พฤติกรรมการร้องและการประเมินประชากรของชะนีแก้มขาวใต้ที่ใกล้จะสูญพันธุ์ในป่าสงวนแห่งชาตินากาย-น้ำเทิน, สาธารณรัฐประชาธิปไตยประชาชนลาว

นายจันทราพร นันทะวงศ์

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SINGING BEHAVIOUR AND POPULATION ESTIMATES OF THE ENDANGERED SOUTHERN WHITE-CHEEKED GIBBON *(NOMASCUS SIKI)* IN NAKAI-NAM THEUN NATIONAL PROTECTED AREA, LAO PDR

Chanthalaphone Nanthavong

Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Environmental Biology

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SINGING BEHAVIOUR AND POPULATION ESTIMATES OF THE ENDANGERED SOUTHERN WHITE-CHEEKED GIBBON *(NOMASCUS SIKI)* IN NAKAI-NAM THEUN NATIONAL PROTECTED AREA, LAO PDR

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ป่าสงวนแห่งชาตินากาย-น้ำเทินเป็น 1 ใน 24 แห่งของพื้นที่อนุรักษ์ในสาธารณรัฐประชาธิปไตยประชาชนลาว ที่มีความหลากหลายทางชีวภาพสูง พื้นที่ศึกษาตั้งอยู่ใน Houay Tong ทางทิศตะวันตกของป่าสงวนแห่งชาติ นากาย-น้ำเทิน ชะนีแก้มขาวเป็นสัตว์เฉพาะถิ่นของประเทศลาวและเวียดนาม ซึ่งกำลังเผชิญอันตรายจากการล่าสัตว์และการสูญเสียที่อยู่อาศัย ดังนั้นชะนีแก้มขาวใต้ได้รับการจัดให้เป็นสัตว์ที่ใกล้จะสูญพันธุ์โดย IUCN การประเมินความหนาแน่นทำให้ได้ข้อมูลพื้นฐานที่จะช่วยให้มีการติดตามประชากรของสิ่งมีชีวิตในระยะยาว การศึกษาครั้งนี้เริ่มตั้งแต่เดือนตุลาคม พ.ศ. 2556 ถึงเดือนพฤษภาคม พ.ศ. 2557 (120 วัน) ทำการสำรวจในพื้นที่สี่เหลี่ยมขนาด 4 ตารางกิโลเมตร จำนวน 30 แห่ง ครอบคลุมพื้นที่ทั้งหมด 120 ตารางกิโลเมตร ในแต่ละแห่งจะทำการฟังเสียงชะนีจำนวน 3 จุดพร้อมๆ กัน โดยให้แต่ละจุดห่างกันประมาณ 500 เมตร เป็นเวลา 4 วันติดต่อกัน การประเมินความหนาแน่นของชะนีทำโดย 3 วิธี วิธีแรกเป็นวิธี Triangulation วิธีนี้ให้ความหนาแน่น 0.93 ถึง 1.20 กลุ่มต่อตารางกิโลเมตร วิธีที่ 2 ใช้ MacKenzie Occupancy model คำนวณโดย Unmarked package ในโปรแกรม R ซึ่งพบว่า ชะนีอาศัยอยู่ในพื้นที่สำรวจ 29 จาก 30 แห่ง หรือร้อยละ 97 วิธีสุดท้ายคือ Royle's N-Mixture model ซึ่งให้ค่า 2.68 กลุ่ม/ตารางกิโลเมตร วิธีสุดท้ายนี้เป็นวิธีที่ดีที่สุดในการหาความหนาแน่นประชากรของชะนีจากการนับเสียงที่ร้อง โดยไม่จำเป็นต้องตามหากลุ่มให้พบ ซึ่งความหนาแน่น 2.68 กลุ่ม/ตารางกิโลเมตร ทำให้ประมาณการได้ว่าอาจมีชะนีมากกว่า 17, 000 ตัว (จากค่าเฉลี่ย 4 ตัวต่อกลุ่ม)

การสุ่มตัวอย่างการฟังเสียงประกอบกับการเก็บรวบรวมข้อมูลด้านสิ่งแวดล้อม ทำให้เข้าใจรูปแบบพฤติกรรมการร้องของชะนีที่สัมพันธ์กับสภาพภูมิอากาศและดาราศาสตร์ (พระอาทิตย์ขึ้น) โดยเฉลี่ยตัวผู้เริ่มร้องที่เวลา 6:13 น. (± 27:17 นาที) ตัวเมียเริ่มร้องที่เวลา 6:16 น. (± 26:52 นาที) และทั้งคู่จะร้องเป็นเวลานานโดยเฉลี่ย 16:43 นาที (± 5:04 นาที ช่วงเวลาตั้งแต่ 2.00 ถึง 37.22 นาที) โดยรวมร้อยละ 83 ของวันที่สำรวจ ชะนีเริ่มเสียงร้องก่อนพระอาทิตย์ขึ้นเฉลี่ย 16:11 นาที สำหรับวันที่เหลืออีกร้อยละ 17 ชะนีเริ่มเสียงร้องโดยเฉลี่ย 7:18 นาที หลังจากพระอาทิตย์ขึ้น ทั้งนี้ อุณหภูมิและพระอาทิตย์ขึ้นเป็นปัจจัยบ่งชี้ที่สำคัญสำหรับช่วงเวลาการร้องของชะนี เช่น อุณหภูมิตอนเช้า

เพิ่มขึ้นและพระอาทิตย์ขึ้นเร็วขึ้นในช่วง 7 เดือนที่ศึกษา ชะนีจะเริ่มร้องเร็วขึ้นด้วย การค้นพบเหล่านี้ช่วยให้เราเข้าใจถึงพฤติกรรมของชะนีและการปรับตัวให้เข้ากับสภาพแวดล้อมที่เปลี่ยนแปลงได้เป็นอย่างดี

สาขาวิชาชีววิทยา

ปีการศึกษา 2556

ลายมือชื่อนักศึกษา__________

ลายมือชื่ออาจารย์ที่ปรึกษา__________

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ลายมือชื่ออาจารย์ที่ปรึกษาร่วม__________

CHANTHALAPHONE NANTHAVONG : SINGING BEHAVIOUR AND POPULATION ESTIMATES OF THE ENDANGERED SOUTHERN WHITE-CHEEKED GIBBON *(NOMASCUS SIKI)* IN NAKAI-NAM THEUN NATIONAL PROTECTED AREA, LAO PDR. THESIS ADVISOR : ASST. PROF. PONGTHEP SUWANWAREE, Ph.D. 78 PP.

BEHAVIOUR/ESTIMATE/*NOMASCUS SIKI*/NAKAI NAM THEUN/LISTENING POST/SINGING

Nakai-Nam Theun National Protected Area (NNT-NPA) is one of twenty-four national protected areas in Lao PDR, maintaining high biodiversity. The research site was located in the western part of NNT-NPA, Houay Tong area. The Southern white-cheeked gibbon (*Nomascus siki*) is an endemic species of Laos and Vietnam. The main threats they face are hunting and habitat loss. Therefore, they have been classified as Endangered in the *IUCN Red-list of Threatened Species*. Density estimates provide baseline data to enable long-term monitoring of populations. From October 2013 to May 2014 (120 days of data collection), 30 grid-cells of 4 km^2 were surveyed, covering a total of 120 km^2. In each grid three listening posts, ~500 m apart, were visited simultaneously for four consecutive days. Three different analysis methods were used to estimate gibbon abundance. First, the triangulation method was used, resulting in densities between 0.93 to 1.20 groups/km^2. Second, the occupancy model in R package Unmarked using the MacKenzie's occupancy model revealed that, of the 30 sites surveyed, 29 were predicted to be occupied (occupancy of 0.97). Finally, Royle's N-Mixture model with Unmarked was performed, resulting in an estimate of 2.68

groups/km^2. The N-Mixture model represents the best alternative to estimate abundance and density from gibbon survey data using count of their calls, without the need of identifying groups. The estimated 2.68 groups/km^2 could mean over 17,000 individuals (with an average group size of 4 individuals.

The auditory sampling was complemented by data collection on environmental data to understand gibbon singing behavior patterns in relation to climatological and astronomical (sunrise) variables. On average, males started calling at 6:13 (± 00:27:17), while females started at 6:16 (± 00:26:52). Duet calls lasted on average for 00:16:43 hrs (± 00:5:04; range 00:02:00 – 00:37:22). Overall in 83% of the sampling days, gibbons started calling before sunrise, on average 00:16:11 hrs before sunrise. For the remaining 17% of the days, gibbons started calling on average 00:07:18 hrs after sunrise. Both temperature and sunrise were strong predictors for the time of call of gibbons: as morning temperature increased and sunrise started earlier over the seven months of the study, gibbons started calling earlier. These finding provide insight into the behavioral ecology of gibbons and their adaptations to a changing environment.

School of Biology	Student's Signature_____________
Academic Year 2013	Advisor's Signature P. Sunan
	Co-advisor's Signature_____________
	Co-advisor's Signature_____________

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LIST OF ABBREVIATIONS

AIC	Akaike Information Criterion
CR	Critically Endangered
CITES	The Convention on International Trade in Endangered Species
EN	Endangered
GPS	Global Positioning System
GIS	Geographic Information System
H.	*Hylobates*
IUCN	The International Union for Conservation of Nature
K	Number of parameters
Lao PDR	Lao People's Democratic Republic
LA	Listening Area
LP	Listening Post
mtDNA	mitochondria Deoxyribonucleic acid
MAF	Ministry of Agriculture and Forestry
N.	*Nomascus*
NNT-NPA	Nakai-Nam Theun National Protected Area
NT2-WMPA	Nam Theun2-Watersged Management and Protection Authority
SPSS	Statistical Package for the Social Sciences
SE	Standard Error
VU	Vulnerable

CHAPTER I

INTRODUCTION

1.1 Rationale and Background

White-cheeked gibbons (*Nomascus siki*) are little known in terms of their distribution and taxonomic status and their behavioural ecology. Surveys in some areas have allowed re-assessment of their global conservation status; however considerable gaps in our knowledge remain. Research on these species is urgently needed. Previously considered as a single species under *N. leucogenys*, the latter was re-evaluated as two distinct species, namely the Northern white-cheeked gibbon (*N. leucogenys*) and the Southern white-cheeked gibbon (*N. siki*), (Thinh et al., 2010). Both species' distribution range limits remain unclear.

Nomascus leucogenys is native to China, Vietnam and Laos but is believed to be virtually extinct from China (Fan and Hou, 2009). In Vietnam, of the few remaining sites where the species has not yet been extirpated from deforestation and hunting, Pu Mat National Park was recently identified as the main national stronghold of the species with an estimated 130 groups (LuuTuong Bach and Rawson, 2011*). Nomascus siki* is endemic to Laos and Vietnam. In Vietnam, remaining populations are essentially small and isolated; the two largest populations are found in Phong Nha-Ke Bang National Park (at least 50 groups) and BacHuongHoa Nature Reserve (at least 23 groups) (Rawson et al., 2011). The world's largest populations of both species are likely found in Laos. Although the distribution and abundance are poorly known in the country, a survey done in 201-2012 revealed a healthy population of gibbons in Nakai-Nam Theun National Protected Area (NNT NPA, hereafter) (Coudrat, 2012). This makes it the ideal research site to establish a long-term conservation and research project on *Nomascus siki*. ashuman encroachment is evident in the area, including illegal hunting and logging, and a long-term ecological research in the area will aid with their protection.

1.2 Research Objectives

The objectives of this research are: 1) to estimate of gibbon density, singing behavior and occupancy model at the research site; 2) propose a survey methodology to define gibbon density; and 3) to test how environmental variables are affecting to gibbon singing behavior.

1.3 Scope and Limitation of the Study

The study sites were depending to two main villages boundary linkage are responsibility. Three main rivers were existing within the research site which was represented area description. In this study, the density estimation and environmental variations are affecting to gibbon calls were investigated. The density estimate was derived from the triangulation method. On this implementations in the field sites were contained various different altitudes within grid-cells. The testing of triangulation method achieving and gibbon singing behavior were test in different analysis programs. The consideration programs were using for several analysis are including ArcMap 10, Mark 7.0 and SPSS Statistic 20, all of this are considering in use for density estimate, occupancy modeling and singing behavior relative by environmental variations data.

CHAPTER II

LITERATURE REVIEW

Gibbons are arboreal and diurnal apes (Geissmann, 2007). They are endemic to southern China, Bangladesh to India and Southeast Asia. The family of *Hylobatidae* is composed of 4 genus: *Hoolock, Hylobates, Nomascus* and *Symphalangus,* with a total of 17 species (Geissmann, 2007 ; Thinh et al., 2010). Their distribution range from India and Bangladesh to the west, tropical China to the North and to the island of Java (Indonesia) to the South. They range between about 15°S to 30°N latitudes and inhabit tropical forests, mostly in semi-evergreen and evergreen forests.

All gibbon species are highly threatened by loss of their habitat and illegal hunting for food, traditional medicine or pets (Rawson et al., 2011; Melfi, 2012). They can have a high value on the international trade which increases the illegal hunting pressure. Four species in the genus *Nomascus* are Critically Endangered (CR), one species of the genus *Hoolock* is Vulnerable (VU) and the 12 remaining species are Endangered (EN) as classified in the IUCN Red List of Threatened Mammals (IUCN, 2012). All gibbon species are listed in Appendix I of CITES (The Convention on International Trade in Endangered Species).

Nomascus siki is threatened by continuing extensive forest destruction within its range mainly in Vietnam and by hunting for illegal trade, for food and/or for pet trade. Numbers have greatly declined and its range has reduced, partly due to their habitat being reduced for infrastructure development such as dams, roads, mines. The principal threat to this species is excessive and un-sustainable hunting (Geissmann et al. 2000; Nguyen Manh Ha et al., 2005; Duckworth, 2008). Therefore, the Southern White-cheeked gibbon is classified as Endangered (IUCN, 2012) also Appendix I of CITES (The Convention on International Trade in Endangered Species, 2012) and List 1 of Laos status conservation (Laos wildlife laws, 2010).

The Southern white-cheeked gibbon (*Nomascus siki*) phenotypically resembles *N. gabriellae* (Geissmann et al., 2000; Konrad and Geissmann, 2006). The species were separate species in 2001 based on mtDNA and vocalization (Thinh et al., 2010). The *N. siki* ranges to the North of *N. gabriellae* in Southern Vietnam and Eastern Cambodia (Mootnick and Fan, 2011). The size of *N. siki* is quite similar to that of *N. leucogenys* with an average weight of approximately 7.5 kg. The male had slightly longer body hair, is dark in coloration with the shape of the white patch on their cheeks and has a black crested with white edges. A large white fur patches at the edge of the mouth are differing from the male of *N. leucogenys* (Figure 2). The female is buff in coloration with a dark crest and a thin edging of white fur around the face as well (Figure 2). Juveniles show a light brown fur color which, in males, turns to black with is (Geissmann et al., 2000; Konrad and Geissmann, 2006).

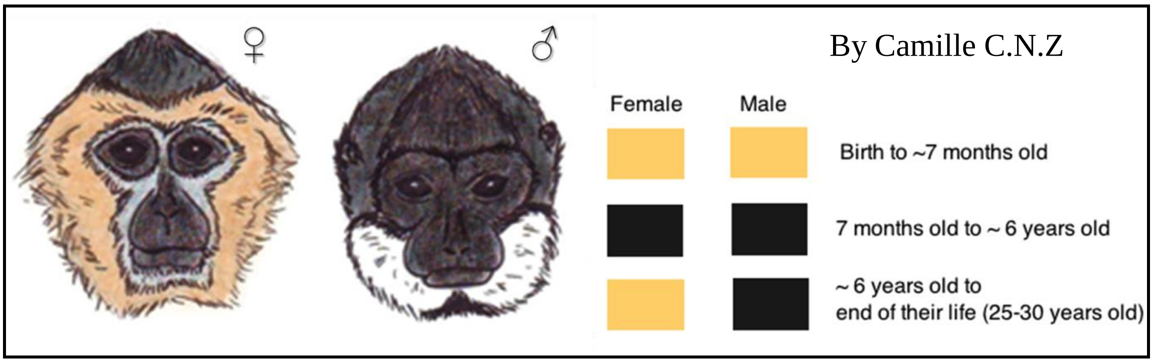

Figure 1 Male and female characteristic, coloration change during their years old.

The species is found in central Laos and central Vietnam between 17°N and about 19.3°N in an apparent overlap range of *N. siki* and *N. leucogenys* between about 19 and 20°N (Geissmann et al., 2000; Mootnick and Fan, 2011). Many populations in Vietnam are supported by little contiguous habitat and experience high a degrees of human disturbance to be considered viable, especially those in forested areas that are not shared with Lao PDR (Geissmann et al., 2000). In Pu Mat National Park encounter rates declined from 22.6 per 100 survey days in 1999 to 14 in 2004 (Grieser-Johns et al., 2004). In a status survey report, Geissmann et al. (2003) recorded six localities where *N. siki* were previously known to occur, of which all but one still had surviving populations at the time. During a survey covering about 15 km^2 of the Phong Nha-Ke Bang National Park (Quang Binh province, central Viet Nam; total area: 858 km^2), 13 gibbon groups were heard, suggesting a density of about 0.7 groups/km^2 (Ruppell, 2007). Three individuals were reported from Khe Giua State forest enterprise (Quang Binh province, central Viet Nam). There are no available population estimates for Lao PDR, but the species was considered widespread and common in all large forest blocks within its distribution area few years ago (Duckworth, 2008; MAF, 2011).

In Vietnam, the species that is found in the lowlands, at an elevations of 30-100 m, in a typical wet tropical forest, like Phong Nha-Ke Bang National Park in central Vietnam in steep karst forest (Ruppell, 2007). In Lao PDR, it is found in as lowland resident of Mekong plains up to 1,800 m, among upper evergreen forest and primary broadleaves forest (Duckworth et al., 1999). The range of the species is thought to be limited to the North by the Kading River while its southern range limit is still unknown in Laos but is believed to be limited by the Bang Hiang River in

Savannakhet Province (Thinh et al., 2010; MAF, 2011). Like other gibbon species, Southern white-cheeked gibbons are arboreal diurnal and mainly frugivorous (Geissmann et al., 2000), however the species has never been studies in the wild and data on its feeding behavior remains unknown. In NNT-NPA is being remained large population, especially Houay Tong area through my study and the studying (Coudrat, 2011) there was showing the best result from the area, the gibbon’s population presence abundantly.

CHAPTER III

METHODOLOGY

3.1 Overview

The literature review was conducted though the study of the gibbon density estimation and calls affective provided triangulation method within the research site (temperature, interaction between calls, comparison of time start and end calling each weather condition even geography on map). These included theories, investigation, methodology, results, analysis and applications. Largely resource information is from journals, technical reports, books and/or even in the website. A summary of the literature review will be given in the thesis. All aspects of the studies mentioned will be documented and incorporated into the thesis. The thesis will discuss the validity and potential applications of the results. It will be submitted at the end of the research.

3.2 Study Area

The study was conducted in Nakai-Nam Theum National Protected Area between 17°34' 18°23' N 105°02' 105°46' E, one of the twenty-four NPAs established by the Ministry of Agricultural and Forestry in 1993 (Robichaud et al., 2001). NNT NPA is located in four different districts: Khamkeuth,Nakai, Gnommalath and Boualapha within Bolikhamxai and Khammouane provinces. To the East, the NPA shares a border with Vietnam of 161 km (NT2 WMPA, 2005). NNT NPA falls in the Annamite

Mountain range. Its approximate size is 3500 km^2 and is the second largest NPA in Laos, with the elevation ranging from 500 m to 1,800 m above sea level (NT2 WMPA, 2005). The dominant vegetation type is upper dry evergreen forest (51.7%) and upper mixed deciduous forest (19.7%), mixed broadleaved-coniferous forest (14.7%), scrub (13.1%) and agriculture land (4.2%) (Figure 2). The NPA is crossed by five main rivers (NT2 WMPA, 2005). The tropical climate at NNT NPA consists of two distinct seasons, summer (April-October), rainy (November-March). Within the protected area the study site was located at Houay Tong, mainly covered by upper dry evergreen forest (NT2 WMPA, 2005).

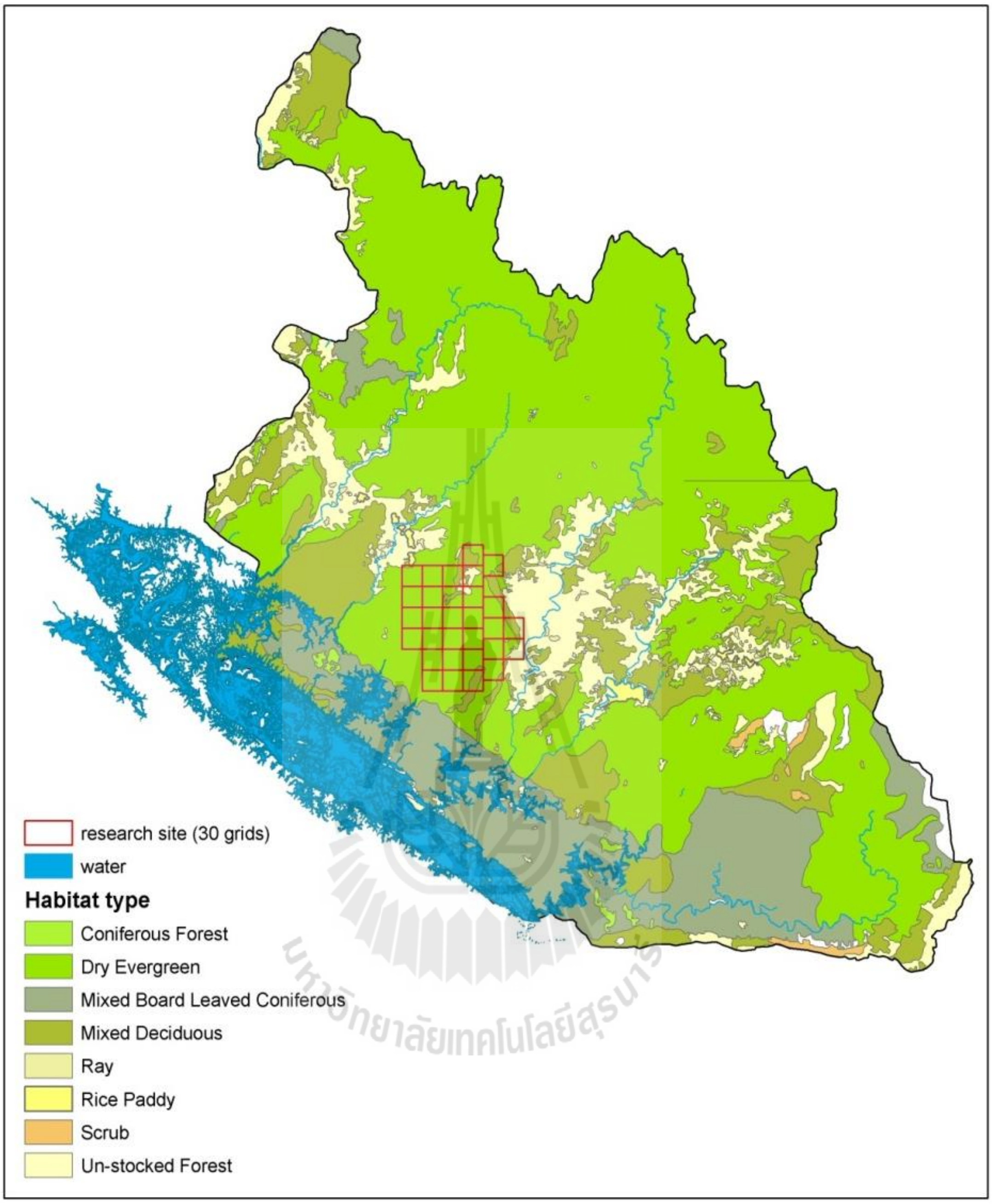

Figure 2 Habitat types (forest types) in Nakai-Nam Theun National Protected Area (NNT NPA) and 30 grid-cells are covering 120 Km^2 of the 4x4 km^2 within the research site.

In NNT-NPA, the large problems to this species are hunters and habitat lost mainly consequence of low patrolling. The research site, located in the Houay Tong area, is surrounded by villages and it is under pressure from an increasing human population around the NPA. Therefore, on the recording of threats is important for area management planning with the laws enforcement effectively.

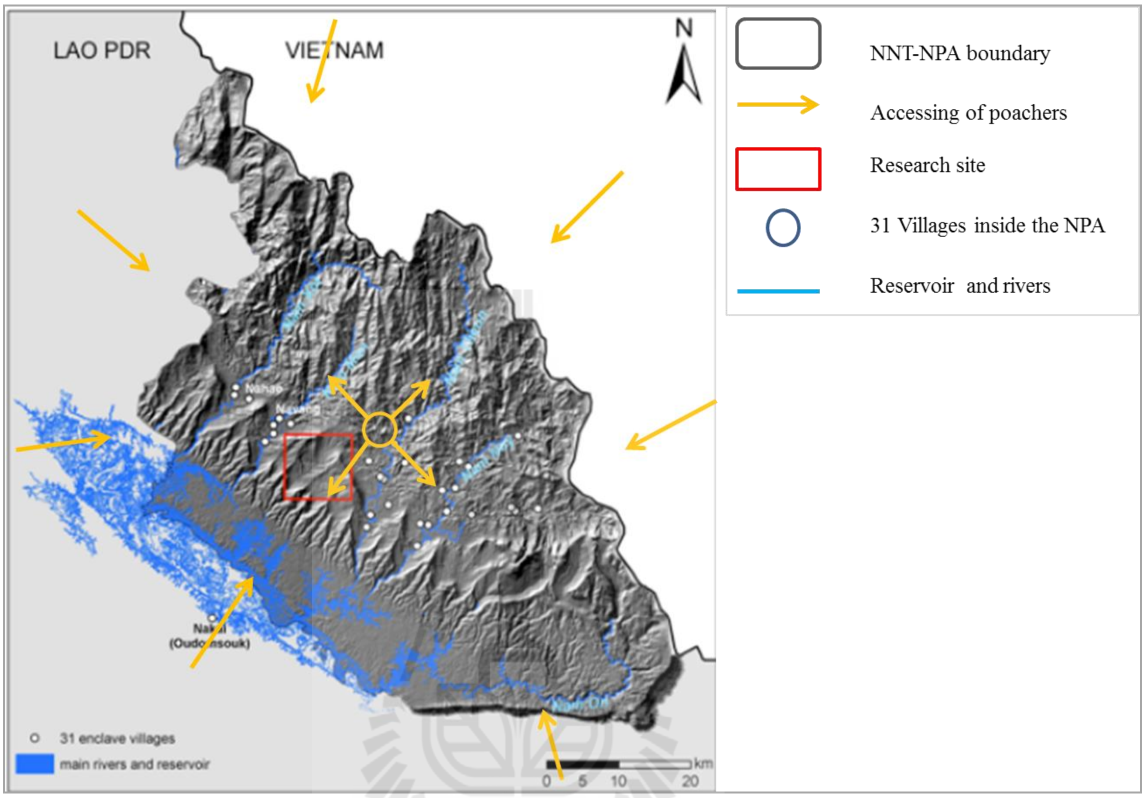

Figure 3 The map of showing for the hunters accessible to NNT-NPA for hunts and any disturbance, By Coudrat, C.N.Z.

3.3 Gibbon Survey

From November 2013 to May 2014, thirty different grid-cells (of 4 km^2 each) were established in the study area (Figure 4). Thirty grid-cells were selects based on (1) statistical needs during data analysis (2) the accessibility of the overall forest. Last two grid-cells (grid number 29 & 30) were conducted only two days because of rains and also a lot of clouds, in the morning, and also very closed to the reservoir that people can come to found foods and illegal logging, no gibbons called in 1.5 km radius within a grid.

3.4 Listening Posts

Triangulation is one of the most used methods for estimating gibbon’s density. Listening area are located on suitable terrains and data are recorded during the high calling seasonal, which depend on the different *Nomascus* species. In each grid-cell we located one listening area, designed on geography map scale 1:50000, with three listening posts in it, for a total of 30 listening area and 90 listening post (Figure 4).

All the thirty listening areas were visited within 5 months for a period 4 consecutive days each. In each listening area (LA) the three listening posts (LP) were located on a straight line (Figure 4). Most listening post were located on mountain ridges and close to available rivers used for camping. LPs were randomly pre-selected on a topographic map 1:50000 and were found by using two GPS “Global Position Status”, a Garmin 62Sc and a Garmin 62S). Each LPs within a LA were located 300m-500m apart depending to topography. When arrived at a new campsite, after moving from the previous one, the team was entered the LPs waypoints in GPSs and used topographic map to assist in reaching it. For each LP were marked an actual GPS location and elevation. The directions from camps to each LPs were recorded to make successive visited easier. The data at each LP were collected by two people. The determination effective listening areas, needed to calculate density, as the areas where a minimum of two listening posts could have heard gibbon calls, within a radius of 2000 m around each post, using ArcGIS 9.3.

The teams were arrived at the listening posts on average at 05:39(6:38-9:40) every morning and left on average at 07:25(4:55-6:00). After gibbons had stopped calling we waited for 30 minutes before came back camp (if without any problems for example rains and cloudy).

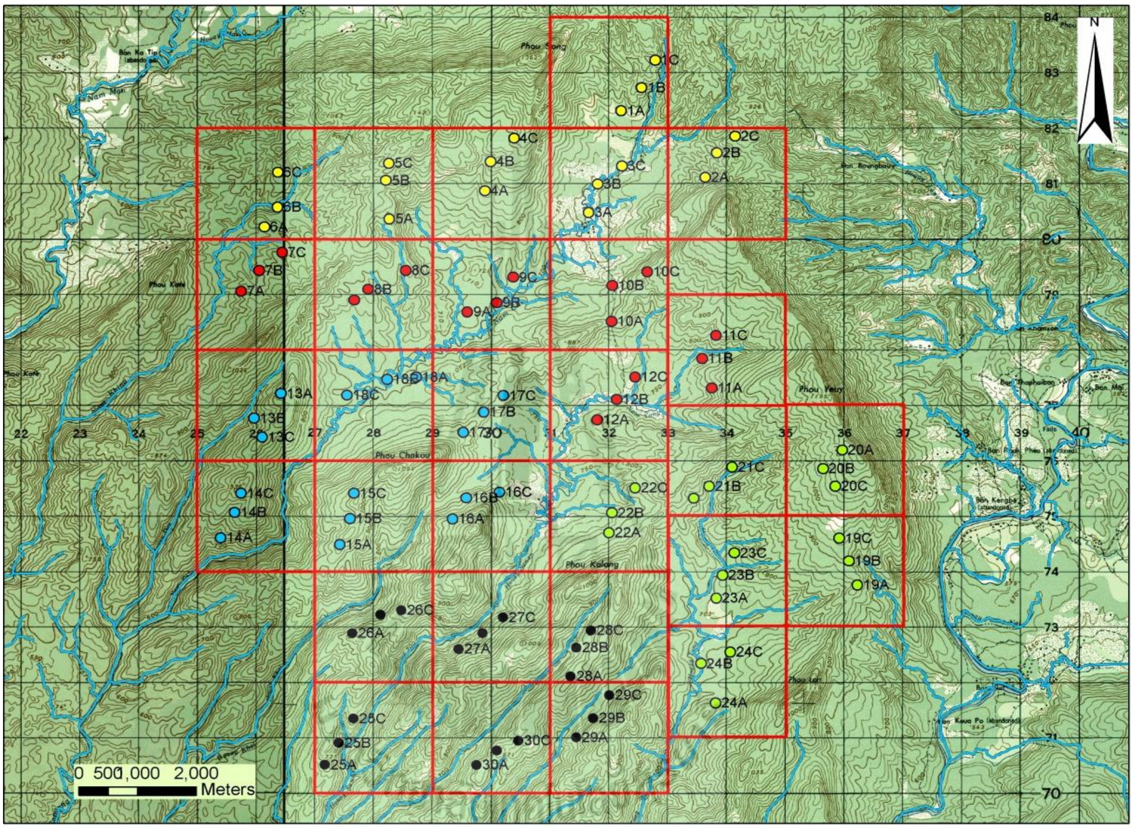

Figure 4 Location of 18 listening posts (within 4 km^2-grids) were visited each time periods of field trips (yellow 1A-B-C to 30A-B-C in black is final) total of 90 LPs visited previously in November-December 2013: 1A-B-C to 6A-B-C(in yellow), in December-January 2014: 7A-B-C to 12A-B-C (in red), in January-February 2014: 13A-B-C to 18A-B-C (in blue), and in March-April: 19A-B-C to 24A-B-C (in green)in a total visited of 120 days.

Table 1 Date of field work (including travels time to field site).

Study sites	Grids number (Period of Time)	Dates (included two days travel/times)
Nam Chae	1-6 (I)	8 November 2013 to 3 December 2013
NamChae	7-12 (II)	17 December 2013 to 13 January 2014
Nam Chae	13-18 (III)	20 January 2014 to 16 February 2014
Houay Tong	19-24 (IV)	9 March 2004 to 4 April 2014
Houay Snap	25-30 (V)	26 April 2014 to 17 May 2014

For each field trip was spends travel a few days maximum by boat from town, motorbikes, tractors and/or walked with the village to village and village nearly foothill. We always stayed at the closest village as much as possible of the field site. Therefore, we need to meet with the village chief to inform him the permission latters, to show our objectives in activities planning. In addition, he had in charge selection of three villagers whom will be assisting us in fieldwork and porters. Four villagers were considered choose to be field assistances. He was in charge of selecting three villagers who would join the field work, and other porters. Four villagers were considered choose to be field assistances. Usually the two villagers would be represented a team leaders, while the two other persons were assist shooting bearings or companion).

3.5 Weather Data Recording

We recorded weather data three times per day (in the morning, mid-day and afternoon) using the *Kestrel 3000* weather station:

- Temperature

- Heat stress index: Heat index is an index that combines air temperature and relative humidity in an attempt to determine the human-perceived equivalent temperature how hot it feels.
- Dew point temperature: The dew point is the temperature at which the water vapor in air condenses into liquid water at the same rate at which it evaporates; at a relative humidity of 100%, the dew point is equal to the air temperature.
- Relative humidity: The relative humidity is the ratio of the partial pressure of water vapor to the saturated vapor pressure of water at a given temperature.
- Maximum wind speed (in a period of about 3 minutes)

3.6 Gibbon Sightings

The collecting of gibbons sighting were used incidental direct sightings, when traveling by foot through the forest. Those activities were effectively known basically current population on that area. The combination data collection in each period and summarized all the results that deriving from the trips then progression reporting information. The team was normally tried to take photos and videos if gibbons were approachable. This were considering to dates and times to catching other factors on their behavior ecology between times spending on the natural trees. We did not collects all the data detecting because of spend a lot of times to stay with it and also would be interrupted to concentrate listening to other groups.

Figure 5 One sub-team data recording.

Figure 6 Advising two sub-teams.

Figure 7 Gibbon group was detected during survey in the morning while their calling bouts to another group with the high feeding tree (Houay Tong Area, photo by C. Nanthavong, March 2014).

3.7 Threats Recording

The teams were constantly records within research site throughout the study which was to investigate threats are affecting sustainability population on the area. Using GPS handle to taking the location points, pictures and any evidences discovered. We noted the dates and times then specify location name that threats were detected are. The determination of threats collecting information was considered in evidence conditions at least 1 year old, for example; the main threats like snares, poacher or hunter camps and remains of animals. However, those recording were includes collectors (villagers who had come to collected forest produces and logging), domestic dogs and weapons that they brought into the special conservation zone in the NPA. We collected all the snare lines that we met (even working or not working) and then destroy or burn including poacher camps after taken the details. All the data were entered into ArcGIS. 10 to display the location on the geography map where the threats are. This would be certainly know how to plans for conservation management long-term project.

Figure 8 Detection of the poacher camp in the forest and discovered some animal's remains, rose woods piece within the camp that they left in previous a few days.

3.8 Data Analysis

3.8.1 Triangulation Method

This study was following the general methodology of Brockelman & Ali (1987) for gibbon surveying. Each gibbon group detected from the listening posts was plotted in ArcGIS 10, using the GPS location of the recorder, the distance and bearing recorded (with the formulae X_{new}=(SIN[bearing in radian]*distance)+$X_{listening\ post}$; Y_{new}=(COS[bearing in radian]*distance)+$Y_{listening\ post}$). Lines were drawn from the listening post to the detected group using the Bearing-Distance tool. On several occasions, females were heard from a listening post but not from the other for the same group, we therefore plotted all the data and only excluded male solo when these where recoded as such by at least 2 listening posts.

For each grid-cell (each with 3 listening posts), we analyzed the data daily in order to use the call timings recorded as cue for group identification and triangulation between listening posts. Due to the occasional imprecision in recording times (mostly due to difficulty to hear the group resulting in late recording) we considered a difference of up to 15 minutes to be acceptable in defining the same group. Estimates of distance to groups were merely used as general indicators, however similarly, the imprecision and observer bias often resulted in incorrect estimates. Therefore, the triangulated groups were approximately positioned at the location where directional lines from listening posts met.

We conducted a first overall analysis, which included all the possible groups based on the data, including potential groups not triangulated (i.e. recorded by only 1 listening post). The listening area for the entire research site was calculated by drawing the contours around circles of 1-km radius around each of the listening posts (excluding overlap areas).

We conducted a second analysis per site, only including groups that could be triangulated (i.e. recorded by at least 2 listening posts). A listening area was calculated for each site by drawing the contours around circles of 1-km radius around each of the 3 listening posts (Figure 19).

Density was estimated using the formulae $\boldsymbol{D=n / A}$, where $\boldsymbol{D}$=density, $\boldsymbol{n}$=total number of groups heard based on mapping of calls and **A**=effective listening area. All located groups at least intersections with the listening area were included in the calculation of density.

3.8.2 Occupancy Model

Occupancy models assume independence of detection between sites (MacKenzie et al., 2006). Therefore we selected one listening area per grid (ensuring the largest distance between neighboring listening posts) and only selected the count of gibbon groups heard up to 1000 m (Figure 10).

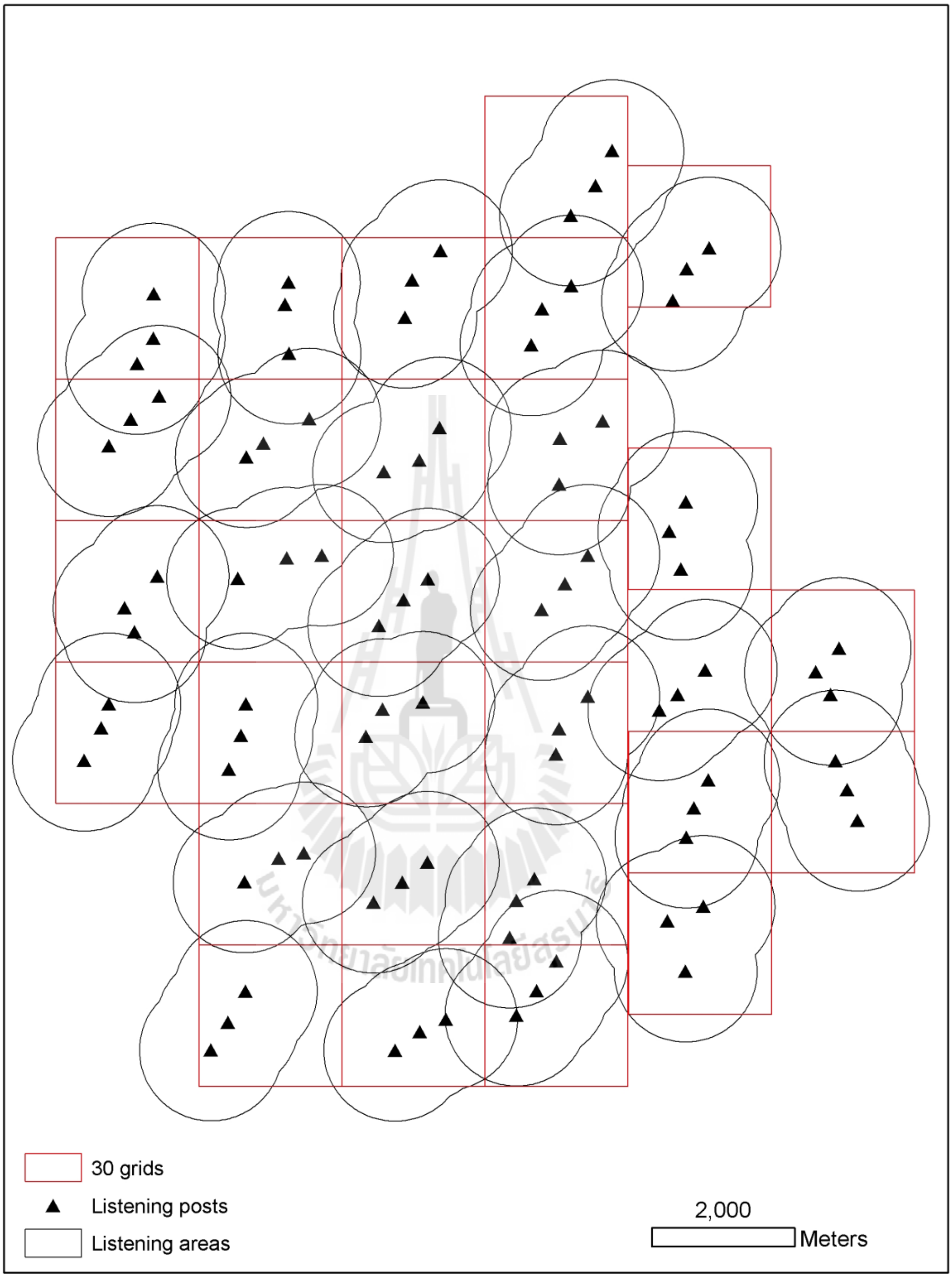

Figure 9 Listening areas for each set of 3 listening posts used to calculate group density.

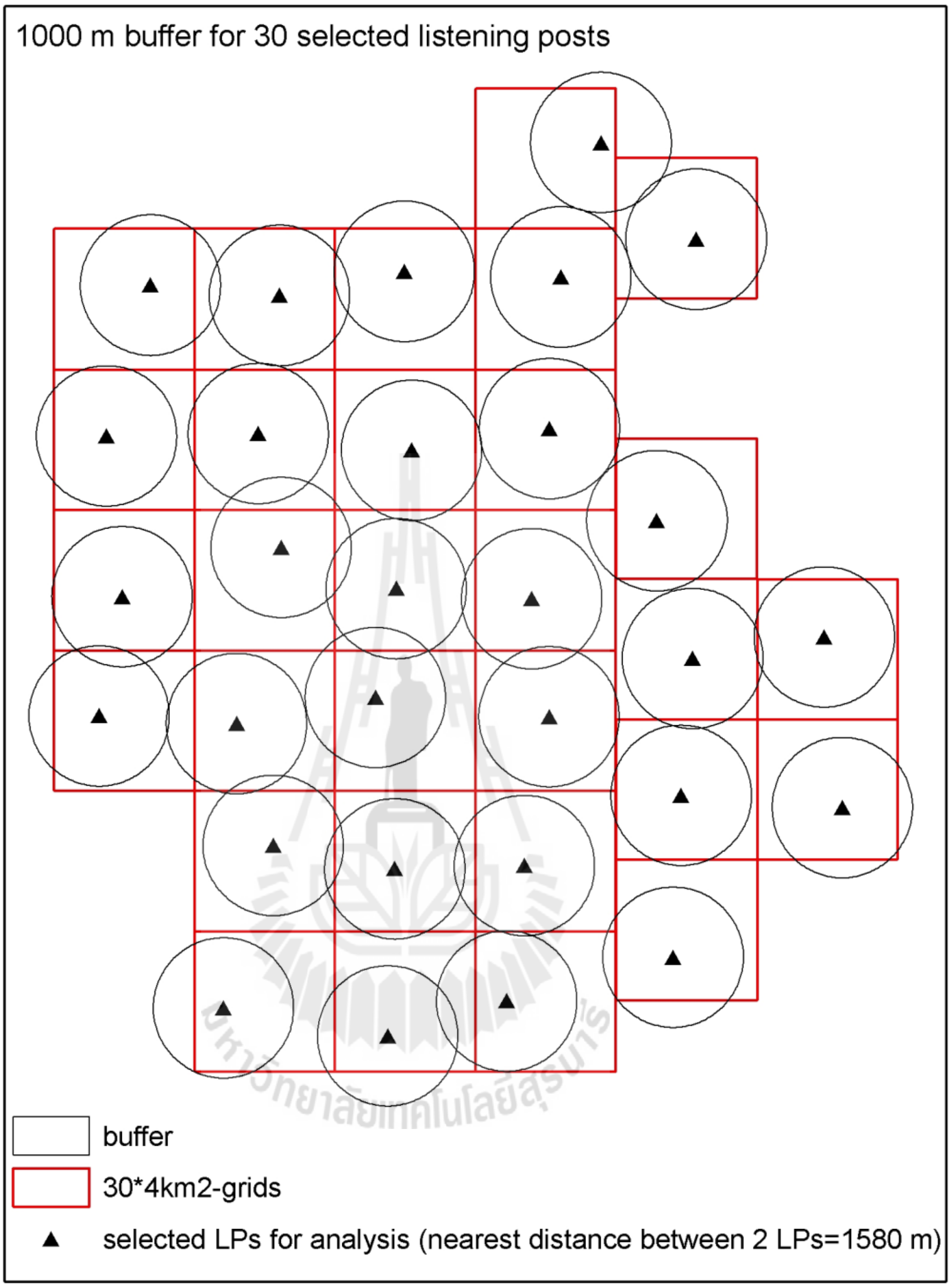

Figure 10 Selected listening posts from which data was used for the occupancy and N-Mixture models.

The only groups recorded up to 1000 m were included in the data for analysis in order to ensure independence of observation between sites. The analysis was performed in the R (v. 3. 1. 0) package 'Unmarked' using the MacKenzie et al.'s function "Occu" (Fiske and Chandler, 2014; Fiske et al., 2014). This study was run in several models with occupancy *psi* as a function of different site-covariates and detection probability *p* as a function of different observation-covariates. The best model was selected using the Akaike Information Criterion statistic (MacKenzie et al., 2006). We present model averages of psi and p for all the models run.

3.8.3 N-Mixture Count Model

We apply the Royle's N-Mixture model to estimate population size from temporally replicated point counts (Royle, 2004). The analysis was performed in the R (v. 3. 1. 0) package "Unmarked" using the function "PCount" (Fiske and Chandler, 2014; Fiske et al., 2014). Data were pre-selected similarly to the occupancy model (Figure 10). Several models were run to model abundance and detection probability as functions of site covariates and survey-day covariates. This study was select the best model based on the AIC statistic, and performs a model fit test on the selected model. We plot the relationship of abundance with site-covariates and of detection probability with survey-day covariates.

3.8.4 Covariates

3.8.4.1 Site Covariates

To explain and/or model gibbon abundance, we used remote sensing data to describe site covariates ("site" = listening area chosen). This was done into ArcGIS 9.3:

- Elevation: raster with one value per hectare, retrieved from http://srtm.csi.cgiar.org
- Distance to large water bodies: produced in ArcGIS 9.3 using the Euclidean distance tool, from large river and reservoir. This variable is used as a proxy for human disturbance as

villages within the NPA are found all along large rivers and the reservoir provide direct access to the NPA by boat for villages outside the NPA.

- Ruggedness: standard deviation of elevation within the site was used to represent an index of ruggedness.

3.8.4.2 Survey-Day Covariates

To model probability of detection of gibbons, the following data were used as survey day covariates:

- Morning temperature
- Morning dew point temperature
- Morning heat index
- Morning wind speed
- Morning relative humidity
- Presence/absence (0/1) of rain
- Observer
- Date

3.8.5 Singing Behavior Analysis

We tested the effect of climatological factors (occurrence/non-occurrence of wind, fog, rain, morning temperature, heat index, dew point temperature, relative humidity, wind speed) and astronomical factor (sunrise) on three dependent variables: time start of male (average of the three listening post per day), call length of the group (from time start of male to time end of the all individuals in the group), number of groups detected per day (average group count for all listening posts per day). To investigate a seasonal variation, based on temperature data, we combined months of December to February as the cold season and months of March to November as the warm season.

All dependent and independent variables were tested for normality prior performing statistical tests; non-parametric tests were used for non-Normal distribution of datasets. Of the three dependent variables, only number of groups heard was normally distributed (Kolmogorov-Smirnov test: $D=0.098$, $df=105$, $p>0.01$); the other two, time start of male call and call length were non-normally distributed. Of the meteorological variables, all but temperature and heat index were non-normally distributed (temperature, $D=0.095$, $df=105$, $p>0.01$; heat index, $D=0.079$, $df=105$, $p>0.01$). Parametric tests on normally distributed variables were only performed if variance was homogenous between groups tested, based on the Levene's test; non-parametric tests were used otherwise.

The present overall singing patterns observed over the study period and a sonogram of a duet call recorded. All statistical tests were performed in SPSS v. 20. All tests are two-tailed and significance level was set at $p<0.01$.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Environmental Data

Environmental data collected over the study are summarized in Table 2 and Table 3. Figure 9 presents the average of data recorded in the morning.

Table 2 Descriptive Statistics on Environmental Data recorded from November 2013 to May 2014 (AM=morning, MID=mid-day, PM=afternoon).

	N	Minimum	Maximum	Mean	Std. Deviation
Sunrise	119	5:30	6:33	6:09	0:20
Sunset	119	17:26	18:25	17:55	0:20
Time AM	115	5:31	9:05	6:19	0:32
Temperature AM	115	5.40	25.00	16.33	4.91
Heat index AM	115	5.90	28.40	17.08	5.42
Dew point temperature AM	114	4.50	24.70	15.39	5.11
Wind speed (max) AM	114	0.00	9.20	1.44	2.00
Time MID	109	11:01	15:10	12:26	0:44
Temperature MID	109	13.90	31.30	22.31	4.25
Heat index MID	109	12.50	36.70	23.94	6.23
Dew point temperature MID	109	8.20	26.20	18.45	5.10

Table 2 (Continued) Descriptive Statistics on Environmental Data recorded from November 2013 to May 2014 (AM=morning, MID=mid-day, PM=afternoon).

	N	Minimum	Maximum	Mean	Std. Deviation
Wind speed (max) MID	108	0.00	8.40	1.88	2.07
Time PM	110	17:19	20:04	18:18	0:29
Temperature PM	110	9.90	27.40	18.98	4.62
Heat index PM	110	10.10	32.90	20.00	5.78
Dew point temperature PM	110	7.70	27.80	17.47	4.99
Wind speed (max) PM	110	0.00	5.50	0.88	1.32

Table 3 Average (and standard deviation) of environmental data for morning record and for sunrise, sunset for each month of the study (n=number of days with data for each month).

	November (n= 18)	December (n=16)	January (n=20)	February (n=15)	March (n=20)	April (n=8)	May (n=16)
Temperature	17.72	9.74	11.70	15.01	18.49	20.83	22.91
	(2.13)	(2.15)	(2.41)	(3.27)	(2.40)	(2.23)	(1.48)
Heat index	18.25	9.91	12.09	15.87	19.20	22.01	24.75
	(2.27)	(1.98)	(2.37)	(3.93)	(2.65)	(2.55)	(2.33)
Dew point	17.04	8.30	10.65	14.59	17.58	20.36	21.99
Temperature	(2.39)	(2.07)	(2.27)	(4.01)	(2.32)	(1.63)	(1.50)

Table 3 (Continued) Average (and standard deviation) of environmental data for morning record and for sunrise, sunset for each month of the study (n=number of days with data for each month).

	November (n= 18)	December (n=16)	January (n=20)	February (n=15)	March (n=20)	April (n=8)	May (n=16)
Wind speed (max)	2.81 (1.84)	1.91 (1.65)	1.34 (1.81)	0.58 (1.61)	1.92 (2.91)	0.38 (0.71)	0.38 (0.70)
Sunrise	6:07 (0:03)	6:24 (0:05)	6:31 (0:01)	6:29 (0:01)	6:04 (0:04)	5:46 (0:09)	5:32 (0:02)
Sunset	17:26 (0:00)	17:33 (0:04)	17:47 (0:06)	18:00 (0:01)	18:12 (0:01)	18:16 (0:02)	18:22 (0:01)

The obtaining of the results was through the *Kestrel 3000* day by day during the research. The exhibition data was highly heat in April to May and colder in December to January.

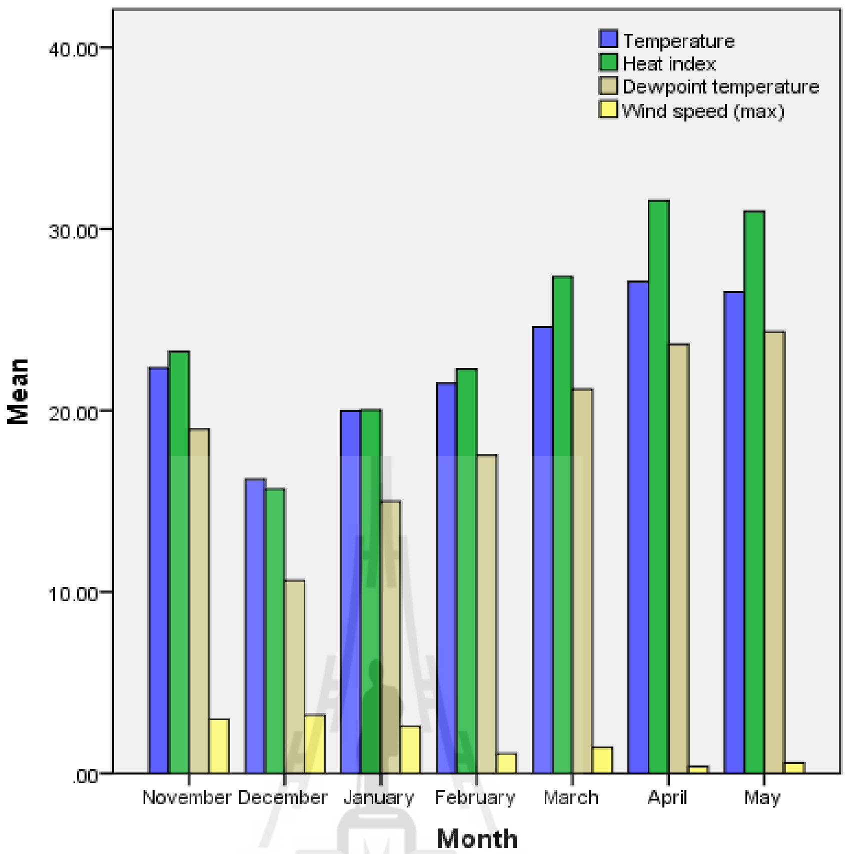

Figure 11 Average of temperatures per month from November 2013 to May 2014 (°C).

Based on the data, we grouped the 7 months of research in two seasons: warm=March to November; cold=December to February. When testing meteorological data between the seven months, all but relative humidity ($H=7.976$, $p>0.01$) were significantly different (sunrise, $H=110.224$, $p<0.01$; rain, $H=17.012$, $p<0.01$; fog, $H=16.990$, $p<0.01$; wind, $H=29.794$, $p<0.01$; temperature, $H=88.148$, $p<0.01$; heat index, $H=88.045$, $p<0.01$; dew point temperature, $H=88.243$, $p<0.01$; wind speed, $H=22.310$, $p<0.01$). Between warm and cold seasons, we found that there was a significant difference in time of sunrise (Mann-Whitney $U=292.0$, $z=-7.616$, $p<0.01$), occurrence of rain ($U=1402.5$, $z=-2.085$, $p<0.01$), temperature ($U=366.5$, $z=-6.88$, $p<0.01$), heat index ($U=394.5$, $z=-6.679$, $p<0.01$) and dew point temperature

(U=368.5, z=-6.771, p<0.01). However there was no significant difference of occurrence of fog (U=1403.5, z=-2.085, p>0.01), wind (U=1563.0, z=-0.831, p>0.01), relative humidity (U=1382.5, z=-1.034, p>0.01) and wind speed (U=1499.5, z=-0.174, p>0.01).

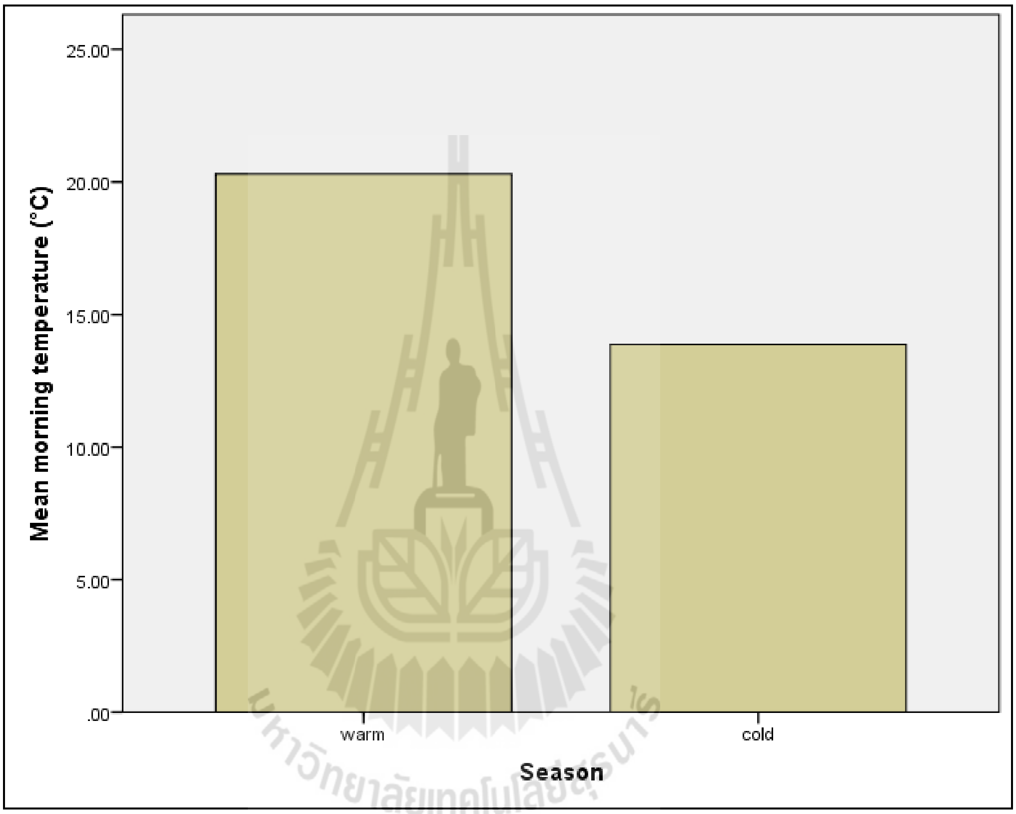

Figure 12 Average of temperature in two seasons of 7 months of the study.

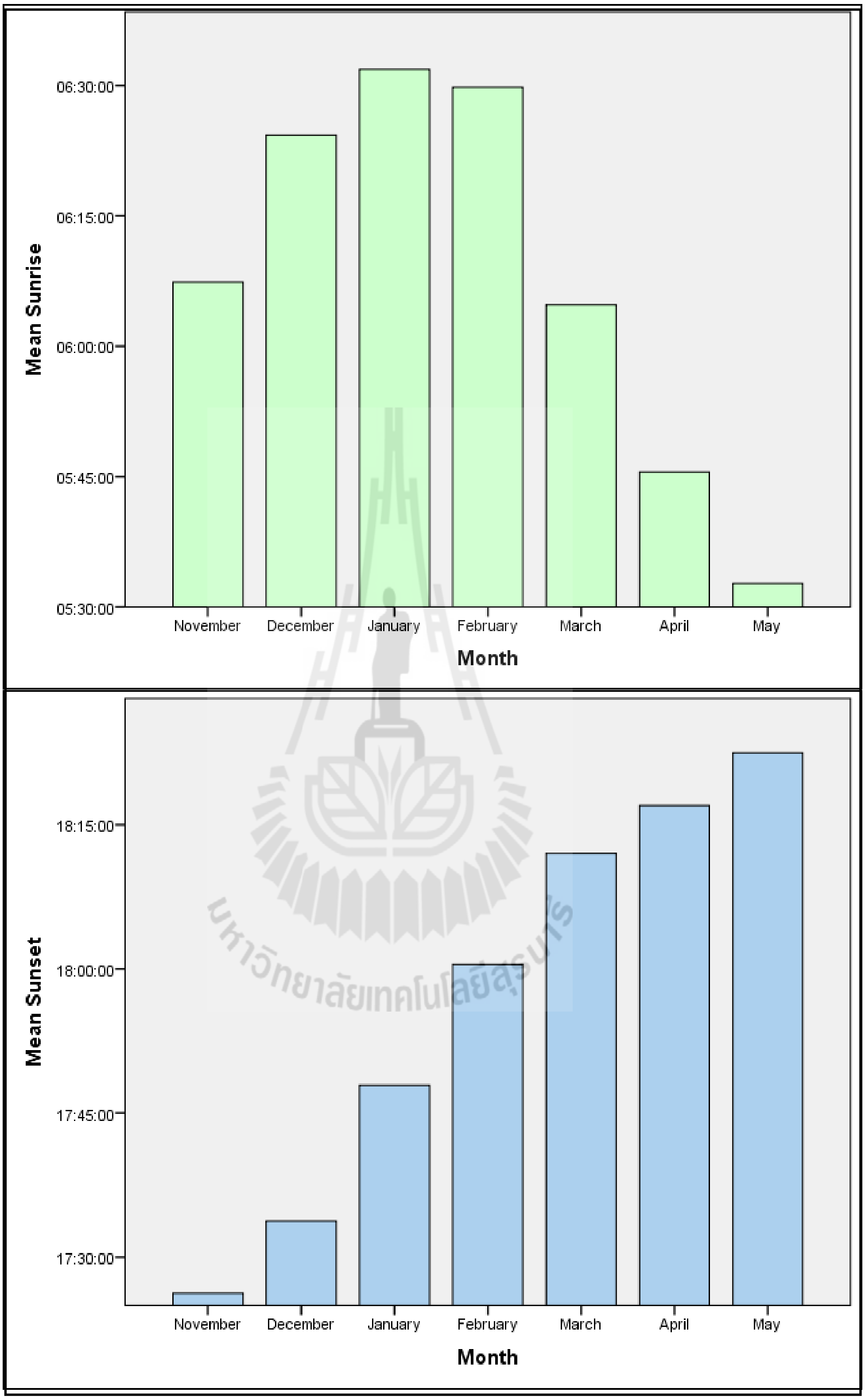

Figure 13 An average of sunrise times (above) in each month and an average of sunset times below of 7 months in the whole study from November 2013 to May 2014.

4.2 Singing Behavior

On average, males started calling at 6:13 (± 00:27:17; range 05:07:39 – 07:58:22), females at 6:16 (± 00:26:52; range 05:12:09 – 08:02:35) and the group stopped calling at 6:28 (± 00:27; range 05:15 – 08:20). Duet calls lasted on average for 00:16:43 hrs (± 00:05:04; range 00:02:00 – 00:37:22). The frequency of time calling in each morning was the highest for groups starting their calls around 6:15 (Figure 14).

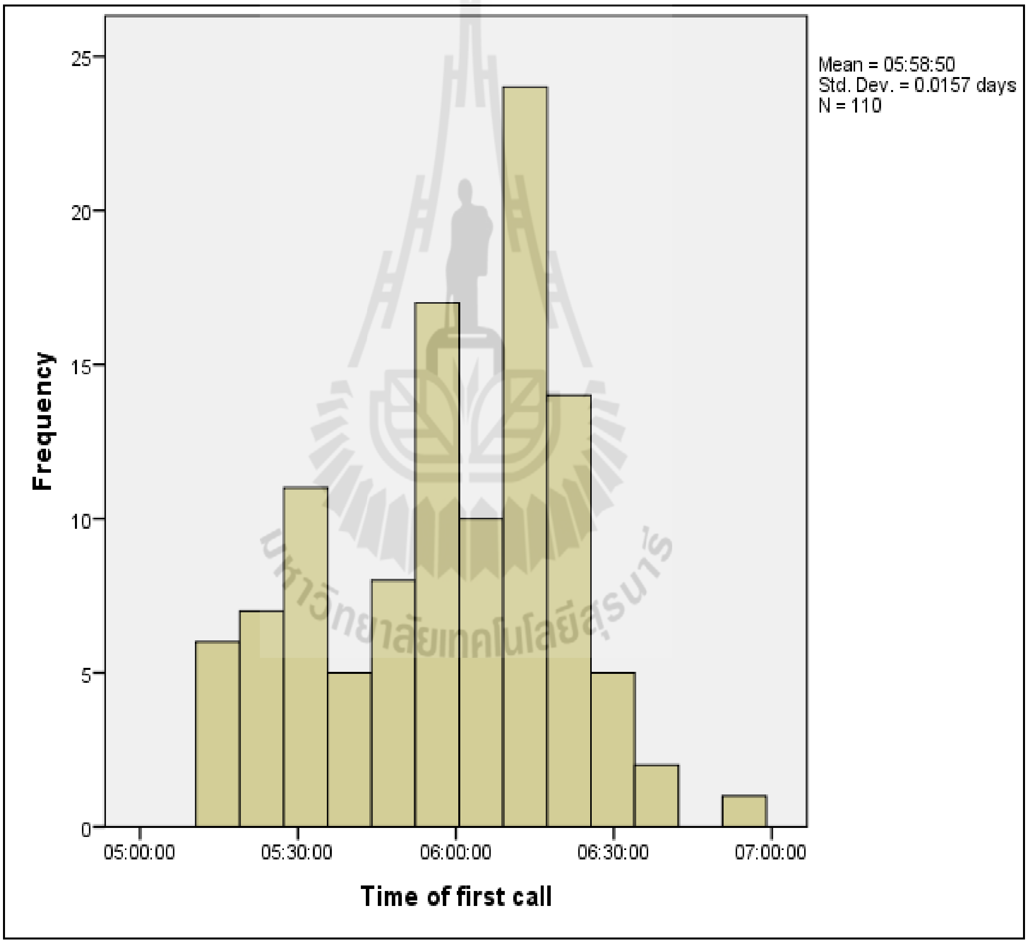

Figure 14 The frequency of time calling in each morning. The variables "morning temperature" and "time of first call" were Normally distributed (Kolmogorov-Smirnov test, D=0.885, p=0.413, n=115 and D=1.187, p=0.119, n=110, respectively).

Pearson's r correlation between the two variables was performed. The daily time of first call (average for the three listening posts) was significantly correlated with daily morning temperature (r=-0.775, p<0.01), with a regression line R^2=0.6 (Figure 15).

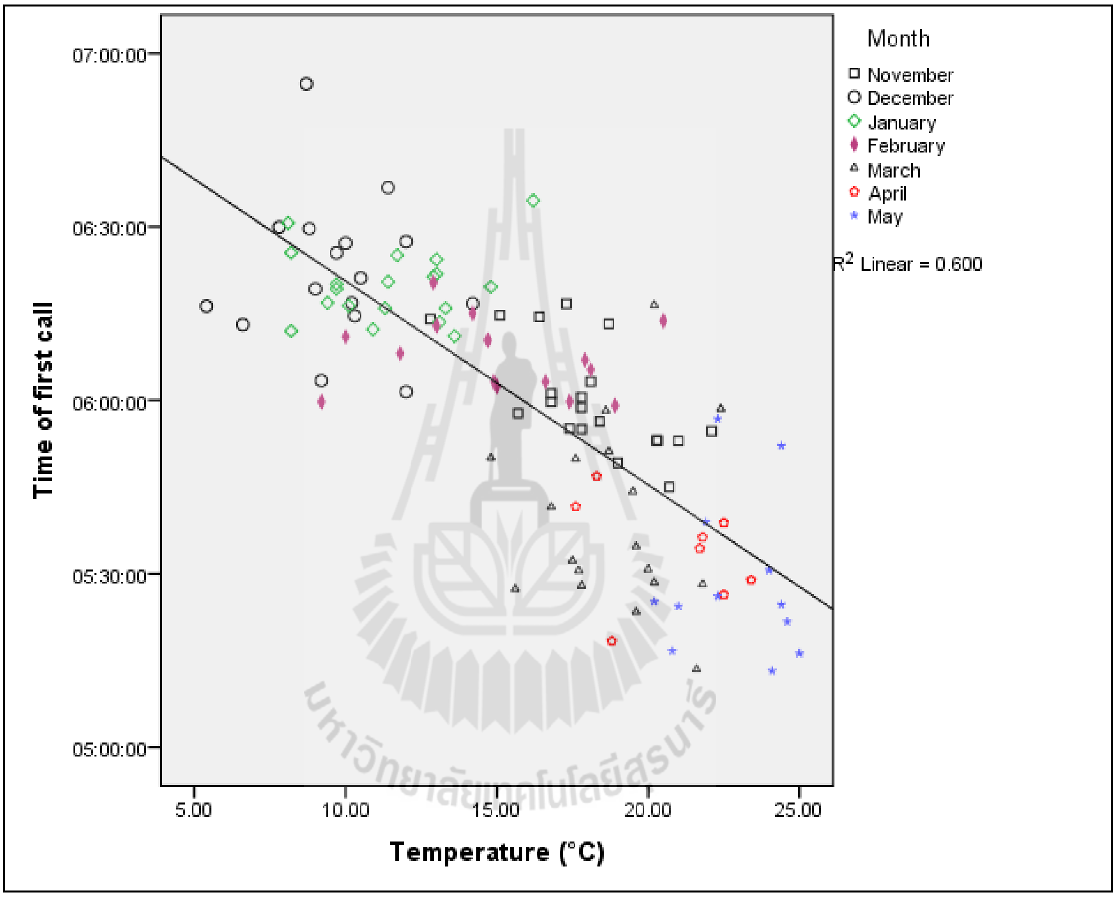

Figure 15 Relationship between times of first call and temperature morning within 7 months.

The classification of temperature data was as followed; (range 5.4 – 25.0) in 4 different classes: (1) 5 – 10.9, (2) 11 – 15.9, (3) 16 – 20.9 and (4) 21 – 25. These found a significant difference of time of first call between the 4 classes (Krustal Wallis test, H=62.368, p<0.01). There was a negative relationship between temperature and time of first call (Figure 16). There was however a significant difference of call length between the 4 classes of temperature (H=0.786, p>0.01).

There was a significant difference in time start of male call (H=84.497, p<0.01) both between the seven months of the study and two seasons (Figure 17 and Figure 18) but not of call length (H=12.574, p>0.01). Similarly the difference was significant between the two seasons (warm/cold) for the time start of male call (Mann-Whitney test, U=610.0, z=-5.033, p<0.01) but not for call length (U=1159.0, z=-1.655, p>0.01).

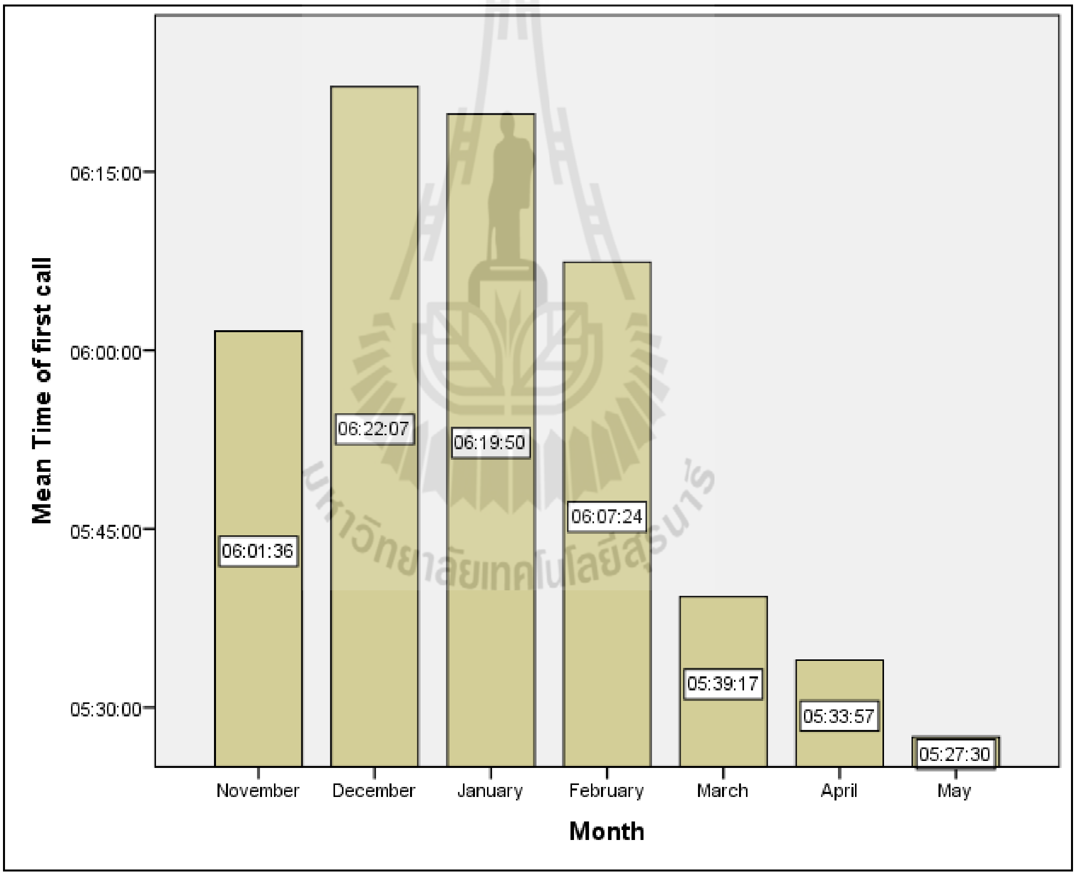

Figure 16 Average time of first call between each of the 7 months of the research (The latest calling was occurred between December to January under the cold season).

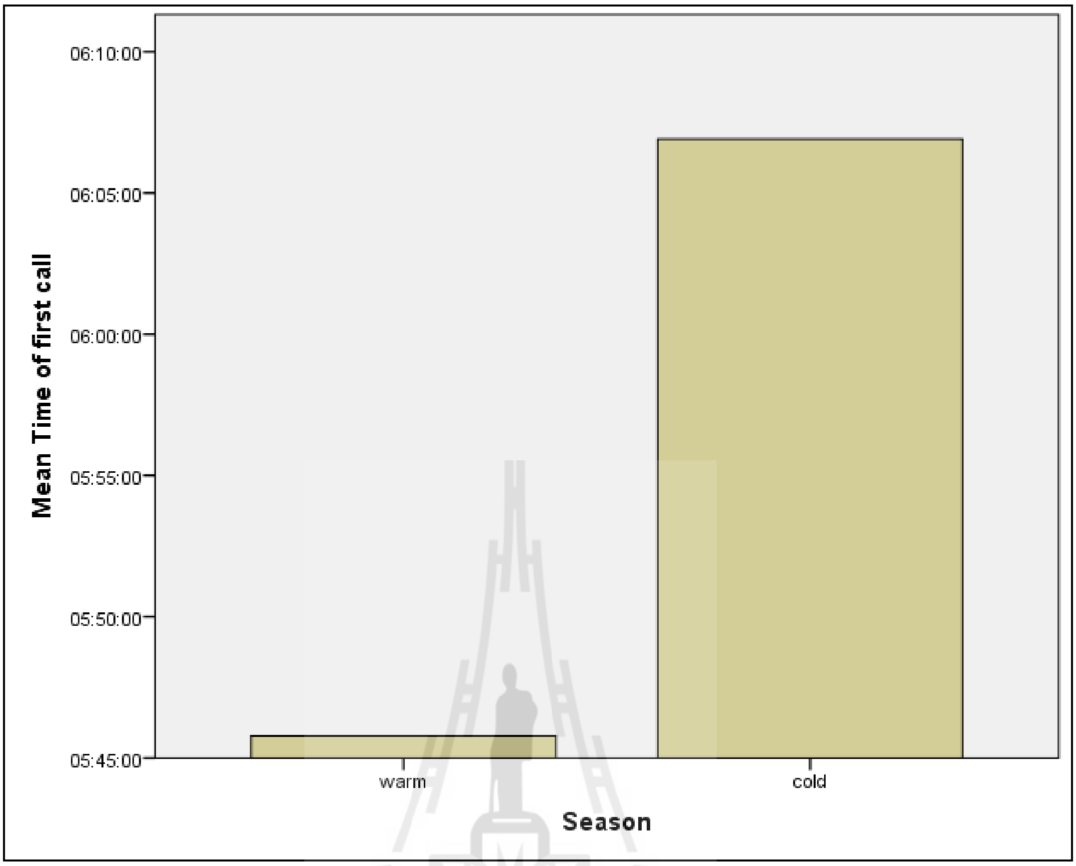

Figure 17 An average between times of first call per seasons throughout 7 months of study in two categories as warm and cold season such as November, March to May is warm and December to February is cold.

We classified the sunrise in four groups: 1=5:30-5:45, 2=5:46-6:00, 3=6:01-6:15, 4=6:16-6:33. The time of first call was significantly different between these four class of sunrise timings (Krustal-Wallis test H=72.352, $p<0.01$) (Figure 18).

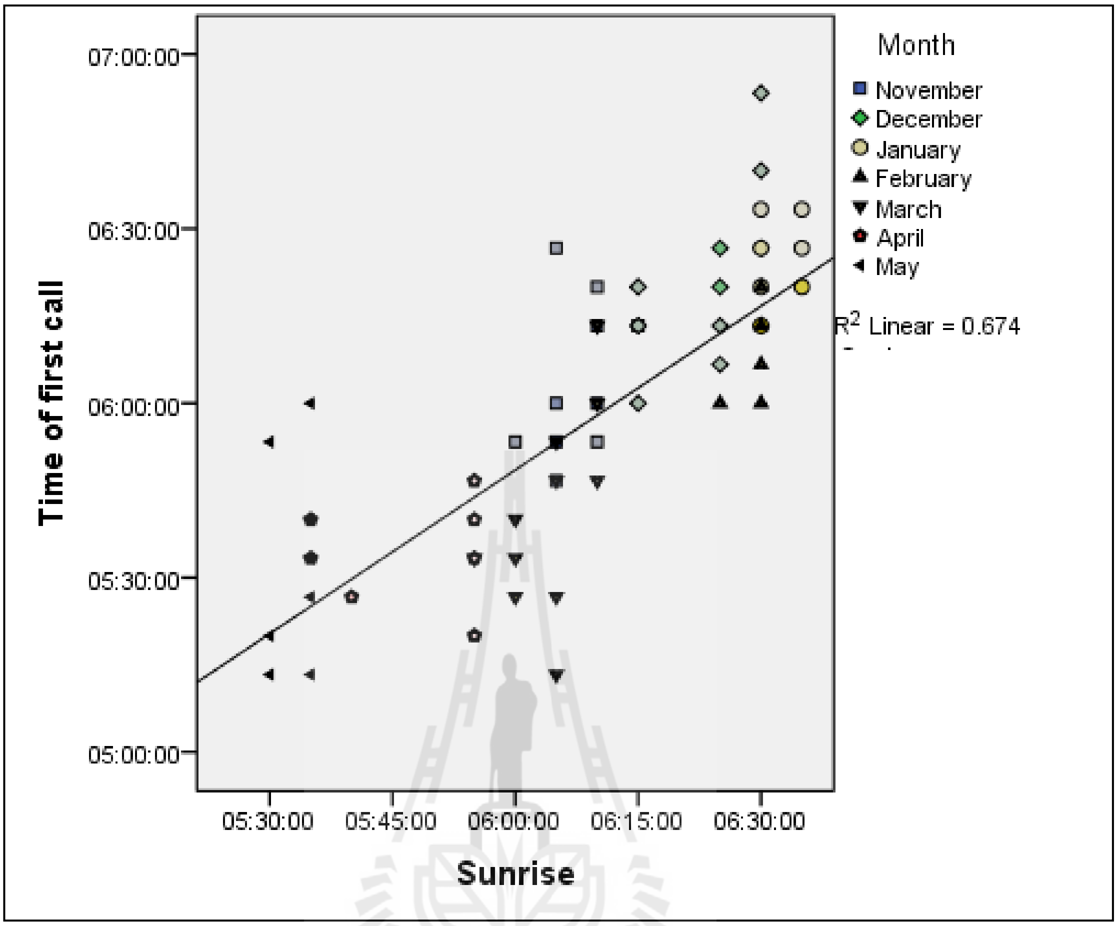

Figure 18 Relationship between times of first call with the sunrise times during 7 months of the research.

Table 4 Average time of first call and time of sunrise for each of the 7 months of the research.

Month	Time of first call	Time of sunrise
November	06:01:36	06:07:22
December	06:22:07	06:24:15
January	06:19:50	06:31:51
February	06:07:24	06:29:48
March	05:39:17	06:04:45
April	05:33:57	05:45:33
May	05:27:30	05:32:42

Overall (n=110 days with available for time of first call) in 83% (n=91 days) of the day's gibbon started calling before sunrise, on average 0:16:11 before the start of sunrise. For the remaining 17% of the days, gibbon started calling on average 0:07:18 after sunrise (Table 4).

Call Timings and Effect of Temperature

On average, males and females started calling a few minutes before sunrise (at 6:13:55 and 6:16:43, respectively) then stopped at 6:28 and calls lasted on average for 0:16:22. The frequency of time calling in each morning was the highest for groups starting their calls around 6:15 (Figure 14). Geissmann and Nijman (2006)'s study on Silvery gibbon (*Hylobates moloch*) found the male sung in choruses with other males from other groups during predawn. The duetting song bouts do not occur in this species. In addition, males and females tend to sing at different times of the day between predawn for male and after dawn for female, however, no male choruses were heard after dawn.

In genus *Hylobates* such as *H. agilis* and *H. lar* the males tend to produce their solo song before or at dawn, but resume again later in the day and also the duet songs occurred when they mate at these times (Geissmann, 2000). Similarly separated periods of male and female solo songs were also observed in Kloss's gibbons (*Hylobates klossii*), (Tenaza, 1976; Whitten, 1980, 1982). In this species also, males preferentially sing solo song bouts before dawn and females preferentially sing solo song bouts after dawn. This may represent another derived characteristics heard by *H. moloch* and *H. klossii* (Geissmann, 1993).

Cheyne (2008) studied *Hylobates albibarbis* in a peat-swamp forest, in central Kalimantan, Indonesia. She found that meteorological factors such as rain and wind significantly influenced onset time of singing and more direct meteorological factors had a greater effect on the singing behavior, though cloud cover and temperature had no significant effect. Similarly, Fen et al. (2009) did not find any effect of temperature nor rainfall on singing behavior of *Nomascus concolor jingdongensis* in China. The latter finding differs from our own findings, where temperature was strongly related to gibbon call timings.

Geissmann (2002) found that the males preferentially utter their song bouts in the early morning hours. The time at which each species tends to produce the majority of duet song bouts (and female solo song bouts) can be divided into two categories: at or soon after dawn (*H. agilis, H. klossii, H. lar, H. moloch, H. muelleri,* and *Nomacus* species and 2-3 hrs later in the morning (*H. pileatus, H. hoolock, S. syndactylus*). Similarly, time of day of male solo song bouts can be divided into two categories: in the dark before dawn (*H. agilis, H. klossii, H. moloch, H. muelleri*) or around dawn (*H. lar*), and about 2-3 hrs after dawn (*H. pileatus*). *Nomascus* species however do not produce solo song bouts unless they are lone animals. In those species where male solo song bouts occur, the solo songs tend to start approximately 1-3 hrs prior to the duet song bouts. In *H. agilis, H .lar* and *H. muelleri*, however, the first peak of singing activity occurs at or even before sunrise.

Table 5 Combined summary of literature data and data resulting from his study, n.a. = not applicable, because mated males do not usually sing solo songs (Retrieved from Geissmann, 2002).

Species	Degree of sex specificity of song repertoire	Male solo song bout	Female solo song bout	Duet song bout	Time of day for duet/female song	Time of day for male song
H. agilis	intermediate	present	absent	present	dawn	pre-dawn/dawn
H. klossii	intermediate	present	present	absent	dawn	pre-dawn/dawn
H. lar	intermediate	present	absent	present	dawn	pre-dawn/dawn
H. molock	intermediate	rare	present	absent	dawn	pre-dawn/dawn
H. muelleri	intermediate	present	absent or rare	present	dawn	pre-dawn/dawn
H. pileatus	intermediate	present	absent	present	later	later
B. hoolock	small	absent	absent	present	later	n.a.
N. concolor	large	absent	absent	present	dawn	n.a.
N.sp. Cf. nsutus	large	absent	absent	present	dawn	n.a.
N. gabriellae	large	absent	absent	present	dawn	n.a.
N. leucogenys	large	absent	absent	present	dawn	n.a.
S. syndactylus	intermediate	absent	absent	present	later	n.a.

In this study, seasons were mainly relevant directly for sunrise with 83% of males starting before sunrise for and 17% calling after sunrise. In Hylobates klossii, In Siberut Island, Indonesia, the females of are more likely to sing, and to sing earlier, on mornings when males have already sung. Also, more females sing on mornings when there has been a large male chorus (Dooley et al., 2013). In our study, females sang on average 3.25 minutes after the males.

Gibbon's Call Length

This study found that the call length of *N. siki* was on average about 19.5 minutes with no significant difference between the 7 months of study. Temperature had no significant effect on call length.

Tenaza (1985) found that the Bornean female gibbon song duration ranged from 8 to 11 (n=8) minutes. Hybrid female was 8-12 (n=13) minutes and comparison with *H. lar* was 16-31 (n=12) minutes. Dooley et al. (2013) found that in *H. klossi* the mean duration of male songs was 44.5 minutes (n=10) and of females, 15.4 minutes. In *H. albibarbis*, Cheyne (2008) found male song bouts were on average 41 minutes. This shoes a great difference in call length between the species from the genus *Hylobates* and *Nomascus* (for species that have been studies so far). Indeed, *Nomascus concolor jingdongensis*, in China, duet calls lasted on average for 14.5 minutes, which is relatively similar for our findings in *N. siki*. We did not investigate the exact call length of females, but it should be a little shorter than for the males given they typically started after the males and stopped before the male.

Table 6 Comparisons of call length between different species study.

Species	Sexual	Average times call length	References
Nomascus siki	-	19.5 minutes	NNT-NPA
H. muelleri	Female	Ranged from 8 to 11 (n= 8) minutes	Tenaza (1985) Borneo
H. klossi	Male	44.5 minutes (n = 10)	Dooley et al., (2013) Indonesia
	Female	15.4 minutes	Dooley et al., (2013) Indonesia
H. albibarbis	-	Song bouts on average 41 minutes	Cheyne (2008) Indonesia

This is combination some of the same study between different species that had been done in the wild. This average of times call length were detected at males and females of each species.

4.3 Estimates of Gibbon Abundance

4.3.1 Triangulation Method

Overall, a total of 152 groups could be counted, of which 146 are within the listening area (122 km^2, Figure 19). This resulted in an estimated density of D=146/122=1.20 groups/km^2.

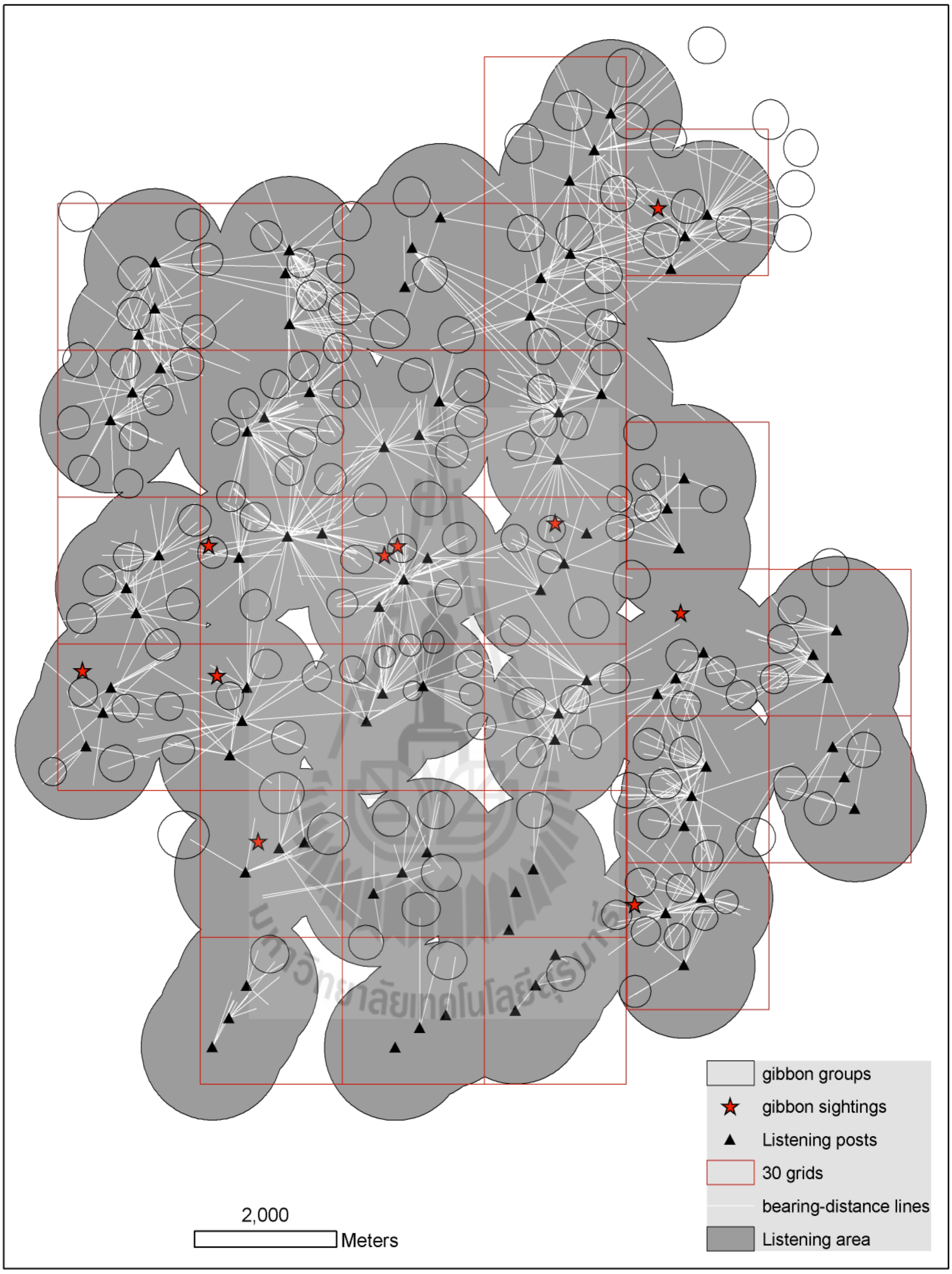

Figure 19 Triangulation analysis for the overall listening area (122 km^2), including groups that were detected from only one listening post.

All gibbon sightings over the study period are indicated on the map. The second analysis conducted per site, only including triangulated groups (i.e. groups detected at least from 2 listening post of the same site), resulted in an average of 4.73 groups detected per site and a site-density average of 0.93 groups/km^2 (Table 7). Overall, this analysis resulted in a total count of 132 groups, therefore an overall density of D=132/122=1.08 groups/km^2.

Table 7 Listening area (contours of 1-km radius circle for the 3 listening posts) of each of the 30 sites, number of triangulated groups and density for each of them.

Site	Listening area	Number of groups triangulated	Number of groups within the listening area	Density (groups/km^2)
1	5.30	6	5	0.94
2	4.96	6	4	0.81
3	5.23	8	7	1.34
4	5.34	2	2	0.37
5	5.13	9	8	1.56
6	5.21	7	6	1.15
7	5.00	7	7	1.40
8	5.00	7	7	1.40
9	5.00	5	5	1.00
10	5.63	7	7	1.24
11	5.00	3	3	0.60
12	5.14	4	4	0.78
13	5.06	7	7	1.38

Table 7 (Continued) Listening area (contours of 1-km radius circle for the 3 listening posts) of each of the 30 sites, number of triangulated groups and density for each of them.

Site	Listening area	Number of groups triangulated	Number of groups within the listening area	Density (groups/km^2)
14	4.88	6	6	1.23
15	5.04	6	6	1.19
16	5.14	7	7	1.36
17	5.03	6	6	1.19
18	5.56	8	8	1.44
19	4.92	3	3	0.61
20	5.00	4	3	0.60
21	4.84	5	5	1.03
22	5.05	7	6	1.19
23	4.87	7	7	1.44
24	5.53	6	6	1.09
25	5.05	1	1	0.20
26	5.01	2	2	0.40
27	5.01	3	3	0.60
28	4.97	0	0	0.00
29	5.02	1	1	0.20
30	4.81	1	1	0.21
Average	5.09	5.03	4.77	0.93
Std	0.20	2.47	2.34	0.45

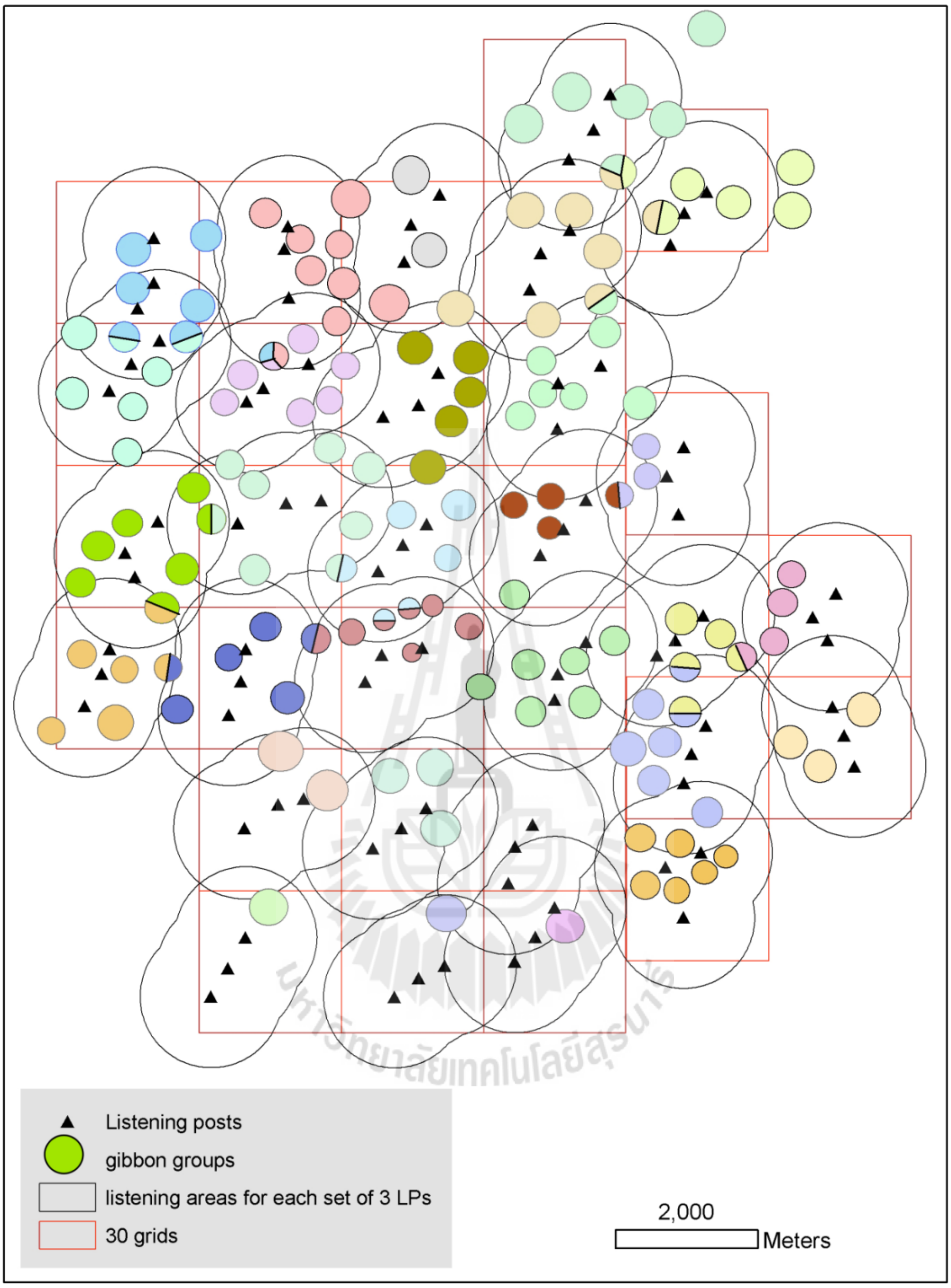

Figure 20 Triangulation analyses per “site” (i.e. contour of 1-km circle radius for each set of 3 listening posts). Groups located only include the ones that were detected by at least 2 listening posts from the same set of three. Groups that are presumed to have been re-detected from different sites are denoted with more than one (one colour per site).

4.3.2 Occupancy Model

We ran 15 models (Table 8). All the models showed no evidence of lack-of-fit based on the χ^2 model fit statistic. Of the 30 sites surveyed, 29 were predicted to be occupied (Table 7). The top-ranking model, based on AIC statistic, was *psi(.)p(temp)*, that is, a constant occupancy of gibbon across sites and a detection probability as a function of temperature. There was a negative relationship between detection probability and temperature (i.e. as temperature increase, probability of detection is predicted to decrease; Figure 21).

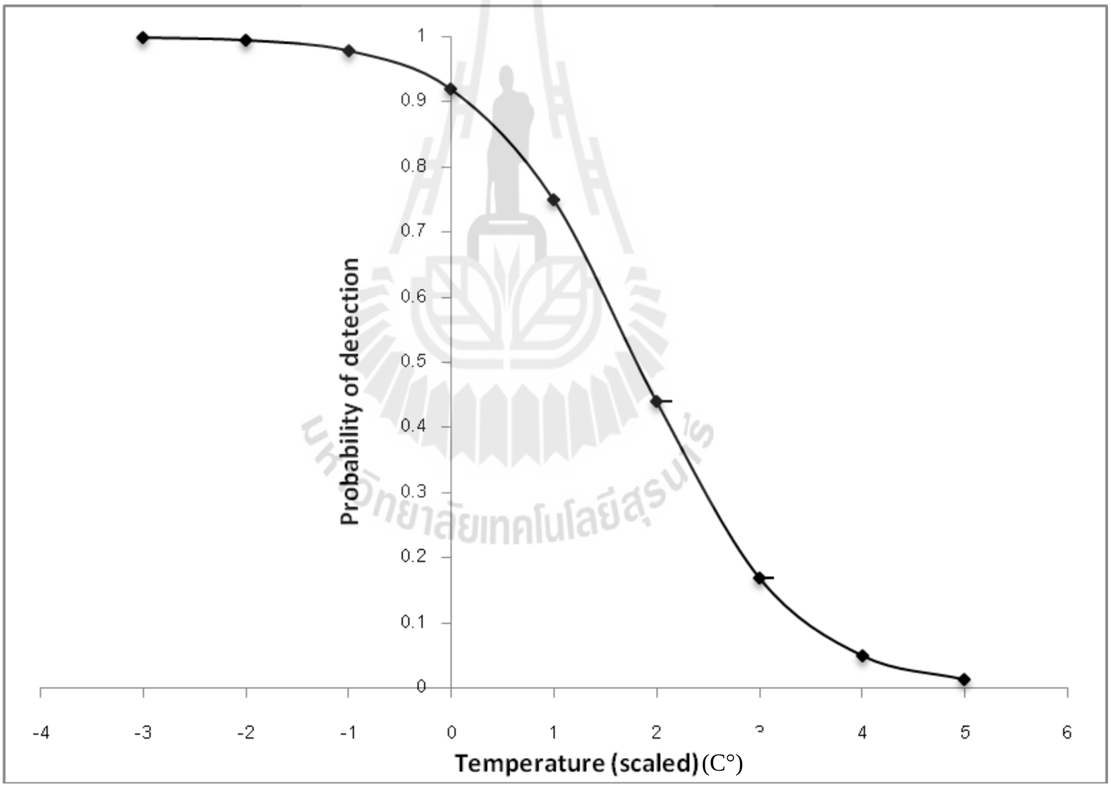

Figure 21 Probability of detection predicted by temperature (on the transformed scale).

Table 8 Results of the 15 models run in R package Unmarked using the MacKenzie et al. occupancy model with "*Occu*" function, to estimate occupancy and probability of detection of gibbon groups for the survey sites; Models are ranked by AIC statistic.

Model name	Ψ (SE)	*p* (SE)	K	AIC	Delta AIC	AIC wgt	p value
psi(.)p(Temp)	1.00 (0.00)	0.92 (0.03)	3	79.79	0.00	0.26	0.47
psi(.)p(Heat)	1.00 (0.00)	0.92 (0.03)	3	79.98	0.20	0.23	0.46
psi(.)p(Wind+Temp)	1.00 (0.00)	0.93 (0.03)	4	80.16	0.37	0.21	0.60
psi(.)p(Temp+Heat)	1.00 (0.00)	0.92 (0.03)	4	81.75	1.96	0.10	0.43
psi(Water)p(Temp)	1.00 (0.00)	0.92 (0.03)	4	81.79	2.00	0.09	0.39
psi(Water)p(Heat)	1.00 (0.00)	0.92 (0.03)	4	81.98	2.20	0.09	0.44
psi(.)p(Rain)	0.97 (0.03)	0.90 (0.03)	3	88.12	8.34	0.00	0.80
psi(.)p(.)	0.97 (0.03)	0.89 (0.03)	2	88.74	8.95	0.00	0.97
psi(Water)p(.)	0.98 (0.03)	0.89 (0.03)	3	89.84	10.05	0.00	0.85
psi(ElevMean)p(.)	0.98 (0.03)	0.89 (0.03)	3	89.92	10.13	0.00	0.11
psi(.)p(Humidity)	0.97 (0.03)	0.90 (0.03)	3	89.95	10.17	0.00	0.66
psi(.)p(Date)	0.97 (0.03)	0.90 (0.03)	3	90.18	10.39	0.00	0.90
psi(.)p(Wind)	0.97 (0.03)	0.89 (0.03)	3	90.52	10.74	0.00	0.85
psi(Rugged)p(.)	0.97 (0.03)	0.89 (0.03)	3	90.73	10.94	0.00	0.89
psi(Water)p(Wind)	0.98 (0.03)	0.90 (0.03)	4	91.61	11.83	0.00	0.56

Ψ (psi)=occupancy for all sites; p=detection probability for all sites; SE=standard error; AIC= Akaike Information Criterion; delta AIC=(model *i*'s AIC) – (top ranking model's AIC); AIC wgt=proportional model's weight for the 13 models; K=number of parameters; p value=probability of observing a test statistic $\geq\chi^2$ (p value>0.05 indicates good model fit).

Table 9 Individual probability of occupancy Ψ per site based on the top-ranking model *psi(.)p(Temp).*

Site	Ψ
1	1.00
2	1.00
3	1.00
4	1.00
5	1.00
6	1.00
7	1.00
8	1.00
9	1.00
10	1.00
11	1.00
12	1.00
13	1.00
14	1.00
15	1.00
16	1.00
17	1.00
18	1.00
19	1.00
20	1.00
21	1.00
22	1.00
23	1.00
24	1.00

Table 9 (Continued) Individual probability of occupancy Ψ per site based on the top-ranking model *psi(.)p(Temp).*

Site	Ψ
25	1.00
26	1.00
27	1.00
28	1.00
29	1.00
30	0.02

4.3.3 N-Mixture Count Model

The same 15 models chosen for the occupancy model were run to estimate abundance of gibbon groups per site (“site”=1km-radius circle around each of the 10 listening posts selected for the analysis=3.14 km^2) and ranked by AIC statistic (Table 8). The best-ranking model was *psi(.)p(Wind+Temp),* a constant abundance of gibbon groups per site and a detection probability affected by wind and temperature.

The abundance of gibbon group per site based on the *psi(.)p(Wind+Temp)* model varied on average from 5.10 to 15.58 groups per site (1.62 to 4.96 groups/km^2) with and overall average of 8.43 groups per site (2.68 groups/km^2). The estimated total number of groups for the entire survey site surveyed (30*3.14 km^2=94.2 km^2) was 252.79 (CI 171 – 348). Based on a group size of 4 individuals per group, the total population can be estimated at ~1000 individuals within the survey site. If extrapolated to the entire NPA and considering a suitable habitat of about 1600 km^2 (based on an habitat suitability model for doucs (Coudrat et al., 2014) which share relatively the same habitat requirements), this would give an estimated 4288 groups and >17,000 individuals (with an average group size of 4 individuals) in NNT NPA as a conservative estimate.

Table 10 The 15 models run in R package Unmarked using the Royle's N-Mixture model with *PCount* function to estimate abundance and detection probability of gibbons for the survey sites; models are ranked by AIC statistic.

Model Name	Ψ (SE)	p (SE)	K	AIC	AIC wgt	p value
psi(.)p(Wind+Temp)	8.430 (1.970)	0.267 (0.064)	4	397.34	0.9100	0.4160
psi(Water)p(Heat)	7.850 (1.950)	0.286 (0.070)	4	403.79	0.0360	0.8510
psi(Water)p(Temp)	7.740 (1.890)	0.290 (0.070)	4	404.66	0.0230	0.1290
psi(.)p(Heat)	8.210 (1.950)	0.278 (0.067)	3	406.14	0.0110	0.8420
psi(.)p(Temp)	8.160 (1.920)	0.280 (0.066)	3	406.93	0.0075	0.2670
psi(.)p(Temp+Heat)	8.210 (1.950)	0.278 (0.067)	4	408.13	0.0041	0.4060
psi(Water)p(Wind)	5.290 (0.853)	0.434 (0.063)	4	409.19	0.0024	0.3170
psi(Water)p(.)	5.330 (0.886)	0.433 (0.065)	3	416.27	0.0001	0.4060
psi(.)p(Wind)	5.340 (0.793)	0.447 (0.060)	3	416.83	0.0001	0.3470
psi(Rugged)p(.)	5.370 (0.865)	0.437 (0.064)	3	420.70	0.0000	0.1580
psi(.)p(Humidity)	5.420 (0.827)	0.440 (0.061)	3	420.91	0.0000	0.1780
psi(.)p(Humidity)	5.420 (0.827)	0.440 (0.061)	3	420.91	0.0000	0.1780
psi(.)p(Rain)	5.840 (1.030)	0.403 (0.067)	3	421.10	0.0000	0.2080
psi(.)p(.)	5.390 (0.830)	0.444 (0.061)	2	423.52	0.0000	0.0792
psi(ElevMean)p(.)	5.400 (0.838)	0.442 (0.062)	3	424.67	0.0000	0.0990
psi(.)p(Date)	5.380 (0.820)	0.446 (0.061)	3	425.46	0.0000	0.0891

Ψ (psi)=abundance of gibbon groups for all sites; p=detection probability for all sites; SE=standard error; AIC=Akaike Information Criterion; delta AIC=(model *i*'s AIC) – (top ranking model's AIC); AIC wgt= proportional model's weight for the 13 models; K=number of parameters; p value=probability of observing a test statistic ≥ χ^2 (p value >0.05 indicates good model fit).

Table 11 Estimate abundance per site and confidence interval (CI) based on the top-ranking model *psi(.)p(Wind+Temp)*.

Site	Mean abundance estimated	CI	
1	8.97	5	- 13
2	9.59	5	- 15
3	7.84	4	- 12
4	5.10	2	- 9
5	10.72	7	- 15
6	7.85	5	- 11
7	7.96	6	- 11
8	10.42	8	- 13
9	7.03	5	- 10
10	10.12	8	- 13
11	5.52	3	- 8
12	5.87	3	- 9
13	6.45	5	- 9
14	7.18	4	- 11
15	6.12	3	- 10

Table 11 (Continued) Estimate abundance per site and confidence interval (CI) based on the top-ranking model *psi(.)p(Wind+Temp)*.

Site	Mean abundance estimated	CI	
16	11.22	8	- 15
17	15.58	12	- 20
18	12.58	10	- 16
19	5.37	2	- 10
20	8.49	5	- 13
21	8.54	5	- 13
22	8.67	6	- 13
23	14.19	10	- 19
24	10.81	7	- 15
25	7.17	4	- 12
26	7.32	4	- 12
27	8.93	5	- 14
28	5.81	2	- 11
29	6.20	2	- 11
30	5.16	1	- 10
average	8.43		

Distance to the main water bodies, elevation and ruggedness were found to be a factor influencing abundance (Figure 22, 23 and 24).

4.4 Comparison of Three Methods Used and Discussion

The three methods gave different estimates of abundance indices. When using the “conventional” method of triangulation, we found that the estimation greatly under-estimating density due to the difficulty to identify the gibbons by triangulation. This method also suffers from the risk of subjectivity when counting groups and choosing the listening area. This method may be more appropriate in very small areas (for example 4 km^2) and where terrain is relatively flat, to allow easy detection and better estimate of exact location when 3 to 4 sets of 3 listening post are positioned in the small area. This has been done with relative success in Kalimantan, Indonesia (Cheyne et al., 2008; Buckley et al., 2006; Phillips, 2006). In addition, the method provides little flexibility and certainty to predict density in relation to covariates.

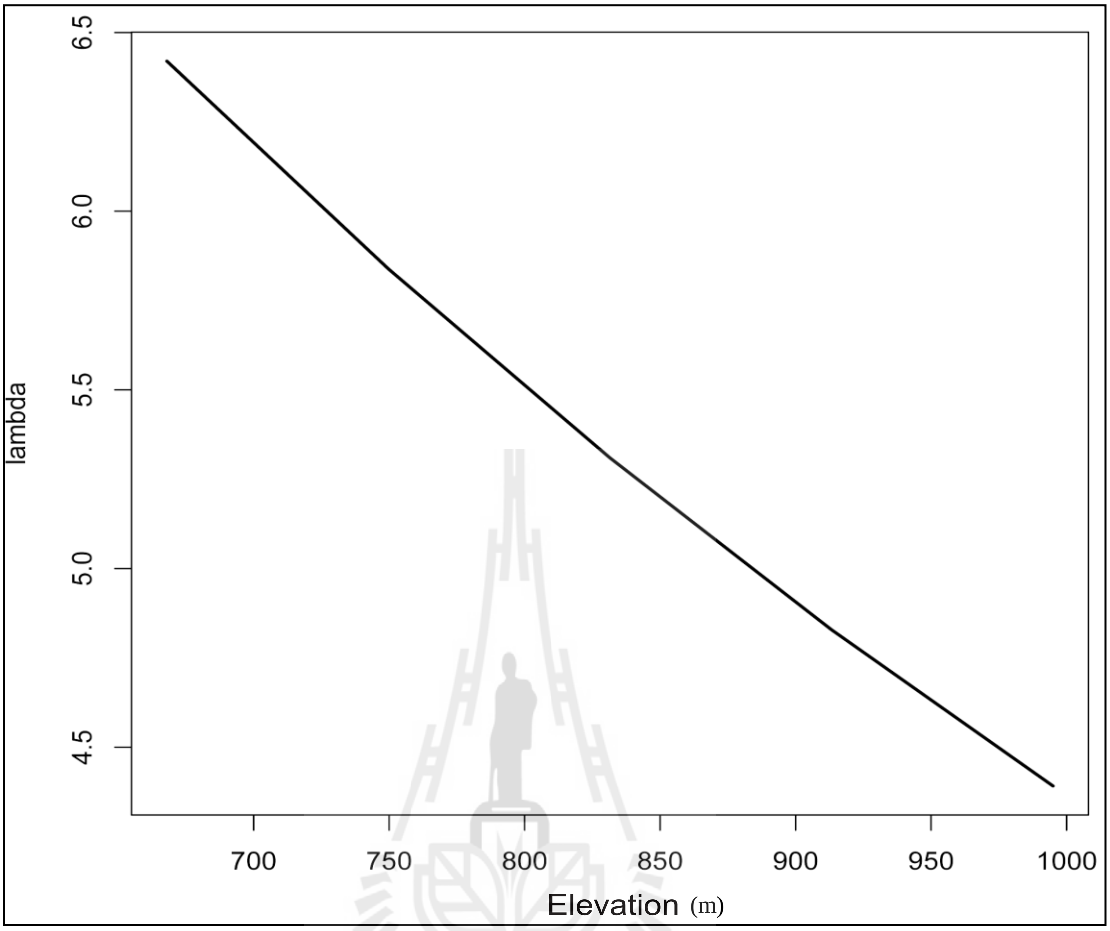

Figure 22 Relationship of abundance of gibbon groups and elevation, based on the Royle’s N-Mixture model.

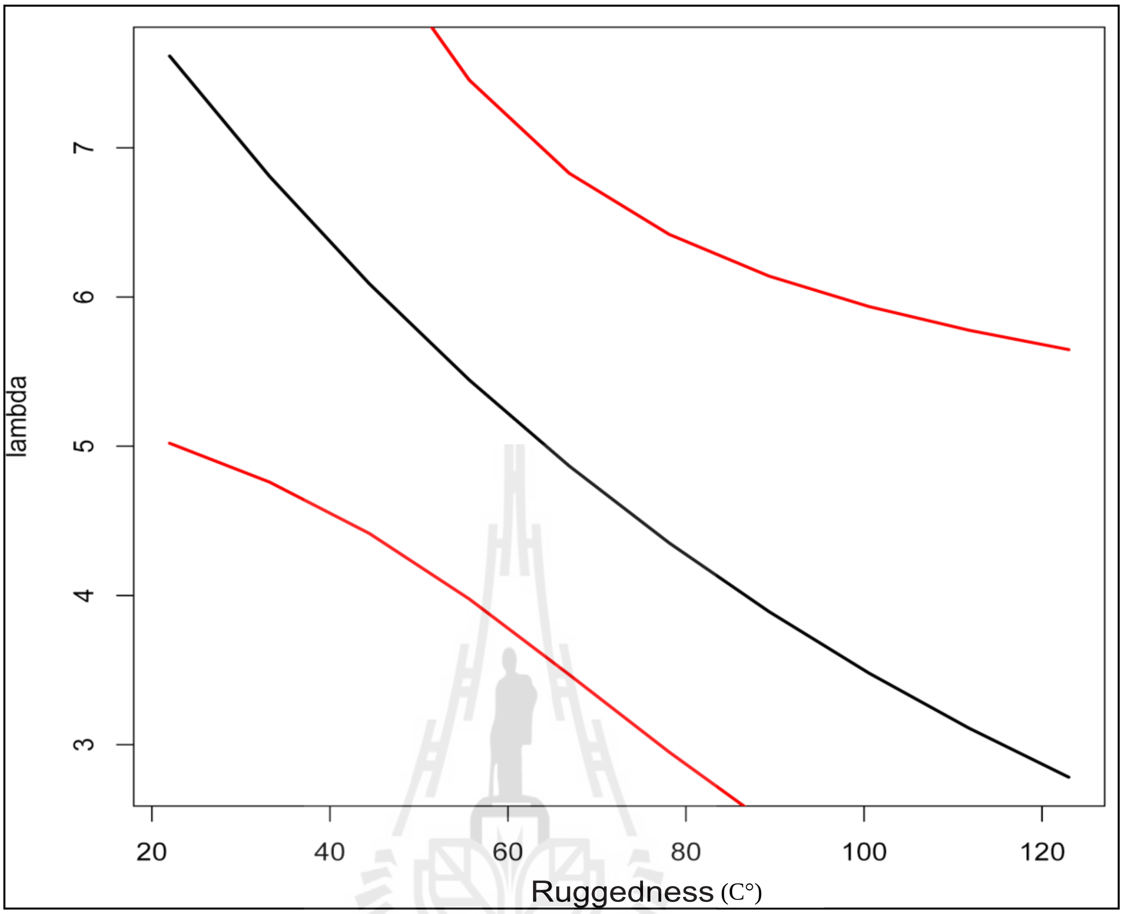

Figure 23 Relationship of abundance of gibbon groups and terrain ruggedness index (i.e. standard deviation of elevation per hectare for each site), based on the Royle's N-Mixture model.

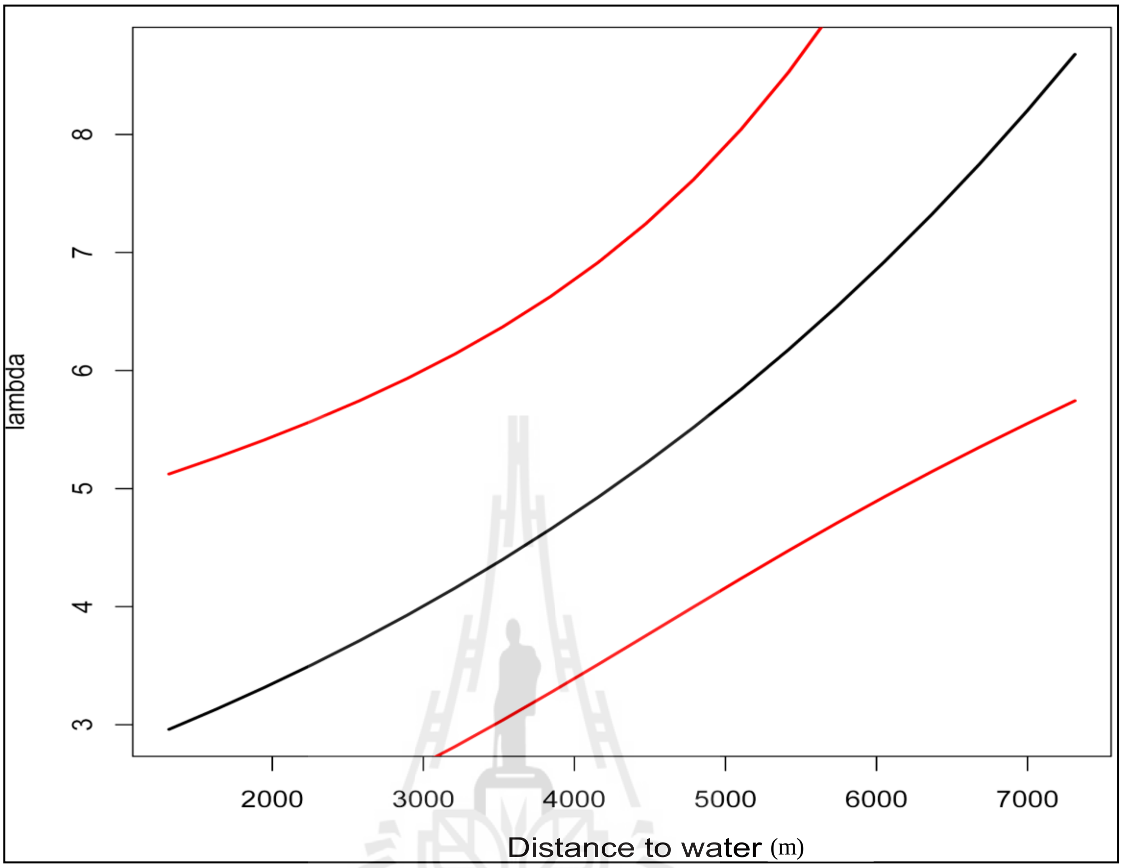

Figure 24 Relationship of abundance of gibbon groups and distance to water, based on the Royle's N-Mixture model.

In comparison, occupancy models can provide good probabilities of occupancy which can then be extrapolated to entire larger areas (when considering habitat suitability within the area in question). However, our study resulted in such high detection history that occupancy was predicted in ca. 100% of grids visited. Occupancy models can also be very useful to predict occupancy and detection of gibbon calls in relation to site or survey-day covariates. In Cambodia, Nielson et al., 2013 found that, using an occupancy model, 83% of the sites surveyed is occupied by *H. pileatus* and that the detectability of the species varies positively with elevation.

The model estimates demonstrated that at high elevations, less than half the number of site visits is needed to attain the same detectability estimate precision as across all elevations.

Occupancy models to estimate an index of primate abundance has rarely been used (Guillera-Arroita et al., 2010; Keane et al., 2012; Nielson et al., 2013) but provides an interesting method due to the relatively easy implementation combined with large area coverage in less time (compared with for example the commonly used distance sampling for primates; Buckland et al., 2010).Occupancy models however does not provide absolute abundance counts of populations and may be more appropriate for long-term monitoring of population and observe population trends for species management.

The N-Mixture model from Royle (2004) represents the best alternative to estimate abundance and density from gibbon survey data using count of their calls. This method has never been used to estimate gibbon population and we tested for the first time this method on our dataset. Given the high sensitivity of the method (shared with the occupancy model) to double counting and requires strict independence between site-observations, this mean that it does not require 3 listening posts per site and therefore decrease the survey effort. In addition, the method does not require identification of groups which is extremely difficult to establish in unfamiliar research sites with unhabituated groups such as our study. Only the count of unmarked groups is necessary which is easy to collect for gibbons via their regular loud calls. We believe this method to be the most reliable and effort efficient for surveying gibbons. With the inclusion of site and observation covariates, the model allows us to investigate relationship of covariates with abundance and probability of gibbon detection. Our model predicted an increasing abundance of gibbons further from large water bodies. This can be explained by the fact that water bodies are zones of access of humans to the forest and also where all villages are clustered. Human disturbance therefore has a negative impact on gibbon abundance at the research site. The model also predicted lower abundance at higher elevation and rugged terrain, however the survey site may be too small generalize these findings.

Table 12 Comparison of density (and occupancy) estimates of several gibbon populations with the use of different methods.

Site	Species	Group Density	Methods	References
NNT-NPA, Laos	*Nomascussiki*	1.2	Triangulation 1*	This study
NNT-NPA, Laos	*N. siki*	1.08	Triangulation 2*	
NNT-NPA, Laos	*N. siki*	0.93	Triangulation 3*	
NNT-NPA, Laos	*N. siki*	2.68	N-mixture*	
Phnom Prich, Cambodia	*N. gabriellae*	0.16	Triangulation	Phan and Gray (2009)
Seima Conservation Forest	*N. gabriellae*	0.71	Triangulation	Rawson et al. (2009)
		0.74	Line transect	
KhaoSoi Dao, Thailand	*Hylobatespileatus*	1.7	Triangulation	Brockelman and Srikosamatara (1993)
SabangauCatchmen, Indonesia	*H. albibarbis*	2.59	Triangulation	Cheyne et al. (2008)
Java, Indonesia	*H. moloch*	1.5-2.4	Triangulation	Geissmann and Nijman (2006)
Java, Indonesia	*H. moloch*	0.6-2.7	Triangulation	
Sabangau, Kalimantan, Indonesia	*H. albibarbis*	1.39-3.92	Triangulation	Hamard et al. (2010)
Siberut Island, Indonesia	*H. klossii*	5.01 5.00	Line Transect Triangulation	Höing et al. (2013)
East Kalimantan, Indonesia	*H. muelleri*	2.4-2.6	Range mapping	Nijman and Menken (2005)
		2.4-2.9	Line transects	
		2.1-2.4	Fixed-Point Count	

Table 12 (Continued) Comparison of density (and occupancy) estimates of several gibbon populations with the use of different methods.

Site	Species	Group Density	Methods	References
Sebangau National Park, Indonesia	*H. agilisalbibarbis*	1.64	Triangulation	Phillips (2006)
Mentawai Islands, Indonesia	*H. klossii*	1.77	Line transects	Whittaker (2005)
		2.08	Triangulation	
KhaoAng Rue Nai, Thailand	*H. pileatus*	1.02	Triangulation	Phoonjampa et al. (2011)
KhaoYai, Pang Sida, Tab Lan National Parks, KhaoSoi Dao and KhaoAngRuNai Wildlife Sanctuaries, Thailand	*H. pileatus*	0.81	Triangulation	Phoonjampa and Brockelman (2008)
NNT-NPA, Laos	*N. siki*	0.97	Occupancy**	This study
ThuaThien Hue and Quang Nam, Vietnam	*N. leucogenys*	0.73	Occupancy	Gray et al. (2014)
Cardamom Mountains, Cambodia	*H. pileatus*	0.83	Occupancy	Neilson et al. (2013)

* Triangulation 1= including all groups (overall); Triangulation 2= only including groups detected by at least 2 LPs (overall); Triangulation3 = only including groups detected by at least 2 LPs (overall average of estimate per site [30 sites]); N-mixture= repeated count of unmaked groups (overall average of estimate per site [30 sites]); **Occupancy = probability of occupancy (overall average of estimate per site [30 sites]

CHAPTER V

CONCLUSIONS

This study's aim was to estimate the population abundance of *Nomascus siki* in Houay Tong site, NNT-NPA, Lao PDR. We found a healthy population in this research area. The data collected allowed me to reach my objective.

Three different methods were used to estimate abundance of gibbons at the research site. The repeat counts of unmarked groups (N-Mixture model first developed for bird count by Royle, 2004) seems to be the most appropriate method for gibbon survey as it avoids subjectivity in identification of groups detected. In conditions like NNT NPA where terrain is rugged and density of gibbons is very high, the triangulation method may not be suitable and may provide unreliable estimates. The estimated 2.68 groups/km^2 could mean over 17,000 individuals (with an average group size of 4 individuals) in NNT NPA (and this is probably a conservative estimate). The population in NNT NPA is likely the largest of the world for that species. However, threats to gibbons in the area may increase in the near future especially from hunting. It is therefore important to start a long-term conservation and ecological study at this site.

The singing behavior was found to be highly seasonal. Based on the results, it is recommended that future surveys for this species be conducted during the warm and dry season from November to May. In the future, detailed analysis of the songs of gibbons throughout NNT NPA could give us better insights into their taxonomical status as NNT NPA seems to be located at a transitional geographic zone between *N. siki* and *N. leucogenys*.

This research is the first ever medium-term study on *N. siki* and provided invaluable information to continue the research at the site for a long term investigation of their behavioral ecology and population management.

Recommendation for Future Work

The main interesting topics for further studies related to this research study should be followed:

(i) To investigate the population density of gibbon species.

(ii) To identify wild gibbons singing behavior.

(iii) To test the variation of environmental data that related to gibbon singing behavior.

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APPENDICES

APPENDIX A

LISTENING POST DATA COLLECTION FORM

Table A1 Listening Post Data Collection Form.

Surveyors:		Date:				Site:				
Time Start:		Time End:				Sun	Clouds	Fog	Rain	Wind
Listening Post#		GPS:	E:							
			N:		Elevation:					
No.	Time Start Male	Time Start Female	Time End	Bearing	Distance	Remark				

APPENDIX B

ENVIRONMENTAL DATA COLLECTION

Table B1 Environmental Data Collection.

Environmental Data Form								
Date	Time	T/w	T/c	Huminity	H.I	dp	Wind Speed	Remark

APPENDIX C

R CODE FOR THE OCCUPANCY

Appendix 3: R code for the occupancy model

```
### verify directory files
dir()
### load packages
library(reshape)
library(lattice)
library(Rcpp)
library(unmarked)
### load data file
gibbon <-read.csv("gibbon_occu.csv")
### Transform .csv file to UnmarkedFrame
for 'occu' function
Umf_gibbon <-
csvToUMF(("gibbon_occu.csv"),long = FALSE,
type = "unmarkedFrameOccu")
###Summary of data
summary(Umf_gibbon)
### Scale covariates
oc <- obsCovs(Umf_gibbon)
oc[,1:6] <-scale(oc[,1:6])
obsCovs(Umf_gibbon) <-oc
sc <- siteCovs(Umf_gibbon)
sc[,1:6] <-scale(sc[,1:6])
siteCovs(Umf_gibbon) <-sc
###test null model with no covs
Null=occu(~1 ~1,data=Umf_gibbon)
###backtransform
backTransform(Null, type="det")
backTransform(Null, type="state")
###lambda models
ms3=occu(~1 ~Water,data=Umf_gibbon)
ms4=occu(~1 ~ElevMean,data=Umf_gibbon)
ms7=occu(~1 ~Rugged,data=Umf_gibbon)
mo1=occu(~Temp ~1, data=Umf_gibbon)
mo2=occu(~Temp+Heat
~1,data=Umf_gibbon)
mo3=occu(~Wind ~1,data=Umf_gibbon)
mo4=occu(~Rain ~1,data=Umf_gibbon)
 mo5=occu(~Wind+Temp
 ~1,data=Umf_gibbon)
 mo6=occu(~Heat ~1,data=Umf_gibbon)
 mo7=occu(~Date ~1,data=Umf_gibbon)
 mo11=occu(~Humidity
 ~1,data=Umf_gibbon)
 mso1=occu(~Temp
 ~Water,data=Umf_gibbon)
 mso2=occu(~Wind
 ~Water,data=Umf_gibbon)
 mso3=occu(~Heat
 ~Water,data=Umf_gibbon)
 ###BACK-TRANSFORMATIONS
 backTransform(ms3, type="det")
lc3 <- linearComb(ms3, c(1, 0), type="state")
backTransform(lc3)
backTransform(ms4, type="det")
lc4 <- linearComb(ms4, c(1, 0), type="state")
backTransform(lc4)
backTransform(ms7, type="det")
lc7 <- linearComb(ms7, c(1, 0), type="state")
backTransform(lc7)
backTransform(mo1, type="state")
lc4 <- linearComb(mo1, c(1, 0), type="det")
backTransform(lc4)
backTransform(mo2, type="state")
lc5 <- linearComb(mo2, c(1, 0, 0), type="det")
backTransform(lc5)
backTransform(mo3, type="state")
lc6 <- linearComb(mo3, c(1, 0), type="det")
backTransform(lc6)
backTransform(mo4, type="state")
lc7 <- linearComb(mo4, c(1, 0), type="det")
backTransform(lc7)
backTransform(mo5, type="state")
lc8 <- linearComb(mo5, c(1, 0, 0), type="det")
backTransform(lc8)
backTransform(mo6, type="state")
lc9 <- linearComb(mo6, c(1, 0), type="det")
backTransform(lc9)
backTransform(mo7, type="state")
lc10 <- linearComb(mo7, c(1, 0), type="det")
backTransform(lc10)
backTransform(mo11, type="state")
lc17 <- linearComb(mo11, c(1, 0),
type="det")
backTransform(lc17)
lc11 <- linearComb(mso1, c(1, 0),
type="state")
backTransform(lc11)
lc11 <- linearComb(mso1, c(1, 0), type="det")
backTransform(lc11)
lc12 <- linearComb(mso2, c(1, 0),
type="state")
backTransform(lc12)
lc12 <- linearComb(mso2, c(1, 0), type="det")
backTransform(lc12)
lc13 <- linearComb(mso3, c(1, 0),
type="state")
backTransform(lc13)
lc13 <- linearComb(mso3, c(1, 0), type="det")
backTransform(lc13)
```

APPENDIX D

R CODE FOR REPEATED COUNT OF UNMARKED GROUP MODEL

APPENDIX 4: R code for the repeated count of unmarked group model

```
### verify directory files
dir()

### load packages
library(reshape)
library(lattice)
library(Rcpp)
library(unmarked)

### load data file
gibbon <- read.csv("gibbon_pcount.csv")

### Transform .csv file to UnmarkedFrame
for 'PCount' function
Umf_gibbon <-
csvToUMF(("gibbon_pcount.csv"),long =
FALSE, type = "unmarkedFramePCount")

###Summary of data
summary(Umf_gibbon)

### Scale covariates
oc <- obsCovs(Umf_gibbon)
oc[,1:6] <- scale(oc[,1:6])
obsCovs(Umf_gibbon) <- oc

sc <- siteCovs(Umf_gibbon)
sc[,1:6] <- scale(sc[,1:6])
siteCovs(Umf_gibbon) <- sc

###test null model with no covs
Null=pcount(~1 ~1,data=Umf_gibbon,
K=100)

###backtransform
backTransform(Null, type="det")
backTransform(Null, type="state")

###lambda models
ms3=pcount(~1 ~Water,data=Umf_gibbon,
K=100)
ms4=pcount(~1
~ElevMean,data=Umf_gibbon, K=100)
ms7=pcount(~1 ~Rugged,data=Umf_gibbon,
K=100)
mo1=pcount(~Temp ~1, data=Umf_gibbon,
K=100)
mo2=pcount(~Temp+Heat
~1,data=Umf_gibbon, K=100)
mo3=pcount(~Wind ~1,data=Umf_gibbon,
K=100)
mo4=pcount(~Rain ~1,data=Umf_gibbon,
K=100)
mo5=pcount(~Wind+Temp
~1,data=Umf_gibbon, K=100)
mo6=pcount(~Heat ~1,data=Umf_gibbon,
K=100)
mo7=pcount(~Date ~1,data=Umf_gibbon,
K=100)
mo11=pcount(~Humidity
~1,data=Umf_gibbon, K=100)
mso1=pcount(~Temp
~Water,data=Umf_gibbon, K=100)
mso2=pcount(~Wind
~Water,data=Umf_gibbon, K=100)
mso3=pcount(~Heat
~Water,data=Umf_gibbon, K=100)

###BACK-TRANSFORMATIONS
backTransform(ms3, type="det")
lc3 <- linearComb(ms3, c(1, 0), type="state")
backTransform(lc3)

backTransform(ms4, type="det")
lc4 <- linearComb(ms4, c(1, 0), type="state")
backTransform(lc4)

backTransform(ms7, type="det")
lc7 <- linearComb(ms7, c(1, 0), type="state")
backTransform(lc7)

backTransform(mo1, type="state")
lc4 <- linearComb(mo1, c(1, 0), type="det")
backTransform(lc4)

backTransform(mo2, type="state")
lc5 <- linearComb(mo2, c(1, 0, 0), type="det")
backTransform(lc5)

backTransform(mo3, type="state")
lc6 <- linearComb(mo3, c(1, 0), type="det")
backTransform(lc6)

backTransform(mo4, type="state")
lc7 <- linearComb(mo4, c(1, 0), type="det")
backTransform(lc7)

backTransform(mo5, type="state")
lc8 <- linearComb(mo5, c(1, 0, 0), type="det")
backTransform(lc8)

backTransform(mo6, type="state")
lc9 <- linearComb(mo6, c(1, 0), type="det")
backTransform(lc9)

backTransform(mo7, type="state")
lc10 <- linearComb(mo7, c(1, 0), type="det")
backTransform(lc10)

backTransform(mo11, type="state")
lc17 <- linearComb(mo11, c(1, 0),
type="det")
backTransform(lc17)
```

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