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Efficiency, bias, and consistency of visual and aural surveys of curassows (Cracidae) in tropical forests

Iván Jiménez,[1] Gustavo A. Londoño[2] and Carlos Daniel Cadena[1,3]

[1]Department of Biology and International Center for Tropical Ecology, University of Missouri-St. Louis, 8001 Natural Bridge Road, St. Louis, Missouri 63121 USA
[2]Avenida 5A # 51-07, Cali, Colombia

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ABSTRACT. Curassows are among the most threatened Neotropical birds, so reliable methods for estimating their abundance are needed to discern distribution patterns and manage populations. Based on the assumptions that the distance to booming curassows cannot be determined reliably and that curassow calling is unpredictable, it has been suggested that curassow abundance should be estimated only through surveys using visual cues. Based on line-transect surveys of Great Curassows (*Crax rubra*) conducted in a lowland tropical forest in Costa Rica, we show that distance to booming curassows can be measured accurately in the field. We also show that line-transect aural surveys sample curassows over large areas across all forest vertical strata and provide precise estimates of their abundance, but are biased towards detecting males. In contrast, line-transect visual surveys sample only small areas of forest understory and are imprecise, but appear not to be biased towards any sex or age class. We argue that the assumption that curassow calling is unpredictable is not well supported, and we recommend the use of surveys using aural cues to estimate curassow abundance efficiently.

SINOPSIS. **Eficiencia, sesgo y consistencia de censos visuales y auditivos de pavones (Cracidae) en bosques tropicales**

Los pavones son unas de las aves neotropicales más amenazadas, y por ende métodos confiables para estimar su abundancia se necesitan para discernir sus patrones de distribución y manejar sus poblaciones. Dando por cierto que es imposible estimar confiablemente la distancia a pavones que se escuchan vocalizar y que el comportamiento vocal de estas aves es impredecible, se ha sugerido su abundancia debe estimarse únicamente con base en conteos de detecciones visuales. Basándonos en conteos de individuos de *Crax rubra* a lo largo de transectos en un bosque tropical de tierras bajas en Costa Rica, demostramos que la distancia a pavones que se escuchan vocalizar sí puede medirse con exactitud en el campo. También mostramos que los conteos de detecciones auditivas muestrean áreas grandes de todos los estratos verticales del bosque y proveen estimaciones precisas de la abundancia de los pavones, pero están sesgados hacia detectar machos. En contraste, los conteos de detecciones visuales muestrean áreas pequeñas del sotobosque y son imprecisos, pero no parecen estar sesgados hacia ninguna clase de edad o sexo. Aducimos que es erróneo suponer que el comportamiento vocal de los pavones es impredecible, y recomendamos el uso de conteos de detecciones auditivas para estimar eficientemente la abundancia de estas aves.

Key words: bird counts, Cracidae, *Crax rubra*, curassows, survey methods

Although curassows (Cracidae) are one of the most threatened avian groups of the Neotropics, many basic aspects of their ecology remain poorly known (Brooks and Strahl 2000). In particular, studies on the temporal and spatial variation of curassow populations and their response to environmental perturbations are urgently needed (Brooks and Strahl 2000). A reliable method for estimating curassow abundance is fundamental for such studies. The standard method (Brooks and Strahl 2000) for estimating curassow abundance is based on surveys of visual cues along line transects (Strahl and Silva 1997), referred to here as visual surveys. This method often yields few records per sampling effort, sometimes one sighting per 20–40 km of line transects (Strahl and Silva 1997; Martínez-Morales 1999). Curassows are sighted infrequently because they are rare, but also because the distance at which they are detected visually is usually very short, often <10 m on average (Silva and Strahl 1991; Hedemark 1993; Santamaría and Franco 1994; Defler and Defler 1997). Consequently, even very long line transects sample small areas and accurate abundance estimations require large sampling efforts (i.e., 10–100 km of transects; Strahl and Silva 1997). If time, resources, and access are limited, this approach is clearly not practical.

[3] Corresponding author. Email: cdc35b@studentmail.umsl.edu

In contrast to visual detections, the booming vocalizations of curassows reveal the presence of birds located >100 m away (Cox et al. 1997; Gutiérrez 1997; Defler and Defler 1997). Thus, aural surveys could be used to estimate curassow abundance more efficiently than with visual surveys. However, few studies focused on cracids (Cox et al. 1997; Gutiérrez 1997) have used vocalizations to estimate curassow abundance. Besides, based on the assumptions that it is virtually impossible to estimate the distance to a booming curassow and that calling is not predictable, it has been suggested that aural surveys are inappropriate for estimating curassow abundance (Strahl and Silva 1997). Here we present a method for estimating curassow abundance based on aural surveys. In addition, we compare this method with visual surveys in terms of efficiency, sex and age classes sampled, and consistency. Finally, we discuss the cogency of the assumptions that have to date disqualified aural surveys for estimating curassow abundance.

STUDY AREA AND METHODS

This study was carried out in a tropical lowland wet forest at La Selva Biological Station, northeastern Costa Rica (McDade et al. 1994). We conducted visual and aural surveys of Great Curassows (*Crax rubra*) between 19 April and 8 May 2000 during the breeding season of these birds (Stiles and Skutch 1989), in eight 1.3-km line transects set along trails labeled every 50 m. Six transects were in primary forest, and two were across secondary forest mixed with successional pastures and plantations. During visual surveys, we counted curassow sightings while walking at ca. 0.9 km/h. In a given day, a single observer surveyed a line transect from 05:15 (ca. 15 min after dawn) to 06:45 in one direction, and from 07:00 to 08:30 in the opposite direction. During aural surveys, we counted detections of booming curassows while walking each line transect at ca. 0.9 km/h in one direction from 1.5 h before dawn (03:30) until dawn (05:00), and then in the opposite direction from 05:15 to 06:45. Aural and visual surveys were conducted simultaneously from 05:15 to 06:45 by the same observer. Each of the eight transects was surveyed three times with each method and at each time of day. The dates at which each transect was sampled and the survey method employed were interspersed during the study period.

Efficiency. The efficiency of a line-transect survey can be evaluated in terms of the area sampled per transect length (Emlen 1971), which depends on the perpendicular distance from the transect line to the birds detected (Bibby et al. 2000; Buckland et al. 2001). We measured the perpendicular distance from the transect line (i.e., the trail) to detected curassows directly by pacing when birds were close to the trail. To measure the perpendicular distance to several birds detected aurally, which were far away from the transect line, we recorded the position from which we first heard them booming relative to trail marks, and then searched for them. During surveys we never spent more than 10 min looking for a booming curassow. Once we found the booming curassow, we determined its position relative to trail labels by pacing with a compass. Finally, we returned to the position from which we first detected the booming vocalization, and resumed walking along the transect. We used trail maps to calculate the perpendicular distance from the birds to the transect line.

The efficiency of a line-transect survey can also be evaluated by examining the extent to which it detects organisms in all the vertical strata in the habitat (Buckland et al. 2001), especially for animals like cracids that use various vertical strata of tall forests. Consequently, for each detected curassow, we recorded whether it was in the canopy (ca. ≥30 m above the ground), subcanopy (>10 m to ca. <30 m), or understory (≤10 m).

Sex and age classes sampled. A critical aspect of survey methods is the sex and age classes sampled (Bibby et al. 2000; Buckland et al. 2001). Thus, we recorded whether detected curassows had male or female/immature plumage (Stiles and Skutch 1989). To increase sample size for visual and aural detections, we walked trails at survey speed (at ca. 0.9 km/h) at times when we were not conducting surveys and recorded data on detection distance, forest vertical strata, and sex and age classes of all curassows detected. At these times we spent up to 30 min locating booming curassows.

Consistency. Agreement between estimates yielded by different survey methods is critical for comparisons involving various methods and for parameter estimation through a

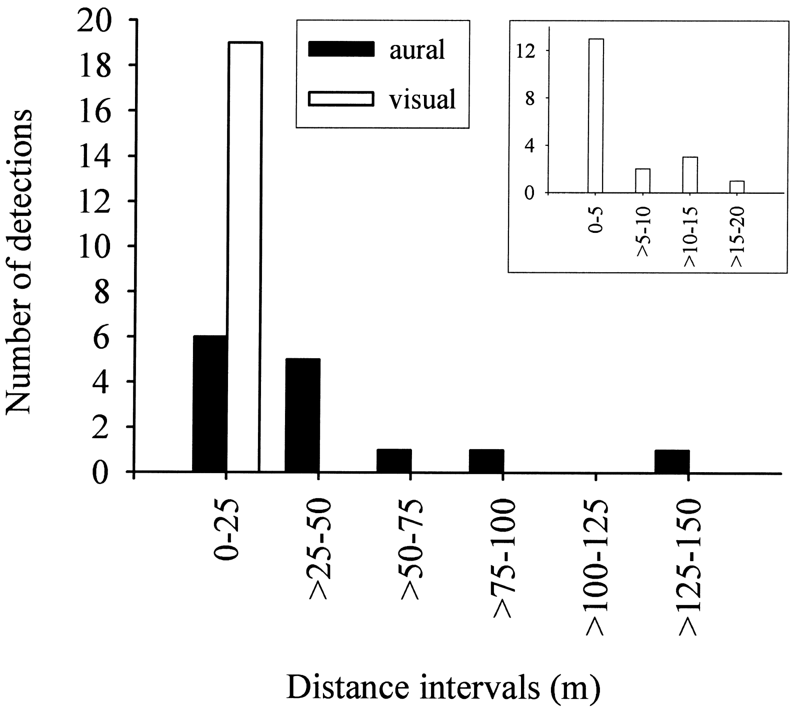

Fig. 1. Distribution of detections among categories of perpendicular distance from the transect line to curassows detected aurally and visually. Curassows were detected aurally over much larger distances than visually. The inset shows the distribution of visual detections in detail, and indicates that most curassows were seen within 5 m of the transect line.

combination of methods (Emlen 1971; Buckland et al. 2001). We used Spearman rank correlation to assess consistency of relative abundance estimates between methods. If two methods are consistent, they should be correlated in terms of number of detections across line transects. Note that two methods can be consistent even if they yield significantly different number of detections. To determine whether visual surveys conducted at different times were consistent, we tested for correlation across line transects between the mean number of curassows sighted during surveys conducted from 05:15 to 06:45 and those conducted from 07:00 to 08:30. Likewise, to assess the consistency of aural surveys conducted at different times, we tested for correlation between the mean number of detections of booming curassows during surveys carried out from 03:30 to 05:00 and those carried out from 05:15 to 06:45. Finally, to assess the consistency between aural and visual surveys, we tested for correlation between the mean number of curassows sighted and the mean number of detections of booming curassows during surveys conducted from 05:15 to 06:45.

RESULTS

Six repeats of visual surveys conducted along transects totalling 10.4 km yielded nine curassow sightings. The same sampling effort using aural surveys yielded 19 detections of booming birds, but data on perpendicular distance, forest strata, and sex/age class was obtained only for eight of these because not all singing curassows were located. Additional observations while walking trails at survey speed yielded 11 visual and six aural detections with data on perpendicular distance, forest strata, and sex/age class.

Efficiency. Aural surveys sampled a much larger area than visual surveys. We often detected booming birds from over 25 m and up to 138 m. In contrast, we never sighted curassows that were more than 20 m from the transect line, and most were within 5 m (Fig. 1).

In addition, aural surveys detected curassows in a broader range of forest vertical strata than visual surveys: all curassows detected visually were in the forest understory, whereas aural surveys detected birds in all three forest strata (three in understory, four in subcanopy, seven in canopy).

Sex and age classes sampled. Aural and visual surveys differed in the sex and/or age of birds detected. Birds detected aurally were invariably males, sometimes accompanied by one bird with female/immature plumage (four of 14 detections). In contrast, visual surveys not only detected males with (seven detections) and without (six detections) attending females, but also birds with female/juvenile plumage with no attending males (six detections).

Consistency. Aural and visual surveys differed markedly in the consistency of relative abundance estimates. Aural surveys performed at different hours yielded consistent estimates of relative abundance. The mean number of booming birds detected during surveys carried out from 03:30 to 05:00 was significantly correlated with the mean number of booming birds detected during surveys carried out from 05:15 to 06:45 ($r_s = 0.87$, $P = 0.004$, $N = 8$ line transects). In contrast, visual surveys performed at different hours did not yield consistent estimates of relative abundance. The mean number of curassows sighted during surveys performed from 05:15 to 06:45 was not correlated with the mean number of curassows sighted during surveys conducted from 07:00 to 08:30 ($r_s = 0.41$, $P = 0.31$, $N = 8$). Finally, aural and visual surveys were not consistent with each other. The mean number of booming birds detected during aural surveys carried out from 05:15 to 06:30 was not correlated with the mean number of birds sighted during visual surveys performed at the same time ($r_s = 0.07$, $P = 0.87$, $N = 8$).

DISCUSSION

Detection distances for sighted birds were very short and similar to those of other curassow surveys (Thiollay 1989; Silva and Strahl 1991; Hedemark 1993; Santamaría and Franco 1994; Defler and Defler 1997). In contrast, curassows were detected aurally over large distances, as reported previously by others (Cox et al. 1997; Defler and Defler 1997; Gutiérrez 1997). Since it is well known that avian sounds are detected over greater distances than visual cues in forest habitats, vocalizations are commonly used for estimating forest bird abundance (Bibby et al. 2000). Thus, it is surprising that aural surveys are not included in the standard method for estimating curassow abundance (Strahl and Silva 1997). This results in part from assuming that it is virtually impossible to estimate distance to booming curassows (Strahl and Silva 1997). We have shown that this assumption is unfounded. Indeed, procedures similar to ours have been used to measure distance to booming Horned Curassows (*Pauxi unicornis*; Cox et al. 1997) and singing individuals of several other bird species (Reynolds et al. 1980).

Measuring accurately the distance to booming curassows, as we propose, assumes that birds move little while singing. During approximately 1500 h of observation of wild curassows (Jiménez et al. 1998, 2001; Parra et al. 2001) we have commonly seen Black (*Crax alector*), Salvin's (*Mitu salvini*), Razor-billed (*Mitu tuberosa*) and Great curassows singing for >1 h from a single perch. Horned Curassows behave similarly (Cox et al. 1997). Thus, movement of booming birds seems unlikely to introduce significant error in detection distance measures.

Since relative abundance estimates derived from raw counts often confound detectability and abundance, distance sampling (Buckland et al. 2001) may be a better approach for estimating bird abundance (Thompson 2002). It has been suggested that visual surveys are appropriate for estimating curassow density through distance sampling (Strahl and Silva 1997). However, the distribution of curassow sightings among distance categories is spiked near zero distance (i.e., detectability falls sharply just off the transect line; Fig. 1). This suggests that visual surveys might yield unreliable density estimates through distance sampling because robust detection function models do not fit spiked distributions (Buckland et al. 2001). The spiked distribution probably resulted from conducting surveys along open trails, as prescribed by the standard method (Strahl and Silva 1997), because observers can see far ahead along trails but not through the forest along the trails' sides. Indeed, conducting surveys along trails is generally considered inappropriate

(Buckland et al. 2001; Thompson 2002), but, since curassow surveys need to be conducted along transects of 10–100 km (Strahl and Silva 1997), it would be impractical to conduct such surveys outside of forest trails. Rather, ways should be found to avoid or account for biases that arise by conducting transects along trails. For instance, despite being conducted along trails, aural surveys produced a distribution of detections among distance categories that falls gradually with distance from the transect line (Fig. 1) and, thus, is amenable for fitting robust detection function models (Buckland et al. 2001). Therefore, in terms of the shape of the detection function, aural surveys seem more appropriate for estimating curassow density through distance sampling than visual surveys.

The differences between visual and aural detections in the vertical strata where curassows were encountered could be due to observers' sighting many of the birds dwelling in the understory, but missing many birds perching quietly in the upper levels of the forest. The same pattern could also result if curassows tend to be in the understory when not singing, but in the subcanopy and canopy when singing. These interpretations are not mutually exclusive, and both are probably correct.

Aural surveys were biased in terms of sex and age as they invariably detected male curassows. This bias is consistent with the idea that only male curassows sing (Delacour and Amadon 1973). Yet, female singing has been documented in Salvin's (Santamaría and Franco 1994), Black (G. A. Londoño et al., unpubl. data), and Nocturnal (*Nothocrax urumutum*; Parker 2002) curassows. In these species, female song is quite different from male song, so it could be quantified separately in aural surveys. Assessing variation of curassow vocal behavior with age is also important to determine the portion of the population sampled by aural surveys. Besides the observation that a wild Salvin's Curassow uttered the booming vocalization for the first time nine months after hatching (Santamaría and Franco 1994), there appears to be no information on the ontogeny of curassow vocal behavior.

Our data show consistency between aural surveys performed at different hours, but no consistency between visual surveys performed at different hours. Temporal inconsistency of visual surveys has important implications since this is considered the standard method for estimating curassow abundance (Brooks and Strahl 2000). This method averages detections across ≥3 km transects surveyed between 06:00 and 10:00 or 16:00 and 19:00 (Strahl and Silva 1997). If the inconsistency among visual surveys results from conducting them at different hours (Blake 1992), estimates obtained by surveying transects at different times of the day might not be comparable. On the other hand, if this inconsistency results from the small area sampled by visual surveys (Fig. 1), several repeated measures would be necessary to acquire a precise average estimate per line transect.

The second assumption that has prevented the use of aural surveys of curassows, that calling is not predictable (Strahl and Silva 1997), is not supported if it refers to booming by curassows, which is highly predictable. Curassows sing more often during the breeding season than at other times (Delacour and Amadon 1973; Santamaría and Franco 1994; Cox et al. 1997; Gutiérrez 1997; Sermeño 1997; Strahl et al. 1997), before than after dawn, and in the morning than in the afternoon (Santamaría and Franco 1994; Cox et al. 1997; Gutiérrez 1997). Thus, aural surveys can be conducted during the breeding season and at hours when curassows are most vocal. The need to conduct surveys at particular seasons and times is common (Bibby et al. 2000; Buckland et al. 2001); this requirement is not exclusive to aural surveys of curassows.

In summary, our results suggest that aural surveys sample curassows over large areas across all forest vertical strata and provide precise estimates of their abundance, but are biased towards detecting males. In contrast, although visual surveys sample only small areas of forest understory and are imprecise, they do not seem to be biased towards any sex or age class. Thus, aural surveys are likely to estimate the abundance of singing curassows with higher efficiency and precision than visual surveys, and the latter might be used to determine the sex and age classes sampled by aural surveys. In the absence of detailed information on singing behavior, aural surveys allow assessing curassow relative abundance, contingent upon the assumption of equal detection probabilities (Mackenzie and Kendall 2002). Thus, when time and resources are limited, we suggest that aural surveys should be used. Restricting the assessment of curassow abundance to visual surveys (Strahl and Silva 1997) may often lead to inconclusive results despite substantial fieldwork (Santamaría and Franco 1994; Defler and Defler 1997). This inefficiency is incompatible with the urgent need to obtain reliable curassow abundance estimates for conservation purposes.

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