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# Habitat Use of the Saola *Pseudoryx nghetinhensis* (Mammalia; Bovidae) Based on Local Sightings in the Northern Annamite Mountains of Lao PDR

**Chanthasone Phommachanh[1,2,3], Dusit Ngoprasert[1], Robert Steinmetz[4], Tommaso Savini[1], and George A. Gale[1]**

**Abstract**

The Saola *Pseudoryx nghetinhensis* (Mammalia; Bovidae) is IUCN Critically Endangered, but its ecology remains almost entirely unknown. Here we present the first characterization of Saola habitat use. We assessed Saola macrohabitat and microhabitat characteristics using Saola sighting location data obtained from local people. The study focused on the Phou Sithon Endangered Species Conservation Area in the northern Annamites of Lao PDR. A geographical information system was used to characterize macrohabitat variables including elevation, abundance of streams, and distance to nearest village associated with each observation. Infinitely weighted logistic regression models were used to assess relationships between detection of Saola and these macro variables. Direct measurements for microhabitat variables for each Saola observation were also collected and compared with other available vegetation data. Twenty-two observations from 18 independent observation points were analyzed. Elevations of the points ranged from 592 to 1,112 m (Median = 747 m) matching previous studies (500–1,400 m). Our regression model indicated abundance of streams affected detection of Saola suggesting it was more likely detected in areas with higher abundances of streams; however, streams were also associated with human travel routes. Our analysis also suggested that Saola were more frequently encountered in primary forest with a high density of trees but were occasionally observed in secondary growth. Most encounters were on animal trails. This information represents an important baseline for future assessments of Saola priority areas, which may assist in searching for possible sites that might harbor this elusive species; however, additional studies of its ecology are urgently needed to guide future management.

**Keywords**

conservation, northern Annamites, *Pseudoryx nghetinhensis*, Saola, local knowledge

## Introduction

The Saola *Pseudoryx nghetinhensis* (Mammalia; Bovidae), a species classified as Critically Endangered by the IUCN (Timmins, Hedges, & Robichaud, 2016) was discovered by scientists in Vietnam in 1992 (Dung et al., 1993). Despite its discovery approximately 25 years ago, and an initial assessment of its ecology (Schaller & Rabinowitz, 1995), scientists still know almost nothing about its behavior, ecology, habitat use, and distribution (Kemp, Dilger, Burgess, & Dung, 1997; Robichaud, 1998; Schaller & Rabinowitz, 1995; Turvey et al., 2015). The Saola has never been observed in the wild by a biologist

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(Robichaud, 1998; WWF, 2004), and it has only been photographed using camera traps four times (Hance, 2013; Robichaud, Vangban, WCS, & IUCN, 1999; Whitfield, 1998), not including a possible photo in Nakai-Nam Theun in 2009 (Saola Working Group [SWG], 2009). Although it was captured alive approximately 20 times (Stone 2006), all animals kept in captivity died shortly afterward, and we are aware of brief observations of captive animals only twice (Robichaud, 1998, 2010).

For rare and difficult to detect species such as the Saola that inhabit steep and remote areas, using information from local people can be invaluable for building an understanding of a species ecology (Rasalato, Maginnity, & Brunnschweiler, 2010; Turvey et al., 2015; Wilhere, 2002). Information derived from local people is increasingly seen as an important source of data for ecological research (Anadón, Giménez, Ballestar, & Pérez, 2009; Parry & Peres, 2015; Steinmetz, Chutipong, & Seuaturien, 2006) and was recently used for a large scale survey of rare species in the Annamites, including the Saola (Turvey et al., 2015). In principle, direct observations of a species by local people are equivalent to other scientific survey data, if the species are reliably identified. Ecologists can potentially collect many local sighting records in less time than standard survey methods such as camera trapping, line transects, or other techniques for surveying animals (Anadón et al., 2009; Wilkinson, 2013). The main disadvantages are that the reliability of local sightings must be evaluated and that locations of sightings are likely to be biased as local observers do not search the forest randomly or systematically. In this study, we assessed habitat use of Saola using sighting location data from local people. Our aim was to provide a basic description of the characteristics of Saola habitat; given how little is known about this critically endangered mammal, this information may be invaluable for future surveys of Saola priority areas in the Annamites, and particularly for finding sites that might harbor this species.

## Methods

### Study Area

Phou Sithon Endangered Species Conservation Area (hereafter PST) is located in Bolikhamxay Province in the northern Annamite Mountains (18–19°N, 104–105°E), Lao PDR. It covers 142 $km^2$ and elevations range between 600 and 1,700 m above sea level. No formal botanical survey of PST has been conducted, but our vegetation sampling described herein indicated that the understory vegetation of PST was dominated by species of Melastomataceae, Zingiberaceae, Arecaceae, and bamboo, similar to known Saola habitat at Bu Huong in Vietnam (Kemp et al., 1997). Adjacent to PST to the west is a proposed extension to PST covering 252 $km^2$. PST was established as a conservation area after the capture of a live Saola in August 2010 (Figure 1; IEWMP, 2010), making it one of the few forest areas in the Saola's range with confirmed sightings of the species. This fact, and the long inhabitance by local people who rely on the forest for their subsistence, make PST an ideal location to gather information about Saola ecology using local observations.

*Documenting local people's observations of Saola.* PST and its proposed extension shares a border with 10 villages and based on previous studies conducted in Laos was presumably used by local people of these villages (Johnson, Singh, Dongdala, & Vongsa, 2003). Because of the 2010 Saola capture in PST and previous surveys assessing the Saola's distribution in Laos, which documented a number of Saola sightings around PST (Phommachanh, 2011), we focused on these 10 villages (Figure 1). We identified local people who had observed Saola in the field by asking village headmen to direct us to likely people, and by directly visiting 339 of the 540 houses in these 10 villages. During these visits, we compiled a list of people who were familiar with the forest and with wildlife in general (regardless of whether they had seen a Saola or not) to facilitate our understanding of how local people utilized the forest adjacent to their villages (see below). To develop this list, a standard questionnaire was used. The interviews took 10 to 15 min per person and were conducted in the Lao language.

For people who said they directly observed Saola, we asked them to describe characteristics of the animal to assess the reliability of their observations. There is only one local name for Saola in these villages, so confusing the name with some other species was unlikely. First, we assessed their familiarity with other ungulates that occur in PST such as Serow *Capricornis milneedwardsii*, Sambar *Rusa unicolor*, Muntjacs *Muntiacus* sp., and Wild Pig *Sus scrofa*. We had them describe those species to establish a context for asking about Saola characteristics; other ungulates could conceivably be misidentified as Saola. Next, we asked them to describe characteristics of Saola, with special attention given to (a) characteristics of the horns, such as whether they were branched or unbranched or parallel and their relative length; (b) body size relative to other ungulates in the study area; (c) body color; and (d) body markings. If the observer could reliably describe Saola based on these characteristics, we felt reasonably confident in using their sighting data. Importantly, at least five of the hunters had Saola skulls and horns in their houses (Phommachanh, 2011; Figure 2) that had been hunted locally, and which they identified as Saola; this indicated that there was unequivocal certainty about the identification of Saola in these communities, at least among some people.

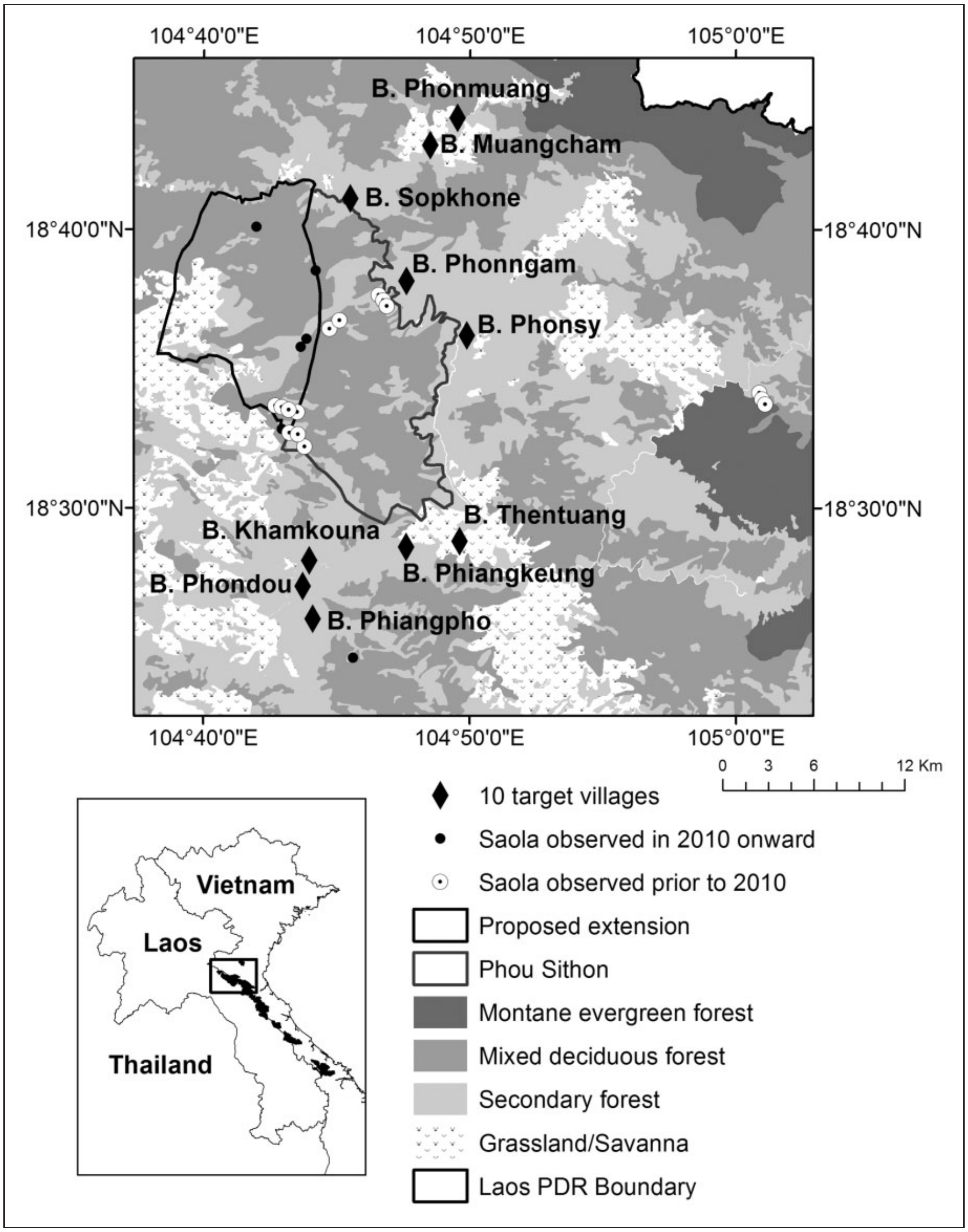


**Figure 1.** Phou Sithon Endangered Species Conservation Area and proposed extension area. A map of the locations of reported Saola sightings during 17 years (1996–2013) overlaid on the primary land cover types. Inset indicates Saola priority areas in both Laos and Vietnam (SWG, 2013).

The author explained the objectives of this study to the informants and that the study design adhered to the laws that govern forestry and wildlife (Ministry of Agriculture and Forestry, 2007) and informed them that any personal information would be kept strictly confidential emphasizing the fact that the project coordinator was a university student rather than a government official. The informants were willing and consented to report their use of the forest and Saola sighting data to us.

We also conducted interviews of informants independently during short side discussions during community mapping sessions (described below) to avoid leading interviewees into answers about their observations. For example, open-ended questioning was used to derive longer answers about the Saola observations mentioned earlier (Newton, Thai, Roberton, & Bell, 2008; Wilkinson, 2013). We did not use reports based on purported tracks or sign, as characteristics of Saola tracks


**Figure 2.** An example of two Saola skulls and horns (probably both male; left) found attached to walls of two hunter's houses in Phonngam village adjacent to the Phou Sithon Endangered Species Conservation Area, Bolikhamxay (PST), Laos (Figure 1). We used characteristics of Saola horns to, along with other characteristics, assess the reliability of local observations by comparing their descriptions of animals seen with other species commonly found in the study area such as Serow *Capricornis milneedwardsii* (right). Horns are found on both sexes of Saola and can reach more than 50 cm in length. For Serow, horns are also found on both sexes and can reach approximately 15 cm in length. Photos of the Saola skulls and horns were taken in 2011. The Serow photo was obtained from camera trapping in 2014 approximately 5 km from the Phonngam Village adjacent to PST.
Photo credit by: Chanthasone Phommachanh, King Mongkut's University of Technology Thonburi, Bangkok, Thailand, Saola Working Group, Species Survival Commission's Asian Wild Cattle Specialist Group, Wildlife Conservation Society, Lao PDR, Vientiane, Laos and Integrated Ecosystem and Wildlife Management Project, Bolikhamxay, Laos.
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and sign are not well documented (Robichaud and Timmins, 2004; Wilkinson, 2013) and we believed similarities with other ungulate species in the area made such data unreliable.

Once the reliability of the Saola observers had been established, we asked each observer to take the first author to the exact locations where the direct observations occurred. We recorded the month of observation, and under what circumstances the observation was made, sighting or during hunting (with a gun, snaring, or by hunting dog). A chi-square test was used to assess possible seasonal differences in the frequency of sightings by comparing the proportion of sightings between the wet (June–October) and dry seasons (November–May). We investigated seasonal differences in the elevation of sightings using a Mann–Whitney test.

In conjunction with locating the Saola observers, we also created maps depicting local use of the surrounding forest to understand the context in which the Saola observations had occurred. This community mapping was also used to understand where local people travel, essentially their survey effort, which was then compared with where the Saola were detected. Areas people used to hunt and collect forest products were then summarized in a geographical information system (GIS; ArcGIS version 10 software) by drawing and defining polygons where people use the forest. Use areas were also mapped based on three categories of relative use (a) areas that local people used rarely, (b) areas that local people used moderately, and (c) areas that local people frequently used. The term ''used frequently'' was defined as areas visited at least 12 times per year, and ''used rarely'' was defined as areas visited only once or not at all in a given year and moderate use for those of intermediate use or had received extensive use in the past but were rarely used currently, particularly areas inside PST which were now protected. Locations outside of these *use* areas had basically unknown levels of human use but were presumed to be places rarely visited.

From the 10 target villages, we identified a total of 85 local people including the headman of each village for community mapping exercises. All interviewees happened to be men because most of the people who engage in extensive hunting or trapping were male. They had a median age of 45 (range 24–68 years) and had spent extensive amounts of time in the forest (>10 days per month). Community mapping was conducted from February 7 to 28, 2014. Each community mapping exercise consisted of a focus group of 6 to 11 people. The community mapping exercise lasted 1 to 2 h per village. A topographic map (printed out in A1 size using ArcGIS), including only larger steams (in our study area most of the water bodies with current were < 5 m wide, thus we refer to these as well as wider bodies as "streams" throughout the manuscript), location of target villages, and mountains, was used as a base map for the community mapping exercises. To start, the primary features of each map were confirmed beginning with the locations of target villages, and then nearby geographic features including names of streams, roads, mountains, and valleys to maximize understanding of the map locally. The coordinator then asked each group member to tell him what areas of the forest they traveled and marked with a bean or button each area on the map particularly where they hunted and collected. The coordinator drew polygons of where people traveled in the forest based on where these men visited. Informants marked areas they visited including along streams, on ridges, tops of mountains, and mineral licks (Figure 3). As mineral licks have been sometimes associated with Saola (Robichaud & Timmins, 2004), we mapped mineral lick locations based on the community mapping and our follow-up surveys to investigate Saola locations in the field. We also asked informants to mark places they had observed Saola whether by hunting or just visual observations. As confirmed Saola records are so rare, we also included two records from camera trapping that occurred approximately 25 km to the east of PST in 1999 (Robichaud et al., 1999). In areas of human use, we also estimated the percent cover of secondary and primary forest from a GIS map (see macrohabitat analysis below) and then used this to compare the relative availability of secondary and primary forest versus the frequency observations of Saola in these two forest types using a chi-square test.

*Microhabitat analysis.* We compared vegetation where Saola were observed with another vegetation dataset, following the same measurement protocol, collected at camera trapping locations as part of a parallel project in PST (Phommachanh, 2014). A total of 26 camera trapping sites and the 18 confirmed, independent Saola locations were compared. The camera-trapping survey was carried out from April 2014 to May 2015. We used vegetation sampled at camera locations which were at least 500 m apart at elevations below 1,200 m; 1,200 m was used as the cutoff as this corresponded roughly to the highest elevation where Saola had been observed in PST. Also our community mapping information suggested that local people spent relatively less time at higher elevations and that the amount of available forest above 1,200 m was relatively small. We used five vegetation subplots at each Saola and camera-trapping location. Each subplot was 50 m apart with the center subplot located at the point where the Saola were observed (or camera located). Each subplot was 11.3 m radius (400 $m^2$) with 5 m radius subplots inside each to measure smaller stems. Every tree with a diameter breast height (DBH) greater than 10 cm was counted in the 11.3 m radius. In each subplot, stems with DBH greater than 1 cm were recorded in three height categories: 0 to 1 m, 1 to 2 m, and >2 m. Percent cover of four ground cover species groups was estimated: *Schismatoglottis cochinchinensis*, coral ferns (family Gleicheniaceae), gingers (family Zingiberaceae), and grasses were measured in percentages in five categories 0%, >0% to 25%, 25% to 50%, 50% to 75%, and 75% to 100%, respectively. Cover of selected species (wild banana, bamboo, rattan, and palms) was also counted as these species were described in habitats where Saola were observed (Schaller & Rabinowitz, 1995). Canopy cover and ground cover were estimated by percentage by using an ocular tube (James & Shugart, 1970), 21 samples per subplot for a total of 105 per Saola or camera observation point. Variables based on counts per plot were standardized to hectares, and then the results were presented graphically. Variables that used percent cover (ground cover of plant groups) also were presented graphically. Mann–Whitney statistics were used to compare microhabitat use points of Saola observations with the selected camera locations. We adjusted $p$ values for multiple comparisons by using the Dunn-Sidak procedure (Sokal & Rohlf, 1995). The median of each measured variable in each of the five subplots of each Saola or camera observation was also presented. Microhabitat conditions might have changed since the Saola sighting at a location, especially for sightings that had occurred many years in the past. We asked local people who observed Saola about memories of the habitat at the time the Saola were observed to assess qualitatively possible changes to the habitat in and around observation points. If notable habitat changes occurred such as from natural processes (e.g., landslides) or human disturbance, measurements were not taken; (only one subplot could not be measured, and this was due to a landslide).

*Macrohabitat analysis.* For each Saola location record, we extracted macrohabitat data using ArcGIS. The landcovers included montane evergreen forest, mixed deciduous forest, secondary forest, savanna, and grassland based on Rundel (1999) and classified by the Wildlife Conservation Society in 2012 (WCS Laos, 2012). Village locations, topographic, and stream data were obtained based on data classified in 2002 (WCS, 2002). We ground-truthed the land cover when visiting the Saola observation points in the field and determined the land cover maps to be reliable. We created 100 m buffers around each Saola observation to assess broad-scale habitat associations (Hefley & Hooten, 2015). We extracted values of selected variables within these buffers focusing on three landscape predictor variables for each Saola observation point: (a) stream abundance, the total length of streams in each buffered area; (b) elevation, the average elevation value within each buffered area; and (c) village, the distance to the nearest village from each Saola observation point. These factors were chosen based on previous reports which suggested that Saola were more likely to be detected in areas close to streams (Robichaud & Timmins, 2004),

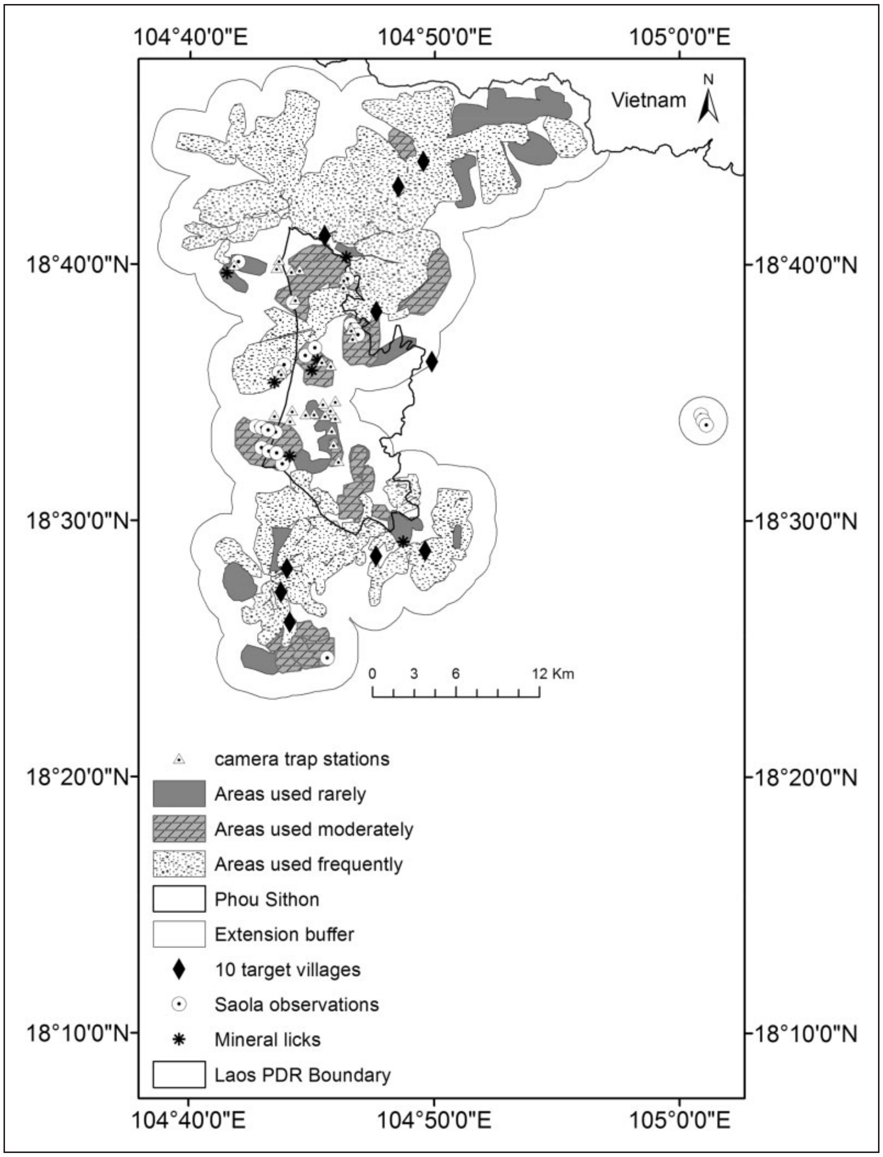


**Figure 3.** A map of the locations of reported Saola sightings 1996 to 2013 in and around the Phou Sithon Endangered Species Conservation Area (PST), Bolikhamxay, Laos. Observations included animals caught in snare traps, shot, photographed by camera traps, or seen. This also includes an assessment of the survey effort as to the level of human use relative to Saola observations. Areas people used to hunt and collect forest products (indicated by use areas) were derived from community mapping. The outermost buffer around the human-use areas (1.7 km radius) was based roughly on a Sambar's (*Rusa unicolor*) home range and used to represent the total available habitat for Saola. Area use histories are also mapped as to where people used to hunt or collect and the relative frequency of use. No local use information was available for the three observation points approximately 25 km east of Phou Sithon. Areas outside the human-use areas also had no available data regarding levels of human use. Lands in Vietnam were excluded from the analysis. The map shows the 26 camera-trapping locations (white triangles) and locations of mineral licks from direct observations and community mapping (black asterisks).

more likely to occur far from villages (Kemp et al., 1997; Schaller & Rabinowitz, 1995) and associated with particular elevations (Timmins et al., 2016). We assumed that these landscape variables did not change appreciably since 2002, and no other more recent land cover data were available.

For this analysis, we used presence-only data, thus random points were used to generate availability data for analysis (Hefley & Hooten, 2015). The available points were generated in ArcGIS by systematic random sampling. As the home range of the Saola is unknown, we used the average home range of a Sambar (9.4 $km^2$; Chundawat, Sanago, Sharma, & Malik, 2007; Sankar, 1994) a species with a similar body size of a Saola to estimate a buffer (1.7 km radius) around the human-use areas to represent the total available habitat for Saola within our study area (Figure 3). Available points were located within the human-use polygons and this buffer area, and were at least 200 m apart (Figure 3). The total number of points generated was 21,423. Thus, we used these 21,423 points to represent available locations for the macrohabitat analysis.

Infinitely weighted logistic regression was used to model the probability of Saola presence using detection data from the local observations and available points described earlier. We used the 18 confirmed, independent Saola locations in the regression analysis. Infinitely weighted logistic regression was used due to the imbalanced dataset in which presence points were much fewer than the available points; this method reduces the effects of the imbalance on parameter estimates (Hefley & Hooten, 2015; Owen, 2007). Continous variables were standardized by centering and scaling (Gelman, 2008). The variables that were highly correlated ($r > 0.5$) were removed from a given model. Model selection was used to compare models in an attempt to select the best model among model sets (Powell & Gale, 2015). The analysis was conducted using Program R version 3.3.0 (R Core Team, 2016).

## Results

### Community Mapping and the Saola Observation Records

We interviewed 85 people in 10 villages. A total of 39% of the people (33/85) claimed to have seen Saola; of these, 17 people unambiguously described the animal as a Saola and not some other species, and we used observations from these informants. The remaining 61% (52/85) of the people had never seen or were not familiar with Saola. Two older men (aged 65 and 71 years) in the village of Phonmuang (the village furthest to the north in the study, Figure 3) described the Saola correctly but had never seen a Saola. The 17 informants observed Saola 20 times between 1996 and 2013 (Table 1). Of these 20 records, 14 were physical captures (mostly in snares), and 6 were sightings in the forest. Along with the two records from camera trapping which occurred approximately 25 km to the east of PST in 1999, we were able assess a total of 22 records (Table 1). Because of the timing of the captures and sightings, we concluded that these 22 records represented at least 15 individuals under the most conservative assumptions that the Saola are wide ranging, and that the camera-trap photos from 1999 represent a single individual which then traveled to PST where it was subsequently captured and that the recent sightings were of a single individual observed independently on four different occasions. These 22 Saola observations occurred at 18 independent locations (the two camera photos were taken within $\sim$400 m of each other in April of 1999, and therefore assessed as a single location). Notably, because 14 of the observations were physical captures (the source for trophies observed in some houses, Figure 2), this provided a high degree of reliability regarding the local identification of the species. Two of the points had multiple observations over time—see below.

Although exact dates were not available, Saola were observed or captured in every month except October and December. Months with the most observations included February, May, June, August, and September (three observations each). There was no significant difference between dry and rainy seasons in terms of frequency of captures (chi-square = 2.09, $p = .14$). There was no obvious seasonal bias as people hunt both during the dry and the rainy season. However, people were less likely to venture into the forest during some months of both seasons, for example, October to November is the rice harvest season and June to July is the time for seedling preparation prior to planting rice. The highest number of Saola captures was in 2008, and the most recent Saola sightings were in 2013 (Figure 4). Saola observations were at elevations ranging from 592 to 1,112 m ($Mdn = 747$ m). There was a significant difference in elevation of observations between seasons (Mann–Whitney U = 23.5, $p = .038$). The median elevation of the dry season (November–May) observations was 716 m ($n = 716$ m), while the median elevation of wet season observations (June–October) was 1,024 m ($n = 1{,}024$); however, we did not have measures of search effort and search areas by local people in the different months of the year.

Although our data were coarse in space and time, there was no clear correlation between frequency of human use in a given area and number of Saola observations (no human-use data were available for the area containing three observations >25 km east of PST). From the areas with the most relative human use, we obtained only two Saola observations; from the areas with the least amount of use, there was one observation (Figure 3). The remaining 16 observations were from areas in or near PST that received modest human use, although this area apparently received more intensive use prior to the official establishment of PST. The areas with the most human use were mostly below 1,074 m elevation ($Mdn = 731$ m). Eleven of the Saola captures occurred within what is now the boundaries of PST at a median distance of 8.5 km from the nearest village. In areas of human use, secondary forest covered roughly 35% of the area (372/1,061 $km^2$), and 56% (599/1,061 $km^2$) was primary forest. The relative availability of forest types versus observations of Saola (19 of 22 observations were in primary forest) suggested that there were significantly more observations of Saola in primary forest than expected by chance (chi-square = 7.01, $p = .008$).

**Table 1.** List of 22 Saola Records in Reverse Chronological Order by Village Based on Interviews and From Field Measurements Adjacent to Five Villages in and Around Phou Sithon Endangered Species Conservation Area.

| No. of point | Observation | Date | Village | Name of place | Trail | Capture method | Elevation | Forest type |
|---|---|---|---|---|---|---|---|---|
| 1 | Caught[a] | 2010/August | Phonngam | H. Toum | On animal trail | Snare | 718 | LED |
| 2 | Caught | 2010/February | Khamkouna | H. Juean | On animal trail | Snare | 962 | MED with MB |
| 3 | Caught | 2010/January–February | Phonngam | N. Kan | On animal trail | Snare | 749 | LED with MB |
| 4 | Caught | 2009/June | Khamkouna | H. Juean | On animal trail | Snare | 962 | MED with MB |
| 5 | Caught | 2008/August | Khamkouna | P. kanseng | On animal trail | Snare | 1086 | MED with MB |
| 6 | Caught | 2008/August | Khamkouna | P. kanseng | On animal trail | Snare | 1086 | MED with MB |
| 7 | Caught | 2008/June–July | Khamkouna | P. kanseng | On animal trail | Snare | 1112 | MED with MB |
| 8 | Caught | 2008/May–June | Khamkouna | H. Namkhaopoun | On animal trail | Snare | 744 | LED |
| 9 | Caught | 2008/April–May | Khamkouna | P. kanseng | On animal trail | Snare | 1089 | MED with MB |
| 10 | Caught | 2007/NA | Khamkouna | H. Juean | On animal trail | Snare | 962 | MED with MB |
| 11 | Caught | 2003/January | Phonngam | H. Tan | On animal trail | Gun | 689 | LSG with MB |
| 12 | Caught | 2002/November | Phonngam | H.Tuen | On animal trail | Snare | 716 | LSG with MB |
| 13 | Caught | 1997/March | Vangban | H. Tar | Off trail | Dog | 592 | LED |
| 14 | Caught | 1996/February | Phonngam | H.Tuen | On animal trail | Gun | 671 | LED with MB |
| 15 | Seen | 2013/September | Sopkhone | H. Pong | On animal trail | – | 699 | LED with MB |
| 16 | Seen | 2013/August–September | Phonngam | N. Kan | On animal trail | – | 705 | LED with MB |
| 17 | Seen | 2013/April–May | Phondou | H. Kamung | Off trail | – | 768 | LED with MB |
| 18 | Seen | 2012/February | Phonngam | H. Madang | On animal trail | – | 816 | MED with MB |
| 19 | Seen | 2003/January | Phonngam | H. Tuen | Off trail | – | 681 | LSG with MB |
| 20 | Seen | 2002/September | Phonngam | H. Tan | On animal trail | – | 1102 | MED |
| 21 | Photo | 1999/April | Vangban | N/A | Off trail | Camera | 657 | LED |
| 22 | Photo | 1999/April | Vangban | N/A | Off trail | Camera | 623 | LED |
| Minimum | | 1996 | | | | | 592 | |
| Maximum | | 2013 | | | | | 1112 | |
| Median/Mode | Caught | 2008 | | | On animal trail | Snare | 746.5 | MED with MB |

*Note*: N/A = not available.
LED is mixed evergreen or deciduous within an elevation range of 500–800 m; LSG is secondary growth within an elevation of 500–800 m; MED is mixed evergreen or deciduous within an elevation of 800—1,200 m; and MB is mixed bamboo forest.
H is “houay” in the Lao language which means stream, N is “nam” meaning river, and P refers to “phu” which means mount (mountain).
[a]This animal was captured alive and photographed.

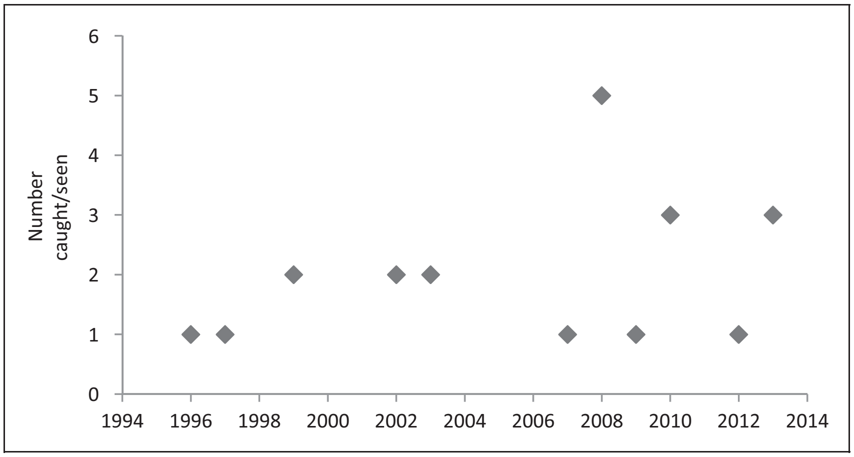


**Figure 4.** Number of Saola observations per year based on this study. The highest number of Saola records coincide to when roads started to be constructed through the area in 2008. The most recent sightings were in 2013 (three sightings) in and around Phou Sithon Endangered Species Conservation Area.

Based on our observations obtained while conducting habitat measurements at the Saola observation points, we found four mineral licks within 11.3 radius of four Saola observations and interviewees reported another three mineral licks in the human-use areas (1,120 m from the closest Saola observation; Figure 3).

## Habitat Associations

Most Saola observations were from captures in snares set on trails or visual observations on trails (17 observations). For other topographic factors, the median slope at the Saola observation points and camera traps was 23° and 29.5°, and the median elevation was 731 and 844 m, respectively. Saola observation points were typically $<$10 m from a stream (13 of 18 locations).

*Microhabitat characteristics.* Ginger cover, grass cover, trees with a DBH $>$ 10 cm, stems with DBH $>$ 1 cm with heights 0 to 1 m, and $>$ 2 m were significantly higher at Soala observation points while canopy height was significantly lower compared with camera-trap points (see Table 2, Figure 5). The other nine variables compared were not significantly different (Table 2, Figure 5).

*Macrohabitat of Saola.* A set of four infinitely weighted logistic regression models were generated to explain the probability of Saola presence. The best fitting model (lowest AICc [Akaike's Information Criterion modified for small sample sizes] and highest AICc weight) included only abundance of streams. The estimated coefficient for abundance of streams was $0.95 \pm SE$ 0.16 (95% CI [0.64, 1.26]), indicating higher probability of Saola presence at higher abundance of streams. Stream abundance was correlated with elevation, thus we did not put them together in the same regression analysis. The other three models included the null model, elevation, and distance to nearest village, the AICc of each of these models was larger than 30 compared with the streams model (Table 3).

We overlaid the distribution of the Saola observation points on a topographic map with 50 m elevation contours and village locations to clarify visually the Saola observation points and macrohabitat features (Figure 6 and Figure 7).

# Discussion

This study is the first quantitative analysis describing the habitat use of Saola. The Saola observations we compiled represent 18 independent locations, a remarkably valuable dataset for this extremely rare animal. Although there was ample evidence that our informants could unambiguously identify Saola, our data could not precisely address the relative movement of these people through the forest. However, our data did indicate that areas with the greatest human use had few detections suggesting that Saola were observed farther from villages or human-use areas than expected, and although distance to village was not supported in our regression model, human use was almost certainly higher nearer the villages. The reasons for why Saola were observed in these areas away from the villages were not apparent based on the variables we measured.

Our habitat model indicated that there was no significant association between Saola and elevation (range of observations 592–1,112 m vs. 440–1,200 m of available habitat); a recent summary report suggested that the Saola were a mid-elevation species occurring mostly between 500 and 800 m (Timmins et al., 2016). However, earlier observations from local people indicated

**Table 2.** A Comparison of Habitat Variables Between Locations Where Local People Observed Saola and Camera-Trapping Locations in and Around the Phou Sithon Endangered Species Conservation Area in the Northern Annamites, Laos PDR. Mann–Whitney Tests Were Used to Compare Between Location Types.

| Variables | Unit | Saola observations ($N = 18$) | | Camera-trapping locations ($N = 26$) | | Mann–Whitney tests ($p$) |
|---|---|---|---|---|---|---|
| | | *Mdn* | *SD* | *Mdn* | *SD* | |
| Canopy height | meters | 27 | 6 | 40 | 13 | .0001* |
| Canopy cover | % cover | 83.3 | 11 | 84.5 | 9 | .19 |
| Ground cover | % cover | 76.7 | 11 | 85 | 9 | .095 |
| Fern | % cover | 6.5 | 7 | 7.5 | 10 | .27 |
| Ginger | % cover | 2.4 | 3 | 0 | 1 | .0003* |
| Grass | % cover | 0.1 | 7 | 0 | 0.3 | .001* |
| *Schistomaglottis* sp. | % cover | 0 | 11 | 0 | 2 | .1 |
| Banana | number | 2.1 | 4 | 0.6 | 2 | .006 |
| Bamboo | number | 12.6 | 12 | 5 | 4 | .004 |
| Rattan | number | 2.8 | 2 | 3 | 3 | .39 |
| Palm | number | 0.4 | 1 | 1 | 3 | .21 |
| Tree DBH > 10 cm | number | 41.2 | 14 | 22 | 9 | .0001* |
| Stem DBH > 1 cm with height 0–1 m | number | 27.9 | 12 | 11.5 | 7 | .0001* |
| Stem DBH > 1 cm with height 1–2 m | number | 13 | 4 | 9.5 | 4 | .039 |
| Tree DBH > 1 cm with height > 2 m | number | 19.2 | 7 | 11.5 | 5 | .0001* |

*Note*: DBH = diameter breast height.
*Experiment-wise significant difference was adjusted to $p < .0034$.

Saola occurred from 500 to 1,400 m (Schaller & Rabinowitz, 1995). Overall, most of the forest below 400 m within the Saola's restricted range in the Annamites of Laos and Vietnam has been lost to human-dominated habitats and thus a high proportion of the remaining forest is over 600 m. In our study, the community mapping data suggested our informants were more likely to utilize lower elevations rather than upper and the relative availability of higher elevation habitats (>1,200 m) was low (7% of PST's land area). It is therefore quite possible the lack of observations above 1,200 m was because local people rarely hunt or gather in such habitat. Thus, more surveys above 1,200 m are likely warranted, especially if hunting pressure is somewhat lower at higher elevations.

Although there has been speculation that Saola move in response to seasonal changes (Robichaud & Timmins, 2004; Timmins et al., 2008), our limited data suggested no seasonality in the frequency of observations; however, there was a significant difference in the elevations of sightings between seasons, with observations being significantly higher during the wet season than dry. There is no clear ecological reason as to why Saola would make seasonal movements in the moderately seasonal climate of its known range which also has relatively modest differences in elevation such as in PST. It is also possible that differences in elevation with season were related to seasonal differences in travel patterns of local people; our anecdotal data suggest that local people access the forest along higher ridgetops during the wet season and along streams at lower elevations during the dry season which would at least partly account for the seasonal differences in the elevations of observed animals.

Given our small dataset, it was not surprising that there was no statistically significant trend in the number of Saola observed through time, although given its status as Critically Endangered, there was no apparent decline either. There were five captures of Saola in 2008 the most of any year in the memory of the local communities. Five qualified people in two villages (Phonngam and Khamkouna, Figure 1) mentioned that 2008 corresponded with the initiation of major road construction in the area and that some community members sold wildlife to construction workers at highly inflated prices, giving them an extra incentive to hunt during this period.

## Habitat Associations

*Microhabitat characteristics.* Our results suggest that the Saola were more likely to be detected in primary forest with a higher density of trees (Figure 6), but they appear also to occur at least occasionally in secondary growth (17% of the observation points); this is also consistent with previous early assessments (Schaller & Rabinowitz, 1995). Only three of 22 Saola observations were in secondary forest. Some have also speculated that the preferred food plant

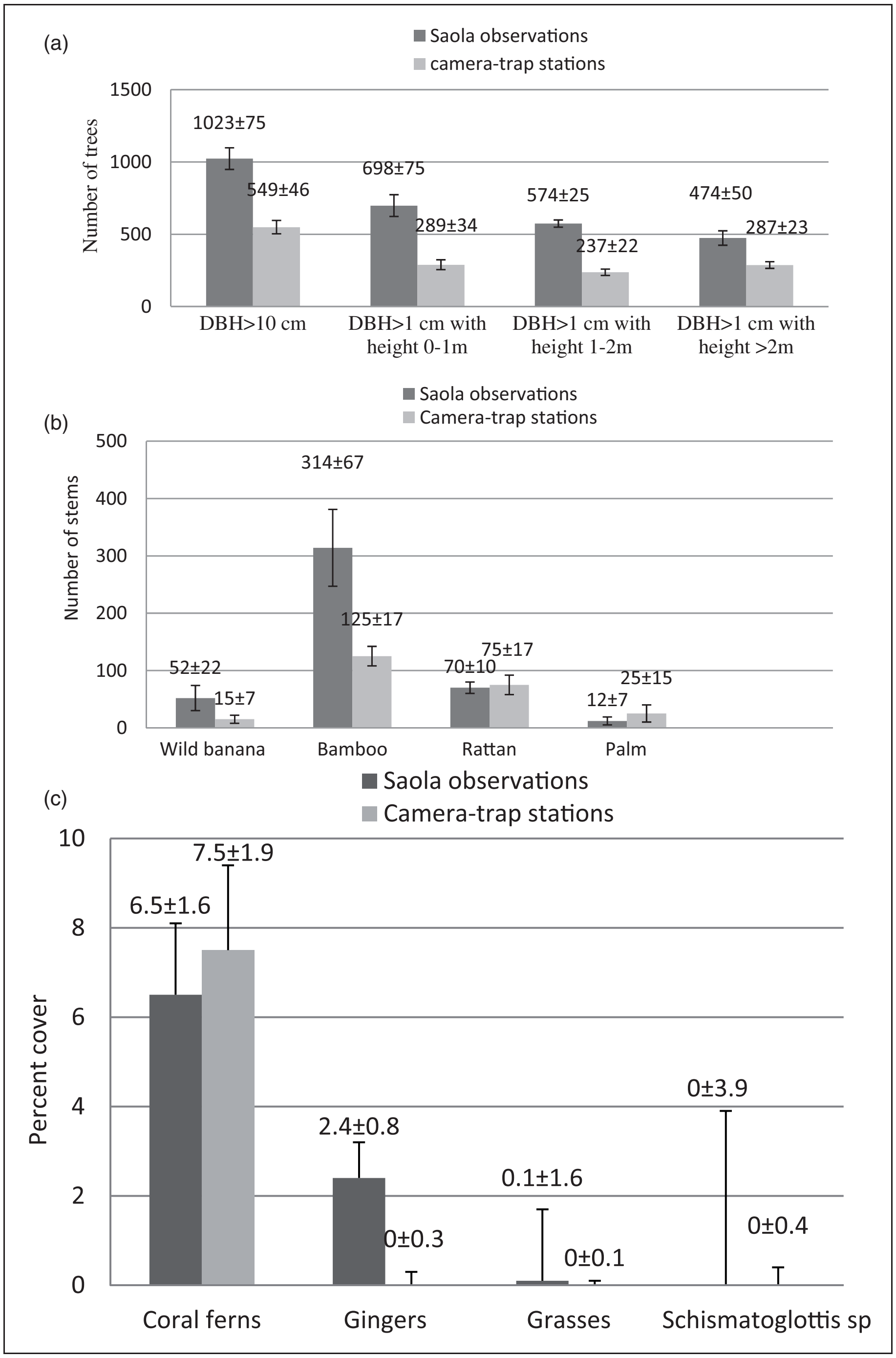


**Figure 5.** (a) Median (± standard error) density of trees and other vegetation per hectare at Saola observation points and randomly selected camera-trap stations, including number of trees of a diameter breast height (DBH) greater than 10 cm and density of stems with DBH greater than 1 cm in three height categories: 0 to1 m, 1 to 2 m, and >2 m based on 11.3 m radius plots; (b) stem density per hectare of four potential indicator species wild banana, bamboo, rattan, and palms (11.3 m radius plots); and (c) percent ground cover of three indicator species groups: coral ferns, gingers, grasses, and Schismatoglottis sp. (genus Araceae)..

*Schismatoglottis cochinchinensis,* which grows mostly along streams may affect the Saola's distribution (Robichaud & Timmins, 2004). However, in PST, *S. cochinchinensis* was scarce, and there was no significant difference in the cover of this plant between the Saola observation points and the available vegetation points, although our cameras used as reference locations were not placed randomly. Systematic vegetation sampling of PST and other potential Saola sites would undoubtedly be useful for future habitat assessments of Saola and other threatened species in the Annamites.

**Table 3.** Results of Infinitely Weighted Logistic Regression Models Explaining the Probability of Presence of Saola in the Phou Sithon Endangered Species Conservation Area.

| Model | *K* | ΔAICc | AICcWt |
|---|---|---|---|
| Abundance of streams | 2 | 0 | 1 |
| Null model | 1 | 31.49 | 0 |
| Elevation | 2 | 31.82 | 0 |
| Distance to nearest village | 2 | 33.02 | 0 |

*Note*. *K* is the number of parameters in the model; ΔAICc is the difference in AICc (model score) value from the top model; AICcWt indicates Akaike model weights.

*Macrohabitat of Saola.* Our best fitting regression models did suggest that a higher abundance of streams was associated with more detections of Saola. It is possible that such areas are associated with preferred food plants; however, streams were also associated with human travel routes, and stream abundance was also negatively correlated with elevation.

Four of the 18 locations were also close to known mineral licks (within 11.3 m radius). The first Saola photograph in the wild was also taken in the vicinity of a mineral lick in Vietnam (Whitfield, 1998), although our data did suggest that Saola were at least sometimes associated with licks (Figure 3), we were unable to conduct

**Figure 6.** Example habitat at Saola observation points in primary forest in the Phou Sithon Endangered Species Conservation Area.

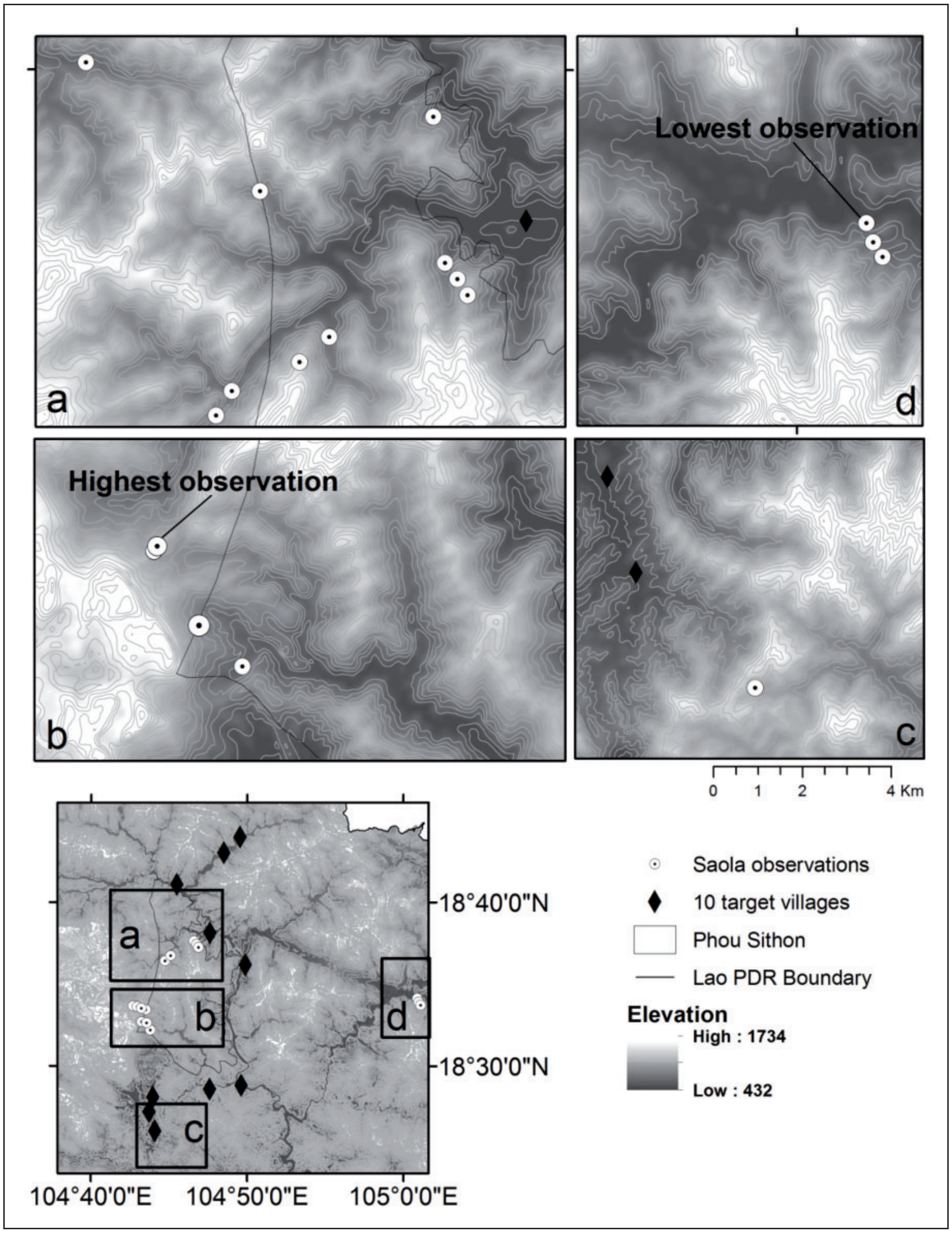


**Figure 7.** Distribution of Saola observation points during the period 1996 to 2013 overlaid on a 50 m contour map classified by WCS Laos, 2002. Lighter areas indicate higher elevations. The maximum elevation in PST is 1,700 m and lowest 600 m. The three observation points approximately 25 km east of PST had the lowest elevations for Saola observations (592 m). The highest Saola observation occurred at 1,112 m. For the entire mapped area, the highest elevation is 1734 m, and 432 m is the lowest. One point, in (b) was associated with three separate Saola captures in 2007, 2009, and 2010 (the largest white circle) and 1.4 km to the north of these points, another area was associated with one point with two independent captures in August of 2008 and two other captures (the medium-sized white circle).

comprehensive mapping of mineral licks due to logistical constraints.

*Other relevant observations and recommendations.* Most observations occurred on animal trails (17 of 18 locations). This is potentially an important finding. This suggested Saola used thin animal trails in particular (not human trails), similar to other species such as Wild pig, Muntjacs, and Serow. Saola were caught by snares, while this means that trails are targeted for snaring by people, and although the Saola are not a target species because it is extremely rare and there is no local or international market for it (SWG, 2009, 2012), Saola use trails and get caught. Only one capture included the use of dogs. It is commonly believed that Saola are easily caught by dogs (Robichaud & Timmins, 2004). However, people do not use dogs extensively around PST.

Three independent Saola observations from 2013 suggest the species might persist at very low densities in PST. Our findings, though confounded to a degree by variation in local survey effort, offer important insights into where any remaining Saola are most likely to occur in PST and elsewhere in the Saola range. Based on the results of this study, upcoming camera-trapping surveys should focus on primary forest as far away from human-use areas as possible. Also, more attention needs to be paid to sites above 1,200 m as they probably receive less human use, and Schaller and Rabinowitz (1995) suggested Saola were recorded at elevations of at least 1,400 m. Mineral licks should be further investigated as well. By limiting Saola observations only to those local people who demonstrated reliable identification of the species, we were confident that the observations used were from those people who were familiar with Saola and could identify it with certainty. Although our study relied solely on local observations, and local people do not necessarily use all habitat types in proportion to their availability in the landscape, we did attempt to at least roughly quantify human use relative to the number of Saola observations.

## Implications for Conservation

Based on interviews, poachers still enter PST illegally thus increased patrolling by protected area staff should be considered, focusing on hunters, particularly professional hunters (Schaller & Rabinowitz, 1995). Although Laos has banned snaring within its protected areas since 1994, snaring continues to be a serious threat to wildlife in the country (Timmins et al., 2016). Hunting regulations must be enforced not just focusing on local villagers and hunters but also construction workers as we suggest here. Raising awareness should also continue, focusing on local people living adjacent to PST emphasizing the value of sustainable management of wildlife. Finally, snare removal in priority Saola sites should be intensified (SWG, 2013) as snares are probably the main threat to Saola (Timmins et al., 2016).

In addition, the very limited knowledge about the species' ranging behavior and foraging ecology remains perhaps the greatest conservation constraint, thus obtaining additional Saola observations in PST and other priority areas should be an immediate focus. The proposed extension area on the western side of PST should be established to protect wildlife and to increase wildlife populations and survival rates of the species like Saola. We also urgently recommend that field data collection (Saola observation points) be incorporated more widely in Saola priority areas in both Laos and Vietnam. Information on likely locations where to search for Saola (as well as confirmed locations) in both Laos and Vietnam along the Annamites need to be rapidly shared in close collaboration to enhance understanding of Saola and their use of habitat. Presumably, the size of the remaining Saola population is extremely small, thus finding remaining individuals is the highest priority.

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