International Journal of Primatology (2019) 40:169–186
https://doi.org/10.1007/s10764-018-0073-3

# An Application of Autonomous Recorders for Gibbon Monitoring

**Thinh Tien Vu**[1] · **Long Manh Tran**[2]

Received: 27 August 2018 / Accepted: 18 October 2018 /

**Abstract**
Population monitoring is very important in wildlife management and conservation. All 18 species of gibbons are considered threatened with extinction and listed on the IUCN Red List of Threatened Species. Thus, understanding and effectively monitoring their population trends and distribution are critical. Thus far, all gibbon surveying and monitoring programs have been conducted by human surveyors; this is expensive, laborious, and dependent on the surveyors' skills. In particular, estimating group density often requires a large sample size with several skilled observers working simultaneously in the field. We used autonomous recorders to record the calls of southern yellow-cheeked crested gibbon (*Nomascus gabbrielae*) for at least 3 days at each of 57 posts in Nam Cat Tien sector, Cat Tien National Park, Vietnam from July to October, 2016. We extracted gibbon calls from the recordings auditorily or visually using spectrograms in RAVEN software. We detected gibbon calls at 40 recording posts during the survey. The proportion of recorders with gibbon calls in the eastern region of Nam Cat Tien sector (mean = 0.79; SE = 0.13) was higher than that in the western region (mean = 0.46; SE = 0.11). The estimated probability of occurrence in the eastern region ($\psi = 0.56$; SE = 0.20) was higher than that in the western region ($\psi = 0.23$; SE = 0.16). Passive acoustic data were useful to investigate spatial variation in the probability of occurrence of gibbon. We recommend using autonomous recorders combined with occupancy model to complement human surveyors in gibbon monitoring in areas with low gibbon density because it is efficient, low cost, and not subject to errors caused by human surveyors. In the areas of high gibbon density, absolute density estimate achieved by human surveyors might be a more suitable indicator.

**Keywords** Bioacoustics · Gibbon · *Nomascus* · Occupancy model · Primate · Song meter

---

Handling Editor: Joanna M. Setchell

✉ Thinh Tien Vu
vutienthinh@hotmail.com

[1] Department of Wildlife, Faculty of Forest Resource and Environment Management, Vietnam National University of Forestry, Xuan Mai, Chuong My, Hanoi, Vietnam

[2] Forest Protection Department, Ministry of Agriculture and Rural Development, No 2, Ngoc Ha, Ba Dinh, Vietnam

## Introduction

Population monitoring is critical in identifying conservation actions and measuring their efficacy (Marsh and Trenham 2008). Monitoring can provide an understanding of extinction risk and changes in wildlife population dynamics (Fonzo *et al.* 2013; Yoccoz et al., 2011). Methods used to monitor wildlife include total counts, line transects, point counts, lure counts, occupancy analysis, and capture–recapture (Buckland *et al.* 1993; Thompson *et al.* 1998; Williams *et al.* 2002), all of which rely on human surveyors. These methods can yield meaningful data, but some are time consuming and expensive.

Passive acoustic monitoring uses recording devices to record the sounds produced by species of interest for subsequent analysis and is useful in wildlife monitoring (Thomas and Marques 2012). Many species produce distinctive sounds to communicate with conspecifics, including to mark a territory, attract mates, or to advertise the presence of potential predators. For vocal species in habitats with visual obstructions, acoustic signals are detectable at greater distances than visual cues and are little affected by weather or time of day. Passive acoustic monitoring has been successfully applied to mammals (Thompson et al., 2010), primates (Kalan *et al.* 2015; Spillmann *et al.* 2015), birds (Tremain et al. 2008; Zwart *et al.* 2014), anurans (Hilje and Aide 2012), insects (Chesmore and Ohya 2004), and other taxa. For vocal species, autonomous recording devices can be more effective than traditional survey methods (Celis-Murillo *et al.* 2012; Zwart *et al.* 2014). Most studies focused on detecting the presence of wildlife species (Chambert *et al.* 2018; Zwart *et al.* 2014), and these presence–absence data can be used with occupancy models to monitor wildlife species (Campos-Cerqueira and Aide 2016; Chambert *et al.* 2018; Kalan *et al.* 2015).

All 18 species of gibbon on the IUCN Red List of Threatened Species are threatened with extinction, with 4 considered Critically Endangered, 12 Endangered, and 1 Vulnerable (IUCN Red List of Threatened Species 2017). All gibbon surveying and monitoring programs to date have been conducted by human surveyors, but this has several disadvantages. First, gibbons usually live in the upper forest canopy and are sensitive to human presence. This makes visual detection of gibbons very difficult in the field, especially in short surveys. Second, although gibbons can be detected by their territorial loud and long song bouts (Geissmann 1993; Geissmann and Orgeldinger, 2000), emitted in the early morning, and although human surveyors can detect the gibbon call from 1 to 2 km, depending on the terrain (Vu and Dong 2015; Vu *et al.* 2016), gibbon groups do not call daily, so 3–5 days are needed to detect most gibbon groups (Brockelman and Ali 1987; Brockelman and Srikosamatara 1993). Third, relying on human surveyors is very expensive and labor intensive, especially given the fact that gibbons are now found only in remote areas (Vu and Dong 2015; Vu *et al.* 2016). These difficulties help to explain why few programs monitor endangered gibbon populations frequently.

Estimates of gibbon group density and population sizes based on current methods may not be accurate enough for monitoring purposes. To estimate the density of gibbons requires accurate determination of both the location of gibbon group and the distance from the gibbon groups to the surveyors. Moreover, calls detected at different times during one day or on different days must be assigned to the correct gibbon groups, and calling probability has to be estimated accurately. Surveyors determine the location of gibbon groups using triangulation for groups detected from at least two listening posts (Gilhooly *et al.* 2015). Theoretically, this method works because gibbons are territorial and occupy a small home range (Brockelman and Ali 1987). If the distance between two gibbon groups detected at different times of a day or on different days is >500 m, they are considered to be two groups; otherwise, they are considered as one group (Brockelman and Ali 1987). This group differentiation requires accurate estimates of gibbon group locations. Mistaking one gibbon group for two different ones or vice versa could lead to a serious bias in gibbon density estimation. This mistake can also bias estimates of the calling probability and the correction factor used to estimate density. Moreover, defining two groups because they are separated by ≥500 m might not work well if gibbon home ranges are not circular. Gibbon home ranges may be elongated or irregular because the habitat is not always uniform (Bartlett *et al.* 2015). In such cases, the same gibbon group can be detected at two locations that are far more than 1000 m apart (Kenyon 2008). By contrast, the home ranges of adjacent groups might overlap (Kenyon 2008), resulting in a failure to differentiate between two neighboring groups. Finally, assuming gibbon groups are differentiated accurately, bias in estimates of calling probability and the associated correction factor can still exist if gibbons far from the listening post are included in the estimation, because calls of such groups may not be detected, and the estimate of calling probability will be negatively biased if those gibbon groups are included (Vu *et al.* 2018b).

Critical assumptions of accurate gibbon location determination might not be met in several situations: 1) If gibbon groups are detected from only one listening post, triangulation cannot be used (e.g., groups 1, 5, and 6 in Fig. 1). The area where triangulation cannot be used might be very large (e.g., 48% in Fig. 1). 2) If listening posts are close together, the overlapping region where triangulation can be used will increase. However, in such cases, two lines used in the triangulations for gibbon groups detected far from the listening posts will be nearly parallel (e.g., groups 2 and 3 in Fig. 1); this causes a large error in determining gibbon group locations (Vu *et al.* 2018a). 3) In flat terrain, the maximum hearing distance is smaller, and therefore the proportion of the area where gibbons can be detected from only one listening post will be higher. If only two listening posts are used simultaneously, the area where triangulation does not work is much larger (58% in Fig. 1). 4) A gibbon group inhabiting the area near the boundary of the maximum hearing distance (e.g., group 2 in Fig. 1) may be detected from two listening posts on a particular day, but might be detected from only one listening post on other days because it moves far away, leading to uncertainty in determining the group location. Omitting gibbon groups detected from only one listening post provides a more accurate estimate (Gilhooly *et al.* 2015) but reduces the area surveyed. Most gibbon surveys include gibbon groups detected from only one listening post in analysis (e.g., Jiang *et al.* 2006; Kidney *et al.* 2016; Vu *et al.* 2016), which can lead to uncertain density estimates (Gilhooly *et al.* 2015).

Bioacoustic data used with an occupancy model (MacKenzie *et al.* 2006) can resolve most of the limitations of traditional monitoring methods for gibbons and offer great potential (Gray *et al.* 2010). Although they cannot be used to estimate absolute density, information on the presence of gibbons is very important for monitoring population trends, especially in areas with low gibbon density. In areas with high wildlife density, even if the density changes, the occurrence probability might not change very much, making presence data less useful (MacKenzie *et al.* 2006).

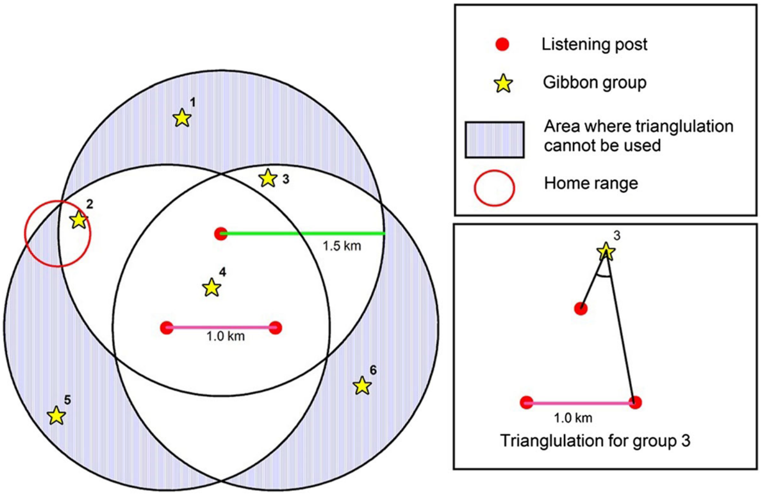

**Fig. 1** Arrangement of listening posts in a normal gibbon survey with a maximum hearing distance of 1.5 km and listening posts 1.0 km apart.

Moreover, recordings collected in gibbon monitoring activities can also be used to monitor other vocal wildlife species. Finally, occupancy modeling can incorporate data collected from several years in a multiseason model, allowing analysis of population trends using a single model, and thus improving accuracy.

Given their habitat and their tendency to avoid human observers, gibbon management could benefit greatly from acoustic monitoring techniques. Gibbons are entirely frugivorous and herbivorous; the diet of yellow-cheeked crested gibbons (*Nomascus gabbrielae*) contains fruits (43.3%), leaves (38.4%), flowers (11.6%), and other plant parts (6.0%) (Bach *et al.* 2017). Therefore, the presence and density of gibbons are strongly affected by forest quality and type (Hamard *et al.* 2010; Phoonjampa *et al.* 2011). Gibbons species prefer rich forest, and especially evergreen broadleaf forest, over other habitat types (Gray *et al.* 2010) because rich forest provides abundant and year-round food resources owing to its high diversity in tree species. In addition, broadleaf forest, especially with high canopy closure, is suitable for gibbon movement.

We used autonomous recorders to detect the presence and to estimate the occurrence probability of the southern yellow-cheeked crested gibbon (*Nomascus gabbrielae*) in Cat Tien National Park, Vietnam. We also examined the effect of forest quality on the probability of the species occurring.

## Methods

### Study Area

Cat Tien National Park (11°21′–11°48′N, 107°10′–107°34′E) is in Southern Vietnam (Fig. 2) and consists of two main sectors: Nam Cat Tien in Dong Nai Province and Binh Phuoc Province with an area of 43,243 ha, and Cat Loc in Lam Dong Province, with an area of 30,635 ha (BI and FIPI 2001) (Fig. 3, 4).

**Fig. 2** Location of Cat Tien National Park in Vietnam, with the western and eastern sections of Nam Cat Tien sector.

We surveyed southern yellow-cheeked gibbons in the Nam Cat Tien sector. The area is quite flat with low hills. The highest peak has an elevation of 372 m (BI and FIPI 2001). We divided the sector into two regions. The eastern region is dominated by rich and medium forest (timber volume > 100 $m^3$/ha, closed canopy) and covers 13,949 ha. The western region is dominated by poor forest (timber volume < 100 $m^3$/ha) and bamboo with an area of 31,354 ha.

## Recording Gibbon Calls

We recorded gibbon calls using four Song meter SM3 recorders (Wildlife Acoustics Inc., Maynard, MA, USA). We placed the recorders at 57 recording posts 100–400 m apart. We used 33 recording posts in the eastern region of Nam Cat Tien sector and 24 in the western region. We placed fewer listening posts in the western region because the habitat is less suitable for gibbons. We placed recording posts at the top of ridges on the hills to

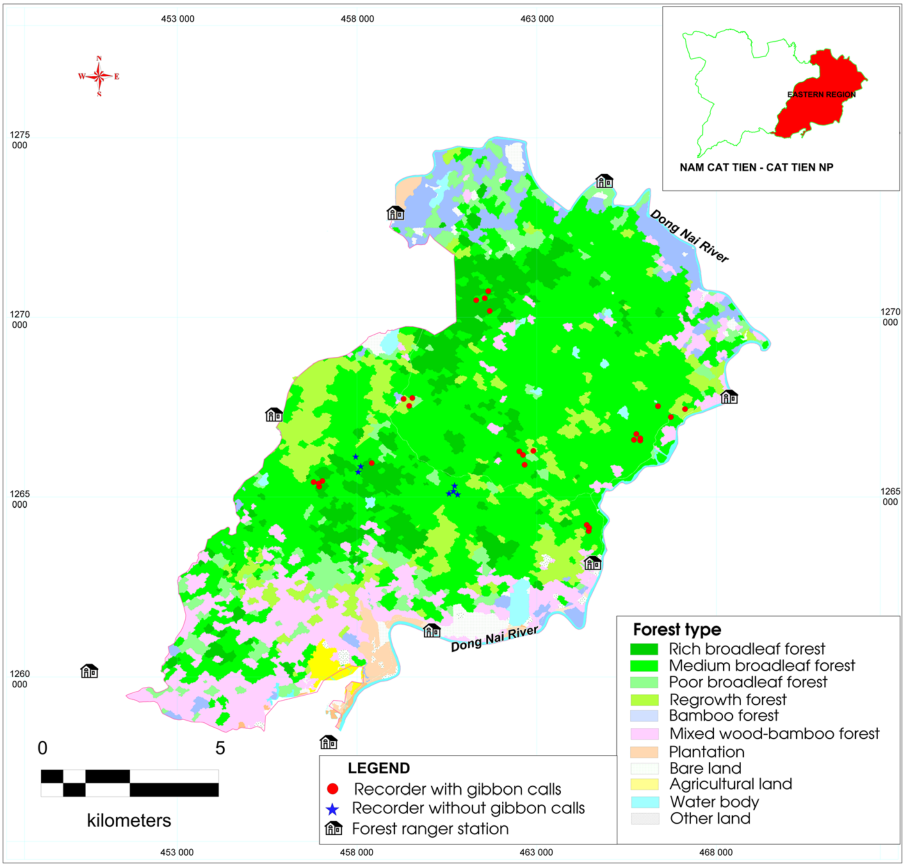

**Fig. 3** Locations of recorders in the eastern region of Nam Cat Tien sector of Cat Tien National Park, Vietnam, in a survey of southern yellow-cheeked gibbons (*Nomascus gabriellae*) using autonomous recorders July–October 2016.

detect gibbon calls more easily. We used a topographic map to select the top of the hills before conducting the field survey. We selected recording posts in areas representative of the whole Nam Cat Tien sector without prior information on gibbon distribution.

We recorded at each post for at least 3 consecutive days from July to October 2016. For human surveys, 3 days are enough to detect 80–90% of gibbon groups in the area surrounding the listening post (Vu *et al*. 2018b). We attached the recorder to a tree and set the device to record from 04:00 to 20:00 h on both channels with a sampling rate of 24,000 Hz at 16-bit mode. Recordings were saved to a SD card at 30-min intervals. We changed batteries and memory disks after 3 days of recording at each post.

## Data Analysis

We used RAVEN software (Cornell Lab of Ornithology, Ithaca, NY, USA) to analyze the sound data. We visually identified calls in the spectrogram view and also listened to the whole recording from 04:00 to 08:00 h to detect gibbon calls. We did not use an automatic sound detection algorithm. Misidentification of gibbon calls was minimized because there is

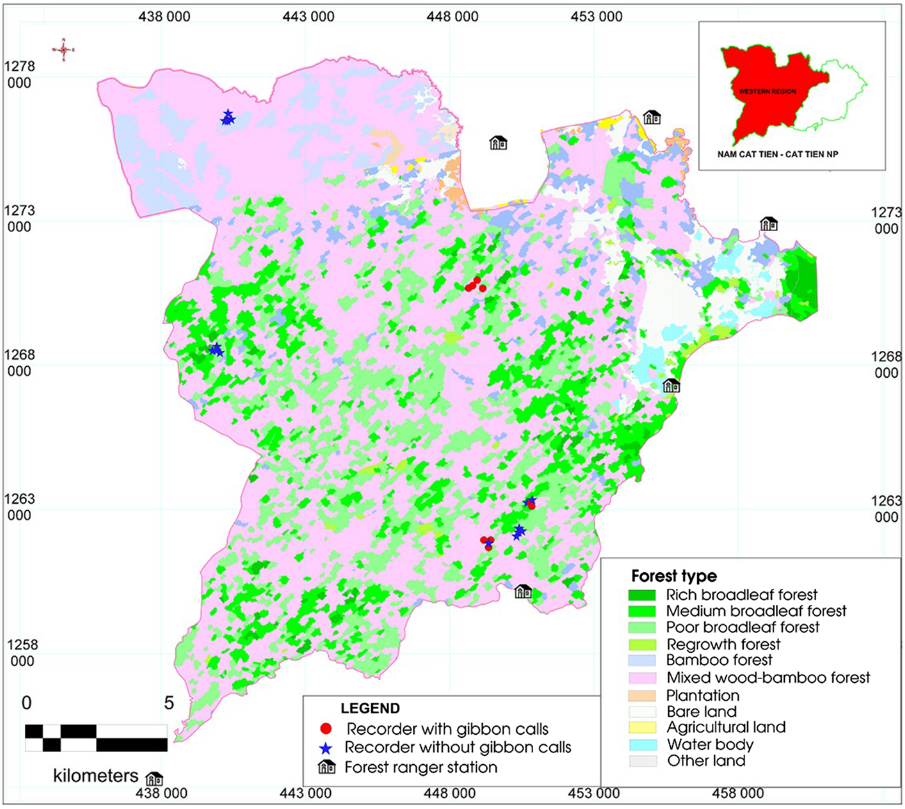

**Fig. 4** Locations of recorders in the western region of Nam Cat Tien sector of Cat Tien National Park, Vietnam, in a survey of southern yellow-cheeked gibbons (*Nomascus gabriellae*) using autonomous recorders, July–October 2016.

only one gibbon species in the area and their call is distinct from that of other wildlife species. If we detected gibbon calls in a recording for a given day at a recording post, we then treated that recording post as “occupied” for that day. We considered a day as an “occasion” in a capture–recapture framework and used the presence data for 3 days to build the history data for each recording post. We used the forest cover map of the National Park (scale 1:10,000; CTNP 2016) to calculate the area of rich and medium broadleaf forest 1 km around each recording post because field trials showed that the recorders can record the gibbon call at an distance up to *ca.* 600–700 m and the gibbon groups usually move within a home range with a radius of *ca.* 300 m (Brockelman and Ali 1987). The map was made using SPOT 6 satellite images with careful ground correction by forest rangers during national forest survey project (CTNP 2016). We created a circle with 1 km radius around each listening post and calculated the area of each forest type within that circle using MapInfo 10.0 (Pitney Bowes Business Insight, Troy, NY, USA). We used the area of rich and medium forest around recording posts as the “forest” covariate when modeling the probability of occurrence.

We used the Occupancy Estimation with detection <1 (MacKenzie *et al.* 2006) in MARK (White and Burnham 1999) to estimate detection probability and the probability that gibbons occurred. We constructed eight models (Table I).

We evaluated and ranked the models using AICc (Akaike's information criterion adjusted for small samples) and ΔAICc (Burnham and Anderson 2002). We examined the importance of the covariates in modeling occurrence probabilities, as well as region, using model rankings (ΔAICc), and cumulative AICc weights ($\Sigma w_i$) (Burnham and Anderson 2002). Cumulative AICc weight for a given covariate is the sum of the AICc weights of all models that contain that covariate. We averaged parameters of interest ($p$ and $\psi$) across the entire model set.

**Data Availability** The datasets analyzed during the current study are available from the corresponding author on reasonable request.

## Ethical Note

Our research did not involve catching, handling, or disturbing wildlife and adhered to the legal requirements of Vietnam and the relevant Principles for the Ethical Treatment of Primates. All authors do not have conflicts associated with this publication.

## Results

### Gibbon Calls Detected

We detected gibbon calls at 40 recording posts during the survey (Table II; Figs. 3, 4). We detected gibbon calls at 21 recording posts during the first day of the 3-day session, 24 recording posts during the second day and 34 recording posts during the third day.

We detected gibbon calls at 28 recording posts in the eastern region and at 12 recording posts in the western region. The proportion of recorders with gibbon calls in the eastern region was higher than that in the western region (Fig. 5). The habitat around recording posts in the eastern region was dominated by rich and medium forests that are suitable for gibbons (Fig. 6).

The habitat around recording posts where we recorded gibbon calls recorded was dominated by rich and medium forests that are suitable for gibbons (Fig. 7). The habitat quality around the posts without gibbon calls is poorer with poor, regrowth forests, mixed wood and bamboo forest, and bamboo forest.

### Occupancy Estimation

When we modeled the occurrence probability, models with detection probability varying by day ranked higher than models with constant detection probability (Table III). The detection probability increased from day 1 to day 3 (Table III).

The model with different occurrence probabilities between the two regions of the sector ranked significantly higher than the models with a common occurrence probability. The cumulative AICc weights for models with different occurrence probabilities between the two regions was high (0.73). We estimated the occurrence probability in the eastern region to be higher than that in the western region (Fig. 8).

**Table I** Models used in the analysis of data collected during a survey of southern yellow-cheeked gibbons (*Nomascus gabriellae*) using autonomous recorders in Cat Tien National Park, Vietnam, July–October 2016

| Model number | Model name | Detection probability (*p*) | Occurrence probability (ψ) |
|---|---|---|---|
| 1 | *p*(.),ψ(.) | *p* does not vary with time | ψ is similar between the two regions of Nam Cat Tien sector (NCTS) of Cat Tien National Park.<br>The area of rich and medium forest (Forest covariate) has no effect on ψ. |
| 2 | *p*(.),ψ(region) | *p* does not vary with time | ψ is different between the two regions of NCTS.<br>Forest covariate has no effect on ψ. |
| 3 | *p*(day), ψ(.) | *p* varies with time | ψ is similar between the two regions of NCTS.<br>Forest covariate has no effect on ψ. |
| 4 | *p*(day), ψ(region) | *p* varies with time | ψ is different between the two regions of NCTS.<br>Forest covariate has no effect on ψ. |
| 5 | *p*(.),ψ(forest) | *p* does not vary with time | ψ is similar between the two regions of NCTS.<br>Forest covariate has an effect on ψ. |
| 6 | *p*(.),ψ(region, forest) | *p* does not vary with time | ψ is different between the two regions of NCTS.<br>Forest covariate has an effect on ψ. |
| 7 | *p*(day), ψ(forest) | *p* varies with time | ψ is similar between the two regions of NCTS.<br>Forest covariate has an effect on ψ. |
| 8 | *p*(day), ψ(region, forest) | *p* varies with time | ψ is different between the two regions of NCTS.<br>Forest covariate has an effect on ψ. |

The models with the area of rich and medium forests around each recording post as covariate ranked higher than the models without this covariate. The cumulative AICc weights of models with covariate "forest" was 0.38 and these models did not appear in the top models; using model *p (*day), ψ (forest) alone, we predicted that gibbon occurrence probability increased gradually as the area of rich and medium forest increased (Fig. 9). The *p*(day), ψ(forest) model ranked highest if we did not divide the study area into two regions.

## Discussion

We found that autonomous recorders detected gibbon calls at most of our listening posts in the eastern region of Nam Cat Tien sector of Cat Tien National Park, suggesting that autonomous recorders can be useful to monitor gibbons. The number of posts where we recorded gibbon calls and the probability of occurrence were lowest on the first day and highest on the third day of three day surveys. The probability of occurrence and percentage of posts with gibbon calls was higher in the eastern region of the sector than in the western region.

We usually set the recorders up the previous afternoon and at some posts we set them up very early in the morning. Thus, the lower number of recording posts with gibbon calls and the lower probability of occurrence on the first day, relative to the other two days of the survey, might be because gibbons avoided the area due to the presence of humans (Reisland and Lambert 2016).

**Table II** Recording posts where we recorded gibbon calls during a survey of southern yellow-cheeked gibbon (*Nomascus gabriellae*) using autonomous recorders in Cat Tien National Park, Vietnam, July–October 2016

| Recording post | Date | Region | *X* (m) | *Y* (m) | Presence | Area of rich and medium forest around post (ha) |
|---|---|---|---|---|---|---|
| 1 | July 19–21, 2016 | Eastern | 467,125 | 1,267,452 | 1 | 140.22 |
| 2 | July 19–21, 2016 | Eastern | 466,373 | 1,267,535 | 1 | 249.08 |
| 3 | July 19–21, 2016 | Eastern | 466,731 | 1,267,231 | 1 | 189.23 |
| 4 | July 23–25, 2016 | Eastern | 462,907 | 1,266,289 | 1 | 261.94 |
| 5 | July 23–25, 2016 | Eastern | 462,618 | 1,266,174 | 1 | 257.66 |
| 6 | July 23–25, 2016 | Eastern | 462,662 | 1,265,900 | 1 | 245.31 |
| 7 | July 26–28, 2016 | Eastern | 457,962 | 1,266,131 | 0 | 267.13 |
| 8 | July 26–28, 2016 | Eastern | 458,407 | 1,265,948 | 1 | 287.71 |
| 9 | July 26–28, 2016 | Eastern | 458,105 | 1,265,861 | 0 | 284.91 |
| 10 | July 26–28, 2016 | Eastern | 485,029 | 1,265,707 | 0 | 292.67 |
| 11 | July 30–Aug. 1, 2016 | Eastern | 461,533 | 1,270,536 | 1 | 309.96 |
| 12 | July 30–Aug. 1, 2016 | Eastern | 461,650 | 1,270,736 | 1 | 310.91 |
| 13 | July 30–Aug. 1, 2016 | Eastern | 461,314 | 1,270,481 | 1 | 311.95 |
| 14 | July 30–Aug. 1, 2016 | Eastern | 461,691 | 1,270,180 | 1 | 285.39 |
| 15 | Aug. 17–19, 2016 | Eastern | 456,948 | 1,265,291 | 1 | 257.23 |
| 16 | Aug. 17–19, 2016 | Eastern | 456,789 | 1,265,417 | 1 | 237.95 |
| 17 | Aug. 17–19, 2016 | Eastern | 457,037 | 1,265,447 | 1 | 247.67 |
| 18 | Aug. 17–19, 2016 | Eastern | 456,932 | 1,265,382 | 1 | 247.36 |
| 19 | Aug. 21–23, 2016 | Eastern | 464,494 | 1,264,061 | 1 | 154.56 |
| 20 | Aug. 21–23, 2016 | Eastern | 464,564 | 1,264,197 | 1 | 156.9 |
| 21 | Aug. 21–23, 2016 | Eastern | 464,463 | 1,264,043 | 1 | 155.43 |
| 22 | Aug. 21–23, 2016 | Eastern | 464,391 | 1,264,231 | 1 | 174.66 |
| 23 | Sept. 18–20, 2016 | Eastern | 459,450 | 1,267,545 | 1 | 245.71 |
| 24 | Sept. 18–20, 2016 | Eastern | 459,539 | 1,267,762 | 1 | 244.65 |
| 25 | Sept. 18–20, 2016 | Eastern | 459,294 | 1,267,738 | 1 | 215.69 |
| 26 | Sept. 21–23, 2016 | Eastern | 460,713 | 1,265,322 | 0 | 276.72 |
| 27 | Sept. 21–23, 2016 | Eastern | 460,683 | 1,265,169 | 0 | 271.36 |
| 28 | Sept. 21–23, 2016 | Eastern | 460,797 | 1,265,077 | 0 | 262.48 |
| 29 | Sept. 21–23, 2016 | Eastern | 460,559 | 1,265,106 | 0 | 270.84 |
| 30 | Sept. 25–27, 2016 | Eastern | 465,881 | 1,266,576 | 1 | 255.14 |
| 31 | Sept. 25–27, 2016 | Eastern | 465,705 | 1,266,596 | 1 | 268.92 |
| 32 | Sept. 25–27, 2016 | Eastern | 465,881 | 1,266,636 | 1 | 261.39 |
| 33 | Sept. 25–27, 2016 | Eastern | 465,772 | 1,266,759 | 1 | 277.87 |
| 34 | Oct. 14–16, 2016 | Western | 450,683 | 1,263,243 | 0 | 89.46 |
| 35 | Oct. 14–16, 2016 | Western | 450,844 | 1,263,107 | 1 | 77.67 |
| 36 | Oct. 14–16, 2016 | Western | 450,859 | 1,263,346 | 0 | 78.23 |

**Table II** (continued)

| Recording post | Date | Region | *X* (m) | *Y* (m) | Presence | Area of rich and medium forest around post (ha) |
|---|---|---|---|---|---|---|
| 37 | Oct. 14–16, 2016 | Western | 450,802 | 1,263,222 | 1 | 82.54 |
| 38 | Oct. 17–19, 2016 | Western | 450,313 | 1,262,080 | 0 | 68.46 |
| 39 | Oct. 17–19, 2016 | Western | 450,401 | 1,262,353 | 0 | 76.61 |
| 40 | Oct. 17–19, 2016 | Western | 450,382 | 1,262,216 | 0 | 75.69 |
| 41 | Oct. 17–19, 2016 | Western | 450,503 | 1,262,262 | 0 | 76.55 |
| 42 | Aug. 11–13, 2018 | Western | 439,922 | 1,268,662 | 0 | 165.15 |
| 43 | Aug. 11–13, 2018 | Western | 439,772 | 1,268,520 | 0 | 168.46 |
| 44 | Aug. 11–13, 2018 | Western | 440,027 | 1,268,449 | 0 | 152.9 |
| 45 | Aug. 11–13, 2018 | Western | 439,899 | 1,268,524 | 0 | 159.94 |
| 46 | Aug. 14–16, 2018 | Western | 449,181 | 1,261,931 | 1 | 37.05 |
| 47 | Aug. 14–16, 2018 | Western | 449,343 | 1,261,678 | 1 | 39.99 |
| 48 | Aug. 14–16, 2018 | Western | 449,418 | 1,261,932 | 1 | 46.25 |
| 49 | Aug. 14–16, 2018 | Western | 449,343 | 1,261,838 | 0 | 41.71 |
| 50 | Aug. 3–5, 2016 | Western | 448,950 | 1,270,956 | 1 | 63.47 |
| 51 | Aug. 3–5, 2016 | Western | 448,651 | 1,270,678 | 1 | 53.28 |
| 52 | Aug. 3–5, 2016 | Western | 448,950 | 1,270,956 | 1 | 63.47 |
| 53 | Aug. 3–5, 2016 | Western | 448,795 | 1,270,764 | 1 | 61.01 |
| 54 | Aug. 7–9, 2016 | Western | 440,418 | 1,276,545 | 0 | 0 |
| 55 | Aug. 7–9, 2016 | Western | 440,199 | 1,276,489 | 0 | 0 |
| 56 | Aug. 7–9, 2016 | Western | 440,287 | 1,276,494 | 1 | 0 |
| 57 | Aug. 7–9, 2016 | Western | 440,308 | 1,276,748 | 0 | 0 |

0 = gibbon calls not recorded; 1 = gibbon calls recorded; coordinates following Projection VN2000

The higher probability of occurrence and percentage of recording posts with gibbon calls in the eastern than the western region of Nam Cat Tien sector reflects findings of an earlier study that estimated that the gibbon density in the eastern region was higher than in the western region (Kenyon, 2008). Gibbon density is affected by forest quality (Cheyne *et al.* 2016; Phoonjampa *et al.* 2011) and the difference in the probability of occurrence and percentage of recording posts with gibbon calls between the two regions is probably because the habitat in the eastern region is dominated by rich and medium forests, while the habitat in the western region is dominated by bamboo, mixed wood-bamboo, and poor forests. Models including forest type did not appear as the top model but this is likely to be because the covariate "region" includes the effect of habitat quality. In addition to the difference in habitat quality between the eastern and western regions, the higher ranking of models containing the covariate "region" may be due to the difference in protection levels between the two regions of Nam Cat Tien. The eastern region has higher protection, with most of the forest <2.5 km from the ranger stations (Fig. 3). In some areas, the ranger stations are located far inside in the national park boundary, and although the eastern region makes up only 31% of Nam Cat Tien, it

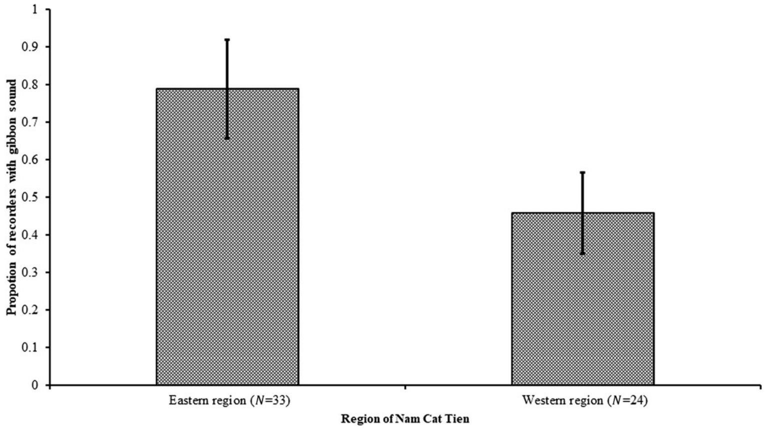

**Fig. 5** Proportion and associated standard error of recorders that recorded gibbon calls in two regions of Nam Cat Tien sector in a survey using autonomous recorders for southern yellow-cheeked gibbons (*Nomascus gabriellae*) in Cat Tien National Park, Vietnam, July–October 2016.

contains more than half of the stations. In the western region, a larger proportion of the forest is >5 km from the ranger stations (Fig. 4). Gibbon density is significantly higher at sites near the ranger stations than at those farther away (Kenyon, 2008). In addition, Dong Nai River serves as a natural barrier protecting the eastern region from illegal entry to the forest by local people and poachers (Fig. 3). In contrast, the western region borders several local communities and Vinh Cuu protected area. There are fewer park rangers, staff, and tourists for poachers to avoid in the western region than in the eastern region.

The occupancy model with passive acoustic data was powerful in modeling spatial variation in the probability of occurrence. This suggests that this method might be

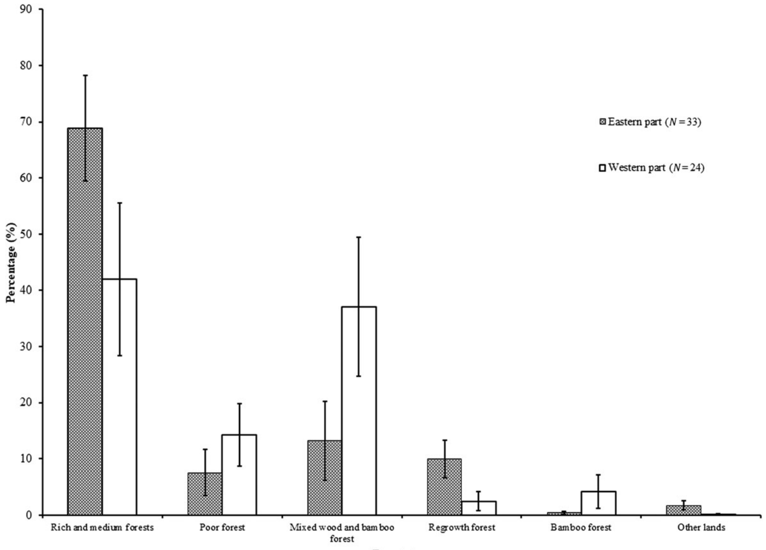

**Fig. 6** Mean and standard error of the percentage of each forest type in a circle with a radius of 1 km around recording posts in two regions of Cat Tien National Park, Vietnam, July–October 2016.

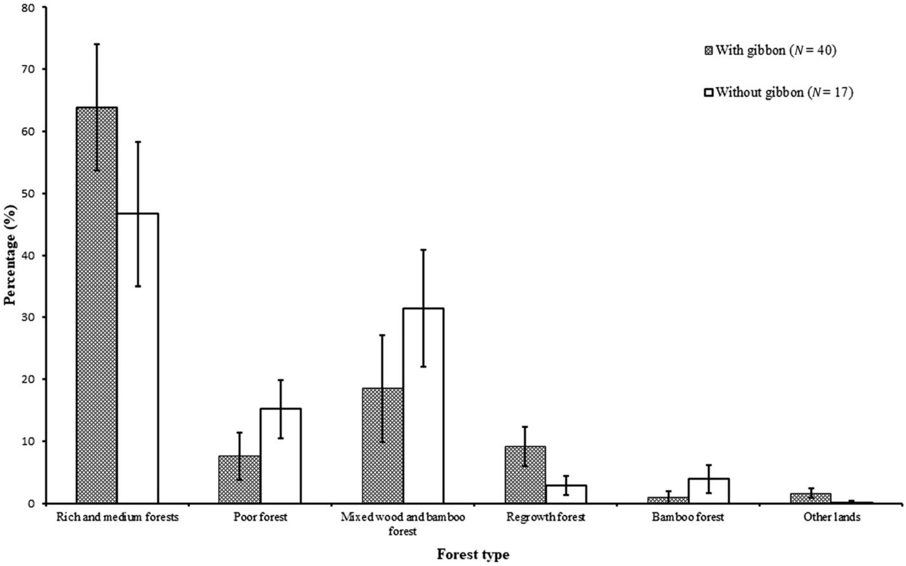

**Fig. 7** Mean and standard error of the percentage of each forest type in a circle with a radius of 1 km around recording posts where we recorded gibbons vs. those where we did not record gibbons in Cat Tien National Park, Vietnam.

useful for modeling temporal variation in gibbon populations. Thus, although the absolute density and exact location of gibbon groups are unknown, using autonomous recorders with occupancy model is a promising tool for gibbon monitoring, especially in remote sites or in regions with few skilled field surveyors.

Detecting trends in wildlife populations is critically important in conservation. Estimation of the probability of occurrence can be used to detect population trends in areas with low gibbon group densities. As occupancy is based on presence/absence data in a geographic area, in the areas of high gibbon group densities, when density increases, occupancy will approach one even as density continues to increase. Thus, occupancy in such cases is a coarser measure than density and changes in density are not necessarily equivalent to changes in occupancy. However, many gibbons can occur at <1.0 group/km$^2$ (Jiang *et al*., 2006; Vu and Dong 2015; Vu *et al*. 2016; *cf.* Nijman 2004; O'Brien *et al*. 2004) and gibbon density is naturally low in unfavorable habitat such as dry forest or mixed wood and bamboo forest (Gray *et al*. 2010). In recording areas smaller than 1.1 km$^2$, with a 600-m radius, recorded calls are likely to come from a single gibbon group. In such cases, comparing estimates of occurrence probability between years can detect decline or growth trends of gibbon populations.

Recorders have several advantages over human listeners in gibbon monitoring. One of the most important advantages is that surveyors avoid the dangers of walking in the forests and climbing slopes or cliffs to get the top of mountains before 05:00 h, when gibbons start to be active. Moreover, a team of two people can set up and recover acoustic recorders in just two working days, often without the need to camp overnight. In contrast, covering three posts simultaneously in a survey requires at least seven people to camp at a site for 3–4 days: at least two people per listening post and a camp

**Table III** Occupancy model selection based on a survey using autonomous recorders for southern yellow-cheeked gibbon (*Nomascus gabriellae*) in Cat Tien National Park, Vietnam, July–October 2016

| Model | AICc | Delta AICc | AICc weights | Model likelihood | Number of parameters | Model estimate | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $p$ (SE) | | | $\psi$ (SE) | |
| | | | | | | $p1$ | $p2$ | $p3$ | Eastern | Western |
| $p$(day), $\psi$(region) | 132.04 | 0.00 | 0.29 | 1.00 | 5 | 0.22 (0.10) | 0.30 (0.11) | 0.52 (0.14) | 0.57 (0.14) | 0.17 (0.10) |
| $p$(.), $\psi$(region) | 132.20 | 0.16 | 0.26 | 0.92 | 3 | 0.32 (0.09) | 0.32 (0.09) | 0.32 (0.09) | 0.61 (0.16) | 0.18 (0.10) |
| $p$(day), $\psi$(forest) | 134.09 | 2.05 | 0.10 | 0.36 | 5 | 0.21 (0.10) | 0.30 (0.12) | 0.51 (0.15) | 0.39 (0.12) | 0.39 (0.12) |
| $p$(.), $\psi$(forest) | 134.20 | 2.16 | 0.10 | 0.34 | 3 | 0.32 (0.09) | 0.32 (0.09) | 0.32 (0.09) | 0.43 (0.14) | 0.43 (0.14) |
| $p$(.), $\psi$(region, forest) | 134.31 | 2.27 | 0.09 | 0.32 | 4 | 0.32 (0.09) | 0.32 (0.09) | 0.32 (0.09) | 0.70 (0.28) | 0.12 (0.15) |
| $p$(day), $\psi$(region, forest) | 134.36 | 2.32 | 0.09 | 0.31 | 6 | 0.22 (0.10) | 0.30 (0.12) | 0.52 (0.15) | 0.65 (0.25) | 0.12 (0.13) |
| $p$(day), $\psi$(.) | 136.03 | 3.99 | 0.04 | 0.14 | 4 | 0.22 (0.10) | 0.30 (0.11) | 0.52 (0.14) | 0.40 (0.14) | 0.40 (0.14) |
| $p$(.), $\psi$(.) | 136.37 | 4.33 | 0.03 | 0.11 | 2 | 0.33 (0.10) | 0.33 (0.10) | 0.33 (0.10) | 0.43 (0.12) | 0.43 (0.12) |

$p$ = detection probability; $\psi$ = occurrence probability; SE = standard error; $p1$, $p2$, $p3$ = detection probability on day 1, 2, and 3, respectively

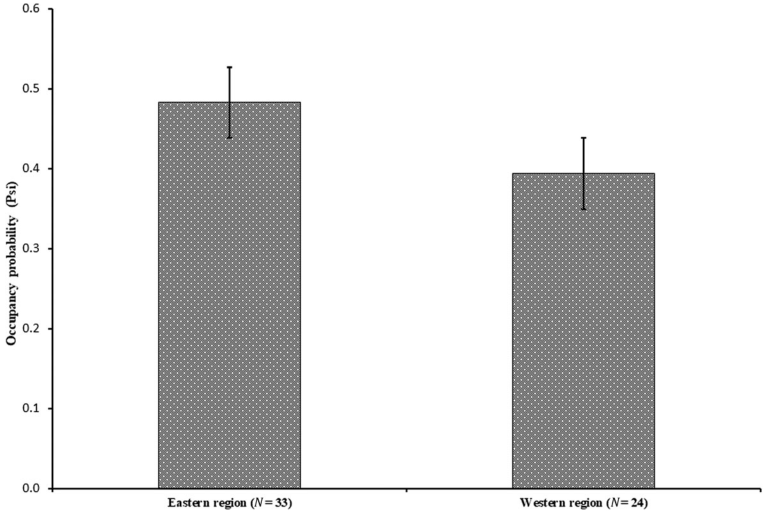

**Fig. 8** Mean and standard error estimated of occurrence probability in a survey of southern yellow-cheeked gibbon (*Nomascus gabriellae*) using autonomous recorders in two regions of Cat Tien National Park, Vietnam, July–October 2016.

keeper. Thus, using autonomous recorders reduces the budget by reducing the number of people involved, and the need to camp.

A disadvantage of monitoring program is that surveyors have to listen to the recordings or use a bioacoustics analysis program to find the gibbon call spectrograms. However, with experience, recordings from three mornings at three recording posts can be easily screened in one day. By our experience, a protected area staff can learn and use the free RAVEN software in fewer than 3 days.

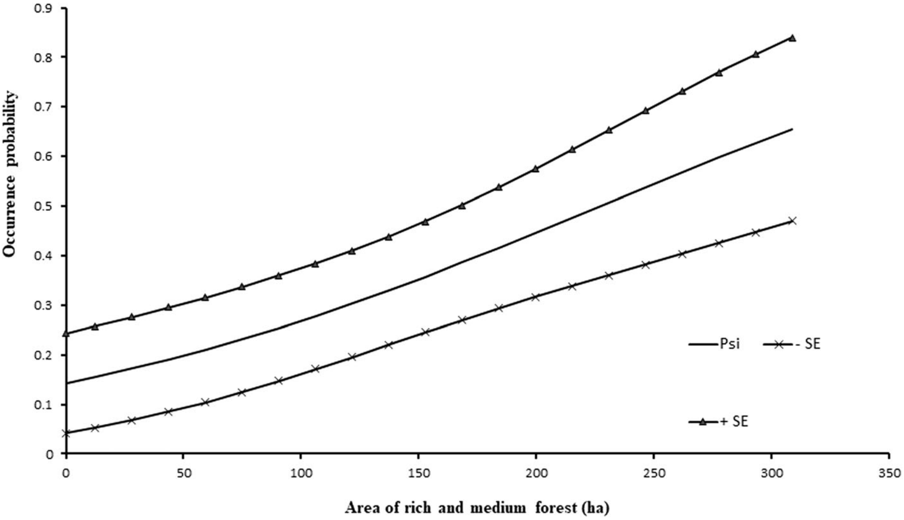

**Fig. 9** Occurrence probability of southern yellow-cheeked gibbons (*Nomascus gabriellae*) vs. the area of rich and medium forest covariate based on the third most important model {$p$(day), ψ(forest)} in a survey using autonomous recorders in Cat Tien National Park, Vietnam, July–October 2016.

Our findings suggest that autonomous recorders with occurrence probability or presence indicators are a promising tool for monitoring gibbon populations in areas with low and medium gibbon density. To monitor occurrence probability or presence in a large area, recorders should be placed throughout the area rather than being clustered, as in this study. Spreading recording posts out also helps to reduce dependency among posts and avoid overdispersion (MacKenzie *et al*. 2006), especially if surveyors wish to use individual covariates to model the detection probability or probability of occurrence. Researchers should set devices to start recording at least one full day after installing the instrument in the field, to reduce the avoidance of recording sites by gibbons. Finally, microphones with similar sensitivity should be used because the distance the recorder can record from depends on the sensitivity of the microphone.

**Acknowledgments** We would like to thank the Vietnam National Foundation for Science and Technology (NAFOSTED) for support given to this project (Grant number 106-NN.06-2015.37). Our gratitude also extends to the forest rangers in Cat Tien National Park for permitting us to conduct the survey. I would also like to thank all the field assistants for helping us with the field survey. We are thankful to Dr. Janice Moore at Colorado State University and Dr. Greg Nagle for help with proofreading of the manuscript. Finally, we thank the reviewers and editors for their insightful comments, suggestions, and corrections.

## References

Bach, T. H., Chen, J., Hoang, M. D., Beng, K. C., & Nguyen, V. T. (2017). Feeding behavior and activity budget of the southern yellow-cheeked crested gibbons (*Nomascus gabriellae*) in a lowland tropical forest. *American Journal of Primatology, 79*(8), 1–14.

Bartlett, Q. T., Light, L., & Brockelman, W. (2015). Long-term home range use in white-handed gibbons (*Hylobates lar*) in Khao Yai National Park, Thailand. *American Journal of Primatology, 78*, 192–203.

BI & FIPI (BirdLife International & Forest Inventory and Planning Institute). (2001). Sourcebook of existing and proposed protected areas in Vietnam. Hanoi: BirdLife International Vietnam Programme and the Forest Inventory and Planning Institute.

Brockelman, W. Y., & Ali, R. (1987). Methods of surveying and sampling forest primate populations. In C. W. Marsh & R. A. Mittermeier (Eds.), *Primate conservation in the tropical rainforest* (pp. 23–62). New York: Alan R. Liss.

Brockelman, W. Y., & Srikosamatara, S. (1993). Estimation of density of gibbon groups by use of loud songs. *American Journal of Primatology, 29*(2), 93–108.

Buckland, S. T., Anderson, D. R., Burnham, K. P., & Laake, J. L. (1993). *Distance sampling*. Dordrecht: Springer.

Burnham, K. P., & Anderson, D. (2002). *Model selection and multi-model inference: A practical information – theoretic approach* (2nd ed.). New York: Springer Science+Business Media.

Campos-Cerqueira, M., & Aide, T. M. (2016). Improving distribution data of threatened species by combining acoustic monitoring and occupancy modelling. *Methods in Ecology and Evolution.* https://doi.org/10.1111/2041-1210X.12599.

Celis-Murillo, A., Deppe, J. L., & Ward, M. P. (2012). Effectiveness and utility of acoustic recordings for surveying tropical birds. *Journal of Field Ornithology, 83*, 166–179.

Chambert, T., Waddle, J. H., Miller, D. A. W., Walls, S. C., Nichols, J. D., & Yoccoz, N. (2018). A new framework for analysing automated acoustic species detection data: Occupancy estimation and optimization of recordings post-processing. *Methods in Ecology and Evolution, 9*(3), 560–570.

Chesmore, E. D., & Ohya, E. (2004). Automated identification of field-recorded songs of four British grasshoppers using bioacoustic signal recognition. *Bulletin of Entomological Research, 94*, 319–330.

Cheyne, S. M., Gilhooly, L. J., Hamard, M. C., Höing, A., Houlihan, P. J., et al (2016). Population mapping of gibbons in Kalimantan, Indonesia: Correlates of gibbon density and vegetation across the species range. *Endangered Species Research, 30*, 133–143.

CTNP (Cat Tien National Park). (2016). Forest cover map of Cat Tien National Park [1:10,000]. Available from http://www.namcattien.org/. Accessed 15 June 2017.

Fonzo, M. D., Collen, B., & Mace, G. M. (2013). A new method for identifying rapid decline dynamics in wild vertebrate populations. *Ecology and Evolution, 3*(7), 2378–2391.

Geissmann, T. (1993). *Evolution of communication in gibbons (Hylobatidae).* PhD dissertation, Zürich University.

Geissmann, T., & Orgeldinger, M. (2000). The relationship between duet songs and pair bonds in siamangs, *Hylobates syndactylus*. *Animal Behavior, 60*, 805–809.

Gilhooly, L. J., Rayadin, Y., & Cheyne, S. M. A. (2015). Comparison of Hylobatid survey methods using triangulation on Müller's gibbon (*Hylobates muelleri*) in Sungai Wain Protection forest, East Kalimantan, Indonesia. *International Journal of Primatology, 36*, 567–572.

Gray, T. N. E., Phan, C., & Long, B. (2010). Modelling species distribution at multiple spatial scales: Gibbon habitat preferences in a fragmented landscape. *Animal Conservation, 13*, 324–332.

Hamard, M., Cheyne, S. M., & Nijman, V. (2010). Vegetation correlates of gibbon density in the peat-swamp forest of the Sabangau catchment, Central Kalimantan, Indonesia. *American Journal of Primatology, 72*(7), 607–616.

Hilje, B., & Aide, T. M. (2012). Calling activity of the common tink frog (*Diasporus diastema*) (Eleutherodactylidae) in secondary forests of the Caribbean of Costa Rica. *Tropical Conservation Science, 5*, 25–37.

IUCN Red List of Threatened Species (2017). Version 2017–1. www.iucnredlist.org.

Jiang, X. L., Luo, Z. H., & Zhao, S. Y. (2006). Status and distribution patterns of black crested gibbon (*Nomascus concolor jingdongensis*) in Wulian Mountains, Yunnan, China: Implications for conservation. *Primates, 47*, 264–271.

Kalan, A. K., Mundry, R., Wagner, O. J. J., Heinicke, S., Boesch, C., & Kühl, H. S. (2015). Towards the automated detection and occupancy estimation of primates using passive acoustic monitoring. *Ecological Indicators, 54*, 217–226.

Kenyon, M. A. (2008). *Ecology of the golden-cheeked gibbon* (Nomascus gabriellae) *in Cat Tien National Park, Vietnam.* PhD dissertation, University of Cambridge.

Kidney, D., Rawson, B. M., Borchers, D. L., Stevenson, B. C., Marques, T. A., & Thomas, L. (2016). An efficient acoustic density estimation method with human detectors applied to gibbons in Cambodia. *PLoS One, 11*(5), e0155066.

MacKenzie, D. I., Nichols, J. D., Royle, J. A., Pollock, K. H., Bailey, L. L., & Hines, J. E. (2006). *Occupancy estimation and modeling: Inferring patterns and dynamics of species occurrence*. New York: Academic Press.

Marsh, D. M., & Trenham, P. C. (2008). Tracking current trends in plant and animal population monitoring. *Conservation Biology, 22*, 647–655.

Nijman, V. (2004). Conservation of the Javan gibbon *Hylobates moloch*: Population estimates, local extinctions and conservation priorities. *The Raffles Bulletin of Zoology, 52*, 271–280.

O'Brien, T. G., Kinnaird, M. F., Nurcahyo, A., Iqbal, M., & Rusmanto, M. (2004). Abundance and distribution of sympatric gibbons in a threatened Sumatran rain forest. *International Journal of Primatology, 25*, 267–284.

Phoonjampa, R., Koenig, A., Brockelman, W. Y., Borries, C., Gale, G. A., et al (2011). Pileated gibbon density in relation to habitat characteristics and post-logging forest recovery. *Biotropica, 43*(5), 619–627.

Reisland, M. A., & Lambert, J. E. (2016). Sympatric apes in sacred forests: Shared space and habitat use by humans and endangered Javan gibbons (*Hylobates moloch*). *PLoS One, 11*(1), e0146891.

Spillmann, B., Noordwijk, V., Erik, M. A., Willems, E. P., Setia, T. M., et al (2015). Validation of an acoustic location system to monitor Bornean orangutan (*Pongo pygmaeus wurmbii*) long calls. *American Journal of Primatology, 77*(7), 767–776.

Thomas, L., & Marques, T. (2012). Passive acoustic monitoring for estimating animal density. *Acoustics Today, 8*, 35–44.

Thompson, M. E., Schwager, S. J., Payne, K. B., & Turkalo, A. K. (2010). Acoustic estimation of wildlife abundance: Methodology for vocal mammals in forested habitats. *African Journal of Ecology, 48*(3), 654–661.

Thompson, W. L., White, G. C., & Gowan, C. (1998). *Monitoring vertebrate populations*. New York: Academic Press.

Tremain, S. B., Swiston, K. A., & Mennill, D. J. (2008). Seasonal variation in acoustic signals of pileated woodpeckers (*Dryocopus pileatus*). *Wilson Journal of Ornithology, 120*, 499–504.

Vu, T. T., & Dong, T. H. (2015). Estimation of northern yellow-cheeked gibbon (*Nomascus annamensis*) population size in Kon Cha Rang Nature Reserve: A new method–using a weighted correction factor. *Vietnamese Journal of Primatology, 2*, 41–48.

Vu, T. T., Tran, V. D., Giang, T. T., Nguyen, H. V., Nguyen, D. M., et al (2016). A mark-recapture population size estimation of southern yellow-cheeked crested gibbon *Nomascus gabriellae* (Thomas, 1909) in Chu Yang Sin National Park, Vietnam. *Asian Primate Journal, 6*, 33–42.

Vu, T. T., Tran, M. L., Nguyen, D. M., Tran, V. D., Doherty, P. F., *et al*. (2018a). A distance sampling approach to estimate density and abundance of gibbon groups. *American Journal of Primatology, 80*(9), 1–7. https://doi.org/10.1002/ajp.22903

Vu, T. T., Tran, M. L., Nguyen, D. M., Tran, V. D., & Ta, T. N. (2018b). Improving the estimation of calling probability and correction factors in gibbon monitoring using the auditory point count method. *International Journal of Primatology, 39*(2), 222–236.

White, G. C., & Burnham, K. P. (1999). Program MARK: Survival estimation from populations of marked animals. *Bird Study, 46*, 120–139.

Williams, B., Nichols, J., & Conroy, M. (2002). *Analysis and management of animal populations*. Cambridge, UK: Academic Press.

Yoccoz, N. G., Nichols, J. D., & Boulinier, T. (2011). Monitoring of biological diversity in space and time. *Trends in Ecology and Evolution, 16*(8), 446–453.

Zwart, M. C., Baker, A., McGowan, P. J. K., & Whittingham, M. J. (2014). The use of automated bioacoustic recorders to replace human wildlife surveys: An example using nightjars. *PLoS One, 9*(7), 1–8.