

## Assessing Avian Point-count Duration and Sample Size Using Species Accumulation Functions

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**Hau-Jie Shiu and Pei-Fen Lee (2003)** Assessing avian point-count duration and sample size using species accumulation functions. *Zoological Studies* 42(2): 357-367. We used 2 species accumulation functions to fit observed data and determine appropriate point-count durations and sample sizes for bird surveys in 3 vegetation types during both breeding and non-breeding seasons. We conducted fieldwork in a grassland, a coniferous forest, and a broadleaf forest in subtropical Taiwan from October 1999 to January 2000 and from March to June 2000. In almost all cases, both the linear dependence model and the Clench model fit the observed data very well. We calculated the duration of point counts required to reach 80% of the predicted asymptote. The point-count duration required in the breeding season was 1 min for the grassland, 2 min for the coniferous forest, and 3 min for the broadleaf forest. During the non-breeding season, the required duration was 3 min for the grassland, 9 min for the coniferous forest, and 6 min for the broadleaf forest. The required samples depend on the goals of a survey, the season, and vegetation types. Our results demonstrate that bird detections vary between seasons and vegetation types. Therefore, when determining the durations and sample sizes of point-counts, investigators should consider characteristics of the detection patterns of the bird communities. We show that asymptotic models can be used to examine these patterns in an objective and rigorous way. <http://www.sinica.edu.tw/zool/zoolstud/42.2/357.pdf>

**Key words:** Bird survey, Count duration, Point count, Species accumulation function, Taiwan.

An accurate assessment of the number of birds in a community is the goal of avian census work. Many factors affect the accuracy of censuses, such as differences among observers, weather, habitats, counting effort, time of day, and season (Recher 1981, Robbins 1981, Skirvin 1981, Rollfinke and Yahner 1990). Because of these factors, bias is almost inevitable in avian censuses. Therefore, obtaining reliable estimates of the parameters of a community is a challenge. Fortunately, some of these sources of bias can be eliminated or diminished by employing standardized sampling regimes.

Point counts are widely used to record birds in terrestrial habitats (Bibby et al. 2000). With this method, observers conduct surveys at predetermined stations during a defined time period. One of the assumptions inherent in this technique is that birds do not move during the count period.

Thus, if a person remained at a survey point long enough, all species in the habitat would appear and be detected. However, longer count periods increase the chance of recording a single bird more than once, because the bird may move or the observer may forget its location (Scott and Ramsey 1981). Also spending longer times at a point increases the chance of recording new birds that move into the counting range from outside the survey area (Granholtm 1983). These effects might influence the accuracy of estimated bird density. In addition, because most birds are rapidly detected within the first few minutes (e.g., Scott and Ramsey 1981, Gates 1995, Petit et al. 1995), longer count periods become inefficient (Gutzwiller 1991, Smith et al. 1993, Lynch 1995), and increasing the amount of time spent at 1 point decreases the number of stations that can be visited per unit of field time (Buskirk and McDonald 1995). On the

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other hand, shorter count periods are more efficient in bird surveys and allow investigators to visit more stations, which increase the statistical power of the data. However, a count period which is too short will result in a smaller sample of the assemblage with many birds potentially being missed (Gates 1995). Thus, count period is obviously a critical factor when determining sampling regimes for avian communities.

Sample size (number of sampling stations and/or repeated visits) is also commonly considered a factor in determining sampling regimes (e.g., Smith et al. 1993, Thompson and Schwalbach 1995, Dettmers et al. 1999). Taking a larger number of samples increases species richness estimates and the precision of individual estimates, but at greater cost. Therefore, the minimum sample sizes required for a sampling regime must be determined. Furthermore, since species richness estimates increase with sampling effort and thereby confound comparisons, many authors (e.g., Elphick 1997, Walther and Martin 2001) have suggested that sampling effort be standardized across all sites. Because there is a tradeoff between the amount of time at each station and the number of stations capable of being visited (Buskirk and McDonald 1995, Ralph et al. 1995), the design of a point count scheme should concurrently consider both the count period and the required sample size.

When designing a sampling scheme for avifauna surveys, ornithologists have often disregarded the detection patterns of particular species, and instead have concentrated on those of certain assemblage parameters, such as species richness

and number of individuals (e.g., Scott and Ramsey 1981, Smith et al. 1998), because the frequencies of bird detections vary among species (Buskirk and McDonald 1995). Two strategies have been commonly used to determine count periods for assessments of assemblage parameters. The first is arbitrarily separating count durations into 2 or more categories (e.g., 0-5 and 5-10 min) and then deciding the count period by comparing the detection efficiencies of these categories (e.g., Lynch 1995). The second is plotting the cumulative number of species against sampling effort and then visually determining the minimum effort required using species accumulation curves (e.g., Scott and Ramsey 1981). These methods, however, are somewhat arbitrary and may create a bias when the curve does not reach an asymptote because of insufficient samples.

Using species accumulation functions to plan field campaigns may avoid the problem caused by a lack of sampling effort. Species accumulation functions were proposed to describe the behavior of the cumulative species-effort relationship (Soberon and Llorente 1993, Gotelli and Colwell 2001). Based on sampling performance, these accumulation models can be used for either interpolating species richness of smaller samples or extrapolating richness beyond the sampling effort. Asymptotic models, in which the probability of adding a new species to the inventory eventually approaches zero, can be used to extrapolate an estimate of richness to an asymptote and hence are useful for determining the sampling effort required to observe a set proportion of species at the same point along the asymptotic model

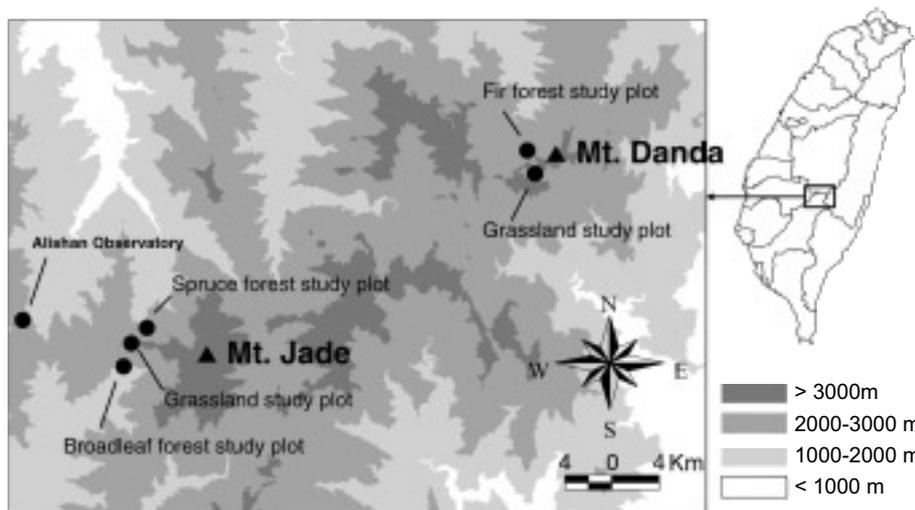


Fig. 1. Map of the study plots at Mt. Jade and Mt. Danda, in central Taiwan.

(Soberón and Llorente 1993, Moreno and Halffter 2000).

At a regional level, biological and physical factors affect the activity of birds and observers' ability to detect individuals (Recher 1981). Census methods have been developed largely in the temperate north. In subtropical Taiwan, however, there is no study related to bird survey methods. Previous research either conducted a short pre-test to determine the survey parameters (e.g., Ding 1993), or followed a rule of thumb (e.g., Shiu 1995). In this paper, we propose to explore the methodology of avian census in terrestrial habitats of Taiwan, and determine appropriate point-count durations and sample sizes for the surveys. We did this by fitting 2 asymptotic models to species accumulation curves. We compared the parameters of these fitted models and calculated the count duration and sample size required to reach 80% and 90% of the asymptotes, and studied the influences of habitat type and season.

### Study areas

We conducted fieldwork in central Taiwan, an island located some 90 km off the southeastern Chinese coast in the subtropical climate zone between 22°N and 25°N latitude and 120°E and 122°E longitude. The study areas were located at Mt. Jade (*Yushan* or Mt. Morrison) and Mt. Danda, approximately 20 km apart (Table 1; Fig. 1). At an

elevation of 2400 m near Mt. Jade, average temperatures in Jan. and July are 5.7 and 14.2°C, respectively. Annual precipitation is more than 3900 mm, and the relative humidity averages 80%-93% (data from the Alishan Observatory, <http://www.cwb.gov.tw/V3.0e/index-e.htm>).

We conducted bird surveys on 5 vegetation plots including 1 in a broadleaf forest, two in coniferous forests, and 2 in grasslands (Table 1). Study plots were less than 25 ha, and the vegetation community of plots can be considered to be homogeneous units.

The broadleaf forest study plot was located on a south-facing slope of Mt. Jade at elevations ranging from 1800 to 1900 m. We conducted bird surveys on this plot during both the non-breeding and breeding seasons. The forest was evergreen with 4 vertical strata (canopy, midstory, shrub, and herb) with a canopy height of 20-25 m. Dominant vegetation included *Castanopsis* spp., *Cyclobalanopsis* spp., *Pasania* spp., *Beilschmiedia erythrophloia*, *Litsea* spp., *Machilus* spp., *Neolitsea* spp., *Turpinia formosana*, and *Schima superba*. This forest is dense and diverse and is typical of climax vegetation at this elevation in central Taiwan (Su 1984).

One of the coniferous forest study plots was in a spruce forest located on a north-facing slope of Mt. Jade at elevations ranging from 2600 to 2650 m. This plot was dominated by *Picea morrissonicola*, with trees ranging 30-35 m tall. The

**Table 1.** Landscape characteristics and bird species richness of the 3 focal vegetation types in central Taiwan during breeding and non-breeding seasons

Vegetation plot	Location	Elevation (m)	Canopy height (m)	Number of vertical strata	Bird species richness		Dominant plants	Dominant bird species
					Breeding season	Non-breeding season		
Grassland	Mt. Danda	2900-2950	0.5-2	1	9	-	<i>Miscanthus transmorrisonensis</i> <i>Yushania niitakayamensis</i>	Streak-throated Fulvetta ( <i>Alcippe cinereiceps</i> )
Grassland	Mt. Jade	2500-2600	0.5-2	1	-	11	<i>Miscanthus transmorrisonensis</i> <i>Yushania niitakayamensis</i>	Streak-throated Fulvetta ( <i>Alcippe cinereiceps</i> )
Coniferous forest	Mt. Danda	2900-2950	20-25	3	19	-	<i>Abies kawakamii</i> <i>Yushania niitakayamensis</i>	Flamecrest ( <i>Regulus goodfellowi</i> ) Streak-throated Fulvetta ( <i>Alcippe cinereiceps</i> ) Formosan Yuhina ( <i>Yuhina brunneiceps</i> )
Coniferous forest	Mt. Jade	2600-2650	30-35	3	-	21	<i>Picea morrissonicola</i> <i>Yushania niitakayamensis</i>	Flamecrest ( <i>Regulus goodfellowi</i> ) Streak-throated Fulvetta ( <i>Alcippe cinereiceps</i> ) Grey-cheeked Fulvetta ( <i>Alcippe morrisonia</i> )
Broadleaf forest	Mt. Jade	1800-1900	20-25	4	29	28	Fagaceae Lauraceae	Grey-cheeked Fulvetta ( <i>Alcippe morrisonia</i> ) Formosan Yuhina ( <i>Yuhina brunneiceps</i> )

shrub layer mainly consisted of *Schefflera taiwaniana*, *Litsea morrisonensis*, *Neolitsea acuminatissima*, and *Pittosporum illicioides*. The herb layer was dominated by *Yushania niitakayamensis*. We conducted bird surveys on this plot during the non-breeding season, from Oct. 1999 to Jan. 2000. In early spring 2000, there was a disturbance from nearby silviculture practices; we therefore conducted surveys on Mt. Danda during the breeding season.

The 2nd study plot in the coniferous forest study plots was a fir forest and was located on Mt. Danda at elevations ranging from 2900 to 2950 m. We only conducted bird surveys on this plot during the breeding season. The fir forest study plot was composed of *Abies kawakamii*, with trees 20-25 m tall. The vertical structure at this site could be distinguished into canopy, shrub, and herb layers. The shrub and herb layers were dominated by *Yushania niitakayamensis*. This community is typical of climax vegetation at elevations ranging from 2900 to 3600 m in Taiwan (Su 1984). The vegetation physiognomy of this plot was similar to that of the spruce forest (Table 1).

One of the grassland study plots was located on a south-facing slope of Mt. Jade at an elevation of 2500-2600 m. We conducted non-breeding season surveys on this plot, from Oct. 1999 to Jan. 2000. Since there was disturbance due to silviculture practices on this plot in spring 2000, we conducted breeding surveys on the 2nd study plot in the grassland study plots located on Mt. Danda at elevations of 2900-2950 m. The dominant vegetation of both plots was *Miscanthus transmorrisonensis* and *Yushania niitakayamensis*, which reached 0.5-2 m in height. The vegetation physiognomy of both grassland plots was similar (Table 1).

## METHODS

### Bird surveys

We established 2 sampling stations in each study plot and conducted bird surveys for estimating bird density and species richness. The sampling stations were spaced approximately 200 m apart and were at least 100 m from any habitat edge. We conducted bird surveys using the point count method with an unlimited radius (Buckland et al. 1993). Surveys were completed 3 times per month on each plot during the non-breeding season (from Oct. 1999 to Jan. 2000) and in the breeding season (from Mar. to June 2000). Bird

counts were conducted within 3 h of sunrise and were carried out only on clear days. We recorded all birds heard or seen during 20 min in total, with 30 s count periods. In total, 24 bird counts were conducted in each vegetation type in each season.

### Data analyses

*Count duration.* In our survey method, we could not avoid the possibility of counting individuals more than once because most birds were detected by listening, and consequently were difficult to identify individually. For this reason, we analyzed species as they were identified, but ignored the number of individuals. We combined the survey data according to vegetation types and seasons. Because the number of species recorded during each 20 min survey sometimes differed among samples, we used the number of species observed at each survey as 100% and converted the cumulative species for each 30 s interval of that survey to a percent of bird accumulation before combination.

To analyze the characteristics of the detection patterns, we first calculated the survey efficiency as:

$$E_t = P_t - P_{t-1};$$

where  $E_t$  is the percent of species detected from time  $t-1$  to  $t$ ,  $P_t$  is the percent of cumulative species detected up to time  $t$ ,  $P_{t-1}$  is the percent of cumulative species detected up to time  $t-1$ , and  $t$  is the number of 30 s counts.

We then analyzed patterns of species accumulation against count duration for vegetation types and seasons. Two species accumulation functions, which are asymptotic models, were used to fit the species accumulations: the linear dependence model and the Clench model (Soberón and Llorente 1993). The linear dependence model is based on the assumption that the accumulation function declines linearly as an increasing number of species is observed. This leads to an exponential function:

$$S(t) = \frac{a}{b} [1 - \exp(-bt)];$$

where  $t$  is a measure of sampling effort,  $S(t)$  is the predicted number of species at  $t$ ,  $a$  represents the increased rate of species observation at the beginning of the sampling,  $b$  is a parameter related to the shape of the accumulation of new species during the sampling, and  $a/b$  represents the predicted

asymptote. Soberón and Llorente (1993) recommended this model for samples from plots of relatively small areas or samples of well-known taxa and suggested that in these situations, eventually all species will be recorded over a finite period. Lamas et al. (1991) investigated the effort  $t_q$  required to register a proportion of the asymptote  $q = S/R$ , where  $R = a/b$ . From the preceding equation, the required effort  $t_q$  is

$$t_q = -\frac{1}{b} \ln(1 - q).$$

The Clench model is derived from the Michaelis-Menten equation (Soberón and Llorente 1993). It assumes that the probability of adding species to the list decreases with the number of species already recorded, but increases over time (Moreno and Halffter 2000). Thus,

$$S(t) = \frac{at}{(1 + bt)}.$$

This model was recommended for larger areas or for taxa for which the probability of adding a new species will improve as more time is spent in the field, until a ceiling is reached (Soberón and Llorente 1993). For this model, the required effort  $t_q$  is:

$$t_q = \frac{q}{[b(1 - q)]}.$$

We fit both models to our field data using a non-linear regression with the Gauss-Newton method in SYSTAT 9 (SPSS 1999).

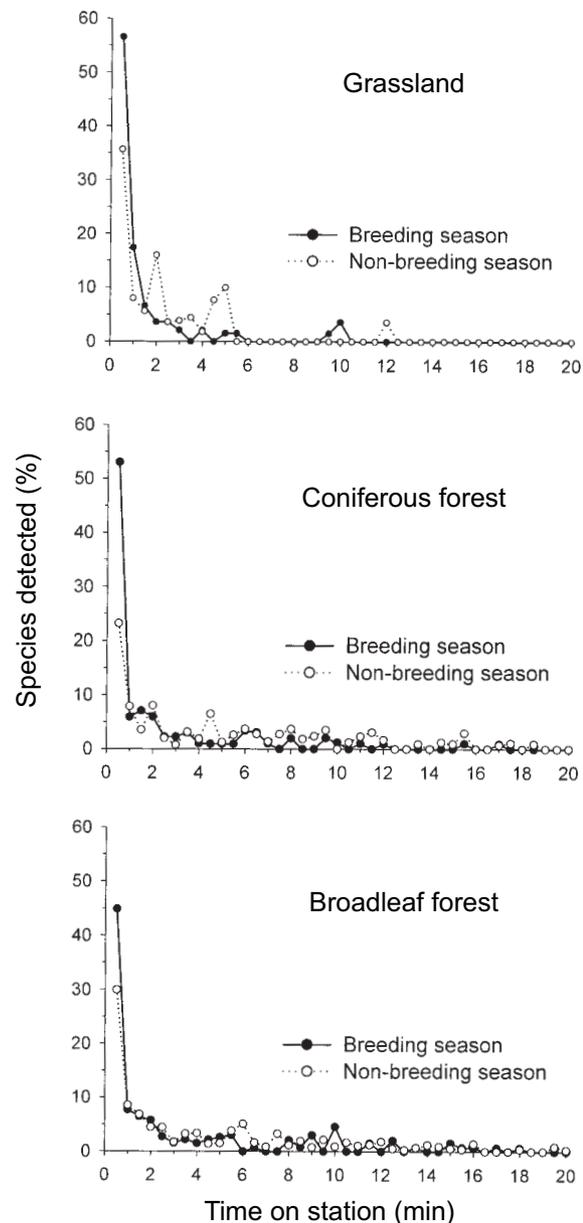
The parameters  $a$  and  $b$  of the functions represent the rate of bird detection and can be used to compare detection patterns among communities (Soberón and Llorente 1993). High detection rates, which rapidly increase the percent of detected species in the first few minutes of a sampling period, should lead to high values of the parameters.

*Sample size.* We calculated bird density for each bird survey using the data recorded during first 6 min of the 20 min count. Bird densities ( $D$ , individuals/ha) for each species in each bird survey were calculated by the following formula (Reynolds et al. 1980):

$$D = \frac{n}{\pi r^2} 10\,000;$$

where  $n$  is the total number of birds observed within the specific basal radius  $r$  (m). The specific basal radius for each species was obtained from Ding (1993) and Shiu (1995).

We generated mean bird density, mean standard deviation of bird density, and number of cumulative species for each sample size (i.e., 1-24) in each plot by 1000 random iterations, from the 24 bird counts using EstimateS software (Colwell 1997). This produces smoothed species accumulation curves, and simultaneously eliminates the effect of the order in which samples were added to the analysis, by averaging over randomizations. We used the number of total species in



**Fig. 2.** Percent of bird species detected per 30 s interval for the 3 focal vegetation types. Survey efficiency in the first 30 s in the breeding season was higher than that in the non-breeding season.

each plot as 100% and converted the number of cumulative species at each sample size to a percent of bird accumulation. We then fit the asymptotic models to these smoothed curves.

## RESULTS

In total, we detected 46 species in all plots in both the non-breeding and breeding seasons. Bird species richness in the broadleaf forest was the highest, followed by the coniferous forest and the grassland habitat for both seasons (Table 1). Because surveys in the grassland and coniferous habitats were conducted at different plots between the seasons, we used bird data from the same plots at Mt. Jade during spring 1999 (HJ Shiu unpubl. data) and data from Mt. Danda in this study to examine the community similarity for both vegetation types. Horn's similarity coefficient between the grassland bird communities was 0.98, and species-abundance curves for both communities were close to the geometric model. Horn's coefficient between the coniferous bird communities was 0.82, and the curves were both close to the log-normal model. The results suggest that the bird communities were similar in the breeding season between plots in the grassland and coniferous habitats.

*Count duration.* The survey efficiency peaked at the beginning of the sampling and significantly decreased for all vegetation types and seasons (Fig. 2). The percent of species detected per 30 s interval generally dropped to fewer than 5% after 2 min. Survey efficiency in the first 30 s in the breeding season was higher than that in the non-breeding season, especially in the coniferous forest (Fig. 2).

Except for 2 cases, both species accumulation models fit the field data well ( $r^2 \geq 0.95$ , Table 2; Fig. 3). The linear dependence model does not fit the observed data well for the broadleaf and coniferous forests in the breeding season ( $r^2 = 0.88$  and  $0.89$ , respectively). The linear dependence model predicted a lower asymptote than the Clench model. Furthermore, except for the coniferous forest in the non-breeding season, the asymptote predicted by the linear dependence model was lower than values derived from the observed data (i.e., the  $a/b$  values were lower than 100; Table 2). On the other hand, the Clench model predicted a higher asymptote than the observed data (Table 2).

Since the calculated parameters ( $a$ ,  $b$ ) for all vegetation types in the breeding season were higher than those in the non-breeding season for both models (Table 2), the detection rates in the breeding season were higher than those in the non-breeding season. In addition, bird surveys in the grassland had higher detection rates than for the other vegetation types during both seasons. Detection rates in the broadleaf forest were lower than those in the coniferous forest during the breeding season, despite the higher species richness in the broadleaf forest. In the non-breeding season, however, detection rates in the broadleaf forest were higher than those of the coniferous forest.

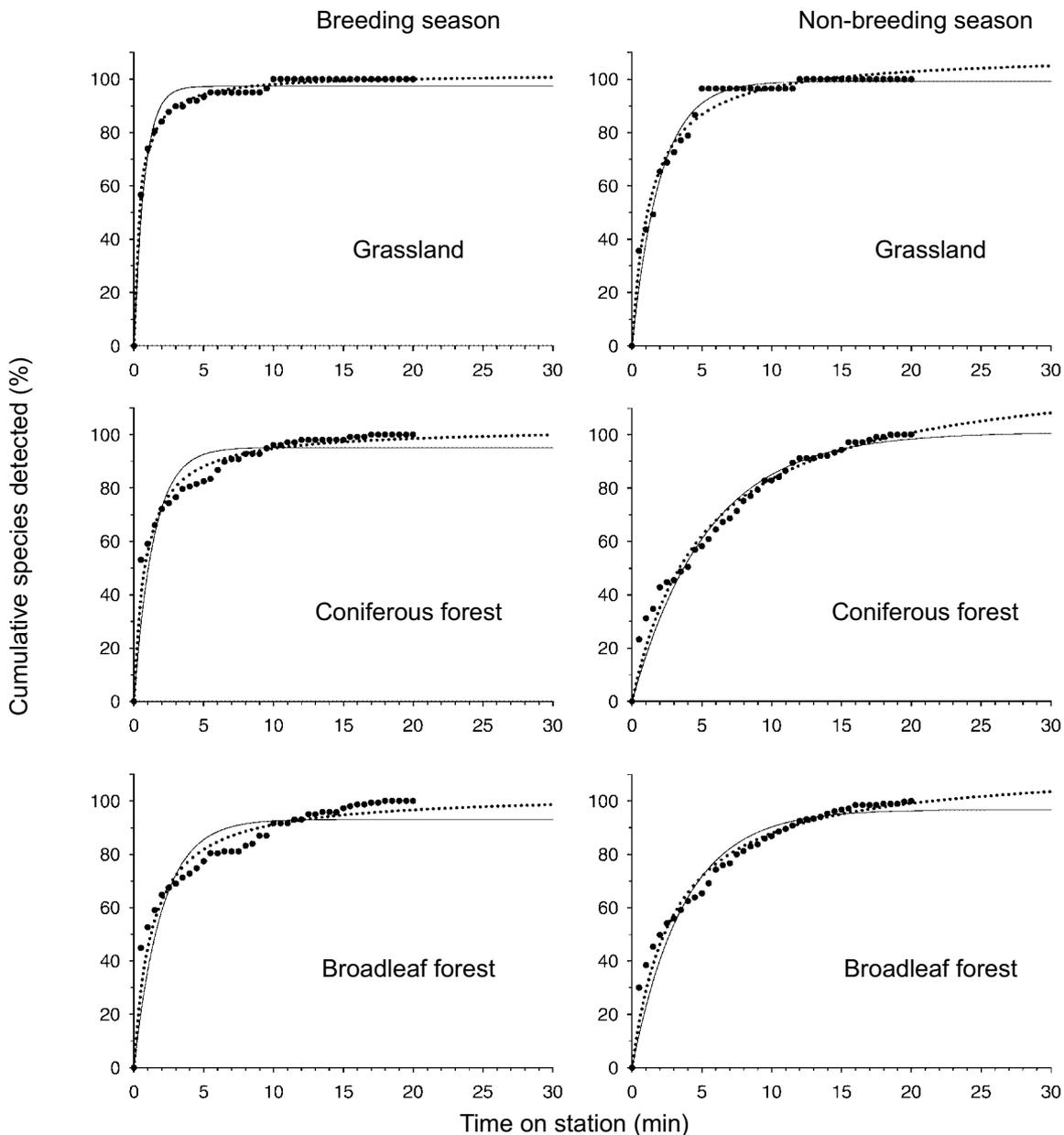
The required count durations increased, especially in the coniferous forest during the non-breeding season, when an acceptable proportion of the asymptotes changed from 80% to 90% (Table 2). For example, based on the Clench model, 5 min counts were required to reach 80% and 12 min counts to reach 90% of the asymptote in the broadleaf forest in the breeding season.

**Table 2.** Parameters and predicted count durations of 2 species accumulation function models fitted to the 3 focal vegetation types during the breeding and non-breeding seasons

Vegetation plot	Linear dependence model					Clench model						
	$a$	$b$	$a/b$	$r^2$	Effort required to reach 80% of the predicted asymptote (min)	Effort required to reach 90% of the predicted asymptote (min)	$a$	$b$	$a/b$	$r^2$	Effort required to reach 80% of the predicted asymptote (min)	Effort required to reach 90% of the predicted asymptote (min)
Breeding season												
Grassland	130.0	1.34	97.4	0.96	1.2	1.7	247.4	2.42	102.1	1.00	1.7	3.7
Coniferous forest	68.6	0.72	95.3	0.89	2.2	3.2	124.6	1.21	102.7	0.97	3.3	7.4
Broadleaf forest	46.6	0.50	93.2	0.88	3.2	4.6	80.0	0.78	102.9	0.95	5.1	11.6
Non-breeding season												
Grassland	49.3	0.50	99.2	0.98	3.2	4.6	83.1	0.76	109.6	0.97	5.3	11.9
Coniferous forest	18.7	0.19	100.9	0.98	8.7	12.4	24.3	0.19	127.1	0.98	20.9	47.1
Broadleaf forest	26.1	0.27	96.8	0.96	6.0	8.5	38.9	0.34	113.6	0.98	11.7	26.3

*Sample size.* Both species accumulation models fit the observed data very well for all vegetation plots in both seasons ( $r^2 \geq 0.96$ ; Table 3). Similar to the results of analyzing point-count durations, the calculated parameters for all vegetation types in the breeding season were higher than those in the non-breeding season for both models. In addition, in the breeding season, parameters of the grassland were the highest, followed by those of the coniferous forest and the broadleaf forest.

Although the mean estimated bird densities were similar between the breeding and non-breeding seasons in all vegetation types, the variation of estimates, as represented by the standard deviation and coefficient of variation (CV), was larger in the non-breeding season (Fig. 4). This suggests that bird surveys in the breeding season would obtain more-precise estimates than in the non-breeding season, if all standard procedures were followed.



**Fig. 3.** Observed and fitted species accumulation curves for the 3 focal vegetation types during the breeding and non-breeding seasons. Black circles represent observed data, solid lines represent predictions of the linear dependence model, and dotted lines show the predictions of the Clench model.

The required sample also substantially increased when an acceptable proportion of the asymptotes changed from 80% to 90% (Table 3), especially for that predicted by the Clench model.

## DISCUSSION

### Standardization of count duration

In practice, the point count method has been conducted with count durations ranging from 2 to 20 min (Bibby et al. 2000). However, most investigators (e.g., Gates 1995, Lynch 1995, Smith et al. 1998) have found that observers quickly record the majority of species within the first few minutes. In general, the detection efficiency, as measured by the frequency of recording new birds per unit of time, reaches a peak at 3-5 min (Buskirk and McDonald 1995, Lynch 1995).

Buskirk and McDonald (1995) studied the tradeoffs between count period and travel time between survey points and found that for any given travel time, an increase in count period decreases the number of counts per hour, but increases the total time spent counting. Many authors have suggested that the design of a point count scheme should not only consider accuracy of bird estimation, but also the tradeoffs of extensive sampling across a number of points or visits with statistical power (e.g., Buskirk and McDonald 1995, Lynch 1995). Ralph et al. (1995) argued that the amount of time spent counting birds at each sampling station is a compromise between acquiring an accurate picture of the birds present at a single station and increasing the statistical power of the effort by sampling a higher number of

stations and birds. Considering the tradeoffs between count duration and travel time, they proposed that the time spent at each wooded or brushy station should be 5 min for counts that have travel times between stations of less than 15 min, and 10 min if travel times are greater than 15 min. Some specific count durations have been commonly used in bird surveys, such as the 3 min count period in the Breeding Bird Survey (Bibby et al. 2000). Many authors have argued that count duration should be designed in accordance with these schemes, or that the recorded data should be separated into those periods and the remaining minutes, because this would promote comparisons with already existing data sets (Buskirk and McDonald 1995, Ralph et al. 1995).

We found that both vegetation and season strongly influenced bird detection parameters. In our study, the required duration of point counts, set at 80% of the predicted richness, differed greatly among seasons and vegetation types. This suggests that a suitable count duration for 1 survey in a particular habitat in a specific season might be insufficient or too long to be effective for surveys conducted in another habitat or season. Hence, count durations designed in accordance with travel times or by applying schemes commonly used will most likely not be efficient for quantifying birds in all locales. Therefore, we suggest that when planning count durations, investigators must consider temporal variance and habitat type.

### Bird detection patterns

Bird detection probabilities are known to be elevated during the breeding season due to frequent singing (Bibby et al. 2000). This might

**Table 3.** Parameters and predicted sample sizes of 2 species accumulation function models fitted to the 3 focal vegetation types during the breeding and non-breeding seasons

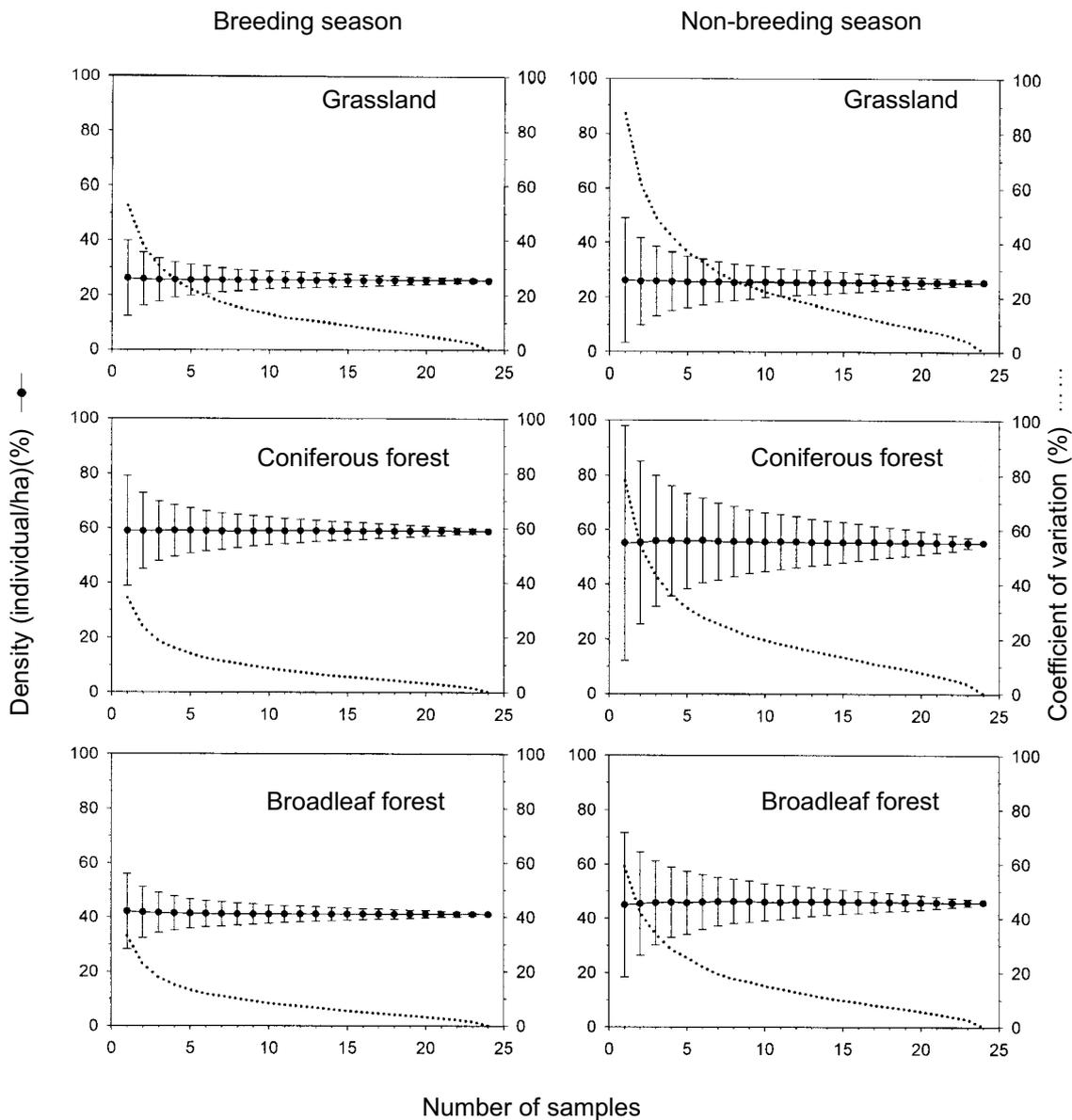
Vegetation plot	Linear dependence model					Clench model				
	<i>a</i>	<i>b</i>	<i>r</i> <sup>2</sup>	Effort required to reach 80% of the predicted asymptote (times)	Effort required to reach 90% of the predicted asymptote (times)	<i>a</i>	<i>b</i>	<i>r</i> <sup>2</sup>	Effort required to reach 80% of the predicted asymptote (times)	Effort required to reach 90% of the predicted asymptote (times)
Breeding season										
Grassland	95.5	0.97	0.99	1.7	2.4	197.2	1.91	1.00	2.1	4.7
Coniferous forest	31.7	0.33	0.96	4.8	6.9	52.1	0.49	1.00	8.1	18.3
Broadleaf forest	17.7	0.19	0.97	8.6	12.2	26.6	0.24	0.99	16.5	37.2
Non-breeding season										
Grassland	14.5	0.15	0.99	10.9	15.6	21.4	0.19	1.00	21.3	47.9
Coniferous forest	11.3	0.12	0.97	13.2	18.9	15.9	0.14	0.99	28.2	63.4
Broadleaf forest	11.3	0.12	0.96	13.2	18.9	16.5	0.15	0.99	26.7	60.0

increase survey efficiencies in the breeding season.

Overall, bird surveys on the grassland had a higher species detection rate than for plots in both types of forest. This is because the physical structure of the grassland habitat was the simplest compared to the other habitat types. Although the structures of the broadleaf and coniferous forests were similar, the bird detection rate in the coniferous forest, which had a lower species richness, was higher than that in the broadleaf forest. Hence, our results suggest that in complex habi-

tats at least, bird detection rates are negatively related to species richness during the breeding season. During the breeding season, spatial distributions of birds are less variable because most birds are nesting and breeding. This produces a community with a relatively stable structure. Therefore, bird survey efficiency may depend on the richness of the community, and surveys conducted on a species-rich community would be expected to require more time to reach the asymptote.

In contrast, in the non-breeding season, the



**Fig. 4.** Total estimated bird density and coefficient of variation for different sample sizes for the 3 focal vegetation types during the breeding and non-breeding seasons. Means and standard deviations shown were generated by 1000 random iterations.

relationship between the detection rate and bird richness in forest study plots was the opposite. In the fall and winter in Taiwan, many birds flock together and rove in search of food (Sun and Wang 1998). This creates avian communities with unstable and variable compositions. The efficiency of a single survey at a point largely depends on chance. Surveys might be more efficient when encountering a large mixed-species flock. However, they might also be very low if the flock is moving outside the study area during sampling periods. The degree of flocking and movement should be relative to bird foraging behaviors and the food resources of a study plot (Greig-Smith 1978, Sun and Wang 1998). Most flocking species are insectivorous, and few are frugivorous, nectarivorous, and granivorous. In our study, avian communities consisted mainly of insectivores in the coniferous forest, and while the insectivores and frugivores were abundant in the broadleaf forest during the non-breeding season. The broadleaf forest supplied more-abundant food resources than did the coniferous forest. Also, the spatial distribution of fruit was fixed and predictable in the broadleaf forest. Therefore, bird community structures in the broadleaf forest were more stable than those in the coniferous forest (HJ Shiu unpubl. data). The movement patterns in birds created the bird detection patterns observed in our study in these vegetation types.

### Required efforts

The count duration required to reach 90% of the predicted asymptote was substantially higher than to reach 80%. Based on our results, we suggest that the acceptable proportion of predicted asymptotes in determining bird point-count durations in Taiwan should be set at 80%. In addition, the required effort predicted by the linear dependence model was lower than that predicted by the Clench model. Moreno and Halffter (2000) suggested that predictions of the linear dependence model could be regarded as the lower limit. Therefore, to obtain the minimum acceptable level of completeness, the required count durations perhaps should follow the linear dependence model.

The required count durations, as we suggested above, are relatively shorter than those used in general practice (e.g., Ding 1993, Ralph et al. 1995, Bibby et al. 2000), and are therefore more efficient in surveys for community studies. However, adopting a shorter period for a count has certain disadvantages. For example, birds that

react to the presence of the observer by becoming silent and immobile may not resume normal behavior during the count period. Also, there will be a greater chance of missing hidden and rare species that vocalize infrequently. In addition, the observer may not have enough time to make careful identifications and to record distances accurately.

The required samples are determined by the objectives, and the temporal and spatial scales of the study. For example, if a survey is focusing on biodiversity inventories, the required samples should be determined to detect a higher proportion of the asymptote. If population trends are of interest, the precision of the estimated densities should be the principal factor considered. Temporal and spatial scales influence the represented pattern of communities (Wiens 1989). While a larger scale of a given habitat would produce a greater variance, investigators can conduct additional bird counts to reduce the variation.

### Species accumulation functions

The main advantage of using accumulation functions when planning field surveys is to increase the objectivity of estimates of the effort required for effective sampling (Soberón and Llorente 1993, Moreno and Halffter 2000). They also increase the rigor of data comparisons. Complete enumeration of all species or individuals at a given point is usually not essential for investigating community patterns or monitoring population trends. The aim of designing count durations and required samples is mainly to observe a set proportion of the asymptote, and for this, species accumulation functions provide an objective method. We argue that the planning of point-count durations and required sample sizes should depend on characteristics of the detection patterns of particular bird communities, and asymptotic models can be applied to do this in a rigorous way.

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