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Optimal sampling of booming Bitterns *Botaurus stellaris*

Brigitte Poulin* & Gaëtan Lefebvre

*Poulin, B. & Lefebvre, G., Station Biologique de la Tour du Valat, Le Sambuc, 13200 Arles, France. (*E-mail: poulin@tourduvalat.org)*

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The Great Bittern *Botaurus stellaris* is a secretive bird that lives in dense reed marshes. Population surveys of this vulnerable species are based on the characteristic vocalization (booms) of males during the breeding season. Probability of detecting a male is highly dependent upon the occurrence of booms, which is assumed to be density-dependent and highly variable over time. We studied booming frequency in relation to time of day, time of season, weather conditions, and bittern density at ten sites in the Camargue, south of France. At each site, twice monthly from 6 March through 18 July 2000, booms were recorded over two periods of 6 h, one centred on sunset, the other centred on sunrise, and both divided into 72 sampling units of 5 min each. The number of bitterns heard within a single 6-h period varied from 0 to 10. Booming frequency was highest in April and May. The proportion of males booming peaked 0–30 min after sunset (68%), and 30–60 min before sunrise (78%). Booming activity decreased significantly under cloudy and rainy conditions, but low temperatures had no effect. Optimal sampling protocols (point count duration and frequency) are suggested for various situations at dawn and dusk, during the peak and low booming periods, and for sites comprising a single or multiple bitterns. Given the daily and seasonal variation in booming frequency, only standardized protocols can provide a faithful estimate of the number of male bitterns across years.

1. Introduction

The Great Bittern *Botaurus stellaris* is a secretive bird inhabiting marshes densely covered with common reed *Phragmites australis*, and is hence difficult to observe (Voisin 1991). The characteristic vocalization (booms) of males during the breeding season (Cramp & Simmons 1977), combined with the recent population decline in several European countries (Tucker & Heath 1994, but see Väisänen *et al.* 1998), has prompted the use of booming activity as a census tool to estimate both population size (Puglisi *et al.* 1995, Kayser *et al.* 1998), and individual survival (McGregor & Byle 1992). Individual recognition based on repeated sound analyses is an accurate tool for monitoring small populations (Gilbert *et al.* 1998), but is inapplicable to national surveys involving large reedbeds with numerous bitterns due to time, cost and accessibility constraints (all males must be recorded simultaneously from a short distance with good recording material several times over the booming season). Likewise, the "constant presence" or "frequent visit" approach, which is commonly used for small reedbeds within natural reserves is hardly applicable when thousands of hectares of reedbeds are involved. In such conditions, an adequate sampling of bitterns for estimating population trends requires (1) a monitoring carried out when a maximal number of bitterns can be detected, (2) a detection probability constant throughout the monitoring period, and (3) a detection probability similar among sites, irrespective of bittern density.

In this paper, we evaluate the minimal sampling effort needed to detect bitterns at a site with a 95% probability based on the analysis of the daily and seasonal patterns of booming activity under low and high bittern density in the Camargue, France. Optimal sampling protocols (point count duration and frequency) are provided for various situations at dawn and dusk, during periods of high and low booming activity, and for sites comprising a single or multiple bitterns. We estimate the effect of weather on booming activity and we propose a methodological approach for estimating the number of booming males within reedbeds of various sizes.

2. Material and methods

2.1. Study sites

Booming activity was recorded from a single point at ten different sites located in the Camargue or Rhone Delta, Mediterranean France (Fig. 1). Based on previous survey (Kayser *et al.* 1998), five sites were selected in small reedbeds (< 10 ha) expected to comprise a single bittern (Fig. 1). One of these sites (Tour Vieille) was abandoned in May following the absence of bittern. The number of bitterns heard during each field visit at these low-density sites varied from zero to one. Five other sites were selected within large reedbeds covering 60 to 400 ha (Fig. 1). The maximum number of bitterns heard from a single point at these sites ranged from five to ten.

2.2. Field methods

Booms, the loudest calls produced by a male bittern, are made of two elements (Cramp & Simmons 1977). Only the second or main element, which consists of a series of one to ten consecutive booms referred to as boom train, was recorded in this study. At each site, twice monthly from 6 March through 18 July 2000, booming activity was noted over two sampling periods of 6 h, one starting 4 h before sunrise and the other starting 2 h before sunset. Each period was divided into 72 sampling units of 5 min each, during which an observer noted the number of booms and boom trains, air temperature (rounded to the closest multiple of 5 °C for the analyses), wind speed on the Beaufort scale, occurrence of rain and percentage of cloud cover at 25% intervals. On each visit, we estimated the total number of distinct individuals heard during the sampling period, which is referred to as the number of booming males. Booming males could be distinguished based on the direction of the call and its characteristics (number of booms, time interval between two booms, booming intervals, occurrence of poor booms, etc.). Detailed booming activity was recorded for up to four males on each visit. Booming frequency of these individuals was calculated as the proportion of males that boomed during a given time interval throughout the 6-h period.

2.3. Statistical analyses

Temporal variations in booming frequency were analysed with one-way ANOVA followed by Scheffé post-hoc tests to identify homogenous groups of means (i.e. those that were not significantly different from each other at $P < 0.05$). Weather conditions were analysed by using the residuals of booming frequency to eliminate the effect of temporal pattern on booming activity. These residuals were further standardized to vary between 0 and 1 to facilitate their comparison.

Optimal sampling protocols were estimated based on the sampling duration and number of samples needed to reach a 95% probability of detecting a bittern present at a site. Detection probabilities refer to the average booming frequency, assuming that any bittern heard once during the 6-h sampling was present for the whole period. Sampling duration was estimated by calculating periods corresponding to a significant increase in detection probability by combining consecutive sampling units of 5 min up to 45 min. The number of samples needed was calculated with the equation

$$(1 - P)^n < 0.05$$

with P = probability of detecting a bittern, and n = the number of samples. This equation provides threshold values in the number of samples needed to decrease

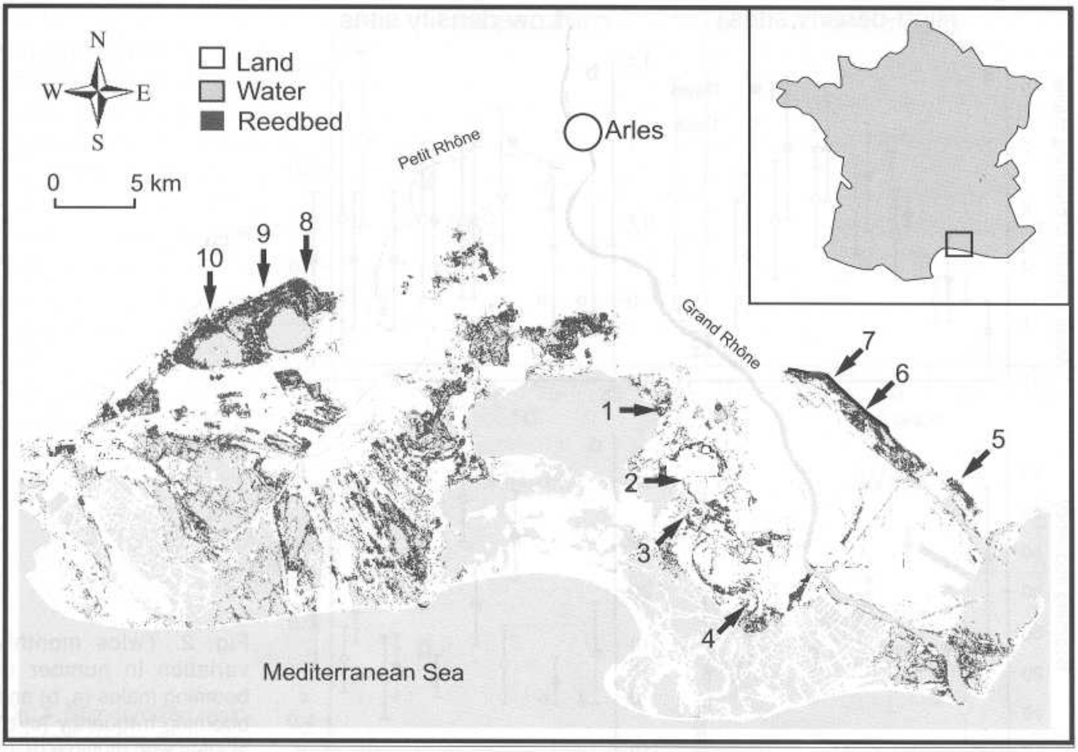

Fig. 1. Distribution map of the reedbed habitat in the Camargue with the location of each study site. Single-bittern sites: 1. Capelière, 2. Baisse Salée, 3. Salin de Badon, 4. Tour Vieille, 5. Sollac. Multiple-bittern sites: 6. Marais du Vigueirat, 7. Marais d'Icard, 8. Je-m'en-repens, 9. Franquevaux, 10. Gallician.

the probability of missing a bittern below 5%. For instance, we need only one sample if P > 95%, two samples if P > 78%, three samples if P > 63%, etc.

3. Results

3.1. Seasonal booming pattern

At sites with multiple bitterns, the number of booming males varied over the season with an average peak of seven (dawn) and five (dusk) individuals per site (Fig. 2a). Throughout the season, the number of booming males was systematically higher at dawn than at dusk (paired $t_{26} = 3.9$, $P < 0.001$). Booming activity differed significantly over time (Fig. 2c) at both dawn ($F_{7,544} = 12.05$, $P < 0.001$) and dusk ($F_{7,531} = 21.26$, $P < 0.001$), being homogeneous and highest from early April through late May (Scheffé test, P = 0.05). During this period, booming frequency averaged 49% (SE = 1.26) at dawn, and 32% (SE = 1.42) at dusk. At sites with a single bittern (Fig. 2b, d), booming frequency was similar at dawn and dusk (paired $t_{28} = 1.68$, $P < 0.10$), but varied significantly over time for both periods (dawn: $F_{7,491} = 6.80$, dusk: $F_{7,423} = 19.54$, $P < 0.001$). The period of homogenous and highest booming frequency was identified as April at dawn, and late April–early May at dusk (Scheffé test, P = 0.05). Since these two periods are included within the peak booming periods observed at higher density sites (which are derived from a much larger sample of males), further analyses will be restricted to April–May as the peak booming season. At single-bittern sites, booming frequency averaged 15% (SE = 1.9) at dawn, and 22% (SE = 2.31) at dusk in April–May.

3.2. Daily booming pattern

Daily booming patterns were analysed by grouping the 5-min sampling units into 30-min periods

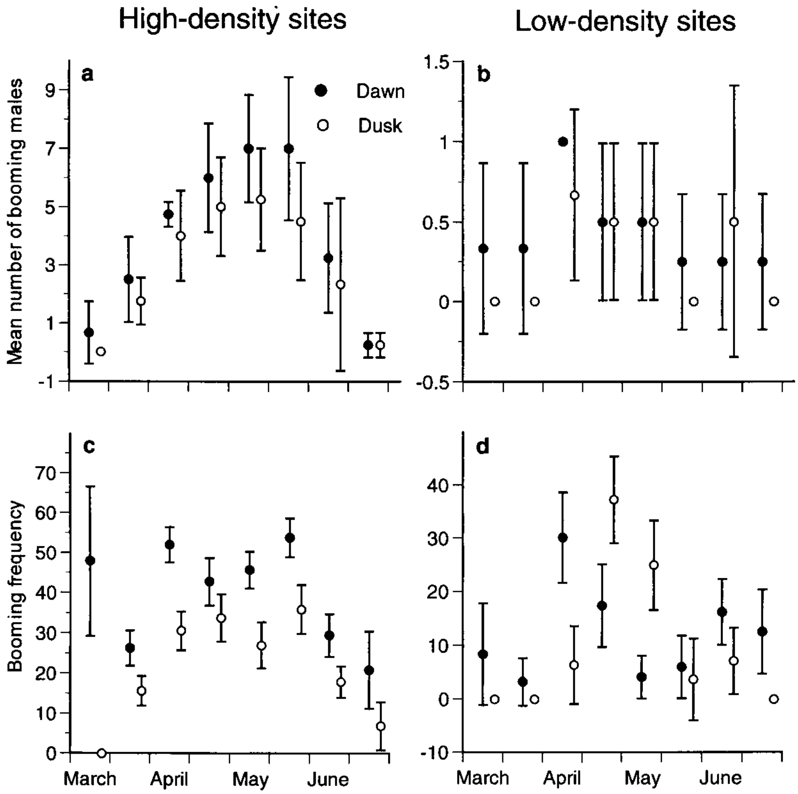

Fig. 2. Twice monthly variation in number of booming males (a, b) and booming frequency (c, d) at sites with multiple (a, c) and single (b, d) bitterns.

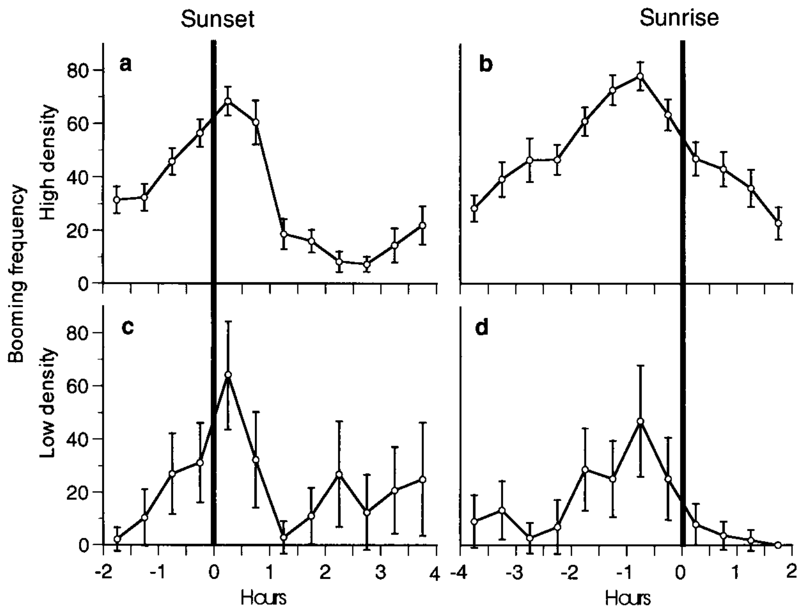

Fig. 3. Variation in mean booming frequency (95% confidence interval) over a 6-h period at dawn (a, c) and dusk (b, d) for sites with multiple (a, b) and single (c, d) bitterns in April–May.

(Fig. 3). The proportion of males booming peaked 0–30 min after sunset (68%), and 30–60 min before sunrise (78%). The mean number of booms (1051 *vs* 248, adjusted $t_2 = -4.8$, $P < 0.001$), and of boom trains (224 *vs* 69, adjusted $t_{21} = -4.3$, $P < 0.001$) per individual were significantly higher

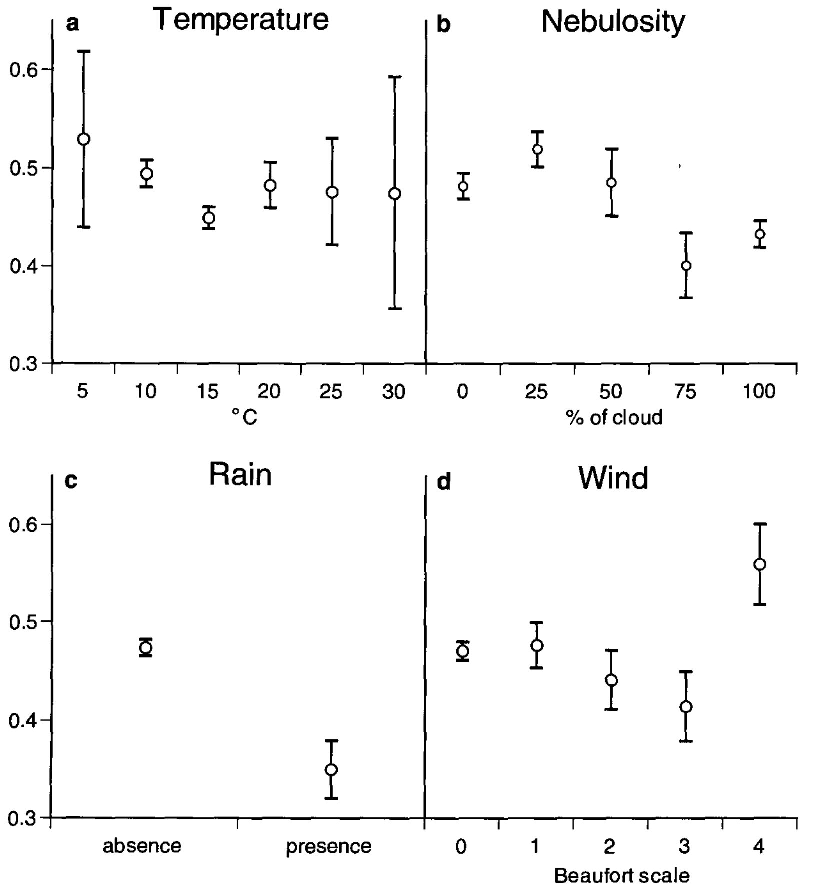

Fig. 4. Standardized residuals in booming frequency (95% confidence interval) in relation to air temperature (a), nebulosity (b), occurrence of light rains (c) and wind speed (d).

at sites with multiple bitterns (Fig. 3). At these sites, booming frequency varied significantly over time at both dawn ($F_{11,276}$ = 32.92, $P < 0.001$) and dusk ($F_{11,276}$ = 63.38, $P < 0.001$). Homogeneous groups with highest booming frequency (Scheffé, $P < 0.05$) were restricted to the 2 h preceding sunrise and from 30 min before to 1 h after sunset. During this period, booming frequency averaged 69% (ES = 1.5) at dawn and 62% (ES = 1.9) at dusk. These values were lower at single-bittern sites, with respectively 31% (SE = 4.0) and 43% (SE = 5.2). Temporal patterns in booming frequencies were similar between sites with single or multiple bitterns when their overall mean values were standardized to 1 (MANOVA, dawn: $F_{1,524}$ = 0.60, P = 0.44; dusk: $F_{1,481}$ = 0.02, P = 0.87).

3.3. Effect of weather on booming activity

April and May sampling was carried out under air temperatures ranging from 2 to 32 °C. Booming activity varied significantly with temperature (F_{15} = 5.76, $P < 0.001$), although no linear pattern emerged (Fig. 4 a). The large sample size (n = 1561 and 2594 respectively) and, hence, the small confidence intervals of the data collected at 10 and 15 °C lead to a significant difference between these two classes (Scheffé, $P < 0.05$), although they were not significantly different from the values observed at other temperatures. Mean booming activity decreased by 9% from 10 to 15 °C, but increased again at 20 °C.

Booming activity also varied according to percent cloud cover (F_{14} = 19.44, $P < 0.001$), with two homogenous groups at 0–50% and 75–100% (Scheffé, $P < 0.05$). Booming activity decreased by 13% with a cloud cover of 75% or more (Fig. 4b). Field work was always initiated in rainless conditions, but the occurrence of light rains during the sampling resulted in a significant effect on booming activity (F_{11} = 22.36, $P < 0.001$), leading to a 25% decrease (Fig. 4c). Booming

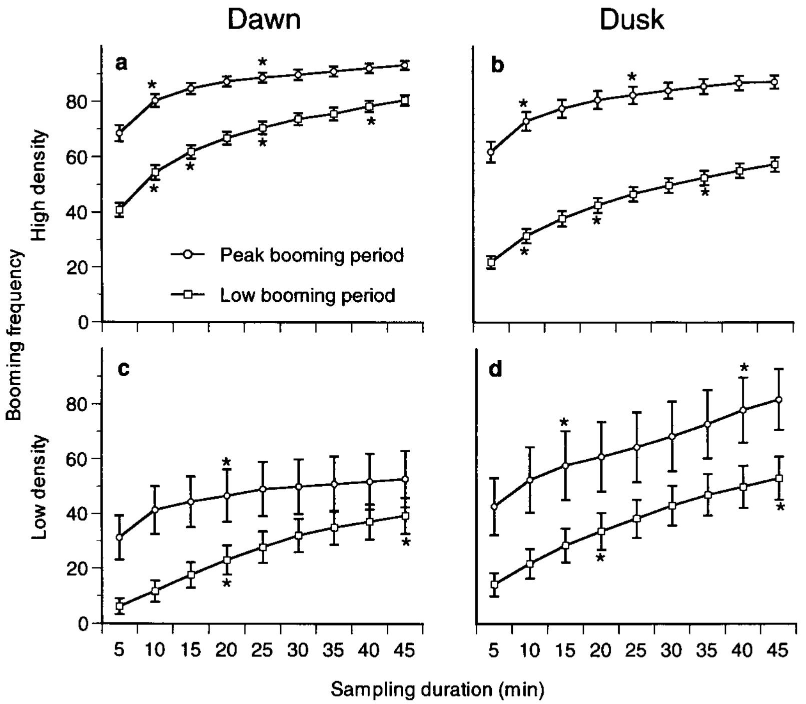

Fig. 5. Mean booming frequency (95% confidence interval) for sampling times of 5 to 45 consecutive min during the peak and low booming periods at dawn (a, c) and dusk (b, d) for sites with multiple (a, b) and single (c, d) bitterns. Sampling times corresponding to a significant increase in probability detection relative to the previous sampling duration are marked with an asterisk.

activity varied according to wind speed ($F_{14} = 7.56$, $P < 0.001$), being significantly higher at 4 on the Beaufort scale (Scheffé $P < 0.05$). Although booming activity increased by 20% at a wind speed above 20 km^{-h}, these cannot be considered as good sampling conditions following the difficulty of hearing and positioning bitterns in windy conditions.

3.4. Optimal sampling schemes

3.4.1. High-density sites

It is not possible to identify individually booming males from one visit to the next, nor to distinguish silent from booming males at any visit. At sites comprising several bitterns, it is therefore important to time the survey with the period of highest detection probability. Given that the proportion of males booming is consistently lower at dusk than at dawn, surveys of high-density sites should be restricted to the peak booming period at dawn (Fig. 5a, 5b). The probability of detecting a booming male during a 5-min sampling at such period corresponds to 66% (Fig. 3a). This proportion increased significantly to 80% for a 10-min sampling, and again after 25 min (Scheffé tests, $P < 0.05$, Fig. 5a). However, because the relationship between the proportion of males detected and the sampling duration is not linear (Fig. 5), increasing sampling duration alone does not allows one to reach a 95% probability detection. The number of samples must be increased as well. Because it is important to maintain a high detection probability on each visit, we propose 2 × 10 min rather than 3 × 5 min as an optimal sampling protocol for high-density sites (Table 1).

3.4.2. Low-density sites

At sites comprising a single bittern, the observer only needs to increase the number of samples until the probability of hearing one booming male reaches 95%.

Sampling can be carried out during a period of low booming frequency with the only disadvantage that sampling effort will have to be increased accordingly (Fig. 5c, 5d). During the peak booming period at dawn, the probability of detecting a bittern within 5 min was 31%, which is substantially lower than at multiple-bittern sites (Fig. 5a, 5c). Only after 20 min did this probability increase significantly (Fig. 5c). Actually, 5 × 20 min is considered as the best optimal sampling protocol for detecting an isolated bittern with a 95% probability during the peak booming period at dawn (Table 1). Outside this period, a 30-min sample provides a similar detection probability than a 5-min sample at the peak booming period (Fig. 5c), and as many as 12 periods of 20 min are needed to reach a 95% probability detection. At dusk, a 5-min sample provides a detection probability of 43% at the peak booming period, and this probability increases significantly to 58% after 15 min, and again after 40 min (Fig. 5d). The best optimal sampling for isolated bitterns would then be 4 × 15 min or 2 × 40 min during the peak booming period at dusk (Table 1). Outside this period, sampling frequency and duration would require a substantial increase (Table 1). A protocol restricted to the peak booming period could also combine dawn and dusk sampling with 2 × 20 min at dawn and 2 × 15 min at dusk, providing a 95% probability of detecting a single bittern.

3.4.3. Sites of unknown bittern density

Our protocols are designed for low and high bittern-density sites. If no bittern survey has ever been conducted, how will an observer know to which category a site belongs? We suggest to start with a 10-min visit during the peak booming period at dawn, which provides a 80 and 42% detection probability at sites of high and low density, respectively. If two bitterns or more are detected, the site probably holds a minimum of three individuals and can be considered as a multiple-bittern site. In this latter case, the observer only has to return to the site for another 10 min to complete the 2 × 10-min protocol. If 0 or 1 bittern is detected after 10 min, the observer should extend the visit to 20 min and follow the 5 × 20-min protocol at dawn or the mixed dawn/dusk protocol of 2 × 20 + 2 × 15 min.

4. Discussion

4.1. Patterns of booming activity

Booming frequency is reported as being typically highest at dusk in April–May (Voisin 1991, Cramp & Simmons 1977), but few quantitative data are available. The mean booming frequency of five bitterns surveyed during 2 h centred on sunset in Italy peaked 20 min after sunset (Puglisi *et al.* 1997). In Britain, booming frequency of a single individual sampled during 24 h peaked during the hour preceding sunrise and in the hour following sunset, with a higher value at dawn than at dusk (Gilbert *et al.* 1994). Our results reveal a peak booming season in April–May with highest booming frequency during the 2 h before sunrise and

Table 1. Optimal sampling protocols during the peak and low booming periods, at low and high-density sites, providing a 95% detection probability of bittern (recommended protocols in bold characters).

High-density sites		Low-density sites	
Peak booming period	Low booming period	Peak booming period	Low booming period
At Dawn			
3 × 5 min	6 × 5 min	9 × 5 min	>20 × 5 min
2 × 10 min	4 × 10 min	**5 × 20 min**	12 × 20 min
	3 × 25 min		6 × 45 min
At dusk			
4 × 5 min	13 × 5 min	6 × 5 min	19 × 5 min
3 × 10 min	8 × 10 min	**4 × 15 min**	7 × 20 min
2 × 25 min	6 × 20 min	**2 × 40 min**	4 × 45 min
	5 × 35 min		

from 30 min before to 1 h after sunset. These results are thus in agreement with the data reported in northern Italy and Britain. Booming frequency was significantly highest at high than at low density sites, having important consequences on sampling duration in the design of optimal protocols. However, it is far more complex to estimate the number of bitterns in large reedbeds where potentially several individuals are present, and although these individuals boom more frequently than isolated individuals, their sampling has to be restricted to the peak period of booming frequency for the count to be as accurate as possible. At low density sites, sampling outside the peak booming period is unlikely to affect estimates of individual numbers as long as the sampling effort is increased to reach a 95% bittern detection probability. Given the apparent little geographic variation in daily and seasonal booming activity, the sampling protocols recommended in this study are probably readily applicable to most bittern sites. A preliminary reduced sampling could nevertheless be useful to confirm the seasonal peak booming period at a given locality. Sampling should not be carried out under rainy conditions, and cloudy skies should be avoided as much as possible. The negative effect of nebulosity suggests a positive effect of moonlight on booming activity.

4.2. Population survey design

In small reedbeds (< 10 ha), bittern surveys should be carried from a single fixed location during two visits of 20 min at dawn and two visits of 15 min at dusk. Because isolated individuals had their booming activity restricted to a relatively short period within the peak booming season, sampling should cover the whole period from early April through late May. Playback of a carefully selected booming sequence could eventually be used after the point count to confirm the absence of bittern (Erwin *et al.* 2002). However, this technique should not be considered as infallible, because some bitterns have been observed to leave the area or become silent after playback (G. Gilbert, pers. comm.).

In medium to large reedbeds where a maximum of two bitterns can be heard from a fixed location, the same sampling design as for small reedbeds should be applied except that more point counts are needed to cover the whole area. Sampling can be carried out at fixed point counts located every 400 m or by walking slowly along a transect at the reedbed edge. In this latter case, a 400-m transect should be completed with the prescribed sample duration (15 or 20 minutes). Acoustic triangulation and characteristics of the calls can be used (see below) to help segregate individuals, especially if the transect approach is chosen.

In medium to large reedbeds where three or more bitterns can be heard from several locations, sampling should be conducted during two visits of 10 min at dawn carried out within a short time interval to reduce the probability of individual movements between visits. Also, to reduce potential bias caused by slight seasonal variations in booming activity from one year to the next, sampling should preferably be conducted in the middle month of the peak period, i.e., between mid-April and mid-May. Counts should be made by groups of two observers distant by 400 m and communicating with walkie-talkie. Each time a bittern booms, the direction of the call is taken with a bearing compass by both observers who agree on an identification code for that individual. Characteristics of the call are noted (number of booms, occurrence of poor booms, time interval between two booms). Priority is given to the birds located between the two observers, even though more birds can be heard from further away. Once the sampling time is elapsed, one observer moves 400 m beyond the other observer (800-m distance) to cover another sampling area/period. The other observer stays at the same point so that he is familiar with the bitterns recorded during the previous sampling period, which is helpful for discriminating the "new" booming males from the ones that have been recorded already. When ≥ 3 bitterns are detected at several points, it becomes necessary to report the observer positions and the bearing angles on a GIS system to estimate the number of males.

5. Conclusion

This population survey design was first applied at the Charnier-Scamandre ecocomplex which comprises 2700 ha of reed marsh in the Camargue (sites 8, 9, 10 in this study). Over 24 linear km of dykes and canals were covered by four people over six days during the peak booming period at dawn. Fifty-four booming males were detected in 2001 compared to 17 based on a previous methodology (Kayser *et al.* 1998). The higher number of bitterns detected with the new protocol was mostly a consequence of (1) restricting the counts to the peak period of booming activity, and (2) reducing the distance between two census points, as the compass of boom is highly variable among individual males. This three-fold increase at a single site represents over 10% of the French bittern population, demonstrating how the integration of behavioural/ecological data in census design may affect population estimates of rare species. This standardized protocol is not designed to provide absolute numbers of male bitterns, but rather to detect a high and constant proportion of males for estimating population trends, and could be especially useful for monitoring the population increase observed in Denmark, Finland and Sweden (Väisänen *et al.* 1998, Broberg 2000).

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Selostus: **Ääntelevien kaulushaikaroiden optimaalisen laskenta-ajankohdan määrittäminen**

Kaulushaikara on piilotteleva kosteikkolaji, jonka runsausarviot perustuvat koirashaikaroiden laskentaan. Koiraiden laskenta puolestaan perustuu ääntelevien yksilöiden esiintymisen kartoittamiseen. Koiraiden ääntelyaktiivisuuden on arvioitu vaihtelevan haikaratiheydestä ja laskenta-ajankohdasta riippuen. Kirjoittajat tutkivat kuinka vuorokaudenaika, vuodenaika, sääolosuhteet ja haikaratiheys vaikuttivat kaulushaikaroiden ääntelyaktiviteettiin kymmenellä tutkimusalueella Camargueessa, Etelä-Ranskassa. Ääntelevia koirashaikaroita etsittiin kaksi kertaa kuukaudessa maaliskuun ja heinäkuun välisenä aikana vuonna 2000. Koiraiden äänet nauhoitettiin. Aineisto jaoteltiin kuuden tunnin jaksoihin eli auringonlaskun ja auringonnousun ajanjaksoihin kuuluviksi. Ääntelevien haikaroiden määrä yksittäisillä tarkkailupaikoilla vaihteli 0–10 haikaran välillä. Ääntelyaktiivisuus oli voimakkainta huhti-toukokuussa. Ääntelevia haikaroita havaittiin kaikkina tutkimuskuukausina enemmän päivänkoitteessa kuin iltahämärässä. Ääntelyaktiivisuudessa havaittiin piikki heti auringonlaskun jälkeen ja ennen auringonnousua. Ääntelyaktiivisuus laski merkittävästi pilvisinä ja sateisina hetkinä, mutta alhaisella lämpötilalla ei havaittu olevan vaikutusta ääntelyaktiivisuuteen. Kirjoittajat toteavat, että laskentoja ei tulisi tehdä sateella eikä myöskään pilvisellä säällä. Kirjoittajat esittävät, että runsashaikaraisilla paikoilla tulisi tehdä kaksi kymmenen minuutin mittaista kuuntelua päivänkoitteessa. Vähähaikaraisilla paikoilla tulisi tehdä viisi kahdenkymmenen minuutin mittaista kuuntelua päivänkoitteessa tai neljä viidentoista minuutin ja kaksi neljänkymmenen minuutin mittaista laskentaa iltahämärässä. Alueilla, joilta ei ole aikaisempia tietoja haikaramääristä, tulisi kirjoittajien mukaan tehdä kymmenen minuutin mittainen kuuntelu päivänkoitteessa. Laskennat pitäisi pyrkiä tekemään haikaroiden vilkkaimpana ääntelyajankohtana; Ranskassa tämä ajoittuu huhti-toukokuuhun.

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