Nest-site Selection and Nesting Ecology of Red-headed Woodpeckers

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This thesis is dedicated to

The Red-headed Woodpecker Recovery Group

If only every species had such dedicated advocates

Abstract

Red-headed woodpeckers (*Melanerpes erythrocephalus*) were once a common and widespread species in the Midwest but have declined sharply in the last 40 years**.** This species is a Minnesota Species of Greatest Conservation Need and an oak-savanna specialist; its decline is ascribed to severe habitat loss throughout the Upper Midwest. Despite numerous oak savanna restoration efforts throughout Minnesota, populations continue to decline, and most restoration sites have failed to attract red-headed woodpeckers. Most restoration focuses on prescribed fire but few studies have examined red-headed woodpecker habitat use and nest success in a long-term managed landscape. This thesis explores red-headed woodpecker nest-site selection and distribution at Cedar Creek Ecosystem Science Reserve (Chapter 1) and also describes a cavity camera system to measure woodpecker nest success (Chapter 2). Using data collected at 102 nest sites and 104 random, non-used sites, logistic regression models showed that woodpeckers preferred low densities of small snags and high densities of trees with dead limbs < 10 m above ground level. Models also showed a preference for large dead nest trees. These results are consistent with other studies and are likely a function of this species' diverse foraging ecology. Examination of the distribution of nests revealed that the highest density occurred in areas burned between 20 - 25 times since 1964. Implementation of a high-frequency burn regime may be effective at creating red-headed woodpecker habitat. The cavity camera system utilized in 2011 was cheaper and easier to assemble than published designs (Chapter 2). One season of use revealed an average of 3 nestlings and two instances of nest depredation.

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Preface

The red-headed woodpecker (*Melanerpes erythocephalus*) is an oak-savanna specialist that has declined dramatically in Minnesota since the 1980s (Sauer et al. 2011). Listed as a Minnesota Species of Greatest Conservation Need (2008), populations continue to decline despite numerous oak savanna restoration efforts occurring throughout the state (Leach and Ross 1995). Although most management efforts utilize prescribed fire as a means of restoration (Au et al. 2008), few studies (e.g., King et al. 2007) have examined red-headed woodpecker habitat selection in managed landscapes.

The University of Minnesota's Cedar Creek Ecosystem Science Reserve (Cedar Creek) began actively managing for oak savanna with prescribed burns in 1964 (Davis et al. 2000). These savannas are home to one of the largest known breeding concentrations of red-headed woodpeckers in the Upper Midwest. This site presents an opportunity to study red-headed woodpecker ecology in a landscape with managed fire frequency. Complete understanding of the habitat preferences of red-headed woodpeckers at Cedar Creek will help direct conservation efforts throughout the region.

This thesis is a compilation of two manuscripts formatted for publication and are not always written in the first person. Chapter formatting follows the requirements of the intended journal. Chapter 1, "Nest-site Selection of Red-headed Woodpeckers in a Fire Managed Landscape," is intended for publication in the Journal of Wildlife Management. Chapter 2, "An Inexpensive Camera System for Monitoring Cavity Nests," has been submitted to Journal of Field Ornithology.

CHAPTER 1: NEST-SITE SELECTION OF RED-HEADED WOODPECKERS IN A FIRE MANAGED LANDSCAPE

Red-headed woodpeckers (*Melanerpes erythrocephalus*) were once a common and widespread species whose breeding range stretched throughout the eastern and central United States and southern Canada (Smith et al. 2000). In the last 40 years, red-headed woodpecker populations have declined sharply, with Breeding Bird Survey (BBS) data indicating a survey-wide loss of ~ 2.8% annually (Sauer et al. 2011). This decline has been especially severe in Minnesota, where BBS data indicate a 6.2% annual loss since 1966 (Sauer et al. 2011). As a result, this species has been identified as a Minnesota Species of Greatest Conservation Need by Minnesota Audubon (2008) and a Region 3 (Upper Midwest) priority species by the U.S. Fish and Wildlife Service (2002).

Red-headed woodpeckers prefer oak savanna habitat characterized by scattered trees and open under- and mid- stories (Smith et al. 2000, Brawn 2006, King et al. 2007). Oak savanna, once widespread in the Upper Midwest, now covers only 0.02% of its pre-European settlement distribution (Nuzzo 1986). Factors that have contributed to this decline include fire suppression and subsequent encroachment by woody species, conversion of land into agriculture, and residential and commercial development (Davis et al. 1997, Grundel and Pavlovic 2007). Loss of oak savanna habitat is likely a main cause of the decline of red-headed woodpecker populations in Minnesota. Despite numerous oak savanna restoration efforts throughout the state, populations have continued to decline (Leach and Ross 1995, Sauer et al. 2011).

Most restoration efforts focus on prescribed fire as a means of restoring oak savanna (Au et al. 2008). Despite this, few studies (e.g., King et al. 2007) have examined red-headed woodpecker habitat selection in managed landscapes. Instead, studies have examined habitat use at unburned sites (Gutzwiller and Anderson 1987, Sedgwick and Knopf 1990, Rodewald et al. 2005) or wildfire sites (Vierling and Lentile 2006, Vierling et al. 2009). A complete understanding of red-headed woodpecker habitat use at a long-term managed site is needed to direct prescribed fire regimes and other restoration activities.

The University of Minnesota's Cedar Creek Ecosystem Science Reserve (hereafter Cedar Creek) began actively managing for oak savanna with prescribed burns in 1964 (Davis et al. 2000). Red- headed woodpeckers are common breeding birds in the open oak woods and, in 2008, Minnesota Audubon began a citizen science monitoring program at Cedar Creek. This site provides the unique opportunity to study red-headed woodpecker nest-site selection in a landscape with long-term managed fire frequency. A better understanding of the habitat preferences of red-headed woodpeckers at Cedar Creek will help direct appropriate management and restoration efforts at similar oak savanna restoration sites. Our objectives in this study were to 1) quantify habitat use by breeding red-headed woodpeckers by comparing habitat characteristics at nest trees with available (random) habitat, and 2) examine the relationship between fire frequency and nest density.

STUDY AREA

Our study was conducted at Cedar Creek Ecosystem Science Reserve, a site owned and operated by the University of Minnesota. Located in east central Minnesota (45°25'N, 93°10'W), Cedar Creek is situated on the Anoka Sandplain, a glacial outwash area characterized by coarse textured soils low in nitrogen (Davis et al. 2000). The majority of our site was dominated by burr oak (*Quercus macrocarpa*) and pin oak (*Quercus palustris*) savannah (Grigal et al. 1974). Shrubs and woody ground species at Cedar Creek include American hazel (*Corylus American*), smooth sumac (*Rhus glabra*), chokecherry (*Prunus virginiana*), Virginia creeper (*Parthenocissus* spp.), and poison ivy (*Toxicodendron radicans*). Dominant grasses and sedges are big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), smooth meadow-grass (*Poa pratensis*), and Pennsylvania sedge (*Carex pensylvanica*) (Grigal et al. 1974).

In 1964, Cedar Creek began a prescribed burning program to restore and maintain oak savanna (Irving 1970). The managed area was divided into 29 burn-management units, and these areas were assigned a fire treatment ranging from complete fire exclusion to burns nearly every year. All prescribed burning occurred in the spring. Our study was conducted in 21 of these burn units which ranged in size from 2.2 to 31.7 ha (Appendix 1).

METHODS

Nest Searches

Red-headed woodpeckers often attempt more than one brood per breeding season (Ingold 1987). To eliminate the potential for counting more than one nest per pair, nest searching took place from 1 June to 15 July during the first brood period (Ingold 1989). Red-headed woodpeckers are conspicuous birds because of their coloration and territorial vocalizations (Smith et al. 2000). They are especially territorial prior to nesting and we used this behavior to locate breeding territories. Some nest cavities were found by observing excavation activities, however we considered nest cavities unconfirmed until feeding of young was observed, nestlings were heard, or nest contents (eggs or chicks) were recorded via video camera (2011 only). For smaller and open burn units, nest searching was conducted by walking the fire break roads around the perimeter while listening and watching for birds. We traversed larger burn units with dense vegetation from corner to corner. We marked potential nest trees with a hand-held Global Positioning System (GPS) unit and with flagging tape tied around the trunk.

From 2008-2011, Minnesota Audubon volunteers supplemented our nest searching efforts at Cedar Creek. Groups were assigned to 2-3 burn units, depending on size. Each group surveyed their sites 3 times during the breeding season to identify potential cavities, confirm breeding activity, and record nest tree information.

Data Collection

Once fledging was confirmed, we recorded characteristics associated with the nest tree and surrounding habitat (Table 1). Our methods followed those of King et al. (2007) and Sedgwick and Knopf (1990) with slight modifications. To include more area in our habitat assessment, we recorded characteristics of the habitat within a 30-m radius around each tree, rather than 11.3- m. We felt that this larger area more fully captured the foraging and roosting activities of nesting woodpecker pairs. When calculating limb tree density, we separated trees with dead limbs below 10-m in height from those with higher limbs. Trees with limbs both above and below 10-m contributed to the total limb tree density. We made this distinction because King et al. (2007) found that red-headed woodpeckers exhibit a stand-level nesting threshold described by limb-tree density. Categorizing trees by the dead branch height allowed us to determine if red-headed woodpeckers were selecting for low or high limbs, a preference potentially influenced by their foraging behavior (Smith et al. 2000).

We characterized available nest sites by recording the same tree and habitat characteristics at 104 non-nest trees (Sedgwick and Knopf 1990). We used ArcGIS 9.3 to generate random points and then determined the closest non-nest tree (≥ 10-cm diameter at breast height; dbh) to the coordinates. The random tree also served as the center of the 30-m circle used for habitat measurements.

We used field notes and photos to identify cavities that were used in consecutive years and included only the first observation in our analyses. We assumed all remaining red-headed woodpecker nests were independent, even though many were presumably produced by the same surviving nesting pairs.

Statistical Analysis

We used logistic regression to identify the habitat and tree characteristics that influence nest-site selection of red-headed woodpeckers at Cedar Creek. Logistic regression was an appropriate tool to analyze our use-availability data because red-headed woodpeckers are conspicuous birds, nests are fairly infrequent on the landscape, and we had a large nest searching effort. Therefore, we assumed that available habitat contained few unidentified nests and that random nest-sites were truly unused (Keating and Cherry 2004). We used $\log_{10}$ transformations to help normalize continuous variables (e.g. tree dbh and height), whereas square root transformation were used for count data such as live and dead tree density.

We incorporated 7 numeric variables into our set of candidate models and the single categorical variable of tree species. These variables were chosen based on previous literature regarding habitat preferences of red-headed woodpeckers (Smith et al. 2000) and of the closely related Lewis's woodpecker (*Melanerpes lewis,* Newlon and Saab 2011). Ground cover, a variable only measured in the 2010 and 2011 field seasons, was added to our top candidate model from all years and examined using data from 2010 and 2011. We conducted correlation analyses on all variables to assess co-linearity. We considered variables with coefficient values $r > 0.60$ to be correlated and we included only 1 correlated variable in a model.

We evaluated candidate models using small sample correction of Akaike's Information Criterion (AIC_c, Burnham and Anderson 2002). Models were ranked by their ΔAIC_c values and we considered models with a $\Delta AIC \leq 2$ to be well supported by the data, provided these models were not simply embellishments of a simpler but higher-ranked model (Burnham and Anderson 2002). We calculated Akaike weights (w_i) to quantify support for individual models and evidence ratios to determine how much "better" our best model was compared to other competitive models. We tested the top candidate model for goodness-of-fit using Pearson chi-square statistic (Hosmer and Lemeshow 1989). Because only one model received substantial support, parameter estimates and standard errors were calculated for only our best-supported model. Using this model, we estimated probability of use at 90% of the observed range of each predictor variable. To examine changes in probability of use based on a single changing variable, we held continuous variables at mean values and set the categorical variable to dead trees (the most commonly used tree type). We performed regression analyses with R version 2.12.1 and R package AICcmodavg (Mazerolle 2011).

Fire Frequency

Our study included burn units that had experienced between 0 and 36 fires in the last 46 years (Appendix 1). Burning typically occurred after breeding activities had started, so we also included the presence or absence (0 or 1) of a spring burn into the analysis. Frequently burned units (30-36) may contain fewer nests than units burned more moderately (20-30). To test the fit of a curvilinear model, we also included a quadratic term of times burned. We used ArcGIS 9.3 to calculate burn unit area (hectares) and $\log_{10}$ transformed nest density (no. nests/area). We conducted a repeated-measures analysis with each of the 4 years incorporated as separate samples and used small sample correction of AIC to evaluate models. We performed this analysis with R version 2.12.1 and R package lme4 (Bates et al. 2011).

RESULTS

We assessed tree and habitat characteristics at 102 red-headed woodpecker nests and 104 random, non-nest sites in 2008-2011 (Fig. 1, Fig. 2). In comparison to random trees, a greater percentage of nests were located in large dead trees. All measures of limb-tree density (low, high, and total) were greater around nests, whereas both snag and live tree densities were higher at random sites (Table 2).

Two models received substantial support ($\Delta AIC_c < 2$, Table 3). The best supported model ($w_i = 0.47$) included the variables of tree species, dbh, limb-tree density (LTD) low, and small snag density, whereas the second ranked model included tree height instead of tree dbh ($\Delta AIC_c = 1.25$, $w_i = 0.25$). The evidence ratio comparing the top two models showed that the first model was 1.9 times more likely than the second model. Furthermore, the variables that distinguished these models, tree height and tree dbh, were positively correlated ($r = 0.61$) and indicated a similar preference for large trees. Because the model that included dbh ranked higher and dbh is easier to measure in the field than tree height, we chose to interpret model 1 as the single top-supported model. The Pearson chi-square statistic indicated that our top model adequately described the data ($\chi^2_{201} = 189.8$, $P = 0.70$).

Parameter estimates from our top model indicated a positive relationship between probability of use and dead trees, dbh, and limb-tree density. Probability of use was negatively related to small snag density (Table 4). Red-headed woodpeckers were more likely to use dead trees (0.67) than pin oaks (0.32) or other tree species (0.10). Estimates of use varied from 0.39 for a dead tree with a 10.7-cm dbh (lower 90% observed range) to 0.82 for a dbh of 61.3 cm (upper 90% observed range). Estimated use varied from 0.43 to 0.88 as the density of trees with low dead limbs (LTD low) increased from 0 to 12. When density of small snags increased from 0 to 26, probability of use decreased from 0.84 to 0.19. Probability of use estimates is contingent on having equal numbers of used and unused sites.

Addition of ground cover to our top-supported model fit to 2010-2011 data resulted in a higher AIC value ($\text{model}_{\text{top model+ground cover}}$; AIC_c= 171.56, w_i= 0.32 versus $\text{model}_{\text{top model}}$; AIC_c= 170.01, w_i= 0.68), indicating that herbaceous ground cover surrounding the nest tree was not predictive of red-headed woodpecker use.

Fire Frequency

One model that examined nest density in relation to fire frequency received substantial support ($\Delta AIC_c < 2$; Table 5). The best supported model included variables for year and the number of times a unit was burned. Parameter estimates indicated a positive relationship between nest density and year ($\beta = 0.04 \pm 0.02$) and times burned ($\beta = 0.01 \pm 0.004$). Examination of the observed points and the density curve based on the top model with 2011 data, showed that the highest red-headed woodpecker nest densities occurred in units that were burned between 20 and 25 times since 1964. Based on our model, the nest density of an area burned 25 times is more than 2 times greater than that of an area burned 5 times (0.33 and 0.12, respectively). Occurrence of a spring burn did not seem to have any detrimental effect on subsequent nest density. Examination of the observed data reveals an apparent decrease in nest density for units burned >25 times (Fig. 3). Despite this trend, the curvilinear model including a quadratic effect of times burned was not competitive (Table 5). A potential explanation for the nonsignificance of the quadratic term is pseudoreplication in the data. Each burn unit and their respective nest densities were incorporated 4 times (for each year) so the 8 observed data points with the highest densities only represent 2 burn units (Fig. 3). The relationship between nest density and times burned is linear when this replication is taken into account.

DISCUSSION

Cedar Creek Ecosystem Science Reserve presents an opportunity to examine red-headed woodpecker habitat selection in a fire managed landscape. We found that red-headed woodpeckers preferred nest sites that contained trees with low dead limbs and fewer small snags. Additionally, the majority of nests occurred in large dead trees. These characteristics are consistent with studies of red-headed woodpecker populations in post wildfire ponderosa pine and aspen woodland, golf courses, and cottonwood floodplains (Sedgwick and Knopf 1990, Rodewald et al. 2005, Vierling and Lentile 2006, Vierling et al. 2009), suggesting that red-headed woodpeckers select similar nest-site attributes regardless of disturbance regime.

The habitat-scale preferences of this species are likely related to their diverse foraging strategies. This species, along with northern flickers (*Colaptes auratus*), pileated woodpeckers (*Dryocopus pileatus*), and Lewis's woodpeckers (*Melanerpes lewis*), are the only North American woodpeckers that commonly feed on the ground (Terres 1991). Red-headed woodpeckers are also considered the most expert and persistent flycatcher in the woodpecker family (Smith et al. 2000). Selection of nest sites containing trees with low dead limbs is likely a function of their propensity for foraging on the ground. Unlike flickers, this species is a sit-and-wait predator that typically uses low observation perches before dropping to the ground for insects or other invertebrates (Jackson 1976). Preference for sites with low dead limbs may reflect the importance of this feeding behavior during the breeding season.

In a study at Necedah National Wildlife Refuge, Wisconsin, King et al. (2007) found that overall limb-tree density was the best predictor of red-headed woodpecker use. They concluded that high limb-tree densities (175 trees/ha) increased the probability of a red-headed woodpecker nest occurrence to nearly 80%. Although we did not find a nesting threshold associated with density of trees with low dead limbs, our results did suggest that dense stand-level decadence, often created by fire, is critical to woodpecker use.

Red-headed woodpeckers exhibited a strong preference for sites with low densities of small snags. This is likely a selection for stand openness, which has been widely documented in other studies (Ingold 1989, Sedgwick and Knopf 1990, Wilson et al. 1995, Rodewald et al 2005, King et al. 2007, Vierling et al. 2009). At Cedar Creek, highly burned areas have very few or no small snags. This is in contrast to infrequently burned units or fire exclusion sites, which retain closed canopies and contain high densities of small snags. Since these two habitats differ greatly, one possible explanation for this preference is that small snag density is a correlate for other habitat characteristics that we did not incorporate in this study. Open overstories allow for greater shrub and understory development and may therefore support higher arthropod densities (Bock and Lynch 1970, Swengel 2001, Vierling and Lentile 2006). Also, low numbers of small snags allow for more space for aerial maneuvers to capture flying insects (Saab et al. 2009, Vierling et al. 2009). Gall and Fernández-Juricic (2009) recorded another flycatching species, the black phoebe, avoiding habitats with shrubby vegetation; their study suggested that stand openness reduces the need to maneuver, and increases the number of potential flight paths that can result in a successful capture.

On the nest-tree scale, the majority (70%) of red-headed woodpecker nests found during our study were located in dead trees. Like Jackson (1976), Gutzwiller and Anderson (1987), and King et al. (2007), we found that most nests in living trees were nevertheless located in dead limbs. Red-headed woodpeckers are weak excavators, and decaying wood likely provides softer nesting substrate (Smith et al. 2000). Consistent with other studies, we found that red-headed woodpeckers tended to select nest trees with the largest diameters (Gutzwiller and Anderson 1987, Sedgwick and Knopf 1990, Vierling and Lentile 2006). Preference for larger trees may be due to their greater ability to provide thermoregulatory stability and protection from predators (Vierling et al. 2009).

Fire Frequency

Cedar Creek is divided into treatment units and has been managed with prescribed burns since 1964. We found a positive relationship between the number of times an area was burned and density of red-headed woodpecker nests. This corroborates other studies examining bird communities over a range of disturbance regimes. Au et al. (2008) found that red-headed woodpeckers were strongly associated with high burn frequencies (~ 0.9 burns/yr) and were only weakly associated with other measured environmental variables. Similarly, Brawn (2006) and Davis et al. (2000) found increased numbers of red-headed woodpeckers in burned oak-savanna habitat, a pattern Davis et al. (2000) suggests is related to lower tree density and an increase in abundance of standing dead trees.

Although number of burns per area ranged from 0 to 36 fires over 46 years, red-headed woodpecker nest density was highest in units burned 20-25 times. Though not statistically significant, the quadratic model and observed nest densities suggested a decrease in nest density at the highest frequencies of burning. There are several explanations for a negative effect of very frequent burning, and additional years of monitoring are needed to clarify this trend. While a moderate burning regime may succeed in creating an oak-savanna habitat with standing dead trees, over-burned areas may result in a treeless savanna. Brawn (2006) suggests that annual burning could result in a shrubless understory and therefore impact regeneration. High fire frequency may negatively affect arthropod assemblages (Swengel 2001) and decrease snag retention rates. High rates of fire may also weaken both dead and live trees, leading to higher tree-fall during wind storms (Morrison and Raphael 1993). During our 4-year study, at least 10 nest trees fell or were compromised during summer storms.

MANAGEMENT IMPLICATIONS

Prescribed fire is an effective method for creating red-headed woodpecker breeding habitat. Management activities meant to target this species should focus on creating and maintaining stand openness and stand decadence, especially in the form of trees with low dead limbs. Supplemental mechanical activities such as removing small trees and girdling large live trees may accelerate the restoration effort.

Similar to other studies, we found that red-headed woodpeckers are associated with higher burn frequencies (Au et al. 2008, Davis et al. 2000). Our results showed that areas that were burned more often (~50% annual fire frequency) contained twice the density of nests than areas burned infrequently. However, we also observed that units burned by > 25 fires showed a potential decrease in woodpecker nest density. We suggest that although managers should implement a high frequency burn regime to create red-headed woodpecker habitat, a different regime may be appropriate for maintaining quality habitat. Management activities that focus on retaining snags and encouraging tree regeneration during fire treatments may also be beneficial.

Table 1. Description of tree and habitat variables measured at red-headed woodpecker nest sites and at random non-nest sites, Cedar Creek Ecosystem Science Reserve, Minnesota, USA, 2008-2011.

Variable	Description
Tree	
Species	Species of live trees
Diameter at breast height (dbh, cm)	Tree dbh; measured with a dbh tape
Tree height (m)	Measured with a clinometer
Condition	Live or dead (snag)
Habitat	
Small-tree density	No. of trees <23-cm dbh (30-m circle)
Medium-tree density	No. of trees 23-69 cm dbh (30-m circle)
Large-tree density	No. of trees >69 cm dbh (30-m circle)
Total live tree density	No. of live trees (30-m circle)
Small snag density	No. of snags ≤12 cm dbh (30-m circle)
Large-snag density	No. of snags >12 cm dbh (30-m circle)
Total snag density	No. of snags (30-m circle)
Limb-tree density (LTD) low	No. of limb trees (those with ≥ 1 m dead limbs below 10 m; 30-m circle)
Limb-tree density (LTD) high	No. of limb trees (those with ≥ 1 m dead limbs above 10 m; 30-m circle)
Total limb-tree density (LTD)	No. of limb trees (those with ≥ 1 m dead; 30-m circle)
Ground cover	% of woody vegetation, herbaceous vegetation or bare ground (30-m circle)

Table 2. Mean and standard deviation of variables measured at 102 red-headed woodpecker nests and 104 non-nest sites at Cedar Creek Ecosystem Science Reserve, Minnesota, USA, 2008-2011.

	Nests		**Random**	
Variable	$\bar{x}$	**SD**	$\bar{x}$	**SD**
Tree condition (% dead)	69.6%	-	32.7%	-
Tree height (m)	13.9	5.2	11.2	5.2
Tree dbh (cm)	38.7	12.8	28.8	15.3
Limb-tree density[a] low	4.8	4.5	2.7	3.5
Limb-tree density high	6.3	5.8	5.8	7.1
Limb-tree density total	11.3	8.3	8.6	8.6
Small snag density	1.8	2.3	10.4	25.1
Total snag density	10.8	8.6	17.4	26.7
Total live tree density	23.2	21.5	40.5	39.7

[a] Number within 30-m radius of focal tree

Table 3. Logistic regression models predicting red-headed woodpecker nest use (n=102) versus random sites (n=104) using habitat data collected at Cedar Creek Ecosystem Science Reserve, Minnesota, USA, 2008 – 2011. Models are ranked from most supported ($\Delta AIC_c = 0$) to least supported; K is the number of parameters in each model. The Akaike weight (w_i) is the weight of evidence for model *i*, given the data and model set.

Candidate Model	K	AIC_c	ΔAIC_c	w_i
1: Tree species, DBH, LTD low[a], small snag density	6	200.46	0	0.47
2: Tree species, LTD low, small snag density, tree height	6	201.72	1.25	0.25
3: Tree species, DBH, LTD low, small snag density, total live density tree	7	202.52	2.05	0.17
4: Tree species, DBH, total LTD[b], small snag density	6	203.92	3.45	0.08
5: Tree species, DBH, total LTD, small snag density, total live tree density	7	205.57	5.11	0.04
6: Tree species, total LTD, total snag density, total live tree density	6	227.89	27.43	0
7: DBH, LTD low, small snag density	4	232.18	31.72	0

[a] Number of trees with dead limbs under 10-m within 30-m radius of focal tree

[b] Number of trees with dead limbs within 30-m radius of focal tree

Table 4. Parameter estimates (β) and standard errors from the best-supported logistic regression model for predicting nest-site selection by red-headed woodpeckers at Cedar Creek Ecosystem Science Reserve, Minnesota, USA, 2008-2011.

Parameter	β	SE
Tree.Species: Dead Tree[a]	-3.21	1.56
Tree.Species: Other[a]	-6.10	1.52
Tree.Species: Pin Oak[a]	-4.71	1.65
DBH (cm)	2.61	1.03
LTD low	0.66	0.17
Small snag density	-0.61	0.16

[a] These terms also function as the intercept for the model, depending on tree species.

Table 5. Model rankings for top supported models used to estimate red-headed woodpecker nest density at Cedar Creek Ecosystem Science Reserve, 2008-2011. Important covariates included the number of times a unit has been burned since 1964 (times burned), occurrence or absence of a spring burn (spring burn) and year. Models were ranked according to differences in Akaike's information criterion (ΔAIC_c) and Akaike weights (w_i). All models included the burn unit as a random effect on the intercept (k = 1 parameters).

Model	AICc	ΔAICc	Deviance	*K*	w_i
Times burned + Year	-13.65	0.00	-23.65	4	0.48
Times burned + Times burned ^{2} + Year	-12.17	1.48	-24.17	5	0.23
Times burned + Spring burn + Year	-11.70	1.95	-23.7	5	0.18
Times burned	-10.22	3.42	-18.22	3	0.09
Times burned + Spring burn	-8.23	5.41	-18.23	4	0.03

Figure 1. Locations of 102 red-headed woodpecker nests found during the breeding seasons of 2008-2011 in 15 burn units at Cedar Creek Ecosystem Science Reserve, Minnesota, USA.

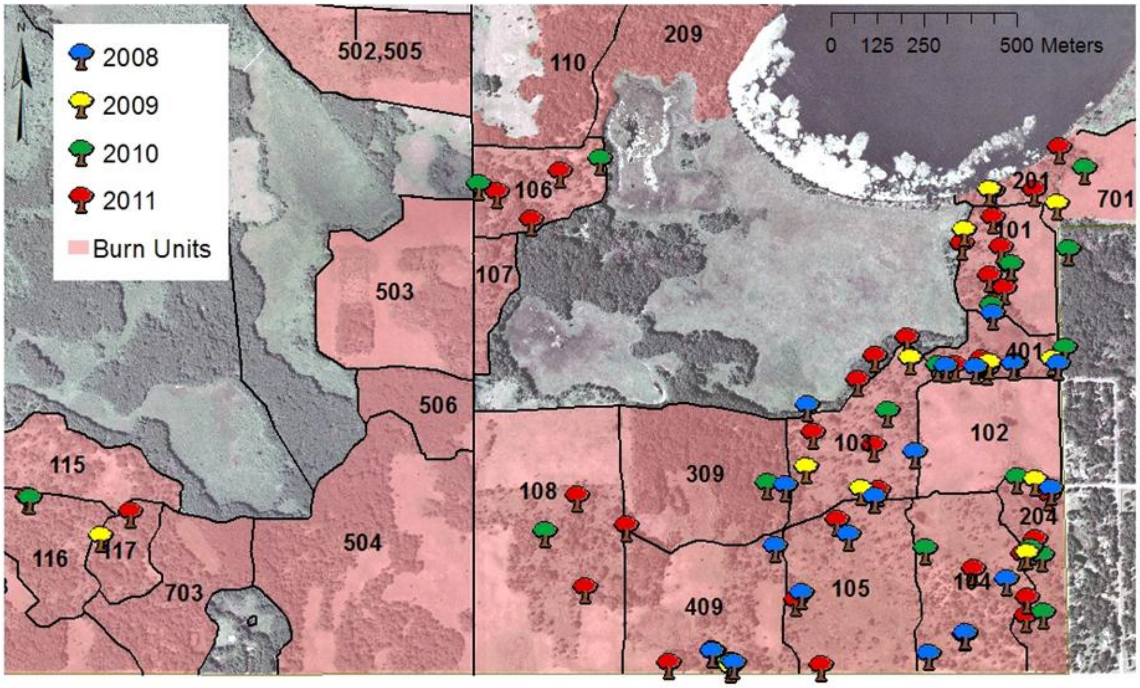


Figure 2. Locations of 104 non-nest sites generated with ArcGIS 9.3 in 21 burn units at Cedar Creek Ecosystem Science Reserve, Minnesota, USA.

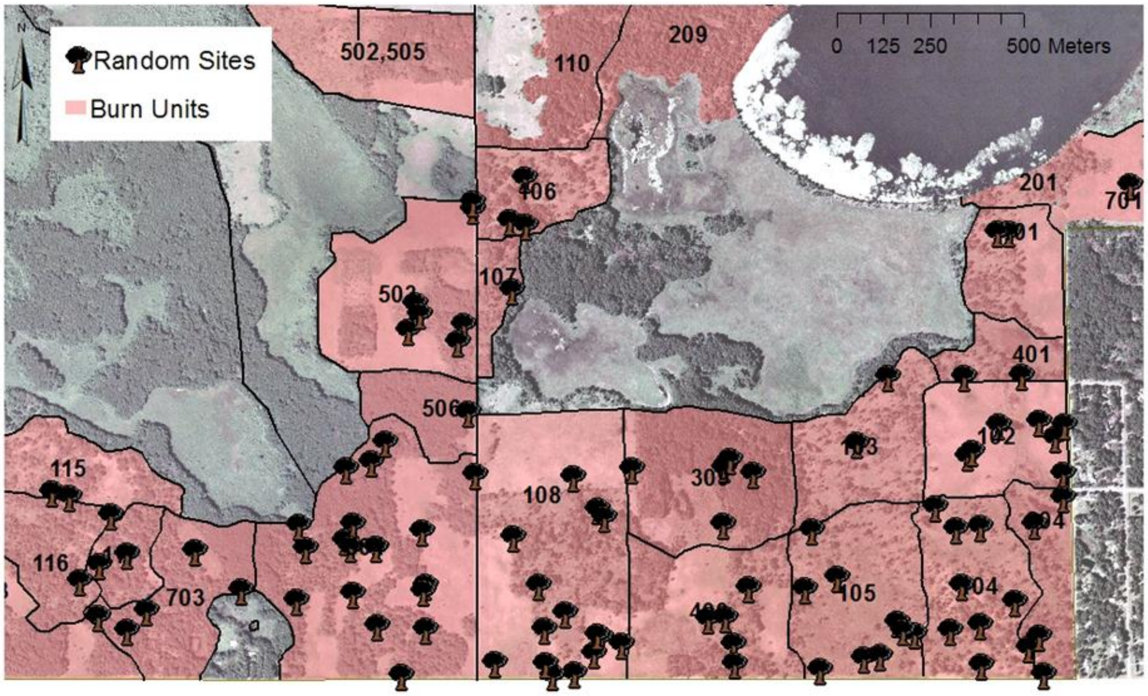
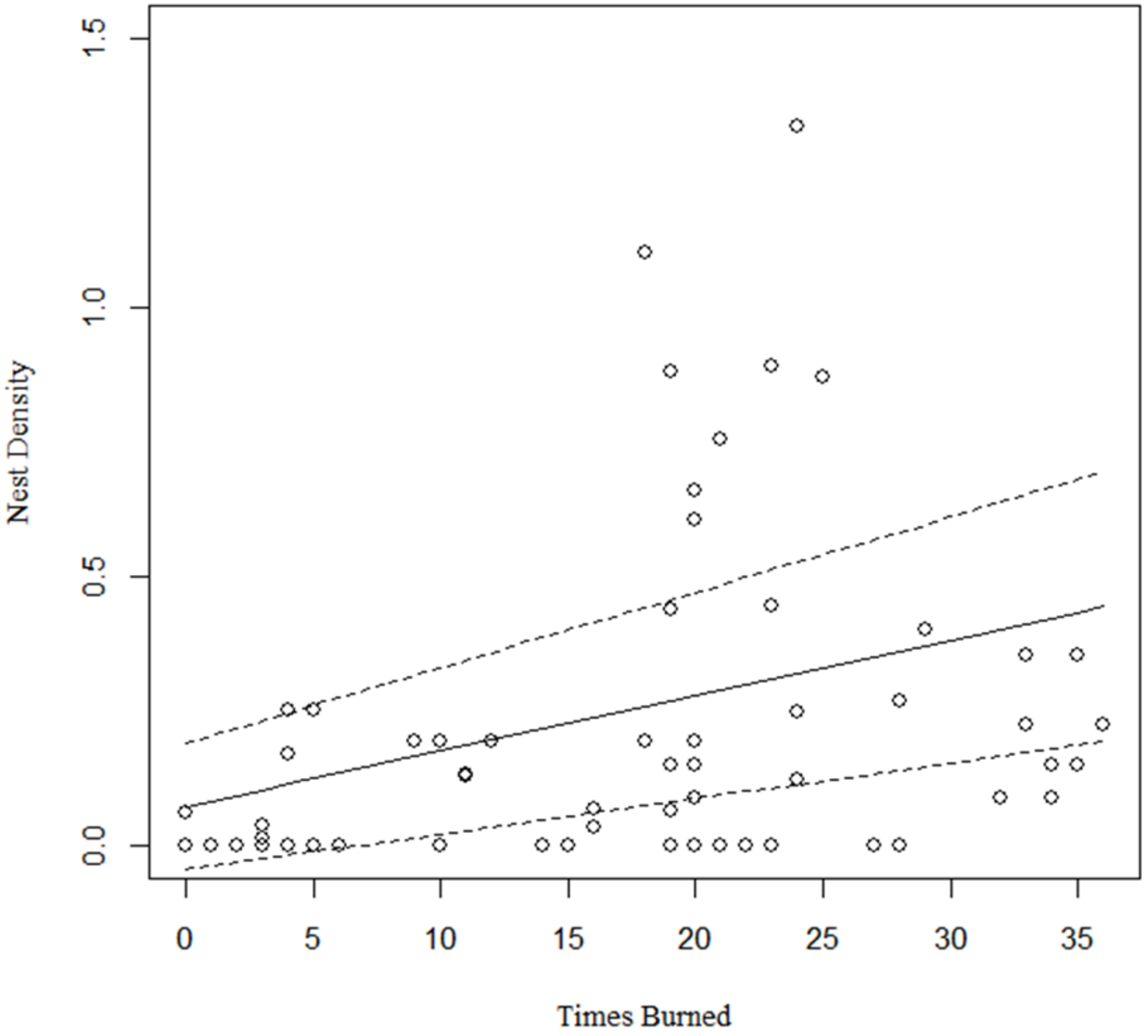


Figure 3. Observed values for nest density and times a unit was burned since 1964 and density curve for 2011 data based on repeated measures equation: density = -0.048 + 0.013 (times burned) + 0.040 (year), where year 2008 was coded as 0. Burn unit was incorporated as a random effect on the intercept (k = 1 parameters). Nest localities (n= 102) were collected at Cedar Creek Ecosystem Science Reserve, Minnesota, USA, 2008-2011.



CHAPTER 2: AN INEXPENSIVE CAMERA SYSTEM FOR MONITORING CAVITY NESTS

Investigators have employed fiberscopes and a variety of pole-mounted cameras to monitor nest cavities (Proudfoot 1996, Purcell 1997, Richardson et al. 1999, Huebner and Hurteau 2007, Luneau and Noel 2010). A commercial model developed by Sandpiper Technologies (Manteca, CA) was used by Richardson et al. (1999) to monitor cavity nests. However, the system costs > $5000 and may not be a viable option for many researchers. Although a less expensive commercial camera is available (~$500, http://www.ibwo.org), the entire pole-mounted system costs ~$900. Alternative systems, like those developed by Luneau and Noel (2010) and Huebner and Hurteau (2007), are less costly, but assembly requires soldering, drilling, and rewiring. A simple, low-cost camera system is needed for researchers studying nest success of cavity-nesting species.

Populations of Red-headed Woodpeckers (*Melanerpes erythrocephalus*) have declined throughout their breeding range and the species is listed as near threatened by the IUCN (Sauer et al. 2011). Information about nesting success is lacking for these woodpeckers, and few investigators have attempted to measure fecundity (Smith et al. 2000). Nest cavities of Red-headed Woodpeckers are often located > 10 m above ground and the mean diameter of nest entrances is 5.6 cm (Smith et al. 2000) so inspection of nests requires a small pole-mounted camera. I developed a low-cost, easily assembled camera for monitoring the nest cavities of Red-headed Woodpeckers. For those who already have a laptop computer that can be used in the field, this system provides a lower-cost (<$500) alternative to existing cavity-camera systems and presents a flexible framework.

METHODS

The camera system I developed was made from commercially available products and most components are available in hardware stores. Little or no alteration of components is needed, allowing for quick assembly. The system consists of a small camera, a cable connecting the camera to a ground-level power source and laptop computer, and a flexible neck connecting the camera to a telescoping pole.

Camera. I chose a camera that met many of my requirements without need for alteration. The camera I used (PLCM22IR, Pyle Audio Inc., Brooklyn, NY; www.pyleaudio.com) is sold as a rear-view camera for automobiles. It is inexpensive (~$22- 44 US) and has 10 infrared light-emitting diodes (LEDs), allowing use in low-light conditions. The camera is small (3.3 cm in height), light-weight (190 g), and produces clear monochrome images (510 x 492 pixels, 380 TV Lines). Once connected to a power source, the camera streams video, allowing use of a ground-level power connection as an on-off switch. To reduce camera height to 2.3 cm and allow monitoring of nests in cavities with a minimum entrance diameter of 4.1 cm, I removed the mounted housing by unscrewing the camera from the housing tube with pliers (Fig. 1).

Cable connection to ground-level power and laptop. I used a cable to connect the camera to a ground-level power supply and laptop. Although other systems are wireless (Huebner and Hurteau 2007, Luneau and Noel 2010), this approach reduces the complexity of the system, the weight of the camera, and overall price. To reach higher nest cavities, I replaced the 5-m video cable included with the camera with a 15-m RCA video cable. The cable I used matched the plug on the camera’s video feed and can be modified to extend the power cable. To connect the video cable to the laptop computer, I used an adaptor (EasyCAP DC60 - USB 2.0 audio/video Creator Capture) that came with video capture software used to view and save video. I connected the video output cord from the camera (yellow) to the RCA cable and then to the cable labeled CVBS (also yellow) on the EasyCAP USB adapter.

The camera requires 12 volts of power to operate and I used a battery holster with 8 AA batteries to provide power and a fully insulated battery snap connector to connect the holster to the cable. Attaching the camera to the ground-level battery involves connecting the wires from three different cables: the camera’s power adapter cable, the RCA cable, and the battery snap connector. To provide power to the camera, I connected the wires coming from the camera to corresponding colored wires at the battery level. I accomplished this via wires within the RCA cable. First, I connected the black adapter cable (included with the camera) to the camera’s power cable. After cutting off the plastic plug of the unused RCA cable, I stripped a small portion of the wires from the adapter and RCA cable and twisted the wires together to make a connection. Cables were attached to the smallest section of the telescoping pole using duct tape, thus reducing cable movement and stress on the connections. I repeated the process of stripping and connecting wires between the RCA cable and the battery snap connector, careful to complete the circuit by connecting the red wire from the camera to the red wire coming from the snap connector. All connections were strengthened by solder. Finally, I wrapped them with electrician's tape.

One set of 8 AA alkaline batteries lasted the entire study period. I extended battery life by disconnecting the power source after monitoring each nest cavity. The laptop battery (Dell Inspiron) was powered down during transport between trees and, with continuous use, lasted 3 to 4 hours.

Connecting the camera to the telescoping pole. Because many Red-headed Woodpecker nests in my study were located in angled limbs, a flexible neck connecting the camera to the pole increased the number of nests I was able to monitor. To accomplish this, I used 16-gauge galvanized steel wire that is flexible enough to be manipulated in the field without tools, but strong enough to maintain its shape. I cut ~50 cm of steel wire and used pliers to wrap one end of the wire twice around the brass screw from the pole. The 15-m telescoping pole (CMR- 50, Crain Enterprises, Mound City, IL) used to elevate the camera came with a screw, which fit the thread pattern at the top of the pole. I wrapped the camera with the steel wire, leaving 25 cm of wire between the camera and the pole. To ensure that the steel wire maintained it shape, I doubled the wire, twisting it to form a cohesive rope (Fig. 2).

RESULTS

From 23 June to 11 August 2011, I used this camera system to inspect 16 Red-headed Woodpecker nests on 47 different occasions at Cedar Creek Ecosystem Science Reserve in Bethel, Minnesota. Nest cavities ranged in height from 3.1 to 8.6 meters.

Images generated during inspections were used to determine the number of eggs and nestlings in nests (Fig. 3A, B).

System use required two people, one to manipulate the telescoping pole and the other to hold the laptop and begin recording. On average, it took 3-5 min to raise the camera, inspect a cavity, and lower the camera. Higher cavities took longer to inspect, especially on windy days, because of the increased difficulty of inserting the camera into cavities.

Eight nests in my study could not be inspected using my camera system because they were too high, located in severely angled limbs, or access was blocked by branches below the cavities. Image clarity was consistent throughout the study, although the connection between the camera and laptop was lost once. This was repaired by re-taping wire connections.

DISCUSSION

My cavity camera system is easier to assemble than other systems and, assuming investigators already have a laptop computer, less expensive (Table 1). Videos obtained with my camera allowed me to determine clutch and brood sizes, approximate fledging dates, and two instances of nest predation. An advantage of my system is that is uses standard, off-the-shelf components. In addition, investigators can alter the system to fit their specific needs. For example, a camcorder compatible with the RCA video cable can be substituted for the laptop computer. Furthermore, as less expensive and better cameras (e.g., smaller cameras) become available, this system can be modified (i.e., method of connecting the camera to the telescoping pole) to accommodate those cameras.

Another advantage of this design is the flexible neck connecting the camera to the telescoping pole. Camera systems without this flexibility (Proudfoot 1996, Richardson et al. 1999, Huebner and Hurteau 2007) can only be used to inspect cavities located at a ~90^o angle to the telescoping pole. My system allows adjustment for slight variation in cavity angles. Although this flexibility increased the number of nests I was able to inspect, several cavities could not be monitored. Those cavities were located in trees that had low limbs blocking access or were at a severe angle.

Using a laptop computer with the cavity-camera system makes it easy to save, edit, and view recorded videos. Few other systems allow researchers to record video (Proudfoot 1996, Purcell 1997, Richardson et al. 1999, Huebner and Hurteau 2007). Luneau and Noel (2010) provided instructions for adding a digital camcorder to their design, but a camcorder was not included in the cost of their overall system. Recording video allows confirmation of nestling and egg counts by multiple independent observers and the inclusion of videos in educational and academic presentations. However, laptop computers do have a limited battery life and must be protected from inclement weather.

Although other cavity-camera systems have employed wireless video cameras (Huebner and Hurteau 2007, Luneau and Noel 2010), no cavities in my study were inaccessible due to the presence or additional weight of the RCA cable. Red-headed Woodpeckers preferentially nest in dead trees or limbs (Smith et al. 2000) so most nest trees or snags in my study had few or no limbs below the cavity and were in fairly open areas. The cable could make use of my system more difficult in denser habitats with many low branches, especially leafed branches.

Table 1. Approximate cost of components needed to build the cavity camera system.

Item	Cost (US)
15-m telescoping pole	$390
Pyle Flush Mount Rear View Camera	$25
USB video capture	$8
15-m RCA cable	$15
8 AA battery holster	$3
9V battery snap connector	$3
16- gauge, 25ft (7-m) galvanized steel wire	$2
Miscellaneous (batteries, duct tape, heavy- duty wire cutters)	$15
Total	$461

Figure 1. The camera base (A) was unscrewed from the housing (B). This was accomplished by grabbing the threaded tube with one pair of pliers while unscrewing the base with a second pair.

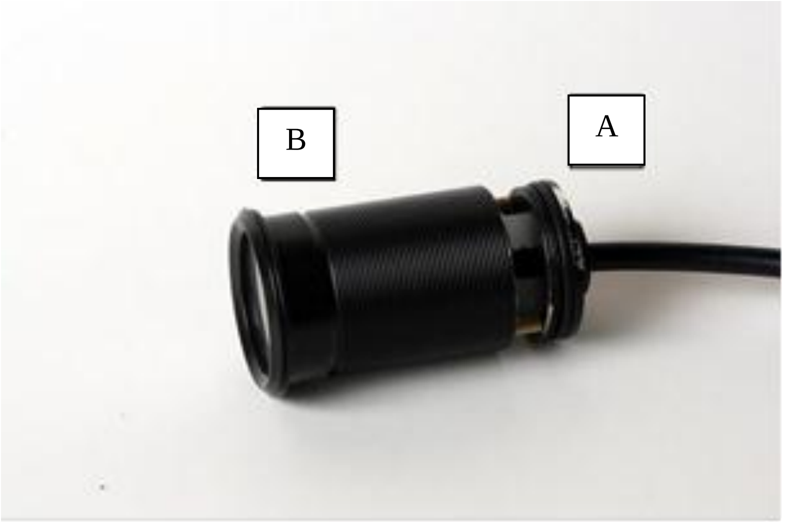


Figure 2. After the camera housing is removed, the camera is connected to the telescoping pole with galvanized steel wire.

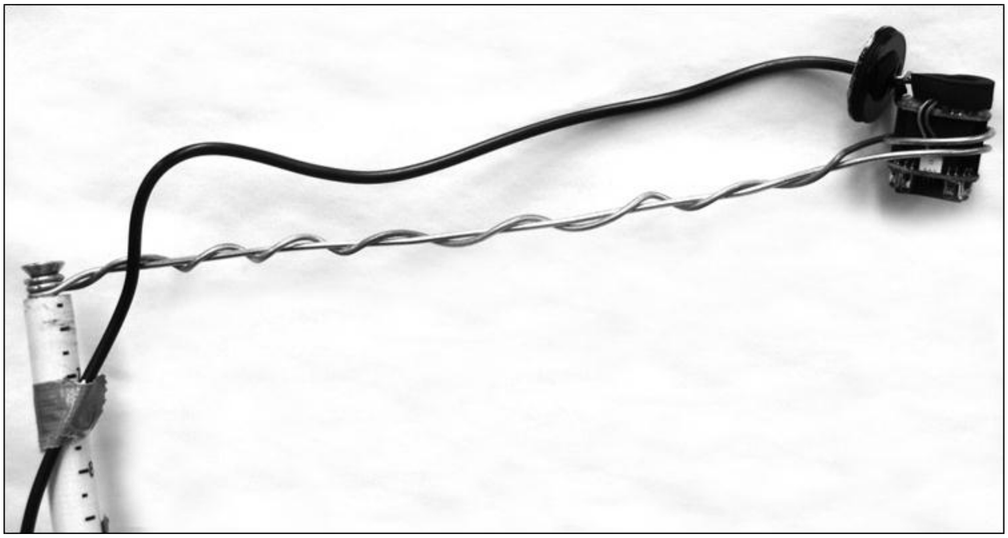
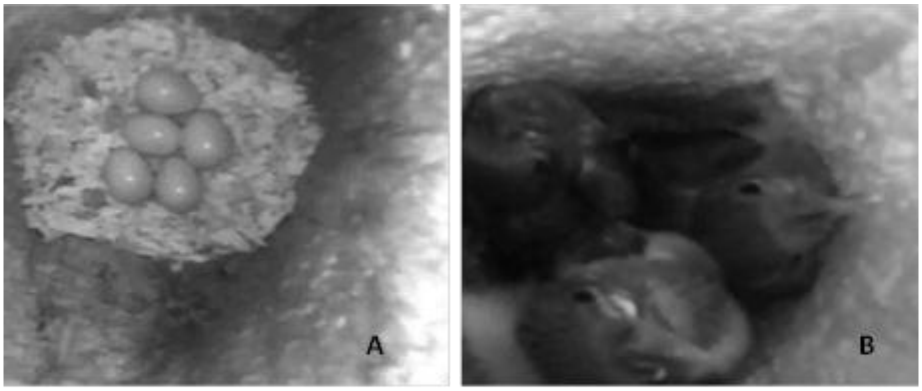


Figure 3. Video images of 5 Red-headed Woodpecker eggs (A) and 3 nestlings (B) captured by the cavity-camera system.



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Appendix 1. Burn units and dates of fire treatments at Cedar Creek Ecosystem Science Reserve, Minnesota, USA. 1964-2011.

Year	**101**	**102**	**103**	**104**	**105**	**106**	**107**	**108**	**115**	**116**	**117**
1964	23-Apr										
1965	28-Apr	7-May	7-Apr	7-May	7-May						
1966	13-Apr	12-Apr	25-Apr	13-Apr	25-Apr	25-Apr	30-Aug				
1967	27-Apr	1-Apr	14-Apr	5-May	5-May	31-Jul	6-Sep	10-Apr			
1968		15-Apr	26-Apr	26-Apr				29-Apr			
1969			12-May	12-May		23-Apr	23-Apr				
1970	4-May			4-May		19-May					
1971			21-Apr	29-Apr	29-Apr			12-May			
1972	8-May	17-Apr	18-May	25-Apr	25-Apr	17-Apr		25-Apr			
1973	26-Apr	26-Apr	16-May	26-Apr	16-May	15-May	16-May				
1974		16-Apr	16-Apr	18-May							
1975		5-May		5-May		12-May	12-May	12-May			
1976	26-Apr		26-Apr	29-Apr		29-Apr					
1977	25-Apr		25-Apr	26-Apr	26-Apr						
1978	1-May	28-Apr	28-Apr		15-May	1-May		10-May			
1979		23-Apr	23-Apr	23-Apr		15-May	23-Apr	15-May			
1980			17-Apr	14-May			14-May				
1981	12-May	7-May	7-May	20-May		5-May	18-May				
1982	20-Apr					24-May		26-Apr			
1987			4-May							6-May	
1988				19-May		18-May		11-Apr			
1989			25-Apr	12-May	12-May		25-Apr			11-May	
1990		3-May	3-May	3-May	3-May	3-May				5-May	
1991	14-May			14-May		14-May					

1992	14-May	8-May	8-May	14-May		14-May		8-May	8-May	8-May	
1993	5-May		12-May	12-May		5-May					
1994			5-May	22-Apr	22-Apr	20-Apr		10-May			
1995	3-May	29-Jan	5-May	12-May							
1996			7-May	16-May	16-May	29-Apr	29-Apr			30-Apr	
1997	1-May		25-Apr			21-Apr		28-Apr	6-May	6-May	
1998			17-Apr								
1999		28-Apr		26-Apr	26-Apr	24-Apr	24-Apr				
2000	2-May		24-May	24-Apr		28-Apr		26-Apr	2-May		2-May
2001	11-Oct	11-Oct	11-Oct	11-Oct	11-Oct						
2002		14-May	30-Apr	14-May		26-Apr	26-Apr			30-Apr	
2003	24-Apr		11-Apr	12-Apr	12-Apr	8-Apr		9-Apr	8-Apr	8-Apr	23-Apr
2004			22-Apr								
2005	15-Apr	14-Apr	14-Apr	14-Apr	14-Apr	21-Apr	21-Apr		21-Apr	21-Apr	21-Apr
2006				27-Apr	27-Apr	19-Apr					
2007	20-Apr	20-Apr	20-Apr	20-Apr	20-Apr		19-Apr	19-Apr			
2008	1-May					1-May			1-May	1-May	1-May
2009	28-Apr	28-Apr	28-Apr	11-May	11-May	22-Apr					
2010			19-Apr	22-Apr			18-Apr	19-Apr		9-Apr	9-Apr
2011	25-Apr	25-Apr	25-Apr	4-May	4-May	25-Apr					

Year	**201**	**204**	**301**	**401**	**409**	**501**	**503**	**504**	**506**	**701**	**703**
1964			16-Apr	23-Apr							
1965		7-May	28-Apr	28-Apr							
1966		13-Apr		13-Apr							
1967	27-Apr	5-May		27-Apr							
1968	26-Apr	26-Apr									
1969		12-May									
1970		4-May		4-May							
1971		29-Apr									
1972	8-May	25-Apr		8-May							
1973	26-May	26-Apr		26-Apr							
1974		18-May									
1975		5-May									
1976	26-Apr	29-Apr		25-Apr							
1977	25-Apr	26-Apr		25-Apr							
1978											
1979	16-May										
1980	21-May										
1981											
1982											
1987											
1988		19-May									
1989											
1990											
1991	14-May										
1992	14-May										

1993	5-May										
1994	21-Apr	22-Apr		21-Apr							
1995	3-May			3-May							
1996	7-May			7-May	13-May		20-Sep				
1997	17-Apr			1-May	29-Apr	24-Apr					
1998							23-Apr	18-Apr			
1999					26-Apr						
2000					26-Apr						
2001	11-Oct	11-Oct	11-Oct	11-Oct						11-Oct	
2002											
2003	24-Apr	12-Apr		24-Apr	9-Apr						
2004	22-Apr			22-Apr	24-Apr						
2005	15-Apr	14-Apr		15-Apr	14-Apr						
2006	19-Apr				27-Apr						
2007	20-Apr	20-Apr		20-Apr	20-Apr					20-Apr	
2008	1-May						1-May	1-May	1-May	1-May	1-May
2009	28-Apr	11-May		28-Apr	5-May		4-May	4-May	4-May	14-May	11-May
2010					19-Apr		8-Apr	9-Apr	9-Apr		9-Apr
2011	25-Apr	4-May		25-Apr	4-May		3-May	4-May	12-Apr	4-May	