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Effective Point-Count Duration for Estimating Bird Species' Richness in Chilean Forests

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Pablo M. Vergara, Jaime E. Jiménez, and Roberto P. Schlatter (2010) Effective point-count duration for estimating bird species' richness in Chilean forests. *Zoological Studies* **49**(3): 381-391. When point counts are used to assess species richness or diversity, optimizing the allocation of sampling effort requires that the effective point-count duration be determined that optimizes the species detection rate at each point. In this study, we used species accumulation functions to estimate the effective point-count duration in 6 different Chilean forests. An effective point-count duration was dependent upon forest habitat, the type of accumulation function, and travel time. The effective count durations predicted by 2 different species accumulation functions, the linear dependence and Clench models, increased with increasing travel time. For short travel times (≤ 10 min), effective count durations were ≤ 5 min and slightly shorter than count durations required to reach 80% of the function asymptote. For long travel times (20-30 min), effective count durations were about 7 min, but shorter than count durations required to reach 90% of the function asymptote. These results show that for travel times of 5 min, the use of effective count durations can result in 50% more points. Effective count durations are suggested when a survey is focused on assessing species richness and the presence of common or conspicuous species. http://zoolstud.sinica.edu.tw/Journals/49.3/381.pdf

Key words: Bird richness, Chilean forests, Effective count duration, Point count.

Point counts are an efficient and inexpensive survey method for estimating the presence and richness of bird species at the scale of individual points (Reynolds et al. 1980, Gutzwiller 1991, Bibby et al. 2000). However, like other sampling methods, point-count estimates can be biased due to factors that affect species detectability such as weather, time of day, season, distance from the observer, habitat structure, and count duration (Robbins 1981, Rollfinke and Yahner 1990, Selmi and Boulinier 2003). Therefore, by minimizing the effects of these factors, it is possible to improve the accuracy of point-count estimates.

Effective point-count monitoring programs require that the trade-off between the count duration and number of stations that can be visited in a given period of time be optimized (Verner 1988, Barker et al. 1993, Buskirk and McDonald 1995, Shiu and Lee 2003). Such a trade-off results from 1) counts of longer duration increase the probability of detecting bird species and consequently the accuracy of species presence and richness estimates (Fuller and Langslow 1984, Verner 1988, Lynch 1995, Petit et al. 1995, Drapeau et al. 1999); and 2) fewer points being sampled reduces the precision of species richness estimates (Barker and Sauer 1993, Buskirk and McDonald 1995).

Optimizing species richness at the point-count scale, rather than at the habitat scale, allows for replicate sampling, and hence measurement errors

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can be directly calculated from field samples (e.g., Drapeau et al. 1999). A methodological approach to optimize the allocation of sampling effort is to determine an appropriate or "effective" point-count duration, i.e., the interval beyond which the species detection rate is not high enough to offset the cost in terms of the time remaining at a point (Gutzwiller 1991, Lynch 1995). Such an analysis can be based on species accumulation curves, for which the cumulative number of species is plotted against on-station sampling time (e.g., Shiu and Lee 2003, Milne et al. 2004, Pierce and Gutzwiller 2004, Gillings et al. 2008). Determining the effective point-count duration using accumulation curves, however, requires that the curves reach an asymptote that depends on the particular optimization criterion used.

Count duration is often determined as the time at a point required for the asymptote using species accumulation curves to reach an arbitrary percentage of the total species present (e.g., Shiu and Lee 2003). Such an approach, however, does not ensure a sample size large enough to detect the total number of species in a habitat or to compare species richness between habitats. This sampling problem becomes important when the amount of time required to move between points (i.e., travel time) is long whereas the total sampling time is short (Barker et al. 1993, Buskirk and McDonald 1995). A method for determining an effective count duration is to minimize the mean square error (associated with the count duration) while maximizing the test power (associated with the sample size) (Barker et al. 1993, Barker and Sauer 1995). The latter analysis, however, is more appropriate for estimating bird density rather than species richness, since that approach is not based on species accumulation curves that account for temporal changes in species detection rates.

In a previous study, Jiménez (2000) observed that the cumulative number of species in an evergreen Chilean forest did not level off during the 1st 10 min of counting on a station, the time interval for which his data were taken. Furthermore, considering those results, Jiménez (2000) suggested that the cumulative detection efficiency for all species was 75% for 5 min surveys. However, he did not take into account the time to move between points when suggesting the time to count at a point. In this study, we used species accumulation functions to estimate the effective point-count duration for estimating species richness of bird communities in 6 different Chilean forests.

Herein, our main aim was to standardize the point-count methodology for monitoring the presence/absence and diversity of breeding bird species in Chilean forests using data taken over longer periods of time (20 min). We assessed the point-count duration through 2 different approaches. First, we fitted point-count data to species accumulation functions and determined point-count durations based on the time required to reach an arbitrary percentage of the function asymptotes. Second, we estimated the effective point-count durations using a criterion based on the marginal value theorem (Charnov 1976), according to which an observer should sample at a point until the species detection rate decreases to a marginal value. According to this proposed approach, observers should remain at each point a longer time when both travel time between points and the number of species at the points are high (e.g., see Charnov 1976, McNair 1982).

MATERIALS AND METHODS

Study habitats

We sampled bird species at 6 forest sites, including forests located in central Chile (Maulino deciduous forest and northern pine plantation), southern Chile (*Nothofagus* 2nd growth forest and southern pine plantation), and the Magellanic region (Magellanic deciduous forest and Magellanic mixed forest) (Fig. 1, Table 1). Although these forests have different climate conditions and present different vegetation compositions, they share most species of birds, with species richness gradually decreasing from northern to southern forests (Vergara and Schlatter unpubl. data, Table 2). They also represent the diversity of forests and the different scenarios found throughout the country.

Central Chilean forests are located along the coastal range of central Chile and have a discrete rainy season (< 1200 mm/yr). Maulino deciduous forests are 2nd growth forests dominated by Roble (*Nothofagus obliqua*) and Roble hualo (*N. glauca*) with a dense understory composed of *Chusquea quila* and *Aristotelia chilensis* thickets. Northern plantations of Monterrey pine (*Pinus radiata*) were > 11 yr old, with an understory vegetation dominated by *Teline monspessulana*, *Rubus ulmifolius*, and other evergreen bushes. Southern forests are located in the lowlands and have a prolonged rainy season (> 2000 mm/yr).

Nothofagus 2nd growth forests are composed mainly of Coigüe (*N. dombeyi*) and Roble. Southern pine plantations were young plantations (5-12 yr old, with understory vegetation dominated by *C. quila*). Magellanic forests are located on Tierra del Fuego I., and their temperatures are lower than those of the former habitats. Magellanic forests include deciduous forests of Lenga (*N. pumilio*) and mixed forests dominated by Lenga and Coigüe de Magallanes (*N. betuloides*) with Michay (*Berberis ilicifolia*) thickets in the understory.

Bird sampling

During the breeding season (Oct.-Dec.), 2 experienced observers surveyed avian richness (species number per point) using fixed-radius point counts (Reynolds 1980, Verner 1988). Point counts were conducted between 05:30 and 08:30 (local time) on days without rain and little or no wind. From 1998 to 2000 we surveyed 18-29 points randomly distributed within each forest type, and located > 400 m away from the forest edge (Table 1). The distance between points was always > 350 m, and each point was sampled once. Bird species were counted in 50 m fixed-radius plots because the detection rate for cryptic species of Chilean forests drops significantly beyond 50 m from the observer, as soft calls are not heard, and the dense vegetation structure does not allow dull-colored or small birds to be observed. Using a relatively short radius also minimizes the probability that the same bird is counted twice on successive points (Jiménez 2000, Vergara unpubl. data). Therefore, we truncated the distance at 50 m in order to simplify analytical procedures and to assure a high probability of detecting all

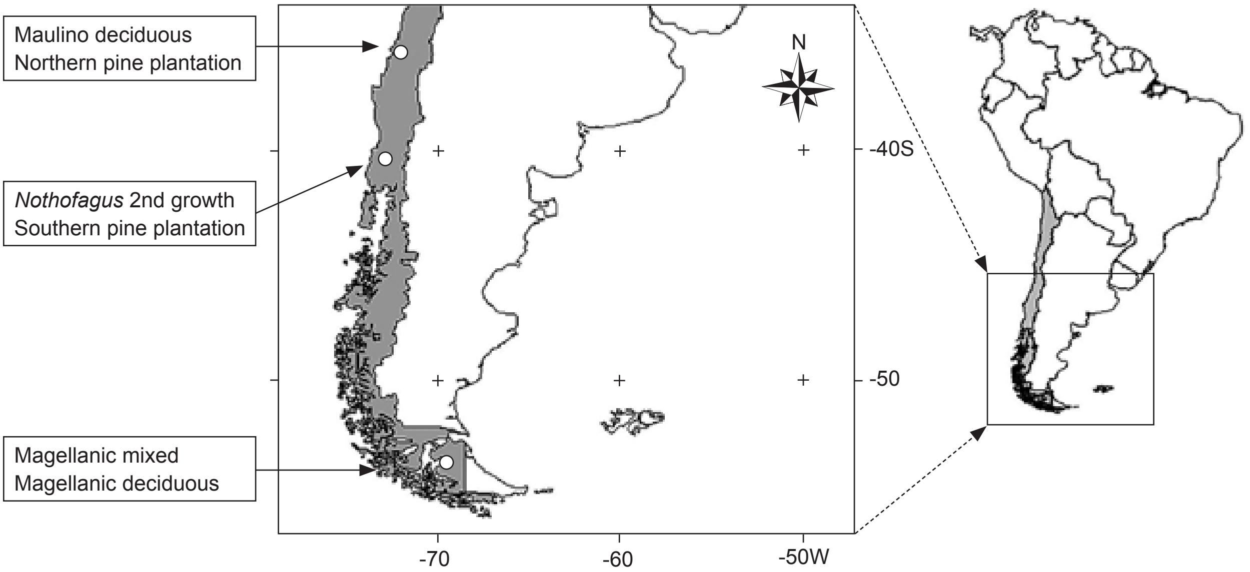

Fig. 1. Map showing the geographical locations of the 6 Chilean forest types studied.

Table 1. Methodological and geographic details of point-count studies conducted in 6 different Chilean forest types

Forest type	Bird species richness	Number of point counts	Sampling date	Locality
Maulino deciduous	29	19	1998	Constitución (35°59'S, 72°41'W)
Northern pine plantation	22	19	1998	Constitución (35°59'S, 72°41'W)
Nothofagus second growth	26	18	1999	Valdivia (39°34'S, 73°35'W)
Southern pine plantation	18	29	1999	Valdivia (40°08'S, 74°20'W)
Magellanic mixed	18	20	2000	Tierra del Fuego I. (54°04'S, 70°03'W)
Magellanic deciduous	14	20	2000	Tierra del Fuego I. (54°08'S, 68°47'W)

species (including cryptic species). At each point, we recorded the bird species within 1 min intervals during a 20 min period. For each species, we only recorded the time until the 1st individual was detected (visually and/or acoustically).

Data analysis

We used species accumulation functions to assess how species accumulated over time in each studied forest. Two models were fitted to the number of bird species recorded until time t [$S(t)$]: the linear dependence model and the Clench model (Soberón and Llorente 1993, Shiu and Lee 2003), which are respectively defined by

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

and

Table 2. Avian species and bird richness recorded in 6 Chilean forest types

	Forest type					
Species	Maulino deciduous	Northern pine plantation	Southern pine plantation	*Nothofagus* 2nd growth	Magellanic deciduous	Magellanic mixed
Anairetes parulus	x	x	x	x	x	x
Asthenes humicola	x					
Aphrastura spinicauda	x	x	x	x	x	x
Callipepla californica	x					
Campephilus magellanicus						x
Carduelis barbata	x	x	x	x	x	x
Colaptes pitius	x	x	x	x		
Colorhamphus parvirostris						x
Patagioenas araucana	x			x		
Curaeus curaeus	x	x	x	x	x	x
Diuca diuca	x	x				
Elaenia albiceps	x	x	x	x	x	x
Enicognathus ferrugineus				x	x	x
Eugralla paradoxa	x	x	x	x		
Glacidium nanum	x	x		x		
Leptasthenura aegitaloides	x	x				
Milvago chimango	x	x	x	x	x	x
Nothoprocta perdicaria	x					
Patagona gigas	x					
Phytotoma rara	x					
Phrygilus patagonicus	x	x	x	x	x	x
Picoides lignarius	x	x		x		
Polyborus plancus				x		
Pteroptochos castaneus	x	x				
Pteroptochos tarnii			x	x		
Pygarrhichas albogularis	x	x		x	x	x
Scelorchilus rubecula			x	x		
Scytalopus magellanicus	x	x	x	x	x	x
Sephanoides sephanoides			x	x		x
Strix rufipes	x			x		
Sylviorthorhynchus desmursii	x	x	x	x		
Tachycineta meyeni	x	x	x	x	x	x
Troglodytes aedon	x	x	x	x	x	x
Turdus falklandii	x	x	x	x	x	x
Xolmis pyrope	x	x	x	x		x
Zonotrichia capensis	x	x		x	x	x
Species number	29	22	18	26	14	18

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

where *a* and *b* respectively represent the increased rate of species observation at the beginning of sampling and the shape of the accumulation of new species during sampling (Soberón and Llorente 1993, Shiu and Lee 2003). Furthermore, the ratio *a*/*b* represents the predicted asymptote (i.e., the expected number of species at the point). We used these 2 models because they have a high goodness of fit (e.g., Shiu and Lee 2003).

Parameters *a* and *b* were estimated by means of nonlinear mixed-effects models using the *nlme* package of R 2.10.1 (R Development Core Team 2008). Nonlinear mixed-effects models are appropriate for species data from several point counts because their error structure includes fixed effects (count duration) and random effects resulting from chance variations in species richness and composition among different sampling points (Pinheiro and Bates 2000, Venables and Ripley 2002).

Effective count duration

For each forest type, we estimated point-count durations using the linear dependence model and the Clench model (see above). First, following Shiu and Lee (2003), we determined the effort (in terms of time) required to register a proportion of the predicted model asymptote (*a*/*b*). For this analysis, we estimated the count durations required to reach 80% and 90% of the asymptote, because these percentages are representative estimates of avian richness at the point scale (Shiu and Lee 2003).

Second, we followed an optimization procedure based on the marginal value theorem (Charnov 1976). According to this theorem, an observer should stay at a point until the species detection rate has decreased to a marginal value, assuming that the sampling effort is constrained by the time available for sampling and the time required to move between points (e.g., Barker et al. 1993). Therefore, an effective point-count duration equals the time at which the detection rate, *R*(*t*), is maximized. The detection rate function can be expressed as:

$$R(t) = \frac{S(t)}{T_t + t},$$

where T_t is the travel time between points. A criterion for maximizing *R*(*t*) is to find the time at which its derivative equals 0 (i.e., $\frac{\partial R(t)}{\partial t} = 0$).

From the linear dependence model and the Clench model, the time derivative of *R*(*t*) equated to 0 respectively leads to the following corresponding expressions:

$$0 = \exp(-b) - \frac{1 - \exp(-b)}{b(c+T_t)}$$

and

$$0 = 1 - \frac{t}{T_t + t} - \frac{bt}{bt+1}.$$

As seen in the above 2 expressions, there is no trivial solution for the effective point-count duration, and this time is not dependent on parameter *a*. Therefore, in order to estimate the effective point-count duration, we used an optimization function (R 2.7.2) that minimized the absolute values of these 2 expressions. Since an important objective of point -count studies is to maximize the total number of sampled points (*n*), we estimated the value of *n* from Barker's (1993) expression as:

$$n = \frac{T+T_t}{T_t+T_c};$$

where T_c is the point-count duration and *T* is the total survey time, which was assumed to be 3 h (05:30 to 08:30), because during this time period the acoustic activity of Chilean forest birds is more intense (Vergara unpubl. data). Arbitrarily, we used T_t values of 10 and 20 min that would represent the time spent by an ob server to respectively move at about 2 and 1 km/h over a mean distance of 350 m between points. Furthermore, during our sampling periods, travel times ranged between 10 and 20 min, which represent values widely used in point-count studies (e.g., Buskirk and McDonald 1995, Barker and Sauer 1995, Esquivel and Peris 2008). We also used more-extreme values for travel times of 5 and 30 min, which represent cases where the observer moves between points at about 4 and 0.7 km/h, respectively.

RESULTS

Overall, 36 bird species were recorded from all sampled forest types. Species richness detected for each forest ranged 14-29 (Table 2). For both the linear dependence and Clench models, r^2 values were relatively low ($0.53 \leq r^2 \leq 0.65$, Table 3). However, significant likelihood ratio tests (LRTs) indicated considerable explanatory power of the species accumulation models in predicting the number of bird species recorded at the point scale (all $p < 0.001$, Table 3).

In the Maulino deciduous and *Nothofagus* 2nd growth forests, parameter *a* was greater than in the other forest types for both models, indicating a higher detection rate in those forest types (Table 3). Similarly, the species asymptotes (*a*/*b*) of the linear dependence and Clench models were greater in Maulino deciduous and *Nothofagus* 2nd growth forests (Fig. 2, Table 3) than in the other forests. However, the Clench model predicted a higher asymptote than did the linear dependence model for all forest types (Fig. 2, Table 3).

An effective point-count duration is dependent on the forest habitat, the type of accumulation function, and the travel time. Point-count durations required to reach 80% and 90% of the asymptotes predicted by the linear dependence model were longer than those predicted by the Clench model (Table 4). For both models, the northern pine plantation and Magellanic deciduous forest respectively had the longest and shortest required count durations (Table 4). Detection rates predicted by the linear dependence model were higher than those predicted by the Clench model, indicating that species accumulate faster if a linear dependence model is used (Fig. 3). In contrast, for all travel times, effective count durations predicted by the linear dependence model were shorter than those predicted by the Clench model (Table 4). For both models and all travel times, the northern pine plantation and Magellanic deciduous forest respectively had the longest and shortest effective count durations (Table 4).

Effective count durations predicted by both models increased with increasing travel time as predicted by the marginal value theorem, because the detection rate is maximized later as the travel time increases (Table 4). For example, based on the linear dependence model, the effective time increased 21%, 19%, and 11% as the travel time respectively increased from 5 to 10, 10 to 20, and 20 to 30 min. For the linear dependence model and travel times ≤ 10 min, effective count durations were always shorter than (or equal to) count durations required to reach 80% of the asymptotes (Table 3). Furthermore, for the Clench model, this result was similar, even for travel times of 20 min (Table 3). For both models and all analyzed travel times, effective count durations were always shorter than count durations required to reach 90% of the asymptotes (Table 3).

The total number of points sampled during a single survey differed between the effective count durations and count durations required to reach 80% and 90% of the asymptote (Table 5). For travel times of 5 and 10 min, a greater number of points could be sampled using the effective count durations instead of the count durations required to reach 80% of the asymptote (Table 5). For example, for a travel time of 5 min, the use of effective count durations involved an average of 10% and 30% more points respectively using the linear dependence and Clench models, and this difference was greater for the northern pine plantation (Table 5). However, for a travel time of 10 min, the use of the effective count duration involved an average of only 1% and 12% more points for each respective model (Table 5). In contrast, the number of points was always smaller

Table 3. Parameters of 2 species accumulation function models fitted to species data from 6 different Chilean forest types. The model goodness-of-fit was assessed using the likelihood ratio test (LRT) and coefficient of determination (r^2)

Forest type	Linear dependence model					Clench model				
	a	*b*	*a*/*b*	LRT	r^2	*a*	*b*	*a*/*b*	LRT	r^2
Maulino deciduous	3.9	0.4	10.6	***	0.57	6.1	0.5	12.0	***	0.64
Northern pine plantation	3.3	0.3	9.5	***	0.53	4.9	0.5	10.8	***	0.56
Nothofagus 2nd growth	4.3	0.4	10.1	***	0.55	6.9	0.6	11.3	***	0.63
Southern pine plantation	3.5	0.4	8.5	***	0.65	5.5	0.6	9.6	***	0.60
Magellanic mixed	3.3	0.4	8.4	***	0.57	5.1	0.5	9.4	***	0.55
Magellanic deciduous	3.6	0.5	7.5	***	0.61	5.8	0.7	8.3	***	0.56

***$p < 0.0001$.

when count durations required to reach 90% of the asymptote were used instead of the effective count durations. This difference exceeded 50% when the travel time was 5 min using the Clench model (Table 5).

DISCUSSION

Since the rate of detection of new species decreases asymptotically as the point-count duration increases, longer counts should improve the accuracy of estimates of species presence and richness (Fuller and Langslow 1984, Dawson et al. 1995, Petit et al. 1995). However, since the detection efficiency tends to peak during the 1st minutes of sampling (e.g., Buskirk and McDonald 1995, Lynch 1995, Shiu and Lee 2003, Fig. 3), it is expected that a survey will not be efficient when the time at a point is longer than the time for which the species detection rate is maximized or when this time is extended beyond the point at which a representative percentage (e.g., 80% or 90%) of the predicted species diversity has been detected. Furthermore, temporal variations in efficiency become important when considering the tradeoff between the count duration and number of points (Ralph et al. 1995).

Results suggested that the likelihood that the effective count duration will be equal to

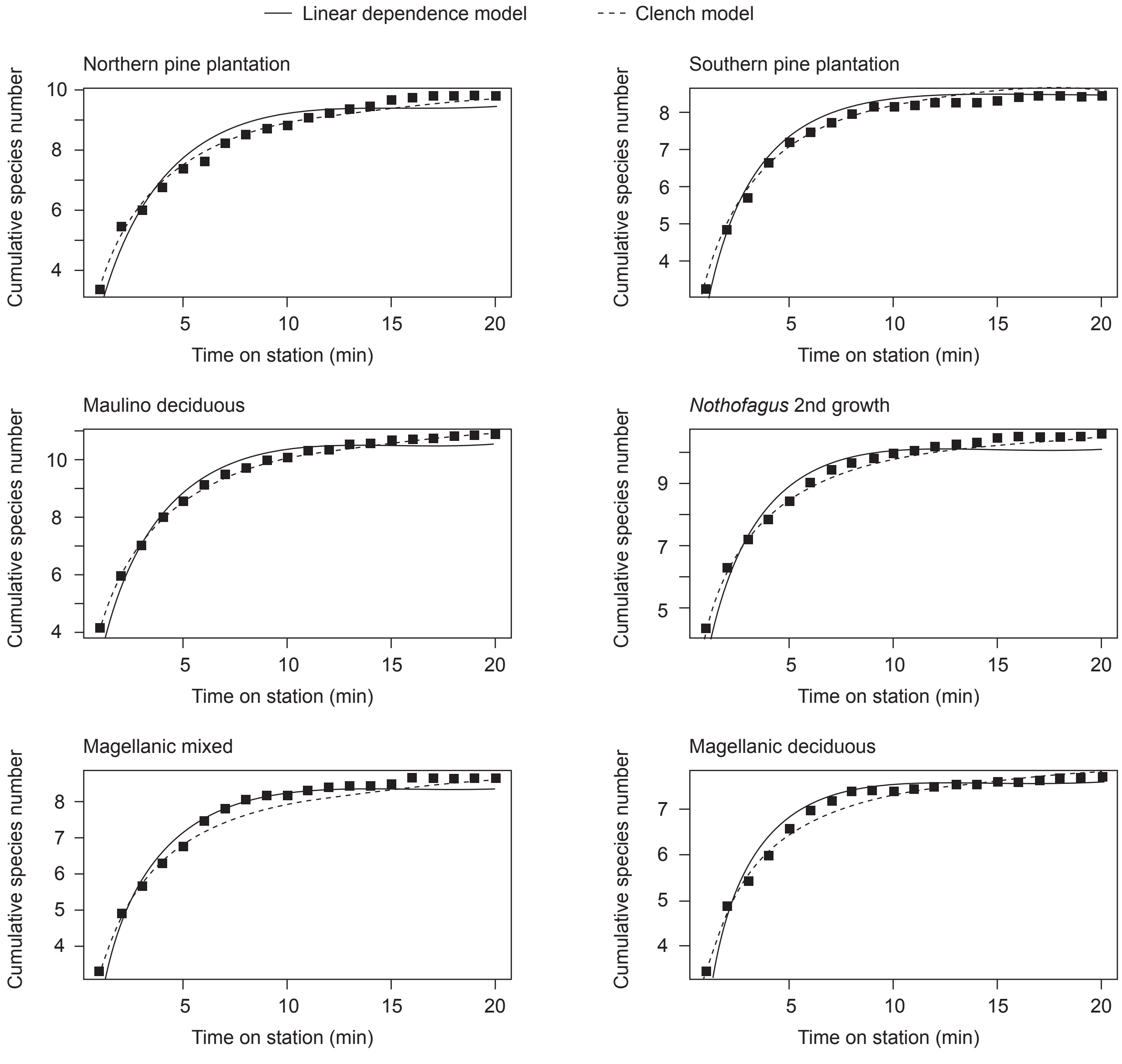

Fig. 2. Species accumulation models (lines) fitted to the observed data (black squares) for 6 different Chilean forest types.

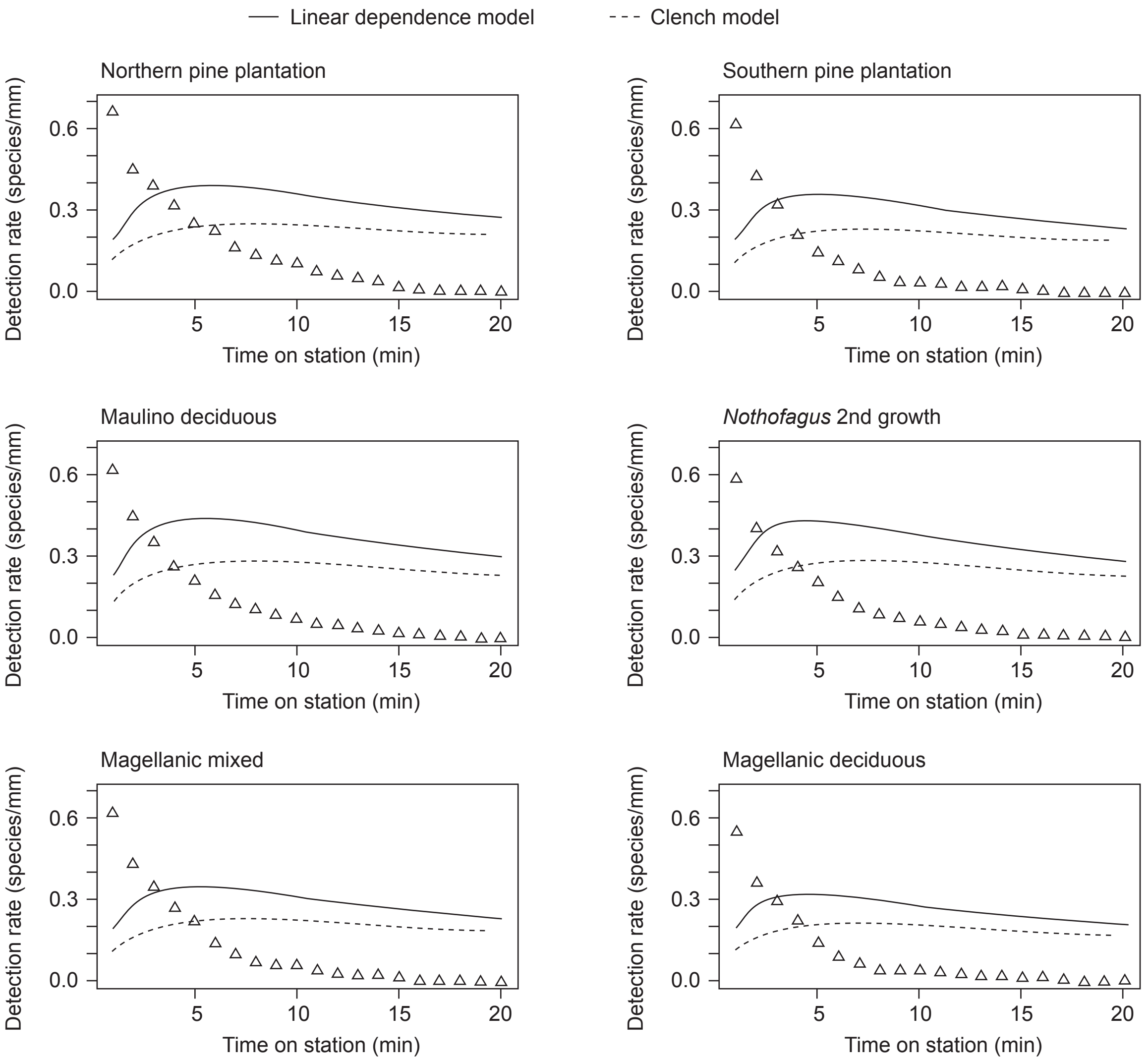

Fig. 3. Species detection rates estimated using 2 species accumulation models and a travel time of 20 min. Triangles represent the observed species detection rate, which was calculated by dividing the cumulative number of species (until time *t*) by the point count duration (*t*) (i.e., without considering the travel time).

Table 4. Predicted effective count durations of 2 species accumulation function models fitted to species data from 6 different Chilean forest types. The count durations were estimated as the times required to reach 80% and 90% of the function asymptotes and the time at which the detection rate was maximized with travel times of 5, 10, 20 and 30 min (effective count duration)

Forest type	Linear dependence model						Clench model					
	Species asymptote (%)		Travel time (min)				Species asymptote (%)		Travel time (min)			
	80%	90%	5	10	20	30	80%	90%	5	10	20	30
Northern pine plantation	4.6	6.6	3.5	4.4	5.6	6.3	8.8	17.6	3.8	5.4	7.6	9.3
Maulino deciduous	4.3	6.2	3.2	4.1	5.2	5.8	7.9	15.8	3.7	5.2	7.3	9.0
Magellanic mixed	4.1	5.9	3.1	4.0	4.9	5.6	7.4	14.8	3.6	5.1	7.1	8.8
Southern pine plantation	3.9	5.6	3.0	3.8	4.8	5.4	7.0	14.0	3.5	4.9	7.0	8.5
Nothofagus 2nd growth	3.8	5.4	2.9	3.6	4.5	5.1	6.5	13.0	3.4	4.9	6.9	8.4
Magellanic deciduous	3.4	4.8	2.7	3.4	4.2	4.7	5.8	11.6	3.3	4.6	6.5	8.0

the required count duration is dependent on the species accumulation function and the travel time. Thus, when the linear dependence model was used, the effective count durations were similar to the count durations required to reach 80% of the predicted asymptote only if travel time was set to 10 min. When the Clench model was used, however, the count durations were relatively similar to each other only if travel time was set to 20 min. Differences in count times derived from species accumulation functions result from differences in detection rates, and these rates were higher in the linear dependence model than the Clench model (Fig. 3). Consequently, effective count durations estimated from the linear dependence model can be considered the durations necessary to obtain the minimum acceptable level of completeness (Moreno and Halffter 2000, Shiu and Lee 2003).

Species detection rates vary among Chilean forests as shown by differences in parameters *a* and *b* of the species accumulation functions. Although parameter *a* and the predicted asymptote were larger in the Maulino deciduous and *Nothofagus* 2nd growth forests (the 2 forest types with the highest bird richness), the northern pine plantation was the habitat with longer effective count durations and longer required count durations (Table 1). This implies that in northern pine plantations, the species detection rate was maximized later than in the other forest types because parameter *b* was smaller, and therefore the mean detection time was longer (Fig. 3). Species detectability in northern pine plantations is probably low because this habitat type either provides more visual obstructions or constitutes a secondary habitat for several bird species of native Chilean forests (e.g., Vergara and Simonetti 2004). In contrast, the Magellanic deciduous forest was the habitat with the shortest effective count duration and the shortest count durations required

Table 5. Total number of points sampled (*n*) during a single survey session using the effective count durations estimated from 2 species accumulation function models in 6 different Chilean forests. The effective count durations maximize the species detection rates for travel times of 5, 10, 20, and 30 min. For each travel time, the percentage difference in the number of points between the effective time and the time required to reach 80% [Δn(80%)] and 90% [Δn(90%)] of the function's asymptote is shown. Positive (Δn > 0) and negative (Δn < 0) values respectively represent the percentage of extra points made using both approaches (see text)

	Linear dependence model											
Forest type	5 min			10 min			20 min			30 min		
	n	Δn (80%)	Δn (90%)	*n*	Δn (80%)	Δn (90%)	*n*	Δn (80%)	Δn (90%)	*n*	Δn (80%)	Δn (90%)
Maulino deciduous	22.4	11.5	26.2	13.4	1.2	12.6	7.9	-3.5	3.8	5.9	-4.4	1.0
Northern pine plantation	21.8	12.0	27.1	13.1	1.2	13.0	7.8	-3.9	3.9	5.8	-4.8	0.9
Nothofagus 2nd growth	23.5	10.5	24.5	13.9	1.1	11.5	8.2	-3.1	3.6	6.0	-3.8	1.0
Southern pine plantation	23.1	10.0	24.3	13.7	0.5	11.2	8.1	-3.6	3.2	5.9	-4.3	0.6
Magellanic mixed	22.8	10.9	25.4	13.6	1.0	12.0	8.0	-3.5	3.6	5.9	-4.2	0.9
Magellanic deciduous	24.1	8.0	21.6	14.2	-0.3	9.5	8.3	-3.6	2.4	6.0	-4.1	0.3
	Clench model											
Forest type	5 min			10 min			20 min			30 min		
	n	Δn (80%)	Δn (90%)	*n*	Δn (80%)	Δn (90%)	*n*	Δn (80%)	Δn (90%)	*n*	Δn (80%)	Δn (90%)
Maulino deciduous	21.4	32.8	58.3	12.5	15.2	41.1	7.3	2.0	23.7	5.4	-2.8	14.9
Northern pine plantation	21.0	36.3	61.1	12.4	18.2	44.3	7.3	4.2	26.6	5.3	-1.3	17.4
Nothofagus 2nd growth	21.9	26.8	53.3	12.8	10.1	35.5	7.4	-1.3	18.7	5.5	-5.2	10.8
Southern pine plantation	21.8	29.5	55.5	12.7	12.3	38.0	7.4	0.2	20.8	5.5	-4.1	12.5
Magellanic mixed	21.6	30.8	56.7	12.6	13.4	39.3	7.4	0.9	22.0	5.4	-3.6	13.5
Magellanic deciduous	22.4	23.5	50.2	13.0	7.5	32.3	7.5	-2.8	16.0	5.5	-6.1	8.7

to reach 80% and 90% of the predicted asymptote. However, this habitat had the poorest species richness and the lowest total bird abundance of all forest types (Vergara and Schlatter 2006). Thus, it is likely that species detectability decreases in habitats that exhibit greater species richness (e.g., Shiu and Lee 2003). This could occur due to a reduction in the observer's ability to detect cryptic species (the songs of which may be masked by conspicuous species), due to an increase in the proportion of quiet or cryptic species, or due to an inverse relationship between the overall species richness and the number of individuals of each species.

The effective count duration increases with increasing travel time because, as predicted by the marginal value theorem, the species detection rate is inversely proportional to the travel time and directly proportional to the percentage of the total survey time actually spent counting (Table 4). Thus, the observer will maximize the number of species detected during a single survey by adjusting the time spent at each point to the effective count time. Effective count durations, as our results suggest, will be shorter or longer than the required count durations depending on the travel time needed. In general, for short travel times (< 10 min), effective count durations are < 5 min; in other words, they are slightly shorter than the count durations required to reach 80% of the asymptote. Shorter count durations result in larger sample sizes and therefore greater statistical power (e.g., Buskirk and McDonald 1995, Lynch 1995). Similarly, Ralph et al. (1995), based on the statistical power obtained from their survey data, proposed that count durations should be 5 min for travel times of < 15 min. In line with these findings, Jiménez (2000) suggested using 5 min count durations for Chilean forests.

Long travel times (≥ 20 min) involve longer effective count durations, and consequently, smaller sample sizes. In such cases, the option of sampling more points by decreasing the count duration would result in a suboptimal decision, because the observer will not maximize the species detection rate, and will spend more time moving between points rather than actually counting birds at the points. Thus, our results suggest that effective count durations when the travel time is long should be about 7 min, which would involve sampling 4% fewer points than if the count duration required to reach 80% of the predicted asymptote is used.

Effective count durations, such as those shown in this study, can be used as a reference for future monitoring or conservation programs of bird communities in fragmented forest regions (e.g., Lee et al. 2005, Ko et al. 2009). However, effective count durations tend to be shorter than the required count durations (when travel times are short). Consequently, effective count duration estimates should be used with caution due to species-specific differences in detectability (e.g., Shiu and Lee 2003). For example, mobile species in Chilean forests, such as Austral parakeets (*Enicognathus ferrugineus*), are detected only with long counts (Jiménez 2000), just like some flock species such as the Austral blackbird (*Curaeus curaeus*). The chance of detecting those species within a fixed radius may be small because they may move long distances before reaching the sampling area, increasing the time required to detect them. We can also include large-sized species such as raptors, large woodpeckers, and forest pigeons in this category. However, the presence of cryptic species could also increase the required duration of point counts in Chilean forests. For example, woodpeckers call infrequently, and their detection demands recognizing the characteristic drumming of each species (Vergara and Schlatter 2004). Understory birds, such as tapaculos (Rhinocryptidae), are also cryptic species that can be detected by the noise emitted when scratching the forest litter for invertebrates. Therefore, we suggest using effective count durations when the survey is focused on assessing species richness and the presence of common or conspicuous species.

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