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# Capsaicin as a tool for repelling southern flying squirrels from red-cockaded woodpecker cavities

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***Abstract:*** The southern flying squirrel (*Glaucomys volans*) is an important kleptoparasite of cavities excavated by the imperiled red-cockaded woodpecker (*Dryobates borealis*). Flying squirrel usurpation of cavities may affect woodpecker productivity, but current efforts to manage flying squirrels are costly and time consuming. We assessed whether capsaicin could deter flying squirrel use of woodpecker cavities on a site in southwest Georgia, USA. Twenty-nine cavity tree clusters received 4 treatments: capsaicin, water, air, and a control (no treatment). Only capsaicin both removed more flying squirrels from the cavity immediately after its application and decreased the probability of a flying squirrel occupying the cavity the next day. The data presented supports the potential of capsaicin to provide a more efficient way for dealing with this common kleptoparasite.

***Key words:*** capsaicin, deterrent, *Dryobates borealis*, *Glaucomys volans*, red-cockaded woodpecker, southern flying squirrel

The federally threatened red-cockaded woodpecker (*Dryobates borealis*; hereafter RCW) is native to pine forests of the southeastern United States (U.S. Fish and Wildlife Service [USFWS] 2003). The RCW creates long-lived cavities in living pine trees (*Pinus* spp.) that are often ≥70 years of age and inoculated with the heart rot fungus (*Phellinus pini*; Conner and Locke 1982, Conner and O'Halloran 1987, Nebeker et al. 1995). The fungus softens the heartwood and is thought to make cavity excavation easier. Even so, cavity excavation can take months or even years to complete (Jackson et al. 1979, Conner and Rudolph 1995), and providing and maintaining a healthy number of suitable cavities is an important part of recovery efforts for the woodpecker.

The RCW cavities are used regularly by other species of cavity-nesting birds (e.g., red-bellied woodpecker [*Melanerpes carolinus*] and red-headed woodpecker [*M. erythrocephalus*]), but among the most common occupants of RCW cavities (other than the woodpecker itself) is the southern flying squirrel (*Glaucomys volans*; hereafter flying squirrel; Conner et al. 1997, Laves and Loeb 1999). In some settings, frequent flying squirrel kleptoparasitism of woodpecker cavities is thought to have an effect on woodpecker productivity through displacement of adults and/or killing of young woodpeckers (McCormick et al. 2004). Flying squirrels are also thought to be dominant when competing for cavities with woodpeckers (Figure 1). Furthermore, once a cavity is occupied by a flying squirrel, the cavity becomes unavailable until the flying squirrel vacates or is forcibly removed via human intervention.

The long-term demographic effects that flying squirrels may have on RCWs are not well known (Kappes and Davis 2008), but many land managers remove flying squirrels from RCW cavities. Regardless of the extraction procedures, squirrel management is labor intensive, often requiring climbing the cavity tree using ladders, and regularly ends with euthanasia of flying squirrels. Depending on how many RCW cavities need to be treated on a property, flying squirrel management can become time-consuming or even nonfeasible. Thus, a more efficient method should be developed that can prevent flying squirrel occupancy of RCW cavities.

Previous research into flying squirrel exclusion and removal has yielded mixed results (Montague et al. 1995, Tyrone 2004). Creating a mechanical barrier against the flying squirrel would be optimal as it would require the least amount of effort and could be used

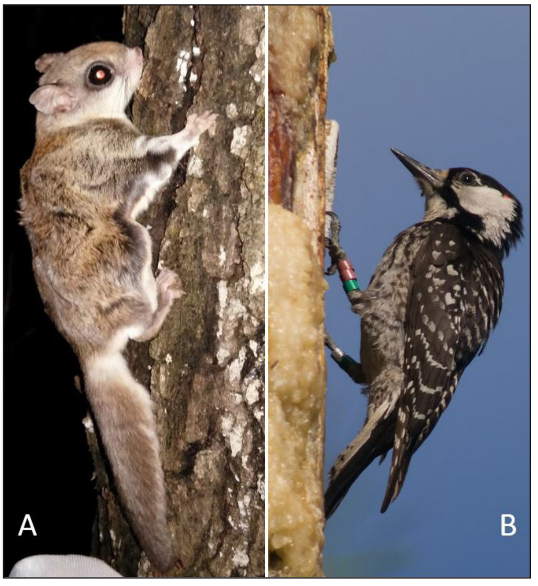


**Figure 1.** The southern flying squirrel (*Glaucomys volans*; A) is a common kleptoparasite on the endangered red-cockaded woodpecker's (*Dryobates borealis*; B) cavities (*photo courtesy of R. Meyer [A] and T. Tanaka [B]*).

long-term. This, however, is difficult due to the flying squirrel being roughly the same size and weight as the RCW (Dolan and Carter 1977). Scent deterrents have been proposed as a less intensive method for reducing flying squirrel kleptoparasitism, but the scents assessed thus far (predator fur and urine, snake musk; Borgo et al. 2006) have not been effective in the field (Stober and Conner 2007).

Capsaicin is a pungent, vanilloid compound found in chili peppers that evokes a burning sensation among many mammals (Jordt and Julius 2002). The same sensation is not evoked regularly among birds (Szolcsányi et al. 1986, Norman et al. 1992, Tewksbury et al. 1999) and has led to the development of mammal-deterring products such as capsaicin-laced bird feed (Fitzgerald et al. 1997) and pepper spray devices to deter dogs and other canines (Lynn 1984). Whether capsaicin evokes similar reactions for flying squirrels has not been explicitly studied, but, if it does, this taxon-specific potency might be used to lessen kleptoparasitism of RCW cavities by flying squirrels. In this study, we assessed whether a commercially available pepper spray (Halt!®, ARI, Inc. Orchard Hill, Georgia, USA) could be used to remove and/or deter flying squirrels from occupying RCW cavities.

# Methods

## Study area

We conducted our study on Silver Lake Wildlife Management Area (30°48′14.5″N, 84°45′03.0″W; hereafter Silver Lake WMA), an approximately 3,700-ha landholding managed by the Georgia Department of Natural Resources in southwest Georgia (Figure 2). Silver Lake WMA consists of a mix of upland pine and bottomland hardwood forests. Upland pines were dominated by longleaf (*Pinus palustrus*), loblolly (*P. taeda*), and shortleaf pines (*P. echinata*) and included mixed oaks such as live (*Quercus virginiana*), post (*Q. stellata*), and water oaks (*Q. nigra*) and black cherry (*Prunus serotina*). Bottomland hardwood forests were comprised mainly of sweetgum (*Liquidambar styraciflua*), water oak, red maple (*Acer rubrum*), and bald cypress (*Taxodium distichum*).

## Treatment application

The RCW cavity trees are typically clustered within a small portion (5–10 ha) of the area (70–150 ha) held by territorial groups. Most of the cavity trees studied here were artificial inserts that had been installed within the past 10 years, not natural cavities (P. Spivey, Georgia Department of Natural Resources, personal communication). The number of inserts found in the cavity tree clusters on Silver Lake WMA averaged 5.5 (range: 2–8 inserts per cluster). We selected 29 of the 36 RCW cavity tree clusters found on Silver Lake WMA to conduct this study and omitted 7 clusters that were inaccessible; 22 of the 29 clusters monitored contained flying squirrels at some point during the study.

We checked for the presence of flying squirrels in artificial woodpecker cavities in each cluster using a wireless peeper camera (http://www.ibwo.org, North Little Rock, Arkansas, USA) mounted to a telescoping pole. If flying squirrels were present, we applied 1 of 4 treatments: (1) capsaicin; (2) water (a control liquid dispensed in the same manner as capsaicin); (3) release of compressed air (also used in capsaicin and water treatments); and (4) no treatment (hereafter control treatment). We limited treatments to cavities containing flying squirrels because the effects capsaicin may have on the RCW are unknown and would need to be evaluated only if capsaicin proved to be

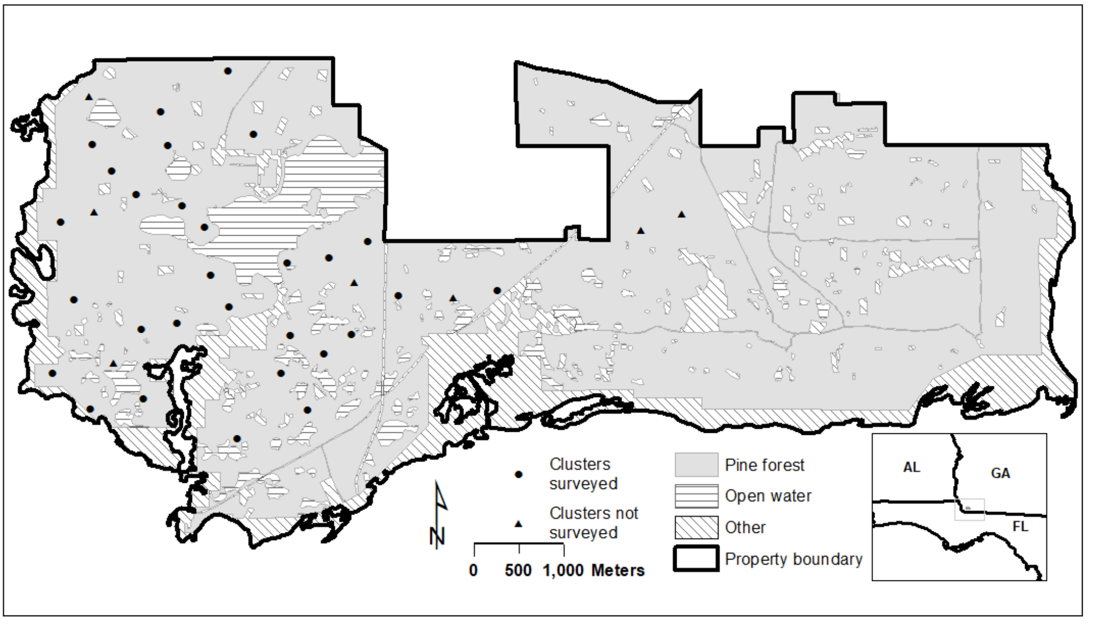


**Figure 2.** Map displaying Silver Lake Wildlife Management Area located in southwest Georgia, USA. Dots (●) refer to red-cockaded woodpecker (*Dryobates borealis*) clusters where flying squirrel (*Glaucomys volans*) surveys were conducted. Triangles (▲) are clusters in which flying squirrel surveys were not conducted.

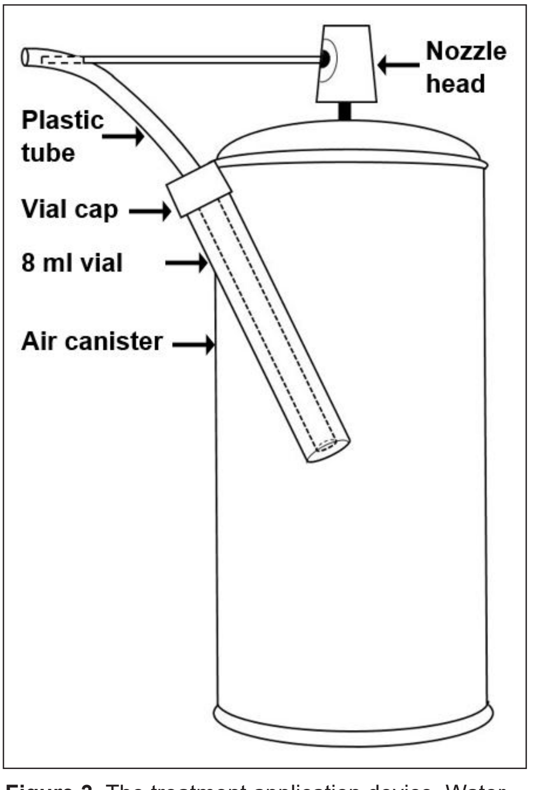


**Figure 3.** The treatment application device. Water and capsaicin treatments are loaded into the 8-ml vial and attached to the cap. When the nozzle head is depressed, compressed air released from the air canister forces the vial's contents out via suction.

effective. The capsaicin treatment consisted of 5 ml of pepper spray with a 0.35% concentration of capsaicin extract dispersed in oil. Use of a commercial product provided consistent treatment dosages and could also facilitate application of the treatments for further study.

Capsaicin, water, and air treatments were dispensed using a canister of compressed air mounted to a telescoping pole (Figure 3). A small tube was fixed to the air canister with a larger 4.8-mm tube around the first tube. The larger tube was connected to an 8-ml vial that contained the capsaicin, water, or air used in these treatments. The larger tube was inserted in the cavity entrance using a second telescoping pole, and pressurized air was then released from the canister by pressing the air canister nozzle against the top of the insert's cavity opening. Pressurized air siphoned out the contents of the vial and aerosolized the liquids as they exited the larger tube (Figure 3) and went directly into the insert. Three seconds of sustained air pressure fully discharged the contents of the vial. Accordingly, air treatments consisted of a 3-second blast of pressurized air. For the control treatment, the canister and tubes were placed on the cavity entrance but no pressurized air was released.

Treatments were applied using a cross-

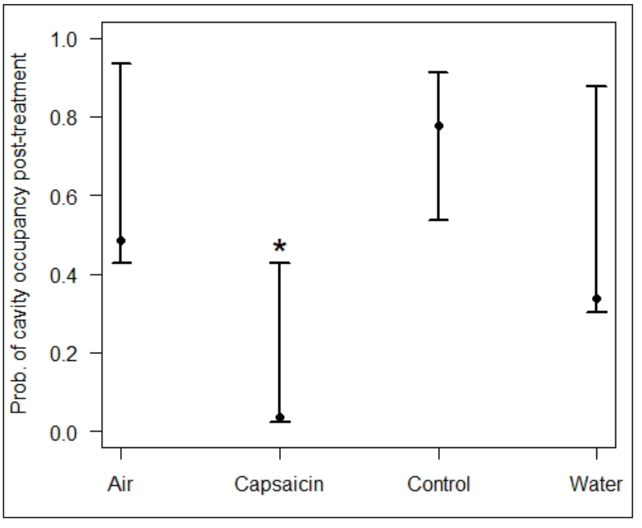


**Figure 4.** The probability of a southern flying squirrel (*Glaucomys volans*) occupying the same cavity 1 day after treatment application. Treatments are relative to control where no treatment was applied. Each treatment is shown with its 95% confidence interval and mean value. Asterisk represents a significant difference from the control.

over design where each cluster was assigned a different weekly treatment over 4 total weeks (July 16, 2018 to August 10, 2018). The order of the treatments was maintained (capsaicin, control, air, and water), but the starting treatment applied for each cluster was randomly selected and the treatment order then followed. We monitored cavities for 1 minute after a treatment was applied and counted the number of flying squirrels that emerged. The following day, we inspected treated cavities again to determine whether flying squirrels had returned and continued to occupy the cavity. The persistence time of the different treatments was unknown, but we believe the order of treatments would have had negligible effects on the results obtained when a different treatment was applied the following week. Treatments also were skipped in weeks when clusters contained no flying squirrels. We chose this methodology to ensure a diverse set of treatments each week to control for weather and other environmental effects from week to week.

### Statistical analysis

All statistics were conducted using program R (R Development Core Team 2016). We used a generalized linear mixed-effects model with a Poisson distribution and the *lme4* package to determine if the number of flying squirrels that emerged from the cavity was affected by the 4 treatments. The number of flying squirrels seen emerging was the dependent variable and the cluster of cavity trees was used as a random effect to account for factors within a cluster that might influence squirrel emergence behavior (e.g., number of secondary cavities available). We also used a generalized linear mixed-effects model with a binomial distribution to assess the effects treatments had on the presence or absence of flying squirrels in a cavity on the following day. The unique cluster identifier was again used as a random effect, and we obtained coefficient of determination for mixed-effects models using the *MuMIn* package in R and methods described in Nakagawa and Schielzeth (2013). An alpha value of 0.05 was used to assess the significance of all statistical tests. We also present average proportions with their respective 95% confidence intervals.

## Results

Of the 161 unique RCW cavities monitored during the study, 54 cavities contained flying squirrels. The number of applications varied slightly among all treatments (control: $n = 22$; air: $n = 21$; capsaicin: $n = 23$; and water: $n = 22$). The probability that a flying squirrel emerged from the cavity was highest for capsaicin treatments (20 squirrels; $\hat{p} = 0.57$, $Z_3 = -2.06$, $P = 0.04$) and differed from air treatment (2 squirrels; $\hat{p} = 0.17$, $Z_3 = -2.35$, $P = 0.02$). However, flying squirrel exodus did not significantly differ between capsaicin and water treatments (5 squirrels; $\hat{p} = 0.40$, $Z_3 = -1.73$, $P = 0.08$; generalized linear model, conditional $R^2 = 0.25$). No flying squirrels emerged when the control treatment was applied (0 squirrels; not analyzed due to the lack of variance). Generalized mixed-effects model also indicated a significant difference between the proportion of cavities that remained occupied by flying squirrels 1-day post-treatment of capsaicin compared to the control ($Z_3 = -3.67$, $P < 0.01$) and no differences among the water and air treatments ($P > 0.34$; conditional $R^2 = 0.41$) relative to the control. The proportion of cavities that remained occupied by flying squirrels the following day was lowest following capsaicin treatments ($\hat{p}$ = 0.04 [0.02–0.42]) and higher among the remaining control ($\hat{p}$ = 0.78 [0.54–0.91]), air ($\hat{p}$ = 0.49 [0.43–0.94]), and water ($\hat{p}$ = 0.34 [0.30–0.88]) treatments (Figure 4).

A follow-up to the study was completed in January the following year to determine if the capsaicin-treated cavities were being used by the RCW. Of the 23 cavities that were sprayed with capsaicin, 13 cavities had fallen due to storm damage from Hurricane Michael and, of those remaining, only 2 cavities were considered suitable for RCW occupation (cavity not rotten or enlarged by other woodpecker species). One of the 2 suitable cavities showed signs of activity (i.e., the presence of active resin-wells [Jackson 1977]), but no RCW was seen roosting in that cavity.

## Discussion

Unlike previous efforts to deter flying squirrels from RCW cavities, capsaicin significantly increased the exodus of flying squirrels and reduced the likelihood of squirrels occupying cavities on the day following treatment. Of the 4 treatments applied, only capsaicin both flushed more flying squirrels from the cavity immediately after its application and also decreased the probability of a flying squirrel continuing to occupy the cavity the next day (Figure 4). Accordingly, use of capsaicin could lead to a much less laborious means of managing squirrel kleptoparasitism of RCW cavities across a broader landscape.

Although the capsaicin treatments outperformed other treatments, capsaicin did not prevent flying squirrel occupancy completely. This could be due to the flying squirrel's communal nature and the possibility that a new individual simply replaced the individual affected by the treatments the following day. We did not mark individual squirrels, and this could bias results higher in terms of the probability that the individuals receiving the initial treatments returned to the cavity the next day.

If this method is to be applied, it is important to consider any adverse effects capsaicin may have to the RCW. Current literature seems to suggest a weak reaction to capsaicin across various bird groups. For example, many birds readily consume capsaicin-treated food (Norman et al. 1992). Little side effects were seen when domestic chickens consumed pepper-treated food for 6 months (Jensen et al. 2003). Additionally, topical applications of capsaicin made on red-winged blackbirds (*Agelaius phonecius*) produced no reaction (Mason and Maruniak 1983). Even direct injections of capsaicin into the eyes of pigeons (*Colomba livia*) produced no protective behavioral response (Szolcsányi et al. 1986). Given these examples, the available literature suggests that many birds react weakly to capsaicin. However, additional research is needed to ensure the imperiled RCW itself does not suffer any negative side effects from capsaicin.

The effect of the oil used to suspend capsaicin could also have potential impacts that will need to be assessed. Monitoring woodpecker use of cavities should be incorporated into future studies because oil can damage feathers or affect eggs if applied during the breeding season (Jenssen 1994). Limiting the application to the period just prior to the breeding season could avoid these potential problems and also focus on a time of the year when fewer juveniles are present and likely to be using cavities. Future studies should also assess powdered forms of capsaicin to mitigate any potential risk posed by oils to feathers and eggs.

It should be considered that deterrence of flying squirrels has the potential to increase the occurrence of other kleptoparasites. Kappes (2008) described a cavity dominance hierarchy where flying squirrels depressed cavity use by both RCWs and red-bellied woodpeckers. Red-bellied woodpecker kleptoparasitism, on the other hand, does not significantly impact flying squirrel use of cavities but does decrease RCW use of cavities. Red-bellied woodpeckers have a greater negative effect on RCWs when flying squirrel numbers are lower. Kappes and Davis (2008) removed flying squirrels from RCW clusters from July to December and found that red-bellied woodpecker numbers increased. If the effects of flying squirrel deterrence using capsaicin are similar to those found with flying squirrel removal, then squirrel management might lead to stronger negative interactions with red-bellied woodpeckers, though this threat would also extend to any site where flying squirrels are currently being actively managed.

The specific season in which flying squirrel management occurs could also play an important role. For example, if capsaicin is used to manage flying squirrels primarily during January to March, it may reduce numbers of both kleptoparasites. Flying squirrels could limit red-bellied woodpecker use of RCW cavities during the post-breeding period when young red-bellied woodpeckers search for vacant cavities (up until late November; Cox and Kesler 2012). Capsaicin treatments applied the following year (January to March) when juvenile flying squirrels are likely to disperse could reduce both kleptoparasites and potentially make more cavities available to the RCWs immediately before breeding season.

Application just prior to the RCW nesting season could also yield positive results if it conditioned flying squirrels to avoid cavities during this important phase of the annual cycle. Flying squirrels may live up to 5 years in the wild (Dolan and Carter 1977), which also means that land managers might not need to reinforce cavity-avoidance behavior as more flying squirrels in the population are conditioned over time. The success of squirrel management also would likely depend on the cavity resources associated with an RCW cluster. For instance, if flying squirrels are cavity-limited, the response to capsaicin hazing may be short-lived. However, any variation in response to the capsaicin treatment could potentially be counteracted by increasing the amount of capsaicin used or by increasing the frequency of applications.

Capsaicin shows promise for use as a flying squirrel deterrent for RCW cavities and does not appear, as of yet, to deter RCW occupation post-treatment. Further research is needed to find the dosage, frequency, and season of application of treatments needed to obtain the optimal result relative to cost and time needed for treatments. However, a capsaicin-based approach appears to have potential for providing a time-saving and cost-effective strategy for dealing with this common kleptoparasite. Alternative sources of capsaicin extract also are readily available (e.g., 2.5% concentrations sold as Miller Hot Sauce®, Hanover, Pennsylvania, USA; Baker et al. 1999), and other non-oil based forms of capsaicin (e.g., dried peppers ground up using commercially available food processing equipment) may also be effective and warrant exploration.

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