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Supporting wildlife conservation by modelling the effectiveness of community-led poacher mitigation

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Abstract: Illegal hunting and poaching are severely threatening biodiversity in Southeast Asia, especially those species that are rare or threatened. Management strategies to address this poaching problem include wildlife patrols that collect and remove wire snares. While studies exist that predict the impact of poaching on biodiversity loss, there are few studies that evaluate the effectiveness of policy strategies. We present a model that predicts how community-led poaching mitigation patrols could help wildlife conservation in the Lao People's Democratic Republic (PDR). The results show that, without intervention, nearly all species will be poached to local extinction over the next 10 years. We show that, with increasing patrol effort, an increasing number of animals and species can be saved. However, there are diminishing returns from increased poaching effort, particularly in terms of species saved – with rare species at most risk of extinction. This is the first time modelling has been undertaken to examine poacher-patrol interaction in the Southeast Asia region. The results—showing positive effect of patrol effort on the number of endangered species saved—are now being used to inform wildlife management policies in the Lao PDR, with implementation of villager-led patrols that support local communities and sustaining natural resources.

Keywords: Biodiversity conservation; Community participation; Lao PDR; Population modelling; Wildlife poaching

1 INTRODUCTION

Poaching of native wildlife is a global problem and is still one of the largest contributors to biodiversity loss in Southeast Asia (SE Asia) (Steinmetz et al. 2014; Vongkhamheng et al. 2013). Given that SE Asia provides habitat to some of the world's most endangered vertebrate species, improving the protection of these species is essential to ensure their survival into the future (Gray et al. 2014; Steinmetz et al. 2010). Illegal hunting and poaching are major stressors in the region. Conservation patrols have been suggested as a solution to illegal hunting and poaching (Becker et al. 2013; Kenney et al. 1995). Engaging local community groups in conservation programs has been widely successful in reducing hunting and poaching pressure on endangered species globally and in SE Asia (Johannesen and Skonhoft 2005; Steinmetz et al. 2014). Further, schemes that promote the conservation of endangered species through community-led patrols benefit local biodiversity and can also improve the livelihoods of local villagers (Johannesen and Skonhoft 2005; Vongkhamheng et al. 2013).

The current study fits within a wider research project that aims to contribute to sustainable development in the Lao PDR. The project—*Effective Implementation of Payments for Environmental Services (PES) in Lao PDR*—is undertaken by the Australian National University, the University of

Western Australia and the National University of Lao, and is funded by the Australian Centre for International Agricultural Research (ACIAR) (Crawford School of Public Policy 2015; Tsechalicha et al. 2014). The environmental service that local villagers will be paid for is wildlife protection, through patrols that aim to control poaching pressure. To evaluate how much money local villagers should be paid, we need information about the likely impacts of community-led patrol on wildlife species. This, in turn, requires transparent estimates, based on the best available knowledge, of the number of species and/or individuals that can be protected by local patrolling efforts. In this paper, we will describe a population model that informs the wider research project by estimating the effect of poaching-mitigating patrols on selected threatened species.

Many existing studies on sustainable wildlife management present ecological models that focus on one or few species, rather than a broad range. Previous studies typically do not estimate the effectiveness of different conservation actions on reducing the poaching problem (Harihar et al. 2014; Watson et al. 2013). Despite the extinction crisis facing SE Asia, there are no published modelling studies on the effect of poaching-mitigating patrols on wildlife populations (Duckworth et al. 2012).

The study described in this paper addresses this gap in knowledge, by presenting a wildlife population model that predicts the effectiveness of poaching-mitigating patrols on multiple endangered species. Our model is developed for a case study region in the Lao PDR (Section 2) to show a clear relation between wildlife patrols and their environmental benefits. The modelling approach is described in Section 3, with results presented in the fourth section. Section 5 discusses the results and concludes the paper.

2 CASE STUDY AREA

This project is being implemented in the Phou Chom Voy Provincial Protected Area (PCV PPA), located in Bolikhamxay Province in the central-east of Laos. The PCV PPA is situated in the Nam Mouane-Nam Gnouang Catchment (Figure 1). The region has a forest cover of over 63%, which is home to many rare species and vegetation types. The area is remote and has limited access roads. Nevertheless, the forests are subject to pressures from deforestation and poaching, which has led the Lao Government to reserve about 18.5% of the Bolikhamxay province as Provincial or National Protected Area (PCV Management Plan 2010). However, even though poaching is illegal in provincial protected areas, protected area laws are poorly enforced or not enforced at all (Duckworth et al. 1999).

The PES-project (Section 1) aims to stem illegal activity in the PCV PPA by implementing community-led wildlife patrols to combat poaching (Crawford School of Public Policy, 2015). We predict the impacts of patrols on species in the PCV PPA, since payments for village-based patrols will be based on the likely number of animals and species protected.

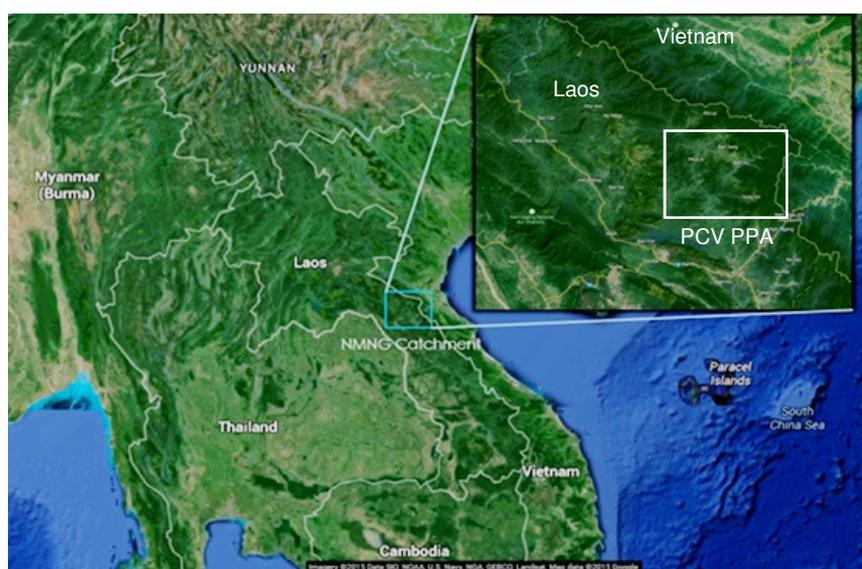


Figure 1. Location of the Phou Chom Voy Provincial Protected Area, Lao PDR. Images adapted from Google Earth.

The PCV PPA is home to many rare and endangered species (Table 1), including red-listed species such as Macaques (*Macaca spp*), Pangolins (*Manis spp*), the Saola (*Pseudoryx nghetinhensis*) and the Annamite striped rabbit (*Nesolagus timminsii*). The populations of these species are in decline, due to over-exploitation and habitat destruction. Illegal hunting is a severe threat and is estimated to greatly impact populations in most of the area, especially impacting ground-dwelling species that are exposed to very high levels of snaring and other forms of ground-level trapping (IUCN 2015).

People living in the Nam Mouane-Nam Gnouang Catchment are predominantly subsistence rice farmers and subsistence hunter-gatherers who rely on small animals such as squirrels and birds as a source of food. However, local subsistence activities are not the main cause of biodiversity loss (Tizard 1996). The removal of endangered species is primarily associated with poachers who target uncommon and endangered species as they tend to be more valuable, not only because of their rarity but for use in traditional food dishes or medicines in neighbouring countries (Tizard 1996). The removal of species through poaching has ecosystem-wide effects, reducing overall ecosystem functionality and resilience, with potential flow-on consequences to local villagers (Vongkhamheng et al. 2013).

3 MODEL DEVELOPMENT

To investigate how poaching impacts conservation species, and test how patrol groups could mitigate poaching pressure, a model was developed in the R software environment (R Core Team). The simulation model runs on a monthly time step. This is in line with the PES project requirements where village patrols are assumed to be on monthly expeditions. In 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 wildlife patrols
- Possible introduction of new poachers and possible movement of poachers and patrols

The model is parameterised using data specific to the PCV PPA. To match proposed patrolling schemes, the PCV PPA was divided up into 1km² grid cells. For each grid cell we estimated habitat quality Q and accessibility to humans A . Habitat quality values are higher in areas with higher forest density or in/next to cells containing waterbodies (Harihar et al. 2014; Simcharoen et al. 2014). Accessibility is determined by proximity to roads, villages and infrastructure.

The model is also parameterised using species-specific data. For each species, the model needs estimates of the initial population P_0 , annual reproduction rate RR , generation length Gen , range of movement $Range$, the probability that the animal will be snared Sn if it enters a grid cell containing snares, the probability that the animal will be killed directly Sh (eg. shot) if it enters a grid cell containing poachers, and the typical group size (Table 1). Annual species' reproduction rate, or 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. The '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 of a defined size within the PCV PPA area, with a preference for cells with higher habitat quality. They are assumed to move throughout this range during each monthly timestep with an equal probability in being in any cell of the range at any time. Wildlife 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.

Poachers and patrols are similarly assigned 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 and/or habitat quality, and can remain fixed or be changed each month. Illegal hunting and poaching in this region occurs by shooting and snaring (Vongkhamheng et al. 2013). Therefore, our 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). Poachers are assumed to move throughout a defined range during each monthly time-step with an equal probability of being in any cell of the range at any time. At each

time step, poachers set snares in the cells in their area. If animals come into contact with poachers then animals are killed with a probability Sh ; and if animals enter a cell with snares then they are killed with a probability Sn .

Village-led patrols are assumed to move throughout their pre-defined range over 25 days of each month with an equal probability of being in any cell of their range at any time. Patrols will find and remove snares in their area with a probability $p_{snarefind}$. If poachers come into contact with patrols, the patrol members will apprehend the poachers with a probability $p_{apprehend}$. At each time step, a new team of poachers may enter the area with a probability $p_{newpoachers}$ and existing teams of poachers and patrols may move area with a probability $p_{poachermove}$ and $p_{patrolmove}$ respectively.

4 DATA AND SCENARIOS

An extensive review of the scientific and grey literature was conducted to determine which threatened or endangered species are currently found in the PCV PPA. This review was augmented by consulting with local experts in the Lao PDR. This process resulted in 19 species to be included in the final model. Data on each species' initial population, 'shoot-ability', 'snare-ability', reproduction rate and mobility was sourced from previous biodiversity studies in the Lao PDR. Where data from Lao were unavailable, information was used from surrounding SE Asian countries, data from global studies, or information for a similar, comparable family species (e.g. *Nesolagus spp*). The best available data was reviewed by local Lao wildlife experts before running model scenarios. The model parameters are listed in Table 1 below. The 'snare-ability' and 'shoot-ability' parameters were estimated for each individual species based on their habitat, size, speed of movement and whether animals live in a group or solitary. The 'snare-ability' and 'shoot-ability' parameters were calibrated based on observed animal losses in the region (Duckworth et al. 2012; Kenney et al. 2005; Steinmetz et al. 2010; Vongkhamheng et al. 2013). This calibration allows for accurate predictions in population and species survival rates with reference to the base scenario (see below). The efficiency of patrols reducing poaching effort is based on realistic data of walking speed, cells visited per day, and snare removal rates reported in other monitoring or poaching studies (e.g. Vongkhamheng et al. 2013; Watson et al. 2013). Additional information on the data collection process, data sources for individual species, calibration process and full model specification is available from the authors upon request.

Table 1. Model parameters used in the PCV PPA wildlife conservation model

Species	Scientific Name	P_0	RR	Gen	Range	Sn	Sh	Group size
Rufous-necked hornbill	<i>Aceros nipalensis</i>	111	2	19	10	0	0.004	5
Asiatic black bear	<i>Ursus thibetanus</i>	114	2	6	70	0.008	0.006	
Tiger	<i>Panthera tigris</i>	1	1	7	200	0.006	0.002	
Clouded leopard	<i>Neofelis nebulosa</i>	5	2	2	35	0.004	0.002	
Sambar	<i>Rusa unicolor</i>	223	1	2	15	0.004	0.008	
Southern Serow	<i>Capricornis milneedwardsii</i>	15	0.68	2.5	5	0.002	0.008	
Large-antlered muntjac	<i>Muntiacus vuquangensis</i>	10	1	0.71	70	0.006	0.008	
Saola	<i>Pseudoryx nghetinhensis</i>	5	1	6	50	0.006	0.008	2
Douc langur	<i>Pygathrix spp</i>	450	1	3	6	0.002	0.01	15
Northern white-cheeked gibbon	<i>Nomascus leucogenys</i>	33	1.25	10	0.17	0.002	0.01	4
Sunda pangolin	<i>Manis javanica</i>	13	1	7	0.45	0.002	0.01	
Chinese pangolin	<i>Manis pentadactyla</i>	2	1.5	7	8	0.002	0.01	
Pygmy slow loris	<i>Nycticebus pygmaeus</i>	16	1	0.58	5	0.002	0.004	

Table 1 (cont). Model parameters used in the PCV PPA wildlife conservation model

Species	Scientific Name	P ₀	RR	Gen	Range	Sn	Sh	Group size
Bengal slow loris	<i>Nycticebus bengalensis</i>	111	1	0.58	5	0.002	0.004	
Large-spotted civet (aka Malabar civet)	<i>Viverra civettina</i>	5	2	1	2	0.006	0.006	
Owston's civet	<i>Chrotogale owstoni</i>	8	2	1	2	0.006	0.006	
Annamite striped rabbit	<i>Nesolagus timminsi</i>	5	2	0.115	0.1	0.006	0.004	
Northern pig-tailed macaque	<i>Macaca leonina</i>	5	1	4	1	0.004	0.01	15
Stump-tailed macaque	<i>Macaca arctoides</i>	25	1	4	1	0.004	0.01	15

We simulated four different model scenarios.

1. Base case (Base) = the base case scenario represents the current situation with poachers and no patrols. As such, it provides the worst-case scenario for sustainable development in the region
2. Low-effort patrols (SC1) = in the low-effort patrol model, 100 of the 223 km² cells are patrolled each month, the probability that patrols apprehend poachers is low (0.1) and the probability that patrols remove poacher camps is low (0.1). The only patrol-poacher interaction in this case is the patrols removing 90% of the snares as they move through grid-cells.
3. High-effort patrols (SC2) = in the high-effort patrol model, the same number of grid cells is patrolled each month (100) but there is a higher likelihood (0.6) that an individual poacher is apprehended if encountered during a patrol, and a 0.9 likelihood that a poacher camp is removed if intercepted. 90% of the snares are removed by patrols when moving through grid cells.
4. High efficiency scenario (SC3) = in this scenario, all cells are patrolled at 100% efficiency, i.e. all poachers are apprehended and all camps removed if they are intercepted. This scenario demonstrates animal survivorship when all 223 km² grid cells are patrolled on a monthly basis, which represents the highest cost patrol scheme but also hypothetically the most effective for mitigating poaching in the area through monthly patrols.

The four management scenarios were run 100 times over a 10 year-period (120 months), to account for the probabilistic elements included in the model (such as the likelihood of an animal being caught or poachers being apprehended). The results reported in Section 5 are the averages over these 100 simulations. At the time of writing, the uncertainty and sensitivity analysis over the 100 simulations are still being completed but are available upon request from the authors. 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.

5 RESULTS AND DISCUSSION

The results clearly show that increasing patrol efforts results in a higher number of individual animals saved (Figure 2), and in a higher number of species surviving (Figure 3). Without any poaching patrol efforts, about 120 animals and less than 2 species would survive in the PCV PPA after 10 years. Increasing patrol effort to the low- and then high-effort scenarios have a larger overall effect on animal counts than on the number of species saved – but there is a marked initial effect on species survival under scenario SC1 compared to the base case (more than 10 species survive on average after 10 years, compared to less than 2 under the base scenario – Table 2).

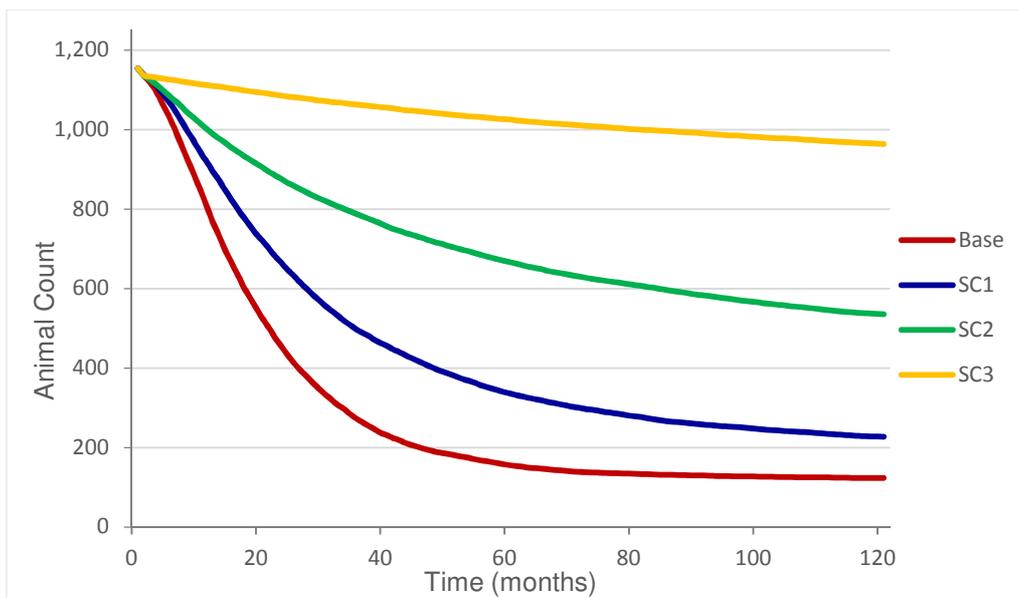


Figure 2. Number of animals remaining in the PCV PPA study area under different poaching management scenarios

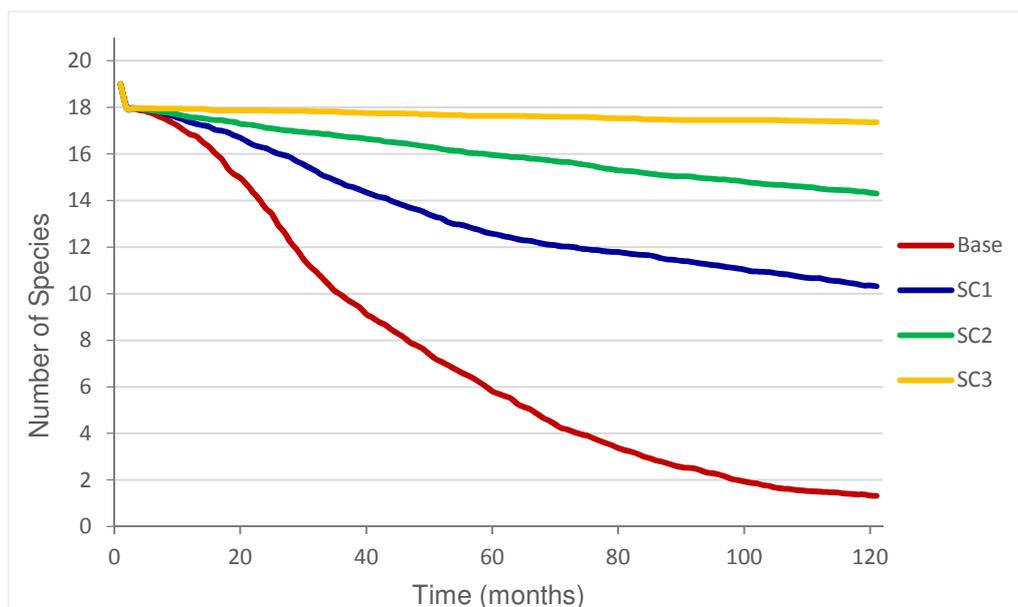


Figure 3. Number of species surviving over a 10-year modelling period under different poaching management scenarios

This suggests that even the most basic patrol scheme modelled will have a substantial impact on preserving species diversity in the region. The reduced rate of species saved represents the fact that some species are very rare, with low initial population counts, and are highly targeted by poachers (with high snare-ability and shoot-ability parameters). These high risk species include the Tiger, Saola and Clouded Leopard spp. The modelling shows that, based on a monthly patrol scheme, these species with very low initial population counts are (on average over the 100 simulations) always poached before management actions can take effect. For the patrol efforts and efficiencies we considered in our modelling (based on realistic estimates that will be used in the PES scheme), these species will ultimately be lost.

The figures and Table 2 further show the impact of poaching is so severe that, when included, poaching always reduces wildlife populations, even under the highest patrolling efficiency scenario. Scenario SC3 is theoretically the most effective for mitigating poaching through monthly patrols, but demonstrates that there is a limit to the effectiveness of wildlife patrols. In our model, community-led patrols move through the area, but are restricted by, for example, their walking speeds and thus the

area they can cover; the fact that snares will not always be found even when a grid-cell is entered; and the limited accessibility due to rough terrain and dense forests. These are all real-world challenges that will need to be considered when rewarding local villagers for their poaching-mitigating patrolling efforts.

Table 2. Average number of animals and number of species surviving at $t = 120$ months. The numbers in parentheses are the percentage increase relative to the base scenario

Scenario	Average number of animals remaining at $t = 120$		Average number of species remaining at $t = 120$	
Base	123		1.3	
SC1	226	(84%)	10.3	(682%)
SC2	535	(335%)	14.3	(983%)
SC3	963	(683%)	17.4	(1215%)

6 CONCLUSION

In this paper, we present a population model that predicts the effectiveness of community-led wildlife patrols to reduce poaching pressure. Our model provides a transparent tool that is being used to inform actual wildlife management in the Lao PDR. The model predictions will inform a 'Payments for Environmental Services' scheme that will pay local villagers to undertake poacher-mitigating patrols. This PES scheme is expected to contribute to biodiversity conservation as well as local livelihoods' development. The predictions from the population model provide a direct input into the amount of payments that could be offered to different level of patrolling efforts by villagers.

It should be noted that, in our model, patrol groups are able to apprehend individual poachers or remove poacher camps when intercepted ($p_{apprehend}$). Realistically, this may need to involve local law enforcers accompanying patrols which would increase the cost of the PES and patrol scheme.

At the current (realistic?) estimates of patrol effort and efficiencies of poacher apprehension, our model results show that even relatively low-effort patrolling schemes are likely to have a substantial benefit for preserving species diversity in the region. Engaging local communities in anti-poaching patrol schemes can thus protect local biodiversity, and provide an income source for local villagers. For this scheme to provide a sustainable source of income, long-term funding sources will need to be secured. Currently, the Lao PDR relies heavily on external donors. However, there may be possibilities to use funds from the Environmental Protection Fund to invest in community-based wildlife management (Irawan et al. 2012).

Our modelling results also show that some of the species at risk may ultimately be lost to the region. One may therefore wish to investigate alternative patrolling strategies. Our model structure is sufficiently flexible to alter the desired time step and update data when more information becomes available (e.g. on wildlife populations P , the probability of finding snares $p_{snarefind}$, or the movement of patrols through the area $p_{patrolmove}$). Currently, our model operates on a monthly time step – which is realistic given the current patrolling contracts, the spatial scale of the area and its rough terrain. Future modelling could consider the effects of alternative patrol contracts with the local communities, such as weekly patrols or patrols that are spatially targeted at known vulnerable habitat areas. The model set-up allows differing patrol methods to be examined, which may help to increase patrol effectiveness and improve survival rates of target species.

Finally, it is worth commenting on the data-poor environment in which this model was developed. There is very little information available about wildlife populations in the Lao PDR, few observations of poacher parties, and no research on the potential effectiveness of village-led wildlife patrols. Our model meets the challenge of this data paucity and the needs of the PES project by including the relevant ecosystem processes populated by the best available data at the time – including literature values from other regions and expert opinion. All parameters in the model are recorded in a transparent manner, allowing for ongoing criticism, refinement and improvement when better information becomes available.

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