**Electronic Supplementary Material**

# The importance of local and landscape-scale processes to wetland occupancy by breeding wood frogs and boreal chorus frogs

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S1. A description of the processes used to develop a cost surface for modeling the probability of occupancy in wood frogs (*Lithobates sylvaticus*) and boreal chorus frogs (*Pseudacris maculata*) in the Kawuneeche Valley (KV) of Rocky Mountain National Park, Colorado. All procedures were conducted in ArcGIS 9.2 (ESRI 1999-2006).

The concept of a cost surface recognizes that biotic and abiotic attributes of a landscape influence the movement of individuals (Compton et al. 2007; Zanini et al. 2008). In practice, costs surfaces are created by assigning relative costs of movement to different land cover types in a map (Theobold 2005; Compton et al. 2007). The relative costs reflect the willingness of an individual to move through a particular land cover type, as well as the effect of the land cover type on the physical condition and survival of the individual (Compton et al. 2007; Zanini et al. 2008).

To develop a cost surface for the KV, we acquired a vegetation map for Rocky Mountain National Park (Salas et al. 2005) and extracted the data for the KV. The vegetation map was developed using data from hundreds of vegetation plots distributed across the park and aerial photo interpretation (Salas et al. 2005). It partitioned the park into patches (i.e., polygons) that were assigned to particular land cover classes (*n* = 44 classes). We combined ecologically similar land cover classes to reduce the number to 26 classes. Even after the reduction, however, data on the movement behavior of wood frogs and chorus frogs were too sparse to assign relative costs to each class without many arbitrary assignments. Therefore, rather than assign relative costs of movement to each land cover class, we identified broad landscape types to which costs could be assigned based on the results of field studies. Though data on chorus frogs are sparse, previous research provides useful information with which to assign relative costs of movement for wood frogs. Based on a review of this literature, we designated landscape types based on two attributes: type of cover (tree, shrub or grass/forb) and moisture regime (wet or dry). We combined these attributes to form six landscape types: i) Types with canopy cover from trees and a wet moisture regime (Tree-Wet), ii) Types with canopy cover from trees and a dry moisture regime (Tree-Dry), iii) Types with canopy cover from shrubs and a wet moisture regime (Shrub-Wet), iv) Types with canopy cover from shrubs and a dry moisture regime (Shrub-Dry), v) Types with canopy cover from grasses and forbs and a wet moisture regime (Grass-Wet), and vi) Types with canopy cover from grasses and forbs and a dry moisture regime (Grass-Dry). We assigned the lowest cost of movement to the Tree-Wet and Shrub-Wet landscape types (Table S1).

Table S1: Costs of movement for wood frogs, *Lithobates sylvaticus*, and boreal chorus frogs, *Pseudacris maculata*, adults and juveniles (in parentheses) through each of 6 landscape types.

| Landscape Type | Cost – Wood Frog | Cost – Chorus Frog |
|---|---|---|
| Tree-Wet | 1 (1) | 1 (1) |
| Shrub-Wet | 1 (1) | 1 (1) |
| Grass-Wet | 2 (3) | 1 (1) |
| Tree-Dry | 5 (10) | 7 (10) |
| Shrub-Dry | 7 (14) | 9 (14) |
| Grass-Dry | 9 (18) | 11 (18) |

Several studies have shown that adult and juvenile wood frogs orient toward areas with canopy cover and moist substrates upon leaving breeding ponds (deMaynadier and Hunter 1999; Vasconcelos and Calhoun 2004; Regosin et al. 2005; Baldwin et al. 2006). Coniferous trees dominate the KV and shrubs in the study area have small leaves. Consequently, relative to much of the area in the eastern portion of the wood frog's geographic range, canopy cover in the KV is relatively sparse. In addition, wood frogs in the western U.S. are not as closely associated with forests as they are in the eastern U.S. (Stebbins 1966). Therefore, we suspect a lack of canopy cover has a smaller impact on costs of movement than moisture regime. Average 24-hr survival probabilities for wood frogs held in enclosures in a forested drainage (comparable to the Tree-Wet landscape type) were approximately 0.55, while survival probabilities in enclosures on a forested ridge (comparable to the Tree-Dry landscape type) and a clearcut area (comparable to the

Grass-Dry landscape type) were 0.15 and 0.06 (Rittenhouse et al. 2008). The survival probabilities indicate a relatively large decline between areas with moist and dry substrates, whereas the decline between the two areas with dry substrates but differences in canopy cover was much smaller. Therefore, we assigned a slightly higher cost of movement to the Grass-Wet landscape type (versus the landscape types that were wet and have canopy cover, Tree-Wet and Shrub-Wet) and made greater increases to the cost of movement through landscape types with a dry regime (Table S1). For the Tree-Dry, Shrub-Dry, and Grass-Dry types, we increased the costs by 4, 6 and 8 cost units relative to the lowest cost landscape types (Table S1). We based these increases on the results from previous studies of movement in wood frogs, as well as the 24-hour survival probabilities from Rittenhouse et al. (2008) described above. For example, Vasconcelos and Calhoun (2004) used drift fences and pitfall traps to capture male, female and juvenile wood frogs as they migrated from a breeding wetland. In pitfall traps 150 m north of the breeding wetland, they caught 8.5, 3 and 22 times the number of males, females and juveniles than in pitfall traps 150 m south of the breeding wetland. The breeding wetland and the pitfall traps to the north were separated by a wetland with no canopy cover, while a dry meadow separated the pitfall traps to the south from the breeding wetland. For adults, these results suggest a cost of movement for the Grass-Dry category 3 to 8.5 times higher than for the Grass-Wet category.

Since data to infer movement costs for chorus frogs are sparse, we primarily based relative costs of movement on the fact that they are smaller than wood frogs, and consequently, have a higher surface area to volume ratio. Therefore, we assigned a higher relative cost of movement through dry patch types (Table S1). Chorus frogs also appear to be less closely associated with forests and other areas with canopy cover (Trenham et al. 2003), so we did not distinguish between the cost of movement through the Tree-Wet and Shrub-Wet and Grass-Wet landscape types as we did for wood frogs (Table S1).

To translate the movement costs assigned to the 6 landscape types to the 29 land cover classes, we sampled the study area by locating 615 ground-truth plots of variable size (0.03 to 7.7 ha). Ground-truth plots were delineated by identifying relatively homogeneous areas with respect to canopy cover and moisture regime and taking spatial coordinates around the boundary of the plot using a hand-held GPS unit (Garmin eTrex©). We concentrated plots in the 8 land cover classes that comprised nearly 95% of the study area. At each plot, the species of tree or shrub that provided the greatest cover was recorded. Regardless of whether canopy cover from trees or shrubs was present, we also recorded the species of understory plant that provided the greatest cover, as well as other common species in the patch. We assigned each plot to one of the six landscape types based on the data from these surveys. We assigned type of cover (Tree, Shrub or Grass) based on the plant species in the plot. Assignment of moisture regime was based on the 1998 National Wetlands Inventory (http://www.fws.gov/nwi/plants.htm). The wetlands inventory classifies plant species into one of five categories: i) obligate wetland (almost always occurs in wetlands), ii) facultative wetland (usually occurs in wetlands), iii) facultative (equally likely to occur in wetlands or non-wetlands), iv) facultative upland (usually occurs in non-wetlands) and v) obligate upland (almost always occurs in non-wetlands). We used this classification to determine if the dominant and common plant species in a plot were associated with wet (obligate or facultative wetland) or dry (obligate or facultative upland) areas. In plots with plant species of differing wetland classifications, we gave priority to the classification of the dominant species and used comments regarding the wetness of the substrate collected during ground-truth surveys.

After the data from the plots were collected, we mapped the locations of the plots and overlaid the map of the plots on the vegetation map of the park. For each land cover class in the vegetation map, we compiled the data from the plots that were located within the class. To assign costs of movement to each land cover class, *LC*, we calculated a weighted-average cost of movement as below:

$$LC = \sum_{i=1}^{6} w_i c_i \ ,$$

where *i* indexes the 6 landscape types (Tree-Wet, Shrub-Wet,… etc.), $w_i$ is the proportion of plots of landscape type *i* within the land cover class, and $c_i$ is the estimated cost of movement through landscape type *i* (Table S1). For example, 27 ground-truth plots were located within land cover class 1 (Table S2). Twenty-one of the plots were classified as the Grass-Dry landscape type, which indicates a high cost of movement through the land cover class. Other plots, however, suggested a lower cost of movement through the class (e.g., three plots were classified as the Shrub-Wet land cover class). Therefore, the weighted-average cost of movement is 7.63 (Table S2), which we rounded to the nearest integer. Consequently, all cells of land cover class 1 were assigned a relative cost of movement of 8 in the cost surface. Some land cover classes contained no ground-truth plots. The total area of these land cover classes represents less than 5% of the study area, and in many cases, they were not near sampled wetlands. We used descriptions of the vegetation communities in these land cover classes from Salas et al. (2005) to assign relative costs of movement.

After assigning a relative cost of movement to each of the 26 land cover classes, we converted the vegetation map into a raster data set (10 m × 10 m cells where the value assigned to each cell was based on the land cover class in the vegetation map that overlapped the centers of the cells). Rather than assign the land cover class to each cell, however, we assigned the relative cost of movement, *LC*, associated with the land cover class and used the resulting raster data set as a cost surface. Because we had different relative movement costs for wood frog adults, wood frog juveniles, chorus frog adults and chorus frog juveniles (Table S2), we created four cost surfaces.

Table S2: Costs of movement for wood frogs, *Lithobates sylvaticus*, and boreal chorus frogs, *Pseudacris maculata*, adults and juveniles (in parentheses) through each of the 26 land cover classes.

| Land Cover Class | Brief Class Description | Cost Wood Frog | Cost Chorus Frog |
|---|---|---|---|
| 1 | Herbaceous upland | 8 (15) | 9 (15) |
| 5 | Herbaceous wetland | 3 (6) | 3 (5) |
| 9 | Alpine ice and rock fields | Barrier | Barrier |
| 13 | Shrub upland | 1 (2) | 1 (1) |
| 15 | Aspen | 2 (4) | 3 (4) |
| 20 | Montane douglas fir | 5 (10) | 7 (10) |
| 22 | Sub-alpine mixed conifer | 4 (8) | 6 (8) |
| 23 | Lodgepole pine | 4 (9) | 6 (9) |

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|---|---|---|---|
| 33 | Juniper | 7 (14) | 9 (14) |
| 34 | Ponderosa pine | 5 (10) | 7 (10) |
| 38 | Limber pine | 5 (10) | 7 (10) |
| 39 | Ribbon forests | 5 (10) | 7 (10) |
| 41 | Disturbed area | 9 (18) | 11 (18) |
| 43 | Blue spruce | 5 (10) | 7 (10) |
| 46 | Talus | 8 (15) | 9 (15) |
| 48 | Exposed soil and cliff faces | 6 (12) | 7 (11) |
| 52 | Lakes and reservoirs | Barrier | Barrier |
| 120 | Riparian shrub | 2 (3) | 2 (3) |
| 141 | Upland shrub – sagebrush | 5 (9) | 5 (8) |
| 142 | Upland shrub – bitterbrush | 7 (14) | 9 (14) |
| 162 | Mixed conifer with aspen | 4 (7) | 4 (7) |
| 190 | Riparian mixed conifer, high elevation | 3 (5) | 4 (5) |
| 191 | Riparian mixed conifer, low elevation | 1 (1) | 1 (1) |
| 501 | Small streams | 4 (6) | 4 (6) |
| 502 | Rivers and large streams | 8 (14) | 10 (14) |
| 999 | Un-vegetated surfaces | 18 (22) | 22 (22) |

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S2. A description of the processes used to delineate cost-based buffers and derive estimates of the amount of seasonal habitat for wood frogs (*Lithobates sylvaticus*) and boreal chorus frogs (*Pseudacris maculata*) around each wetland in the Kawuneeche Valley (KV), Rocky Mountain National Park, Colorado. All procedures were conducted in ArcGIS 9.2 (ESRI 1999-2006).

We used the ‘Cost Allocation’ tool in ArcGIS 9.2 (ESRI 1999-2006) to delineate cost-based buffers around each wetland. For each cell in a raster data set, the ‘Cost Allocation’ tool determines the minimum cost distance from a cell to the nearest source cell. In this project, source cells represented the sampled wetlands. Starting with the outermost source cells for a wetland, the ‘Cost Allocation’ tool computes a minimum cost distance from those cells to the next set of adjacent cells (moving away from the wetland). It repeats this procedure for the next set of adjacent cells such that the minimum cost distance for each set of adjacent cells represents a cumulative minimum cost to the nearest source cells. In this way, minimum cost distances are calculated for each ring of cells growing away from the source cells. The algorithm can be stopped when a pre-defined maximum cost distance is reached. For example, when estimating the amount of seasonal habitat within 1000 cost meters of a sampled wetland for wood frogs, the algorithm stopped when the cumulative minimum cost distance to an adjacent cell exceeded 1000 cost meters from the nearest source cell. The set of cells within the pre-defined maximum cost distance comprise a cost-based buffer or allocation zone (Theobold 2006).

After the buffer for each wetland was defined, we summed the amount of available wetland, streamside, and upland habitat within it. To identify different habitat types within the buffers, we acquired a vegetation map for Rocky Mountain National Park (Salas et al. 2005) and extracted the data for the KV. The vegetation map was developed using data from hundreds of ground-truthed plots and aerial photo interpretation (Salas et al. 2005). It partitioned the park into patches (i.e., polygons) that were assigned to particular land cover classes ($n$ = 44 classes). We combined ecologically similar land cover classes to reduce the number to 26 classes. We assigned land cover classes from the vegetation map to one of the types of seasonal habitat or as non-habitat (Table S3). For example, data from ground-truth plots indicated that land cover classes 5, 13, 15, and 120 were wetlands. Therefore, we defined them as wetland habitat (Table S3). If the description of a land cover class and the data from ground-truth plots were vague with respect to the assignment of seasonal habitat type, we defined the class as non-habitat.

Table S3: Classification scheme used to convert land cover types into one of the three seasonal habitat types (wetland, streamside, and upland).

| Land Cover Class | Brief Class Description | Habitat Type |
|---|---|---|
| 1 | Herbaceous upland | Upland |
| 5 | Herbaceous wetland | Wetland |
| 9 | Alpine ice and rock fields | Non-habitat |
| 13 | Shrub upland | Wetland |
| 15 | Aspen | Wetland |
| 20 | Montane douglas fir | Upland |

| | | |
|---|---|---|
| 22 | Sub-alpine mixed conifer | Upland |
| 23 | Lodgepole pine | Upland |
| 33 | Juniper | Upland |
| 34 | Ponderosa pine | Upland |
| 38 | Limber pine | Upland |
| 39 | Ribbon forests | Non-habitat |
| 41 | Disturbed area | Non-habitat |
| 43 | Blue spruce | Upland |
| 46 | Talus | Non-habitat |
| 48 | Exposed soil and cliff faces | Non-habitat |
| 52 | Lakes and reservoirs | Non-habitat |
| 120 | Riparian shrub | Wetland |
| 141 | Upland shrub – sagebrush | Non-habitat |
| 142 | Upland shrub – bitterbrush | Upland |
| 162 | Mixed conifer with aspen | Non-habitat |
| 190 | Riparian mixed conifer, high elevation | Non-habitat |
| 191 | Riparian mixed conifer, low elevation | Non-habitat |
| 501 | Small streams | Streamside |
| 502 | Rivers and large streams | Streamside |
| 999 | Un-vegetated surfaces | Non-habitat |

Finally, we used the 'Combine' tool to generate a count of the number of cells of each seasonal habitat type within each buffer and transferred those counts into a spreadsheet.

Literature cited:

Salas D, Stevens J, Schulz K (2005) Rocky Mountain National Park, Colorado: 2001-2005 vegetation classification and mapping. Technical Memorandum 8260-05-02. U.S. Bureau of Reclamation. Denver, Colorado

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