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# Assessing the distribution, roosting site characteristics, and population of *Pteropus lylei* in Thailand

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**Abstract.** Lyle's flying fox (*Pteropus lylei*) is classified as Vulnerable by the International Union for Conservation of Nature and Natural Resources; therefore, assessing the population distribution and density of *P. lylei* is fundamental to its conservation and management. We combined community-based and field surveys to update information on the distribution and population of *P. lylei* in Thailand. Questionnaires were distributed to 2,024 government officers across 26 provinces (covering 20.29% of the area of Thailand), in a region previously identified as a *P. lylei* distribution hotspot. A total of 623 (30.78%) replies were obtained from the surveyed provinces. The field survey validated the results of the questionnaire, with 67.65% of respondents correctly identifying *P. lylei* in their area; there were 30 roosting sites, a total population of 75,016 bats, and a total roosting area of 1,328,720 m$^2$. The roosting sites of *P. lylei* were at an average elevation of 23.73 m, and near rivers and bodies of water; 53% of roost sites were located within Buddhist temples. In addition, bat hunting areas were reported around 57% of the roost sites, and 62% of the total bat population was located near these sites. Our results confirm that close proximity between *P. lylei* and human populations is common. It is imperative that we continue to improve our understanding of *P. lylei* habitat requirements to develop land-management strategies and conservation policies that simultaneously protect *P. lylei* and safeguard public health.

**Key words.** bat, colony, community-based, flying fox**,** hunting, Thailand

## INTRODUCTION

The Lyle's flying fox *(Pteropus lylei*) is classified as Vulnerable by the IUCN Red List due to substantial population decline (Bumrungsri et al., 2008). It is also listed in Appendix II of the CITES (CITES, 2015). *P. lylei* belongs to the Old World fruit bat family, Pteropodidae. *P. lylei* is found in colonies of 100–1,000 individuals in Thailand, Cambodia, and Vietnam, and in small, distinct areas in southern China (Bumrungsri et al., 2008). This species is present only in the mainland of lower central and eastern Thailand (Boonkird & Wanghongsa, 2004; Duengkae et al., 2015). *P. lylei* has been reported to have a foraging distance of 2–23 km (Weber et al., 2015), and its flying speed can reach 49.83 km/h (Hondo et al., 2010). Adult *P. lylei* weigh 390–480 g and have a forearm length of 145–160 mm (Francis, 2008). *P. lylei* seems to develop satellite colonies as a precursor to changing roosting sites (Boonkird & Wanghongsa, 2004; Weber et al., 2015).

Threats to *P. lylei* in Thailand include hunting and loss of roosting habitat (Boonkird et al., 2007; Bumrungsri et al., 2008). Habitat loss (including roost site loss) or disturbance and disease have been identified as major threats to many flying fox species (Mickleburgh et al., 1992; Hutson & Racey, 2002; Daszak et al., 2004; Kingston, 2010). In addition, flying fox are hunted by humans for food (Craig et al., 1994; Wacharapluesadee et.al., 2006), which may lead to human exposure to zoonotic pathogens (Wacharapluesadee et al., 2006; Harrison et al., 2011). The importance of these factors varies from place to place, and this variation affects the species that are targeted by hunters and the methods that they employ, which in turn affect the impact of hunting on wildlife and the likely effectiveness of different conservation interventions (Harrison et al., 2016). In Thailand, *P. lylei* is protected by the Wildlife Preservation and Protection Act, B.E. 2535 (1992), which prohibits hunting, possession, and trade or export, and it is protected within designated areas, which include national parks, wildlife sanctuaries, non-hunting areas, and religious establishments (temples and mosques). However, bat hunting and the consumption of bat blood and other products still occur in some regions of Thailand (Wacharapluesadee et al., 2006). Poaching is considered a major threat to Thailand's wildlife (Department of National Parks, Wildlife and Plant Conservation, 2013). In addition, lower central and eastern Thailand has a high human population density, and habitat degradation and clearing of

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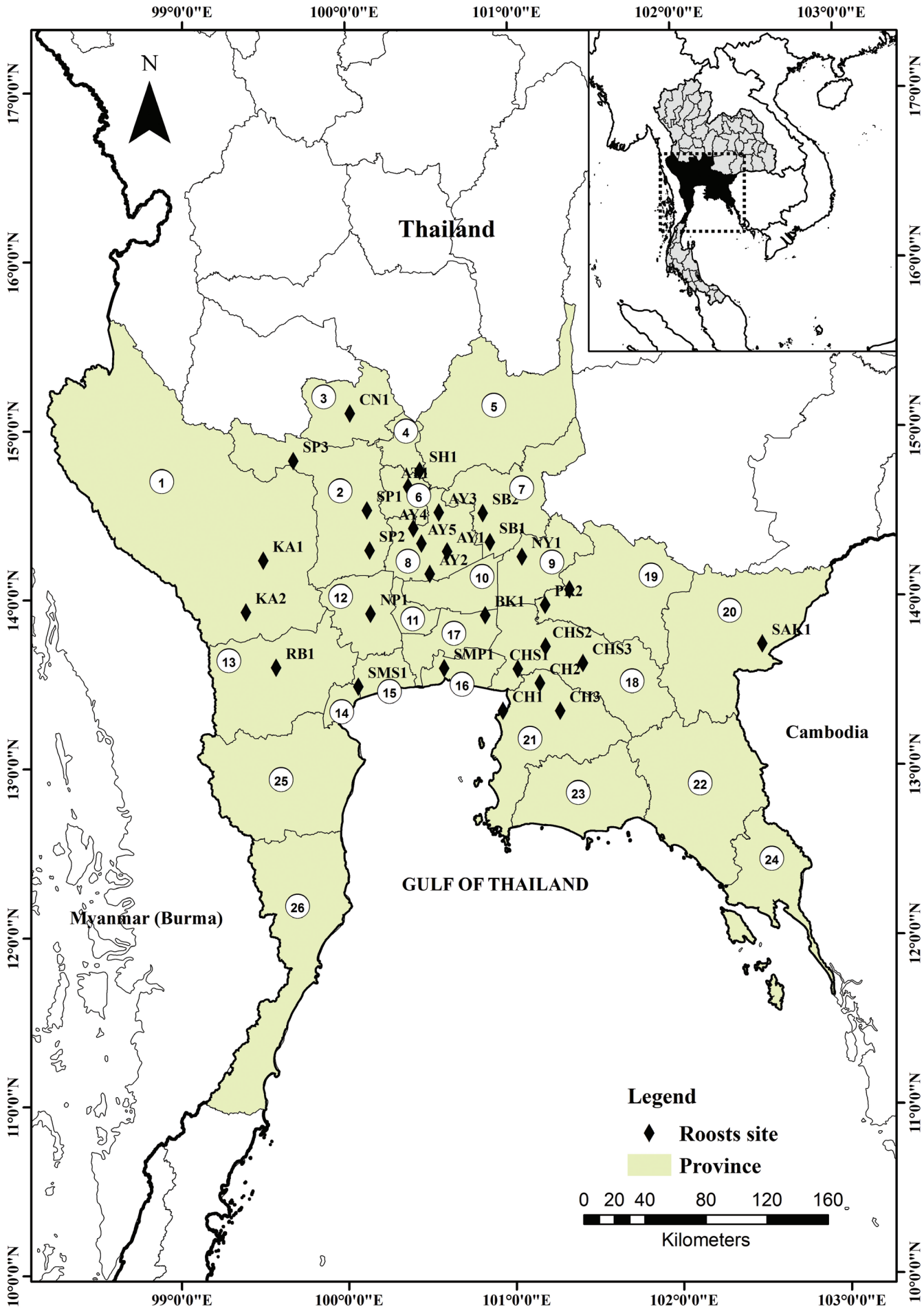


Fig. 1. Study area and location of *Pteropus lylei* roosts in Thailand.

land for agriculture and urban communities continue (Royal Forest Department, 2016).

Despite the need to conserve this globally threatened species, little is known about its roosting ecology and population distribution, particularly in Thailand. Further, there is limited information available for establishing a baseline, which will aid education and conservation efforts. In addition, *P. lylei* feeds on both cultivated and forest fruits (Weber et al., 2015; Aziz et al., 2016), and increases in the population of this species could potentially lead to conflict with local fruit growers. Hence, understanding *P. lylei*'s habitat selection and population characteristics of *P. lylei* could provide information useful for the design of forest-management strategies to preserve their roosting and foraging sites.

In this study, we investigated aspects of bat hunting in different sub-districts of Thailand to develop plans for monitoring and conserving *P. lylei* and reducing the impacts of habitat loss and bat hunting. The information from this study will be used to understand the specificity of roost site characteristics and to investigate the spatial proximity of roost sites to available shelters or resources. The correlation of such spatial characters of roosting sites and related threats are also examined. This study sought to identify and describe the characteristics of *P. lylei* roosting sites and to estimate the total population of *P. lylei* in Thailand. The information on threats was gathered using a community-based approach and field surveys. Knowledge of the habitat characteristics, effects of human factors, potential range, and spatial distribution may assist in the management of *P. lylei*, which is both a threatened species and a possible host of newly emerging diseases.

## MATERIAL & METHODS

**Study area.** Thailand, located in Southeast Asia, has a tropical climate affected by seasonal monsoon winds (i.e., southwest and northeast monsoons). Thailand is divided into 77 provinces, which are categorised into five regions (northern, southern, eastern, western, and central). Each province is divided into districts, and the districts are further divided into sub-districts. This study covered 26 provinces, all located within the western, eastern, and central regions of Thailand. The total study area covered 104,124.26 km$^2$ (20.29% of Thailand's total land area) (Fig. 1). Study sites were selected from among provinces that overlapped with the projected distribution of *Pteropus lylei* according to the most recent assessment of the IUCN Red List (Fig. 1) (Bumrungsri et al., 2008; Duengkae et al., 2015).

**Community-based questionnaire survey.** We distributed questionnaire surveys regarding *P. lylei* roosting sites to the chief executives of sub-district administrative organisations in 1,974 sub-districts within 25 provinces in Thailand, and to the directors of 50 districts in Bangkok, the capital city. Each sub-district and district has an Environmental Division of Public Health operated by the chief executive of the sub-district administrative organisation (Fig. 2). This division plays a role in surveying and collecting data on natural resources and environmental conditions within their jurisdiction. In addition, the flying fox, with its highly visible roosting sites and large colonies, is well known to all local Thai people. Questionnaires were enclosed within hand-addressed official envelopes, from the Faculty of Medicine, Chulalongkorn University, Bangkok, Thailand, and marked "WHO Collaborating Centre for Research and Training on Viral Zoonoses." Enclosed within each envelope was a brief cover letter on university letterhead, a one-page questionnaire, including an information sheet on *P. lylei*, and a stamped, self-addressed envelope for return of the completed survey. The cover letter emphasised the important role of surveillance in the early warning of emerging diseases in bats in an attempt to encourage the recipients. The *P. lylei* information sheet contained a picture of the species and details of its appearance to assist with identification. Recipients were also assured of the anonymity of the survey. The questionnaire was concerned with the characteristics of *P. lylei* and included an image, three multiple-choice questions (including one about bat hunting), and one short-answer question. It was designed to take less than 5 minutes to complete (Supplementary Material 1). Recipients were asked to complete the survey only with reference to their sub-district's area of responsibility.

**Field survey.** Community-based wildlife surveys are most useful when they obtain information regarding the presence of a species that is easily identifiable. These types of surveys have proven an effective tool in describing the distribution of several such species (Lunney et al., 2000; Lunney & Matthews, 2001), although some caution must be exercised in the use of this information due to the possibility of species misidentification. To address this issue, we validated the presence of *P. lylei* using community-based wildlife surveys and field surveys by a team of trained field biologists. The field survey team had prior experience in identifying and working with bats. *P. lylei* was captured at every roosting site, and each individual was identified as *P. lylei* following Francis (2008) as part of a survey and surveillance of infectious diseases from flying foxes in Thailand conducted by the Department National Parks, Wildlife, and Plants. Data on the locations of roosting sites and bat populations were collected from previous surveys and survey questionnaires reported in this study. The field-survey teams identified the locations of *P. lylei* roosts based on the replies from the survey questionnaires. We contacted the survey respondents for more information about the location of roosting sites and then visited those locations to collect data. The field survey teams recorded the GPS coordinates of each active roost and estimated the total population of *P. lylei* by means of direct sightings and by using digital cameras and unmanned aerial vehicles (UAVs). The population estimation counts were performed during the day at roosting sites. Each technique used depended on reaching the roosting site and establishing direct sightings of *P. lylei* individuals. The direct sighting technique was used for roosting sites that were easy to reach and observe, digital cameras were used at roost sites that were easy to reach but difficult to observe, and drones were used at roosting sites in inaccessible areas. The direct sightings required two observers from the field-survey team

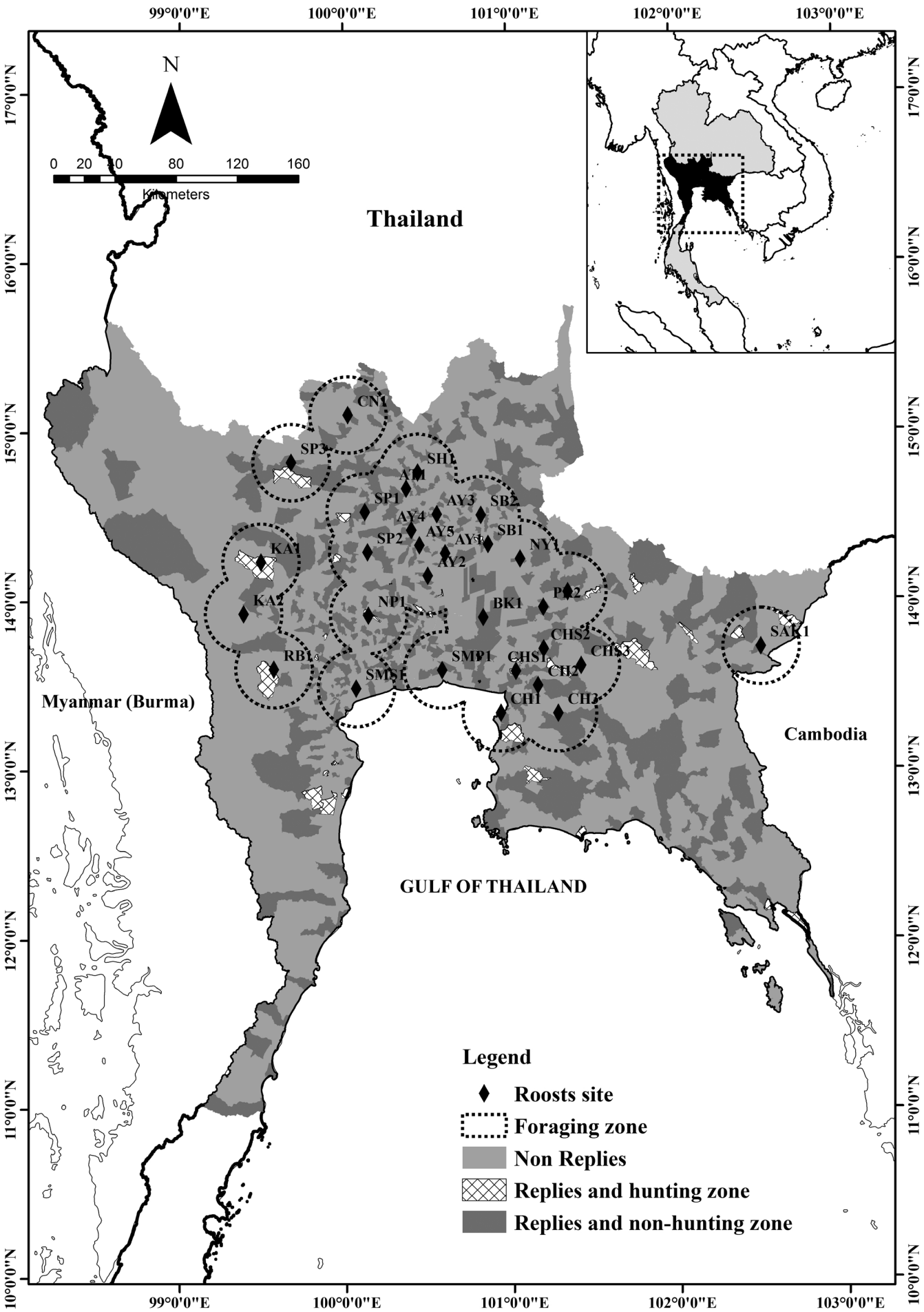


Fig. 2. *Pteropus lylei* roosting sites and foraging zones; questionnaire respondents and bat hunting zones are marked in each sub-district.

to quantify the population of *P. lylei*. The mean of the two independent observers' counts at each roost site was used in the analyses. Digital cameras or drones were used to take photos of and around each colony, and then the total population of *P. lylei* at each roosting site was enumerated from the photos.

**Derivation of roost site characteristics.** For each roosting site identified, we used ArcGIS and Google Earth to characterise and delineate the habitat area available to *P. lylei*. A map layer containing locations of the roosting sites was overlaid on the map of the rivers and water bodies, Buddhist temples, and elevation in raster format. We then extracted values to points on a multiple raster data in ArcGIS. The Euclidean distance to the nearest river or water body and to the nearest temple was calculated in ArcGIS. The maps of rivers and bodies of water and a raster map (30 m resolution) of elevation were provided by the Department of National Parks, Wildlife, and Plant Conservation (DNP). The Ministry of Transportation provided a map of Buddhist temples. To determine *P. lylei* roost area, we overlaid the layer of the roosting sites on Google Earth images and then created the smallest possible convex polygon enveloping every individual roosting location in the colonies.

## RESULTS

**Questionnaire survey response rate and accuracy.** Of the 2,024 surveys distributed, a total of 623 (30.78%) respondents from all of the 26 provinces surveyed (33.76% of all provinces in Thailand) filled out and returned the questionnaires between October 2015 and January 2016 (although not all respondents provided answers to every question). Roosting sites of *P. lylei* were reported in 20 of the surveyed provinces; 34 of the 623 respondents (5.46%) reported roosting sites (Fig. 2).

**Field survey roosting site.** Our field survey validated the presence of *P. lylei* at 34 roosting sites in Thailand from November 2015 to October 2016 (Fig. 3). Our community-based questionnaire enabled us to confirm the presence of bats at 15 roosting sites previously reported by Duengkae et al. (2015) and Thanapongtharm et al. (2015) (44.12%), and at 8 new *P. lylei* roosting sites (23.53%) (Table 1). We found misidentifications and sites not used by *P. lylei* from respondents at 11 reported (32.35%) sites. Of these, seven roost sites identified from the community-based surveys were found to be those of insectivorous bats and other species of frugivorous bats (20.59%), and two reported temporary roosting sites were those of *Pteropus hypomelanus* (5.88%). Two of the reported roost sites were inactive, i.e. presumably previously occupied, but not currently occupied, by *P. lylei* (5.88%).

**Characteristics of roosts.** In total, 30 *P. lylei* roosts in Thailand were examined in this study (8 new roosts), including sites reported by Duengkae et al. (2015) and Thanapongtharm et al. (2015) (21 roosting sites); 1 roosting site (KA2) described by a personal contact was also included. The sites were distributed among 16 provinces. Most sites were in central, western, and eastern Thailand (Fig. 1 and Table 1). Almost all of the roosting sites were located below an altitude of 105 m and within 1.5 km of a river or perennial water body or 2.8 km of a Buddhist temple (Table 1).

Furthermore, 16 of the 30 roosts (53%) were located within temples, while the number of roosts located on private property, common property, and state property was 8 (27%), 3 (10%), and 3 (10%), respectively (Table 2).

**Population estimate.** From the field survey conducted in 2016, we estimated the numbers of *P. lylei* at 10 roosting sites (AY4, AY5, CH3, CN1, KA1, NP1, RB1, SP3, SMP1, and KA2) and conducted population counts at 20 roosting sites, as was done previously by Duengkae et al. (2015). The overall estimated roosting population was 75,016, and the mean number of individuals per roost was 2,501 ± 1,688.77 (range: 523–7,991 bats). More than 1,000 bats were found in 90% of roosts. The largest and the smallest colonies were in temple located at CH2 (7,991 bats), and KA2 (523 bats) respectively. The roosting sites were overlaid on Google Earth maps to quantify roost areas: the total roost area was 1,328,720 $m^2$, and the mean roost size was 44,290.67 ± 79,004.85 $m^2$ (range: 5,472–435,700 $m^2$).

**Hunting data.** The results of our questionnaire survey indicated bat hunting in 27 sub-districts, 23 districts, and 13 provinces of Thailand (Fig. 1). Bat hunting was equally distributed among study areas in western, eastern, and central Thailand. Hunting in some form was reported in 15 of the 27 sub-districts identified as *P. lylei* foraging zones (25 km from the roosting sites), and 12 of the 27 sub-districts were outside of these foraging zones. Of the 30 total roost sites, 17 (57%) included foraging zones (within a 25 km radius from a roosting site), and 46,590 (62%) of the total population of 75,016 *P. lylei* lived in areas where hunting occurred (hunting areas) (Table 3).

## DISCUSSION

In this study, the field survey validated the questionnaire survey responses and showed true identifications in 67.65% of cases and misidentifications in 32.35% of cases. The community-based wildlife survey added to the considerable existing knowledge of wildlife within the general community, but also highlighted the need to interpret such information cautiously and recheck questionnaire survey results with field surveys conducted by researchers or wildlife experts. Community-based wildlife surveys are practical for studies covering a large area or conducted at a countrywide scale. This was the case for our study, as we covered an area of 104,124.26 $km^2$, and the researchers could not obtain data from every square kilometre. In addition, a community-based wildlife survey can reduce survey costs and time.

**Characteristics of roosts.** Our field observations indicated that the roost sites of *P. lylei* are usually near a body of water or a river, and safe undisturbed roosting locations, such as Buddhist temples. The average distance from a roost site to the nearest body of water was 208.82 m, as the

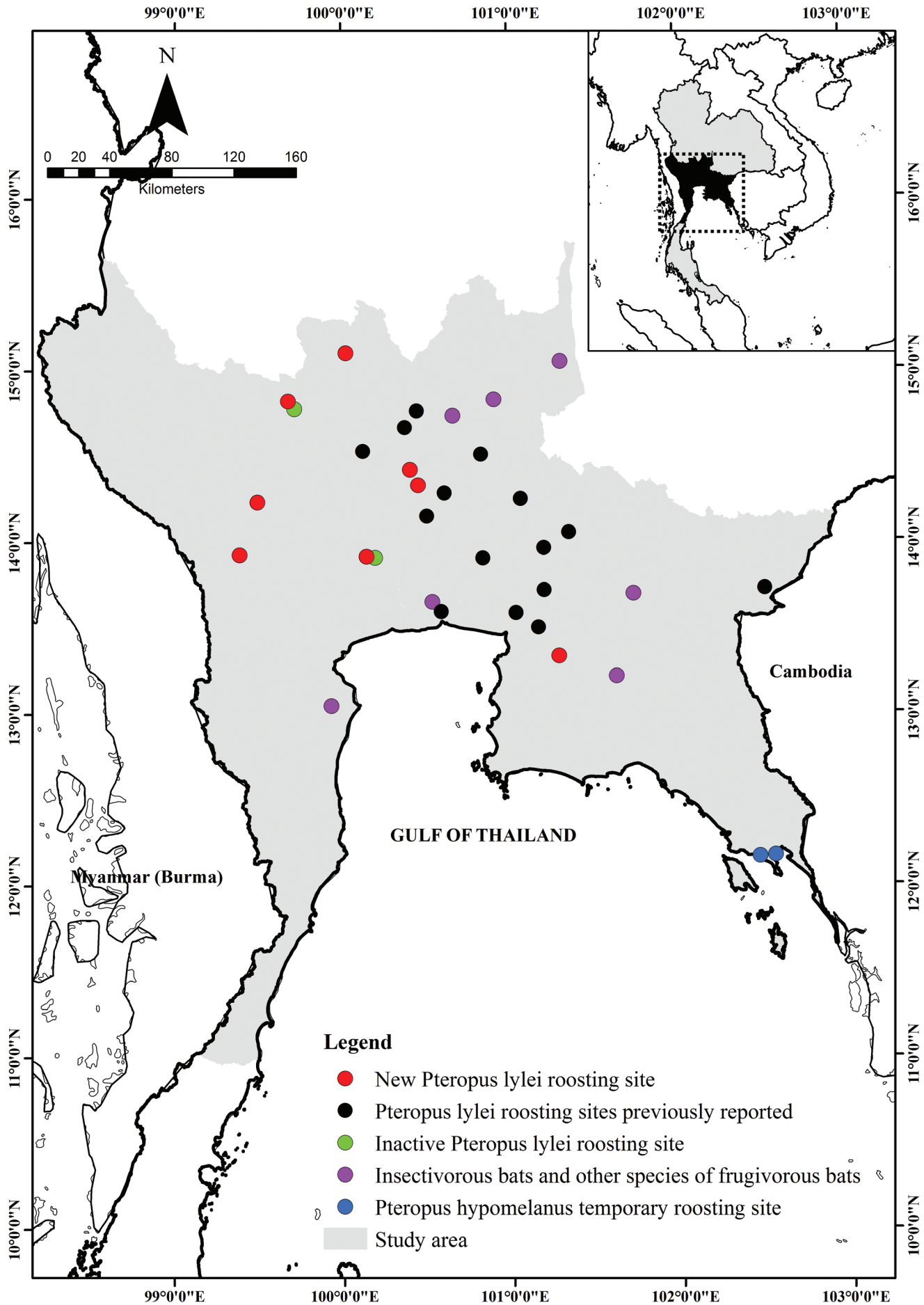


Fig. 3. Roosting sites responded (total number: 34) according to responses from community-based questionnaire, and result of a field survey to validate survey data.

Table 1. Description of roosts and population estimates for *Pteropus lylei* in Thailand. *New roosting site of *Pteropus lylei* identified in this study; NA = Not Applicable.

| No | Roost Code | Province | Population | Roost area ($m^2$) | Elevation (m) | Distance to water body (m) | Distance to temple (m) |
|---|---|---|---|---|---|---|---|
| 1 | AT1 | Ang Thong | 1293 | 24850 | 13 | 150.00 | 0 |
| 2 | AY1 | Phra Nakhon Si Ayutthaya | 1319 | 5472 | 9 | 127.28 | 0 |
| 3 | AY2 | Phra Nakhon Si Ayutthaya | 2647 | 17,280 | 9 | 174.93 | 0 |
| 4 | AY3 | Phra Nakhon Si Ayutthaya | 1950 | 10,620 | 10 | 30.00 | 0 |
| 5 | AY4* | Phra Nakhon Si Ayutthaya | 1500 | 26,190 | 10 | 123.69 | 752 |
| 6 | AY5* | Phra Nakhon Si Ayutthaya | 1889 | 13,380 | 13 | 67.08 | 0 |
| 7 | BK1 | Bangkok | 2000 | 24,560 | 10 | 30.00 | 2802 |
| 8 | CH1 | Chon Buri | 1000 | 435,700 | 0 | 127.28 | 781 |
| 9 | CH2 | Chon Buri | 7991 | 18,100 | 11 | 30.00 | 0 |
| 10 | CH3* | Chon Buri | 2500 | 10,110 | 40 | 394.59 | 283 |
| 11 | CHS1 | Chachoengsao | 681 | 13,270 | 11 | 42.43 | 1020 |
| 12 | CHS2 | Chachoengsao | 6128 | 17,300 | 11 | 67.08 | 0 |
| 13 | CHS3 | Chachoengsao | 1500 | 51,230 | 34 | 42.43 | 350 |
| 14 | CN1* | Chai Nat | 3576 | 69,970 | 20 | 216.33 | 711 |
| 15 | KA1* | Kanchanaburi | 2000 | 32,090 | 70 | 570.79 | 1236 |
| 16 | KA2* | Kanchanaburi | 523 | 29,410 | 46 | 123.69 | 0 |
| 17 | NP1* | Nakhon Pathom | 1518 | 12,770 | 12 | 218.40 | 721 |
| 18 | NY1 | Nakhon Nayok | 2319 | 64,060 | 23 | 67.08 | 0 |
| 19 | PR1 | Prachin Buri | 3852 | 10,320 | 13 | 30.00 | 0 |
| 20 | PR2 | Prachin Buri | 1239 | 36,090 | 8 | 67.08 | 0 |
| 22 | SAK1 | Sa Kaeo | 5292 | 49,130 | 69 | 1425.24 | 2028 |
| 23 | SB1 | Saraburi | 3164 | 10,940 | 9 | 247.39 | 0 |
| 24 | SB2 | Saraburi | 3470 | 18,280 | 17 | 218.40 | 0 |
| 25 | SH1 | Sing Buri | 2335 | 8474 | 16 | 94.87 | 0 |
| 26 | SMP1 | Samut Prakan | 1000 | 139,600 | 10 | 134.16 | 492 |
| 27 | SMS1 | Samut Songkham | 4000 | 31,710 | 8 | 161.56 | 1575 |
| 28 | SP1 | Suphan Buri | 3043 | 24,490 | 19 | 108.17 | 0 |
| 29 | SP2 | Suphan Buri | 711 | 5854 | 5 | 42.43 | 0 |
| 30 | SP3* | Suphan Buri | 3000 | 42,350 | 81 | 108.17 | 1473 |
| | | Summary | 75016 | 1,328,720 | NA | NA | NA |
| | | Mean | 2500.53 | 44,290.67 | 23.73 | 208.82 | 520.83 |
| | | Standard deviation | 1688.77 | 79,004.85 | 25.51 | 303.78 | 734.68 |

Table 2. *Pteropus lylei* distribution by property type.

| Property type | No. of roosts | Percentage of all roosts | Total population (mean) | Percentage of total population | Remarks |
|---|---|---|---|---|---|
| Temple | 16 | 53 | 43,873 (2,742) | 58 | AT1, AY1, AY2, AY3, AY5, CH2, CHS2, KA2, NY1, PR1, PR2, SB1, SB2, SH1, SP1, SP2 |
| Private property | 8 | 27 | 18,652 (2,332) | 25 | AY4, BK1, CH3, CHS3, CN1, KA1, RB1, SMS1 |
| Common property/ public land | 3 | 10 | 3,199 (1,066) | 4 | CH1, CHS1, NP1 |
| State property | 3 | 10 | 9,292 (3,097) | 12 | SAK1, SMP1, SP3 |

Table 3. Number of *P. lylei* roosts within foraging zones and total *P. lylei* population roosting in hunting areas.

| Threats | No. of Roosts | % Total Roosts | Total No. of Bats | % Total Population | Remark |
|---|---|---|---|---|---|
| Hunting area | 17 | 57 | 46590 | 62 | AT1,AY2,CH2,CH3,CHS1, CHS2,CHS3,KA1,KA2,NP1, PR1,RB1,SAK1,SH1,SP1, SP2,SP3 |
| Non-hunting area | 13 | 43 | 28426 | 38 | AY1,AY3,AY4,AY5,BK1, CH1,CN1,NY1,PR2,SB1, SB2,SMP1,SMS1 |
| Overall | 30 | 100 | 75016 | 100 | |

availability of water or a river near the bat roost is important for thermoregulation because flying foxes drink and dip their bellies in water to resist the worst of the heat during the day (Welbergen et al., 2017). Roosting sites were also within 520.83 m of Buddhist temples, on average, and these appear to be animal sanctuaries based on religious practices and Thai law; they are not disturbed, and no poaching of animals occurs. Temples appear to provide key roosting habitats for *P. lylei*. In total 16 out of 30 (58%) of the roosts were located in temples and contained 53% of the total *P. lylei* population (see Table 2). Temples may provide shelter and protection for bats, and the availability of suitable roost trees is probably higher at temple sites (Boonkird et al., 2006). A number of the roosts located on private property contained areas of relatively undisturbed natural forest and had lower population densities than those located in temples. Private property is an important refuge for bats: 25% of the total population of *P. lylei* was located at such sites, which may be key to protecting this species. However, private property may also carry a high risk of land use change, depending on the landlord. Therefore, plans for the conservation of *P. lylei* should encompass strategies for managing private property. Other types of property ownership, i.e., common property and state property (on which logging is prohibited by law), may provide pockets of undisturbed land suitable for use as roosting sites, and therefore can also be important refuges for *P. lylei.*

***P. lylei* roost site and population status.** Of the 16 roost sites and 37,837 bats included in a 2004 survey, we found that all 16 roosts were still occupied (Boonkird & Wanghongsa, 2004). The distribution of roost sites and the size of the *P. lylei* population have increased, although this may be partially explained through the use of new methods and the community survey, which have enabled a more thorough count. We identified 30 roost sites—an increase of 88%—and an estimated 75,016 individual bats (mean number of bats per site = 2,501 ± 1,688.77, an increase of 98%). This expansion is highlighted by the increase in the number of roosts. Although it is possible that some roost sites remain undiscovered, it is unlikely that any permanent or substantial colonies of *P. lylei* would have gone undetected due to the detailed knowledge of the species among local people and the large area of human habitation. However, it remains possible that some active roosts or roosts located in inaccessible areas were not located during our surveys. Hence, our population estimate should be considered as a minimum estimate. As discussed below, the true population of *P. lylei* could be substantially larger. However, it is also possible that some colonies could not be located, for example if they had moved into inaccessible areas such as mangrove forests or remote areas.

**Threats and hunting practices.** Although almost all bats are protected by Thai law (The Government Gazette, 2003), which makes hunting illegal (Wildlife Preservation and Protection Act, 1992), bat hunting was reported in the 27 sub-districts surveyed in this study (1.33% of the study area), and hunting areas occupied approximately 56% (15 sub-districts) of the foraging zones of *P. lylei*. Other bat species were found in 12 sub-districts in the hunting areas. The importance of bats as a source of protein to local people needs further assessment. However, it is clear that local people use bats for food purposes, and some locals even drink bat blood. Furthermore, regarding the results pertaining to the habits of bat hunters and consumers in Thailand, 95% of people who hunted bats took no precautions when capturing the bats, and they did not wash their hands after catching them; no bat consumers wore gloves during the cooking of bat products (Chumkaeo et al., 2014). Bats have long been known as a vector for rabies and may be an important natural reservoir for other deadly emerging viruses, including Hendra virus, Nipah virus, severe acute respiratory syndromes such as the coronavirus, the Ebola virus, and the Marburg virus (Chua et al., 2000; Hsu et al., 2004; Leroy et al., 2005; Li et al., 2005). Direct contact with bats may therefore pose a risk of infection by deadly emerging viruses (Wacharapluesadee et al., 2006).

Within Thailand, remnant tracts of forest are being replaced rapidly by agricultural land. Forest cover has declined from 43% of Thailand's land area in 1973 to just over 31% in 2015 (Royal Forest Department, 2015). Deforestation results in a loss of roosting sites, population, and potential food sources. Additionally, encroachment of agricultural land into forests may increase the accessibility of colonies and increase conflict between bats and fruit farmers (as farmers often place nets over trees). *P. lylei* eats both wild and cultivated fruit, consuming 34 plant species (most of which are also used by humans). The majority of edible plants consumed

are fruits, with mangoes (*Mangifera indica*) being the most frequently eaten fruit; bananas (*Musa* sp.) ranked second and tamarind (*Tamarindus indica*) ranked third (Weber et al., 2015). Figs (*Ficus* spp.) represented the most commonly consumed genus, accounting for 20.6% of all edible plant species consumed. Most of the fruits consumed by *P. lylei* in Thailand are also consumed by other flying foxes in the Asia-Pacific region, most notably mangoes and other commercial fruits such as cashews and tamarinds (Weber et al., 2015). As a result, fruit farmers may take steps to protect their fruit trees against frugivorous bats. The loss of forestland leads to a shift in roosting sites to be closer to villages (and thus humans) and Buddhist temples, which act as sanctuary locations. This can influence both bat and human health. *P. lylei* is one of three species of flying fox (genus *Pteropus*; *P. lylei*, *P. hypomelanus*, and *P. vampyrus*) that have been identified as major vectors of the Nipah virus in Thailand (Wacharapluesadee et al., 2005). This exploratory study suggests that widespread bat hunting occurs in Thailand, and that there is a high rate of contact exposure between bats and humans. The geographical distribution of bat hunting suggests that interventions to reduce pathogen spillover resulting from hunting could target specific locations, which may potentially limit the spillover of zoonotic diseases.

This study represents an update of information on, and census of, *P. lylei* population densities and roosting sites across Thailand. In total, 75,016 individuals of *P. lylei*, distributed among 30 roosting sites, were found in Thailand. Roosting sites were located at low altitudes and at short distances from rivers, perennial bodies of water, and temples. The mean *P. lylei* roost area size was 44,290.67 $m^2$. Our data show that 53% of *P. lylei* roosts are located within temples. These suggests these factors could be used to understand or study the distribution and ecological niche of *P. lylei*. Approximately 57% of the roost sites and 62% of the total population of *P. lylei*, are located within hunting areas. The number of roosting sites of *P. lylei* located in non-protected areas and/or hunting areas is a cause for concern. It is crucial to bear in mind that despite the widespread distribution and high local abundance of this species in Thailand, *P. lylei* could be endangered in the near future by ongoing threats and the high proportion of colonies residing outside protected areas. However, effective management strategies could be applied to ensure the long-term conservation of *P. lylei*. Habitat suitability management for *P. lylei* is needed urgently, as is habitat suitability modelling for all such species, especially in light of increased habitat loss due to deforestation. Unprotected areas that are potential habitats and that could sustain large populations of *P. lylei* need to be identified, and the protected status of currently designated protected areas needs to be managed and reinforced.

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## SUPPLEMENTARY MATERIAL

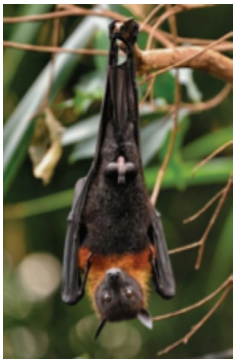
Supplementary Material 1. Survey Questionnaire on *P. lylei* Flying Fox (LFF) Roosting Sites.

**Name** _____ **Tel. Number** _____

**Address** _____ **Sub-district** _____

**District** _____ **Province** _____

**Please consider the below characteristics of LFFs before answering the questions.**

<table>
<tr>
<td>  <br>Head and body = 16 cm</td>
<td>  <br>Wingspan = 1 m</td>
</tr>
<tr>
<td>  <br>In flight</td>
<td>  <br>Roosting site</td>
</tr>
</table>

**Please put a ✓in each ❑ to denote your answers.**

1. Have you ever seen an LFF in your district?
   - ❒ No (skip to #3)
   - ❒ Yes (flying overhead). Location: _____
   - ❒ Yes (foraging for food). Location: _____
   - ❒ Yes (roosting site). Please give details in #2
2. Where is the roosting site of LFFs in your sub-district?
   Location: _____
3. Have you been bat hunting in your responsibility area (sub-district)?
   ❒ Yes; hunt but not to consume ❒ Yes; hunt to consume ❒ No
4. Is there a pig farm in your sub-district?
   ❒ Yes (small farm) ❒ Yes (large farm) ❒ No