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A comparison of two methods to estimate butterfly density

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The Pollard-Yates transect is a widely used method for sampling butterflies. Data from these traditional transects are analyzed to produce density estimates, which are then used to make inferences about population status or trends. A key assumption of the Pollard-Yates transect is that detection probability is 1.0, or constant but unknown, out to a fixed distance (generally 2.5 m on either side of a transect line). However, species-specific estimates of detection probability would allow for sampling at farther distances, resulting in more detections of individuals. Our objectives were to (1) compare butterfly density estimates from Pollard-Yates line transects to those that incorporate distance sampling, (2) estimate how detection probabilities for butterflies vary across sampling distances and butterfly wing lengths, and (3) offer advice on future butterfly sampling techniques to estimate population density. We conducted Pollard-Yates transects and distance-sampling transects in central Iowa in 2014. For comparison to densities derived from Pollard-Yates transects, we used Program DISTANCE to model detection probability (p) and estimate density (D) for eight butterfly species representing a range of morphological characteristics. We found that detection probability among species varied greatly beyond 2.5 m, with variation apparent even within 5 m of the line. Such variation corresponded with wing size, where species with larger wing size generally had higher detection probabilities. Distance sampling provided more robust density estimates at these greater distances and detection probability was often considerably <1.0, particularly for smaller, cryptic species such as the least skipper. Estimated detection probabilities ranged from 0.53 to 0.79 across the eight species. We recommend that researchers integrate distance sampling into butterfly sampling and monitoring, particularly for studies utilizing survey transects >5 m wide and when smaller species are targeted.

A Comparison Of Two Methods To Estimate Butterfly Density

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Abstract
The Pollard-Yates transect is a widely used method for sampling butterflies. Data from these traditional transects are analyzed to produce density estimates, which are then used to make inferences about population status or trends. A key assumption of the Pollard-Yates transect is that detection probability is 1.0, or constant but unknown, out to a fixed distance (generally 2.5 m on either side of a transect line). However, species-specific estimates of detection probability would allow for sampling at farther distances, resulting in more detections of individuals. Our objectives were to (1) compare butterfly density estimates from Pollard-Yates line transects to those that incorporate distance sampling, (2) estimate how detection probabilities for butterflies vary across sampling distances and butterfly wing lengths, and (3) offer advice on future butterfly sampling techniques to estimate population density. We conducted Pollard-Yates transects and distance-sampling transects in central Iowa in 2014. For comparison to densities derived from Pollard-Yates transects, we used Program DISTANCE to model detection probability (p) and estimate density (D) for eight butterfly species representing a range of morphological characteristics. We found that detection probability among species varied greatly beyond 2.5 m, with variation apparent even within 5 m of the line. Such variation corresponded with wing size, where species with larger wing size generally had higher detection probabilities. Distance sampling provided more robust density estimates at these greater distances and detection probability was often considerably <1.0, particularly for smaller, cryptic species such as the least skipper. Estimated detection probabilities ranged from 0.53 to 0.79 across the eight species. We recommend that researchers integrate distance sampling into butterfly sampling and monitoring, particularly for studies utilizing survey transects >5 m wide and when smaller species are targeted.

Introduction

Ecologists have often struggled with the need to estimate the probability that an organism is detected during a survey, given that it is present. This concept is widely referred to as detection probability (Burnham & Anderson, 1984). Early studies tended to ignore it and assumed that all organisms were detected during surveys (Mackenzie et al., 2005). Later work shifted towards developing methods to directly estimate detection probability, which include distance sampling (Eberhardt, 1968; Gates, 1968; Buckland et al., 2001; Buckland et al., 2004), multiple-covariate distance sampling (Marques et al., 2007), mark-recapture (e.g., Haddad et al., 2008; Pellet et al., 2012), double observers (Nichols et al., 2000; Koneff et al., 2006), and a synergy of distance-sampling and double-observer methods (Kissling & Garton, 2006). If detection probability is estimated to be less than 1.0, that information is used to correct estimates of density and abundance to account for the fact that some fraction of the population is almost always missed during surveys (Buckland et al., 2010). Still, despite heightened awareness of imperfect detection and advances in statistical software, estimation of detection probability is widely lacking (Kellner & Swihart, 2014; Kral et al., 2018). For example, in a quantitative review of 537 papers from 1971-2011, Kellner and Swihart (2014) found that only 23% of ecological studies had accounted for imperfect detection.

The importance of addressing concerns about detection probability has clear and important implications for conservation biology. Conservation plans often address the need to know the size of the population of interest (Yoccoz et al., 2001; McGill, 2006; Farr et al., 2022), and such estimates repeated in time are useful for estimating the trend of the population (Buckland et al., 2001). The conditions for surveying a population can change over time for many reasons – differences in habitat, changes in observers, and a host of other factors. As such, trends that rely on changes in relative abundance may be biased because they assume that detection probability remains constant. Studies that directly estimate detection probability can greatly minimize this source of bias, result in more robust inferences about the population, and lead to more informed conservation actions. Many types of surveys are used to estimate the size of a population, and one of the most common is line transects (Buckland et al., 2001). For decades, researchers have been using line transects to survey and derive population estimates for a variety of taxa, including birds (e.g., Childers & Dinsmore, 2008; Newson et al. 2008), desert tortoises (Swan et al., 2002), marine mammals (Barlow et al., 2001; Calambokidis & Barlow, 2004), and marsupials (Lollback et al., 2015). Traditional fixed-width line transects include the assumption of perfect detection within a specified width. Distance sampling enables us to test this assumption by assigning a distance (or distance bin) to each individual detected.

For butterfly surveys, the standard Pollard-Yates line transect has been the most extensively used means of surveying butterflies since the early 1990s (e.g., Brown & Boyce, 2001; Collier et al., 2006; Nowicki et al., 2008). This method involves walking at a slow pace (ca. 10 m/min) along a predetermined line and counting only butterflies seen within a prescribed width, often 5.0 m (i.e., 2.5 m to either side of the observer; Pollard & Yates, 1993). An implicit assumption of these transects is that detection probability of butterflies is 1.0, or that detection probability is constant across the survey period. Violating this assumption means that estimates of density or abundance may not be comparable, and that any changes detected could result from true changes in the population or from changes in survey conditions (e.g., different observers). Data from Pollard-Yates transects are often converted to density estimates and used to make inferences about populations. But a considerable body of research with varied taxa has illustrated that the assumption of perfect detection, even within a small area, is often unmet (Mackenzie et al., 2005). Fortunately, there are additional survey methodologies that can be used to directly estimate detection probability and thus yield “corrected” density estimates. One such approach is distance sampling (Burnham & Anderson, 1984). Prior to 2000, distance sampling was rarely used for butterflies (Brown & Boyce, 1998), and imperfect detection as a concept was widely unaccounted for in the majority of invertebrate papers (Kellner & Swihart, 2014). Since then, researchers have summarized the need to address sampling bias that stems from variation in butterfly detectability (Dennis et al., 2006; Kéry & Plattner, 2007; Haddad et al., 2008; Nowicki et al., 2008), and several studies have incorporated distance sampling into the traditional Pollard-Yates framework (Powell et al., 2007; Moranz, 2010; Isaac et al., 2011; Kral-O’Brien et al., 2020). However, a literature review on butterfly sampling methodologies (Kral et al., 2018), suggested that incorporating distance sampling is still rare. Not accounting for imperfect detection can result in underestimates of true abundance (Burnham & Anderson, 1984), which may have implications for conservation or management decisions when accurate population estimates are desired.

In this study, our objectives were to (1) compare butterfly density estimates from Pollard-Yates line transects to those that incorporate distance sampling, (2) estimate how detection probabilities for butterflies vary across sampling distances and wing length, and (3) offer advice on future butterfly sampling techniques to estimate population density. Wing length was chosen as a detection covariate because it is a useful proxy for overall butterfly size.

Materials & Methods

Study Area and Site Selection

Our study was conducted at four public properties (Harrier Marsh Waterfowl Production Area, Marietta Sand Prairie State Preserve, McCoy Wildlife Management Area [WMA], and Rock Creek Marsh WMA) in central Iowa, each of which was included in the ongoing Iowa Multiple Species Inventory and Monitoring (MSIM) program (Kinkead, 2006). Sites were selected to represent a range of habitats appropriate for butterfly species that inhabit typical habitats (e.g., prairies and thickets) and ensure that our surveys would detect sufficient numbers to estimate detection probability for multiple species. Harrier Marsh (170 ha) and McCoy WMA (177 ha) are located in the Des Moines Lobe of the Prairie Pothole Region, while Marietta Sand Prairie (93 ha) and Rock Creek WMA (343 ha) lie nearby in the Southern Iowa Drift Plain (Prior 1991).

Although most of the former prairies, marshes, and savannas in these landforms have been converted to row-crop agriculture (Reeder & Clymer, 2015), our study sites collectively encompass a mixture of floodplain wetland, prairie-pothole marsh, upland meadow, restored dry-mesic prairie, and shrubby thickets.

Butterfly surveys

To eliminate observer effects, a single observer (SSP) conducted all surveys, which took place between 24 July and 24 August 2014 to coincide with prolific flight periods for many species common to this region (Schlicht et al., 2007). Each of the four sites were visited seven times during this period (n = 28 surveys) with an average of 3.67 days (SD = 2.44 days) between visits across all sites. Due to logistical constraints all sites were not visited on the same day, but we attempted to space visits evenly across the survey window for all sites. In accordance with MSIM protocol (Kinkead, 2006), based on techniques developed by Shepherd and Debinski (2005), surveys were conducted along a single 400-m long, 5-m wide line that had been placed on the centerline of an established 10.4-ha sampling hexagon at each property. For the Pollard-Yates transect, the observer walked at a steady pace (ca. 10 m/min) down the middle of the transect line and recorded number and species for butterflies detected within the 5-m wide transect corridor. Behavior (i.e., flying, nectaring, resting, basking, mineralizing, ovipositing, and courting) at initial detection of each individual was also recorded. Butterfly nomenclature and taxonomic sequence adhered to those of Opler et al. (2010).

On each site visit, the single observer (SSP) also conducted unlimited-distance line transects in the opposite direction on the same transect line. All aspects of sampling techniques (e.g., pace during survey) matched the methodology of the Pollard-Yates transects, with one difference: for each individual detected, the observer assigned it to one of nine distance bins based on its perpendicular distance from the transect line (bin 1 = 0-1 m, bin 2 = 1-1.75 m, bin 3 = 1.75-2.5 m, bin 4 = 2.5-5.0 m, bin 5 = 5.0-10 m, bin 6 = 10-25 m, bin 7 = 25-50 m, and bin 8 = >50 m) during the count. These detection-distance categories were arranged in such a way to allow for comparison to the established 5-m sampling width of the Pollard-Yates line transects (S. Shepherd, Iowa Department of Natural Resources, pers. comm.). To allow butterflies sufficient time to settle following sampling disturbance, we waited 10 min before beginning the second transect and we alternated the survey type (Pollard-Yates or distance sampling) that was conducted first on a given visit. We completed all surveys between 9:00 a.m. and 6:00 p.m. and during warm temperatures (≥ 20°C), low cloud cover (<70%), calm winds (<16 km/h), and no precipitation. All weather variables were measured immediately before and after the completion of each transect.

Eight

Data analyses

We selected a suite of eight butterfly species (least skipper [*Ancyloxypha numitor*], cabbage white [*Pieris rapae*], clouded sulphur [*Colias philodice*], orange sulphur [*Colias eurytheme*], little yellow [*Pyrisitia lisa*], eastern tailed-blue [*Cupido comyntas*], monarch [*Danaus plexippus*], and viceroy [*Limenitis archippus*]) for analyses. Species were chosen to meet the minimum sample size recommended by Thomas et al. (2010) for analysis in Program DISTANCE and to represent a range of sizes that could contribute to detection probability. Program DISTANCE fits the data to a function relating detectability to distance from the line, provides an estimate of detection probability, and estimates a "corrected" density for each species (Buckland, 2004; Thomas et al., 2010).

Density was estimated differently for the two sampling approaches. For standard Pollard-Yates transects, we calculated density (number/ha, or total number of detections divided by area sampled) by site and across sites. We were unable to calculate a measure of precision for these estimates because a) the number of surveys per site was low (7), and b) for some species there was considerable variation in peak flights even within our short survey window. For unlimited-distance transects, we used Program Distance (v6.2) to estimate detection probability (and associated sampling coefficient of variation [CV]) along with density for each species by site and across sites. We considered only the four models endorsed by Buckland et al. (2001) ([1] uniform key function with cosine adjustments, [2] half-normal key with cosine adjustments, [3] half-normal key function with Hermite polynomial adjustments, and [4] hazard rate key function with simple polynomial adjustments). These models demonstrate characteristics that meet the distance sampling assumption of monotonically decreasing probability of detection from the line. Model fit was evaluated using the chi-square goodness-of-fit test in Program Distance. We used AIC model selection (Burnham and Anderson 2002) to choose the best approximating model for each species, with truncations made at 50 m, 5 m, and 2.5 m. The latter two cut-points enabled further comparison to the densities produced via the 5-m wide Pollard-Yates transects.

Results

Eight species had a sufficient number of detections for our analyses and included least skipper (n = 350), cabbage white (n = 117), clouded sulphur (n = 158), orange sulphur (n = 291), little yellow (n = 414), eastern tailed-blue (n = 247), viceroy (n = 88), and monarch (n = 301). The two smallest species, least skipper and eastern tailed-blue, were detected in categories extending only out to the 5-10 m and 10-25 m bins respectively, whereas the other six species were recorded in all eight bins. However, in all instances, the two outermost bins accounted for a small proportion (<10%) of the detections, and the median detection distances occurred in the following bins for each species: least skipper (1-1.75 m), cabbage white (1.75-2.5 m), clouded sulphur (2.5-5.0 m), orange sulphur (2.5-5.0 m), little yellow (2.5-5.0 m), eastern tailed-blue (1-1.75 m), viceroy (2.5-5.0 m), and Monarch (2.5-5.0 m). For every species, >80% of individuals were identified as flying, basking, or nectaring at time of detection, with resting, mineralizing, courting/mating, and ovipositing butterflies composing the remainder.

What the proportion of each behavior?

Butterfly detectability varied by distance and species' morphology. Within the standard Pollard-Yates transect (i.e., < 2.5 m from the transect line), detectability among all species was >0.90, and for several species was estimated at 1.0. However, species-specific detectability began to decrease at distances >2.5 m (Table 1). At the 2.5-5.0 m bin, detection probabilities ranged from 0.53 for the least skipper to 0.79 for the much larger, more conspicuous monarch (Table 1). At this distance, the top model for all species included a hazard-rate key and simple polynomial adjustments. Additionally, a post-hoc analysis also revealed a strong positive correlation (r = 0.91) between mean wing length and detection probability, suggesting that detection probabilities were greater for larger species.

The corresponding species-specific densities varied by sampling methodology. Densities derived from distance sampling were greater than those from the Pollard-Yates transects for all species but little yellow and monarch (Fig. 1). Generally, species occurring in the highest densities were Least Skipper, Eastern Tailed-Blue, and Little Yellow according to distance sampling and Pollard-Yates. However, Pollard-Yates estimates suggest Eastern Tailed-Blue and Little Yellow occur at similar densities (Eastern Tailed-Blue: 23 no/ha, Little Yellow: 22 no/ha), while distance sampling predicted more than double the number of Eastern Tailed-Blue compared to Little Yellow (Eastern Tailed-Blue: 33 no/ha, Little Yellow: 15 no/ha) (Fig. 1).

Discussion

Our study found that detection probabilities of eight common, widespread butterfly species in Iowa were at or near 1.0 in the standard Pollard-Yates transect but dropped considerably when the sampling area extended >2.5 m from the line transect. Detection probability was positively correlated with mean wing size and was greatest for the largest, most conspicuous species. Below we discuss our findings in the larger context of methods to estimate butterfly densities, and then comment on how the inclusion of distance sampling can help with conservation and management decisions for this taxon.

Species-Specific Detection Probabilities

As expected, detectability varied considerably among the eight butterfly species, with an upward trend that generally corresponded to median wing size. This is similar to the detailed findings of Kral-O'Brien et al. (2020), who found that detection probabilities of butterflies in the Great Plains were greater for species with larger wingspans and brighter colors. The biggest exception in our study was that of little yellow, which produced the third-highest detection probability while having the third-smallest median wing length. Perhaps this detection probability stemmed from this species' tendency to flutter conspicuously just above the tops of Chamaecrista fasciculate, a widespread species that serves as the butterfly's favored hostplant in Iowa (Schlicht et al., 2007). The eastern tailed-blue and least skipper are equally short-winged. However, the eastern tailed-blue exhibits more conspicuous nectaring and breeding behavior, as males patrol and females oviposit high on flower buds of favored host plants like the long-stemmed *Lespedeza capitata* (Opler et al., 2010), which was prevalent along our study transects (Iowa DNR MSIM program, unpublished data). Conversely, the weak-flying least skipper often remains low amongst grasses (Opler et al., 2010). Two very closely related species (orange sulphur and clouded sulphur) produced nearly identical detection probabilities, consistent with their similar size, behaviors, and interrelatedness (Wheat & Watt, 2008; Opler et al., 2010; Dwyer et al., 2015). Likewise, the brightly colored, wide-ranging viceroy's detection rate was exceeded only by that of its larger, Mullerian co-mimic: the monarch (Ritland & Brower, 1991; Ritland, 1995).

Various studies have demonstrated that the Pollard-Yates line transect is susceptible to sampling bias resulting from differences in detectability (Dennis et al., 2006; Kéry & Plattner, 2007; Moranz, 2010; Isaac et al., 2011). Although we did not find the expected variation in detectability close to the line (<2.5 m), we did find considerable differences in interspecific detectability when considering detections at distances exceeding the boundaries of the standard Pollard-Yates transect (>2.5 m). Moranz (2010) and Isaac et al. (2011) provided the groundwork for utilizing distance data with Pollard-Yates transects to estimate population-density. This study adds to the existing literature by providing species-specific and methodological considerations for when sampling bias may be most prevalent. For example, when targeting smaller butterflies or species that occur in low densities, researchers may seek to extend their sampling area and incorporate detection probabilities into estimates of population density. A useful follow-up to our study might involve assessment of site-specific (e.g., vegetation) effects, as Brown and Boyce (1998) and Haddad et al. (2008) also documented differences in detectability among sites.

Conclusions

In our study, there was minimal variation in detectability at the width (5 m) employed by the traditional Pollard-Yates transect. Consequently, fixed-width transects assuming perfect detection may be adequate for estimating population densities if the target species are large and commonly found. However, if the research objective is to adequately sample the butterfly community or to target smaller, less common species, then incorporating distance sampling may be necessary. Narrow transects might not adequately sample large habitat blocks, and avoidance behavior by faster species (e.g., viceroy) might lead to poor counts. By broadening transects and incorporating distance sampling, researchers are likely to detect rarer species and provide more robust estimates of population densities, which may have important implications for conservation actions that rely on accurate population and community estimates. Given the interspecific variation in detectability in our study and other studies (Moranz, 2010; Isaac et al., 2011), and the observer variation summarized by Kéry and Plattner (2007) and Isaac et al. (2011), we recommend incorporating distance sampling whenever possible, especially when transects that are >5 m wide.

Line transects are straightforward in their implementation and can be used to repeatedly sample butterflies at multiple sites across a broad region in a short window of time. Distance sampling can be easily incorporated into the line-transect framework and analyzed using Program Distance (Buckland, 2006), which provides density estimates and associated measures of precision. As such, distance sampling, especially when used in conjunction with other methods like mark-recapture, represents an effective tool to survey butterflies and guide the management and conservation of butterfly populations.

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Figure 1

Butterfly density estimates from two survey techniques

Species-specific butterfly densities (number/ha) are compared for eight Iowa butterflies. Densities were derived from Pollard-Yates line transects and transects incorporating distance sampling (with truncation at 5 m), in Iowa in 2014. Vertical bars depict 95% confidence intervals.

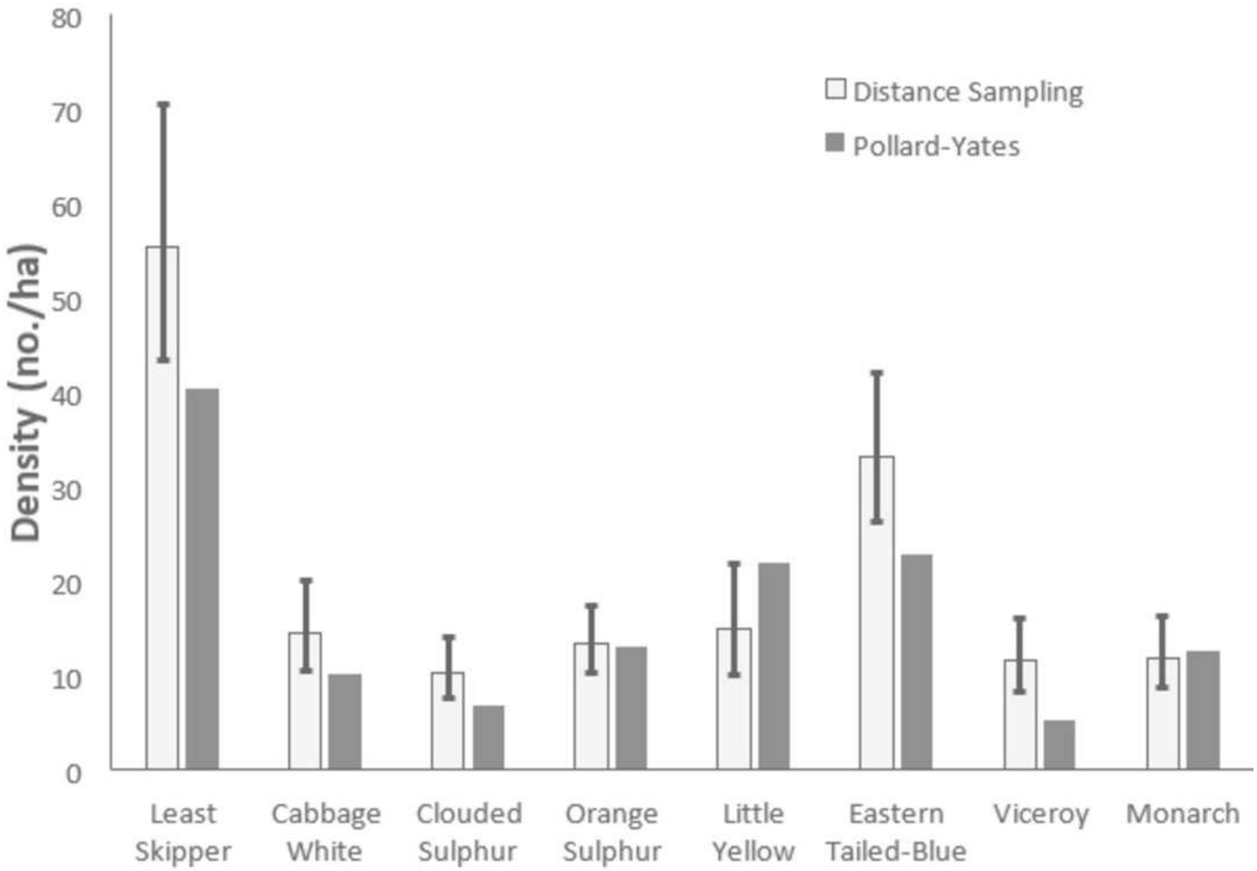
80
70
60
50
40
30
20
10
0
Density (no./ha)
Distance Sampling
Pollard-Yates
Least Skipper
Cabbage White
Clouded Sulphur
Orange Sulphur
Little Yellow
Eastern Tailed-Blue
Viceroy
Monarch

Table 1 (on next page)

Top models for eight butterfly species in Iowa, 2014

For each species, we report the median wing length, model type, Akaike Information Criterion corrected for small sample size (AICc), species-specific detection probability (p), and associated coefficient of variation (CV). Included with model type is the expansion term, with the number of expansion adjustments in parentheses. Estimates are from distance sampling analyses where data were truncated at a distance of 5.0 m. Only the best model is shown for each species and was used for all inferences (see text for details).

Table 1:

Top models for eight butterfly species in Iowa, 2014. For each species, we report the median wing length, model type, Akaike Information Criterion corrected for small sample size (AICc), species-specific detection probability (p), and associated coefficient of variation (CV). Included with model type is the expansion term, with the number of expansion adjustments in parentheses. Estimates are from distance sampling analyses where data were truncated at a distance of 5.0 m. Only the best model is shown for each species and was used for all inferences (see text for details).

†Species (median wing length)	Model, expansion (no. adjustments of orders)	AICc	p	CV (%)
Least skipper (2.55 mm)	Hazard rate key, cosine (1)	583.26	0.53	16.75
Eastern tailed-blue (2.55 mm)	Uniform key, simple polynomial (2)	393.76	0.57	11.91
Little yellow (3.80 mm)	Hazard rate key, cosine (1)	408.28	0.67	16.19
Cabbage white (5.15 mm)	Hazard rate key, cosine (4)	182.47	0.61	16.18
Orange sulphur (5.25 mm)	Hazard rate key, cosine (1)	334.96	0.66	13.45
Clouded sulphur (5.40 mm)	Hazard rate key, Hermite polynomial (4)	335.13	0.66	15.69
Viceroy (7.45 mm)	Uniform key, simple polynomial (2)	127.34	0.76	16.71
Monarch (10.5 mm)	Hazard rate key, cosine (1)	544.98	0.79	16.19

†Species are ordered by increasing median wing length (mm) (Opler et al. 2010).