

FACTORS RELATED TO OCCUPANCY OF BREEDING WETLANDS BY FLATWOODS SALAMANDER LARVAE

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Abstract: The flatwoods salamander (*Ambystoma cingulatum*) was listed as federally threatened in 1999. Alteration of habitat was considered the main threat to the species, especially the loss of habitat for larval flatwoods salamanders that develop in isolated, seasonally flooded wetlands. Our objectives were to evaluate a suite of within-pool factors (i.e., vegetation structure, water level, and an index to presence of fish) that could influence occupancy of breeding wetlands by larval flatwoods salamanders on Eglin Air Force Base in Florida, USA. We dip-netted for larval salamanders from January through March 2003–2006 and we measured a suite of vegetation characteristics in 2006–2007. Further, in 2006 we measured the level of water and relative presence of fish over the salamander breeding season. Site occupancy over the four year period was best described by a model that incorporated high herbaceous vegetation cover and open canopy cover. Detection probability was assessed, but it varied among years and was not included in the model. Our study suggests that managing the breeding habitat of flatwoods salamander for open canopies and dense herbaceous vegetation may contribute to this species' recovery.

Key Words: *Ambystoma cingulatum*, *Ambystoma bishopi*, conservation, Florida, prescribed fire

INTRODUCTION

The flatwoods salamander (*Ambystoma cingulatum* Cope) was listed as federally threatened in April 1999 (United States Department of the Interior, Fish and Wildlife Service [USFWS] 1999). The recovery of *A. cingulatum* across their geographic range has been complicated further by evidence that the distribution really represents two species, *A. cingulatum* and *A. bishopi* Goin (Pauly et al. 2007). The populations examined in this study represent the newly recognized species of flatwoods salamander (*A. bishopi*) that is restricted to the northern coastal plain of the Gulf of Mexico. The recognition that there are two species rather than one has resulted in what were 59 populations being split into 37 populations of *A. cingulatum* and 22 populations of *A. bishopi* (Pauly et al. 2007, USFWS 2005). Therefore, this taxonomic change has elevated the conservation priority of these salamanders and highlights the need for more active management to avoid extinction. In addition, critical habitat for both species has been proposed and *A. bishopi* has been proposed to be listed as an endangered species under the U.S. Endangered Species Act (USFWS 2008).

Loss and alteration of habitats was considered the main threat and the cause of population declines to flatwoods salamanders (Means et al. 1996, Palis 1996, USFWS 1999). Similar to other ambystomatid salamanders, the habitat used by flatwoods sala-

manders differs greatly between larvae and adults. Adults are fossorial and occur in mesic, longleaf pine flatwoods and savannas (Palis 1996). Adult flatwoods salamanders migrate to breeding sites, which consist of isolated ephemeral wetlands, on rainy nights from October–December (Means 1972, Anderson and Williamson 1976, Palis 1996). The quality of surrounding nonbreeding habitat used by adult flatwoods salamanders is likely a factor related to occupancy of pools; however, here we focus on within-pool factors that may attract adults and may lead to recruitment of larvae.

Although several hypotheses have been proposed about environmental conditions that constitute high quality larval habitat versus degraded habitat, such as hydroperiod and attributes of vegetative cover (USFWS 1999), there has been little quantitative research relating these conditions to the presence or abundance of flatwoods salamander larvae (Sekerak et al. 1996). In this paper we report the results of quantitative analyses of three factors: vegetation, water level, and relative presence of fish. Because flatwoods salamander larvae can be difficult to detect (Bishop et al. 2006), we incorporated estimates of detection into the models as well.

A potential factor for the decline of flatwoods salamanders is that components of breeding and larval habitat have degraded over time (USFWS 2008). In particular, the suppression of fire during

the growing season may explain the premature drying of breeding wetlands (Bishop and Haas 2005) because a lack of fire may facilitate encroachment of woody vegetation (Kirkman 1995), leading to an increase in evapotranspiration (Huxman et al. 2005). In many locations prescribed burning is conducted during the dormant season (i.e., winter months) when conditions are better for controlling fire (Bishop and Haas 2005). However, this season also overlaps with the recharge of water into ephemeral wetlands, which will inhibit fire from entering the wetlands. Further, dormant season fires may cause re-sprouting of woody vegetation and increase stem densities of shrubs in longleaf pine (*Pinus palustris* Mill.) associated wetlands (Clewell 1989, Smith et al. 1997, Drewa et al. 2002). In contrast, growing season fires are more likely to cause mortality of woody stems (Clewell 1989, Smith et al. 1997, Drewa et al. 2002). Growing season burns also may increase seeding of wiregrass (*Aristida stricta* Michx.) (Outcalt 1994) and other dominant herbaceous species (Brewer and Platt 1994), which may provide larvae with opportunities for foraging and cover (Sekerak et al. 1996). Dormant season burns may also overlap with the winter breeding season of some amphibians and may affect breeding migrations (Semlitsch 2000, Schurbon and Fauth 2003). Thus, support for growing season burns to maintain high quality breeding habitat for amphibians of the fire-maintained longleaf pine ecosystem of the southeastern coastal plain has been increasing (Schurbon and Fauth 2003, Means et al. 2004, Bishop and Haas 2005), although data to support its value are sparse.

Another potential threat to flatwoods salamanders in breeding wetlands is fish, which may be either predators or competitors of flatwoods salamander larvae. Historically, fish were thought to be absent from most ephemeral wetlands (Semlitsch 1988, Hopey and Petranka 1994), but fish have been documented in flatwoods salamander breeding sites (Palis 1996). Fish may migrate into wetlands during seasonal floods (Palis 1996). Invasion of fish may also result from a change in disturbance regimes (Maret et al. 2006). Activities such as road building may alter the hydrology of nearby streams and wetlands, and potentially facilitate movement of fish. Anuran tadpoles and eggs were depredated by mosquitofish (*Gambusia affinis* Baird and Girard) in the western United States (Lawler et al. 1999) and Australia (Komak and Crossland 2000). Larval Sonoran tiger salamanders (*Ambystoma tigrinum stebbinsi* Lowe) have been negatively affected by *G. affinis* and other predatory fish in Arizona (Maret et al. 2006). Mole salamander (*A. talpoideum* Hol-

brook) eggs and larvae were susceptible to predation by fish in South Carolina (Semlitsch 1988). As competitors, *Gambusia* can cause declines in some groups of invertebrate prey (Hurlbert and Mulla 1981), including prey of flatwoods salamanders (Whiles et al. 2004). Under laboratory conditions, *G. holbrooki* Girard can eat 3.5 times more mosquito larvae than *A. talpoideum* larvae (DuRant and Hopkins, in press). Therefore, fish predators and competitors in amphibian breeding wetlands may decrease recruitment of adult salamanders via direct mortality of eggs and larvae or via competition for invertebrate prey.

Our goal was to examine which within-pool factors (i.e., vegetation characteristics, water-levels, and/or presence of fish) may limit successful breeding of flatwoods salamanders. Although these factors have been discussed previously by several authors in the literature, quantitative tests have been lacking. Therefore, we related vegetation characteristics, water level, and the presence of fish to occupancy and detection of larval flatwoods salamanders over time.

STUDY AREA

We evaluated the occupancy and detection of flatwoods salamander larvae in 18 previously occupied breeding wetlands on Eglin Air Force Base (Eglin), Florida from 2003 through 2006. These sites were wetlands that were occupied by flatwoods salamanders at least once since 1993. Fourteen wetlands were located in the East Bay Flatwoods East in Okaloosae County, one wetland was located in the East Bay Flatwoods West in Santa Rosa County, and three wetlands were located in Oglesby's Flatwoods in Okaloosae County. Each of these three designated flatwoods regions was considered a population for recovery (USFWS 2005). The flatwoods ecosystem was historically a fire-maintained longleaf pine, slash pine (*Pinus elliotii* Engelm.), and wiregrass savanna with low, flat topography. The breeding sites of flatwoods salamanders are ephemeral wetlands that fill with water in the fall and winter months. These wetlands had overstories of longleaf pine, slash pine, pond cypress (*Taxodium ascendens* Brongn.), and blackgum (*Nyssa sylvatica* Marsh.) and have open to dense midstories dominated by myrtle-leaved holly (*Ilex myrtifolia* Walter) and Chapman's St. John's-wort (*Hypericum chapmanii* Chapman).

The soil series of the breeding wetlands were most frequently Rutlege, but also include Chipley and Hurricane, Dorovan, Leon, and Pactolus (Natural Resources Conservation Service 2007). The uplands

surrounding the wetlands had a canopy dominated by longleaf pine and slash pine and an open to moderately dense understory. During the study period, rainfall in northwest Florida ranged from 106 cm in 2006 to 197 cm in 2005 (unpublished data, Florida Automated Weather Network).

The historic fire return interval of flatwoods was thought to have been 1–3 years in both the uplands (Stout and Marion 1993, Frost 1995) and depression wetlands (Frost 1995). Prescribed fire was used as a management strategy in the surrounding uplands of the breeding wetlands, but it is unlikely fire entered the wetlands because prescribed fire was implemented during the dormant season, when the wetlands contain water. Average return interval for prescribed fire on Eglin was approximately five years in the uplands (Eglin Integrated Natural Resources Management Plan 2002).

METHODS

We conducted surveys of larval flatwoods salamanders once per month in January, February, and March, 2003–2006, in each of 18 known breeding wetlands, for a total of three surveys/year/wetland. Due to a severe drought in 2007, the breeding wetlands never attained sufficient water levels to support reproduction. Breeding occurs primarily during the fall as wetlands begin filling with water and the larval period lasts from 11–18 weeks (Palis 1995b). Therefore, the months of January–March, when larvae have reached sufficient size for detection, are considered the most effective months for sampling flatwoods salamander larvae (Bishop *et al.* 2006). We used model SH-2 and SH-2D (Mid-Lakes Corporation, Knoxville, TN) dip-nets with a 3 mm mesh size (USFWS 2005) and conducted timed, systematic searches to sample salamander larvae. When multiple observers were used, effort was considered the sum of each surveyor's effort (*i.e.*, total effort).

In 2006, we recorded the presence of fish in the study wetlands during dip-net surveys for salamanders. We included the presence of either *G. holbrooki* or *Esox americanus* Lesueur, both capable predators and/or competitors of larvae as a single factor, relative presence of fish. Although other techniques may have been more effective at sampling fish, those that were caught during our larval dip-net sampling were using the same areas as the flatwoods salamander larvae and were thus most likely to interact with the larvae.

In 2006–2007, we described the structural vegetation characteristics of the 18 study wetlands using vegetation plots that were systematically placed every 20 m along a single transect. Wetlands had

between 3–11 vegetation plots that were subsequently averaged to acquire wetland-scale habitat characteristics. Transects were started in the ecotone surrounding the wetland and oriented along the long axis of the wetland. We examined percentage of canopy cover, basal area, percentage of herbaceous cover, and percentage of woody debris as potential descriptors of larval flatwoods salamander habitat. We measured percent canopy cover using a spherical densiometer and basal area using a Jim-Gem Cruz-All (Forestry Suppliers Inc., Jackson, MS). We used the Daubenmire (1959) cover class scale to estimate the percentage of herbaceous vegetation and woody debris by visually estimating the percentage of each variable in a 0.5 × 0.2 m rectangular plot. We recognize that the measurement of habitat structure at the end of the study is less than ideal, but the variables that we selected were not likely to appreciably change under normal conditions (*i.e.*, there were no fires or mechanical treatments within any of the wetlands during the 5 year period). Further, remeasurement of these sites in 2008 showed similar patterns as the data from 2006–2007.

We monitored water levels at the 18 sites twice a month from January–March in 2006. Each site had two water level markers, 1 marker near the center of the wetland and a second at the wetlands edge. We used the monthly average from both readings and both markers for subsequent analyses.

Statistical Analyses

We used a multiple-season occupancy model (MacKenzie *et al.* 2003) to estimate the occupancy of flatwoods salamanders. Occupancy in this analysis was more appropriately interpreted as a measure of “survival” or persistence of the flatwoods salamander populations (Mackenzie *et al.* 2006) because the sites of interest are known to have been occupied historically. First, we modeled occupancy and detection from 2003–2006 as a function of vegetation characteristics and year, and we assumed the extinction rate to be constant because we were primarily interested in occupancy and detection. We developed models that incorporated different vegetation characteristics as descriptors of occupancy (ψ), and year, total effort, and a constant parameter were used to describe detection (p). The result was a set of 23 models that were most biologically relevant to flatwoods salamander larvae. Next, we used a single season occupancy model (MacKenzie *et al.* 2002) to assess the influence of vegetation characteristics, water levels, and presence of fish on the occupancy of wetlands and detection of flatwoods salamander larvae in 2006. For this

Table 1. Means and standard errors (SE) of vegetation characteristics for occupied wetlands versus wetlands where flatwoods salamander larvae were not detected on Eglin Air Force Base, Florida, 2003–2007.

| Vegetation Characteristic | \bar{X} (Occupied) | SE | \bar{X} (Not Detected) | SE |
|---------------------------------|----------------------|-----|--------------------------|-----|
| Canopy Cover (%) | 42.6 | 5.2 | 44.7 | 8.1 |
| Basal Area (m ² /ha) | 5.9 | 0.7 | 10.1 | 2.1 |
| Herbaceous Cover (%) | 67.6 | 8.2 | 40.1 | 7.0 |
| Woody Debris (%) | 20.6 | 5.9 | 19.2 | 2.0 |

analysis, we developed models that incorporated vegetation characteristics, water levels, and/or presence of fish as descriptors of occupancy (psi), with month, total effort, water levels, and a constant parameter being used to describe detection (p). This resulted in a set of 22 models that we hypothesized to be the most biologically relevant to flatwoods salamander larvae. We performed both analyses in Program Presence 2.1 (Hines 2006) and we used an information theoretic approach using Akaike's Information Criteria (AIC) to examine the relative strength of each model (Burnham and Anderson 2002).

RESULTS

From 2003 through 2006, we located flatwoods salamander larvae in three, six, three, and four of the 18 wetlands each year, respectively. Over the course of this study, we conducted 161 individual surveys and flatwoods salamander larvae occupied seven different wetlands. Canopy cover ranged from 1.7–78.5% (\bar{X} = 43.9%, SE = 5.2), cover of herbaceous vegetation ranged from 9.0–94.4% (\bar{X} = 50.8%, SE = 6.1), woody debris ranged from 6.7–54.2% (\bar{X} = 19.7%, SE = 2.5), basal area ranged from 0.0–19.3 m²/ha (\bar{X} = 8.5 m²/ha, SE = 1.4), and water levels ranged from 0.0–60.0 cm (\bar{X} = 5.5 cm, SE = 2.1) at all 18 sites combined (Table 1). We captured *Gambusia holbrooki* at 8 of 18 wetlands and *Esox americanus* at 4 of 18 wetlands. All sites where *E. americanus* were detected also contained *G. holbrooki*.

Based on our hypothesized models from the 2003–2006 data, herbaceous vegetation and canopy cover were the best habitat descriptors of occupancy by flatwoods salamanders (Figure 1), and year was the best descriptor of detection (Table 2A). This model received a significant amount of the support, with a model weight of 38%. Individual site estimates of occupancy ranged from 3.1–86.9% (\bar{X} = 33.5%, SE = 6.0), and detection of larvae was variable among years and ranged from 7.4–92.1% (\bar{X} = 45.9%, SE = 3.7). Differential sampling effort was not an important component of detection and was not

present in any of the top models. When larvae were detected, mean total effort was 39 minutes (SE = 8) and when larvae were not detected, mean total effort was 41 minutes (SE = 3).

Lastly, based on our hypothesized models related to occupancy in 2006, herbaceous vegetation was the most important covariate predicting occupancy of larvae, and month and water level were the best predictors of detection (Table 2B). For both the multiple-season and single-season analyses, herbaceous vegetation was consistently included in the best supported models, and percent cover of herbaceous vegetation was 1.7 times greater in the seven occupied sites compared to the 11 sites that were not occupied during this study (Table 1).

DISCUSSION

The overall occupancy from 2003–2006 of the 18 known flatwoods salamander breeding wetlands was relatively low (33.5%) given that all but one site had a prior history of being occupied. Detection rates were moderate (45.9%) and suggest that when the larvae were present detecting them is likely with

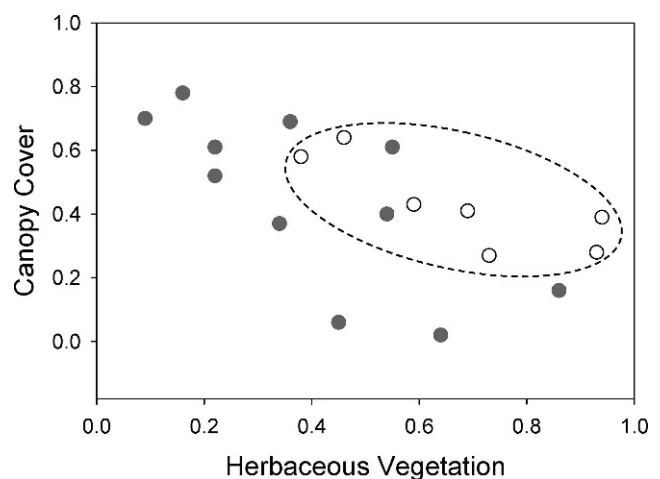


Figure 1. Herbaceous vegetation and canopy cover in 18 wetlands used historically by flatwoods salamander larvae. Open circles denote occupied sites and the closed circles denote sites where no salamander larvae were detected from 2003–2006.

Table 2. Top four model results including AIC, change in AIC (Δ AIC), model weight (W_i), and the number of parameters (K) for occupancy (psi) and detection (p) of flatwoods salamander larvae at 18 known breeding wetlands on Eglin Air Force Base, Florida for A) 2003–2006 and B) 2006 only.

| Model | AIC | Δ AIC | W_i | K |
|--|--------------|--------------|-------------|----------|
| A. 2003–2006 | | | | |
| psi(herbaceous veg., canopy), p(year) | 90.16 | 0.00 | 0.38 | 8 |
| psi(herbaceous veg.), p(year) | 91.52 | 1.36 | 0.19 | 7 |
| psi(herbaceous veg., woody debris),p(year) | 91.67 | 1.51 | 0.18 | 8 |
| psi(herbaceous veg., basal area), p(year) | 93.52 | 3.36 | 0.07 | 8 |
| B. 2006 only | | | | |
| psi(herbaceous veg.), p(month, water level) | 32.53 | 0.00 | 0.27 | 6 |
| psi(herbaceous veg.), p(month) | 33.34 | 0.81 | 0.18 | 5 |
| psi(herbaceous veg., canopy),p(month, water level) | 33.92 | 1.39 | 0.13 | 7 |
| psi(herbaceous veg., canopy),p(month) | 34.73 | 2.20 | 0.09 | 6 |

multiple visits (as suggested by Bishop *et al.* 2006). Over the 4 year period we detected flatwoods salamander larvae in 7 of 18 wetlands. In 10 of the 11 wetlands where larvae were not detected occupancy had not been confirmed since the mid-1990's (i.e., two had detections in 1993, eight in 1994; Palis 1995a). In the remaining wetland, two adults were captured as part of a drift fence survey in 2002 (Bishop 2004), but no larvae have been detected since 1993. The interval since larvae were observed in the 1990s would have been sufficiently long to allow some sites to develop more dense canopies and increase basal areas of overstory and midstory vegetation, which might have inhibited growth of herbaceous vegetation. However, two sites where larvae were not detected had similar percentages of canopy cover and herbaceous cover to sites that were occupied (Figure 1).

Herbaceous cover was the primary vegetation characteristic that predicted occupancy of flatwoods salamander larvae in both analyses (Table 2). Biologically, herbaceous vegetation likely provides both foraging habitat (Whiles *et al.* 2004) and escape refugia (Palis 1995b) for larval flatwoods salamanders as well as attachment sites for egg masses for adult females (Palis 1996). Our data suggest that managing ephemeral wetlands in pine flatwoods for herbaceous cover and an open canopy may improve breeding habitat for flatwoods salamanders. Similarly, Sekerak *et al.* (1996) found that flatwoods salamanders (*A. cingulatum*) were captured in areas with higher amounts of sedges and other herbaceous vegetation and were infrequently captured in open water or areas with only detritus. The dusky gopher frog (*Rana sevosa* Goin and Netting), another endemic amphibian of the Gulf Coastal Plain, also requires isolated, ephemeral wetlands with open canopies (Thurgate and Pechmann 2007).

Growing season prescribed fires may be a useful management option in the sites because fires in this season effectively decrease canopy cover (Drewa *et al.* 2002), stimulate herbaceous growth (Clewley 1989, Brewer and Platt 1994, Outcalt 1994), and are more likely to burn into the wetland. However, fire regime may not necessarily need to shift completely to growing season fires because some evidence suggests that some herbaceous plants benefit from fires in both dormant and growing seasons (Hiers *et al.* 2000). Thus if conditions allow fire to enter the wetland, either season might be a viable option. In our study upland fire was last documented around nine wetlands (six lacking and three with larvae detection during this study) in 2004, three in 2001 (all with larvae detection), and six in 1995 (five lacking and one with larvae detection). The 2004 fires occurring during this study did not enter the wetlands. Whether fires in 1995 and 2001 entered the wetlands is unknown.

Time (i.e., month and year) was an important covariate to estimate detection, which highlights the importance of conducting multiple surveys to avoid incorrect classification of occupied sites. Bishop *et al.* (2006) evaluated the importance of multiple survey events for detection of flatwoods salamander larvae and recommended a minimum of two survey events within a breeding season. Our results support this conclusion because our mean detection probability was < 50% and we observed variation in detection among months and years. The water level of breeding wetlands was important to detection in the 2006 model, and provides additional support for sampling wetlands at least twice within a season.

The influence of fish on the presence of flatwoods salamander larvae was not a component of the well-supported models. The predator/competitor community may not be a major influence on salamander

larvae at sites with high levels of herbaceous vegetation because invertebrate food is plentiful and flatwoods salamander larvae have access to protective cover. We recognize that additional factors that were not measured (e.g., adult terrestrial habitat quality) could have also contributed to occupancy of wetlands.

CONCLUSIONS

Successful management of habitat used by larval flatwoods salamanders may require techniques to control encroachment of woody vegetation and to stimulate herbaceous vegetation. Based on the literature (e.g., Sharitz et al. 1992, Frost 1995), growing season prescribed fires would mimic natural disturbance regimes and likely create desired habitat conditions. However, an increase in urbanization within the coastal plain ecosystem where flatwoods salamanders reside has slowed the use of growing season burns. Instead, dormant season fires are used fairly frequently (Bishop and Haas 2005). However, burn success into wetlands themselves is not well documented, and fires during this season might actually increase growth of woody vegetation (Smith et al. 1997, Drewa et al. 2002). Managers may need to consider a targeted, multiple-step approach similar to that suggested for protection of cavity trees used by Red-cockaded Woodpeckers (*Picoides borealis* Vieillot) that includes mechanical treatment prior to a prescribed burn (Williams et al. 2006). For example, to increase herbaceous vegetation and open the canopy of breeding sites of flatwoods salamanders, it may be necessary to burn surrounding uplands during the dormant season to create a "safety" strip and secondly to conduct a prescribed fire within the perimeter of the wetland during the growing season. Mechanical treatments (e.g., brush saws and chainsaws) might enhance herbaceous vegetation and moderate levels of canopy cover (Thurgate and Pechmann 2007), and provide a more long-term opening in the canopy than dormant season fires. Resprouting of woody vegetation could be minimized by basal application of herbicides. However, mechanical methods may compact soil (even if only from foot traffic) or harm migrating adults and metamorphs. Given that growing season fire is the natural driver in the system, restoring it to the system may have ecosystem benefits other than enhancing salamander habitat.

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