oak	1	February	1283
Boardinghouse	0	March	44.1
Bucklick	0	March	47.3
Coles Fork A	0	March	55.9
Falling Rock A	0	March	46.8
Falling Rock B	0	March	48.3
Field Branch A	0	March	40.5
Goff	0	March	49.6
Little Millseat A	0	March	44.2
Little Millseat B	0	March	45.4
Miller	0	March	36.9
Mulberry	0	March	51.2
Tome	0	March	50.8
Bee Branch Far	1	March	1386
Bee Branch Near	1	March	1354
Big Hollow	1	March	1545
Hickory Log	1	March	2080
Spice	1	March	1772

Stillrock	1	March	1631
Turkey	1	March	750
Unnamed White Oak Left	1	March	487
Unnamed White Oak Right	1	March	1474
Wharton	1	March	2140
White Oak	1	March	1553

APPENDIX D-PICTURES OF LOGGER SET-UP

Solinst Levelogger was placed inside a PVC tube with numerous holes, attached to rebar with metal wire and a u bolt. Additionally, a rope was tied to the Levelogger and a nearby tree. Mesh was taped to the front and back of the PVC tube to limit sedimentation and detritus entering the PVC tube.

Example of PVC tube displacement after a large rain event.

APPENDIX E-ADDITIONAL TABLES

E.01 Specific p-values from grab sample analyses

E.01.1 Table of p-values for differences of least square means for May 2013-2015, corresponding to between-site type specific conductance difference for each year.

2013	2014	2015
<0.0001	<0.0001	<0.0001

E.01.2 Table of p-values for differences of least square means for May 2013-2015, corresponding to within-site type specific conductance difference between years.

Site Type	2013/14	2014/15	2013/15
Reference	0.5466	0.4792	0.93936
MTR/VF	<0.0001	0.0002	0.0003

E.01.3 Table of p-values for differences of least square means for April 2015-March 2016, corresponding to between-site type specific conductance difference for each month.

Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

E.01.4 Table of p-values for differences of least square means for April 2015-March 2016, corresponding to within-site type specific conductance difference between consecutive months.

Site Type	Apr.-May	May-June	June-July	July-Aug.	Aug.-Sept.	Sept.-Oct.	Oct.-Nov.	Nov.-Dec.	Dec.-Jan.	Jan.-Feb.	Feb.-Mar.
Reference	0.93	0.93	0.91	0.97	0.96	0.89	0.82	0.99	0.96	0.97	0.93
MTR/VF	0.04	0.16	<0.0001	0.10	0.48	<0.0001	<0.0001	0.52	<0.0001	<0.0001	0.10

E.02 Site-specific hydroperiod calculations the entire time loggers were out (March–December 2015) and for the growing season (April 15-October 15, 2015). Cells equal the proportion of time with water flow in relation to the number of records for the time period, calculated using Levelogger compensated level or conductivity readings. Units=percent of time with flowing water.

Site Type	Site	March-December			April 15-October 15		
		Level Calculation	Conductivity Calculation	Number of Records	Level Calculation	Conductivity Calculation	Number of Records
MTR/VF	Bee Branch Near	100	100	26562	100	100	17655
	Big Hollow	100	100	26661	100	100	17657
	Stillrock	100	87.90	26663	100	81.73	17656
	Turkey	100	100	26480	100	100	17560
	Unnamed White Oak Right	100	99.99	26656	100	99.99	17656
	Wharton	100	96.07	26663	100	99.27	17658
Reference	Cole's Fork A	34.37	33.25	26500	32.22	48.61	17658
	Falling Rock B	22.90	11.72	26563	29.42	17.63	17657
	Field Branch A	3.08	18.90	26570	3.61	28.44	17654
	Little Millseat A	4.48	26.86	26572	1.28	23.79	17657
	Miller	0.42	14.30	26427	0.17	21.40	17655
	Mulberry	70.01	56.59	26634	70.51	65.84	17656

E.03 Summary of salamander captures by species in spring 2013, 2014, and 2015 in MTR/VF and reference stream reaches.

Species	Reference			MTR/VF		
	2013	2014	2015	2013	2014	2015
D. fuscus adults	61	144	164	18	17	30
D. fuscus larvae	-	32	49	-	5	11
D. monticola adults	98	158	109	13	11	20
D. monticola larvae	-	35	13	-	0	2
Desmognathus combined larvae	145	-	-	23	-	-
E. cirrigera adults	45	28	39	4	5	5
E. cirrigera larvae	80	251	182	9	6	11
G. porphyriticus adults	1	0	1	0	0	0
G. porphyriticus larvae	75	85	104	2	5	12
P. ruber adults	1	4	2	0	0	0
P. ruber larvae	18	28	37	5	3	4
UNIDENTIFIED						
Desmognathus adults	36	0	25	2	0	3
Desmognathus larvae	0	0	19	0	0	0
G. porphyriticus or *P. ruber* larvae	0	0	8	0	0	0
TOTALS						
Desmognathus larvae total	145	67	81	23	5	13
E. cirrigera	125	279	221	13	11	16
G. porphyriticus	76	85	105	2	5	12
P. ruber	19	32	39	5	3	4

REFERENCES

Angel, P., V. Davis, J. Burger, D. Graves, and C. Zipper. 2005. The Appalachian regional reforestation initiative. Appalachian Regional Reforestation Initiative, US Office of Surface Mining. Forest Reclamation Advisory No. 1.

Barrett, K., B. S. Helms, C. Guyer, and J. E. Schoonover. 2010. Linking process to pattern: Causes of stream-breeding amphibian decline in urbanized watersheds. Biological Conservation 143:1998-2005.

Bernhardt, E. S., B. D. Lutz, R. S. King, J. P. Fay, C. E. Carter, A. M. Helton, D. Campagna, and J. Amos. 2012. How many mountains can we mine? Assessing the regional degradation of central Appalachian rivers by surface coal mining. Environmental Science and Technology 46:8115-8122.

Bernhardt, E. S., and M. A. Palmer. 2011. The environmental costs of mountaintop mining valley fill operations for aquatic ecosystems of the central Appalachians. Annals of the New York Academy of Sciences 1223:39-57.

Cecala, K. K., W. H. Lowe, and J. C. Maerz. 2014. Riparian disturbance restricts in-stream movement of salamanders. Freshwater Biology 59(11):2354-2364.

Chambers, D. L. 2011. Increased conductivity affects corticosterone levels and prey consumption in larval amphibians. Journal of Herpetology, 45:219-223.

Chen, J., S. C. Saunders, T. R. Crow, R. J. Naiman, K. D. Brosofske, G. D. Mroz, B. L. Brookshire, and J. F. Franklin. 1999. Microclimate in forest ecosystem and landscape ecology. BioScience 49(4):288-297.

Comont, R. F., H. E. Roy, R. Harrington, C. R. Shortall, and B. V. Purse. 2014. Ecological correlates of local extinction and colonisation in the British ladybird beetles (Coleoptera: Coccinellidae). Biological Invasions 16:1805-1817.

Connette, G.M., S.J. Price, and M.E. Dorcas. 2011. Influence of abiotic factors on activity in a larval salamander assemblage. Southeastern Naturalist 10(1):109-120.

Danstedt, R. T. 1975. Local geographic variation in demographic parameters and body size of *Desmognathus fuscus* (Amphibia: Plethodontidae). Ecology 56(5):1054-1067.

Datry, T., S. T. Larned, and K. Tockner. 2014. Intermittent rivers: A challenge for freshwater ecology. BioScience 64(3):229-235.

Dorazio, R. M., J. Martin, and H. H. Edwards. 2013. Estimating abundance while accounting for rarity, correlated behavior, and other sources of variation in counts. Ecology 94(7):1472-1478.

Environmental Protection Agency. 1972. Federal Water Pollution Control Act. 33 U.S.C. 1251-1387.

Feder, M. E. 1983. Integrating the ecology and physiology of Plethodontid salamanders. Herpetologica 39(3):291-310.

Fritz, K. M., S. Fulton, B. R. Johnson, C. D. Barton, J. D. Jack, D. A. Word, and R. A. Burke. 2010. Structural and functional characteristics of natural and constructed channels draining a reclaimed mountaintop removal and valley fill coal mine. Journal of the North American Benthological Society 29(2):673-689.

Gamble, L. R., K. McGarigal, and B. W. Compton. 2007. Fidelity and dispersal in the pond-breeding amphibian, *Ambystoma opacum*: Implications for spatio-temporal population dynamics and conservation. Biological Conservation 139:247-257.

Grant, E. H. C., L. E. Green, and W. H. Lowe. 2009. Salamander occupancy in headwater stream networks. Freshwater Biology 54:1370-1378.

Grant, E. H. C., J. D. Nichols, W. H. Lowe, and W. F. Fagan. 2010. Use of multiple dispersal pathways facilitates amphibian persistence in stream networks. Proceedings of the National Academy of Sciences of the United States of America 107(15):6936-6940.

Green, D. M. 2003. The ecology of extinction: Population fluctuation and decline in amphibians. Biological Conservation 111:331-343.

Greenberg, A. E., L. S. Clesceri, and A. D. Eaton. 1992. Standard Methods for the Examination of Water and Wastewater, 18th ed. Washington, DC: American Public Health Association.

Griffith, M. B., S. B. Norton, L. C. Alexander, A. I. Pollard, and S. D. LeDuc. 2012. The effects of mountaintop mines and valley fills on the physicochemical quality of stream ecosystems in the central Appalachians: A review. Science of the Total Environment 417-418:1-12.

Gu, W., and R .K. Swihart. 2004. Absent or undetected? Effects of non-detection of species occurrence on wildlife-habitat models. Biological Conservation 116:195-203.

Hanski, I. 1999. Metapopulation Biology. Oxford University Press, Oxford.

Hill, M. F., A. Hastings, and L. W. Botsford. 2002. The effects of small dispersal rates on extinction times in structured metapopulation models. The American Naturalist 160(3):389-402.

Hitt, N. P., and D. B. Chambers. 2014. Temporal changes in taxonomic and functional diversity of fish assemblages downstream from mountaintop mining. Freshwater Science 33(3):915-926.

Hitt, N. P., M. Floyd, M. Compton, and K. McDonald. 2016. Threshold responses of blackside dace (*Chrosomus cumberlandensis*) and Kentucky arrow darter (*Etheostoma spilotum*) to stream conductivity. Southeastern Naturalist 15(1):41-60.

Johnson, J. E., and A. S. Goldberg. 1975. Movement of larval two lined salamanders (Eurycea bislineata) in the Mill River, Massachusetts. Copeia 3:588-589.

Jung, R. E., P. Nanjappa, and E. H. C. Grant. 2004. Stream salamander monitoring: Northeast refuges and parks. Northeast Amphibian Research and Monitoring Initiative. USGS Patuxent Wildlife Research Center.

Karraker, N. E., J. P. Gibbs, and J. R. Vonesh. 2008. Impacts of road deicing salt on the demography of vernal pool-breeding amphibians. Ecological Applications 18:724-734.

Kleeberger, S.R. 1985. Influence of intraspecific density and cover on home range of a plethodontid salamander. Oecologia 66(3):404-410.

Lindberg, T. T., E. S. Bernhardt, R. Bier, A. M. Helton, R. B. Merola, A. Vengosh, and R. T. Di Giulio. 2011. Cumulative impacts of mountaintop mining on an Appalachian watershed. Proceedings of the National Academy of Science of the United States of America 108:20929-20934.

Lowe, W. H. 2003. Linking dispersal to local population dynamics: A case study using a headwater salamander system. Ecology 84(8):2145-2154.

Lowe, W. H., M. A. McPeek, G. E. Likens, and B. J. Cosentino. 2008. Linking movement behavior to dispersal and divergence in plethodontid salamanders. Molecular Ecology 17:4489-4469.

MacKenzie, D. I., J. D. Nichols, J. E. Hines, M. G. Knutson, and A. B. Franklin. 2003. Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. Ecology 84(8):2200-2207.

Macneale, K. H., B. L. Pecharsky, and G. E. Likens. 2005. Stable isotopes identify dispersal patterns of stonefly populations living along stream corridors. Freshwater Biology 50(7):1117-1130.

Mazerolle, M. J., L. L. Bailey, W. L. Kendall, J. A. Royle, S. J. Converse, and J. D. Nichols. 2007. Making great leaps forward: Accounting for detectability in herpetological field studies. Journal of Herpetology 41(4):672-689.

Messinger, T., and K. S. Paybins. 2003. Relations between precipitation and daily and monthly mean flows in gaged, unmined and valley-filled watersheds, Ballard Fork, West Virginia, 1999-2001. Water resources investigation report 03-4113. U.S. Geological Survey.

Miller, J. E., G. R. Hess, and C. E. Moorman. 2007. Southern two-lined salamanders in urbanizing watersheds. Urban Ecosystems 10:73-85.

Miller, W. L., J. W. Snodgrass, and G. E. Gasparich. 2015. The importance of terrestrial dispersal for connectivity among headwater salamander populations. Ecosphere 6(10):1-9.

Muncy, B. L., S. J. Price, S. J. Bonner, and C. D. Barton. 2014. Mountaintop removal mining reduces stream salamander occupancy and richness in southeastern Kentucky (USA). Biological Conservation 180:115-121.

Negley, T. L., and K. N. Eshleman. 2006. Comparison of stormflow responses of surface-mined and forested watersheds in the Appalachian Mountains, USA. Hydrological Processes 20(16):3467-3483.

Nowakowski, A. J., and J. C. Maerz. 2009. Estimation of larval stream salamander densities in three proximate streams in the Georgia Piedmont. Journal of Herpetology 43(3):503-509.

Office of Surface Mining. 1977. Surface Mining Control and Reclamation Act. 30 USC.1201 et seq.

Office of Surface Mining Reclamation and Enforcement. 2015. “Stream Protection Rule; Office of Surface Mining Reclamation and Enforcement, Interior; Proposed Rule”, 80 Federal Register 143 (27 July 2015): 44436-44698.

Organ, J. A. 1961. Studies of the local distribution, life history, and population dynamics of the salamander genus *Desmognathus* in Virginia. Ecological Monographs 31(2):189-220.

Orser, P. N., and D. J. Shure. 1975. Population cycles and activity patterns of the dusky salamander, *Desmognathus fuscus fuscus*. American Midland Naturalist 93(2):403-410.

Palmer, M. A., E. S. Bernhardt, W. H. Schlesinger, K. N. Eshleman, E. Foufoula-Georgiou, M. S. Hendryx, A. D. Lemly, G. E. Likens, O. L. Loucks, M. E. Power, P. S. White, and P. R. Wilcock. 2010. Mountaintop mining consequences. Science 327:148-149.

Petranka, J. W. 2010. Salamanders of the United States and Canada. Washington D.C.: Smithsonian Books.

Phillippi, M. A., and A. Boebinger. 1986. A vegetational analysis of three small watersheds in Robinson Forest, Eastern Kentucky. Castanea 51(1):11-30.

Pond, G. J. 2010. Patterns of Ephemeroptera taxa loss in Appalachian headwater streams (Kentucky, USA). Hydrobiologia 641:185-201.

Pond, G. J. 2012. Biodiversity loss in Appalachian headwater streams (Kentucky, USA): Plecoptera and Trichoptera communities. Hydrobiologia 679:97-117.

Pond, G. J., M. E. Passmore, N. D. Pointon, J. K. Felbinger, C. A. Walker, K. J. G. Krock, J. B. Fulton, and W. L. Nash. 2014. Long-term impacts on macroinvertebrates downstream of reclaimed mountaintop mining valley fills in central Appalachia. Environmental Management 54:919-933.

Price, S. J., K. K. Cecala, R. A. Browne, and M. E. Dorcas. 2011. Effects of urbanization on occupancy of stream salamanders. Conservation Biology 25(3):547-555.

Price, S. J., B. L. Muncy, S. J. Bonner, A. N. Drayer, and C. D. Barton. 2016. Effects of mountaintop removal mining and valley filling on the occupancy and abundance of stream salamanders. Journal of Applied Ecology 53:459-468.

R Development Core Team. 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Royle, J. A. 2006. Site occupancy models with heterogeneous detection probabilities. Biometrics 62(1):97-102.

Royle, J. A., and M. Kéry. 2007. A Bayesian state-space formulation of dynamic occupancy models. Ecology 88(7):1813-1823.

SAS Library. 1997. Repeated Measures ANVOA Using SAS PROC GLM. UCLA: Statistical Consulting Group. The University of Texas at Austin. Retrieved from http://www.ats.ucla.edu/stat/sas/library/repeated_ut.htm.

Schrott, G. R., K. A. With, and A. W. King. 2005. On the importance of landscape history for assessing extinction risk. Ecological Applications 15(2):493-506.

Sjögren, P. 1991. Extinction and isolation gradients in metapopulations: The case of the pool frog (*Rana lessonae*). Biological Journal of the Linnaean Society 42:135-147.

Tilman, D. 1993. Species richness of experimental productivity gradients: How important is colonization limitation? Ecology 74(8): 2179-2191.

U.S. EPA (Environmental Protection Agency). 2011. A field-based aquatic life benchmark for conductivity in Central Appalachian streams. Office of Research and Development, National Center for Environmental Assessment, Washington, DC. EPA/600/R-10/023F.

Webster, J. R. 1983. The role of benthic macroinvertebrates in detritus dynamics of streams: A computer simulation. Ecological Monographs 53(4):383-404.

Wickham, J., P. B. Wood, M. C. Nicholson, W. Jenkins, D. Druckenbrod, G. W. Suter, M. P. Strager, C. Mazzarella, W. Galloway, and J. Amos. 2013. The overlooked terrestrial impacts of mountaintop mining. BioScience 63(5):335-348.

Willson, J. D., and M. E. Dorcas. 2003. Effects of habitat disturbance on stream salamanders: Implications for buffer zones and watershed management. Conservation Biology 17(3):763-771.

Wood, P. B., and J. M. Williams. 2013a. Impact of valley fills on streamside salamanders in Southern West Virginia. Journal of Herpetology 47(1):119-125.

Wood, P. B., and J. M. Williams. 2013b. Terrestrial salamander abundance on reclaimed mountaintop removal mines. Wildlife Society Bulletin 37(4):815-823.

Zipper, C. E., J. A. Burger, J. G. Skousen, P. N. Angel, C. D. Barton, V. Davis, and J. A. Franklin. 2011. Restoring forests and associated ecosystem services on Appalachian coal surface mines. Environmental Management 47:751-765.

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