# The Influence of Meadow Moisture Levels on Activity of Small Mammal Nest Predators in the Sierra Nevada, California

Author(s): M. Constanza Cocimano, Michael L. Morrison, Heather A. Mathewson, and Lisa M. Vormwald

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# THE INFLUENCE OF MEADOW MOISTURE LEVELS ON ACTIVITY OF SMALL MAMMAL NEST PREDATORS IN THE SIERRA NEVADA, CALIFORNIA

M CONSTANZA COCIMANO, MICHAEL L MORRISON, HEATHER A MATHEWSON, AND LISA M VORMWALD

*Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX 77843*

ABSTRACT—High nest predation rates are one of the main sources of nesting failure in passerines. Mountain meadows in the Sierra Nevada have been intensively modified, reducing meadow wetness and potentially favoring easy access for mammalian predators to reach nesting areas in the meadow interior. We conducted mammal trapping in wet and dry areas of montane meadows during May through August of 2007 and 2008 to identify the assemblage of potential mammalian nest predators and determine the relationship between activity and meadow wetness. Chipmunk (*Tamias* spp.) activity was primarily restricted to dry areas. Activity of Yellow-pine Chipmunks (*Tamias amoenus*) was >90% higher in dry versus wet areas. Deer Mice (*Peromyscus maniculatus*) were equally active in both site types in 2007, but declined and were only captured in wet areas in 2008. Overall activity was higher in 2007 and 2008 for both wet and dry areas (68% and 52%, respectively). Our results suggest that increasing the proportion of inundated areas in meadows may reduce small mammal activity (for instance Yellow-pine Chipmunks) and potentially reduce nest predation.

Key words: California, *Empidonax traillii*, meadows, passerine, predators wetness, Sierra Nevada, small mammals, Willow Flycatcher

Studies in the Sierra Nevada, California, suggested that predation by terrestrial vertebrates significantly reduced nest success of the California state endangered Willow Flycatcher (*Empidonax traillii*), and other species such as Yellow Warbler (*Dendroica petechia*; Cain and others 2003) and Dusky Flycatcher (*E. oberholseri*) that nest in riparian areas (Cain and Morrison 2003). Meadows in the Sierra Nevada have been intensively modified by livestock grazing, road construction, timber harvesting, changes in fire regimes, and recreational activities (Ratliff 1982; Green and others 2003; Fites-Kaufman and others 2007). These activities have led to a decrease in meadow wetness (Green and others 2003), which in turn facilitates the establishment and expansion of Lodgepole Pine (*Pinus contorta*) farther into meadows (Fites-Kaufman and others 2007). In the Sierra Nevada, Cain and others (2003) found that meadow wetness, distance to isolated trees, and distance to forest edge were related to predator activity. The presence of water may prevent terrestrial mammalian activity in inundated (standing water) areas (Picman and others 1993; Jobin and Picman 1997; Cain and others 2003; Fletcher and Koford 2004; Hoover 2006); thus restoring higher water levels may inhibit some predators from accessing nests, increase recruitment and survival of riparian deciduous shrubs, and improve habitat for passerine prey (wasps, flies, moths, caterpillars, and bees) (Erman 1984; Green and others 2003).

Rodents are known nest predators (Liebezeit and George 2002; Bradley and Marzluff 2003). Among rodent species, Douglas' Squirrel (*Tamiasciurus douglasii*), Deer Mice (*Peromyscus maniculatus*), and chipmunks (*Tamias* spp.) have been photographed predating abandoned Yellow Warbler nests baited with eggs in montane meadows in the Sierra Nevada (Cain and others 2003); we have no data on specific rodent predators of Willow Flycatcher nests in our study region. Based on the work of Cain and others (2003), we predicted that wet meadows would show lower small mammal abundance and activity relative to dry meadows. Our goal, using the same general study areas as Cain and others (2003), was to evaluate the activity and abundance of small mammals in meadows by:

(1) determining the relative abundance, activity, and distribution of small mammals in meadows of the Sierra Nevada; (2) determining the influence of meadow wetness on the activity and abundance of potential nest predators; and (3) providing management recommendations for the implementation of restoration practices to improve meadow conditions for passerines such as the California state endangered Willow Flycatcher.

## METHODS

### *Study Area*

Our study sites were part of a long-term demography study of Willow Flycatchers located in montane meadows in central Sierra Nevada, California (Bombay 1999; Bombay and others 2003; Cain and others 2003). The area presents a mountainous topography and a naturally fragmented landscape. Meadows were associated with streams and small headwater rivers, pond and lake margins, or spring and seeps (Ratliff 1982; Bombay and others 2003). Forests dominated by Lodgepole Pine (*Pinus contorta*) surrounded the meadows, which predominately consisted of herbaceous plants (*Carex* spp. and *Juncus* spp.) and willows (*Salix lemmonii* and *S. geyeriana*). Willows were distributed along streams and in clumps scattered throughout the meadows (Bombay and others 2003; Cain and others 2006). Meadows ranged in size from 25 to 103 ha and elevations ranged from 1900 to 2700 m. Temperatures in the summer ranged from an average overnight low of 3°C to an average daily high of 26°C (Western Regional Climate Center 2008).

### *Study Site Selection*

We selected 10 study sites (meadows) that presently or historically supported populations of Willow Flycatchers in the north-central Sierra Nevada (Bombay 1999; Green and others 2003) in the Lake Tahoe Basin Management Unit and Tahoe National Forest (El Dorado, Placer, Nevada, and Sierra counties), and Department of Fish and Game lands (Warner Valley, Plumas County); specific meadows and geographic locations are in Cocimano (2009). Specific sampling areas (wet and dry, see below) were then selected from within each of these meadows (8 in 2007, and 7 in 2008).

### *Wetness Conditions*

We used the line-intercept method (Bonham 1989) to evaluate the wetness conditions of wet and dry areas in each meadow every 3 m along the trap lines. We classified soil surface moisture as dry, saturated, or inundated, and measured water depth. We defined soil as inundated soil where there was standing surface water, as saturated soil where water seeped to the surface after pressing on the ground, and as dry soil where no surface moisture was present or seeped to the surface when pressed. We calculated the overall percentage of sampling points with inundated soils, and mean water depth for each wet and dry area in each meadow.

In each meadow we classified wet and dry areas, where wet areas were where at least 60% of the line intercept (described below) was wet (with saturated and inundated soils). We randomly determined the order in which each meadow would be sampled. Of the approximately 422 ha of meadows included in our study, only about 59 ha (14%) were dominated by willow (Bombay 1999; Bombay and others 2003). Of this willow-covered area, about 30 ha (7%) were excluded from trapping to avoid disturbing nesting Willow Flycatchers.

### *Mammal Sampling*

To evaluate mammal abundance and activity in different wetness conditions across the meadows, we live-trapped small mammals in May to August of 2007 and 2008. In each of the wet and dry areas of the meadows, we set Sherman live traps (extra large [7.6 × 9.5 × 30.5 cm] and large [7.6 × 8.9 × 23.5 cm]) 10 to 15 m apart within willow clumps along trap lines running from the forest edge to the center of the meadow. We focused on willow because it is the predominate shrub in the meadows we studied, and many meadow-nesting passerines use this substrate for nest placement and foraging. Although the number of traps we set was proportional to the available wet and dry area in a meadow, trapping density (about 100 traps/ha) was approximately equivalent across sites. We set traps ≥30 m from known Willow Flycatcher territories to avoid disturbance. We sampled each wet and dry area only once each summer, except Truckee Marsh, which we sampled twice (with 1 month separation) in 2008 and considered the 2 trapping sessions as 1 sample.

We baited traps with oatmeal and peanut butter, supplied the traps with polyester filling to provide insulation, and checked traps 2 (or occasionally 3) times during 4 consecutive nights in each of the wet and dry areas in each meadow. The number of trap checks was the same for all traps during a 24-h period and was varied to ensure animals did not become stressed due to weather conditions. We identified, sexed, aged, and fur-clipped captured animals and released them at the capture site. We did not fur-clip shrews due to their small size and released them without marking at the capture sites. In inundated areas, we attached a floating structure made of Styrofoam (30 × 60 × 3.5 cm for extra large traps, and 30 × 30 × 3.5 cm for large traps) to the bottom of traps and tied each to the surrounding vegetation. In dry areas we set traps directly on the ground in the vegetation and covered them with soil, moss, or woody debris for protection and insulation.

We calculated trapping effort for wet and dry sections of each meadow as total number of trap nights (TTN), where TTN = number of nights × number of traps −0.5 CBE. CBE is the number of traps that were found closed but empty and is used as a correction factor (Nelson and Clark 1973).

We calculated both an overall and species-specific index of mammal activity (IA) for wet and dry areas in each meadow. We calculated each IA as the total number of captures divided by TTN, and multiplied this by 100 to standardize to 100 trap nights.

We also calculated relative abundance (RA) values for each species as the number of new individuals captured in each trapping session divided by TTN and again multiplied by 100 to standardize to 100 trap nights. Because we did not mark shrews (*Sorex* spp., see below), we used a conservative method to calculate their relative abundance by counting all the individuals (dead and alive) captured during the 1st night. Then, for subsequent nights we subtracted from the total captures for each night the cumulative number of shrews found alive in the previous nights to avoid double counting individuals that could have been recaptures.

### *Data Analyses*

Prior to statistical analyses, we tested the data for normality and homogeneity of variances. We used scatter-plots to examine trends in the data and used Spearman correlations (Zar 1984:318–320) to examine relationships between the small mammal dependent variables (relative abundance and index of activity). Relative abundance and activity of small mammals were highly correlated ($r_s > 0.5$, $P < 0.05$) for both wet and dry areas during 2007 and 2008. We chose to use the index of activity when testing for differences between wet and dry areas, and between years, because the index of activity could be a better predictor of the probability of nests to be predated in comparison with the index of relative abundance (Cain 2001; Cain and others 2003). We used Mann-Whitney U tests (Zar 1984:139–141) to compare both small mammal activity indices and wetness conditions (1) between years for wet (saturated + inundated) and dry areas, and (2) between wet and dry areas each year. We used Spearman correlations to test the relationships between the dependent and independent variables, and to test for changes in the small mammal variables. For all analyses we set alpha at 0.05, and used SPSS 14.0 (SPSS Inc., Chicago, Illinois, USA) statistical software.

## RESULTS

### *Mammal Sampling*

We used 1097 traps for a cumulative sampling effort of 4278.5 trap-nights between 2007 and 2008 (Cocimano 2009). During 2007 and 2008, we obtained 880 captures and 534 individuals of 12 species (see Fig. 1 caption for list of species and acronyms).

*Small mammal distribution and composition*.—In 2007, we captured 9 species in wet areas and 10 species in dry areas; whereas in 2008 we captured 6 species in wet areas and 7 species in dry areas. Among meadows, only SOREX was present at all sites in both years. PEMA was present at 8 (89%) sites in 2007 and only 1 (14%) site in 2008; MILO was present at 7 (78%) sites in 2007 and 4 (57%) in 2008; TAAM was present at 6 (67%) sites in 2007 and 6 (86%) sites in 2008; ZAPR and MIMO were present at 5 (56%) of the sites in 2007, and 4 (57%) and 1 (14%) respectively in 2008. The remaining species (MUER, SOPA, TASE, TASP, only in 2007; TADO only in 2008; and SPBE, in both years) were present in ≤3 sites (see Cocimano [2009] for details).

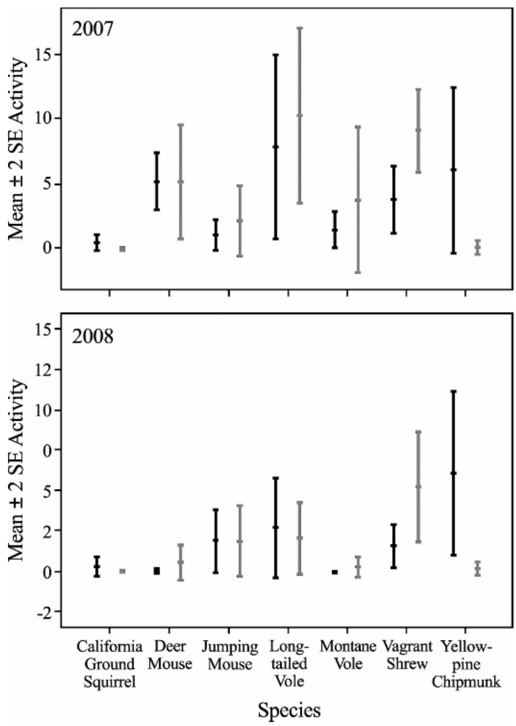


FIGURE 1. Index of activity of small mammal species (number of captures of each species/100 trap-nights) between dry (black lines) and wet (gray lines) areas in 2007 (top) and 2008 (bottom), Sierra Nevada, California: Long-tailed Vole (*Microtus longicaudus*, MILO), Montane Vole (*Microtus montanus*, MIMO), Deer Mouse (*Peromyscus maniculatus*, PEMA), Vagrant Shrew (*Sorex vagrans*, SOREX), California Ground Squirrel (*Spermophilus beecheyi*, SPBE), Yellow-pine Chipmunk (*Tamias amoenus*, TAAM), and Jumping Mouse (*Zapus princeps*, ZAPR). Species with few captures and thus not depicted here were: Short-tailed Weasel (*Mustela erminea*, MUER), Water Shrew (*Sorex palustris*, SOPA), Douglas' Squirrel (*Tamiasciurus douglasii*, TADO), Shadow Chipmunk (*Tamias senex*, TASE), and Lodgepole Chipmunk (*Tamias speciosus*, TASP).

*Small Mammal Activity*.—We compared the differences in activity between wet and dry areas for each small mammal species (Fig. 1). In 2007, the only species that presented a significant difference in activity between the 2 site types were SOREX ($U = 12$, $n = 17$, $P = 0.021$) and TAAM ($U = 13.5$, $n = 17$, $P = 0.015$). SOREX was 58% more active in wet than in dry areas, whereas TAAM was 96% more active in dry areas versus wet areas, with only 1 individual recorded in wet areas. Although the activity of the rest of the species was not statistically different between dry and wet areas, overall in 2007, 6 (55%, $n = 11$) species (MILO, MIMO, MUER, SOREX, TASP, ZAPR) were more active in wet areas, 1 (9%) species (PEMA) was equally active in both site types, and 4 (36%) species (SOPA, SPBE, TAAM, TASE) were more active in dry areas (Fig. 1).

In 2008, only TAAM presented significant ($U = 5$, $n = 14$, $P = 0.008$) differences in activity between wet and dry areas, with 97% more activity in dry areas compared to wet areas. Overall in 2008, 3 (38%, $n = 8$) species (MIMO, PEMA, and SOREX) were more active in wet areas than in dry areas, 4 (50%) species (MILO, SPBE, TAAM, TADO) were more active in dry areas, and 1 (13%) species (ZAPR) was equally active in dry and wet areas (Fig. 1).

We compared the index of activity for each species between years for wet and dry areas, considering only those species that were present in both years. For wet areas, only 3 species (MUER, TASE, and TASP) were present in 2007, and only the differences for 2 species were statistically significant: PEMA was 90% ($U = 11$, $n = 15$, $P = 0.033$) more active in 2007 and MILO was 80% ($U = 10$, $n = 15$, $P = 0.031$) more active in 2007 (Fig. 1). In general, the different species we found were more active during 2007; 3 species (MIMO, PEMA, and MILO) were $>50\%$ more active and 3 species (SOREX, TAAM, and ZAPR) were $<50\%$ more active in 2007 compared to 2008. For dry areas, 4 species (MIMO, MUER, SOPA, and TASE) were present only in 2007 and 1 species (TADO) was present only in 2008; only the difference for 1 species was statistically significant: PEMA was 99% ($U = 4$, $n = 16$, $P = 0.002$) more active in 2007 than in 2008 (Fig. 1). In general, the different species found in this study were more active during 2007, except that TAAM was equally active in both years and ZAPR was more active in 2008. Three species (PEMA, MILO, SOREX) were $>50\%$ more active in 2007, and the rest of the species presented $<50\%$ difference between years.

The overall index of activity was different between 2007 and 2008 for both wet ($U = 6$, $P = 0.011$, $n = 15$) and dry ($U = 11$, $P = 0.030$, $n = 16$) areas. The mean overall index of activity in wet areas was 68% higher in 2007 versus 2008; whereas in dry areas the mean index of activity was 52% higher in 2007 than in 2008.

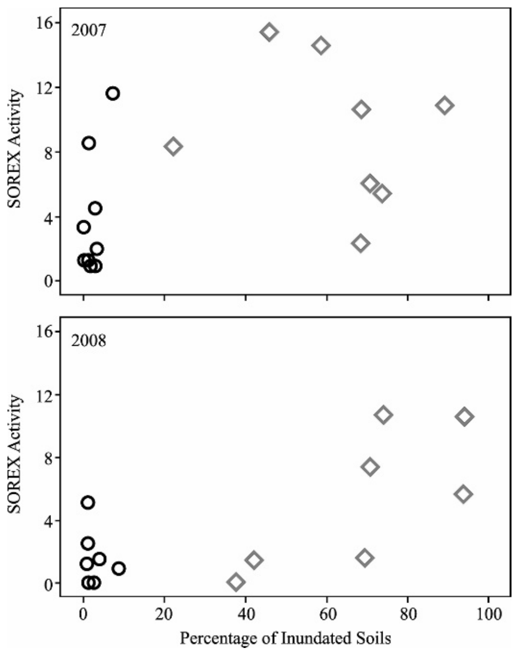


FIGURE 2. Relationship between index of activity of shrews (SOREX) and percentage of inundated soils in dry (circles) and wet (diamonds) areas in 2007 (top) and 2008 (bottom), Sierra Nevada, California. Activity index is the number of captures/100 trap-nights.

*Small Mammal Activity and Wetness Conditions*

Only 2 species showed significant correlations between the index of activity and wetness conditions (see Cocimano [2009] for results for all species studied). We found a positive relationship between the activity of SOREX and percentage of inundated soils for both years (2007: $P = 0.022$, $r_s = 0.549$, $n = 17$; 2008: $P = 0.042$, $r_s = 0.550$, $n = 14$). The relationship in 2007 may not have been linear, with the highest level of activity towards the middle wetness conditions of inundated soils (about 40% inundated) (Fig. 2, top). In 2008, the same pattern was observed although the highest level of activity occurred above 70% of inundated soils (Fig. 2, bottom).

We found a negative relationship between TAAM activity and percentage of inundated soils for both years (2007: $P = 0.002$, $r_s = -0.687$, $n = 17$; 2008: $P = 0.006$, $r_s = -0.692$, $n = 14$). The relationship was not linear, with most of the activity of TAAM concentrated in dry areas, and when wetness increased (above 5 to 10% inundated) the activity of TAAM was null or low (only 2 captures in wet areas out of about 180 captures total in 2 y) (Fig. 3).

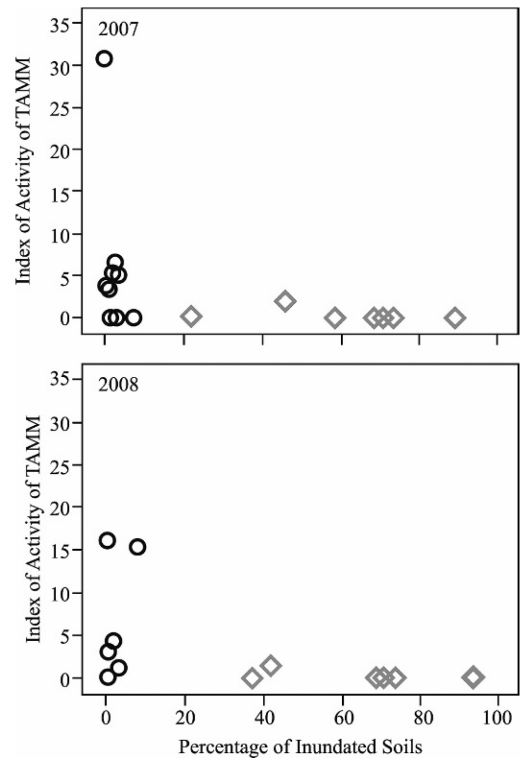


FIGURE 3. Relationship between index of activity of Yellow-pine Chipmunk (TAAM) and percentage of inundated soils in dry (circles) and wet (diamonds) areas in 2007(top) and 2008 (bottom), Sierra Nevada, California. Activity index is the number of captures/100 trap-nights.

## Discussion

We predicted that abundance and activity of chipmunks and squirrels would be lower in areas with wetter conditions. Of all the species that were present in both years, chipmunk activity was primarily limited to dry areas, with only 2 captures (1 in 2007 and 1 in 2008) of Yellow-pine Chipmunks in wet areas; whereas voles, mice, and shrews were active in both site types (shrews had higher activity in wet sites). This suggests that Yellow-pine Chipmunks are not likely to be potential predators in wet areas of the meadows.

Of the most active species in this study, Yellow-pine Chipmunks and Deer Mice are often documented as nest predators (Verbeek

1970; Sieving and Wilson 1998; Bradley and Marzulff 2003). Various chipmunk species (*Tamias* spp.) and Deer Mice have been photographed predating Yellow Warbler nests in our study sites, with chipmunks being the most common predator photographed (43%, $n = 14$) (Cain and others 2003). Therefore, nests located in drier areas could be affected by both chipmunks and Deer Mice; whereas Deer Mice could be the most important predator in wet areas.

We found a change in species distribution and abundance between years in our study sites. Deer Mice were one of the most widely distributed species in 2007, but we only captured 2 individuals at 1 site in 2008. Several studies have discussed the fluctuations of small mammal populations in relation to changes in cone production in mountains of California (Morrison and Hall 1998; Wilson and others 2008). Water levels in our study areas change from year to year depending upon precipitation and snow pack at the beginning of the season (Mathewson 2010). The variability of available water during the growing season affects the forest seed production, which in turn influences the small mammal populations that feed on seeds (Schnurr and others 2002; Boutin and others 2006; Kuhn and Vander Wall 2008). The 2 y when we conducted our field work were particularly drier than average (California Data Exchange Service 2009), and the dry conditions in 2007 may have affected seed production for the fall of 2007, which caused Deer Mice to almost disappear from the majority of our study sites in 2008. Shrews, chipmunks, and Long-tailed Voles were also widely distributed among and across meadows in 2007, but the presence of shrews and chipmunks did not decrease as remarkably between years as did Deer Mice.

Reducing nest predation could help increase juvenile recruitment and help increase the abundance of Willow Flycatchers and other nesting passerines. There are, of course, other predators of nests (for instance snakes and birds) that affect overall rates of nest loss in meadow-nesting birds. Nevertheless, restoring the hydrology of the meadows by increasing the amount of inundated soils will help deter predators such as Yellow-pine Chipmunks from nesting areas, and will help inhibit forest encroachment (Green and others 2003).

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