Modeling the Relationship between Landscape Structure and Amphibian Breeding

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Modeling the Relationship between
Landscape Structure and Amphibian Breeding

Submitted in Partial Fulfillment of the Requirements for Graduation with Honors to
the Department of Natural Sciences at Carroll College,
Helena, MT.

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April 10, 2000
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ABSTRACT

Amphibians serve as indicators of the health of the environment in which they live. Identification of elements in the environment important for amphibian persistence can be used to construct a quantitative habitat model. This model can provide information about the ecological requirements of a particular species. In this study, I examined the long-toed salamander (*Ambystoma macrodactylum*) and the spotted frog (*Rana luteiventris*) in the Lump Gulch Drainage in the Helena National Forest, Montana. Ponds were surveyed and various landscape features were measured. I found spotted frog breeding to be significantly associated with pond area and amount of submergent vegetation. Long-toed salamander breeding was significantly associated with pond area, amount of submergent and emergent vegetation, and distance to nearest breeding pond. My results suggest these factors may be important in determining the distribution of spotted frogs and long-toed salamanders in Western Montana.
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</table>
Introduction

Amphibians serve as important indicators of the overall condition of the environment (Blaustein, 1995). One reason for this is the close associations they form with their habitats. During their lifetime, they are in contact with two separate elements of the environment. As larvae, amphibians live in the water and, after morphogenesis, the adult forms have the ability to live in terrestrial environments for short periods of time. Additionally, amphibians have thin delicate skin in the adult form, and unshelled eggs, which allows for direct exposure to any harmful toxins in the environment (Stebbins and Cohen, 1995). Because amphibians are such good indicators of the health of an environment, they may forewarn us about factors affecting them in the environment that may also affect humans (Blaustein, 1995).

With amphibians serving as an indicator of environmental health, there was great concern when, in the 1990’s, large numbers of amphibians were discovered to be in decline. Numerous studies have been performed in an attempt to explain these losses. Studies performed in Yosemite National Park by Fellers (cited in Hileman, 1998) have determined five species, that had been carefully surveyed in the early 1900s, have recently shown serious declines (Hileman, 1998). Additionally, other areas have experienced declines, such as Yellowstone and Grand Teton National Parks in Wyoming (Stebbins and Cohen, 1995). This has precipitated some concern as it may indicate something is seriously wrong with the environment. It has been proposed that the causes for species decline are multifactorial, working synergistically to produce their effect (Hileman, 1998).
Some of the causes for amphibian decline have been classified. Amphibian mortality is known to be caused by pathogens, UV radiation, pollutants, and habitat destruction (Stebbins and Cohen, 1995). In particular a chytrid fungus has been observed to cause amphibian decline in two distinct geographical areas, by interfering with cutaneous respiration and water uptake (Halliday, 1998). Additionally, UV rays have been determined to cause amphibian decline. In a study by Blaustein et al. (1994), UV radiation was determined to cause the destruction of the eggs of some amphibian species. In a study exploring the effects of pollution on embryonic salamander survivorship, Turtle (2000) found that salamanders survived poorly in heavily contaminated roadside pools. Habitat destruction is also a known cause of amphibian declines. For example, a survey in western North Carolina found that clear cutting forests lead to increased mortality for many amphibian species (Blaustein, 1995). Thus, it is important to consider the amount of habitat necessary to sustain a population and how that habitat should be distributed across the landscape.

Identifying important elements to an environment can provide a basis for conservation and ultimately the preservation of amphibian species. Landscape ecology examines the structure of a heterogeneous area that is composed of several ecosystems (Molles, 1999). Ecosystems in each landscape may be defined as distinct areas known as patches. The hierarchical nature of landscape structure can be further broken down within each patch. For example, a wetland may be considered a patch within a landscape region or a pond may be considered a patch within the overall wetland. Patch characteristics such as size, isolation, and quality may be measured to assess their association with the presence of a species. For example, we might look at
the area of the pond, vegetation data relating to the pond, and the water chemistry of
the pond. We can then determine which of these factors are associated with
amphibian presence or absence. Factors found to be associated with amphibian
presence may be used to construct a quantitative habitat model.

A predictive model of amphibian-habitat associations provides an important
management tool for the maintenance of amphibian biodiversity (Crisafulli, 1997). A
model can provide information about the ecological requirements of a particular
species by relating small landscape features with the presence of amphibians. This in
turn can lead to a preservation policy from wildlife managers responding to these
disruptions in the environment that cause declines in populations (Rice, 1993).

Previous studies testing landscape features on amphibian populations suggest
that population size and isolation influence persistence. Halley, et al. (1996), found
initially occupied ponds were likely to persist if they supported more than 40 females
or were within 0.5 km of a pond with more than 40 females. In another report Hokit
(1999-a) found *Ambystoma macrodactylum* and *Rana luteiventris* breeding was
positively associated with pond size. Using logistic regression, Sjögren-Gulve and
Ray (1996) created a model to explain how habitat variables govern pond occupancy.
In particular, they found that the presence of large-scale forestry increased the risk of
local extinction. More importantly, their model was able to predict regional
dynamics fairly accurately.

An important approach in understanding the decline in amphibians may be in
comparing populations of amphibians resistant to decline with those experiencing
decline. Two of the most common amphibians in the Helena National Forest are the
long-toed salamander, *Ambystoma macrodactylum*, and the spotted frog, *Rana luteiventris*. The ubiquitous nature of these species in the Lump Gulch Drainage make them excellent specimens for study. They are present in a large selection of ponds and in numbers conducive to statistical analysis. I examined the effects of landscape elements on breeding activity of amphibians in western Montana. Factors I examined included, the area of the pond, the amount of emergent and submersgent vegetation, distance to nearest pond with breeding activity, and water quality measurements of pH and conductivity. I then created a logistical model quantifying the relationship between amphibian breeding and landscape structure.
METHODS AND MATERIALS

Collection of Landscape and Habitat Data

I surveyed ponds located in the Lump Gulch Basin (USGS topographic map Chessman Reservoir) of the Helena National Forest, 15 km south of Helena, MT. I first performed a visual survey of each pond by walking its perimeter. The presence of eggs or tadpoles demonstrated breeding. Visible egg masses were identified as being either the long-toed salamander or the spotted frog, and the relative numbers of eggs or tadpoles were estimated for each pond. I also recorded the amount of adults and juveniles encountered for each amphibian species.

I estimated the area of each pond by measuring the diameter in an east-west, and north-south direction, averaging the measurement to obtain the mean radius, and then calculating the area as $\pi r^2$. I used a measuring tape for ponds smaller than 10 m in diameter and a range finder for larger ponds. I used a GPS unit to acquire location data for each pond and measured pH and conductivity.

To quantify vegetation and substrate types, I placed 1 m$^2$ plots divided into 10 cm$^2$ units into each of the 4 quadrants of the pond (e.g. NE, SE, SW, NW). Plots were located in areas representative of the substrate and vegetation types in that quadrant. One plot was established in each quadrate for ponds less than 10 m in diameter, two plots per quadrate were established in ponds 20-30 m in diameter, and three plots per quadrate in ponds greater than 30 m in diameter. I determined the
dominant vegetation and substrate type for each 10cm² unit in each plot and recorded the total number of units for each vegetation and substrate type for each plot. Vegetation types included emergent plants (e.g., carex) and submergent (e.g., pondweed) plants. Substrate types were broken into the following categories: sand; small gravel; large gravel; cobble; boulder; muck; and coarse detritus. I estimated the percent coverage of each vegetation and substrate type by dividing the total number of 10cm² units dominated by a particular type by the total number of units possible.

Analysis of Data

Landscape and habitat data were compared between breeding and non-breeding pond sites. First, logistic regression analysis was used to test for differences between breeding and non-breeding sites with respect to each individual factor. Then, those factors for which a significant difference was detected were used to construct a multi-factor logistic regression function. This multi-factor function was constructed using the principle of parsimony such that only the fewest number of factors necessary to explain the data were incorporated in the final model.
RESULTS

Logistic regression analysis revealed two factors for spotted frogs and four factors for long-toed salamanders that were significantly different between breeding and non-breeding sites (Table 1).

For spotted frogs, the area of the pond and the percent of submergent vegetation were both significantly related to breeding activity (Fig. 1 and Fig. 2, respectively).

For long-toed salamanders, pond area, percent emergent vegetation, percent submergent vegetation, and distance to the nearest pond containing *Ambystoma* were found to be significantly related to breeding. Area (Fig. 3) and submergent plants (Fig. 4) were positively associated with breeding while emergent vegetation (Fig. 5) and distance (Fig. 6) were negatively associated with breeding activity.

Multifactor logistic regression analysis suggests that both area and submergent plants are necessary to fully explain the differences between breeding and non-breeding sites for spotted frogs. Simple models with one or the other factor alone did not fit the data as well as the model with both factors (Table 2). The final multifactor logistic model for spotted frogs was:

\[
P = \frac{\exp(0.53A + 0.027S - 3.34)}{[1 + \exp(0.53A + 0.027S - 3.34)]}
\]
where $A$ is area in squared meters, $S$ is percentage coverage of submergent vegetation, and $P$ is the probability of finding spotted frog breeding in a pond with these coefficients.

Four factors were considered in the construction of a predictive model for long-toes salamander including area, emergent vegetation, submergent vegetation, and distance. Multifactor logistic regression analysis suggested that only three of the four factors were necessary to accurately predict long-toed salamander breeding activity (Table 3). A model including area, emergent vegetation, and distance was not significantly different from the full model containing all four factors, suggesting that the three-factor model fit the data as well as the four-factor model.

The final model for the long-toed salamander was:

$$P = \frac{\exp(0.76A - 0.04E - 0.01D - 3.39)}{1 + \exp(0.76A - 0.04E - 0.01D - 3.39)}$$

Where $E =$ emergent vegetation, $D =$ distance to nearest pond.
Table 1
Statistical Analysis of breeding and landscape structure.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Coefficient</th>
<th>SE</th>
<th>Wald’s Stat.</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rana luteivantris</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td>0.57</td>
<td>0.12</td>
<td>24.32</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Emergent Vegetation</td>
<td>0.01</td>
<td>0.01</td>
<td>0.50</td>
<td>0.478</td>
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<tr>
<td>Submergent Vegetation</td>
<td>0.03</td>
<td>0.01</td>
<td>17.49</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Distance</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.39</td>
<td>0.528</td>
</tr>
<tr>
<td>PH</td>
<td>-0.22</td>
<td>0.21</td>
<td>1.10</td>
<td>0.293</td>
</tr>
<tr>
<td>Conductivity</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>1.79</td>
<td>0.180</td>
</tr>
</tbody>
</table>

| **Ambystoma macrodactylum**   |             |     |               |         |
| Area                          | 0.64        | 0.12| 27.2          | <0.001* |
| Emergent Vegetation           | -0.03       | 0.01| 5.42          | 0.019*  |
| Submergent Vegetation         | 0.02        | 0.01| 10.13         | 0.001*  |
| Distance                      | -0.01       | <0.01| 5.56         | 0.018*  |
| PH                            | -0.29       | 0.23| 1.57          | 0.209   |
| Conductivity                  | 0.01        | <0.01| 3.07         | 0.079   |

1Walds statistic calculated using logistic regression procedures.

Table 2
Comparison of models for Rana

<table>
<thead>
<tr>
<th>Model</th>
<th># of parameters</th>
<th>loss function</th>
<th>Comparison</th>
<th>Chi-square</th>
<th>Degrees of freedom (df)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.Area+Submergent</td>
<td>3</td>
<td>225.18</td>
<td>1 vs.2</td>
<td>14</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>2. Area</td>
<td>2</td>
<td>239.18</td>
<td>1 vs.2</td>
<td>14</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>3.Submergent</td>
<td>2</td>
<td>251.8</td>
<td>1 vs.3</td>
<td>26.6</td>
<td>1</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

1Loss function calculated using logistic regression procedures.
<table>
<thead>
<tr>
<th>Model</th>
<th># of parameters</th>
<th>Loss function</th>
<th>comparison</th>
<th>Chi-square</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Full</td>
<td>5</td>
<td>184.29</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. A+E+S</td>
<td>4</td>
<td>202.42</td>
<td>1 vs. 2</td>
<td>18.13</td>
<td>1</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>3. E+S+D</td>
<td>4</td>
<td>221.48</td>
<td>1 vs. 3</td>
<td>37.19</td>
<td>1</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>4. A+S+D</td>
<td>4</td>
<td>188.22</td>
<td>1 vs. 4</td>
<td>3.93</td>
<td>1</td>
<td>&lt;0.05</td>
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<tr>
<td>5. A+E+D</td>
<td>4</td>
<td>187.52</td>
<td>1 vs. 5</td>
<td>3.23</td>
<td>1</td>
<td>&gt;0.05*</td>
</tr>
<tr>
<td>6. A+D</td>
<td>3</td>
<td>193.00</td>
<td>5 vs. 6</td>
<td>5.48</td>
<td>1</td>
<td>&lt;0.05</td>
</tr>
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</table>
Figure 1
Comparison of mean pond area (±SE) for sites with (yes) and without (no) spotted frog breeding activity.

Figure 2
Comparison of percent submergent vegetation (±SE) for sites with (no) and without (yes) spotted frog breeding activity.
Figure 3
Comparison of mean pond area (±SE) for sites with (yes) and without (no) long-toed salamander breeding activity.

Figure 4
Comparison of percent submergent vegetation (±SE) for sites with (yes) and without (no) long-toed salamander breeding activity.
**Figure 5**
Comparison of percent emergent vegetation (±SE) for sites with (yes) and without (no) long-toed salamander breeding activity.

**Figure 6**
Comparison of distance to nearest breeding pond (±SE) for sites with (yes) and without (no) long-toed salamander breeding.
DISCUSSION

My results suggest that spotted frogs and long-toed salamanders are influenced by landscape and habitat factors at the pond scale. Breeding activity for both the frogs and salamanders was positively associated with pond size and the amount of submergent vegetation. Additionally for the salamanders, emergent vegetation and the distance to an occupied neighboring pond was negatively associated with breeding activity.

A positive association between patch area and extinction risk is one of the most widespread observations in ecology (Schoener and Schoener, 1983). The area of a patch is often associated with population size and area-extinction associations are most often explained by stochastic processes acting differently on small versus large populations (Gilpin and Soule, 1986). Patch size is known to influence vital rate characteristics such as dispersal rate (Stamps, et al. 1987), fecundity (Robinson, et al. 1995), individual growth (Pearman, 1993), and population density (Bowers and Matter, 1997).

The size of habitat patches is often associated with the probability that a patch is occupied by amphibian or reptile species (Hokit, et al. 1999). My results concur with these studies and suggest that spotted frogs and long-toed salamanders are influenced by such stochastic and/or deterministic factors as described above. It is likely larger ponds provide more resources (e.g., food, shelter, breeding locations) and can support larger populations relatively immune to temporal fluctuations in abundance. Also, larger ponds typically have a longer hydroperiod: the ability to
retain water for a longer portion of the summer season. Skelly (1997) has observed that tadpoles grow larger and have a higher probability of survival if adult frogs oviposite eggs in ponds with a longer hydroperiod. By the end of the summer season, many smaller, more ephemeral ponds dry up before tadpoles have the opportunity to metamorphose. Hydroperiod may also explain the negative association between long-toed salamander breeding activity and the amount of emergent vegetation. Visual observations suggest that small shallow ponds (i.e., those with a shorter hydroperiod) have more emergent plants than do large deep ponds.

Refugia can provide individuals protection from predators and parasites (Molles 1999). There are many different types of refuge such as, burrows, trees, air, water (if a terrestrial predator), and land (if an aquatic predator). Greenburg and Oritz (1994) found that some subordinate species of birds depend on the presence of a dense understory vegetation to avoid more aggressive species. Additionally, Sih (1991) observed that salamander larvae moved into vegetation to escape predation.

I found salamander breeding to be associated with a high amount of submergent vegetation. The vegetation may provide areas where tadpoles can hide to escape predators such as fish and large invertebrates, giving them enough time to develop to the point where they can escape. Additionally, this habitat feature may play a role in the process of oviposition. Salamanders attach egg masses to vegetation and other structures beneath the water (Leonard, 1993). Thus, submergent vegetation may provide refugia or oviposition sites for salamanders, and increase the probability of population persistence.
The degree of patch isolation is often negatively associated with patch occupancy (Hokit, et al. 1999). This is because migration between habitat patches can supply immigrants that will stabilize population fluctuations (Hanski, 1994). Hokit et al. (1999) found that the farther a scrub patch was from the nearest neighboring patch, the less likely the patch would be occupied by Florida scrub lizards (*Sceloporus woodi*). Additionally, more isolated patches of meadow habitat support lower densities of butterflies (Molles, 1999). The closer patches are to each other, the easier it is for butterfly migration to supplement the population.

I found a significant negative relationship between salamander breeding activity and pond isolation. Halley (1996) observed the same relationship for the common toad and the crested newt. An isolated pond, may not obtain enough migrating salamanders to stabilize population fluctuations. If the pond is also small in size and lacks submergent vegetation, there may be little chance that it can support a population of salamanders.

Habitat patch size, isolation, and quality all influence the persistence of regional collection of populations (Hanski 1994). My results suggest that all three factors may be important in determining the distribution spotted frogs and long-toed salamanders in Western Montana. Through their interactions with other organisms, amphibians are key components of many wetland ecosystems. An estimated 20 percent of the wetland habitat has been destroyed in the state of Montana (Dahl, 1990). This number is tentative at best as most wetland habitat has not been surveyed or mapped in Montana. The relatively poor knowledge of wetland habitat in the state coupled with the poor knowledge we have of the distribution, biology, and status of
Montana amphibians highlights the need to undertake thorough inventories of our public lands. As far as spotted frogs and long-toed salamanders are concerned, my results suggest the highest priority should be given to large, well-connected wetlands with long hydroperiods.
ACKNOWLEDGEMENTS

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LITERATURE CITED


