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The Northern Flying Squirrel (*Glaucomys sabrinus*) as a Potential Predator of Marbled Murrelet (*Brachyramphus marmoratus*) Eggs.

Abstract

Marbled murrelet (*Brachyramphus marmoratus*) populations have been declining in North America for over a decade. As a result, the bird was listed as threatened by the U.S. Fish and Wildlife Service in 1992. Nest predation has been posed as one reason for the decline and several forest rodents, including northern flying squirrels (*Glaucomys sabrinus*), are potential nest predators. We investigated whether the northern flying squirrel was capable of preying upon eggs similar in size to marbled murrelet eggs. We determined whether sex or age at capture from the wild affected a squirrel's tendency to attack an egg. We exposed a captive colony of northern flying squirrels to multiple experiments using a single egg from bobwhite quail (*Colinus virginianus*), blue grouse (*Dendragapus obscurus*), pigeon (*Columba livia*), and chicken (*Gallus domesticus*) with chicken eggs being most similar in size to marbled murrelet eggs. Age at capture and sex of squirrels did not influence predatory behavior. We found that flying squirrels were only able to break through eggs quail-sized and smaller, so flying squirrels are unlikely predators of marbled murrelet eggs. Both gape of the mouth and eggshell thickness could limit egg predation, so eggs with thinner shells and eggs smaller than quail eggs are potential prey for flying squirrels.

Introduction

During the later part of the 20th century, marbled murrelet (*Brachyramphus marmoratus*) populations have been declining in North America (Ralph et al. 1995), and in September, 1992 the U.S. Fish and Wildlife Service listed the species as threatened in Washington, California, and Oregon. Certain researchers believe that marbled murrelets are declining in Alaska (Piatt and Naslund 1995, Piatt 1998), but others believe that definitive evidence for the decline is lacking (Hayward and Iverson 1998a,b). Potential causes for the decline in the United States include pollution and oil spills, habitat loss due to the reduction and fragmentation of late successional forests, and predation at the nest (Ralph et al. 1995).

Marbled murrelets most often nest in the forest canopy at a height ranging from 57.4 ± 8.2 to 73.1 ± 10.4 m in Washington, Oregon, and California (Nelson 1997) making murrelet nests vulnerable to avian and arboreal mammalian predators. Marbled murrelets leave the nest unattended while foraging, which may also increase probability of predation (Nelson and Hamer 1995). Marbled murrelets in the Pacific Northwest nest upon natural platforms with a mean length of 320 mm and a mean width of 220 mm covered in preexisting litter, moss, and lichen which serves as nesting material (Hamer and Nelson 1995). Birds then place their eggs in a depression in the nesting substrate. Predators of marbled murrelet eggs include the common raven (*Corvus corax*), the Steller's jay (*Cyanocitta stelleri*), certain accipiters, several species of forest owls, rodents, and potentially, the American crow (*Corvus brachyrhynchos;* Nelson and Hamer 1995). Northern flying squirrels are most abundant in forests typical of murrelet nesting habitat (Carey 1996), and are reputed to eat eggs and nestlings (Wells-Gosling and Heaney 1984). In addition, northern flying squirrels have been photographed in the wild preying upon quail eggs (Vander Haegen and DeGraaf 1996). Marzluff et al. (1999) frequently photographed them at artificial marbled murrelet nests, suggesting that northern flying squirrels may commonly encounter bird nests.

Given that egg size may limit the ability of rodents to prey upon eggs (i.e. DeGraaf and Maier 1996; Roper 1992, but see Craig 1998), we tested the ability of a captive colony of northern flying squirrels to open eggs of different sizes to determine if marbled murrelet eggs are vulnerable to nest predation by the squirrels. We then determined a threshold egg size beyond which squirrels could not open eggs. We also determined if predatory behavior varied by sex or the age at which squirrels were taken into captivity.

Materials and Methods

We simulated marbled murrelet nests by constructing nest platforms that were 229 mm wide by 310 mm long with slight edges on each side to keep eggs from rolling off the platforms. We placed a mat of *Bryoria* spp. lichen on the simulated nest platform and placed a single egg in a depression in the lichen because marbled murrelets lay a single egg (Nelson and Hamer 1995). On multiple occasions, we exposed a captive colony of flying squirrels to the simulated nest containing an egg from chicken (*Gallus domesticus*), blue grouse (*Dendragapus obscurus*), pigeon (*Columba livia*), or northern bobwhite quail (*Colinus virginianus*). The width and length of each egg was measured before each trial and eggshell thickness values were obtained after each trial using dial calipers (SPI, model 31-415). Grouse and pigeon eggs were collected from wild nests in western Washington, chicken eggs were purchased from a supermarket, and quail eggs were obtained from a private breeder in Wyoming.

We used a captive population of 15 northern flying squirrels held at the University of Wyoming in Laramie, WY, during experiments. Squirrels were held indoors in an enclosure approximately 2.7 m tall, 3.7 m wide, and 2.4 m long, but were exposed to ambient temperature and light via an open window. The enclosure contained five nest boxes and two trees held by metal tree stands. Most squirrels were collected from the Payette National Forest in central Idaho in the summers of 1996-1998. Five males and five females were captured as adults. One male and three females were captured as juveniles, whereas one male was born in captivity in July 1998. All squirrels were full grown adults at the time of the trials. Pregnant and lactating females were removed from all trials to avoid infanticide.

Prior to observation, each squirrel in the colony was marked with non-toxic permanent markers on the ventral side to distinguish sex and age at capture. The squirrels were fed *ad libitum* Purina rodent feed along with nuts, mushrooms, and *Bryoria* spp. lichen. For each trial, an observer entered the enclosure approximately 20 minutes before sunset and attached the nest platform to a tree and placed a single egg on the platform. The platform and egg were easily viewed from outside the enclosure using red lights and an ultraviolet light. Animals were observed during their first evening activity period only. Egg type, time of emergence from boxes, foods available to the animals, age class of individuals present, absent individuals, time and duration of each visit to the nest platform, the sex and age at capture of each animal that visited the platform, and the behavior observed at the platform were recorded. Animals classified as adults were greater than a year old at capture and juveniles were less than a year old at capture. Observation lasted the duration of the first activity period, usually two to three hours and ceased when most animals returned to the nest boxes. Trials were conducted from March through August 1999.

Statistical Analyses

We compared egg width and eggshell thickness among bobwhite quail, pigeon, blue grouse, and chicken eggs and used a one way ANOVA with Tukey-Kramer multiple comparisons on the means (Zar 1974). We used chi square test of homogeneity (Jelinski 1991) to determine if the tendency to bite an egg was independent of age at capture and sex of squirrels. We grouped squirrels based on sex and age at capture and compared groups based on the number of biting visits to the total number of animal nights (number of nights observed multiplied by the number of squirrels in each category observed per night) for age at capture and sex based on the outcome of the tests for effects of sex and age. We used chi square analysis to determine (1) the effect of egg type on success in breaking the egg and (2) the effect of egg type on the attraction of squirrels to eggs. Egg attractiveness was determined by the ratio of platform visits that involved biting to overall platform visits by egg type. In addition, we calculated the total time (in seconds) that squirrels were attempting to bite each egg type and the total time that squirrels were on the platform for each egg type. Given the time spent on the nest platform, we examined the proportion of time biting the egg and time not biting the egg and then tested the proportion on egg types using a *Z* approximation of a binomial distribution (Zar 1974). For all analyses, we used a = 0.05 to determine significance.

Results

Eggs differed in width (F = 259.71, df = 3,15, $P < 0.001$) and eggshell thickness (F = 31.58, df = 3,19, $P < 0.001$). In general, eggshell thickness increased with egg size. Quail eggs had a width of 19.42 ± 0.77 (SE) mm, pigeon eggs were 29.54 ± 0.59 mm wide, grouse were 37.75 ± 0.94 mm wide, and chicken eggs were 42.31 ± 0.44 mm wide. Eggshell thickness values were: quail, 0.11 ± 0.02 mm, pigeon, 0.27 ± 0.02 mm, grouse, 0.33 ± 0.03 mm, and chicken, 0.37 ± 0.01 mm. All possible multiple comparisons were significantly different for egg width, but eggshell thickness results yielded four significant comparisons; Quail-Pigeon, Quail-Grouse, Quail-Chicken and Pigeon-Chicken. Quail eggs were significantly different from all other egg types for both egg width and eggshell thickness (Table 1).

Tendency to bite an egg was not affected by squirrel age at capture ($\chi^2 = 0.40$, df = 1, $P = 0.94$) or sex ($\chi^2 = 1.96$, df = 1, $P = 0.58$). As a result, we pooled results from all squirrels for remaining analyses. Squirrels were attracted to eggs equally, regardless of egg type ($\chi^2 = 4.34$, df = 3, $P = 0.23$), but quail eggs were successfully eaten more often than the other egg types ($\chi^2 = 26.67$, df = 3, $P < 0.001$); squirrels were successful in breaking through only quail eggs. When comparing the proportions of time biting egg and time on platform by egg type, interesting patterns emerge (Table 1). Quail eggs were not handled for long periods of time because squirrels were successful in breaking through these eggs quickly. Of unopened eggs, squirrels spent significantly more time attempting to open the smallest eggs, suggesting that they considered smaller eggs to be a food source more than larger eggs.

TABLE 1. Comparison statistics for egg types. For pairwise comparisons of proportions of time biting egg compared to total time on platform by egg type, *t* statistics and *P*-values are given. For multiple comparisons on egg width and eggshell thickness, values are differences in means.

Comparison	*t* statistic (*P* value)	Egg Width	Eggshell Thickness
Quail-Pigeon	13.33 (0.006*)	-10.12*	-0.15*
Quail-Grouse	6.38 (0.024*)	-18.33*	-0.22*
Quail-Chicken	2.73 (0.112)	-22.89*	-0.26*
Pigeon-Grouse	20.87 (0.002*)	-8.21*	-0.06
Pigeon-Chicken	21.29 (0.002*)	-12.77*	-0.10*
Grouse-Chicken	8.18 (0.015*)	-4.56*	-0.04

* denotes significance at $\alpha \le 0.05$.

Discussion

Northern flying squirrels were able to penetrate bobwhite quail eggs, but were not able to break through larger and thicker-shelled eggs. Rodents may be gape-limited in their ability to open eggs (i.e., DeGraaf and Maier 1996; Roper 1992). If gape limits the ability of northern flying squirrels to open eggs, marbled murrelet eggs are likely safe from predation by squirrels, for our squirrels could not open eggs that were considerably smaller (pigeon eggs) than those of marbled murrelets which are 37.6 ± 1.4 mm (SD) in width and 59.8 ± 2.2 mm (SD) in length (Nelson 1997). Hypothetical gape limitations, however, should be considered with caution, for recent work suggests that rodents may open eggs of a size larger than their gape should allow. Blight et al. (1999) found that *Peromyscus* sp. on Triangle Island off British Columbia opened eggs of rhinoceros auklets (*Cirorhinca monocerata*), despite these eggs being much larger than their gape should allow. Craig (1998) showed that chipmunks (*Tamias* spp.) use leverage to open quail eggs by orienting eggs between their bodies and the nest until the small end is exposed. Chipmunks then break through the small end of the egg. We did not observe flying squirrels using leverage to break open eggs. Squirrels would hold eggs in their forepaws and occasionally hold eggs next to their bodies, but the eggs did not touch the edge of the nest platform while squirrels were trying to break through. These conflicting results suggest that a complete understanding of egg predation by rodents will require further experimentation.

In this study, quail eggs (shell thickness of 0.11 ± 0.02 mm) were potential prey for flying squirrels, but pigeon eggs (shell thickness of 0.27 ± 0.02 mm) were not. These results suggest that the threshold eggshell thickness for predation by flying squirrels lies between 0.11 ± 0.02 mm and 0.27 ± 0.02 mm. Given that this threshold range includes the marbled murrelet shell thickness of

0.21 mm (Sealy 1975), marbled murrelet eggs may be potential prey for flying squirrels, especially if eggshell thickness determines success of egg predation. However, it is likely that eggshell thickness and egg width interact to determine whether a mammalian predator can open an egg. Therefore the large size of marbled murrelet eggs in combination with their eggshell thickness likely prevent flying squirrels from opening these eggs.

The tendency and ability of our squirrels to consume smaller eggs suggests that northern flying squirrels may be significant egg predators of many forest-nesting passerines, particularly those with eggs smaller than pigeon eggs. This is supported by work with captive squirrels in Washington state, where Bradley and Marzluff (unpublished data) showed that northern flying squirrels will readily consume eggs from zebra finches (*Taeniopygia guttata*; eggs 15.8 ± 0.03 (SE) mm x 10.8 ± 0.03 mm, shell thickness = 0.076 ± 0.001 mm), yet cannot open small chicken eggs (eggs 50.3 ± 0.25 x 39.1 ± 0.18 mm, shell thickness = 0.256 ± 0.002). It is unlikely that adult passerines could successfully defend their nest against a flying squirrel (Bradley and Marzluff, unpublished data).

In conclusion, it is unlikely that northern flying squirrels are capable of preying on marbled murrelet eggs. If squirrels are gape-limited in their ability to prey on eggs, those of marbled murrelets are too large to be opened, for our egg width threshold was less than that of a marbled murrelet egg. However, if the ability of squirrels to prey on eggs is limited by the thickness of the shell alone, marbled murrelet eggs may be vulnerable to predation by northern flying squirrels; our shell thickness threshold range included the thickness reported for marbled murrelet eggs. We believe that both eggshell thickness and egg size determine predation success and as a result flying squirrels are likely unable to break open marbled murrelet eggs. Our results show that northern flying squirrels are capable of preying on eggs quail-sized and smaller, suggesting that they may be nest predators of small, forest-nesting passerines.

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