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APPLICATION OF BIOACOUSTICS IN THE SURVEY AND MONITORING YELLOW – CHEEKED CRESTED GIBBON (*Nomascus gabriellae*) IN CAT TIEN NATIONAL PARK

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PREFACE

I. INTRODUCTION

Recently, wildlife survey using automatic sound recording and bioacoustics analysis methods have been developed. This technique has been successfully applied to some wildlife species. For species that emits a typical sound, bioacoustics method will address the limitations of traditional monitoring methods. For example, gibbons can be detected from a distance of up to 2-3 km through their loud and long calls. However, up to now, no studies have been conducted to apply bioacoustics technique to monitor rare and endangered gibbon species. The application of automatic sound recording device and bioacoustic analysis might be very potentialy useful in the monitoring of gibbons in Vietnam.

Although gibbons are a priority group of wildlife for surveys in recent years in Vietnam, there are still many areas where gibbon population size has not been determined yet. This has a negative influence on the conservation for this species group. Therefore, with the consent of the university, I chose the topic "Application of bio-acoustics in the survey and monitoring yellow-cheeked crested gibbon (*Nomascus gabriellae*) in Cat Tien National Park", with the aim of applying quantitative methods and automatic recording devices to survey and monitor gibbons, making contributions to providing the database of the the yellow-cheeked crested gibbon in Cat Tien National Park in particular and in Vietnam in general.

Cat Tien National Park located at the end of the Annamite Range, the transitional zone approaching down to the southern plain, so the terrain has both low mountains and hills, natural forest is still rich and diverse. This area has been identified as being in the distribution range of the yellow-cheeked crested gibbon. Additionally, the area has several habitat types favored by gibbon species. Therefore, the survey process, especially arranging listening and recording posts are advantageous. The chance to detect gibbons is also very high. Moreover, there has been no similar research conducted in the park recently. Therefore, the I chose Cat Tien National Park as the study site.

II. OBJECTIVES AND SCOPE OF THE STUDY

2.1. Research objectives

- Applying the quantitative methods in the survey and monitor yellow-cheeked crested gibbon (*Nomascus gabriellae*) in Cat Tien National Park.

- Applying the autonomous recording devices in surveying and monitoring the yellow-cheeked crested gibbon and assessing the influence of weather factors on the singing frequency of yellow-cheeked crested gibbon (*Nomascus gabriellae*) in Cat Tien National Park.

- Providing information on the status and distribution of yellow-cheeked crested gibbon (*Nomascus gabriellae*) in Nam Cat Tien subdivision, Cat Tien National Park for conservation planning.

- Assessing the importance of the yellow-cheeked crested gibbon population in Cat Tien National Park by comparing the size of the gibbon population in the study area with other reserves and national parks.

2.2. Research object

Yellow-cheeked crested gibbon (*Nomascus gabriellae*) in Nam Cat Tien subdivision, Cat Tien National Park.

2.3. Research scope

- The dissertation focuses on the surveying the yellow-cheeked crested gibbon (*Nomascus gabriellae*) population using auditory point count method to estimate population density and size.

- The study area is Nam Cat Tien subdivision, Cat Tien National Park.

- Time for Fieldwork: from July to October 2016.

Chapter 1
OVERVIEW OF RESEARCH ISSUES
1. Distribution and status of yellow-cheeked crested gibbon in Vietnam

Before 2000, the presence of yellow-cheeked crested gibbons has been recorded in many sites, especially in the Central Highlands provinces, such as Dak Lak and Lam Dong (Geissmann et al., 2000). After 2000, several surveys for yellow-cheeked crested gibbon were carried out and the distribution range the yellow-cheeked crested gibbon was determined from about 110N to 130N (Luu Quang Vinh et al., 2018).

In Vietnam, yellow-cheeked crested gibbon has a wide range of distribution, and the population size is quite large, although the number of populations has declined sharply over the last decade (Nadler & Brockman, 2014). However, these populations are only concentrated in certain special-use forests. In the last decade, about 330 groups of yellow-cheeked crested gibbon have been recorded in Vietnam (Luu Quang Vinh et al., 2018), of which, the largest population of yellow-cheeked crested gibbon in Vietnam was recored in Cat Tien National Park, with 149 groups, followed by Bu Gia Map National Park with 88 groups. Therefore, Cat Tien National Park and Bu Gia Map National Park are considered as key conservation sites for the yellow-cheeked crested gibbon (Rawson et al., 2011). In addition, Bi dup - Nui Ba National Park, Chu Yang Sin National Park, Phuoc Binh National Park, Nam Nung Nature Reserve, and Ta Dung Nature Reserve are also support viable population of yellow-cheeked crested gibbon, because these protected areas have large and low-impact forests (Vu Tien Thinh et al., 2016). Yellow-cheeked crested gibbon were also recorded in Yok Don National Park, Loc Bac Forest Enterprise (Lam Dong Province), Ninh Son Forest Enterprise (Ninh Thuan Province), Hon Ba Nature Reserve (Khanh Hoa province), Easo Nature Reserve (Dak Lak province), the Ayunpa proposed Nature Reserve (Gia Lai province) (Rawson et al., 2011). However, the locations of gibbon groups were not specific.

2. Distance method in surveying and monitoring wildlife

In the wildlife survey, there are two common methods used: line transect method and point count method. Data collected from these two methods can be

used to analyze by Distance method and Distance software.

- Line transects method:

The line transects method is often used for areas with favorable terrain. The surveyors walk along the line transect, counting and recording the number of individuals and measure the distance from the line to the detected animals (Figure 1.1.a).
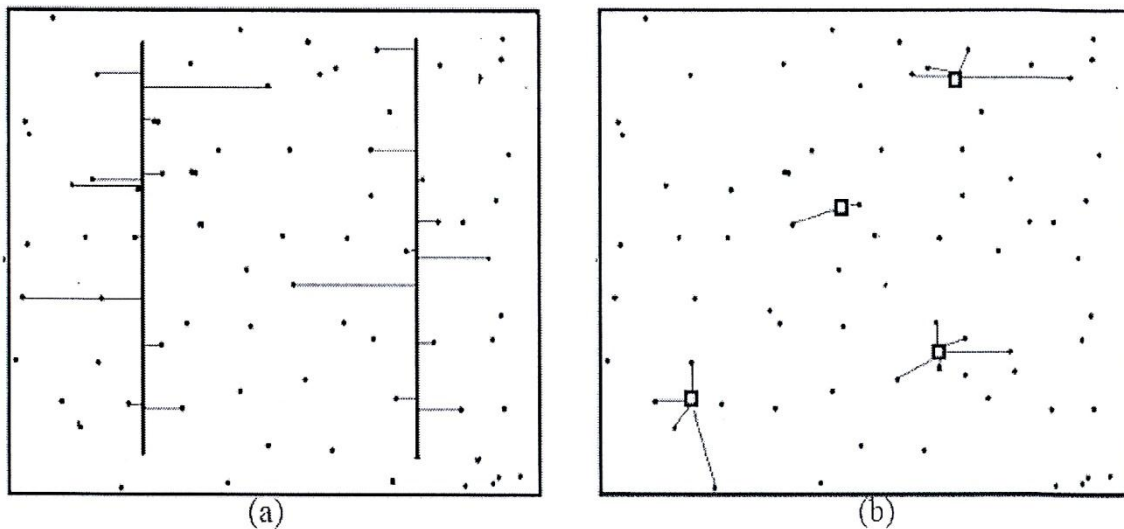

(a)   (b)

Figure 1.1: Simulation of line transects method (a) and point counts or sample plots (b).

(Source: Nguyen Hai Tuat et al., 2009)

- Point counts method:

Surveyors often sit at several points in the survey area and count the number of individuals of the species of interest, azimuth angle to the animals, and the distance from the listening post to the animals (Figure 1.1.b).

3. Method of using automatic recording devices

In Vietnam, bioacoustics techniques are only used to describe the sound of some wildlife species. So far, no study has been carried out to apply this technique in monitoring biodiversity in Vietnam.

Over the world in general and in Vietnam in particular, except a research of Vu Tien Thinh et al. (Study on the current situation of northern buffed-cheeked gibbon in Ngoc Linh Nature Reserve, Quang Nam Province using bio-acoustic method and automatic recording devices), to date, no studies have been conducted to apply bio-acoustic technique to monitor gibbons. The application of automatic recording devices and bio-acoustic analysis could play

an important role in surveying and monitoring gibbon populations.

4. Research on the sounds of gibbons in Vietnam

Female and male crested gibbons (*Nomascus spp*) emit calls, and the sound spectrum of these species is easy to be determined and distinguished with other species (Van Ngoc Thinh et al., 2010b). Konrad and Geissmann (2006) described in detail the sound spectrum of the gibbon group. Sound spectrum samples of crested gibbon species is shown in Figure 1.2; specifically: female individual call (Figure 1.2a), male individual (Figure 1.2b), male mature, female mature and sub-adult individual (Figure 1.2c), the image with the arrow sign is the sound spectrum of the sub-adult gibbon.
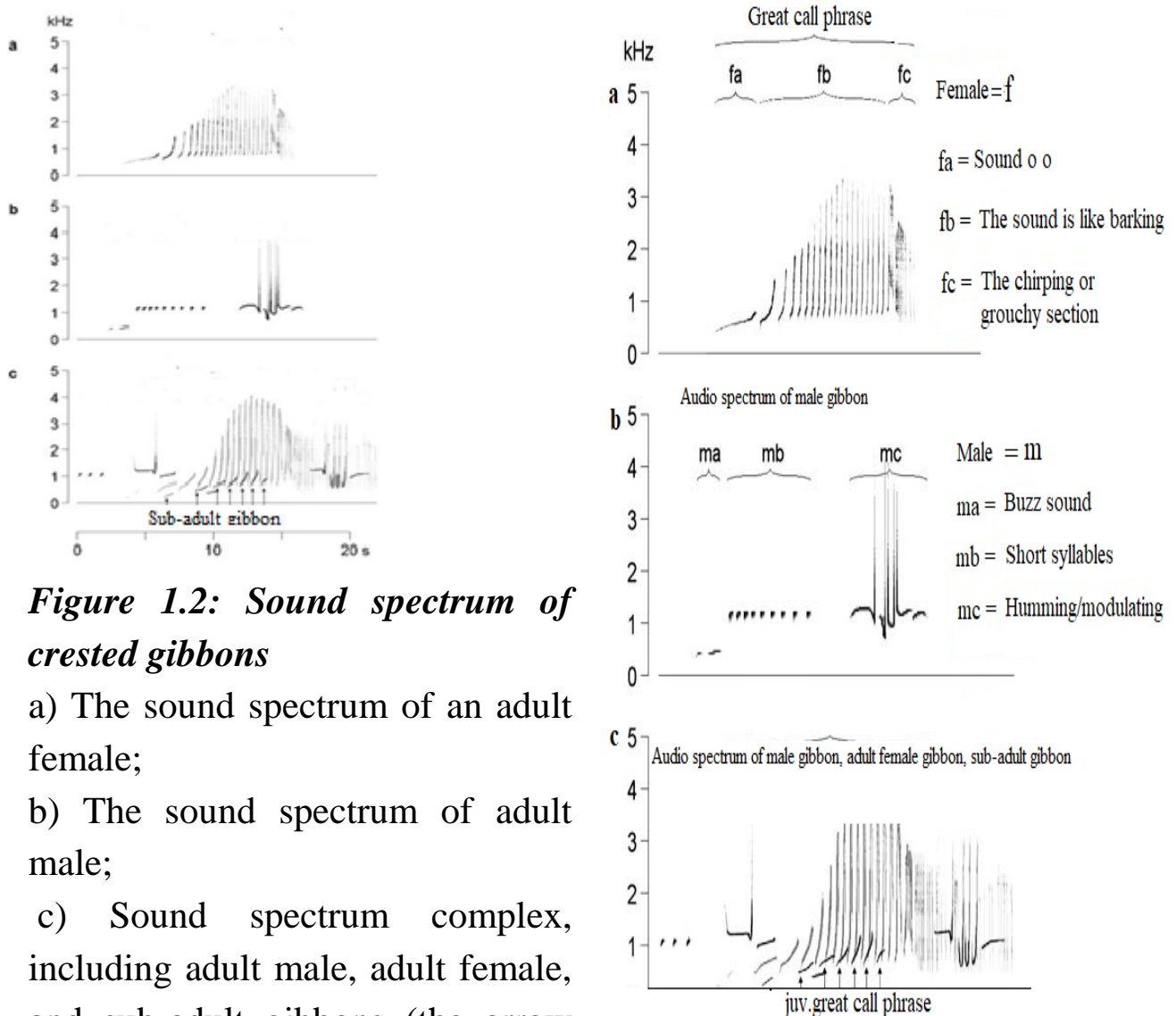

Figure 1.2: Sound spectrum of crested gibbons

a) The sound spectrum of an adult female;

b) The sound spectrum of adult male;

c) Sound spectrum complex, including adult male, adult female, and sub-adult gibbons (the arrow part).

(Konrad and Geissmann, 2006).

Chapter 2
CONTENT AND RESEARCH METHODS

2.1. Research contents

2.1.1. Applying the distance sampling method in surveying yellow-cheeked crested gibbon.

2.1.2. Applying automatic recording devices for surveying and monitoring yellow-cheeked crested gibbon.

2.1.3. Comparing the population size of yellow-cheeked crested gibbon in the study area with other nature reserves and national parks.

2.1.4. Proposing solutions to conserve yellow-cheeked crested gibbon in Cat Tien National Park.

2.2. Methodology

2.2.1. Method of surveying yellow-cheeked crested gibbon in the field

- Using traditional auditory point count method to survey for gibbons (Brockelman & Ali, 1987).

- Using automatic recording devices to survey for gibbons. Four wide-spectrum sound recorders (SM3, Wildlife Acoustics Inc.) were installed at 40 different points, being spaced from 500 to 1000 meters apart to record the call of yellow-cheeked crested gibbon.

2.2.2. Data analysis

- Using distance sampling method to analyze the data collected from the survey for yellow-cheeked crested gibbon.

- Applying the bioacoustics analysis method in surveying and monitoring yellow-cheeked crested gibbons.

2.2.3. Comparing the population size of yellow-cheeked crested gibbon in the study area with other nature reserves and national parks

- Data on the population size of yellow-cheeked crested gibbons in other nature reserves and national parks was collected from published documents.

- The population size of yellow-cheeked crested gibbon in the study area was compared to those of other nature reserves and national parks.

2.2.4. Proposing solutions for conservation

- The information on the organization of Cat Tien National Park, the status of

the protection and conservation activities of the Management Board in National Park was assessed; threats and dangers to the yellow-cheeked crested gibbon was identified;

- Research results were analyzed, conservation solutions were proposed.

Chapter 3
RESULTS AND DISCUSSION

3.1. Results using traditional method and using distance method in analyzing data collected from a survey for yellow-cheeked crested gibbons

3.1.1. The location and distribution of yellow-cheeked crested gibbons were discovered in the study area by traditional method

3.1.1.1. The number and location of groups of yellow-cheeked crested gibbons

In the process of investigating yellow-cheeked crested gibbon in Nam Cat Tien subdivision, the authors recorded the gibbon groups 130 times, including 93 times in the eastern part of Nam Cat Tien subdivision and 37 times recorded in the western part. A total of 44 groups of yellow-cheeked crested gibbon recorded in Nam Cat Tien subdivision. Of these, 27 groups were recorded in one survey day, 13 groups were recorded during the two survey days, only 4 groups were recorded in all three survey days.

3.1.1.2. Location and distribution of gibbon group in Nam Cat Tien subdivision

With a total of 47 listening posts surveyed from July to October 2016, the total area covered was 7,742.75 ha, accounting for 17.09% of the total area of Nam Cat Tien subdivision. In this surveyed area, the habitat area suitable for gibbon was 7,481.47ha. The area of rich broadleaf evergreen forests and medium broadleaf evergreen forests surveyed were 52.81% and 34.30%, respectively.

The gibbon groups were recorded mainly in the eastern part of Nam Cat Tien subdivision with a total of 37 groups in forest compartment No. 6, 14, 15, 26, 30, 31, 32. In the western part of Nam Cat Tien subdivision, the number of gibbon groups detected was quite small, a total of only 7 gibbon groups recorded in forest compartment 8, 13, 19, 41 and 324; in these areas, the forest status is mainly mixed between wood plants and bamboo.

During the survey, a total of 44 groups of yellow-cheeked crested gibbons were recorded, of which 32 groups were recorded in rich and medium broadleaf evergreen forests, accounting for 72.73%. Specifically, 11 groups were recorded in rich broadleaf evergreen forests, 21 groups in medium

broadleaf evergreen forests, 04 groups in poor broadleaf evergreen forests, 03 groups in regrowth broadleaf evergreen forests, 05 groups in a mixed forest between wood and bamboo.

3.1.2. Estimate the gibbon daily calling probability and the correction factor

Based on the analysis results of Vu Tien Thinh et al., (2018), to accurately estimate the probability of singing, only the gibbon groups with distance to listening point smaller than <700 was used. Excel package by Vu Tien Thinh & Rawson (2011) was used to estimate the probability of calling in one day in the study area. The daily calling probability was p1 = 0.460, for two survey days was C2 = 0.70; for the three survey days was C3 = 0.84.

3.1.3. Estimate the density and the number of groups of yellow-cheeked crested gibbons using the traditional method

3.1.3.1. Determine the maximum listening distance

During the survey, 19 groups of yellow-cheeked crested gibbons were recorded from at least two listening posts on the same day. The location of the gibbon group was determined using triangulation. The nearest distance from the surveyor to the gibbons was 180 meters and the furthest distance was 1300 meters. With the groups recorded at a distance from 1250 meters to 1300 meters, the volume of the calls was often small or very small. On the other hand, at the distance above 1320 meters the calls of gibbons cannot be recorded. Although there are some listening posts with a distance smaller than 1300 meters, but the calls cannot be detected. This may be because listening ability was affected by weather factor such as wind and rain. Therefore, I selected 1300 meters as the maximum hearing distance to calculate the surveyed area.

3.1.3.2. Estimate population size of yellow-cheeked crested gibbon by traditional method

The number of gibbon groups recorded in two sectors of Nam Cat Tien subdivision was very different, so the estimations were conducted separately in the eastern and western parts of the subdivision (Table 3.1.)

Table 3.1: Estimation indicators of population size of gibbon groups in eastern and western parts of Nam Cat Tien subdivision (95% confidence interval)

Index	Eastern part	Western part
Area (km^2)	139,50	313,54
No. gibbon groups	37	7

recorded in the survey		
Density (groups/km^2)	0,67 (0,56 – 0,79)	0,33 (0,23-0,42)
Estimated number of gibbon groups in the entire region	93 (77,55 – 108,38)	102 (82,05 – 131,75)

The estimation of the number of gibbon groups in the entire Nam Cat Tien subdivision was 195 groups (Table 3.1), in which, the density of gibbon groups in the eastern region was higher than the western region.

3.1.4. Estimated density and the number of gibbon groups using distance sampling method

3.1.4.1. Estimated density by distance sampling method

Hazard-rate function was ranked as the best model to simulate the probability of detecting gibbon groups (GOF: P-value = 0.98) (Table 3.2, Figure 3.1). The probability of detecting a call of gibbon groups within 1,200m was 0.63 (0,54–0,74).

Table 3.2: Model selection results to estimate the probability of detecting gibbon groups during the survey in Nam Cat Tien subdivision

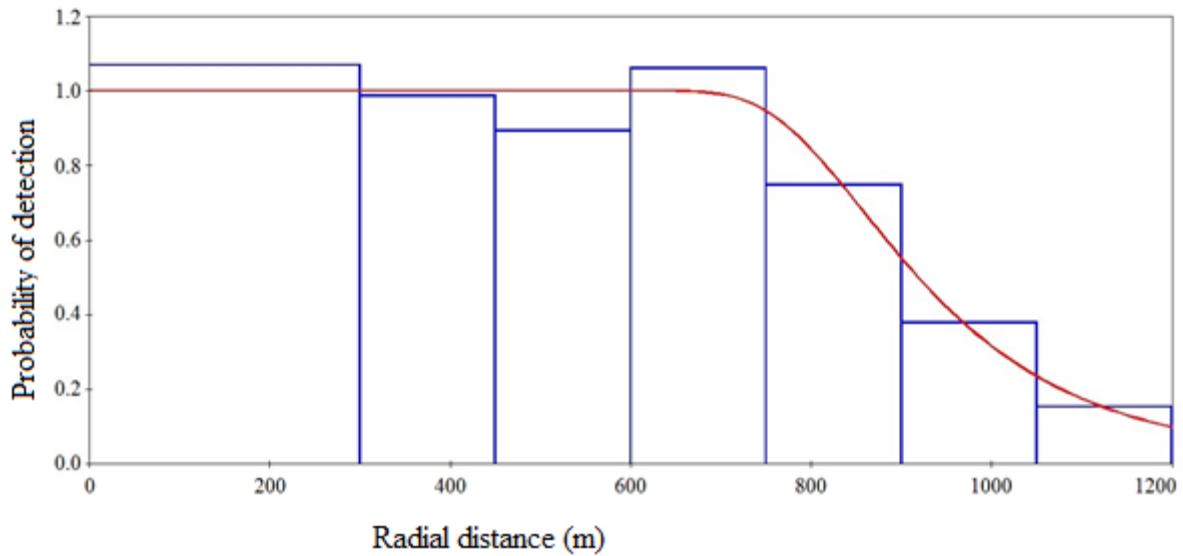| Function	AICc	χ^2	P_value GOF test	Detection probability (95% CI)
Hazard-rate + cosine	463.81	0.46	0.98	0.63 (0.54-0.74)
Uniform + simple polynomial	463.92	2.75	0.75	0.50 (0.45-0.56)
Uniform + cosine	466.15	0.70	0.87	0.54 (0.27-1.00)
Half-normal + hermite polynomial	467.96	4.57	0.32	0.52 (0.30-0.90)

Figure 3.1: Probability detection function g(x) (Hazard-rate model with cosine expansion) for calling gibbon groups in a survey for southern yellow-cheeked crested gibbon (Nomascus gabriellae) in Cat Tien National Park in 2016.

The estimated density in the eastern part of Nam Cat Tien subdivision was higher than that of the western part (Table 3.3). The population size of gibbons in Nam Cat Tien subdivision was estimated to be 325 groups (232 - 455).

Table 3.3: Estimate density and number of groups of yellow-cheeked crested gibbons in 2016

Region	Area (km²)	Density (groups/km²)	No. groups (groups)
Eastern part	139.49	1.01 (0.62-1.65)	141 (86-230)
Western part	313.54	0.59 (0.37-0.94)	184 (115-295)
Total	**453.03**	**0.72 (0.51-1.00)**	**325 (232-455)**

At the distance > 700 m, the probability of detecting gibbon calls was significantly reduced. At the distance of more than 700m, the detection of gibbons' call can be dependent on the weather, wind direction, speed, and terrain. If the decrease in the detection probability at above 700m was not taken into account, the density and population size of the gibbons would be smaller than the real ones, about 40% smaller than the reality.

3.1.4.2. Comparing estimation results between traditional method and distance method

The comparison results showed that, if the traditional method was used, the

number of gibbon groups will be smaller than reality. If estimates by traditional method were divided by 0.63, then the estimated results will correspond to the results obtained by the distance sampling method. This suggested that the distance method should be widely used in the survey and monitoring gibbon species (Table 3.4):

Table 3.4: Comparison of estimated results between traditional method and distance method

| No.	Index	Results by traditional method	Results by distance sampling method
1	Averaged density of gibbon groups in Nam Cat Tien subdivision	The average density estimated in this study was 0.5 groups/km² in the entire Nam Cat Tien subdivision	The average density estimated in this study was 0.72 groups/km² in the entire Nam Cat Tien subdivision
2	Density of gibbon groups	Eastern part: 0.67 groups/km² Western part: 0.33 groups/km+	Eastern part: 1.01 groups/km² Western part: 0.59 groups/km²

3.2. Survey results using automatic recording devices

3.2.1. The characteristics of the call of yellow-cheeked crested gibbon

3.2.1.1. Sound spectrum of yellow-cheeked crested gibbon

   a) Sound spectrum of male gibbon:

Sound spectrum analysis of male gibbon (Figure 3.2):
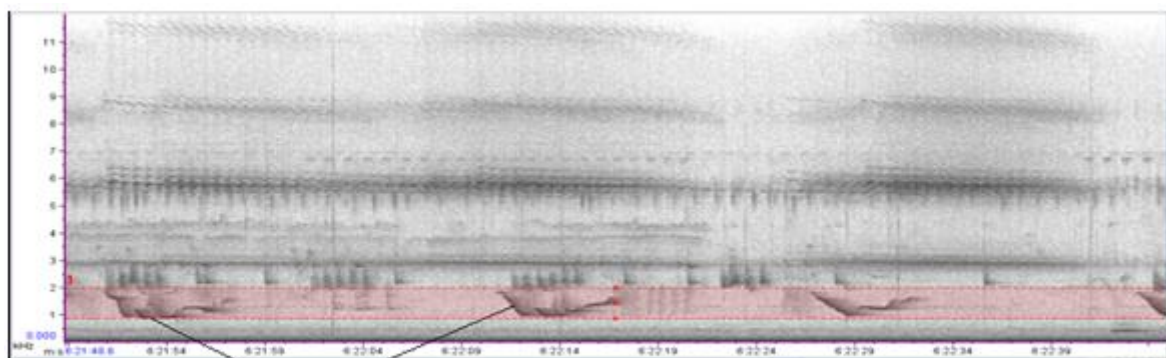
Sound spectrum of male yellow-cheeked crested gibbon

Figure 3.2: Sound spectrum of call of male yellow-cheeked crested gibbons

The results of sound analysis by RAVEN software showed that the sound spectrum of male gibbon tended to move horizontally, the degree of oscillation of the sound frequency is longitudinally narrow. The frequency ranged from about 800 kHz to 2000 kHz. The male gibbons often sings first

and then the female Gibbon followed.

b) *Sound spectrum of female and sub-adult gibbons:*

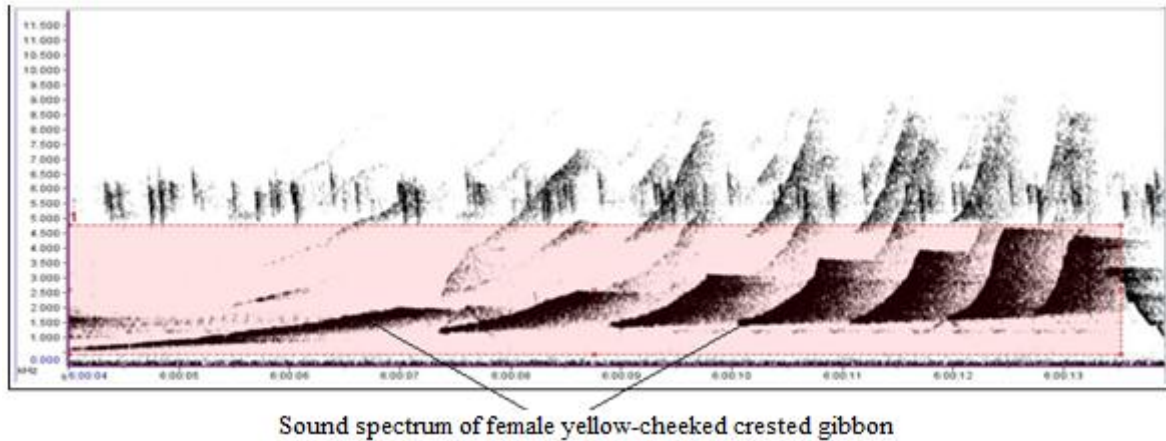Sound spectrum analysis of female gibbons (Figure 3.3)

Sound spectrum of female yellow-cheeked crested gibbon

Figure 3.3: Sound spectrum of female yellow-cheeked crested gibbon

- Sound spectrum of female and sub-adult gibbons (Figure 3.4)

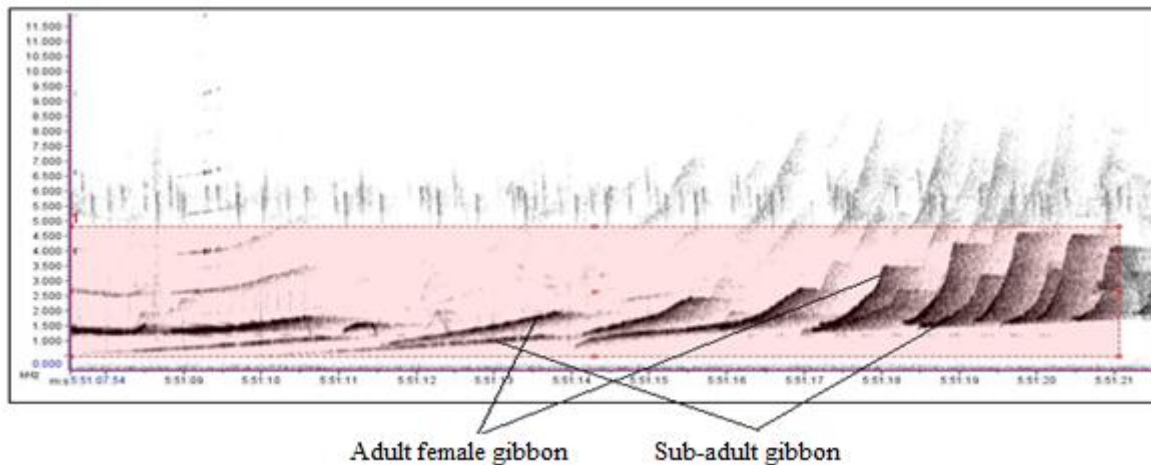Adult female gibbon   Sub-adult gibbon

Figure 3.4: Sound spectrum of female and sub-adult gibbons

The results of the analysis using RAVEN software showed that the the sound spectrum of female gibbons in Nam Cat Tien subdivision tended to go up vertically, the level of frequency variation is very large, from the low frequency of about 400 kHz to high frequency of about 4900 kHz; the duration of each call is lengthened to about 15 seconds.

3.2.1.2. Analyzing the structure of gibbon groups using sound spectrum

a) Gibbon groups have only male gibbon

During the survey, many recordings has the calls emitted by one male gibbon. For example, the call analysis obtained from CT305188 recorder at 06:21 on 31st July 2016 showed that the group contained only 01 male gibbon and this male individual called continuously (Figure 3.5):
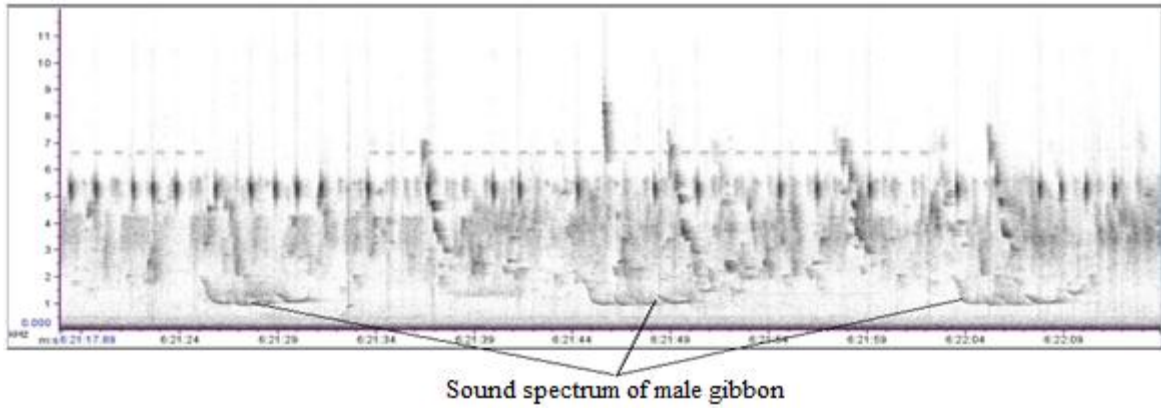
Sound spectrum of male gibbon

Figure 3.5: Sound spectrum of groups with only one male gibbon

b) Structure of gibbon groups includes 01 male and 01 female gibbons

The sound spectrum obtained from CT304814 device, recorded on 22nd July 2016 at 06:18, was emitted by a group consisting of 01 male gibbon and 01 female gibbon. These male and female gibbons called continuously (Figure 3.6).
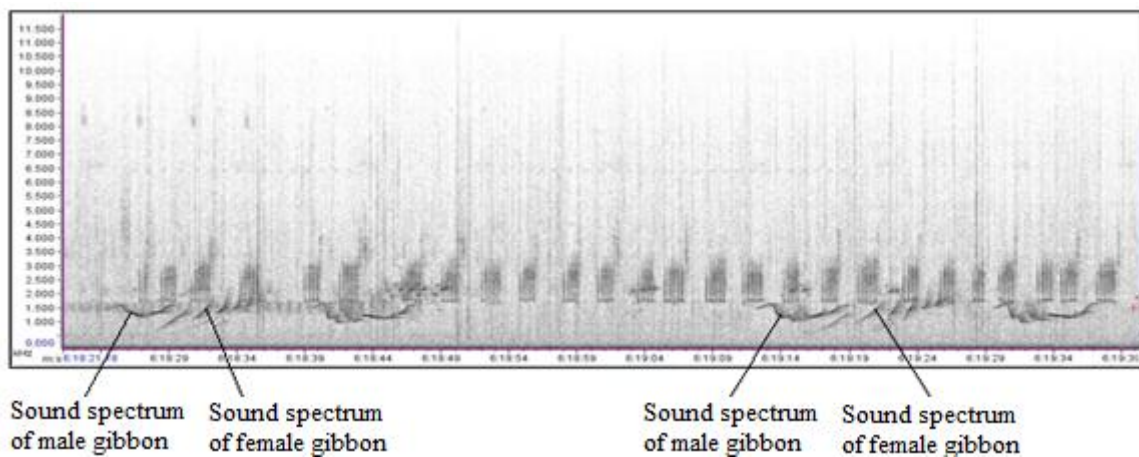

Sound spectrum of male gibbon   Sound spectrum of female gibbon   Sound spectrum of male gibbon   Sound spectrum of female gibbon

Figure 3.6: Sound spectrum of the groups including 01 male gibbon and 01 female gibbons

c) Gibbon groups including 01 male and 02 female gibbons

Sound spectrum obtained from CT304785 recorder, recorded on 25th July 2016 at 06:20, was emitted by a group consisting of 01 male gibbon and 02 female adult gibbons, and male gibbon sings continuously (Figure 3.7).
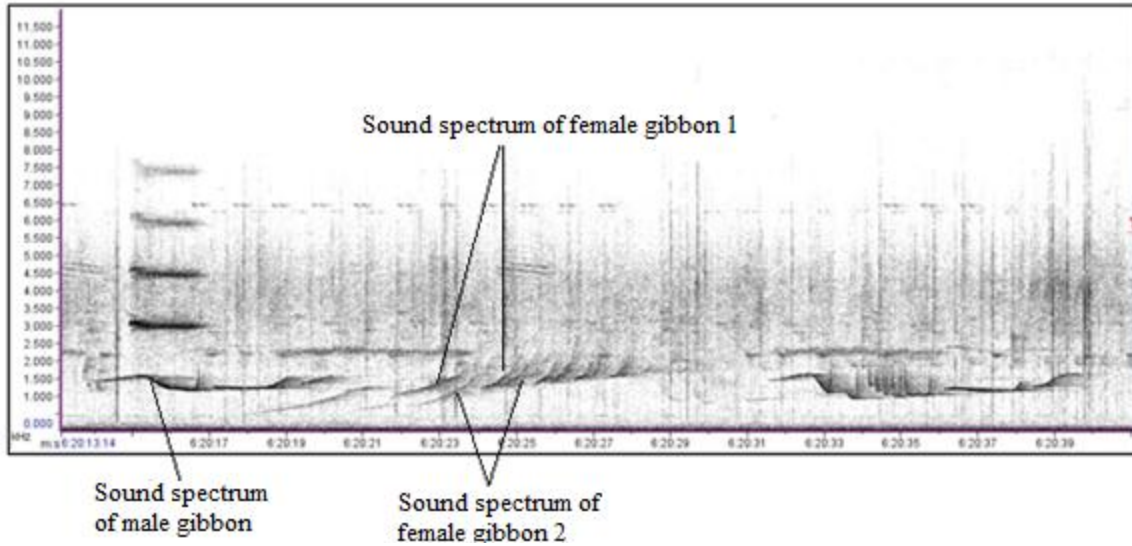
Figure 3.7: Structure of the group including 01 male and 02 female adult gibbons

d) Structure of groups includes male gibbon, female gibbon and sub-adult gibbon

Sound spectrum obtained from CT 304814 device, recorded on 29th July 2016 at 5:51, emitted by a group including 01 male gibbon and 02 female gibbons, of that 01 animal is sub-adult female (Figure 3.8):
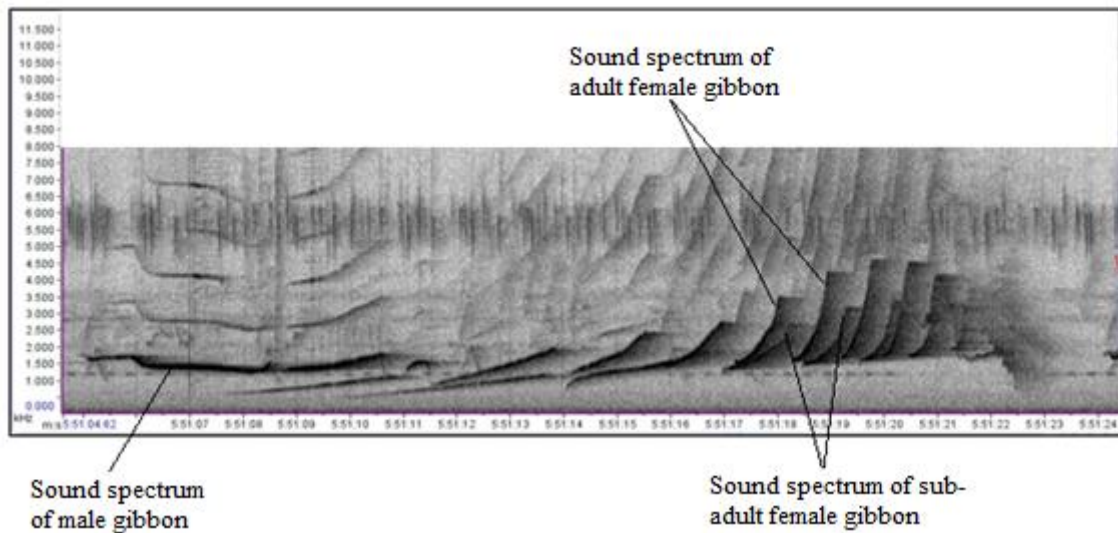

Figure 3.8: Structure of group including 01 male and 02 female gibbons, of that 01 individual is sub-adult female

đ) The structure of gibbon groups including 02 male gibbons and 02 female gibbons, and a sub-adult gibbon

Sound spectrum obtained from CT305188 device, recorded on 24th July 2016 at 5: 51, was emitted by a group including 02 male gibbons and 02 female gibbons, of those 01 animal is sub-adult gibbon gibbon (Figure 3.9):
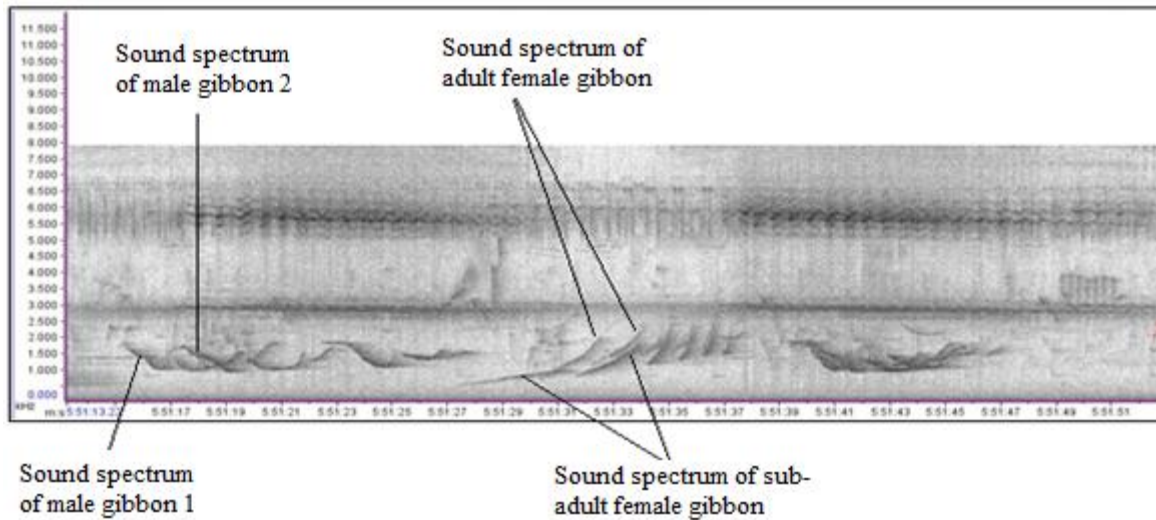
Figure 3.9. Structure of groups includes 02 male gibbons and 02 female gibbons, of those has 01 female sub-adult gibbon

3.2.1.3. Summarizing sound spectrum analysis results and gibbon group structure in Nam Cat Tien subdivision

Based on the results of the sound spectrum analysis, gibbon in the study area had five basic structures, including: (1) groups with only male gibbon; (2) group with 01 male gibbon and 01 female gibbon; (3) groups with 01 male gibbon and 02 adult female gibbons; (4) group with 01 male gibbon, 01 female gibbon and 01 sub-adult gibbon; (5) group with 02 male gibbons, 02 female gibbons and 01 sub-adult gibbon.

Among the five gibbon group structures, the group with 01 male gibbon and 01 female gibbon was the most popular. The groups which have 01 male and 01 female and may have young offspring have been recorded by many authors for *Nomascus* species, for example, with northern white-cheeked gibbon (Ruppell 2013).

3.2.2. Frequency of calling by time during a day

- Calling starting time: yellow-cheeked crested gibbon usually started singing from 5:30 AM to 6:00 AM (accounting for 47.6%), a very few started before 5:30 AM and after 8:00 AM no gibbons started singing.

- Calling ending time: The time when gibbons finished singing was mainly from 6:00 AM- 6:30 AM in the morning (accounting for 46.0% of the time when gibbon groups finished singing).

3.2.3. The length of the calls

The results showed that gibbon calls lasted mainly from 10-15 minutes during a day, accounting for 30.2%; very few have a calling time length from 40

to 55 minutes, and no groups have a singing time longer than 55 minutes.

3.2.4. The influences of weather factors on the gibbon calling frequency

3.2.4.1. Influence of early morning rains on gibbon calling frequency

- During the survey, there were 20 rainy days; in which, gibbons still called in 11 days (accounting for 55% of the rainy days), gibbons did not sing in 9 days (accounting for 45% of the rainy days).

- During the survey, there were 89 days without rain; in which, gibbons singed in 65 days (accounting for 73% of non-rainy days) did not sing in 24 days (accounting for 27% of the number of non-rainy days).

- The above results showed that rain has a great influence on the frequency of recording gibbons' calls. If the rains were from medium to heavy, the recording ability of gibbon calls would be low; gibbons only called in the slightly rainy days (all the days in that gibbons called were slightly rainy, accounting for 100%)..

3.2.4.2. Influence of rain fin the previous night on gibbon calling frequency

The rains from the previous night did not affect the frequency of singing in the morning of yellow-cheeked crested gibbon much. Therefore, the weather of the previous night will not affect the decision to survey on the next morning.

3.2.4.3. Influence of the wind on gibbon calling frequency

Wind has a great influence on the gibbon singing frequency or the ability to record the calls. The percentage of recording calls on windless days was 2 times higher than that of windy days. When it is windy, gibbons may not sing or the gibbon's calls cannot travel to the recorders, especially on high wind days.

3.2.4.4. Influence of fog on gibbon calling frequency

The results showed that the foggy weather had little effect on gibbon singing frequency. The percentage of foggy days and none-foggy days in that gibbons sang was approximately the same. When it is foggy, the ability of appearing gibbons' singing behavior was still very high.

3.2.5. The locations of the yellow-cheeked crested gibbon groups recorded

The call of gibbons was recorded at 40 points during the entire survey. Twenty-one recorders recorded the gibbon calls on the first day, 24 recorders recorded the gibbon calls on the second day, and 34 recorders recorded the gibbon calls on the third day. Number of recorders recorded the gibbons calls on the first day was the lowest that could be due to disturbance. The recorders are usually placed in the previous afternoon or early in the morning. Human

presence may cause gibbons to avoid the area near the recording posts on the first day (Reisland & Lambert 2016). In the second and third days, the number of recorders that could record gibbon calls increased.

Gibbon calls was recorded at 24 recording points in the eastern part and 12 points in the western part. The percentage of recorders that recorded gibbon calls in the eastern part was higher than that of the western part. This can be explained by the fact that the eastern part is dominated by rich and medium broadleaf evergreen forests.

In addition to the difference in habitat quality between the eastern and western parts, the difference in the percentage of occurrence between the two parts may be due to the difference in protection level between the two parts of Nam Cat Tien subdivision. The eastern part is better protected, with most locations within the forest <2.5 km away from Ranger Stations. Although the eastern part accounts for only 31%, it has more than a half of Forest Protection Stations. In the western part, most of the area is far from Ranger Stations.

3.2.6. Advantages and disadvantages of using recorders compared to human surveys

The comparison of advantages and disadvantages is shown in Table 3.5.

Table 3.5: Comparison of advantages and disadvantages between traditional method and method of using automatic sound recorders

No.	Indicators	Surveys by humans	Method of using automatic sound recorders
1	Number of employees	Require a lot surveyors; In order to ensure a high level of reliability, several survey listening post at the same time are needed, so many people are needed.	Require fewer surveyors, only 01 investigator is needed and she/he can install many devices to survey at the same time; The investigator then come and move the devices to another place.
2	Quality of labor	Many people with experience in field surveys are needed	Investigators with experience is not required. The investigators just need to know the device installation.
3	Degree of accuracy	Depends on the surveyor and varies by year	Not depend on the surveyors and between year comparison is easy and accurate.
4	Cost	Cost is high because many	It is costly for only the first

		surveyors are involved	time, an average of 20 million/device. One protected area can buy 3-5 devices for the first time and can use many year later; Only 1-2 people are needed to install the devices.
5	Time to conduct a survey in a day	Investigators have to get up early in the morning (at 3-4 AM) and move into the forest in difficult and unsafe conditions.	People go to install the devices in the previous afternoon and do not have to move into the forest in the dark.
6	Time of year	The rainy season or the forest fire season is often avoided due to the usage of many labors	Can be conducted at any time of the year
7	Camping in the forest	Usually surveyors have to camp to approach the listening post by 5:00 AM.	Camping is not needed, for example, surveyors can install devices at any site in Cat Tien National Park within one day.
8	Monitoring indicator	Density, number of groups, percentage of occurrence	Percentage of occurrence
9	Data analysis	Complex, sometimes depends on the subjectivity of the data analysts.	Complex but it takes only a short time to train

3.3. Comparing the gibbon population size in the study area with other protected areas

The population of yellow-cheeked crested gibbon (*Nomascus gabriellae*) in Cat Tien National Park is the largest gibbon population in Vietnam (Table 3.6).

Table 3.6: Comparison of gibbon population size in Nam Cat Tien subdivision with other protected areas

No.	Areas	Area (ha)	No. gibbon groups (groups)	Information source
1	Bu Gia Map National Park	25.926	124	Hoang Minh Duc et al. (2010a)
2	**Nam Cat Tien Subdivision**	**45.303**	**325**	**This study (distance method)**

No.	Areas	Area (ha)	No. gibbon groups (groups)	Information source
3	Chu Yang Sin National Park	59.531	166	Vu Tien Thinh et al. (2016)
4	Bi Dup –Nui Ba National Park	63.938	≥25	Luu Hong Truong & Le Khac Quyet (2010)
5	Phuoc Binh National Park	19.814	≥4	Hoang Minh Duc (2007)
6	Nam Nung Reserve	10.499	30	Dong Thanh Hai et al. (2011)
7	Ta Dung Reserve	18.893	12 - 18	Hoang Minh Duc et al. (2010b)
8	Dong Nai Cultural and Natural Reserve	100.303	15	Nguyen Manh Ha et al. (2010)
9	Snoul Wildlife Sanctuary	75.000	850	Traeholt et al. (2005)
10	Nam Lyr Wildlife Sanctuary	47.500	330	Traeholt et al. (2005)
11	Seima Biological Conservation Area	303.400	646-972	Rawson et al., (2009)
12	Phnom Prich Wildlife Sanctuary	222.500	360	Phan Chana and Gray (2009)

Cat Tien National Park is one of special-use forests that are less affected by human being. Nam Cat Tien subdivision is surrounded by Dong Nai river and other natural forests of La Nga Forestry Company, Dong Nai Cultural and Natural Reserve.

3.4. Proposing solutions to conserve yellow-cheeked crested gibbon in Cat Tien National Park

3.4.1. Limitations of conservation of Cat Tien National Park

b1. Forest resource protection (habitat of gibbon species) in Cat Tien National Park is entirely carried out by Forest rangers, which is located at the key areas. However, the quantity of forest ranger force is still small compared to the actual needs and has not been supplemented. Therefore, forest ranger has not met all the requirements of the forest protection activities.

b2. The arrangement of only staffs of the International Science and Cooperation Department and the Center for Wildlife Rescue, Conservation and Development to participate in monitoring and conservation activities is unreasonable. Forest rangers have to be involved in the biodiversity monitoring

activities.

b3. Due to the lack of funding and manpower, there has been no annual monitoring programs for gibbons, therefore, immediate intervention activities have not been implemented.

b4. The violation increased, especially in some cases the violators attacked the forest rangers.

3.4.2. Threats to yellow-cheeked crested gibbon in Cat Tien National Park

1. Forest lost and degradation will indirectly threaten gibbon population in Cat Tien National Park. Annual deforestation situation still continues to happen (in 2016, 8,384 m^2 of forest land was lost; In 2017, 3,193 m^2 of forest land was lost).

2. The hunting, trapping of wild animals in Cat Tien National Park, including gibbons, still happen. According to the annual report in 2016, there were 29 animal lost in 2016, and 22 animals died in 2017. There are still a large number of traps and guns in the surrounding local communities.

3. People's awareness of the role and scientific value sof wildlife (including yellow-cheeked crested gibbon) has not been significantly improved, creating negative impact on forest resources.

3.4.3. Proposing solutions to conserve yellow-cheeked crested gibbon

Four groups of solution are proposed to better conserve the gibbon population in Cat Tien National Park (Table 3.7).

Table 3.7: Measures contributing to improving the effectiveness of the conservation of yellow-cheeked crested gibbon in Cat Tien National Park

No.	Solution/Action	Threats and limitations are resolved
I	**Monitoring gibbon population**	
1	Integrating biodiversity monitoring into patrol activities conducted by forest rangers	HC: b2
2	Deploying yellow-cheeked crested gibbon monitoring program using automatic sound recording devices and bio-acoustic analysis following the proposed monitoring plan. Human resources for recording gibbon calls are forest rangers, and human resources participated in sound analysis is staffs of Department of Science and International Cooperation.	HC: b2

3	The use of sound recorders can also support the forest protection by detecting chainsaw and other violations.	HC: b1 HC: b2 HC: b3
II	**Improving manpower**	
1	Training to improve the capacity of staff in charge in rescue and conservation, especially forest rangers who directly carry out forest protection and animal rescue activities in the field.	HC: b3 HC: b5,
2	Collaborating with schools in the surrounding areas to organize training courses, seminars to raise conservation awareness toward protecting forests and wildlife.	MĐD: 3
III	**Strengthening forest and biodiversity management and protection**	
1	Reorganizing the management system of National Park by adding more rangers for Forest Protection Force; there must be a regulation on management and coordination of all parts of the management apparatus to implement the tasks of protecting forest resources. In each area where gibbons distribute at high density, increased patrol efforts are needed.	HC: b1, b2,
2	Strictly protect of broadleaf evergreen forest; restore poor forest ecosystems, especially those derived from broadleaf evergreen forests to ensure the habitat quality for gibbon.	HC: b1 MĐD: 1
3	Improving network of forest protection forces; assisting people in building village regulation on forest protection, wildlife protection and gibbon protection.	MĐD: 2 MĐD: 3
4	Implementing propaganda activity, encouraging local people not to use gibbon as food or for other purposes.	MĐD: 2 MĐD: 3
5	Increasing investigation forest and biodiversity law violators.	HC: b4 MĐD: 2
IV	**Financial solutions**	
1	Strengthening international cooperation, attract the aid of international organizations, especially wildlife protection organizations for financial support.	HC: b3
2	Developing projects supporting to improve the quality of poor ethnic minorities living in buffer zone of the National Park.	HC: b3 MĐD: 2

Note: HC: Limitations; MĐD: Threats

3.4.4. Proposing a monitoring plan for yellow-cheeked crested gibbon in Cat

Tien National Park

1. Specific objectives

- Proposing suitable monitoring indicators for yellow-cheeked crested gibbon that are easy to implement.

- Identifying gibbon population and distribution trends.

- Identifying tendency of the altering population situation and gibbon's distribution.

- Assessing the appropriateness and effectiveness of conservation activities carried out and adjusting management activities accordingly.

2. Monitoring plan

- Collecting relevant document.

- Interview method.

- Field monitoring.

+ Surveying using automatic sound recorders: Placing the automatic sound recorders at selected points; using broad-spectrum sound recorder (SM3, Wildlife Acoustics Inc.).

+ Monitoring indicators

- The points with gibbon calls recorded (P), was calculated using the formula [3.1]

$$P = \frac{n}{N} \qquad [3.1]$$

n: The number of recording points having a gibbon calls.

N: Total number of points.

b) The local extinction rate (P_1) was calculated by the formula [3.2]

$$P_1 = \frac{n2}{n} \qquad [3.2]$$

n2: The number of points recording gibbon calls in the previous year but do not record any gibbon call this year.

n: The number of points having gibbon calls in the previous year.

This indicator shows the local extinction rate in National Park. If this indicator is greater than zero, hunting is possibly occurring in the National Park.

- Indicator of recolonization rate (P_2) was calculated using the formula [3.3]

$$P_2 = \frac{n1}{N1} \qquad [3.3]$$

n1: Number of recording points without gibbon calls in the previous year, but record the gibbon calls in the current year.

N_1: Number of recording points without gibbon calls in the previous year.

- Time of fieldwork: From April to May every year.

- Equipment: broad-spectrum sound recorder SM3 (Wildlife Acoustics Inc.) (Quantity: 03 devices); large capacity memory card (128 GB type).; Software: RAVEN software (Cornell Lab of Onithology), Mapinfo software; GPS; specialized backpack for field equipment.

3. Expected results

- Distribution map of yellow-cheeked crested gibbon in Nam Cat Tien subdivision.

- Indicators represent the current situation of the species in the monitoring area.

- Threats to gibbon population.

- Solutions to conserve gibbon population.

CONCLUSION

1. Application of distance method in the survey yellow-cheeked crested gibbon.

Density and population size estimates between the traditional method (there are 195 gibbon groups in the study area) and the distance sampling method (there are 325 gibbon groups in the study area) are different. However, the distance sampling method takes into account the detection probability less than 1 for gibbon groups far from the surveyor. Therefore, distance sampling method should be used to estimate gibbon population.

2. Application of automatic sound recording devices in investigating and monitoring yellow-cheeked crested gibbon

- The sound spectrum of yellow-cheeked crested gibbon (*Nomascus gabriellae*) in the study area is basically consistent with the sound spectrum of crested gibbon genus *Nomascus* described by Konrad and Geissmann (2006).

- By analyzing the sound spectrum obtained from the automatic sound recorders, the dissertation has identified the structure of gibbon groups in the study area, including 05 basic structures.

- The preferred habitat of yellow-cheeked crested gibbon is broadleaf evergreen forest, especially medium to rich forest.

- Most groups of yellow-cheeked crested gibbons start calling from 5:30 AM to 6:00 AM, and finished calling from 6 AM to 6:30 AM.

- It is better to avoid rainy or windy days. If automatic recorders are used, the recording time should be extended to compensate for the days with unfavorable weather.

3. Comparing gibbon population size in the study area with other nature reserves and national parks.

Cat Tien National Park is one of the most important areas for yellow-cheeked crested gibbon (*Nomascus gabriellae*) conservation in the world.

4. Solutions for conserving yellow-cheeked crested gibbon in Cat Tien National Park

- It is necessary to rearrange management system of the National Park.

- Focusing on building a network to protect forests and protect wildlife

with the participation of local people.

- Encouraging local people not to use gibbon as food or other purposes.

- Automatic sound recording devices and sound analysis methods should be used in gibbon monitoring activities in National Park.

- A monitoring program for yellow-cheeked crested gibbon was developed for Cat Tien National Park.

DANH MỤC CÁC BÀI BÁO ĐÃ CÔNG BỐ

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