Popul Ecol (2014) 56:507–512
DOI 10.1007/s10144-014-0433-6

THE SOCIETY OF POPULATION ECOLOGY

ORIGINAL ARTICLE

Loss of nesting sites is not a primary factor limiting northern Chimney Swift populations

Trina M. Fitzgerald · Elisabeth van Stam · Joseph J. Nocera · Debra S. Badzinski

Received: 14 May 2013 / Accepted: 14 January 2014 / Published online: 7 February 2014

Abstract Aerially-foraging insectivorous bird populations have been declining for several decades in North America and habitat loss is hypothesized as a leading cause for the declines. Chimney Swifts (*Chaetura pelagica*) are a model species to test this hypothesis because nest site use and availability is easily assessed. To determine if nest site availability is a limiting factor for Chimney Swifts, we established a volunteer-based survey to inventory and describe chimneys ($n = 928$) that were used or unused by swifts. A logistic regression model showed that swifts preferred chimneys with a greater length exposed above the roofline and greater inside area, which were not associated with residential buildings. The average chimney used by swifts extended 2.86 m above the roofline with an internal area of 10,079 cm^2. The regression model represents the range of nest-site conditions that swifts will tolerate; this was used to build a linear discriminant function (ldf) that had an *I*-index of 82 % (measure of prediction success). We applied the ldf coefficients to predict chimney occupancy in three southern Ontario communities. Of 366 open chimneys, the ldf classified 139 as suitable but only 24.4 % were occupied by swifts. Given that >75 % of suitable sites were unoccupied, swifts are likely not experiencing competition from habitat saturation. Our results suggest that Chimney Swift populations, and likely other aerially-foraging insectivorous birds, are limited primarily by other processes not measured in this study, such as changes in prey.

Keywords Aerial insectivores · *Chaetura pelagica* · Citizen Science · Habitat loss · Population declines

T. M. Fitzgerald
46 Anne St., Millbrook, ON L0A 1G0, Canada

E. van Stam · D. S. Badzinski
Bird Studies Canada, Port Rowan, ON N0E 1M0, Canada

J. J. Nocera
Ontario Ministry of Natural Resources, Trent University, Peterborough, ON K9J 7B8, Canada

D. S. Badzinski (✉)
Stantec Consulting Ltd., 200-835 Paramount Drive, Stoney Creek, ON L8J 0B4, Canada
e-mail: debra.badzinski@stantec.com

Introduction

Populations of aerially-foraging insectivorous birds (hereafter "aerial insectivores") have declined substantially in recent decades (Böhning-Gaese et al. 1993; Nebel et al. 2010), which have been attributed to reduced prey populations and loss of available habitat (Evans et al. 2007; Grüebler et al. 2010). It is difficult to disentangle the respective roles of these stressors, in part because it can be challenging to estimate nest site availability (Gibbons et al. 1995; Cornelius et al. 2008). The Chimney Swift (*Chaetura pelagica*) is well-suited for such an investigation because nest site availability can be assessed easily and the species is easily detected and monitored.

Among aerial insectivores, Chimney Swifts (hereafter "swifts") have shown especially precipitous population declines (Nebel et al. 2010; Rioux et al. 2010) and loss of nesting sites has been considered by some to be the primary limiting factor (Cink and Collins 2002; Kyle and Kyle 2005; COSEWIC 2007). The porous masonry chimneys, with which swifts are commonly associated, are no longer the predominant structures for heating exhaust in non-residential buildings; most are now made of metal or high-density concrete. Further, existing chimneys are increasingly undergoing closure to prevent entry by animals (e.g., chimney caps) or increase safety (e.g., metal flue liners) which discourages use by swifts. The lack of suitable new chimneys and the closure of existing chimneys are reducing nest site availability for swifts across their range, but whether this reduction is yet limiting their populations has remained purely speculative.

Swifts require large vertical cavities for nesting and roosting, and the interior of those cavities must allow for swifts to cling to porous but stable surfaces. Typically, one nesting pair of swifts occupies a structure throughout the breeding season, while roosting (especially during migration) is done communally. Occasionally, a nesting pair may attempt to nest in a roosting site. Prior to the late 17th century, swifts were mostly found nesting and roosting in large, hollow trees, but quickly became associated with nesting in stone chimneys as mature forests in North America were cleared (Graves 2004). Today, swift nests are found almost solely in chimneys while nests in natural cavities are noteworthy observations (e.g., Blodgett and Zammuto 1979; Graves 2004).

To investigate the role of nest site availability in limiting swift populations, we initiated a large-scale volunteer program (Ontario SwiftWatch) to monitor nest-site use across southern Ontario, Canada, where the species is listed as Threatened at both the provincial and federal levels. By engaging volunteers, we were able to cover a large geographic area, which would not otherwise have been possible. Urban residents were engaged at two levels: (1) surveillance monitoring to locate and count numbers of Chimney Swifts at chimneys; and (2) directed research to evaluate nest site availability as a potential cause of decline. Volunteers monitored and evaluated chimneys to identify which chimneys were occupied and unoccupied by nesting swifts. We estimated nest site availability in three different communities, all with known levels of chimney closure, and compared that to occupancy patterns in those communities.

The pattern of population decline across most species of North American aerial insectivores, in which insectivory is a universally shared trait, strongly suggests that changes to foraging ecology play a role. Despite this, and that aerial insectivores occupy a wide range of habitats (from cities to forests), a less parsimonious suggestion is often made that loss of habitat is responsible for population declines on a species-by-species basis. Habitat loss may play a role in some areas, for instance swifts are known to use artificial nesting towers in the southern United States but unilaterally avoid them in Canada (Finity and Nocera 2012); thus, our analytical approach tests the prediction that nest site availability for swifts will exceed nest site use by swifts, and is thus not a population limiting factor, in southern Ontario.

Methods

Chimney inventories and surveys

We used data from the Citizen Science program Ontario SwiftWatch to examine nest and roost chimney characteristics that are important to swifts in urban areas. Volunteers inventoried chimneys in 36 communities, from 2009 to 2011, throughout southern Ontario, Canada. In a few of the communities, volunteer effort was supplemented with surveys by Bird Studies Canada staff to fill in some data gaps. Chimneys included in this study were located in one of three ways: (1) in larger urban centres, we used an adaptive searching approach to increase precision (Salehi and Brown 2010) and focused on areas known to have had, or likely to have, chimneys in active use by swifts. At these sites we measured the physical characteristics of all open chimneys in the vicinity of the focal chimney (which varied among communities based on accessibility and road layout). By pre-selecting areas with known or likely occupied chimneys we avoided biasing samples with inactive chimneys (Salehi and Brown 2010). (2) In smaller communities, a complete inventory of all open chimneys within the community was conducted. (3) In the remaining communities, open chimneys were located on a casual basis and chimney characteristics were recorded.

For each chimney detected, observers noted whether the chimney was accessible to swifts and recorded the following characteristics for all such open chimneys: shape (round, square, or rectangular), length and width or diameter, height exposed above the roofline, total height, number of open flues, type of building to which it was attached (residential or non-residential), number of stories, and construction material. We also classified the surrounding habitat following urban zoning descriptions: low-density housing (single detached houses), medium-density housing (townhouses), high-density housing (apartment buildings), industrial, regional facility (schools, arenas, and town buildings), open, downtown, and commercial.

Observers confirmed whether a chimney was active or inactive through standardized presence/absence surveys at open chimneys conducted during the spring migration (14–26 May), nesting (9–25 June), post-breeding roosting (7–23 July), and fall migration (4–18 August) periods. One or more observers were responsible for monitoring a set of chimneys throughout the study period. Starting approximately 30 min before sunset, observers would traverse a survey area noting swift activity (e.g., individuals circling or diving toward a chimney). Once activity was detected, observers would watch a chimney until entry was confirmed or until it was too dark to observe swifts (approximately 20 min after sunset). Chimneys were visited at least twice weekly during each observational period; once an active status was confirmed (i.e., swift seen entering chimney) the chimney was not revisited again in that period. For a subset of active chimneys, we inspected the interior of the chimney for evidence to confirm nesting and counted the number of birds entering a chimney to identify substantial communal roosts (≥25 swifts observed entering in one evening).

Statistical analyses

We first eliminated one variable from any pair of variables that showed a strong correlation (i.e., we accounted for multicollinearity; Graham 2003), which reduced the candidate predictive variable set and eliminated the need to provide for interactions in models.

Using data from 559 chimneys (199 occupied, 360 unoccupied), we then built logistic regression models to assess whether presence or absence of nesting swifts in a chimney, at any point in the survey period, varied as a function of seven fixed variables: building type, zoning class, chimney material, number of open flues, chimney shape, chimney area, and height above roofline. We created a final best-fit model by sequentially removing variables with non-significant (z test; $P > 0.05$) parameter estimates, or those not contributing to a reduction in the overall deviance (χ^2 test, $P > 0.05$). These models were built with data from those communities that monitored only active chimneys and a randomly-chosen 50 % of observations ($n = 367$) from all communities that monitored both active and inactive chimneys (Barrie, Cambridge, Pembroke, and Stratford). We withheld 50 % of the data ($n = 366$) from communities that performed complete chimney inventories for testing purposes (see below).

To test how use of a chimney by swifts was related to chimney availability, we used the final best-fit model to develop a linear discriminant function (Ripley 1996) with the data used in the logistic regression as the "training set". The discriminant function calculates the relative weights (coefficients) of each habitat variable and can be used to predict and classify whether a chimney should be active or inactive. We applied the discriminant function to the independent data (the "test set") that were randomly chosen and withheld from the above logistic regression analysis.

All statistical analyses were conducted using *R* version 2.13.2 (R Development Core Team 2011), using the MASS package (version 7.3–17) for the linear discriminant analysis. We set $\alpha = 0.05$ for all tests.

Results

We first reduced the candidate predictive variable set by eliminating one variable from any pair of variables that showed a strong correlation. Total chimney length and the length of chimney exposed above the roofline were correlated ($r = 0.64$). Therefore, we opted to eliminate chimney length as we felt it was adequately captured by height above roofline and the latter variable has a more direct management application as it is easier to manipulate when chimneys are decommissioned or maintenance is required. The number of stories and the type of building were also correlated ($r = 0.78$) and we retained the building type as the more meaningful variable in that it corresponded to zoning descriptions and urban planning.

The best-fit model for chimney occupancy patterns retained variables of chimney length exposed above roofline ($z = 2.95$, $P = 0.003$), chimney area ($z = 4.32$, $P = 0.00002$), and whether a building was categorized as residential ($z = -8.40$, $P \leq 2^{-16}$); none of the 95 % confidence intervals for the three variables in this model included 0. Chimney Swifts more often occupied larger and longer chimneys (Figs. 1, 2); the average chimney used by swifts extended 2.86 m above the roofline and had an internal area of 10,079 cm^2, whereas the average chimney

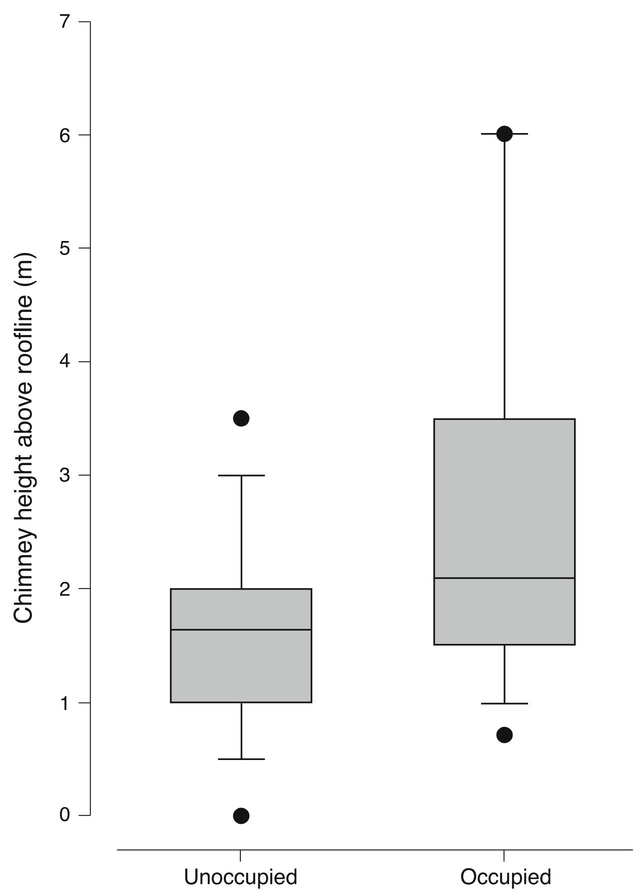

Fig. 1 The length of chimney exposed above a building's roofline in relation to whether the chimney was occupied by Chimney Swifts. *Boxes* represent quartiles and mean, and the *circles* represent the 5th and 95th percentiles

not used by swifts extended 1.4 m above the roofline and had an internal area of 3,346 cm^2. Seventy-three percent of non-residential chimneys were occupied, whereas only 14 % of residential chimneys were occupied.

The linear discriminant function (ldf) of the training data set established prior probabilities of a chimney being vacant as 0.62 and being occupied as 0.38. The ldf coefficients were −1.89 for whether a building was residential, 0.00004 for chimney area, and 0.14 for the height exposed above roofline. The model with these coefficients correctly back-predicted occupancy in the training set (i.e., had an *I*-index of) 82 % of the time. We applied the ldf coefficients to the test set to predict occupancy among 366 open chimneys. The ldf classified 139 of them as suitable but only 34 of those chimneys were occupied.

Because 18 roost chimneys were included in the training set, we rebuilt the logistic regression models and ldf with these data removed to determine the influence these chimneys may have had on the relationships we detected. We found that there was no influence of roost chimneys on the relationships we detected, as the *I*-index for the ldf with and without roost chimneys removed did not differ. Further, the parameter estimates of the logistic regression model changed only by a magnitude of 0.017–0.096 and the 95 % confidence intervals for the three variables still did not bound 0.

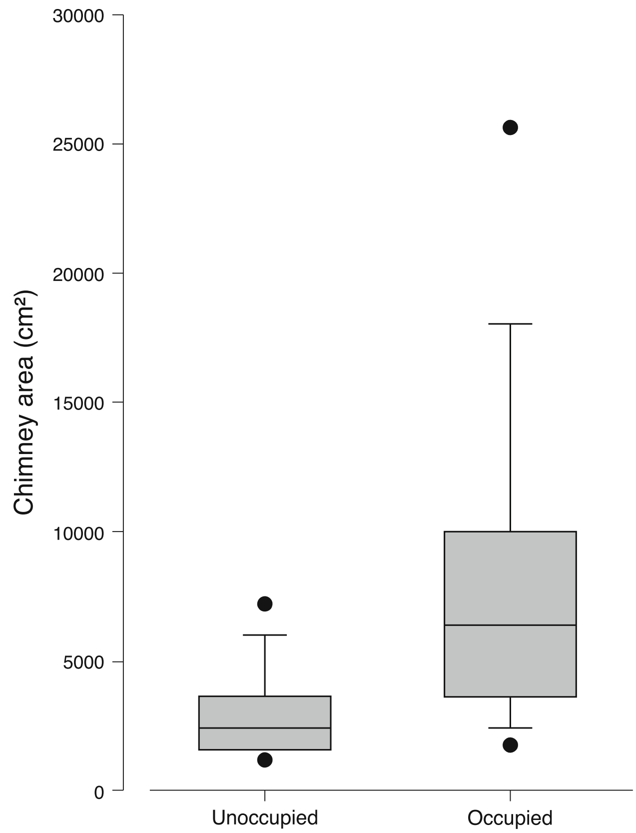

Fig. 2 The inside area of chimneys in relation to whether the chimney was occupied by Chimney Swifts. *Boxes* represent quartiles and mean, and the *circles* represent the 5th and 95th percentiles

Discussion

For this study, we used data collected by Citizen Scientists participating in Ontario SwiftWatch to help disentangle causes of decline for the Chimney Swift in southern Ontario. While traditionally, Citizen Science projects have focused on collecting long-term, broad-scale surveillance monitoring data (e.g., Breeding Bird Survey, Christmas Bird Count), hypothesis-driven Citizen Science projects are becoming more common (Dickinson et al. 2010, 2012). While one of the goals of Ontario SwiftWatch is to locate and monitor nest and roost sites, we added hypothesis-based components to the core program. This approach not only allowed us to address an important conservation question (are nest sites limiting?) in a cost-effective manner but also to raise awareness of urban biodiversity and foster a local stewardship ethic.

If chimney availability were a limiting factor for breeding swifts in Ontario, then we would expect to find a high occupancy rate in suitable nesting chimneys. We found no support for this hypothesis; only 24.5 % of seemingly suitable and available chimneys were occupied in three communities with complete chimney occupancy surveys. It is unlikely that swifts were avoiding some unmeasured feature in the remaining 75.5 % of suitable and available chimneys which were unoccupied. Factors we did not measure, such as internal temperature or air flow, surely varied among study chimneys; nonetheless, this variation is unlikely to be the salient feature of non-occupancy as these chimneys were all deemed “suitable” and thus were structurally similar to occupied chimneys (and therefore largely within favorable thermoregulatory limits for swifts).

The most parsimonious explanation for the lack of habitat saturation is that some other environmental factor that we did not measure is more strongly limiting swift populations, such as prey availability. For example, Nocera et al. (2012) recently showed that historical declines in swift populations in Ontario are correlated to changes in insect abundance; our study indirectly supports this hypothesis by eliminating habitat limitation as a potential primary driver of swift population declines in the same region. Our results also add strength to the assertion that artificial nesting towers (designed by Kyle and Kyle 2005) remain unoccupied in Ontario because habitat may not be in short supply (Finity and Nocera 2012). Further to this, there seem to be architectural challenges related to temperature in artificial towers in Ontario that may render them unsuitable (Finity and Nocera 2012; D. Badzinski, unpublished data).

Swifts tended to occupy chimneys in non-residential buildings, a finding consistent with the patterns observed by Wheeler (2013). Swifts also tended to occupy chimneys that were larger and longer (Figs. 1, 2), which may be a result of numerous factors that we did not measure such as favorable thermoregulatory properties, light levels, greater protection from predators, or ease of finding the habitat. The relationship between occupancy rates and the length of the chimney above the roofline suggests that thermoregulation may be particularly important, especially given that most swift nests are found in the upper 3 m of a chimney (Kyle and Kyle 2005).

Unlike chimney area, which could only be altered by rebuilding, the length of chimney that is exposed above a roofline is a more tractable management variable, for instance it can be altered as needed. When chimneys are decommissioned, a common strategy is either to remove the chimney entirely or shorten the portion above the roofline; landowners regularly ask how much they can shorten a chimney if swifts are known to use it (Nocera, unpublished data; Pickett, personal communication). Our results suggest that the exposed portion of a chimney above a roofline should not be shortened.

Our results contrast with the contention that chimney closure rates are the primary threat to swift populations (Cink and Collins 2002; Kyle and Kyle 2005; COSEWIC 2007). We suggest that swift populations, at least in our study area, are currently more limited by other factors we did not measure such as prey availability, which represents a much more daunting management challenge. Further, given the lack of occupancy by swifts in artificial structures (Finity and Nocera 2012), we contend that the effort and expense of construction of artificial towers in southern Ontario may be better directed elsewhere until a better design is achieved that ameliorates any thermoregulatory problems that may exist.

However, it is important to recognize that there is a finite supply of suitable nesting chimneys for swifts, and that although swift populations may not currently be limited by chimney availability in Ontario, they inevitably will be if habitat loss continues unabated. Because our study was limited to Ontario, we cannot assume that the patterns we observed apply across the species' range. Our study has illustrated a lack of habitat saturation only at the species' northern range edge, which is where population declines might be expected to be most visible (Lawton 1993). Nonetheless, conservation of suitable chimneys (which we found to be larger, longer, and attached to non-residential buildings) will become an increasingly important activity regardless of location as chimney closure rates increase in the future.

Acknowledgments We are grateful for the dedication of Ontario SwiftWatch participants, whose efforts in collecting data for this project made this study possible. We particularly thank Winifred Wake, Nature London, Barrie SwiftWatch, Cambridge SwiftWatch, Guelph SwiftWatch (especially Mike Cadman), Halton SwiftWatch, Kingston Field Naturalists, Ottawa SwiftWatch, Pembroke SwiftWatch (especially Lauren Kruschenske), Stratford SwiftWatch, and two summer interns. We are also grateful for the coordination and promotion of Ontario SwiftWatch by Kathy Jones, Kristyn Richardson, and Doug Tozer. Financial assistance for this project was provided by the Government of Ontario and the Government of Canada.

References

Blodgett KD, Zammuto RM (1979) Chimney swift nest found in hollow tree. Wilson Bull 91:154

Böhning-Gaese K, Taper ML, Brown JH (1993) Are declines in North American insectivorous songbirds due to causes on the breeding range? Conserv Biol 7:76–86

Cink CL, Collins CT (2002) Chimney Swift (*Chaetura pelagica*). In: Poole A (ed) The birds of North America. Cornell Lab of Ornithology, Ithaca, p 646

Cornelius C, Cockle K, Politi N, Berkunsky I, Sandoval L, Ojeda V, Rivera L, Hunter M Jr, Martin K (2008) Cavity-nesting birds in neotropical forests: cavities as a potentially limiting resource. Ornitol Neotrop 19S:253–268

COSEWIC (2007) COSEWIC assessment and status report on the Chimney Swift *Chaetura pelagica* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa

Dickinson JL, Zuckerberg B, Bonter DN (2010) Citizen science as an ecological research tool: challenges and benefits. Annu Rev Ecol Evol Syst 41:149–172

Dickinson JL, Shirk J, Bonter D, Bonney R, Rhiannon Crain L, Martin J, Phillips T, Purcell K (2012) The current state of citizen science as a tool for ecological research and public engagement. Front Ecol Environ 10:291–297

Evans KL, Wilson JD, Bradbury RB (2007) Effects of crop type and aerial invertebrate abundance on foraging barn swallows *Hirundo rustica*. Agric Ecosyst Environ 122:267–273

Finity LK, Nocera JJ (2012) Vocal and visual conspecific cues influence the behavior of Chimney Swifts at provisioned habitat. Condor 114:323–328

Gibbons D, Gates S, Green RE, Fuller RJ, Fuller RM (1995) Buzzards *Buteo buteo* and Ravens *Corvus corax* in the uplands of Britain—limits to distribution and abundance. Ibis 137:S75–S84

Graham MH (2003) Confronting multicollinearity in ecological multiple regression. Ecology 84:2809–2815

Graves GR (2004) Avian commensals in Colonial America: when did *Chaetura pelagica* become the chimney swift? Arch Nat Hist 31:300–307

Grüebler MU, Korner-Nievergelt F, von Hirschheydt J (2010) The reproductive benefits of livestock farming in barn swallows *Hirundo rustica*: quality of nest site or foraging habitat? J Appl Ecol 47:1340–1347

Kyle P, Kyle G (2005) Chimney Swifts: America's mysterious birds above the fireplace. Texas A&M University Press, College Station

Lawton JH (1993) Range, population abundance and conservation. Trends Ecol Evol 8:409–413

Nebel S, Mills A, McCracken JD, Taylor PD (2010) Declines of aerial insectivores in North America follow a geographic gradient. Avian Conserv Ecol. doi:10.5751/ACE-00391-050201

Nocera JJ, Blais JM, Beresford DV, Finity LK, Grooms C, Kimpe LE, Kyser K, Michelutti N, Reudink MW, Smol JP (2012) Historical pesticide applications coincided with an altered diet of aerially-foraging insectivorous chimney swifts. Proc R Soc B Biol Sci 279:3114–3120

R Development Core Team (2011) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna

Rioux S, Savard J-PL, Shaffer F (2010) Scientific and cost effective monitoring: the case of an aerial insectivore, the chimney swift. Avian Conserv Ecol. doi:10.5751/ACE-00425-050210

Ripley BD (1996) Pattern recognition and neural networks. Cambridge University Press, Cambridge

Salehi M, Brown JA (2010) Complete allocation sampling: an efficient and easily implemented adaptive sampling design. Popul Ecol 52:451–456

Wheeler H (2013) Foraging patterns of breeding chimney swifts (*Chaetura pelagica*) in relation to urban landscape features. MSc thesis, Trent University, Peterborough, Ontario