Effective Implementation of Payments for Environmental Services in Lao PDR

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MODELLING THE EFFECTS OF ANTI-POACHING PATROLS ON WILDLIFE DIVERSITY IN THE PHOU CHOMVOY PROVICINAL PROTECTED AREA

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Eric J. Hay[a], Marit Kragt[a], Michael Renton[b], Chanthavy Vongkhamheng[c]

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[a] School of Agricultural and Resource Economics, University of Western Australia
[b] School of Plant Biology, University of Western Australia
[c] Lao Wildlife Conservation Association (Lao WCA)

Abstract

Worldwide, wildlife poaching results in significant losses to biodiversity, especially for those species which are most vulnerable and at risk of extinction. Strategies exist for reducing poaching pressure, including anti-poaching patrols that collect and remove wire snares. Studies are available that focus on the impact of poaching. Yet, not much work evaluates the effectiveness of poaching mitigation actions. We outline a modelling methodology that aims to predict the effectiveness of different management strategies on the poaching problem in the Phou Chomvoy Provincial Protected Area, Bolikhamxay Province, Lao PDR. Wildlife management in the study involves the local community through villager-led anti-poaching patrols. The goal is to develop a quantified relationship between patrol inputs and biodiversity outcomes. The results show that, without patrols, 18 out of the 19 species investigated would be poached and removed from the protected area over the next ten years. At low levels of patrol-effort ten species would survive. With increasing patrol effort, the total number of animals and species saved increase, but with diminishing marginal effect on species count improvement. At the highest patrol-effort management scenario modelled, all species are saved except for one; the Northern Pig-Tailed Macaque, which goes extinct under all management scenarios. This is the first time modelling has been undertaken at this scale to examine poacher-patrol interaction in the Southeast Asia region. Our work shows a positive effect of patrol effort on the number of endangered species saved. This work will be used to inform protected area management policy in Lao PDR, specifically, the development of Payment for Environmental Services schemes.

Key words: Anti-poaching Patrols; Biodiversity; Bio-physical Modelling; Payment for Environmental Services; Protected Area Management

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1. Introduction

This research report develops an ‘environmental production function’ that quantifies the relationship between anti-poaching patrol effort and biodiversity outcomes through species population modelling within the Phou Chomvoy Provincial Protected Area (PCV PPA). The ‘environmental production function’ will be an integral component of a pilot Payment for Environmental Services (PES) scheme that is being developed within the project ‘Effective Implementation of PES in Lao PDR’ (henceforth called ‘PES project’). It will be used to convert inputs (anti-poaching patrols) into outputs (biodiversity outcomes). This conversion is required to link environmental services supply and demand within the pilot PES scheme.

This report not only provides an ‘environmental production function’ for the pilot PES scheme but also a modelling framework that can be used to inform future PES schemes focused on biodiversity protection that may be developed and implemented in Lao PDR. The model development was conducted partly as the Honours Project of Mr. Eric Hay at the University of Western Australia. This report draws on Research Report 8: Phou Chomvoy Provincial Protected Area: A Biodiversity Baseline Assessment (Vongkhamheng 2015) and Research Report 9: Providing incentives for biodiversity protection: anti-poaching patrolling in the Phou Chomvoy Provincial Protected Area (Scheufele et al. 2016). Research Report 8 provided the results of a wildlife baseline survey, while Research Report 9 provided an overview of the wildlife protection scheme based on community engagement and anti-poaching patrols.

2. Background to the issue

Poaching is a global problem that significantly impacts biodiversity through direct removal of target species (Pratt et al., 2004; Steinmetz et al., 2014; Vongkhamheng et al., 2013). Poaching is a biodiversity conservation problem that can have far-reaching ecosystem and environmental health effects (Becker et al., 2013; Robbins et al., 2006). Poaching also has socio-economic impacts such as the reliance observed in some African and Asian communities on poaching as a source of income or as a source of primary consumption (Pratt et al., 2004; Steinmetz et al., 2014).

Poaching is defined as violations of conservation rules, including illegal hunting, resource use, and extraction (Robbins et al., 2006; Conteh et al., 2015). Most poaching methods include baited traps and wire snares that not only catch the target animal but also anything else that may come into contact with the trap as bycatch (Becker et al., 2013). The indiscriminate nature of snare trapping leads to excessive damage to all species occupying targeted areas, exemplified by large ungulates being caught as bycatch of tiger poaching (Vongkhamheng et al., 2013). Furthermore, removal of key species, or those which provide top-down control such as tigers and other apex predators, has widespread effects on the entire ecosystem (Burkholder et al., 2013; Colman et al., 2014). Complex ecosystem-wide interactions make understanding the poaching problem difficult and finding the most effective solutions to poaching harder still.

The complexity of poaching and the often sensitive nature of poaching management have implications for conservation species and also for local communities that may rely on hunting for food and subsistence (Steinmetz et al., 2014; Pratt et al., 2004). A major gap in knowledge is the effect of poaching mitigation measures on biodiversity (Steinmetz et al., 2014). This is complicated in the Lao context due to the limited availability of species counts and abundance data (Vongkhamheng et al., 2013). The aim of this research report is to fill this knowledge gap in the presence of deficient data.

Lao PDR is an internationally recognised biodiversity hotspot[1]. Logging and hunting represent the greatest contributors to habitat destruction and loss of animal life (Timmins &

[1] See Appendix 1 for conservation species list.

Vongkhamheng 1996). These activities occur both legally through controlled and subsistence hunting and logging, and illegally through land clearing, degradation and poaching (Timmins & Vongkhamheng 1996; Johnson et al., 2003; Vongkhamhen et al., 2013; Steinmetz et al., 2014). There is little information about the impacts of these activities on threatened and endangered species in Lao PDR. Summarising and comparing what little information exists is difficult because methods for investigating endangered species vary greatly (Vongkhamheng et al., 2013). The problem with past studies is that they lack ecosystem-wide data, focussing on single target areas (Timmins & Vongkhamheng 1996), or are comprised of generalised information from many biodiversity surveys and are thus lacking comprehensive, species-level quantitative data (Johnson et al., 2003). Informing national policy based on conclusions from the currently sparsely available biodiversity studies in Lao PDR is risky because data are not representative for the country as a whole. Furthermore, using general biodiversity data to investigate interactions between poaching and animals at a species level will be difficult. At best the data will contain large variances or errors (Steinmetz et al., 2014). Despite these limitations, our modelling efforts are based on strict assumptions and the best available data from SE Asia, including a baseline survey conducted as part of the PES project (Vongkhamheng 2015).

3. Research objectives

The overall goal of this study is to produce an ‘environmental production function’ that quantifies the relationship between anti-poaching patrol effort and biodiversity outcomes such as the number and population sizes of endangered species. The general effectiveness and direct impacts of anti-poaching patrols are investigated through population modelling. The four objectives of the research presented in this report are to:

1. Identify the target species for conservation efforts (based on a list of target species selected within the PES project);
2. Identify available and appropriate management options to combat poaching (based on the Lao-Australian Wildlife Protection Scheme developed within the PES project);
3. Examine how target species are impacted by poaching;
4. Investigate the link between poaching management options, species numbers and population size; and,
5. Predict the effects of anti-poaching patrols on species number and population sizes.

4. Description of the study site

The Phou Chomvoy Provincial Protected Area (PCV PPA), situated in the Nam Mouane-Nam Gnouang Catchment, is located within Bolikhamxay Province in the central-east of Lao PDR (Figure 1). The PCV PPA is located within the Annamite Ranges, a large mountain formation along the Lao PDR/Vietnamese border (Tizard 1996). Bolikhamxay Province has a forest cover of over 63%. This produces an economic value for the area but is subject to pressures from deforestation and poaching (PCV Management Plan 2010). The forests are home to rare species and vegetation types, which has lead the Lao PDR Government to reserve about 18.5% of the Bolikhamxay Province as Provincial or National Protected Area (PCV Management Plan 2010). Although protected areas are marked by signs along their borders in the forest, and policies define poaching and logging within protected areas as illegal, protected area laws are poorly enforced or not enforced at all (Duckworth et al., 2012). Thus the PCV PPA, located in an area rich in biodiversity and with mixed human use, is a useful case study location to examine the impacts of anti-poaching patrol schemes.

Local subsistence farmers rely on the presence of small animals such as squirrels and birds for a source of meat. However, this is not the main cause of biodiversity loss in the area (Johnson et al., 2003). The removal of species at damaging levels is primarily associated with poaching (Hilborn et al., 2006; Pratt et al., 2004). Poachers target endangered species as they are more valuable. Their value is derived from their rarity but also from their use in traditional food dishes and as medicines in neighbouring countries (Pratt et al., 2004). The Lao locals do not target the same species for food or medicine as poachers, except for rare use of the critically endangered Chinese Pangolin in traditional medicine (Johnson et al., 2003). There is a human-animal conflict in the study area, and these interactions have historically led to losses in biodiversity.

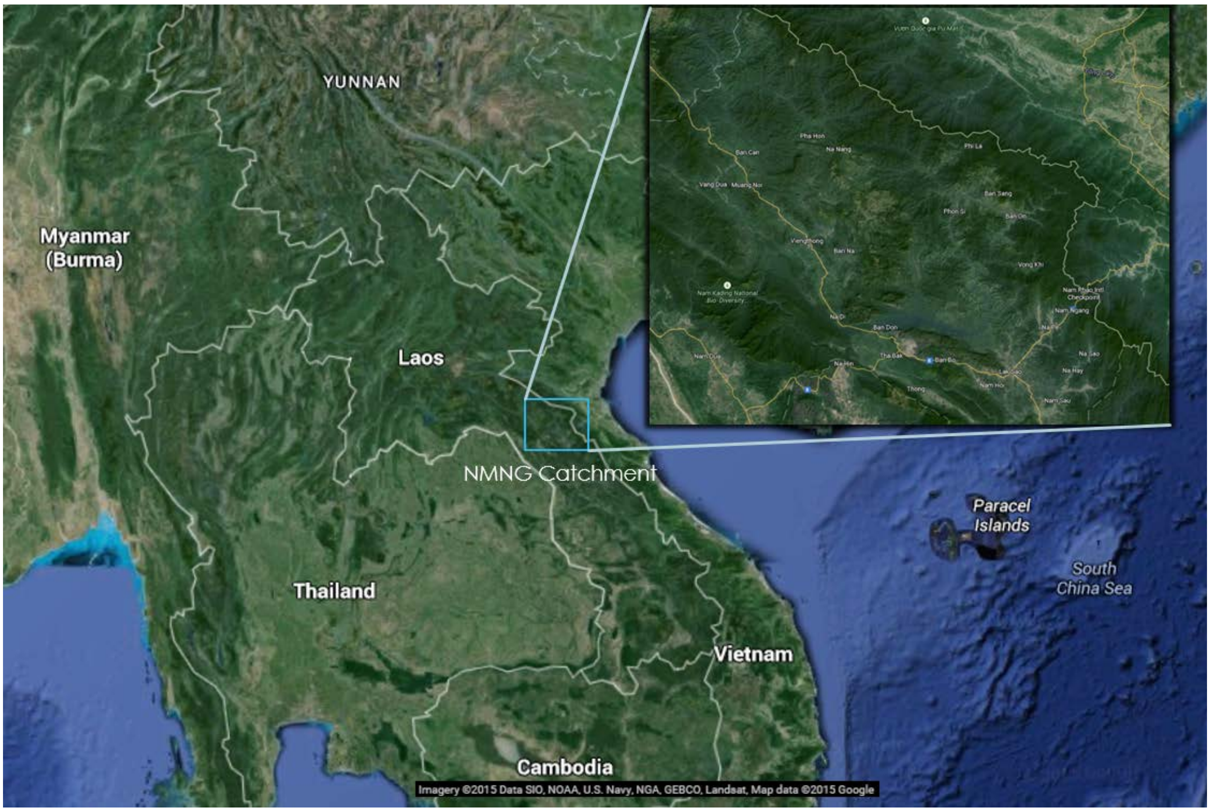

Figure 1. Phou Chomvoy Provincial Protected Area within the wider Nam Mouane-Nam Gnouang catchment, Lao PDR. Images adapted from Google Earth.

5. Poaching in Lao PDR

Poaching is a global problem resulting in declines in the populations of many endangered species (Hilborn et al., 2006; Pratt et al., 2004). Reasons for poaching include poverty, under-management of hunting, ill-defined and defended protection areas, and demand for ingredients in traditional medicines and food dishes (Pratt et al., 2004). The act of illegal hunting via snare traps has the negative effect of indiscriminately harming non-target species as bycatch, and is a severe problem in Lao PDR (Becker et al., 2013; Steinmetz et al., 2014). Studies have shown that conservation efforts and funding for anti-poaching or poaching management have direct and positive impacts on species counts (Hilborn et al., 2006; Johannesen & Skonhoft 2005).

Whether poaching is considered a “problem” depends on which animals are targeted by poachers and whether they are conservation species. In the context of this report, poaching is defined as the illegal removal or killing of conservation-target or endangered species from protected areas. In this, we are more conscious of the conservation status of the target species than under the general poaching definition described in the introduction. It is also important to consider that poachers in our study region use both snares and guns (Johnson et al., 2003) and are likely to shoot other target species when checking traps, to maximise their catch for a given poaching effort.

Involving the local community into the conservation discussion, management planning and anti-poaching patrolling has been largely successful in mitigating poaching globally and in South-East Asia (Johannesen & Skonhoft 2005; Steinmetz et al., 2014). Linking community with their natural wildlife, management and tourism has been successful in Africa, where conservation and development projects provide community-led management efforts and also income for locals (Johannesen & Skonhoft 2005). Within South-East Asia community outreach programs have been shown to reduce poaching pressure by a factor of four (Steinmetz et al., 2014). These findings are indicative of the power of including the local community in formulating and implementing management plans, and the influence that local people have on poaching levels.

Patrols that monitor a given area and remove snares have been shown to discourage poaching (Becker et al., 2013; Vongkhamheng et al., 2013). Anti-poaching patrols, either community-based or conducted by local authorities, aim to remove snares and directly apprehend poachers to promote recovery of biodiversity within controlled areas. The effectiveness of anti-poaching patrols on biodiversity is based on patrolling effort, whereby more patrols covering a wider area will have greater effects then small patrols occurring at a low frequency (Vongkhamheng et al., 2013). However, the direct link between patrol efforts on biodiversity metrics such as species counts and population sizes is still unclear. Further research is needed to quantify that link (Steinmetz et al., 2014).

Quantitative modelling of poaching is still relatively novel, with few studies from before 2014 (Conteh et al., 2015). Studies have shown that poaching is a problem that causes global damage to biodiversity (Hilborn et al., 2006; Pratt et al., 2004), but few have focused on the effectiveness of poaching control and management (Steinmetz et al., 2014). The research presented in this report aims to fill this knowledge gap by analysing the impacts of anti-poaching patrols on species-level count data.

The effectiveness of any conservation effort can be enhanced by acknowledging the wildlife dependencies on for example bush-meat for protein intake of local villagers and communities within the area (Aziz et al., 2013). Both biodiversity conservation goals and the needs of local people need to be considered to ensure the success of a conservation scheme (Aziz et al., 2013). The PES approach is one way to ensure that local villagers receive income from supplying environmental services (in this case through anti-poaching patrols), and that biodiversity is conserved.

6. Target species identification

The investigation of the impacts of poaching and anti-poaching patrols on wildlife populations in the PCV PPA is based on 19 target species selected within the PES project (see Section 1). The selection was made based on:

1. The conservation significance of the species, both globally and nationally.
2. Confirmation from expert opinion and survey data that the species is likely to exist in the study area.
3. The species being targeted by poachers.
4. Being listed in the PCV PPA Management Plan.

Species-level data were required for the model, including initial population estimates and birth rates. Each of the selected species is briefly described below, and initial data (collected through an investigation of the scientific and grey literature and expert consultation) used in the modelling are summarised in Table 1.[2]

Table 1. Initial data for selected species

Species	Initial population	Annual reproduction rate‡	Range (km^2)	Generation length (years)	Data sources
Rufous-necked hornbill	111	2	10	19	IUCN 2016; Jinamoy *et al.*, 2014; Kinnaird & O'Brien 2007; Humphrey & Bain 1990; Tifong *et al.*, 2007; Taylor 2011
Asiatic black bear	114	2	70	6	IUCN 2016; Lindburg & Baragona 2004; Servheen *et al.*, 1999; Stringham 1990; Hwang *et al.*, 2010
Tiger*	1	1	200	7	IUCN 2016; Hebblewhite *et al.*, 2014; Chapron *et al.*, 2008; Simcharoen *et al.*, 2014
Clouded leopard	5	2	35	2	IUCN 2016; Mohamad *et al.*, 2015; Najera *et al.*, 2015
Sambar	223	1	15	2	IUCN 2016; Steinmetz *et al.*, 2010; O'Brien *et al.*, 2003
Southern Serow	15	0.68	5	2.5	IUCN 2016; Ochiai & Susaki 2002; Rivrud *et al.*, 2010; Ochiai & Susaki 2007
Large-antlered muntjac	10	1	70	0.71	IUCN 2016; Timmins *et al.*, 1998; Chapman *et al.*, 1993; Dubost *et al.*, 2011

[2]See Appendix 1 for a full list of globally significant species that are likely to exist within the PCV PPA.

Species	Initial population	Annual reproduction rate‡	Range (km^2)	Generation length (years)	Data sources
Saola	5	1	50	6	IUCN 2016; Therrien *et al.*, 2007; Schaller & Rabinowitz 1995; Kemp *et al.*, 1997
Douc langur	450	1	6	3	IUCN 2016; Bailey 2014; Ruempler 1998; Coudrat et al 2014; Phiapalath *et al.*, 2011
Northern white-cheeked gibbon	33	1.25	0.17	10	IUCN 2016; Fan *et al.* 2015; Eames & Robson 1993; Bach & Rawson 2011; Malone & White 2007; Nature 2014
Sunda pangolin	13	1	0.45	7	IUCN 2016; Zhang *et al.*, 2015; Duckworth et al 1999; Heath & Coulson 1997
Chinese pangolin	2	1.5	8	7	IUCN 2016; Tizard 1996; Heath 1992; Newton *et al.*, 2008; Heath & Coulson 1997; Zhang *et al.*, 2015
Pygmy slow loris	16	1	5	0.58	IUCN 2016; Duckworth 1994; Starr *et al.*, 2011; Zimmermann 1989; Das *et al.*, 2015; Radhakrishna & Singh 2004
Bengal slow loris	111	1	5	0.58	IUCN 2016; Das *et al.*, 2015; Radhakrishna & Singh 2004
Large-spotted civet	5	-2	2	1	IUCN 2016; Mallinson 1973; Lynam *et al.*, 2005; Jennings & Veron 2011; Zhou *et al.*, 2014; Ray 1995
Owston's civet	8	2	2	1	IUCN 2016; Veron *et al.*, 2004; Zhou *et al.*, 2014
Annamite striped rabbit	5	2	0.1	0.115	IUCN 2016; Can *et al.*, 2001; Singleton 1994; Larzul *et al.*, 2014; Haugen 1942
Northern pig-tailed macaque	5	1	1	4	IUCN 2016; Malaivijitnond *et al.*, 2012; Krishna *et al.*, 2006; Albert *et al.*, 2013; Westergaard *et al.*, 1999
Stump-tailed macaque	25	1	1	4	IUCN 2016; Karanth *et al.*, 2010; Krishna *et al.*, 2006; Albert *et al.*, 2013; Westergaard *et al.*, 1999

Notes: ‡ Effective reproduction rate used in the modelling is this annual rate divided by two, assuming half of existing populations are female. The Southern Serow did not have an equal number of males and females for a given breeding group, and thus has an adjusted reproduction rate, scaled accordingly (see species description).

Rufous-necked Hornbill

Aceros nipalensis, also known as the Rufous-necked Hornbill, is a species similar to the charismatic Toucan, with a large beak and colourful body. It is heavily poached in Lao PDR (IUCN 2016). The Hornbill *spp.* is classified as Globally Vulnerable and faces the problems of poaching and deforestation, with land clearing in Lao for plantations and rice paddies leading to reductions in suitable evergreen forest habitat (IUCN 2016). The Rufous-necked Hornbill is already extinct in Nepal. Without conservation effort a similar fate is predicted in Lao PDR (Duckwoth *et al.*, 2012; IUCN 2016). Initial population estimates from experts for the model development are high for the Hornbill *spp.* (at 111) though this does not mean that they are without risk from poaching (Jinamoy *et al.*, 2014; Tifong *et al.*, 2007). The generation length is 19 years, and reproduction within this species occurs very slowly (Taylor 2011; IUCN 2016).

Asiatic Black Bear

Ursus thibetanus, or Black Bear, is classified as Globally Vulnerable, and at risk in Lao PDR due to deforestation and increasing human pressure from the construction of roads and new hydroelectric power plants, along with poaching for its skins, paws and gall bladders (IUCN 2016). Also known as the *Himalayan Black Bear*, this species finds refuge in the thick evergreen forests of Lao PDR, with the PCV PPA providing suitable habitat (IUCN 2016).

Populations are in severe decline in Lao PDR and globally (IUCN 2016). Population estimates for the PCV PPA are high because the environment is an ideal habitat for this Bear species. However, poaching pressure is also high due to the value of the species. (IUCN 2016, Stringham 1990; Servheen *et al.*, 1999).

Tiger

Panthera tigris, or Tiger, is classified as Critically Endangered (IUCN 2016). Its numbers are in global decline (IUCN, 2015; Hebblewhite *et al.*, 2014; Chapron *et al.*, 2008). The forests of Lao PDR provide an excellent habitat. (Chapron *et al.*, 2008). Current population estimates range from 2,000 to 3,000 mature individuals remaining globally, with a decreasing trend (IUCN, 2015). Given the small area of the PCV PPA and the large home range of the Tiger spp, the initial tiger population was modelled as two individuals, so that breeding could occur if both animals survive. Within the model, it is possible that one or both tigers are poached before reproduction can occur, in which case the species will go extinct in the area. Tigers typically have one or two cubs per breeding season, but only breed when conditions are favourable and when sufficient prey exists (Chapron *et al.*, 2008). Given the rich biodiversity of PCV PPA, it is assumed that breeding occurs annually with one cub produced per female for the purposes of this model (Chapron *et al.*, 2008; Simcharoen *et al.*, 2014).

Clouded Leopard

Neofelis nebulosa, or Clouded Leopard, is classified as Globally Vulnerable and is a conservation target for Lao PDR (IUCN 2016). The Leopard spp. is poached for its uniquely-coloured pelt, and is also faced with habitat reduction across its range due to deforestation (IUCN 2016). Only five individuals are included in the PCV PPA model as the Leopard occurs in low densities and has a large home range in SE Asia (Mohamad et al., 2015; IUCN 2016).

Sambar

Rusa unicolor, also known as 'Indian Sambar' or 'Sambar Deer' is classified as Globally Vulnerable (IUCN 2016). Its populations are consistently in decline in recent years across its range (IUCN 2016). Sambar is able to adapt to many types of habitat. Population estimates for the case study area are relatively high, with an initial count of 223 individuals. However the species is relatively easily targeted by poachers due to its high density.(O'Brien et al., 2003; IUCN 2016). The deer is prized for its antlers among trophy hunters (IUCN 2016). The sequential hunting of antler-bearing males leads to female-skewed populations and their eventual demise, even from large initial numbers—as shown in another study of Sambar population recovery following poaching (Steinmetz et al., 2010).

Southern Serow

Capricornis milneedwardsii, or The Southern Serow (also called Chinese Serow) is classified as Vulnerable, and occurs in Lao PDR and surrounding countries (IUCN 2016). The Serow spp. is a conservation target because local populations are being encroached by agricultural clearing and human expansion. Further, the animal is highly valued by locals for its meat and fur and for use in medicines (IUCN 2016). Though the species still occurs throughout Lao PDR, densities are diminishing and the population estimate for the PCV PPA is relatively low; set at 15 individuals (IUCN 2016; Ochiai & Susaki 2002). The Serow has a slow reproductive rate and long generation length relative to other mammals examined. Because no data are available for the Southen Serow, information about the generation length from a study on the Japanese Serow is used (Ochiai & Susaki 2002; Ochiai & Susaki 2007). Given its slow reproductive rate, the species is more susceptible to long-term damage by poaching. Whether the initial population is enough to maintain the species will be tested. For wild breeding populations of the Southern Serow, the ratio of males to females is 1:0.7, and this had to be accounted for when calculating the effective reproduction rate (Ochiai & Susaki 2002).

Large-antlered Muntjac

Muntiacus vuquangensis, or Large-antlered Munjac, is under poaching pressure in Lao PDR with a similar population structure to the Saola or Tiger (IUCN 2016). The Muntjac has not reached the low levels of Saola or Tiger though, but is classified as Endangered by the IUCN (IUCN 2016). It is prized for its antlers, pelt and meat. While not targeted directly by local hunters, it is hunted along with many other more common species (Timmins & Vongkhamheng 1996; IUCN 2016). The population estimate used for the PCV PPA comes from field sightings in Lao PDR (Timmins et al., 1998). Other species information was found by looking at similar species of the same order, because data for the Muntjac spp. are sparse (Chapman et al., 1993; Dubost et al., 2011; IUCN 2016).

Saola

Pseudoryx nghetinhensis, Saola (also called Spindlehorn Bovid) was first observed in 1992 in Vietnam and was found to also occur in Lao PDR in small densities (Schaller & Rabinowitz 1995). It is classified as Critically Endangered (IUCN 2016). In 1995, the population estimate for Lao PDR and Vietnam was a few hundred individuals (Schaller & Rabinowitz 1995). The current estimate for the Lao PDR population is approximately 750 individuals (IUCN 2016). Due to the range of population estimates available, and the fact that there are no scientific studies on the species, it is difficult to estimate the existing population in the case study region. Therefore, initial estimates were based on the size of the suitable habitat in the PCV PPA compared to the total Saola population in Lao. This led to an initial population estimate of five Saola in the PCV PPA. The Saola is rare and easily caught by poachers. Therefore, the population could be less than five individuals. Scientific data for the Saola are lacking, thus the reproduction rate of the white-tailed deer *Odocoileus virginianus* was used instead for modelling, as it is similar in size and assumed to have the same reproductive capacity (Therrien *et al.*, 2007).

Douc Langur

Pygathrix nemaeus, or Red-shanked Douc Langur, is a small primate native to Lao PDR classified as Endangered (IUCN 2016). It is at risk from deforestation and over-exploitation through poaching (Bailey 2014; Coudrat et al 2014). Although it has a large population in Lao PDR, this population is one of the few remaining globally and is therefore important for the conservation of the species (IUCN 2016). The Langur has a smaller reproductive capacity and longer generation length than comparable primates, and is therefore at greater risk from over exploitation (Ruempler 1998).

Northern White-cheeked gibbon

The Northern White-cheeked gibbon, *Nomascus leucogenys*, is deemed locally extinct in China, with only fragments of small populations remaining in Lao PDR (Fan et al., 2015). Human disturbance such as logging and poaching have resulted in its status of Critically Endangered (IUCN 2016). As the Gibbon spp. lives in small family groups of four to five, they are easily identified by poachers who can then capture or kill the whole group (Fan et al. 2015; IUCN 2016). Estimates for remaining wild populations range from singular groups to a maximum of ten observed at a Nature Reserve in Vietnam. Therefore population estimates for modelling in the PCV PPA are conservative (Eames & Robson 1993; Bach & Rawson 2011; IUCN 2016). Based on an area-based comparison of similar protected areas in SE Asia and population density estimates, the initial population used was 33 individuals (Bach & Rawson 2011; Eames & Robson 1993). Approximately eight groups of the gibbon spp. are assumed to reside within the PCV PPA, given that a group generally consists of four individuals (Eames & Robson 1993).

Sunda Pangolin

Manis javanica, or the Sunda Pangolin, is classified as Critically Endangered and is one of the two Pangolin species considered in this research (IUCN 2016). The Pangolin is targeted by poachers for its meat and scales, which are used medicinally in Lao PDR and China (IUCN 2016). With increasing intensity, a decline of more than 80% of historic populations has been experienced. The species is native to Lao PDR and surrounding countries, with losses to populations greatest in northern parts of its range (China and Lao PDR) driven by demand from the illegal wildlife trade (IUCN 2016). The Sunda Pangolin population estimate for the PCV PPA came from a study conducted in Lao PDR (Duckworth et al 1999), while generation length and reproduction rate were sourced from a Chinese study on the species (Zhang et al., 2015). Population density is low for this species, with an estimate of 13 individuals assumed for the PCV PPA (Duckworth et al 1999).

Chinese Pangolin

Manis pentadactyla, or Chinese Pangolin, is classified as Globally Critically Endangered (IUCN 2016). Because they are not migratory, local extinctions are unlikely to be replaced through immigration. This Pangolin spp. prefers forests but has also been found in agricultural pastures, increasing the risk of human-animal interaction (IUCN 2016; Heath 1992). The main causes of decline are poaching and habitat loss (IUCN 2016; Heath 1992; Tizard 1996). The species range extends from southern Lao PDR north into China, and east to Northern India and Nepal (Heath 1992). Sightings are rare in Lao PDR, with only two reports of live sightings in the last ten years (IUCN 2016; Tizard 1996). Global population data don't exist, and due to the small number of recent sightings of the Pangolin spp. the population estimate for modelling was set at two for the PCV PPA. Of the species selected for modelling, the Chinese Pangolin is the only one reported to be used by villagers as medicine (Johnson et al. 2003).

Pygmy Slow Loris

Nycticebus pygmaeus, or Pygmy Slow Loris, is one of two Loris species considered in the model. The species is classified as Vulnerable, and is rarer than the Bengal Slow Loris (IUCN 2016). Population decline is around 30% over three generations (IUCN 2016). The reproduction rate is slow with singular offspring produced annually per breeding couple (Zimmermann 1989, Das et al., 2015). The population estimate for the PCV PPA is 16 individuals, based on a study in Cambodia and subsequent field surveys (Starr et al., 2011; Das et al., 2015).

Bengal Slow Loris

Nycticebus bengalensis, or Bengal Slow Loris, is classified as Vulnerable and is experiencing a population decline similar to the Pygmy spp. due to poaching (IUCN 2016). The population estimate for the Bengal spp. is higher than the Pygmy spp.(IUCN 2016; Radhakrishna & Singh 2004). This species was previously classified as Data Deficient, and due to the paucity of currently available data it is arguably still Data Deficient (IUCN 2016). Data for the generation length was therefore attained from a proxy study on the Slender Loris spp. (Radhakrishna & Singh 2004).

Large-spotted Civet

Viverra megaspila, or the Large-spotted Civet, is classified as Vulnerable. It is only found in SE Asia, specifically Cambodia, China, Lao PDR, Malaysia, Myanmar, Thailand and Vietnam (IUCN 2016). Population fragmentation is a key concern for the Civet as they require predominantly evergreen forest. Ongoing deforestation is leading to enhanced susceptibility to poaching (IUCN 2016). The species prefers habitat below 400m (IUCN 2016). It is therefore likely to be present near low-lying areas within the PCV PPA such as those associated with large water bodies, being topographical low-points. The civet is hunted for its meat for traditional Chinese and Vietnamese medicine, which drives poaching pressure within these countries and in surrounding areas including Lao PDR (IUCN 2016).

Owston's Civet

Chrotogale owstoni, or Owston's Civet, is slightly more common than the Large-spotted Civet, though it is still classified as Vulnerable (Jennings & Veron 2011; IUCN 2016). Facing a similar population decline as the Large-Civet spp. due to habitat fragmentation and poaching, its main differences lie in the restricted range of Owston's Civet (IUCN 2016). The Owston's Civet is restricted to China, Lao PDR and Vietnam (IUCN 2016). This species prefers highland areas with evergreen forest, but has also been observed in lowlands and montane, broadleaf, bamboo and even heavily degraded forest (IUCN 2016; Timmins & Cuong 2011). The broader dispersion of habitat preference may enhance the human-animal conflict faced by the Owston's Civet. Because the species is confirmed to thrive in the Evergreen Forest of the Annamite Mountain Ranges, it is very likely to be found within the PCV PPA (Timmins & Cuong 2011).

Annamite Striped Rabbit

Nesolagus timminsi, or Annamite Striped Rabbit, is the only species considered which is classified as Globally Data Deficient, though most likely fits the Near Threatened or Endangered categories (IUCN 2016). It is only known to occur in Lao PDR and Vietnam, with sightings in the central and northern Annamite Mountain Ranges (IUCN 2016). Brief field sightings are the extent of data on known occurrence of the Rabbit. Population estimates are based on the summary of these data combined with studies showing that the rabbit is less common than the Saola (Can et al., 2001; IUCN 2016). Because no data were available for aspects such as generation length, reproductive capacity or home range size, these were all inferred from other rabbit species (Singleton 1994; Haugen 1942; Larzul et al., 2014). The Annamite rabbit is mainly poached for traditional medicine (IUCN 2016).

Northern Pig-tailed Macaque

Macaca leonine, or the Pigtail Macaque, is classified as Vulnerable (IUICN 2016). The species prefers lowland forests and is affected by land-clearing activities (IUCN 2016). The macaque is highly valuable as a pet which is trained to climb trees and gather coconuts, with well-trained individuals being sold for $1,000 US in markets in Thailand (IUCN 2016). The males of the species in particular are valued for coconut-gathering and their removal can lead to female-skewed populations, and severe impairments to breeding regimes and social structures (IUCN 2016).

Stump-tailed Macaque

Macaca arctoides, or the Stump-tailed or Bear Macaque, is classified as Vulnerable (IUCN 2016). It is severely affected by human activities such as logging, agriculture, and cultivation of lowland crops, as well as being targeted by poachers for traditional medicine and by local villagers and subsistence farmers for its meat (IUCN 2016). The main difference between the Stump-tailed and Northern Macaque species are their uses and relative abundances within the study area. The Stump-tailed macaque occurs in roughly five times the density of the Northern Pig-tailed macaque, but it is also targeted much more aggressively by poachers and locals (IUCN 2016; Karanth et al., 2010).

Further information about the species and data sources used is provided in Appendix 2.

7. Methods

7.1 Model overview

To investigate how poaching and anti-poaching patrols would impact on the selected conservation species, a simulation model was developed in R. R is a statistical package and programming language that is freely available online (www.r-project.org).

The simulation model runs on a monthly time step. For each month the following processes are simulated:

- Wildlife death from illegal snares
- Wildlife death from illegal direct hunting (shooting, collection, etc.)
- Wildlife maturation and reproduction
- Reductions in number of poachers and/or snares as a result of anti-poaching patrols
- Possible introduction of new poachers and possible movement of poachers and anti-poaching patrols

The model is informed using data specific to the PCV PPA. The generic population model captures the following 'environmental production function':

$$P_{t,i} = f\,(Q, A, P_{0i}, RR_i, Gen_i, Range_i, P_{sn}, P_{sh}, Grp, P_E) \quad (1)$$

where the current population $P_{t,i}$ of species i is a function of information about the PCV PPA area, species-specific information, and patrolling effort and effectiveness $[P_E]$.

Information about the PCV PPA was included in habitat quality $[Q]$ and accessibility to humans $[A]$. To match the proposed patrolling schemes, the PCV PPA area was divided up into 1km^2 grid cells. Habitat quality and accessibility were estimated for each 1km^2 grid cell. Habitat quality values are higher in areas with higher forest density or in/next to cells containing waterbodies. Accessibility is determined by proximity to roads, villages and infrastructure.

Species-specific information consists of the initial population of species i $[P_{0,i}]$, annual reproduction rate $[RR_i]$, generation length $[Gen_i]$, and the movement of a species over a defined range $[Range_i]$. Also included was the probability an animal will be snared if in a grid cell containing snares $[P_{sn}]$, the probability it will be or killed directly (e.g. shot) if in a grid cell containing poachers $[P_{sh}]$, and the typical group size $[Grp]$. Annual reproduction rate, i.e. the annual average offspring per sexually mature female, is used to predict the number of new offspring at each time step. Generation length captures the time in years between the birth of an individual and the time at which it is first sexually mature. Group size represents, where applicable, the size of family groups for a given species; it is set to one if animals typically live individually. Individuals or groups are assigned a range area of the defined size within the PCV PPA area, with a preference for cells with higher habitat quality. They are assumed to move throughout this range area over each month with an equal probability of being in any cell of the range at any time. The range area is fixed for the life of an individual/group. Species dispersal and recruitment beyond area boundaries are assumed to be zero as we are interested in numbers of animals saved within the protected area.

Patrolling effort and effectiveness are introduced in this paragraph and further defined in Section 7.3. Poachers and anti-poaching patrols are assigned to a specific area of a given size within the PCV PPA (i.e. an area throughout which they move). This area may be set to depend on accessibility $[A]$ and/or habitat quality $[Q]$, and to remain fixed, or to change each month. Illegal hunting and poaching in this region occurs by snaring and direct methods such as shooting or collection. Therefore, the model simulates the possibility of a species being snared or shot at each time step (where ‘shooting’ includes being killed directly by poachers in any way). At each time step, poachers set snares in the cells in their area and anti-poaching patrols find and remove snares in their area with a probability $[p_{snarefind}]$. Poachers are assumed to move throughout their range over each month with an equal probability of being in any cell of the range at any time, while anti-poaching patrols are assumed to move throughout their range over 25 days of each month with an equal probability of being in any cell of the range at any time. If poachers come into contact with anti-poaching patrols then poachers are apprehended with a probability $[p_{apprehend}]$. If animals come into contact with poachers then animals are killed with a probability $[P_{sh}]$, and if animals enter a cell with snares then they are killed with a probability $[P_{sn}]$. At each time step, a new team of poachers may enter the area with a probability $[p_{newpoachers}]$ and existing teams of poachers and anti-poaching patrols may move within the area with a probability $[p_{poachermove}]$ and $[p_{patrolmove}]$, respectively.

7.2 Landscape parameterisation

7.2.1 Mapping inputs

The PCV PPA was broken up into grid cells. Dividing the area into grid cells allows for specific attributes to be assigned to each cell, which can govern species and human movements that are critical to modelling over time.

The PCV PPA boundary was first mapped using an image taken from Google Earth and an outline provided in the Phou Chomvoy Provincial Protected Area Management Plan 2011 – 2015, displayed below in Figure 2.

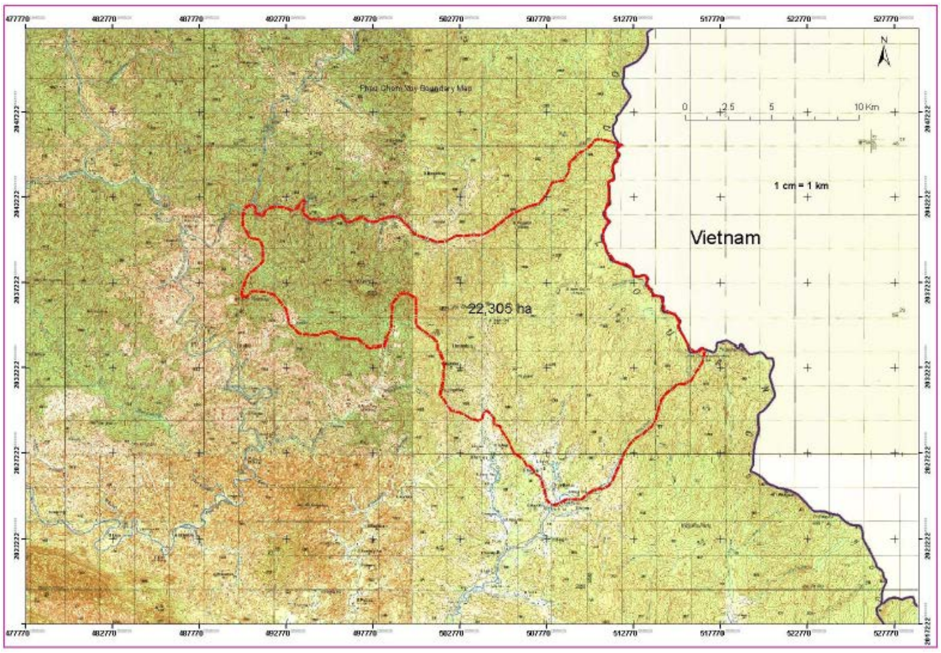

Figure 2: PCV PPA boundary from the Phou Chomvoy Provincial Protected Area Management Plan 2011-2015 (Anon, 2010)

Using the scale from Google Earth (right image, Figure 3), an array of 1km^2 grid cells was overlayed to form the basis of the model. The grid-overlayed map was replicated in Excel, so that each grid cell is represented by one cell in Excel (left image, Figure 3).

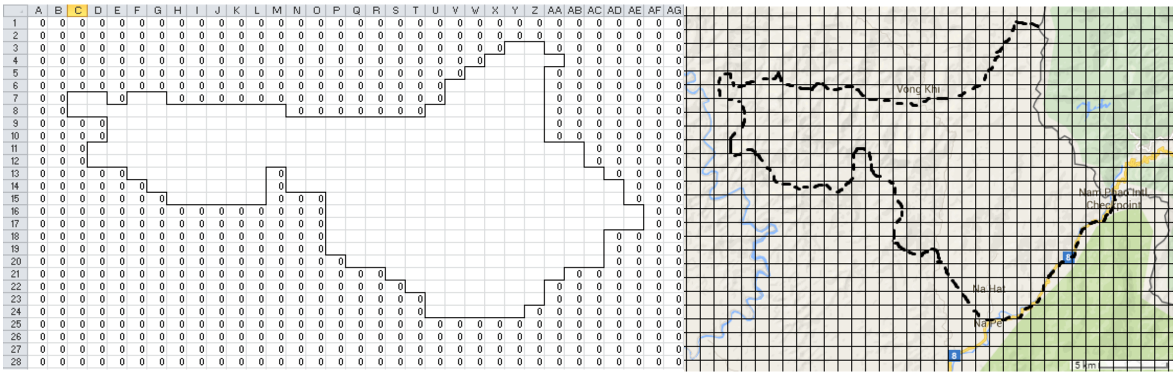

Figure 3. The base map in Excel (left), and its original creation overlay made with a Google Earth image (right).

7.2.2 Accessibility

Google Earth imagery was used to inspect the PCV PPA for roads $[R]$ and villages $[V]$ within and surrounding the PCV PPA. These were plotted within a base boundary map in Excel, for use in R (Figure 4).

Villages were assigned an accessibility value of 1, and roads that of 0.7, as they are relatively accessible but being small dirt roads, they require travel time from any village to get to. The accessibility of the remaining cells was defined using the drop-off function:

$$A = MAX\left\{ {}^{1}/_{(0.1\,mvd + 1)}, {}^{0.7}/_{(0.1\,mrd + 1)} \right\} \qquad (2)$$

Where A is the accessibility value of a cell, mvd is the minimum distance from that cell to a village and mrd is the minimum distance from that cell to a road. The MAX argument means that the maximum of the two values (one based on distance from the nearest village and the other based on distance from the nearest road) is used. This equation ensures that accessibility reduces the further away the cell is from a village or road.

Accessibility can be altered by changing the “accessibility constant” 0.1 in Equation 2. A higher number will lower the overall accessibility drop-off function, while a lower constant will increase the accessibility of the region. Thus, a higher (lower) constant will mean that patrols and poachers are restricted to areas closer to roads or villages (or a wider area).

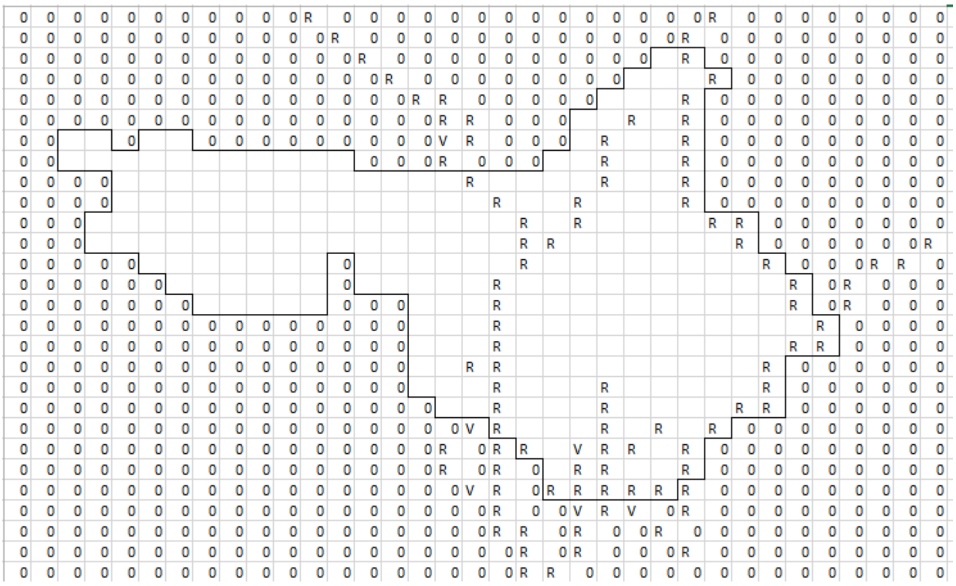

Figure 4. Plotting of roads (R) and villages (V) in Excel within the PCV PPA boundary.

The accessibility map created thus is shown in Figure 5. Roads and villages that lie outside the boundary of the PCV PPA were included in the accessibility calculations so they may still influence accessibility values within the boundaries according to the drop-off function. The accessibility calculations follow the logic of Timmins & Vongkhamheng (1996) that areas further from roads or villages are harder to get to and thus less likely to be targeted by poachers.

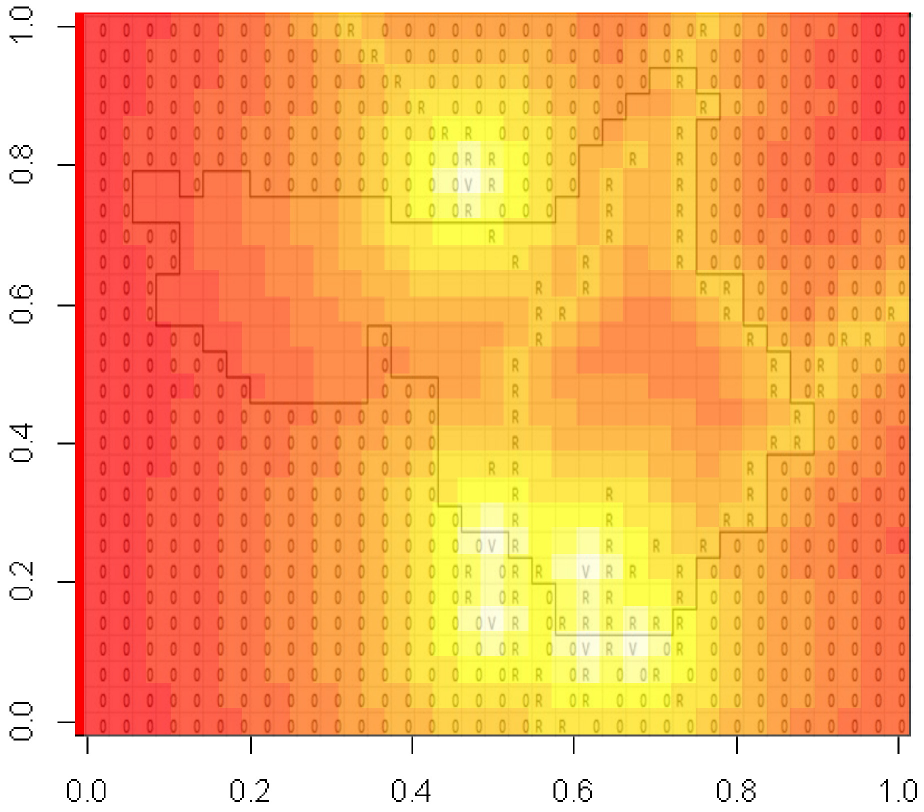

Figure 5. Accessibility map generated in R. The lightest cells (white) represent villages with accessibility of 1; light grey/bright yellow cells are roads with an accessibility of 0.7; darker cells (shades of orange and red) represent limited accessibility.

The image above (Figure 5) shows that accessibility reduces as you move away from villages (white cells) and roads (bright yellow cells), representative of the density of forests in the area. The accessibility input map defines where both poachers and anti-poaching patrols have access. In our analysis, the drop off function (Equation 2) determines—for each individual cell—the likelihood that during an iteration that poachers or patrols will move through that cell. Cells with low accessibility are those far away from villages or roads. These have a low likelihood of being entered by humans, but it is still possible, reflecting the fact that there may be bush tracks in the region that are not captured on any of the input maps used in the model development. The accessibility map was combined with a boundary map to ensure both patrols and poachers are restricted to stay within the protected area boundaries at all times during model simulations. The setup of accessibility values for each grid cell allows modelling of realistic human movement over time, and the allocation of poachers and anti-poaching patrols that are more likely to target or enter areas with a higher accessibility value. The model also allows these assumptions to be changed with relative ease, to study scenarios where poachers and/or patrols move further from roads and villages, or even preferentially target more remote areas.

7.2.3 Habitat quality – Water proximity and forest cover

The habitat quality $[Q]$ for each grid cell is based on two factors: proximity to water and forest cover. More specifically, the habitat quality value of a cell is the sum of the cell's forest cover value and its water proximity value (as defined below). This habitat quality influences which cells are selected when defining an animals home range.

A similar approach to mapping accessibility was used to map the major water bodies within the PCV PPA. Images were used from Google Earth, and a topographical map from the Phou Chomvoy Management Plan which contained detailed small waterways as well as larger water bodies (PCV Management Plan 2010). Water bodies were added to the boundary map in Excel, with a distinction between minor water ways $[m]$ and large water bodies $[w]$ (Figures 6 and 7).

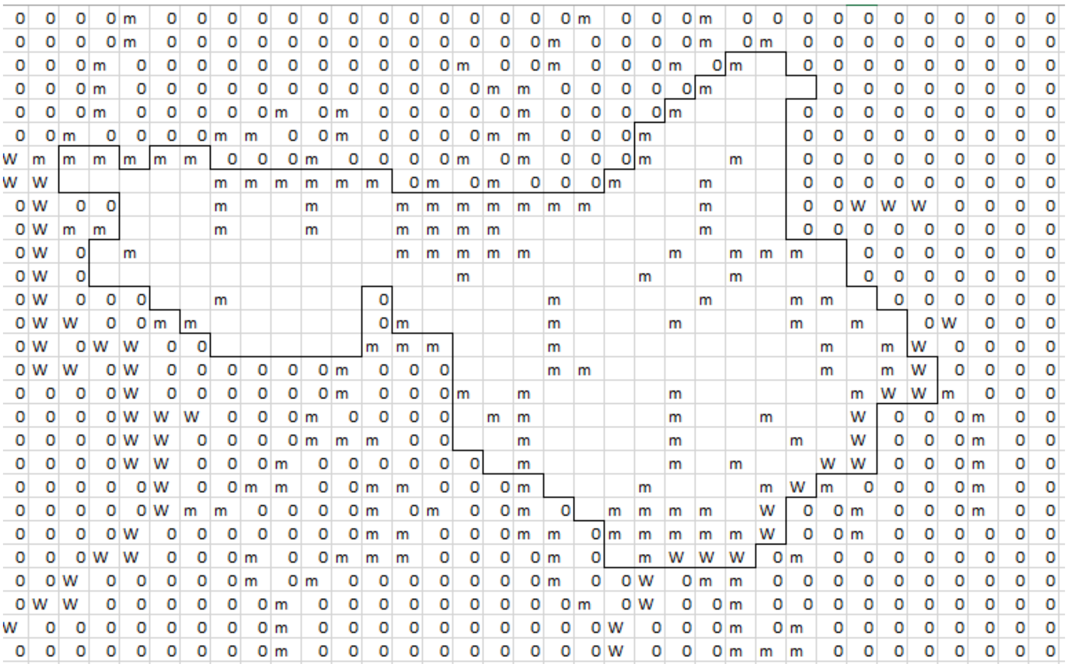

Figure 6. Waterway Excel inputs.

As in the accessibility map, waterways outside the PCV boundary are included for the purpose of habitat quality calculation. This is to ensure that the influence of these waterways inside the study area's boundary is included in the model. The model still limits all interactions and species movement to within the boundary. The impact of water proximity on habitat quality was then estimated for all cells using the drop-off function:

$$W = \text{MAX}\{{}^{1}/_{(0.3\,mwd + 1)}, {}^{0.7}/_{(0.3\,mmd + 1)}\} \qquad (3)$$

where W is the habitat quality of a cell based on water proximity, mwd is the minimum distance of the cell to a major water body, and mmd is the minimum distance of the cell to a minor water body. Figure 6 displays how proximity to waterways impacts habitat quality according to the drop-off function in equation 3. This figure shows that there are many areas near waterbodies, reflecting the excellent habitat quality of the area with ample access to water.

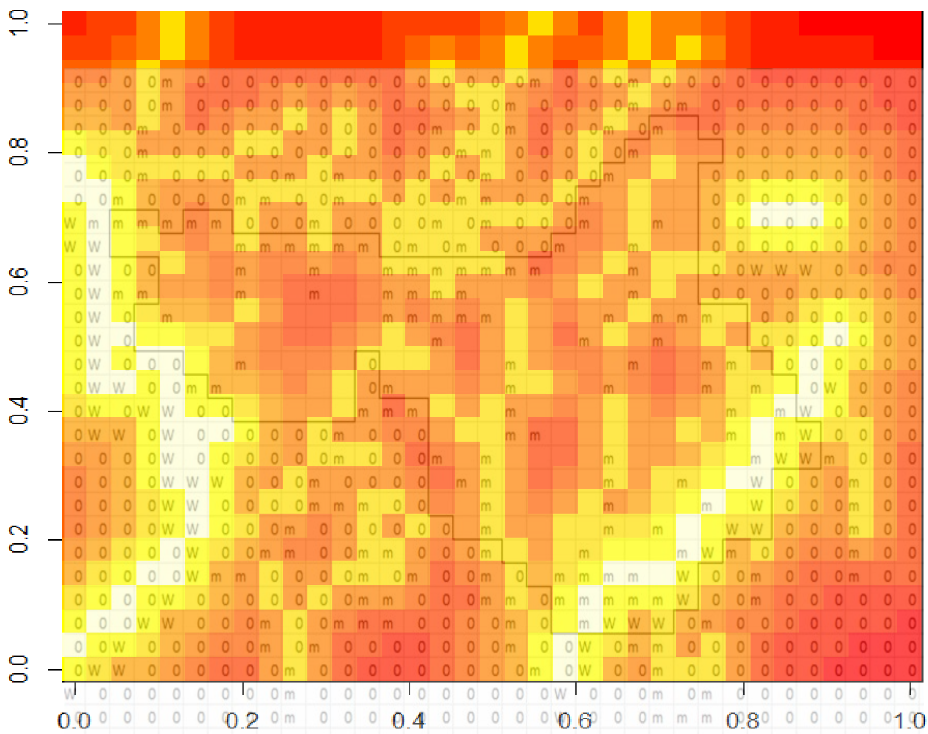

Figure 7. Illustration of the impact of proximity of waterways on habitat quality. The lightest cells (white) cells represent major waterways, while light grey/yellow cells represent minor waterways. The darkest cells (red) cells are far from a waterway and thus have a low habitat quality.

The specification of forest cover involved values being entered manually for each cell. A value of 1 represents 100% forest cover in a cell, which occurs in the majority of the area within the protected area. The accessibility Excel map that already had villages and roads plotted (Figure

4) was used as a starting point. Small roads were assigned values of 0.8 or 0.9 depending on their width, the value being an estimate of forest cover percentage for the particular cell (Figure 8). Villages were mapped at 0 to 0.1 cover. Areas around villages were often significantly cleared, such as cleared fields or cropping areas. These areas were assigned a vegetation cover of 0.2. All observations were made from Google Earth and Google Maps Earth images, by first comparing the village or road position to the base map of PCV PPA with grid cells to find the appropriate cell, then examining surrounding areas to assign values between 0 and 1. Cells of lower forest cover were those immediately surrounding villages, and some next to roads in the south of the protection area where there has been extensive forest clearing for cropping (Figures 8 and 9).

0	0	0	0	0	0	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0	0	0	1	0.9	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0	1	1	1	0.9	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0.8	0	0	0	0	0	1	1	1	0.9	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0.8	0	0	0	1	1	0.9	1	0.9	0	0	0	0	0	0	0	0	0
0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0.1	0.6	0	0	0	1	0.9	1	1	0.9	0	0	0	0	0	0	0	0	0
0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0.8	0	0	0	1	1	0.9	1	1	0.9	0	0	0	0	0	0	0	0	0
0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0.8	1	1	1	1	0.9	1	1	0.9	0	0	0	0	0	0	0	0	0
0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.8	1	1	0.9	1	1	1	0.9	0	0	0	0	0	0	0	0	0
0	0	0	1	1	1	1	1	1	1	1	1	1	0.9	1	1	1	1	1	0.8	1	0.9	1	1	1	1	0.9	0.9	0	0	0	0	0	0	0
0	0	0	1	1	1	1	1	1	1	1	1	0.9	1	1	1	1	1	1	0.8	0.9	1	1	1	1	1	1	0.9	0	0	0	0	0	0	0.9
0	0	0	0	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0.8	1	1	1	1	1	1	1	1	0.9	0	0	0	0.9	0.9	0
0	0	0	0	0	0	1	1	1	1	1	1	0	1	1	1	1	1	0.6	0.9	1	1	1	1	1	1	1	1	1	0.9	0	0.9	0	0	0
0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	1	1	1	0.6	0.9	1	1	1	1	1	1	1	1	1	0.9	0	0.9	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0.5	0.9	1	1	1	1	1	1	1	1	1	1	0.8	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0.5	0.9	1	1	1	1	1	1	1	1	1	0.9	0.9	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0.8	0.5	0.9	1	1	1	1	1	1	1	1	0.9	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0.6	0.6	0.9	1	1	0.8	1	1	1	1	1	0.9	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0.6	0.6	0.9	1	0.7	0.6	1	1	1	1	0.8	0.8	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.7	0.9	0.9	0.6	0.6	1	0.8	1	0.6	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0	0.8	0.9	0.5	0.1	0.5	0.9	0.8	0.8	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0	0.6	0.9	0.9	0.8	0.6	0.6	0.8	0.6	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.6	0.9	0.8	0.8	0.6	0.2	0.2	0.6	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.6	0.8	0.9	0.1	0.2	0.1	0	0.8	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.6	0.6	0	0.6	0	0	0.8	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.6	0	0.6	0	0	0	0.8	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 8. Forest cover Excel inputs.

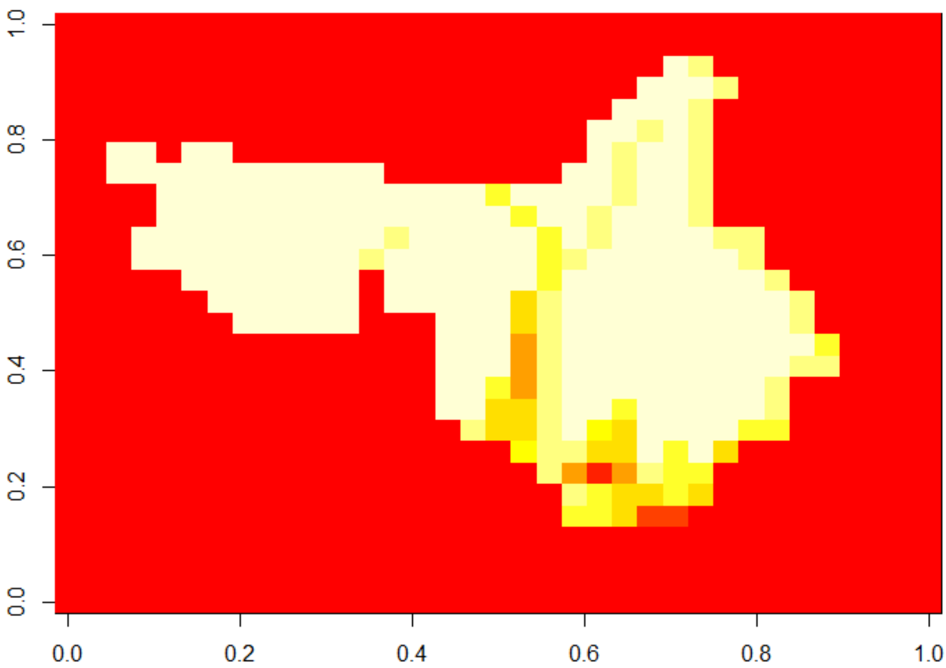

Figure 9. Plot of estimated forest cover. The darkest cells (red) represent zero forest cover or areas outside the PCV PPA boundary. The white cells represent 100% forest cover, with a graded scale of yellow to red (light to dark) as forest cover decreases.

7.3 Representation of human activities

7.3.1 Poacher inputs

The representation of poacher groups within the model is based on the accessibility map and a threshold accessibility value, because snare density is greatest near human infrastructure (i.e. roads, villages, and proximity to crops) (Watson et al., 2013). Poacher groups are assumed to operate only in areas with an accessibility of greater than 0.4. This threshold value is reasonable given the high forest density, with a groundcover of close to 100% and impenetrable bamboo thickets (Tsechalicha et al. 2014). Each poacher group is assumed to target a fixed number of cells (Figure 10). These cells make the poaching 'range' of that group. Targeted cells are selected at random from all cells within the boundary of the PCV PPA protected area, with a weighted probability for each cell equal to the cells accessibility value. The first of these cells is assumed to be the poachers' bases.

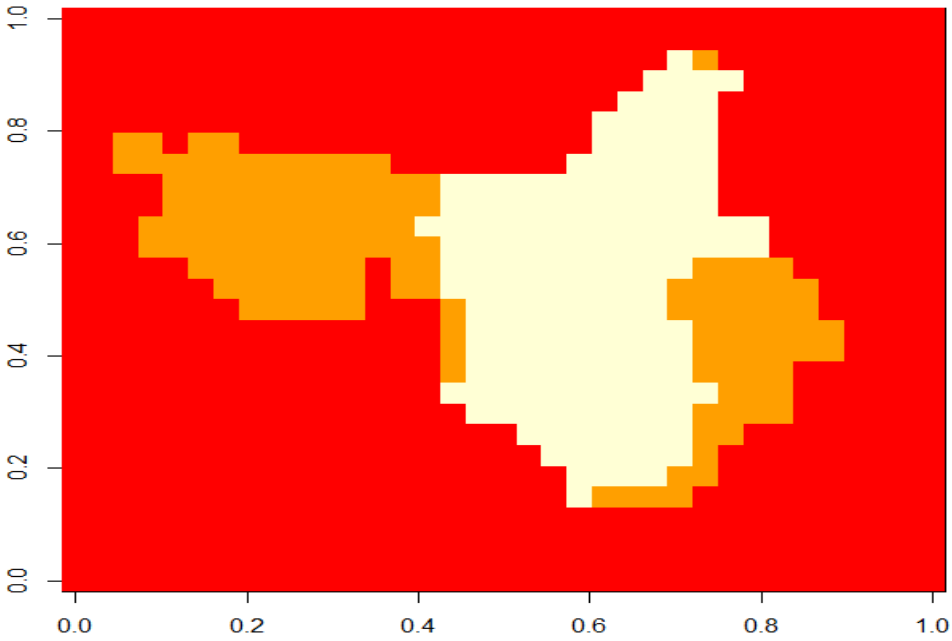

Figure 10. An example of total cells targeted by poacher groups. There are 3 groups of 25 cells.

The poachers are assumed to set a snare line in each cell within their exploited area, with a density of 100 snares per km^2 following field data on snaring methods (Nguyen 2009). While this snare density is not directly used in the model, it informs the likelihood that a species is caught when moving through a cell (snare-ability, *Sh*). There is a certain probability that poachers move their base and exploited areas each month. This movement, if it occurs, can result in new areas being targeted monthly, and is the most realistic simulation of poacher activities possible given current understanding of poaching methods (Becker et al., 2013; Vongkhamheng et al., 2013).

7.3.2 Patrol inputs

Patrols also have a ‘range’, that is, a number of cells within the protected area that they are assumed to move through while conducting anti-poaching patrols. The model allows various options for selecting the cells patrolled, including

- the most accessible cells (those with the highest accessibility value)
- accessible cells (randomly selecting from all cells, with each cell having a weighted probability equal to its accessibility value)
- cells that are suitable for animals (randomly selecting from all cells, with each cell having a weighted probability equal to its habitat quality value)
- purely random (randomly selecting from all cells, with each cell having an equal probability)

The various options allow different general patrolling strategies to be evaluated. The number of cells patrolled per month and the total number of patrol days per month must be specified. Varying the number of cells patrolled per month allows to the evaluation of different levels of total anti-poaching patrol effort. Varying the total number of patrol days per month allows the evaluation of the effect of focusing the patrolling effort over longer or shorter periods. It is assumed that the number of cells patrolled each day is equal to the number of cells patrolled per month, divided by the total number of patrol days per month. If the number of cells patrolled is greater than the total number of cells in the area, then all cells are patrolled once, and the remaining cells selected according to the selection criteria as described above. If the number of cells patrolled is greater than twice (or three times, etc.) the total number of cells in the area, then all cells are patrolled twice (or three times, etc.), and the remaining cells selected according to the selection criteria as described above. The model is designed so that in future specific planned patrolling designs can be specified and evaluated.

The model calculates the probability that an anti-poaching patrol will come into contact with a poacher group on any given day, based on the assumption that both the poacher group and the patrol are equally likely to be in any particular cell within their ‘range’ at any particular time. This is then translated to a probability of an encounter over a full month. If an encounter occurs, then the poachers are apprehended with a specified probability. This can be set low to represent a situation where a patrol has no legal powers of apprehension, or high to represent a situation where a patrol has power to apprehend (includes police or militia). The model also determines whether an anti-poaching patrol finds each existing poacher group base at some time during the month. If the patrol finds a poacher base, then the base is assumed to be removed with another user-specified probability.

Patrols can also find and remove the snares in the cells that they patrol. The probability that a patrol will find and remove the snare line in a cell in which they patrol must be specified. We set the value at 0.6 to reflect that even though snare lines are long, sometimes greater than 100 metres, they will not necessarily be detected every time a patrol enters a cell following expert recommendation and literature confirmation (Becker et al., 2013). Setting this value to less than one allows for the possibility that a patrol will fail to find the snare line within a cell when one is present, and can be varied according to the assumed likelihood of snare detection, which is unlikely to ever be 100% (Becker et al., 2013). It is assumed that if the snare line is found, then all snares within a cell are removed or at least rendered ineffective, otherwise it remains fully effective.

The likelihood of patrols finding cells which are targeted by poachers, snare lines and poacher camps is determined by the model's functional specification. The model predicts the cells which are selected by poachers and patrols based on accessibility of the area. The constraints of accessibility combined with poaching being more likely in areas of high habitat quality H allow for the accurate dynamic prediction of poacher camp locations, and the setting of patrol routes. If selected cells between poachers and patrols overlap, there is a probability that the snares in the cell are removed. If the cell also contains a poacher camp, there is a probability that this camp is removed. The model dynamically predicts poacher movement at a monthly time step, while permitting the alteration of patrol routes, patrol effort and frequency. This movement of patrols and poachers provides greater (and more realistic) predictive power than relying on an area-wide probability for patrols to find snares or camps.

A summary of the parameters related to human activities is presented in Table 2, along with the values which were used in all model scenarios.

Table 2. Human input values.

Parameter	**Value**	**Source**
Number of poacher groups	3	Steinmetz *et al.*, 2014; Vongkhamheng *et al.*, 2013; Johnson *et al.*, 2003
Max number of poacher groups	3	
Poacher group 'range' size	5x5 (25 cells)	Steinmetz *et al.*, 2014; Vongkhamheng *et al.*, 2013; Johnson *et al.*, 2003
Number of months (runs)	120	
Probability of new poacher group replacing those removed (Scenario SC3)	0.3	
Initial snare density per grid cell	100	Nguyen 2009
Total number of cells patrolled	100	
Number of patrol teams	2	
Cells patrolled per day	3	Vongkhamheng *et al.*, 2013
Probability that snares are removed by patrols	0.6 – 0.9	Becker *et al.*, 2013; Personal communication Dr. Vongkhamheng, 2016
Probability of poacher group being apprehended by patrols	0.6 – 0.9	Vongkhamheng *et al.*, 2013; Personal communication Dr. Vongkhamheng, 2016

7.4 Animal species representation

Each species represented in the model is defined by a set of parameter values (Table 3.) Some species are assumed to live and travel in small or family groups, while other species are assumed to live and move individually. At model initialisation, the number of groups of a species is assumed to be its initial population size divided by its group size (rounded to the nearest integer). The cells that make up the range or territory for each animal group (or individual if group size is one) are selected at random from all cells within the protected area at model initialisation. Each cell has a weighted probability of selection equal to the habitat quality of the cell, where the habitat quality is an average of the forest cover score and proximity to water, as described previously. If the range of a species is less or equal to one, then only one cell is selected, otherwise the number of cells selected for a group is equal to its range size.

Table 3. Species-level inputs: snare-ability, shoot-ability, group size (one if not specified), range size (grid cells = km2), initial population, years to reproductive maturity and reproduction rate (surviving young per reproductive female per year).

Species	Snare-ability	Shoot-ability	Group Size	Range	Init. Pop.	Yrs to Maturity	Rep. Rate
Rufous-necked hornbill	0	0.004	5	10	111	19	1
Asiatic black bear	0.008	0.006	1	70	114	6	1
Tiger	0.006	0.002	1	200	2	7	0.5
Clouded leopard	0.004	0.002	1	35	5	2	1
Sambar	0.004	0.008	1	15	223	2	0.5
Southern Serow	0.002	0.008	1	5	15	2.5	0.34
Large-antlered muntjac	0.006	0.008	1	70	10	0.71	0.5
Saola	0.006	0.008	2	50	5	6	0.5
Douc langur	0.002	0.01	15	6	450	3	0.5
Northern white-cheeked gibbon	0.002	0.01	4	0.17	33	10	0.63
Sunda pangolin	0.002	0.01	1	0.45	13	7	0.5
Chinese pangolin	0.002	0.01	1	8	2	7	0.75
Pygmy slow loris	0.002	0.004	1	5	16	0.58	0.5
Bengal slow loris	0.002	0.004	1	5	111	0.58	0.5
Large-spotted civet	0.006	0.006	1	2	5	1	1
Owston's civet	0.006	0.006	1	2	8	1	1
Annamite striped rabbit	0.006	0.004	1	0.1	5	0.115	1
Northern pig-tailed macaque	0.004	0.01	15	1	5	4	0.5
Stump-tailed macaque	0.004	0.01	15	1	25	4	0.5

Initial species parameters are shown in Table 3. The snare-ability and shoot-ability parameters are defined as probabilities between 0 and 1 that a species enters a new cell, is snared or is shot.

Animals can be killed by snares. For each group, in each month, the model calculates the proportion of the group's territory that contains snares. Based on the assumption that the group is equally likely to be in any cell within its territory at any given point in time, the model then calculates the probability that the group is exposed to snares on a given day. This is then multiplied by the 'snare-ability' of the animal to give the probability that the group is caught by snares on a given day, and then this is transformed to a monthly probability of being snared. Based on this monthly probability, whether the group is actually snared in that month is determined stochastically. If the group is snared it is removed from the simulation. For those species that live in groups, it is assumed that if the group is snared then all individuals in the group are killed (Fan et al. 2015; Johnson et al. 2005).

Animals can also be killed by poachers directly, such as by shooting, hunting or simple collection in the case of smaller, slower animals. For each animal group, the daily probability that the group encounters a poacher group is determined in the same way as the probability of the anti-poaching patrol encountering a poacher group. This probability of encounter is then multiplied by the 'shoot-ability' of the species, and then transformed to a monthly probability of being shot/hunted/collected. Based on this monthly probability, whether the group is actually shot/hunted/collected in that month is determined stochastically and if so, then it is removed from the simulation. For those species that live in groups, it is assumed that if the group is shot/hunted/collected then all individuals in the group are killed (Fan et al. 2015; Johnson et al. 2005).

Animals also reproduce. The initial age of each animal is randomly selected from a uniform distribution between zero and twice the species age to reproductive maturity. The age of each individual is tracked as the simulation runs. Half of all individuals are assumed to be female. Any female that has reached reproductive maturity may produce young in any given month. The actual amount of young produced is drawn from a Poisson distribution with an expected value of 1/12th of the species reproductive rate, ensuring that the expected number of young produced per reproductive female is the defined reproductive rate. The total number of groups of a species are assumed not to occupy an area greater than the total protected area; that is, the number of groups of a species is constrained to be less than or equal to the total protected area divided by the species range size. If this maximum area is exceeded, no further reproduction is possible for a species. For simplicity, any young produced are assumed to immediately occupy a new range; this range is determined in the same way as the range of the initial animals was determined at model initialisation.

8. Model scenarios

Four different model scenarios are simulated. The scenarios are designed to represent potential anti-poaching patrol structures. These scenarios are based on past patrol efforts, walking pace and snare collection efficiency described in studies about species monitoring and patrolling in Lao PDR and Zambia (Vongkhamheng et al., 2013; Becker et al., 2013). The scenarios set out below are ranked to represent increasing patrol effort.

1. Base case (Base): The base case scenario represents the current situation with poachers and no anti-poaching patrols. As such, it provides the worst-case scenario for biodiversity in the region. It predicts species extinctions in the next ten years without intervention. The base scenario was calibrated based upon expert predictions regarding animal extinctions.
2. Low-effort anti-poaching patrols (SC1): 100 of the 223 km^2 cells are patrolled each month, the probability that patrols apprehend poachers is moderate (0.6), and the probability that patrols remove poacher camps is low (0.1). The patrol-poacher interaction in this case is that patrols remove snare lines as they move through grid-cells at 60% efficiency. The low probabilities of poacher apprehension and camp removal mimic the minimum effects of patrols on poachers; even if patrols do not directly confront poachers, the presence of patrols in the area may abate poaching pressure to some degree.
3. Medium-effort anti-poaching patrols (SC2) based upon project-target values or those most likely to result from the fist implementation of the patrol scheme. The same number of grid cells is patrolled each month (100) but there is a higher likelihood (0.8) that an individual poacher is apprehended if encountered by a patrol, and a 0.6 likelihood that a poacher camp is removed if intercepted. The same proportion of snare lines per grid cell is removed by patrols as in SC1 (60%). This scenario is designed to represent patrols having authority in the area, operating at a reasonable efficiency.
4. High-effort anti-poaching patrols (SC3): All 223 cells are patrolled at higher efficiency than other scenarios: 90% of poachers are apprehended and all camps are removed if they are intercepted. The snare removal efficiency is increased to 80%. SC3 demonstrates how many animals may survive when all 223 km^2 grid cells are patrolled on a monthly basis with high effort. This represents a high-cost patrol scheme but also theoretically more effective for mitigating poaching in the area through monthly patrols. Note that, patrols

still have to come into contact with poachers, poacher-targeted grid cells, or poacher camps to be able to remove them. This condition is realistic since it is unlikely that 100% of all poacher-targeted cells will be patrolled. There remains a chance that the patrols will not come into contact with poacher groups. SC3 would require a member of the police or militia to be part of the patrol to ensure apprehension of poachers

The four management scenarios were run 100 times each over a ten-year-period (120 months). The model was also run without any poaching or patrols, to verify that species reproduction is captured realistically in the model. These verification runs showed, as expected, a steady increase in wildlife populations over the ten-year period in the complete absence of hunting or poaching.

The model was run for ten years to capture long-term trends in populations, as we expect that populations may recover to some degree under some of the patrol schemes. The model iterations can readily be adjusted to suit specific temporal scales. For the purposes of this research report, having a long time period was considered necessary to understand and visualise impacts of the management scenarios.

For each scenario, 100 model iterations were used to account for the internal model stochasticity, resulting in variance within the results for each individual scenario. Running multiple iterations of the model captures the various probabilistic effects included in the model, such as animals, anti-poaching patrols and poachers moving based on some likelihood, or the random interaction of poachers, animals and patrols. The mean value from 100 iterations was used as a representative average of the likely outcome of that scenario.

9. Assumptions

Due to the lack of primary data in the study area, and to facilitate the modelling efforts, a number of assumptions were made. These assumptions are listed below.

1. All interactions (animal movement, poaching activities and anti-poaching patrols) are limited to the PCV PPA by adding a boundary map to all data-sets and maps used in R. Species recruitment and dispersal from and to outside the PCV PPA are assumed to be zero, as the focus is on the numbers contained within the protected area.

2. The anti-poaching patrol team size is based on five individuals and their efficiency at walking and removing snare lines are set at $3km^2$ grid cells per day and removing 60% of snare lines, except in SC3 where an increase in efficiency is examined with 80% of snares removed per patrolled cell (Vongkhamheng et al., 2013; Becker et al., 2013). The number of patrol teams is set to two. These can be altered to test different patrolling scenarios.

3. Poacher groups are not defined at an individual level, but defined by the size of the area targeted by poachers (set at 20 grid cells per poacher group). This is based on the effective area that a small group of poachers could target and monitor over a month (Steinmetz et al., 2014; Vongkhamheng et al., 2013; Johnson et al., 2003). We assume that poacher groups are limited to a handful of individuals, and that these groups are independent, however their poaching areas may overlap. If multiple poacher groups target the same area, snare density is simply multiplied by the number of poacher groups and the probability that an animal is caught is increased.

4. The maximum number of poacher groups that can target the PCV PPA is restricted to a maximum of three at any time. If a poacher group is removed, a new one may enter the area and set up a camp once per month with a low likelihood of occurrence (0.3). This is to simulate the effects of enforcement, that once poachers know that they will be removed and penalised, they or new groups are less likely to enter the area.

5. All species included in the model currently exist within the PCV PPA. The data used for species information are often based on other areas in SE Asia or elsewhere because individual species data do not exist. While field-sightings and expert opinion confirm

the occurrence of many of these species within the area, typically no species counts are available for Lao PDR.

6 Species hunt-ability parameters Sn and Sh are based on how common the species is, how likely it is to be seen by poachers, the animal behaviour (nocturnal, elusive, avoids humans etc.), group size, and population size. Sn and Sh were initially arbitrarily defined as being between 0 and 0.5 (the most likely animals to be caught would be caught only 50% of the time). Initial model runs showed extinction patterns where species were extinct too quickly relative to predicted extinctions, and the hunt-ability parameters were calibrated according to predicted extinctions in the next 3-4 years of many endangered species (Duckworth et al., 2012; IUCN 2015/2016). The best fit result was achieved when Sn and Sh ranged between 0 and 0.01 (See Results, Base scenario Figures 11 and 12).

The assumptions stated above are representative of the current understanding of the poacher-patrol relationship, species and population data available for Lao PDR and SE Asia, and can all be readily altered within the model. Future studies should focus on quantifying these assumptions, so that, rather than a probabilistic model, the model can be based on field data and observations.

Note that data collection is anticipated under the PES project. As the patrol scheme progresses, data will be collected through the monitoring tasks of the patrol teams. These data can subsequently be used to continually refine and improve the model.

10. Results

The model outputs show that increasing anti-poaching patrol effort leads to higher numbers of individual animals (Figure 11), and to higher numbers of species surviving (Figure 12). Without any patrol effort (the Base case), 494 animals and less than five species would survive in the PCV PPA after ten years. Increasing patrol effort (scenarios SC1, SC2 and SC3) has a marked effect on the number of animals protected and on species survival, compared to the Base (see also Table 4 below).

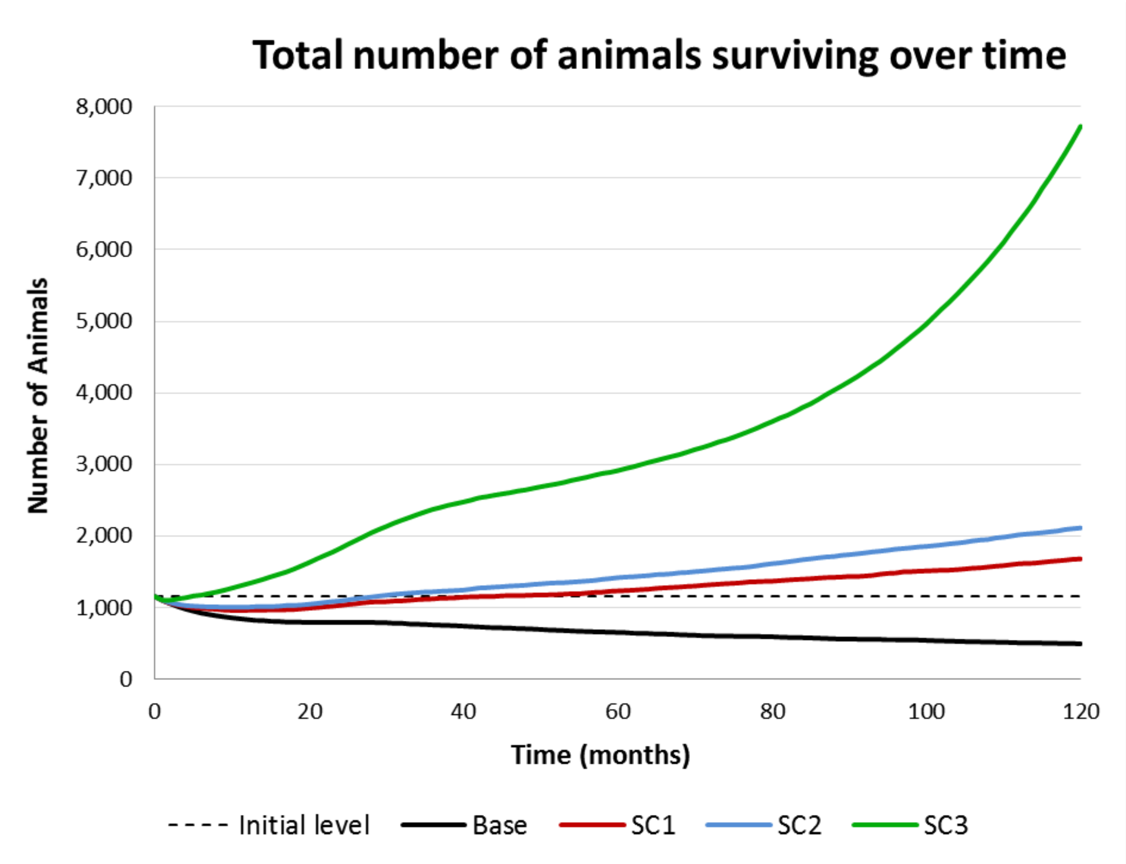

Figure 11. Number of animals remaining in the PCV PPA study area under different poaching management scenarios over a 10-year modelling period.

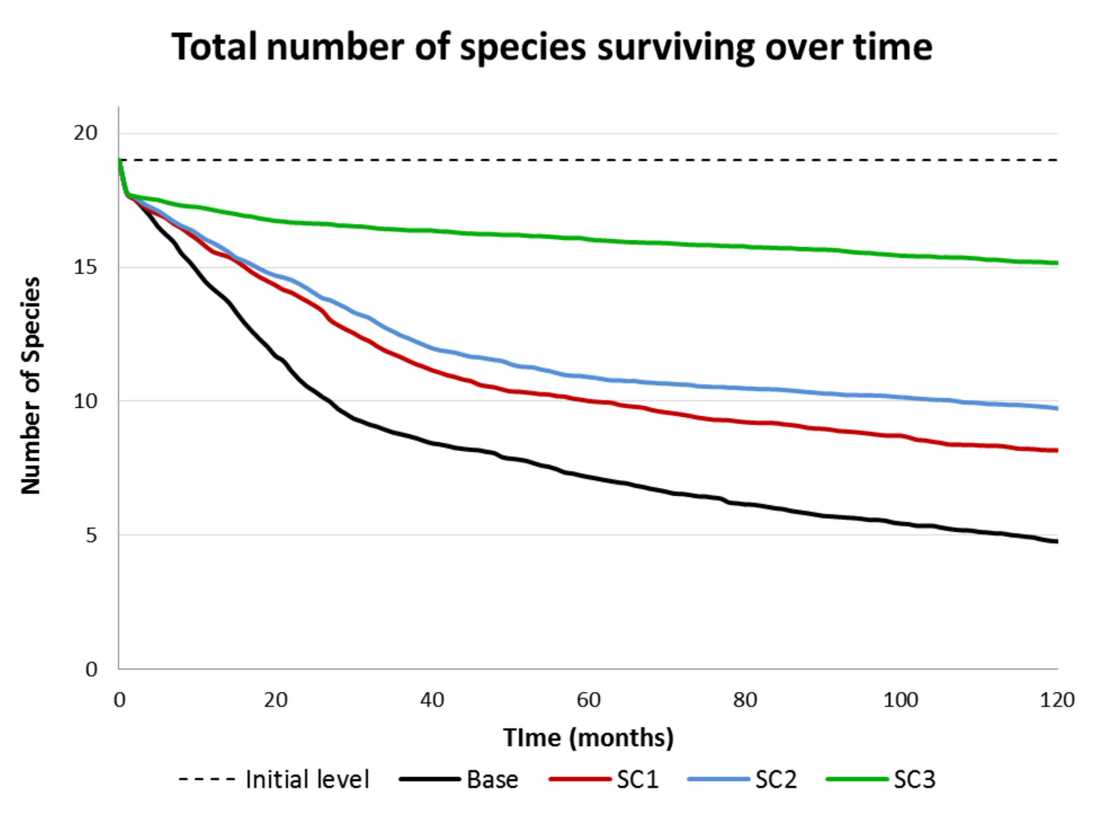

Figure 12. Number of species surviving over a 10-year modelling period under different poaching management scenarios.

These results suggest that even the most basic patrol scheme SC1 will have an impact on preserving species diversity in the region. The diminishing return of species saved as effort increases represents the fact that some species are very rare, with low initial population counts, and have high species hunt-ability [Sn and Sh]. High risk species include the Northern Pig-Tailed Macaque, Tiger, Saola, Asiatic Black Bear, Large-Antlered Muntjac and Clouded Leopard species. Even under a higher effort patrolling scenario (SC2 and SC3), such high-risk species may go extinct (see also Figure 13).

Table 4. Final mean number of animals and of species surviving at t = 120 months for each management scenario.

Scenario	Average number of animals remaining at *t* = 120	Average number of species remaining at *t* = 120
Base	493	4.8
SC1	1,678	8.2
SC2	2,112	9.7
SC3	7,724	15.2

Even though the total number of animals in the PCV PPA increases when anti-poaching patrols are implemented, the total number of species will always decrease over time from the initial 19 species. Scenario SC3 is theoretically the most effective for mitigating poaching through monthly patrols, but demonstrates that there is a limit to the effectiveness of protecting species through anti-poaching patrols. Patrols move through the area, but are restricted by, for example, their walking speeds and thus the area they can cover; by the fact that snares will not always be found even when a grid-cell is entered; and by the limited accessibility due to rough terrain and dense forests.

To link the modelling outputs with the choice experiment survey developed for the PES project, the model predictions are presented as the number of different species protected in the PCV-PPA (‘Species diversity’ attribute) and the percentage of animals lost (‘Poaching’ attribute) (Table 5). The number of species protected represents the increase in species diversity compared to the base case scenario. For example, if 6.5 species survive after 6 years under the base case, and 9.5 species survive under SC1, then the number of species protected under SC1 relative to the base case scenario is 3.0.

The percentage of animals lost is relative to the initial number of animals in the PCV PPA. These percentages become negative after one-four years under the patrolling scenarios, because the number of animals increases compared to the initial population levels at *t=0* (negative losses).

Table 5. Number of different species protected and percentage of total animal numbers poached under different patrol management strategies (over various time frames)

		Scenario			
Attribute	**Time frame**	**Base**	**SC1**	**SC2**	**SC3**
Number of different species protected by patrols, compared to base case scenario	1 yr		1.4	1.7	2.9
	3 yrs		2.9	3.7	7.6
	6 yrs		3.0	4.1	9.3
	10 yrs		3.4	5.0	10.4
Percentage of animals poached (lost), compared to population levels at $t = 0$	1 yr	28%	17%	13%	-15%
	3 yrs	34%	3%	-6%	-106%
	6 yrs	48%	-14%	-32%	-184%
	10 yrs	57%	-45%	-83%	-569%

The last set of results presented consists of the survival rates for each species under the different scenarios (Figure 13). The Bengal Slow Loris and the Rufous-necked Hornbill survives in all scenarios, while other species such as the Asiatic Black Bear, Tiger, Clouded Leopard, Large-antlered Muntjac and Saola require a high patrol-effort management scenario to maximise the likelihood of survival (Figure 13). The Northern Pig-Tailed Macaque always succumbs to poaching, and does not survive under any of the management scenarios tested.

Animals of the same order but different species (such as the two Macaques, Loris and Civet species) were of interest as they varied in their species survival rate despite being similar types of animals. The key difference lies in the initial population estimates, which resulted in the more common species of the two being more likely to survive in different scenarios (Figure 13). The largest discrepancy between survivals of species was for the two Macaque species, where one was always poached to extinction and the other generally survived.

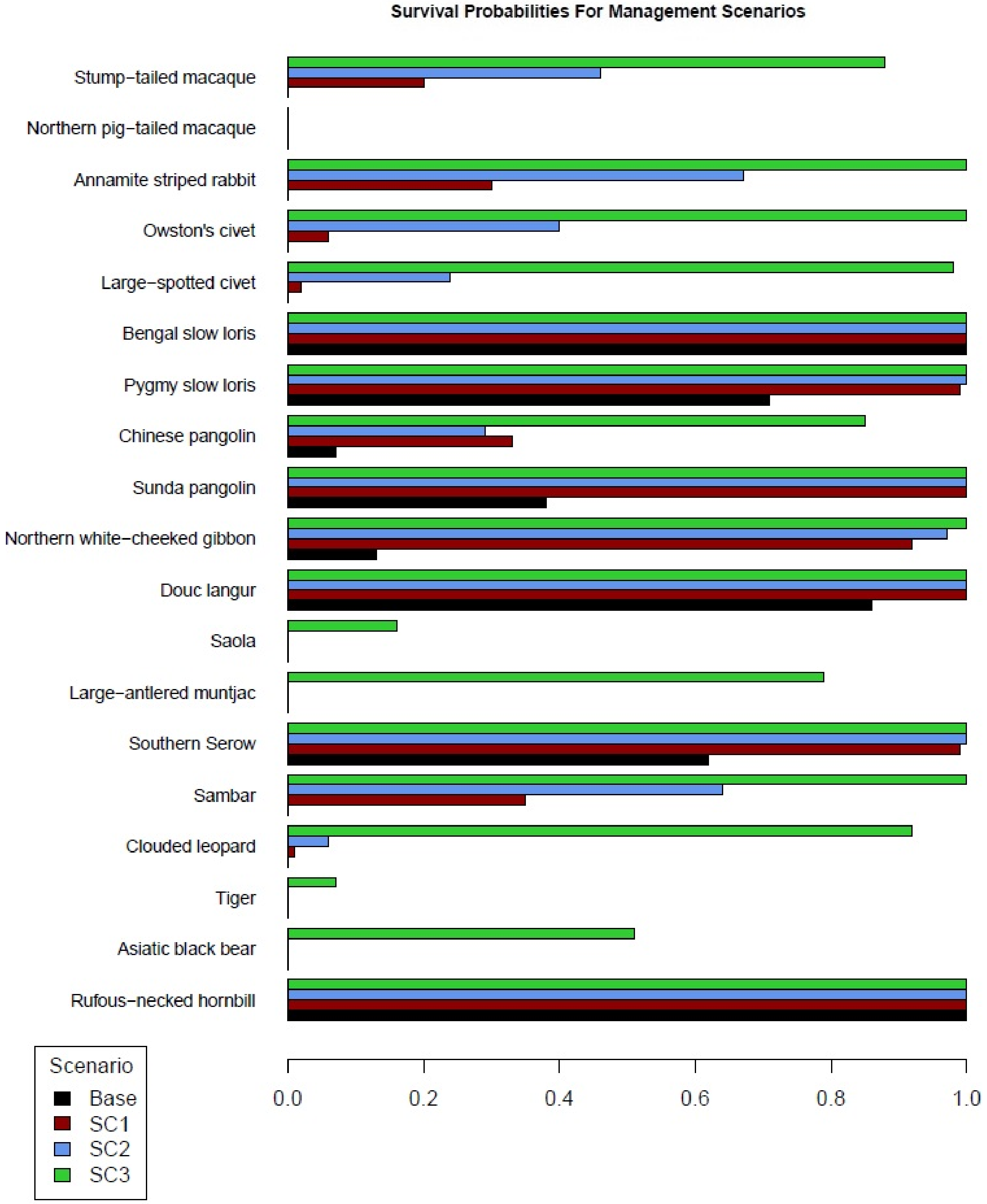

Figure 13. Probability of survival for each species under alternative management scenarios. This is a model output detailing the likelihood of survival for each species out of the 100 runs tested for each management scenario. A value of 0.5 means that of the 100 runs, the animal persisted to the final month 50 times (50% survival) for that particular scenario.

10.1 Sensitivity Analysis

To test the variability of the model predictions in this probabilistic model, scenario SC2 was run 100 times per altered variable. The mean of final species and animal count were recorded, together with their standard errors. This analysis serves as a check of internal model consistency. The predicted number of species and animals surviving when running scenario SC2 with the same set of input variables ranged from -1% to +2% relative the base output for SC2. This internal variability is solely due to the probabilistic nature of the model.

Further sensitivity analysis was conducted to test how uncertainty in the input variables would influence the model outcomes. The full results of this analysis are included in Appendix 3. In this Section, spider charts show how the model predications (total number of animals and total number of species surviving after 120 months) vary when input variables are altered. All sensitivity analyses are run for scenario SC2. Figures 14 and 15 below show the sensitivity of model output when species input parameters are varied by +/- 20% relative to their base values.

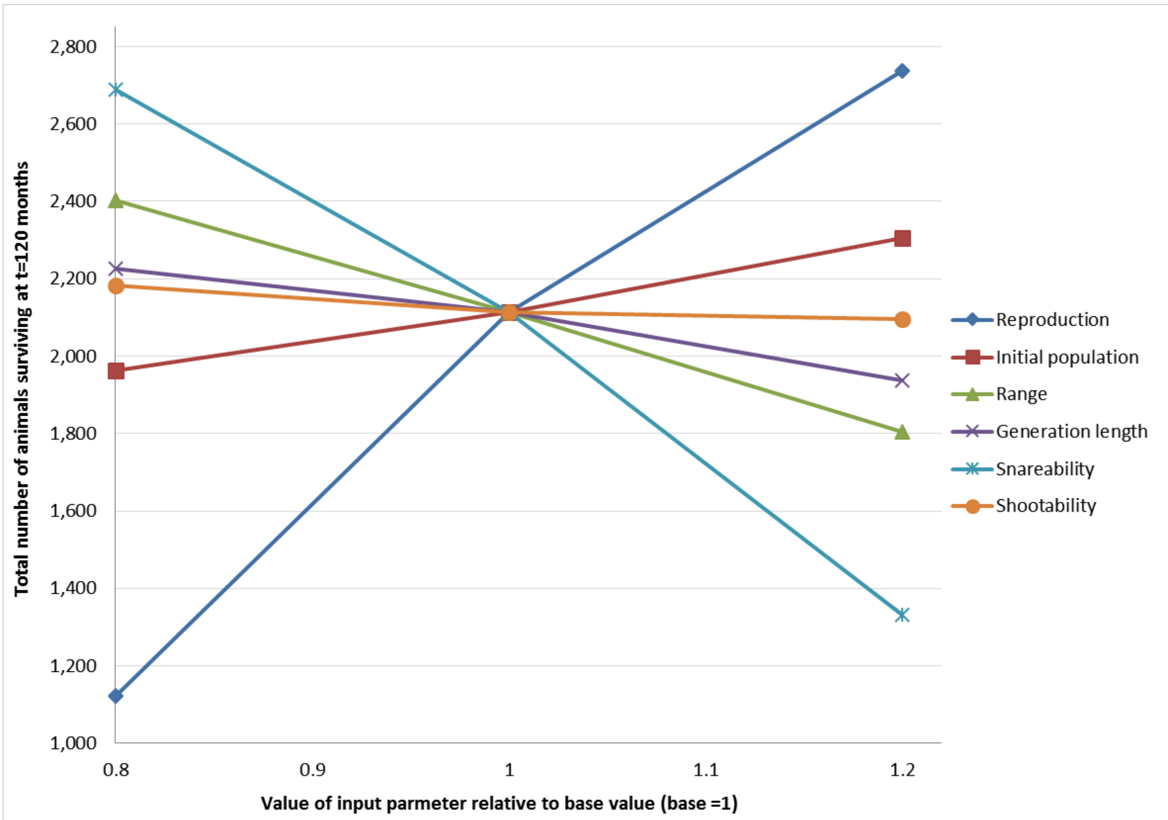

Figure 14. Sensitivity of predicted total number of animals surviving at t=120 months. Species' input variables are varied by +/- 20% relative to the base value (base value = 1)

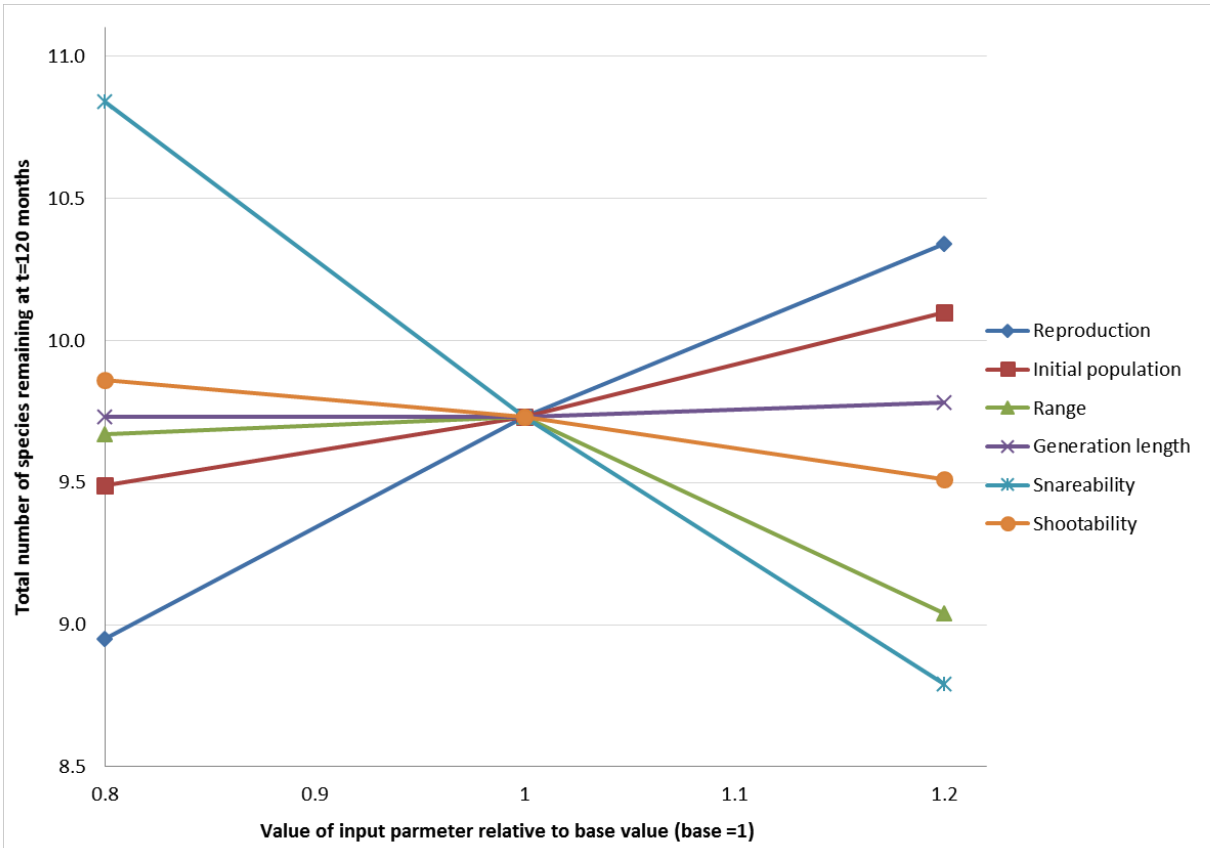

Figure 15. Sensitivity of predicted total number of species surviving at t=120 months. Species' input variables are varied by +/- 20% relative to the base value (base value = 1).

Changes in the input variables has the expected impacts on final model output. When species reproduction rate and initial populations are higher, the amount of species and animals which survive increases (Figures 14 and 15). Similarly, when the 'huntability' parameters *Snareability (Sn)* and *Shootability (Sh)* are reduced, more animals and species survive over time (Figures 14 and 15).The model is not very sensitive to changes in generation length. In our model, the 'generation length' variable impacts the age structure of the population and the amount of offspring generated. Increasing generation length means animals will live longer and have more offspring over their lifetime. Increasing generation length by 20% reduced the final animals count by 8% (Figure 14 and Appendix 3), and had a negligible effect on species (+1%, within the probabilistic variation of the model). A reduction in the animal count arises because the larger number of animals available have a higher chance that they are impacted by poaching. To determine the generation length of each species, we typically consulted more than one data source (see Appendix 2: Data Sources). Generation length is one of the least uncertain input variables in our model.

When species' range increases, the total number of animals and species surviving decrease by 15% and 7% respectively. This is because the animals are spatially restricted to the conservation area, therefore if they have a higher mobility species have a higher chance of coming into contact with poachers. A smaller range results in higher survival rates, as animals are less likely to come in contact with poacher groups. This result also demonstrates that animals with a larger range may be more susceptible to poaching in the PCV.

Figures 16 and 17 below show the sensitivity of the model output to changes in human input variables (poaching and patrol variables). Of the human input variables, the number of cells patrolled had the highest impact on model outputs. Increasing the number cells patrolled from 100 to 125 (a 25% increase), increased the total number of animals surviving by 32.5% relative to the base in SC2. This shows how patrols are effective at removing snares and increasing animal survival, even with only a moderate increase in area patrolled.

Model outputs were only moderately sensitive to the probability of new poacher groups. A higher chance of poacher incursion negatively impacted animal survival and species counts. Changes in the probability of new poacher groups had a larger effect on the total number of animals surviving (+/- 6% approximately; Figure 16) than on species survival (Figure 17).

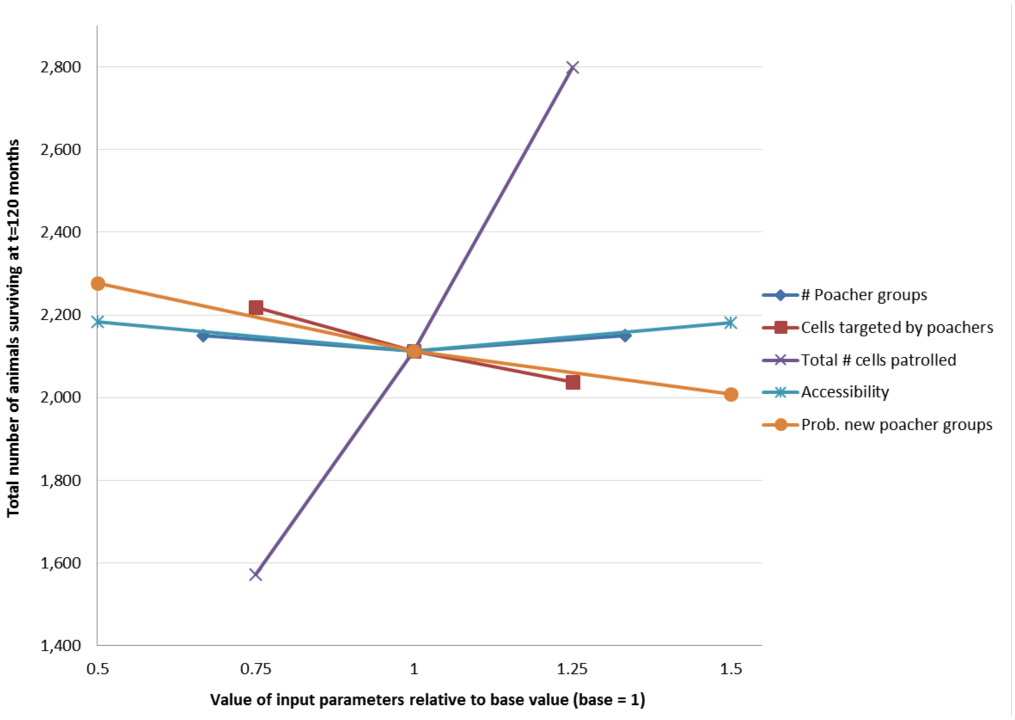

Figure 16. Sensitivity of predicted total number of animals surviving at t=120 months. Human input variables are varied relative to their base input value (base value = 1).

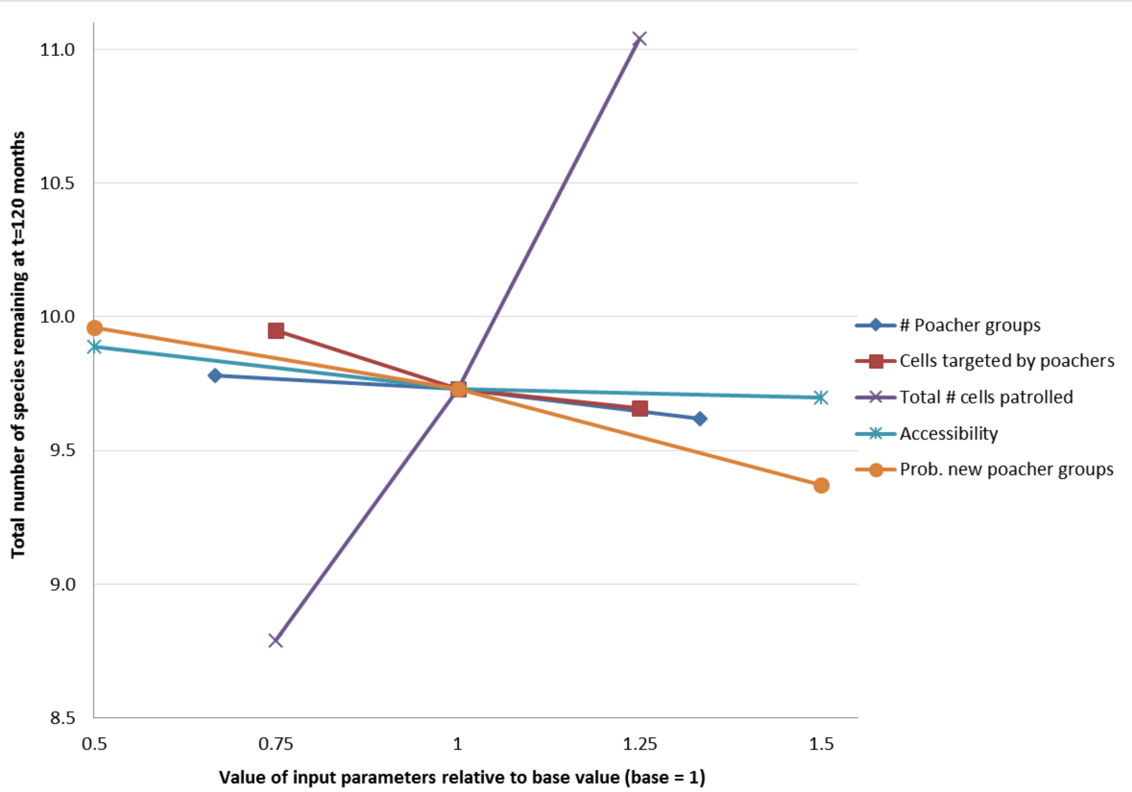

Figure 17. Sensitivity of predicted total number of species surviving at t=120 months. Human input variables are varied relative to their base input value (base value = 1).

Finally, the number of animals and species surviving was not sensitive to changes in the accessibility parameter. Altering the accessibility parameter resulted in a +3% change in animal count, and a 0% to 2% change in the number of species surviving. These changes are within the variability caused by the model's stochasticity itself and can hence not be uniquely attributed to the accessibility parameter.

Other human inputs parameters; the number of cells targeted by poacher groups and the number of poacher groups, have limited influence on model outputs. Reducing/increasing the number of poacher groups did not affect the number of animals or number of species surviving beyond the model's internal variability (Figures 16 and 17). Increasing/decreasing poacher effort by changing the number of cells they target, reduces/increases the number of animals surviving by about 4-5% (Figure 16). These changes are logical: higher poacher effort (cells poached and number of poacher groups) results in slightly fewer animals surviving.

11. Conclusions

Poaching has a negative impact on the populations of endangered species in the Lao PDR's Phou Chomvoy Provincial Protected Area (PCV PPA). The results presented in this model are consistent with current knowledge of the damaging effects of poaching in protected areas (Pratt et al. 2004; Vongkhamheng et al. 2013; Steinmetz et al. 2014). The model results show not only this relationship, but quantify species-level information from a relatively unknown and data-poor area. All modelling assumptions are stated in this research report. These assumptions were based upon the best available information at the time.

Two species; the Bengal Slow Loris & Rufous-necked Hornbill, survived under all poaching-patrol scenarios. This is because these species are smaller, harder to see, and not impacted by snares on the ground. Furthermore, the Loris *spp.* has a high initial population estimate and a low range, therefore it has a high survival chance compared to other species considered. It is likely that ground-dwelling birds and birds with wider mobility ranges will be more impacted by poaching.

In contrast, some other species require high patrolling efforts, such as in management scenario SC3, to ensure a chance of survival over the ten-year modelling period. These are the most highly endangered species with low initial population counts: Asiatic Black Bear, Northern Pig-Tailed Macaque, Tiger, Clouded Leopard, Large-antlered Muntjac and Saola. Often, the species are also the most valuable to poachers. One species, the Northern Pig-Tailed Macaque, was always poached to local extinction due to its scarcity, large group size and high likelihood of being snared. Because the Northern Pig-Tailed Macaque resides in large groups, they are easy to find for poachers and when one is found the whole group is caught. The group size and initial population are important parameters determining a species' survival. It is these important parameters for which data was often not available for the PCV PPA. In the model, estimates are based on species densities in other areas. Future studies should aim to gather better population data for threatened species in the PCV PPA, to improve our predictions of extinction probability.

The management scenarios investigated, SC1-SC3, are example scenarios constructed based on available knowledge of anti-poaching patrolling and poaching techniques. They demonstrate example 'environmental production functions' to simulate the outcomes (i.e. the population size and numbers of different species) of different types of patrolling scenarios.

Scenario SC3, the high patrol effort scenario, is the only management strategy that results in the survival of the majority of species considered. While this scenario is potentially more costly, SC3 results in saving a number of species which are predicted to otherwise be nationally extinct in Lao PDR over the next five to ten years, and is the only scenario which has been shown to give the rarest of species considered a chance at survival.

The model developed can be used as a tool for policy-makers, by allowing model users to change input variables to represent different strategies. The input parameters included in the model's R script can be readily altered to examine other management strategies – such as changing patrol effort or patrolling efficiency. Patrolling effort could be altered by changing the number of patrol groups in the simulations, to examine the effects of increasing patrol frequency. Patrol efficiency can be captured by the percentage of snares collected by patrols per grid cells, or by the number of cells patrolled per day. In our current model runs, the number of cells patrolled per day is set at three cells for all scenarios. If patrols become more efficient, they may move through cells quicker and therefore clear cells at a higher rate. The amount of terrain covered is also likely to vary in different seasons. For example, it is likely to be easier to move through the terrain in the dry season compared to the wet.

Better quantitative species-level data are essential to further modelling effort in this area. Population counts, species surveys and data on poacher camps and methods would improve parameterisation of the model and thus improve the accuracy of model outputs. It is expected that these data will become available as the patrolling scheme progresses.

Nevertheless, the model demonstrates a method that can be applied in situations that lack species-level data. Our research provides a start to understanding and quantifying the effects of poaching and anti-poaching patrol effort in Lao PDR, which has not been attempted previously. Quantifying population estimates through modelling provides a transparent basis for decision-makers and managers.

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Appendix 1: Species likely to be present in the PCV PPA

Species list of conservation targets, confirmed to likely be present within the PCV PPA. The IUCN (International Union for Conservation of Nature) conservation status, National and Global significance of each species are also included. Data from Tizard 1996; The IUCN Red List of Threatened Species 2015; World Wildlife Fund 2015; Johnson et al. 2012; Johnson et al. 2003.

English name	Scientific name	Class	Lao Law category$^{\alpha}$	IUCN category$^{\beta}$	National priority$^{\gamma}$	Global significance$^{\delta}$
Sun bear	*Ursus malayanus (helarctos m.)*	Mammal	I	VU	high	high
Asiatic black bear	*Ursus thibetanus*	Mammal	I	VU	acute	high
Tiger	*Panthera tigris*	Mammal	I	EN	acute	high
Leopard	*Panthera pardus*	Mammal	I	NT	high	mid
Clouded leopard	*Pardofelis 58ebulose (Neofelis n.)*	Mammal	I	VU	high	high
Marbled cat	*Pardofelis marmorata*	Mammal	I	VU	int	mid
Southern Serow	*Naemorhedus sumatraensis (Capricornis s.)*	Mammal	I	VU	n	n
Douc langur	*Pygathrix nemaeus*	Mammal	I	EN	high	high
Northern white-cheeked gibbon	*Nomascus leucogenis*	Mammal	I	CR	high	high
Sambar	*Cervus unicolor*	Mammal	I	VU	n	n
Saola	*Pseudoryx nghetinhensis*	Mammal	I	CR	acute	very high
Large-antlered muntjac	*Munitacus vuquangensis*	Mammal	I	EN	n	n
Roosevelts' muntjac	*Munitacus rooseveltorum*	Mammal	I	DD	?	high
Smooth-coated otter	*Lutra perspicillata*	Mammal	I	VU	high	mid
Sunda pangolin	*Manis javanica*	Mammal	I	CR	high	mid
Chinese pangolin	*Manis pentadactyla*	Mammal	I	CR	high	high
Pygmy slow loris	*Nycticebus pygmeaus*	Mammal	I	VU	n	n
Bengal slow loris	*Nycticebus bengalensis*	Mammal	I	VU	n	n
Large-spotted civet	*Viverra megaspila*	Mammal	I	VU	int	high
Owsten's civet	*Hemigales owstoni (Chrotogale o.)*	Mammal	I	VU	int	high
Annamite striped rabbit	*Nesolagus timminsi*	Mammal	I	DD/NT-EN	n	n

English name	Scientific name	Class	Lao Law category[α]	IUCN category[β]	National priority[γ]	Global significance[δ]
Chinese three-striped box turtle	*Cuora trifasciata*	Reptile	I	CR	acute	high
Big-headed turtle	*Platysternon megacephalum*	Reptile	I	EN	high	high
Indochinese box turtle	*Cuora galbinifrons*	Reptile	I	CR	high	high
Impressed tortoise	*Manouria impresa*	Reptile	I	VU	high	low
King cobra	*Ophiophagus hannah*	Reptile	I	VU	int	low
Rock python	*Python molurus (bivittatus)*	Reptile	I	VU	int	mid
Great hornbill	*Buceros bicornis*	Bird	I	NT	high	low
Rufus-necked hornbill	*Aceros nipalensis*	Bird	I	VU	high	medium
Long-billed vulture	*Gyps indicus*	Bird	I	CR	acute	mid
Crested argus	*Rheinardia ocellata*	Bird	I	NT	high	high
Lesser mouse deer	*Trangulus javanicus*	Mammal	II	DD/VU	n	n
Northern pig-tailed macaque	*Macaca leonida*	Mammal	II	VU	n	n
Stumped-tail macaque	*Macaca arctoides*	Mammal	II	VU	n	n
Binturong	*Arctictis binturong*	Mammal	II	VU	high	low
Keeled box turtle	*Pyxidea mouhotii*	Reptile	II	EN	high	high
Four-eyed turtle	*Sacalia quadriocellata*	Reptile	II	EN	int	high
Elongated tortoise	*Indotestudo elongata*	Reptile	II	EN	high	low
Southeast Asian softshell turtle	*Amyda cartilaginea*	Reptile	II	VU	int	low

Notes:

α: Lao Law categories: I: prohibited species, no hunting allowed; II: managed species, customary hunting allowed but restricted; III: general, hunting allowed but with some restrictions.

β: IUCN categories: CR: critically endangered; EN: endangered; VU: vulnerable; NT: near-threatened.

γ: National priority levels: acute: species with very low population levels that are unlikely to persist unless all remaining habitats are protected; high: species which can be maintained if immediate and effective action are taken to manage threats to them, and are vulnerable to habitat loss and hunting and without action are likely to be reduced to critical levels; and intermediate: poorly studied species which are likely acute or high National priority status but for which status information is lacking.

δ: Global significance levels: very high: species is close to global extinction; high: small global population or range remaining, with Lao comprising a large proportion of remaining individuals; moderate: species has a small regional population, but numerous outside the region and Lao populations comprise a significant proportion of remaining individuals; low: the species occurs in large numbers in Lao or neighbouring countries and there is no direct role in the Lao population in international conservation.

Appendix 2: Species population data sources

Rufous-necked hornbill

PCV population and home range based upon Thailand data, as there were no studies from Laos (Jinamoy et al., 2014; Tifong et al., 2007). Studies were from protected areas of similar forest type to that of the PCV PPA. Two different range estimates were found which contradict each other of groups of two or groups of five (Kinnaird & O'Brien 2007; Humphrey & Bain 1990). If groups sizes are to be used in the model, an estimate between two and five would be acceptable based on this information. Generation length from IUCN Red List, confirmed from Taylor 2011 study. Group size from Jinamoy et al., 2014 and Tifong et al., 2007.

Asiatic black bear

Range data from studies in Taiwan (Hwang et al., 2010), and confirmed by Lindburg & Baragona 2004. A North American study and predictive modelling study were used for birth rate and generation length, confirmed by data on the IUCN Red List (Stringham 1990; Servheen et al., 1999; IUCN 2016).

Tiger

Range data from Eastern Russia study (Hebblewhite et al., 2014) and Thailand study (Simcharoen et al., 2014). Generation length from IUCN, confirmed by Chapron et al., 2008. Population density from IUCN, and is generally proportional to prey abundance as is the birth rate (Chapron et al., 2008; Simcharoen et al., 2014).

Clouded leopard

Range data from the IUCN. Population density from SE Asia (Thailand, Nepal, India) study by Mohamad et al., 2015. Birth rate from Najera et al., 2015. Generation length from captive breeding study (Murphy 1976).

Sambar

Generation length and reproduction rate from IUCN, and confirmed by the Steinmetz et al., 2010 study based in Thailand. Population density from O'Brien et al., 2003 from a study in Sumatra, Indonesia. Range from IUCN.

Southern Serow (Chinese Serow or Southwest China Serow)

Population density and birth rate: Ochiai & Susaki 2002, a study in Japan based on 24 years of data. Range based on a study of Red deer as there were no studies on the home range of the Serow spp. Generation length from study on the Japanese serow (Ochiai & Susaki 2007).

Large-antlered muntjac

Generation length: IUCN. Range data from Chapman et al., 1993 study on Mutjac spp. in England, as there is no available data for Lao or Southeast Asia. Birth Rate from Dubost et al., 2011 study on deer in China, as no available birth data on the specific Muntjac spp. Population estimate was obtained from Timmins et al., 1998 based on field sightings and historical records from the PCV PPA study area in Lao. Generation length of Muntiacus muntjak used, from Dubost et al., 2011.

Saola

Population estimate from Kemp et al., 1997, based from villager surveys and field records from a nature reserve in Vietnam. PCV PPA presence confirmed by Schaller & Rabinowitz 1995. Birth rate and generation length based upon White-tailed Deer study by Therrien et al., 2007 as there is no data availble on Saola reproduction. The home range is an estimate based on available information from the IUCN. Group size of 2 common (Kemp et al., 1997) but can be up to 6 (Schaller & Rabinowitz 1995).

Douc langur

Density and range from Coudrat et al 2014 study in Lao, confirmed by Bailey 2014. Generation length and birth rate from captive observations, Ruempler 1998. Group size from Phiapalath et al., 2011.

Northern white-cheeked gibbon

Density from Vietnam studies (Bach & Rawson 2011; Eames & Robson 1993); generation length from Nature 2014; range from a survey in China (Fan et al. 2015). Reproduction data from Malone & White 2007; which was a study on the Javan Gibbon as no reproduction data is available from the Northern White-cheeked gibbon. Group size from Eames & Robson 1993.

Sunda pangolin

Range data was taken from a study on Cape pangolins as no data is available on the Sunda pangolin (Heath & Coulson 1997). Reproduction rate and generation length from Zhang et al., 2015 and population estimate from Duckworth et al 1999 study based in Lao.

Chinese pangolin

Range data was taken from a study on Cape pangolins as no data is available on the Chinese pangolin (Heath & Coulson 1997). Reproduction rate from Heath 1992; generation length from Zhang et al., 2015. Population estimate from Newton et al., 2008 review of hunting and previous sightings in Vietnam.

Pygmy slow loris

Population density data from study in Cambodia (Starr et al., 2011); confirmed by Das et al., 2015 field surveys. Reproduction data from Zimmermann 1989 from a study in Germany on the slow loris Nycticebus cougang. Range data from Das et al., 2015 study on the Bengal slow loris. Generation length from study of the Slender loris (Radhakrishna & Singh 2004).

Bengal slow loris

Reproduction data from Zimmermann 1989 and IUCN, Range from Das et al., 2015. Population estimate and generation length from IUCN. Generation length from study of the Slender loris (Radhakrishna & Singh 2004).

Large-spotted civet

Reproduction rate from Mallinson 1973 from an American study of captive African civets. Population estimate from camera trapping study in Thailand, Myanmar and Malaysia (Lynam et al., 2005) combined with an aerial-estimate from modelling (Jennings & Veron 2011). Range data from a Chinese study on the masked palm civet as there was no data available for the Large-spotted civet (Zhou et al., 2014). Generation length from Ray 1995, a study and summary of the characteristics of the African civet.

Owston's civet

Reproduction rate from Mallinson 1973 from an American study of captive African civets. Range data from a Chinese study on the masked palm civet as there was no data available for Owson's civet (Zhou et al., 2014), confirmed to have a home range which overlaps the PCV PPA by Veron et al., 2004. There was no population density data available so the estimate is based upon the Owston civet being slightly more common than the large-spotted civet (Jennings & Veron 2011; IUCN 2016). Generation length from Ray 1995, a study and summary of the characteristics of the African civet.

Annamite striped rabbit

Generation length was obtained from a study on rabbit reproduction in France (Larzul et al., 2014) and home range data from the cottontail rabbit were used (Haugen 1942) as no data is available on the Annamite striped rabbit. Reproduction data was found in a study on rodent control by Singleton 1994, again on the general rabbit spp. rather than the Annamite striped rabbit as data is unavailable. A population estimate was assumed based upon the rabbit likely being rarer than the Saola (Can et al., 2001) and from IUCN summaries.

Northern pig-tailed macaque

Birth rate for Stump-tailed macaque used, as none could be found for the Northern spp. (Krishna et al., 2006). Home range data from a study in Thailand on the Northern macaque spp. (Albert et al., 2013). Population estimate from field survey in Thailand (Malaivijitnond et al., 2012). Generation length from a study on the Rhesus macaque (Westergaard et al., 1999). Group size from Malaivijitnond et al., 2012.

Stump-tailed macaque

Home range of the Northern macaque spp. was used as no data on range available for the Stump-tailed spp. (Albert et al., 2013). Similarly, the birth rate from the Northern spp. was used as data was lacking on the Stump-tailed spp. (Krishna et al., 2006). Population density from occupational occurrence modelling in India (Karanth et al., 2010). Generation length from a study on the Rhesus macaque (Westergaard et al., 1999). Group size from Malaivijitnond et al., 2012.

Appendix 3: Sensitivity Analysis results

Species Input Parameters	Base value	Rep+20%	Rep-20%	Pop+20%	Pop-20%	Range+20%	Range-20%	Gen+20%	Gen-20%	Sn+20%	Sn-20%	Sh+20%	Sh-20%
Mean number of animals surviving	2113	2737	1123	2305	1964	1805	2402	1938	2226	1331	2688	2096	2182
Standard error (t=120)	42.4	30.2	31.0	35.5	44.6	30.6	49.9	40.0	43.5	36.5	25.0	38.9	35.7
% Change to # of animals	n/a	30%	-47%	9%	-7%	-15%	14%	-8%	5%	-37%	27%	-1%	3%
Mean number of species surviving	9.7	10.3	9.0	10.1	9.5	9.0	9.7	9.8	9.7	8.8	10.8	9.5	9.9
Standard error (t=120)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
% Change to # of species	n/a	6%	-8%	4%	-2%	-7%	-1%	1%	0%	-10%	11%	-2%	1%

Human Input Parameters	SC2 base va	High	Low
Number of poacher groups	3	4	2
Cells targeted by poacher group	20	25	15
Total cells patrolled	100	125	75
Accessibility	0.1	0.05	0.15
Probability of new poacher groups	0.4	0.6	0.2
Base model repeats	n/a	n/a	n/a

Human Input Parameters	Animals	S.E.	% Change	Animals	S.E.	% Change	Species	Species	S.E.	% Change	Species	S.E.	% Change
Animals base value: 2112.78	High			Low			Base val.	High			Low		
N. poacher groups	2149	39.7	2%	2150	41.2	2%	9.7	9.6	0.1	-1%	9.8	0.1	1%
Cells targeted by poacher	2039	41.2	-4%	2220	37.8	5%	9.7	9.7	0.1	-1%	10.0	0.1	2%
Total cells pat.	2798	40.7	32%	1573	43.2	-26%	9.7	11.0	0.1	13%	8.8	0.1	-10%
Accessibility	2181	39.2	3%	2183	40.2	3%	9.7	9.7	0.1	0%	9.9	0.1	2%
P. new poacher group	2008	43.6	-5%	2277	40.3	8%	9.7	9.4	0.1	-4%	10.0	0.1	2%
Base model repeats	2154	38.2	2%	2125	43.3	1%	9.7	9.7	0.1	-1%	10.0	0.1	2%