AVIAN CONSERVATION
& ECOLOGY

VOLUME 14, ISSUE 1, ARTICLE 8

Purves, E. F., C. Myles Falconer, D. C. Tozer, and K. Richardson. 2019. Timing matters: cloud cover and date influence probability of detecting nesting Chimney Swifts (*Chaetura pelagica*). *Avian Conservation and Ecology* 14(1):8. https://doi.org/10.5751/ACE-01339-140108

Research Paper

Timing matters: cloud cover and date influence probability of detecting nesting Chimney Swifts (*Chaetura pelagica*)

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ABSTRACT. One third of bird species in North America need immediate conservation action. Effective management and recovery actions for species of conservation concern require accurate methods of monitoring species occurrence that limit the incidence of nondetection error (when a species is falsely recorded as absent when it is present). The Chimney Swift (*Chaetura pelagica*) is experiencing widespread population declines in North America, possibly, in part, because chimneys used for nesting or roosting are being capped or demolished. In particular, the presence of nesting swifts in a chimney can be difficult to determine, and thus, it is important to design survey protocols that limit the incidence of nondetection error. Here, we used data from Bird Studies Canada's Citizen Science program, Ontario SwiftWatch, and dynamic occupancy models to examine factors influencing the probability of detecting Chimney Swifts at nest sites. We found that the probability of detecting Chimney Swifts at nest chimneys decreased with increasing cloud cover. We also found some support suggesting that detection increased moderately with date over the course of the nesting period (June-July). Based on our findings, we recommend that surveys aiming to identify Chimney Swift nest sites in southern Ontario, Canada should be conducted for at least one hour under clear skies, and as late in the nesting period as possible. The results of this study will inform survey design to reduce the incidence of false negatives during chimney surveys for nest occupancy, and as a result, help reduce Chimney Swift nesting habitat disturbance and loss.

Le choix du moment: la couverture nuageuse et la date ont une influence sur la probabilité de détecter les Martinets ramoneurs nicheurs

RÉSUMÉ. Un tiers des espèces d'oiseaux d'Amérique du Nord nécessitent des mesures de conservation immédiates. Des mesures efficaces de gestion et de rétablissement des espèces menacées exigent des méthodes précises de surveillance de l'occurrence des espèces qui limitent l'incidence des erreurs de non-détection (lorsqu'une espèce est faussement enregistrée comme étant absente alors qu'elle est présente). Le Martinet ramoneur (*Chaetura pelagica*) connaît un déclin généralisé de sa population en Amérique du Nord, peut-être en partie parce que les cheminées utilisées pour la nidification ou le repos sont recouvertes ou démolies. En particulier, la présence de Martinets nicheurs dans une cheminée peut être difficile à déterminer. Il est donc important de concevoir des protocoles de relevé qui limitent l'incidence des erreurs de non-détection. Ici, nous avons utilisé les données du programme de science citoyenne SwiftWatch d'Études d'Oiseaux Canada, Ontario, ainsi que des modèles dynamiques d'occupation pour examiner les facteurs influant sur la probabilité de détecter des Martinets ramoneurs aux sites de nidification. Nous avons constaté que la probabilité de détecter des Martinets ramoneurs près des cheminées utilisées comme nichoir diminuait avec l'augmentation de la couverture nuageuse. Nous avons également trouvé des éléments suggérant que la détection augmentait modérément avec la date durant la période de nidification (juin-juillet). D'après nos résultats, nous recommandons que les relevés visant à identifier les sites de nidification du Martinet ramoneur dans le sud de l'Ontario, au Canada, soient effectués par temps clair, pendant au moins une heure, et aussi tard que possible pendant la période de nidification. Les résultats de cette étude amélioreront la conception des relevés afin de réduire l'incidence des faux négatifs lors des relevés des cheminées pour déterminer l'occupation du nid et, par conséquent, contribueront à réduire les perturbations et la perte de l'habitat de nidification du Martinet ramoneur.

Key Words: *aerial insectivore; Chaetura pelagica; Chimney Swift; Citizen Science; detection probability; dynamic occupancy model; habitat loss*

INTRODUCTION

One-third of North America's bird species require immediate conservation action because of ongoing population declines and threats (North American Bird Conservation Initiative 2016), including climate change, pollutants, invasive species, and habitat loss and degradation (Robbins et al. 1989, Gurevitch and Padilla 2004, Both et al. 2006, Nocera et al. 2012, Hallmann et al. 2014, Stanton et al. 2018). Effective conservation planning and management actions for these species require accurate and cost-effective methods of monitoring species occurrence. However, for rare and even common species, nondetection error, when a species is falsely recorded as absent when it is present, can occur during occupancy surveys as a result of cryptic species behavior, low population density, or inadequate sampling effort due to limited time and resources (Gu and Swihart 2004). Nondetection error can result in inaccurate conclusions about species occupancy and

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mislead management actions (Kellner and Swihart 2014). In particular, reducing rates of nondetection error for at-risk species that typically occupy habitat types with higher risk of destruction should be a conservation focus to help species recovery.

The Chimney Swift (*Chaetura pelagica*) is one such species of bird that frequently occupies habitat at high risk of destruction or disturbance (COSEWIC 2007, Fitzgerald et al. 2014). Chimney Swifts are aerial insectivorous birds that nest and roost in human-made structures, including wells, silos, barns, and most commonly, old masonry chimneys (Steeves et al. 2014). This species is also experiencing widespread population declines in eastern North America (Cadman et al. 2007, Nebel et al. 2010, Smith et al. 2015, Michel et al. 2016). North American Breeding Bird Survey data indicate a population reduction of approximately 90% in Canada since 1970 (ECCC 2017), and data from the second Breeding Bird Atlas of Ontario (2001–2005) indicate substantial population declines and distributional losses compared to the first atlas (1981–1985; Cadman et al. 2007). Consequently, the Chimney Swift is listed as Threatened in both Canada and the Province of Ontario under the Species at Risk Act (2009) and Endangered Species Act (2009), respectively.

Though the cause(s) behind the population declines is not clear, reductions in the availability of aerial insects for food, as well as destruction of suitable nesting and roosting habitat, are frequently cited as the leading causes of Chimney Swift population declines (e.g., COSEWIC 2007, Nocera et al. 2012, Fitzgerald et al. 2014, Steeves et al. 2014). In particular, the availability of porous masonry chimneys that Chimney Swifts typically use for nesting and roosting is declining on account of chimney capping and screening to prevent animal entries, demolition of older buildings for redevelopment, and installation of metal liners and spark arresters for insurance purposes (Fitzgerald et al. 2014, Stewart et al. 2016, Wake 2016). For example, 47 out of 162 (29%) chimneys known to be used by nesting or roosting Chimney Swifts in London, Ontario between 2004 and 2013 were lost by 2015, mainly because of demolition or capping (Wake 2016). Although there is evidence suggesting that the availability of suitable chimney habitat is currently not limiting Chimney Swift populations in parts of their breeding range, the number of suitable sites is projected to continue to decline over the next several years as masonry chimneys are demolished or altered (Gauthier et al. 2007, Fitzgerald et al. 2014, Zanchetta et al. 2014). Thus, limiting the destruction of suitable nest and roost chimneys, as well as disturbance at these sites, is an important conservation objective for this species.

Reducing the incidence of habitat loss and disturbance requires a survey protocol that reliably determines if a chimney is used by roosting or nesting Chimney Swifts, and thus limits nondetection error, i.e., when a chimney occupied by Chimney Swifts is deemed unoccupied. Although examining the interior of a chimney or its cleanout for evidence of use, e.g., nests, eggshells, feathers, or guano, is the most reliable method of determining occupancy, access can be difficult. Therefore, occupancy is often determined by conducting surveys from the ground and observing if swifts enter or exit the chimney opening. Roost chimneys can typically be identified by conducting surveys around sunset during migration and the breeding season when groups of nonbreeding individuals conspicuously enter chimneys to roost communally (Stewart and Stewart 2010, Steeves et al. 2014; Bird Studies Canada, *unpublished data*). However, nest chimneys can be more difficult to confirm because of the cryptic and less predictable behavior of breeding Chimney Swifts. Only one breeding pair usually occupies a nest chimney, although one to two nonbreeding "helpers" have been documented at nest sites (Fischer 1958, Dexter 1969). Furthermore, a breeding pair makes inconspicuous trips in and out of the chimney throughout the day to build a nest, incubate eggs, or feed young (Kendeigh 1952, Fischer 1958, Stewart and Stewart 2010, Steeves et al. 2014).

We investigate factors influencing the probability of detecting Chimney Swifts at active nest chimneys in order to make recommendations on a survey protocol that reliably determines nesting occupancy of chimneys and thus reduces nondetection error. Previous studies have shown that the time between chimney entries and exits by nesting Chimney Swifts varies with weather, time of day, and nestling age (Kendeigh 1952, Fischer 1958, Zammuto et al. 1981, Stewart and Stewart 2010, 2013). In this study, we examine how temporal (time of day and season) and weather variables influence the probability of detecting Chimney Swifts at nest sites in southern Ontario, Canada. Our ultimate goal in doing so was to develop survey guidelines to reduce nondetection error during nest chimney surveys, which, in turn, will increase the number of active nest chimneys identified and subsequently conserved and protected as part of actions to help reverse or stabilize declining populations.

METHODS

Study area

We recruited volunteers from Bird Studies Canada's Citizen Science program, Ontario SwiftWatch, to monitor known nest sites of Chimney Swifts in seven urban centers throughout southern Ontario, including Barrie, Fort Erie, Kingsville, London, Stratford, Tillsonburg, and Toronto (Fig. 1).

Fig. 1. Locations of urban centers where we studied detection probability of nesting Chimney Swifts, *Chaetura pelagica* (red dots). Numbers beside dots indicate the number of nest chimneys within each urban center. Circle size is proportional to sample size.

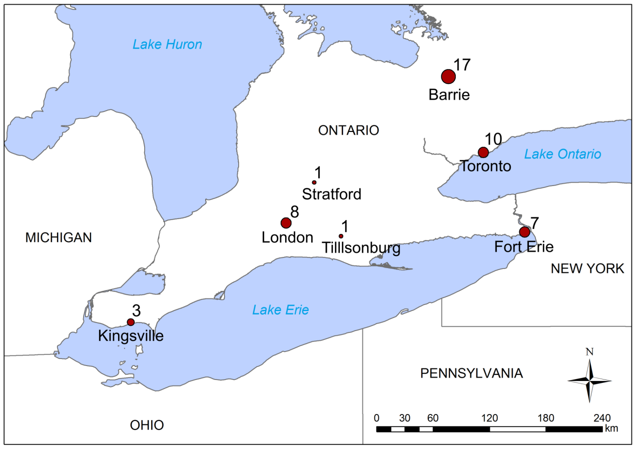


Table 1. Variables included in models explaining detection probability of Chimney Swift (*Chaetura pelagica*) at nest sites, as well as associated biological mechanisms and directions (+/−) of predicted effects.

Variable	Mechanism	Predicted effect
Air temperature	Air temperature influences length of foraging and/or brooding bouts, which affects frequency of chimney entries/exits (Zammuto et al. 1981)	+/−
Wind speed	Wind speed influences foraging efficacy and length of foraging bouts, which affects frequency of chimney entries/exits (Zammuto et al. 1981)	−
Cloud cover	Cloud cover influences foraging efficacy and length of foraging bouts, which affects frequency of chimney entries/exits (Lack and Lack 1951, Finlay 1976, Turner 1983)	−
Time of day	Parental care demands of young change with time of day, and/or time of day influences foraging efficacy and length of foraging bouts, which affect frequency of chimney entries/exits (Zammuto et al. 1981)	+/−
Time of season	Parental care demands of eggs/young change as nesting season progresses, which affects frequency of chimney entries/exits (Kendeigh 1952, Fischer 1958, Zammuto et al. 1981, Stewart and Stewart 2010)	+

Chimney surveys

Volunteers surveyed nest chimneys during the peak Chimney Swift nesting season (June–July) in 2016. All volunteers were experienced in identifying Chimney Swifts and with the monitoring protocols. Chimneys included in this study had been identified by volunteers as being occupied by nesting Chimney Swifts in a previous year, either through inspection of the chimney interior or ground observation of daytime activity, i.e., chimney entries and exits by Chimney Swifts. Observation of daytime activity at a chimney can be used to differentiate between roost and nest chimneys because Chimney Swifts typically return to roost chimneys only at sunset, whereas swifts visit nest chimneys throughout the day during the breeding season to nest build, incubate eggs, or feed young (Stewart and Stewart 2010).

At each nest chimney, volunteers conducted one to four standardized surveys between 1 June and 31 July, with up to one survey in each two-week period: early June (1 June–15 June), late June (16 June–30 June), early July (1 July–15 July), and late July (16 July–31 July). During each survey, one to two observers monitored the nest chimney for 60 min and recorded activity, i.e., Chimney Swift entered/exited chimney or no entry/exit, during each of the six 10-min intervals. Observers started surveys anytime between 0900 EST and one hour before sunset. If two or more surveys were conducted at a chimney, at least one survey was conducted during the day (0900 EST-1700 EST) and one in the evening (1700 EST-sunset). The mean number of days between consecutive surveys at sites was 14.6 days. Volunteers recorded air temperature (Celsius), wind speed (Beaufort scale), and proportion of cloud cover (to the nearest 10th) at the beginning of the survey. Surveys were not conducted if it was raining.

Statistical analysis

We used R version 3.3.1 (R Core Team 2016) with the unmarked package (Fiske and Chandler 2011) to conduct all analyses. To evaluate variables (see Table 1 for a list with associated mechanisms and predictions) affecting the detection probability of Chimney Swifts at nest sites, we fit dynamic occupancy models with removal design using the "colext" function in unmarked. Dynamic occupancy models are typically used in multiseason studies because of their hierarchical nature, i.e., repeated visits within repeated years. We opted to use dynamic occupancy models in our single-season study as we applied a similar hierarchical sampling protocol: we used repeated 10-min intervals during a 60-min survey, which was repeated at sites during different two-week periods, i.e., "seasons," between 1 June and 31 July. We used a removal model because we were interested in determining the minimum length of time required to detect Chimney Swifts entering or exiting nest sites, rather than the frequency at which they are detected. In addition, we preferred a removal design because we suspected nonindependence between 10-min intervals within the 60-min survey on account of prolonged foraging and within-chimney bouts of nesting Chimney Swifts, especially earlier in the nesting season. In a removal occupancy model design, encounter events are only modeled until the first detection and sites only need to be observed until the species is first detected (MacKenzie and Royle 2005, Kéry and Royle 2016). For each 60-min survey in our study, we assigned each 10-min interval a binary value: Chimney Swift detected entering or exiting chimney = 1, Chimney Swift not detected entering or exiting chimney = 0. We then replaced observations during the 60-min survey with NAs if they occurred after the first detection. We scaled all continuous covariates by transforming data to a Z-distribution (mean = 0, standard deviation = 1). Independent variables were not strongly correlated (Spearman's rank: $-0.4 < r < 0.4$).

We constructed 75 candidate models explaining variation in detection probability of Chimney Swifts entering or exiting nest chimneys. We listed all possible combinations of linear and quadratic date and time of day effects on detection probability, crossed with all combinations of weather variables, including air temperature, wind speed, and cloud cover. We did not include urban center as a variable in our models because we assumed the same patterns of detection across urban centers given their relatively close proximity within the Chimney Swift's breeding range. Our candidate model set also included null and global (full) models. All multivariate models included only additive effects, i.e., no interactions.

Because we were interested in only detection probability (p), we did not include variables in the initial occupancy (Ψ), colonization (γ), or extinction (ε) components of the models, and thus, expected these parameters to be constant across the duration of the study. Initial occupancy in the model is the occupancy for the first "season" or two-week period in our study. We carried out model selection using Akaike's Information Criterion (AIC). We considered the best model to be the model with ΔAIC equal to zero. We addressed model uncertainty using model averaging of the parameter estimates from the model confidence set (ΔAIC ≤ 6; Richards 2005) with the AICcmodavg package (Mazerolle 2017). We computed the model-averaged parameters using the natural average method (Burnham and Anderson 2002). We tested the fit of the most complex model using parametric bootstrapping and the chi-square goodness-of-fit test using the frequencies of detection histories; P values > 0.05 indicated adequate fit (Fiske and Chandler 2019).

We estimated the probability of detecting Chimney Swifts over a 60-min survey period as a function of covariates using predicted values derived from model-averaged estimates, while holding all other variables at their median values. We calculated detection probability across all 10-min intervals in a survey using $p_s = 1\text{-}(1\text{-}p_i)^6$, where p_s is the probability of observing at least one entry or exit of Chimney Swift during a 60-min survey, and p_i is the probability of observing at least one entry or exit of a Chimney Swift during a 10-min survey interval. We also used the null model to calculate the average detection probability across a 60-min survey, including confidence intervals calculated using the delta method. We ranked the relative strength of the influence of all of the factors we considered through direct comparison of model-averaged coefficients, which was possible given that all covariates were standardised by z-transformation prior to modeling. We also estimated detection probability as a function of the length of survey using predicted values derived from model-averaged estimates.

RESULTS

Volunteers completed 136 surveys (63 daytime, 73 evening), with one to four surveys at 47 nest chimneys in seven urban areas in southern Ontario (Fig. 1). Chimney Swifts were detected during at least one survey at all but three chimneys (9 out of 136 surveys had zero detection during 60 min). Based on the null model, the probability of initial occupancy, colonization, and extinction were 0.96 (± 0.04 SE), 0.002 (± 0.052 SE), and 0.12 (± 0.05 SE), respectively. Average detection probability across a 60-min survey was 0.87 (95% CI: 0.80, 0.92). The most complex model adequately fit the observed data ($\chi^2 = 315$, $P = 0.99$).

The best model (ΔAIC = 0) explaining variation in detection probability of Chimney Swifts included linear date and cloud cover (Table 2). However, the best model had an Akaike weight of 0.11, which is only 1.4 times higher than the second best model. Furthermore, the best model is closely followed by seven other models with a ΔAIC < 2, although most of these models included date and cloud cover effects.

Model-averaged coefficients for the model confidence set (ΔAIC ≤ 6) showed that cloud cover had the strongest influence, followed by linear date, air temperature, wind speed, and time of day (Table 3). Using model-averaged estimates, we found that cloud cover had a negative effect on detection probability (Fig. 2). Linear date had a positive effect on detection probability, where detection probability remained greater than 0.95 between 25 July and 1 August. However, the confidence limits for the model-averaged estimate of linear date slightly overlapped zero, and detection probability was 0.86 at the beginning of the nesting period and increased to 0.96 by the end of the nesting period (Fig. 2). We also made model predictions for the effect of length of survey on detection probability for early and late nesting periods under clear and overcast skies using model-averaged estimates of the candidate model set. Under these survey scenarios, only clear skies (0% cloud cover) during the late nesting period resulted in greater than 0.95 detection probability (Fig. 3).

Table 2. Model selection results from 75 candidate dynamic occupancy models used to explain variation in detection probability of nesting Chimney Swifts (*Chaetura pelagica*). Only the confidence model set (ΔAIC < 6), plus full and null models, are shown. K = number of estimated parameters for each model, AIC = Akaike's Information Criteria, ΔAIC = relative difference in AIC compared to best (top) model, w_i = Akaike weights.

Model[†]	K	AIC	ΔAIC	w_i
Ψ(.) γ(.) ε(.) *p*(D+C)	6	454.81	0.00	0.11
Ψ(.) γ(.) ε(.) *p*(D+C+Tmp)	7	455.38	0.57	0.08
Ψ(.) γ(.) ε(.) *p*(C)	5	455.52	0.71	0.08
Ψ(.) γ(.) ε(.) *p*(W+C)	6	456.30	1.49	0.05
Ψ(.) γ(.) ε(.) *p*(D+W+C)	7	456.54	1.73	0.05
Ψ(.) γ(.) ε(.) *p*(D2+C)	7	456.65	1.84	0.04
Ψ(.) γ(.) ε(.) *p*(D2+C+Tmp)	8	456.71	1.90	0.04
Ψ(.) γ(.) ε(.) *p*(T+D+C)	7	456.73	1.92	0.04
Ψ(.) γ(.) ε(.) *p*(D+W+Tmp+C)	8	456.88	2.07	0.04
Ψ(.) γ(.) ε(.) *p*(T+D+C+Tmp)	8	457.21	2.40	0.03
Ψ(.) γ(.) ε(.) *p*(C+Tmp)	6	457.27	2.46	0.03
Ψ(.) γ(.) ε(.) *p*(T+C)	6	457.49	2.68	0.03
Ψ(.) γ(.) ε(.) *p*(W+Tmp+C)	7	457.58	2.77	0.03
Ψ(.) γ(.) ε(.) *p*(D2+W+Tmp+C)	9	458.19	3.38	0.02
Ψ(.) γ(.) ε(.) *p*(T+W+C)	7	458.20	3.39	0.02
Ψ(.) γ(.) ε(.) *p*(D2+W+C)	8	458.40	3.59	0.02
Ψ(.) γ(.) ε(.) *p*(D2+T+C+Tmp)	9	458.43	3.62	0.02
Ψ(.) γ(.) ε(.) *p*(D2)	6	458.49	3.69	0.02
Ψ(.) γ(.) ε(.) *p*(T+D+W+C)	8	458.52	3.71	0.02
Ψ(.) γ(.) ε(.) *p*(D2+T+C)	8	458.55	3.74	0.02
Ψ(.) γ(.) ε(.) *p*(T2+D+C)	8	458.67	3.86	0.02
Ψ(.) γ(.) ε(.) *p*(T+D+W+Tmp+C)	9	458.83	4.02	0.01
Ψ(.) γ(.) ε(.) *p*(T2+D+C+Tmp)	9	459.13	4.32	0.01
Ψ(.) γ(.) ε(.) *p*(D)	5	459.17	4.36	0.01
Ψ(.) γ(.) ε(.) *p*(T+C+Tmp)	7	459.24	4.43	0.01
Ψ(.) γ(.) ε(.) *p*(T2+C)	7	459.44	4.63	0.01
Ψ(.) γ(.) ε(.) *p*(T+W+Tmp+C)	8	459.47	4.66	0.01
Ψ(.) γ(.) ε(.) *p*(T2+W+C)	8	460.07	5.26	0.01
Ψ(.) γ(.) ε(.) *p*(D2+T+W+Tmp+C)	10	460.07	5.26	0.01
Ψ(.) γ(.) ε(.) *p*(D2+W)	7	460.11	5.30	0.01
Ψ(.) γ(.) ε(.) *p*(T2+D2+C+Tmp)	10	460.35	5.54	0.01
Ψ(.) γ(.) ε(.) *p*(D2+T+W+C)	9	460.37	5.56	0.01
Ψ(.) γ(.) ε(.) *p*(T2+D+W+C)	9	460.42	5.61	0.01
Ψ(.) γ(.) ε(.) *p*(D2+T)	7	460.46	5.65	0.01
Ψ(.) γ(.) ε(.) *p*(T2+D2+C)	9	460.46	5.65	0.01
Ψ(.) γ(.) ε(.) *p*(D2+Tmp)	7	460.47	5.66	0.01
Ψ(.) γ(.) ε(.) *p*(T2+D+W+Tmp+C)	10	460.77	5.96	0.01
Ψ(.) γ(.) ε(.) *p*(Global)	11	462.02	7.21	< 0.01
Ψ(.) γ(.) ε(.) *p*(.)	4	462.09	7.28	< 0.01

[†] Model terms: D = linear date, D2 = quadratic date, T = time of day, T2 = quadratic time of day, C = cloud cover, Tmp = air temperature, W = wind speed.

Table 3. Model-averaged coefficients from the candidate model set (ΔAIC < 6) explaining variation in detection probability of nesting Chimney Swifts (*Chaetura pelagica*).

Coefficient	Estimate	Unconditional SE	Lower CI (2.5%)	Upper CI (97.5%)
Intercept	-0.745	0.198	-1.134	-0.357
Cloud cover	-0.403	0.138	-0.674	-0.132
Date	0.271	0.170	-0.061	0.603
Temperature	-0.176	0.164	-0.497	0.144
Wind speed	-0.107	0.146	-0.392	0.179
Time of day	0.023	0.152	-0.275	0.321
Date^2	-0.121	0.164	-0.443	0.201
Time of day^2	0.015	0.206	-0.388	0.419

Fig. 2. Detection probability of Chimney Swifts (*Chaetura pelagica*) at nest chimneys as a function of time of season (Julian date; 160 = 8 June, 210 = 28 July) and cloud cover (%) based on repeated 60-min ground-observational surveys. Vertical red lines depict the date range (25 July–1 August) when mean detection probability is > 95%. Dotted lines depict 95% confidence limits.

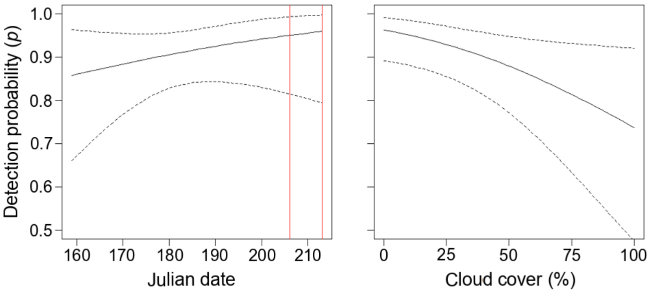
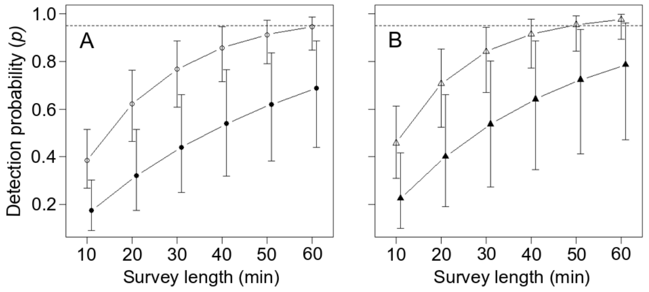


Fig. 3. Detection probability of Chimney Swifts (*Chaetura pelagica*) at nest chimneys in (A) early nesting season (23 June) and (B) late nesting season (20 July) as a function of length of survey (min) based on repeated 60-min ground-observational surveys from model-averaged estimates of the candidate model set. Open symbols depict estimates where cloud cover equals zero. Filled symbols depict estimates where cloud cover equals 100%. Horizontal dotted line indicates a threshold level of 95%. Vertical bars depict 95% confidence intervals.



DISCUSSION

Overall, we found that initial occupancy during the first "season" or two-week period was high (0.96), which was not surprising given that we only included chimneys known to be used for nesting in previous years. There were few changes in chimney use over the following two-week periods, including almost no colonization of sites (0.002) and some extinction (0.12), which might have been a result of nest failure. We found that detection probability of Chimney Swifts at nest chimneys was negatively influenced by increasing cloud cover. We also found weak evidence that detection probability was positively influenced by increasing date within the nesting period. Surveys conducted for 60 min under clear skies and during the late nesting period (late July) resulted in a mean detection probability of 0.95 or higher. All other scenarios resulted in lower detection probabilities (Figs. 2 and 3).

The results of our study suggest that the probability of detecting Chimney Swifts at nest sites is higher when cloud cover is low. Chimney Swifts are aerial insectivores that rely on the availability of flying insects for prey, including food to provision young, e.g., beetles, true bugs, caddisflies, stoneflies, ants, and bees (Fischer 1958, Nocera et al. 2012). Weather conditions that reduce insect abundance or availability will likely result in poorer foraging efficiency for swifts, and thus, fewer visits to nest chimneys. For example, studies of other aerial insectivores have shown negative effects of cloud cover on both aerial insect abundance and rates of food-provisioning to young (Lack and Lack 1951, Finlay 1976, Turner 1983). Cloudy conditions could lead to longer foraging bouts, possibly further away from nest sites, because of the challenges of finding or catching aerial insects, and ultimately reduce detection probability at nest sites. Chimney Swifts might also perceive darker skies as a cue for imminent inclement weather, resulting in extended incubation or brooding bouts inside the chimney (Steeves et al. 2014). We did not measure cloud type, e.g., stratus versus cumulus clouds, in our study, however, there could be an interaction of cloud type and cloud cover effects on detection probability. For example, Chimney Swifts might make fewer entries and exits at nest sites during periods of high cumulonimbus cloud cover than periods of high cirrus cloud cover, as the former typically precedes inclement weather. In addition, increasing cloud cover, particularly of darker, lower forming clouds, might negatively affect an observer's ability to accurately detect Chimney Swifts entering or exiting a chimney because of reduced visibility.

Though linear date appeared in the top-ranked model (Table 2), support for this model was low (Akaike weight = 0.11) and several other models ranked similarly high (ΔAIC < 2). As well, the 95% confidence limits around the parameter estimate for linear date included zero (Table 3). However, linear date had a reasonably large effect size compared to the other less important covariates, and we know time of season is biologically important for detection probability of adult Chimney Swifts at nest sites based on previous studies (Zammuto et al. 1981, Stewart and Stewart 2010). In particular, we found that detection probability was highest later in the nesting season, i.e., late July. The month of July coincides with the nestling-rearing period of most Chimney Swifts in the northern portion of their breeding range, e.g., New York, Ontario, and Manitoba (Fischer 1958, Stewart and Stewart 2013, Steeves et al. 2014; Bird Studies Canada, *unpublished data*). Adults should be entering and exiting chimneys more frequently to feed growing young at this time compared to earlier in the season when breeding pairs are nest building or incubating eggs, i.e., early to mid-June. Consistent with our findings, previous work in Manitoba found that Chimney Swift adults visited nests more frequently in July during nestling rearing (6–8 visits per hour between mid-July and fledging) than in June during incubation (1–2 visits per hour; Stewart and Stewart 2010, 2013). We did not find evidence of time of day effects on the detection probability of Chimney Swifts entering or exiting nest chimneys, although previous work on Chimney Swifts and other insectivorous birds during the nestling-rearing period found that adults tended to visit nests more frequently in the early morning or early evening compared to mid-day (Pinkowski 1978, Walsh 1978, Zammuto et al. 1981).

Based on our findings, we recommend that observational surveys conducted from the ground that aim to identify active Chimney Swift nest sites in southern Ontario, Canada should be conducted for at least one hour during clear sky conditions, and as late in the nesting period as possible. One-hour surveys conducted under clear skies between 25 July and 1 August will likely have the highest detection probability of 95% or more. One-hour surveys conducted earlier in the nesting period will likely have lower probability of detection, but still 86% or higher. Surveys should be at least 60 min in duration because surveying for less time under most scenarios results in much lower probability of detection. If surveys occur earlier in the nesting period during June or in less optimal weather conditions, increasing the duration of the survey might result in higher detection probability. At seven chimneys included in our study, Chimney Swifts were detected during the first and last visits, but not during a middle visit, suggesting that a longer survey might have resulted in positive detection. Alternatively, three or more 20-min visits (or perhaps other arrangements totalling 60 min of observation) might also reduce the chances of nondetection error. During surveys, the chimney opening should be continuously observed for the entire survey period to reduce the chance of false negative results because Chimney Swifts entering or exiting a nest site can be easily missed (E. Purves, *personal observation*). Our findings suggest that time of day does not influence detection probability when surveys start between 0900 and one hour before sunset. Previous work has shown that frequency of nest visits by adult Chimney Swifts varies with time of day, but no statistical testing was conducted on these data (Zammuto et al. 1981). We also recommend avoiding surveying when cloud cover is greater than 10%. It is important to note that observational surveys conducted from the ground should only be considered the most reliable method of determining nest occupancy in cases where the chimney interior cannot be inspected for direct evidence of nesting.

Other factors not included in our models that could influence detection probability of Chimney Swifts at nest sites include predators in the vicinity of nests (Ghalambor and Martin 2000, Fontaine and Martin 2006), weather conditions preceding the day of surveying that affect nutritional demands of adults and young (Rose 2009), brood size, which positively affects the number of food-provisioning trips made by adult swifts (Lack and Lack 1951, Zammuto et al. 1981), additional "helper" adults attending young (Steeves et al. 2014), number of observers conducting the occupancy survey, and nest failure. In particular, rates of nest failure in Chimney Swifts are not well understood in Ontario, but in Manitoba, 19 of 30 monitored nesting attempts between 2007 and 2013 failed (63%; Stewart and Stewart 2013). Chimney Swifts at northern latitudes are typically single-brooded (Baicich and Harrison 1997, Stewart and Stewart 2010, 2013); however, renesting following early nest failure is possible (Dexter 1969). For example, in Kansas, up to 60% of breeding Chimney Swifts renest following a heavy rainfall event (Steeves et al. 2014). Any nests that fail because of extreme weather or other reasons would not likely be detected following the recommended protocol if nest failure occurred before late July and renesting was not attempted by the breeding pair. In future studies, the dynamic occupancy design used in our study could be used to estimate nest failure by modeling extinction probability. In addition, although adult Chimney Swifts have high nest site fidelity (Fischer 1958, Dexter 1992), traditionally occupied nest sites can sometimes go unoccupied during at least one year between occupied years (Bird Studies Canada, *unpublished data*). Thus, chimneys that are unoccupied during any given season might still provide available and suitable nesting habitat for Chimney Swifts in a future year.

In conclusion, we found evidence that cloud cover and, to some extent, date influence the probability of detecting Chimney Swifts at active nest chimneys, which has important implications for survey protocol design. The results of this study provide recommendations on a survey protocol that will increase the chances of accurately identifying nest chimneys, and thus, reduce the incidence of nondetection error during chimney surveys. Limiting nondetection error during chimney surveys is an important strategy for reducing Chimney Swift nesting disturbance and habitat loss, and might be important for reversing or stabilizing Chimney Swift population declines, particularly as the number of suitable nest sites continues to decrease over time.

Responses to this article can be read online at:
http://www.ace-eco.org/issues/responses.php/1339

Acknowledgments:

We would like to first and foremost thank the dedicated Ontario SwiftWatch volunteers for their tireless efforts in monitoring and stewarding Chimney Swifts. Special thanks are owed to the Chimney Swift monitors in Barrie, Essex County, Fort Erie, London, Stratford, and Toronto, whose valuable time and effort made this project possible. We are grateful to I. Brinckmann, L. Goodridge, D. Riley, P. Tremblay, and W. Wake for helping to coordinate and recruit monitors in their communities for this project. Financial assistance for this project was provided by the Government of Ontario and the Government of Canada. We thank two anonymous reviewers for comments that improved the paper.

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