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METHODS FOR MONITORING POPULATIONS OF PANGOLINS (PHOLIDOTA: MANIDAE)

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Methods for monitoring populations of pangolins (Pholidota: Manidae)

Prepared by the IUCN SSC Pangolin Specialist Group

and IUCN Global Species Programme

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Executive summary

There are eight species of pangolin, four of which are native to Asia and four native to Africa, all of which are primarily threatened by overexploitation for illegal international trade and local use. However, despite high levels of exploitation, both historic and contemporary, there is a dearth of quantitative data on and knowledge of pangolin populations, with few exceptions. There are also inherent challenges to detecting and monitoring pangolins, including a lack of knowledge of their ecology and behaviour and the fact that they evade detection in non-targeted biodiversity surveys (Khwaja *et al.*, in prep.; Willcox *et al.*, 2019). However, there is an urgent need for robust ecological monitoring methods for pangolins, in order to better understand the status of populations and the impact of exploitation with which to inform conservation management and policy-making at the local to international level. This need has been recognised by CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) by pangolin range states, and by the IUCN SSC Pangolin Specialist Group.

The aim of this guidance is to equip pangolin range states and conservation practitioners with methods that can be used to detect and monitor pangolin populations, including estimating occupancy, abundance and other parameters of interest. It was developed using a combination of systematic literature reviews, a questionnaire with selected experts, and a three-day workshop held in Cambridge, UK in July 2018. It is intended that this document, including future iterations, will provide guidance for government agencies and conservation practitioners seeking to detect, monitor and generate knowledge of pangolin populations in order to inform conservation management. Information is provided on the methods used to develop this guidance, an introduction to pangolin biology and ecology, challenges to and opportunities for detecting and monitoring pangolin populations, and key research needs for monitoring pangolins. Given the limited knowledge of pangolins, researchers and conservationists are encouraged to synthesise and publish incidental pangolin records that they possess to help fill these knowledge gaps.

A proposed approach to pangolin monitoring is presented in addition to a number of methods for monitoring the species. The proposed approach incorporates principles of both targeted and adaptive monitoring in order that future pangolin monitoring avoids the pitfalls of surveillance monitoring. Incumbent to this approach is hypothesis testing about ecological systems and how the target of monitoring (i.e. populations of pangolins) may respond to management decisions, which requires a comprehensive understanding of the underlying ecological systems being studied. While there is not yet such an understanding for pangolins, key research needs to fill knowledge gaps are discussed. Fourteen methods are presented that either have immediate application to the detection and monitoring of one or more species (burrow counts, social research, camera trapping, non-invasive genetic sampling [gNIS], telemetry and detection dogs), methods that have potential application but have not been applied to specific species yet, and methods that have theoretical application but application is dependent on field testing and evaluation (arboreal camera trapping, point counts, artificial nest boxes, exhaustive plot surveys, acoustic monitoring, invertebrate-derived DNA [iDNA]). The application of citizen science is also discussed. In some instances applicable methods have been combined (e.g., burrow counts and camera trapping) and for a number of methods application is dependent on the generation of basic ecological knowledge (e.g., home range size estimates).

If selecting methods for detecting and monitoring pangolin populations it is advisable to read through this guidance in its entirety before selecting methods for implementation. In addition, specific research and monitoring questions, the local context, and available resources will need to be considered when deciding on the most appropriate method(s) to use. Consideration should also be given to existing knowledge on the status of pangolin populations at sites, if it exists, and whether more active monitoring methods may be appropriate (e.g., burrow counts, detection dogs) where densities and detection rates will be very low, compared to passive (‘wait and see’) methods (e.g., camera trapping). There are likely to be sites and circumstances where much more frequent repeat monitoring is needed (e.g., where poaching levels are high) compared to others, while habitat heterogeneity, topography and other circumstances may prevent using a successful approach at other sites even for the same species. In almost all cases it will also be important to collect data and information on hunting/poaching pressure at sites as a key determinant of pangolin presence, occupancy, abundance or other parameter of interest, as well as habitat and other environmental variables. A further key consideration is whether application of a specific method could result in adverse consequences for the target species. For example, if the use of artificial nest boxes would make it easier for poachers to harvest pangolins, the method should not be used. It is also advisable when designing monitoring programmes based on this guidance to seek appropriate expertise at the design stage. This will likely mean involving statisticians, ecological monitoring experts and social scientists to ensure that the design of monitoring programmes is robust and have sufficient statistical power to detect changes in the parameter(s) of interest. In developing this guidance, every effort has been made to consider the variability of sites, habitats, species and local contexts but there are likely circumstances not covered by this guidance. In such circumstances, method selection should be based on the monitoring or research question being asked, the local context and expert advice.

1. Introduction

Pangolins (Pholidota: Manidae) are small to medium-sized myrmecophagous mammals adorned with individual, overlapping scales made of keratin. There are eight species globally, four of which are native to Asia, the Chinese pangolin *Manis pentadactyla*, Indian pangolin *M. crassicaudata*, Sunda pangolin *M. javanica* and Philippine pangolin *M. culionensis*, and four that are native to sub-Saharan Africa, the black-bellied pangolin *Phataginus tetradactyla*, white-bellied pangolin *P. tricuspis*, giant pangolin *Smutsia gigantea* and Temminck's ground pangolin *S. temminckii*. The placement of the species in three genera *Manis, Phataginus* and *Smutsia* is based on morphological and genetic evidence (Gaudin *et al.*, 2009; Gaubert *et al.*, 2018). However, CITES follows the nomenclature adopted by Wilson and Reeder (2005) which places all species in the genus *Manis*.

All species of pangolin are primarily threatened by overexploitation for illegal international trade and local use, having been categorised as Critically Endangered, Endangered or Vulnerable on The IUCN Red List of Threatened Species (IUCN, 2018). However, despite high levels of exploitation, both historic and contemporary, there is a dearth of quantitative data on and knowledge of pangolin populations. The need for ecological monitoring methods for pangolins was discussed in CITES in the late 1990s (see CITES, 2001a, b) but subsequently received little concerted or coordinated attention. Consequently, existing assessments of pangolin status have relied on proxy measures including local ecological knowledge and international trade, trafficking and market dynamics (e.g., Zhang 2009; Nash *et al.*, 2016; Willcox *et al.*, 2019). An exception is South Africa which has national population estimates based on extrapolated densities (see Pietersen *et al.*, 2016a). Estimates also exist for China (see Wu *et al.*, 2002, 2004). This general lack of knowledge is in part due to pangolins being understudied compared to many species (Challender *et al.*, 2012), but also due to a number of inherent challenges in detecting and monitoring the species. For example, they do not use forest trails or other easily identifiable routes when traversing habitat and often go undetected in non-targeted biodiversity surveys (Khwaja e*t al.*, in prep.; Willcox *et al.*, 2019).

There is an urgent need for the development of ecological monitoring methods for pangolins. The best available evidence indicates that populations of Asian pangolins have declined severely as a result of overexploitation, by more than 95% in some places according to some estimates (Duckworth *et al.*, 1999). Similarly, in the last decade, there has been a transfer of international trafficking attention to Africa, with estimates suggesting that the scales of many tens of thousands of African pangolins have been illicitly traded to Asian markets (Challender and Waterman, 2017; Heinrich *et al.*, 2017). Robust monitoring and survey methods for pangolins are needed in order to better understand the status of populations and the impact of exploitation. This information is needed to inform conservation management at local and national levels and policy-making at the international level (e.g., CITES). Such assessments are also critical to understanding the effectiveness of conservation interventions designed to mitigate the threats that pangolins face. This urgent need has been recognised by CITES in Res. Conf. 17.10 *Conservation of and trade in pangolins*, by pangolin range states at the First Pangolin Range States meeting held in 2015 (Anon, 2015), by the IUCN SSC Pangolin Specialist Group in its 2014 global action plan 'Scaling up Pangolin Conservation' (Challender *et al.*, 2014a) and in national and regional pangolin conservation strategies developed since (e.g., Lee *et al.*, 2018).

This guidance was developed as part of a project, 'Equipping pangolin range states to better implement CITES and combat wildlife trafficking through developing monitoring methodologies', funded by the U.S. Fish and Wildlife Service and implemented by the IUCN SSC Pangolin Specialist Group in collaboration with the IUCN Global Species Programme. It is hoped that this document, including future iterations, will provide guidance for government agencies and conservation practitioners seeking to detect, monitor and generate knowledge of pangolin populations in order to inform conservation management.

2. Methodology

In order to develop this guidance a number of activities were undertaken including systematic literature reviews, a questionnaire on detecting and monitoring pangolins that was completed by experts, and a three-day workshop that was held in Cambridge, UK in July 2018.

Two systematic literature reviews were completed in late 2017–early 2018 to evaluate the effectiveness of methods applied to detecting and monitoring pangolin populations and species ecologically similar to pangolins respectively. Both reviews followed best practice guidance developed by the Collaboration for Environmental Evidence (2013). The first review comprised an evaluation of all traceable efforts to survey for and monitor pangolin populations, including attempts to detect and survey populations, produce population estimates, assess conservation status, and ecological research undertaken (see Willcox *et al.*, 2019). The second review evaluated the effectiveness of applied methods to detect and monitor populations of species that are ecologically similar to pangolins in order to identify methods that may have application to pangolins (see Ingram *et al.*, 2019).

An online questionnaire was subsequently developed through which to solicit expert insight on existing application of methods to monitoring pangolin populations, associated challenges and opportunities, notable successes and failures, and key research needs to inform effective monitoring programmes. The questionnaire was completed by 65 respondents comprising invited academics, researchers and conservation practitioners working directly on pangolin monitoring projects or with appropriate expertise. The questionnaire was completed in June and July 2018 using SurveyMonkey.

The systematic reviews and questionnaire were used to inform a three-day workshop ‘Developing ecological monitoring methods for pangolins’ held in Cambridge, UK on 24–26th July 2018. The workshop convened 36 practitioners, researchers and academics with expertise on pangolins, ecological monitoring programmes and statistics. This included individuals working in 16 pangolin range states across the distribution of the eight species: Cameroon, Central African Republic, China, Côte d'Ivoire, Gabon, Ghana, Kenya, Liberia, Malaysia, Nepal, Pakistan, Philippines, Taiwan, Singapore, South Africa and Uganda.

The workshop included sessions focused on: 1) determining the most appropriate conservation management questions for pangolins; 2) challenges and opportunities for effective detection and monitoring of populations; 3) experiences of detecting and monitoring pangolins; 4) the pros, cons, challenges and potential solutions for the application of specific methods for different species; and, 5) for the most appropriate methods, the development of guidance on: a) the parameter of interest (e.g., occupancy, abundance), b) sampling design, c) effort and resource allocation, and d) intended statistical analyses. Methods were designed following guidance on long-term ecological monitoring presented in Gitzen *et al*. (2012), but also considered targeted and adaptive monitoring approaches, recognising limitations to surveillance monitoring (see Nichols and Williams, 2006; Lindenmayer and Likens, 2009).

While certain methods have proven and immediate application to specific species of pangolins, others require piloting and further field testing and evaluation to determine their feasibility and suitability for monitoring pangolins. In some cases methods are dependent on the generation of basic ecological knowledge to inform their application (e.g., home range size to determine appropriate sampling units). Key research needs to inform monitoring are presented in Section 5.

3. Introduction to pangolin biology and ecology

Pangolins are widely distributed in Asia and Africa. In Asia, this extends from northern and eastern Pakistan, south throughout the Indian subcontinent including Sri Lanka, and from the Himalayan foothills east, including Bhutan, Nepal and parts of Bangladesh, across southern China, including Taiwan and Hong Kong, and south throughout mainland and parts of island Southeast Asia, including the Palawan faunal region in the Philippines (Gaubert, 2011; Challender *et al.*, 2014b). In Africa, three species *P. tricuspis*, *P. tetradactyla* and *S. gigantea* occur in west and central Africa, while *S. temminckii* ranges across east and southern Africa and fringes parts of central Africa (Kingdon *et al.*, 2013).

Pangolins occur in a range of habitats including tropical and sub-tropical forests, bamboo, coniferous and broadleaf forests, arid thorn forests, and riverine and swamp forests, savannah woodland and grasslands, savanna-forest mosaics, and artificial landscapes including gardens and monoculture plantations (Gaubert, 2011; Kingdon *et al.,* 2013). Most species are likely habitat generalists, and their distribution is largely determined by that of their prey species; pangolins are myrmecophagous, predating on ants and termites and are prey selective (Irshad *et al.*, 2015; Pietersen *et al.*, 2016b). However, they are known to consume other insects (Irshad *et al.*, 2015). As predators of ants and termites, pangolins perform an ecosystem service by regulating social insect populations. Pangolin distribution and presence may also be determined by water source availability, though *S. temminckii* is largely water independent (Pietersen *et al.*, 2016a). Hunting and poaching pressure is likely to be a key determinant of pangolin presence and occupancy, but the animals can persist in diverse habitats if not persecuted.

All pangolin species are solitary, except when mating or rearing young, and predominantly nocturnal, though most species have been observed active during the day (e.g., Richer *et al.*, 1997; Pietersen *et al.*, 2014). An exception is *P. tetradactyla* which is diurnal (Booth, 1960; Kingdon *et al.*, 2013). The eight species can be distinguished by size and weight, by scale disposition, size and colour, the presence/absence of a tail pad at the tail tip and tail length among other characteristics (Pocock, 1924; Gaubert and Antunes, 2005). Adult weights range from around 2 kg for *P. tricuspis* and *P. tetradactyla* to about 33 kg for *S. gigantea* (Table 1).

Reports suggest that some pangolin species are sexually dimorphic, with males being 10-50% larger than females (Phillips and Phillips, 2018), but this does not apply to all species, including *S. temminckii* (Kingdon *et al.*, 2013; D. Pietersen, unpubl. data). All species give birth to one young at parturition, and though twins have been reported, they are considered to be rare (MacDonald, 2006; though see Mahmood *et al.*, 2015a). Gestation periods between species reportedly range from 140 to 372 days (Chin *et al.*, 2011; Kingdon *et al.*, 2013; Zhang *et al.*, 2015). Available evidence indicates a defined breeding season for *M. crassicaudata* (July–October; Mahmood *et al.*, 2015a) and *M. pentadactyla* (Zhang *et al.*, 2016), while for *M. javanica, S. gigantea* and *S. temminckii*, breeding is aseasonal (Kingdon, 1971; Zhang *et al.*, 2015), and for *P. tricuspis* and *P. tetradactyla* it is continuous (Kingdon *et al.*, 2013). The Asian species may breed annually; a single wild female *M. pentadactyla* in Taiwan has been observed giving birth in consecutive years (N. Sun, *pers. comm.* 2018); frequency of breeding is otherwise unknown but could be annual or biennial. Weaning of young typically occurs at 4-7 months of age (Lim and Ng, 2008a; Kingdon *et al.*, 2013), but young *S. gigantea* do not become independent until their mother gives birth again (Kingdon *et al.*, 2013). Age at sexual maturity is not known for all species, but is reached at 1–1.5 years of age in *M. pentadactyla* and *M. javanica* (Zhang *et al.*, 2015; 2016). Population recruitment rates for all species are unknown. Lifespan in the wild is unknown, and though rare, in captivity pangolins have lived up to 19 years (Wilson, 1994; Yang *et al.*, 2007).

Four pangolin species are fossorial, i.e. burrow dwelling: *M. pentadactyla, M. crassicaudata, S. gigantea* and *S. temminckii*. Each of these species digs their own burrows, with the exception of *S. temminckii* which typically uses burrows dug by other species (e.g., aardvark *Orycteropus afer*). Giant pangolins are also known to use burrows dug by other species (H. Khwaja, *pers. comm.*). Burrows

Table 1. Locomotor category, activity pattern, body mass, estimated home range size and density estimates for pangolins

Species	Locomotor category*	Activity pattern**	Body mass (kg)***	Home range size	Estimated density (individuals/km^2 unless detailed otherwise)
Manis pentadactyla	F	N	3.64	69.9 ha, ♂ (n = 3), Northern Taiwan 24.4 ha, ♀ (n = 1), Northern Taiwan Lu (2005)	0.043/km^2, Guangxi, China 12.8/km^2, Taiwan Chinese National Forestry Administration (2008), Pei (2010)
*Manis crassicaudata*****	F	N	11.96		0.0001 – 0.37/km^2, Potohar Plateau, Pakistan 0.36/km^2, Margalla Hills, Pakistan 0.044/km^2, Khyber Pakhtunkhwa, Pakistan 5.69/km^2,Yagirala Forest Reserve, Sri Lanka Irshad *et al.* (2015), Mahmood *et al.* (2015b, 2018), Pabasara (2016)
Manis javanica	A, F, S	N	4.54	36.4 – 90.7 ha, ♂ (n = 4), Singapore 6.97 ha, ♀ (n = 1), Singapore Lim and Ng (2008a, c)	
Manis culionensis	A, F, S	N	4.54	59 – 120 ha, ♂ (n = 3), Philippines 47 – 75 ha, ♀ (n = 2), Philippines Schoppe and Alvarado (2016; in prep, a).	Mean adult density: 2.5±1.4/km^2 Schoppe and Alvarado (in prep. b)
Phataginus tetradactyla	A	D	2.09		
Phataginus tricuspis	A, F, S	N	1.54		0.84/km^2, Lama Forest Reserve, Benin (dry season) Akpona *et al.* (2008)
Smutsia gigantea	F	N	33.00		
Smutsia temminckii	F	N	9.59	9.28 – 22.98 km^2, ♂ (n = 4), Sabi Sands, South Africa 0.65 – 6.66 km^2, ♀ (n = 8), Sabi Sands, South Africa 10.0 ± 8.9 km^2 for adults (n = 7), 7.1 ± 1.1 km^2 for juveniles (n = 6), Kalahari, South Africa Swart (2013), Pietersen *et al.* (2014)	0.11/km^2 Gokwe, Zimbabwe 0.12 reproductively active adults/km^2, Sabi Sands, South Africa 0.24/km^2 (overall), Sabi Sands, South Africa 0.16/ km^2 reproductively active adults/km^2, Kalahari, South Africa 0.23/km^2 (overall), Kalahari, South Africa Heath and Coulson (1997), Swart (2013), Pietersen *et al*. (2014)

*F = Fossorial, A = Arboreal, S = Scansorial. **N = Nocturnal, D = Diurnal. ***From Myhrvold *et al.* (2015). ****Density estimates in Pakistan are based on one active burrow equating to one pangolin, but this assumption requires further testing.

typically comprise feeding or resting burrows, though resting burrows are sometimes dug adjacent to subterranean ant nests or termitaria. Resting burrows are characteristically much larger than feeding burrows with longer entrances, one or more excavated chambers, and may have multiple entrances and exits (Trageser *et al.*, 2017; Bruce *et al.*, 2018). Pangolins are known to construct a false wall when occupying resting burrows, seemingly to avoid detection by and/or afford protection from predators (Trageser *et al.*, 2017; Karawita *et al.*, 2018). Although fossorial, these species will use other resting structures and spaces including between tree buttresses, under large rocks, in dense grass/thickets, and under fallen logs.

Three pangolin species are semi-arboreal: *M. javanica*, *M. culionensis* and *P. tricuspis*. Adept climbers, they rest in tree hollows and fallen tree trunks and logs, and within the forks of tree branches among other structures. *Mani culionensis* is known to rest in trees and under rocks (Schoppe and Alvarado, 2015). Each of these species has a fleshy tail pad on the ventral side of the tail tip; the tails are prehensile and serve as a fifth limb when climbing and are capable of supporting the animal's full body weight. Typically, fossorial and semi-arboreal pangolins will rest in a burrow for 2–3 nights before moving to another burrow (Lim and Ng, 2008a; Pietersen *et al.*, 2014; N. Sun *pers. comm.* 2018)

Phataginus tetradactyla is almost exclusively arboreal but will descend to the ground to cross open areas (including roads), including when pregnant and carrying a juvenile (M. Gudehus, unpubl. data). Some reports suggest this species is semi-aquatic because it is an able swimmer, like all pangolins, and purportedly moves across its range using swamps and flooded areas (Gaubert, 2011). However, numerous subsequent records of this species occurring in lowland forests away from water bodies casts doubt on this notion; records from along river banks and riverine forests may be due to breaks in the forest canopy enabling detection. Like the semi-arboreal species, *P. tetradactyla* relies heavily on its tail when climbing.

Little is known about social structure in pangolins. Research suggests that *M. pentadactyla, P. tricuspis* and *S. temminckii* are polygynous, with males occupying mutually exclusive home ranges, each of which overlaps with those of several females (Heath and Coulson, 1997; Kingdon *et al.*, 2013). Other research has, however, suggested that *S. temminckii* may be monogamous with the home ranges of a single male and female closely mirroring each other (Pietersen *et al.* 2014). *Manis culionensis* may also be polygynous (Schoppe *et al*., in prep). *Phataginus tricuspis* is territorial (Kingdon *et al.*, 2013) but territoriality is poorly understood in *S. gigantea*. In contrast, *S. temminckii* does not defend a territory, but like some other pangolin species it does scent mark using urine (Kingdon *et al.*, 2013). Existing research has produced some estimates of parameters important to ecological monitoring programmes, including home range size and densities, though various knowledge gaps remain for serval species (see Table 1). This information suggests that *S. temminckii* occurs at naturally low densities (Pietersen *et al.*, 2014); in contrast, *M. pentadactyla* has been recorded at densities of up 12.8 pangolins/km^2 in Taiwan (Pei, 2010).

Pangolins do not vocalise but they do make considerable noise when digging into or tearing apart ant nests and termitaria (Willcox *et al.*, 2019) and sniff and exhale audibly while foraging. They have a distinctive odour, and some species also secrete a foul-smelling scent from glands near the anus (Kingdon *et al.*, 2013). They do not make latrines but will conceal their scat; *M. javanica* is known to bury its faeces in captivity (Willcox *et al.*, 2019), *S. temminckii* buries its scat or defecates in burrows (D. Pietersen and W. Panaino, *pers. obs.*), and *P. tetradactyla* has been observed defecating in tree hollows high up in the forest canopy (R. Cassidy, *pers. obs.*). Pangolins otherwise leave a number of field signs including burrows (feeding and resting), footprints and tracks, tail drags, claw marks, and feeding signs (e.g., disturbed ant nests and termitaria). However, confidently attributing such signs to pangolins, as opposed to other species, and/or distinguishing signs between sympatric pangolin species, is challenging, and in many cases is impossible based on visual assessments alone. Predators of pangolins include large cats (e.g., lion, tiger, leopard, clouded leopard), sun bears, pythons, hyenas, possibly jackals, and chimpanzees (Lim and Ng, 2008b; Kingdon *et al.*, 2013; Phillips and Phillips, 2018).

4. Challenges and opportunities

4.1 Challenges to detecting and monitoring pangolins

There are a number of challenges to detecting and monitoring pangolins. They include a lack of detailed information and knowledge of the ecology and behaviour for most species with which to inform the design of suitable monitoring protocols, challenges to the application of specific methods, and practical constraints to monitoring in terms of logistical and resource issues. The latter includes the need for conservation practitioners to generate funding for staff time to undertake monitoring; lack of capacity in local organisations in pangolin range states; problems associated with acquiring necessary permissions to complete monitoring; restrictions limiting the application of specific methods (e.g., prohibition on taking dogs into national parks in Thailand) and, the presence of hazardous species (e.g., elephant, lion, and tiger) at sites where monitoring is to be conducted. Although recognising these issues, the remainder of this discussion focuses on challenges associated with the actual application of methods for detecting and monitoring pangolin populations.

A major challenge to monitoring pangolins is a lack of knowledge of the species' life history, ecology and behaviour. Although some basic knowledge exists (see Section 3), many gaps remain that would aid in the design of monitoring protocols. For instance, the absence of home range size estimates for multiple species, including across habitat types and seasons, makes it difficult to accurately determine suitable sampling units for various species. Lack of information on pangolin densities (see Table 1), again including across different habitat types and by season, prevents approximate estimation of pangolin populations by scaling up site densities across the extent of geographic ranges (e.g., Hearn *et al.*, 2017). Little is known about habitat use, preferences (though see Swart, 1996; Wu *et al.*, 2003; Mahmood *et al.*, 2014; Pietersen *et al.* 2014) and whether pangolin ecology differs between natural habitats and artificial and degraded landscapes (Lim and Ng, 2008c). Micro-habitat use is also not well understood. For example, it is currently not known what determines the use of different resting structures (e.g., tree hollows, fallen logs, dens, tree forks, swamps) by different species and the extent of trail use by different species. Equally, if and how levels of activity and circadian patterns differ between species, by season, the lunar phase, and climatic conditions, remains largely unknown (though see Pietersen *et al.*, 2014) but will influence detectability and application of methods discussed in this guidance document. In addition, over-exploitation has resulted in some pangolin populations being left in difficult-to-access mountainous areas, particularly in parts of South-east Asia, which while providing some protection from hunting, presents challenges to the application of standard monitoring techniques.

There are also challenges and limitations to detecting and monitoring pangolins using specific methods. Pangolins have been infrequently recorded on camera-traps set as part of general biodiversity surveys (Willcox *et al.*, 2019), especially where populations have been heavily depleted. For example, in an analysis of available camera trap records across Asia incorporating more than 100 surveys and over 290,000 trap nights, resulting detection rates for *M. javanica*, *M. crassicaudata* and *M. pentadactyla* were lower than 0.01 (detections per five-day sampling occasions; Khwaja *et al.*, 2019). Placing camera traps at suspected or known field signs over 13,260 camera-trap-nights did not improve detection rates for *M. javanica* (ZSL, 2017); it also did not guarantee detection of *S. gigantea* in Cameroon (Bruce *et al.*, 2018). Placing camera traps randomly did generate sufficient detections (47 in 29,188 trap nights) to model *M. javanica* occupancy for three study sites in Borneo, but only when combined with detection information across a community of mammal species using Bayesian methods (Wearn *et al.*, 2017). Camera traps may have some application for ground-dwelling pangolins where populations have not gone through substantial declines or where they can be used at sufficient scale and density, though the resources involved may make this prohibitively expensive (Willcox *et al.*, 2019). Due to their pelage characteristics and the current image sensor resolution of commonly-used camera traps it is not yet possible to identify individual pangolins using natural 'marks' such as the scale pattern and disposition of individuals (though see Section 4.2), which precludes the use of capture-recapture methods for estimating density. Estimating densities using camera traps without individual recognition (Rowcliffe *et al.*, 2008) is in its infancy but is a current active research area (e.g., Augustine *et al.*, 2018; Stevenson *et al.*, 2018).

Further frustrating detection and monitoring efforts is the fact that attributing field signs to pangolins is challenging (perhaps with the exception of burrows for some species; see below). This is because the animals create signs (e.g., feeding signs, scratch marks) that are similar to many other species (e.g., mongoose, red river hog, monitor lizards, duikers and porcupines among others), and sympatric pangolin species, and in many instances, it is not possible, even for experienced surveyors, to confidently determine that signs were made by a pangolin, or indeed a specific pangolin species. Additionally, pangolin scat is buried, left in burrows, or reportedly deposited in tree hollows, hindering the direct application of scat-based methods (e.g., estimating occurrence based on scat or using DNA-based capture-recapture).

Burrow occupancy and burrow count/density methods have been applied to pangolins but challenges remain to their application. Locating burrows is difficult for multiple species. They may be concealed by vegetation or in difficult to access locations. For example, *M. pentadactyla* is reported to prefer burrows on slopes with a gradient of 30-60° with a high degree of undergrowth (see Wu *et al.*, 2003). Equally, *S. gigantea* and *S. temminckii* are known to use resting structures other than burrows, though determination of when and under what conditions is unknown for *S. gigantea.* Research on *S. temminckii* suggests use of structures other than burrows is opportunistic; dispersing individuals tend to use these structures with adults with established home range invariably using burrows (Pietersen *et al.*, 2014). It is also difficult to identify and locate resting structures for semi-arboreal and arboreal pangolins meaning burrow or den-based methods cannot be applied to these species. For example, resting structures may comprise tree hollows at different heights or within fallen logs, or under large rocks among others. Additionally, confidently identifying pangolin burrows, and burrows excavated by other species but which are being used by pangolins, is also a challenge, as can be distinguishing between feeding and resting burrows. A lack of knowledge on burrow occupancy is another challenge. It is not known how many burrows individual pangolins use over time or the rate at which new burrows are created or commandeered, with one exception. Lin (2011) estimated that over 249 tracking days in Taiwan, a male *M. pentadactyla* used 72–83 resting burrows and a female, 30–40 resting burrows. It is otherwise known that some species, including *M. javanica* and *S. temminckii*, tend to use one burrow for 2–3 nights before moving to another (Lim and Ng, 2008a; Pietersen *et al.*, 2014). Equally, there have been observations of *M. crassicaudata* where three individuals were using one burrow at the same time (Mahmood *et al.*, 2015a).

Nocturnal surveys have been used to monitor pangolins but also present challenges. Pangolins do not have a strong eye shine which precludes detection (Willcox *et al.*, 2019), and when this method was attempted on *M. javanica* in Singapore, the animals moved away when they detected the presence of surveyors (H. Nash, *pers. comm.*). The probability of detection using this method is insufficient for population monitoring. In Malaysian Borneo, night transects resulted in only one detection of *M. javanica* per 50 km walked (O. Wearn, *pers. comm.*), while transects conducted at night by vehicle resulted in zero sightings despite a transect length of 200 km (O. Wearn, *pers. comm.*). Conversely, conducting transects along swept pathways in tropical forest (to avoid creating noise from leaf litter) in Central African Republic did result in the detection of *P. tricuspis* with comparatively little survey effort (see Willcox *et al.*, 2019).

Radio-telemetry based methods have been successfully used to monitor *M. pentadactyla*, *P. tricuspis* (e.g., Pagès, 1975), *S. temminckii*, and seemingly *M. culionensis* (see Willcox *et al.*, 2019. However, a key challenge is not being able to locate the animals when they are in burrows (N. Sun, *pers. comm.*). For other species, in particular *M. javanica*, a key challenge is preventing the detachment of radio-tags. This follows detachment rates of up to 80% in the first 14 days of tracking, despite the application of methods used for other pangolin species (Willcox *et al.*, 2019). Other challenges associated with telemetry-based methods include the breakage of equipment during foraging and burrow entry (e.g., antennas), the size and lifespan of batteries, equipment cost, and GPS accuracy, all of which could be improved.

A number of other methodological challenges have also been identified. Although pangolins are known generally to prey on ants and termites, there is currently insufficient information on more specific prey preferences for most species, and if and how this changes by season, in order to inform potential monitoring methods targeted towards prey species. Finally, while local communities can be a valuable source of information and data on pangolins, challenges to applying social science research methods include uncertainty regarding the reliability of data and site level recall, the ability of local people to differentiate between sympatric pangolin species, and issues of trust over sharing information and data.

4.2 Opportunities for detecting and monitoring pangolins

Despite the challenges outlined above, there are myriad opportunities for improving detection and monitoring of pangolins, and existing methods have had some success. Based on estimated densities of mature *S. temminckii* and its geographic range in South Africa, Swaziland and Lesotho, Pietersen *et al.* (2016a) estimated the mature population size in this region to be within the range of 7,002–32,135 individuals, and most likely 16,329–24,102 individuals. Populations in China have also been estimated (see Wu *et al.*, 2002, 2004). In addition, long-term research has been conducted in Taiwan, which has demonstrated the application of a variety of methods for monitoring populations, including burrow occupancy and mark-recapture methods to estimate population size, the application of radio-telemetry and camera trapping. This research is generating knowledge of *M. pentadactyla*, for example on social structure, burrow occupancy and breeding ecology (e.g., Pei, 2010; Sun *et al.*, 2018). The presence of all eight pangolin species has also been detected using camera traps, and there has been success in estimating multi-year trends in occupancy and abundance, albeit imprecisely, using camera-trap data for *M. javanica* but only when combined with detection information from a community of mammal species using Bayesian methods (Wearn *et al.*, 2017). Radio-telemetry methods have enabled estimates of home range size for *M. culionensis* and *S. temminckii* (Table 1). Local ecological knowledge has been used to assess the status of species including *M. pentadactyla* (Nash *et al.*, 2016).

Conservation research on pangolins is being undertaken by an increasing number of government agencies, academics and conservation practitioners across pangolin range states on all eight species.

This includes research to fill important knowledge gaps (see Section 5) and methods encompassing radio telemetry, camera trapping, citizen science, social science research methods, burrow counts, occupancy and mark-recapture methods, transect-based methods, night surveys, and detection dogs, among others. These efforts are having some success. Recent research on *S. gigantea* in Gabon has generated reasonable detection probabilities using camera traps (K. Abernethy, *pers. comm.*), and similar research is underway in Uganda (S. Nixon, *pers. comm.*), while detection dogs have been successfully trialled in the detection of *M. pentadactyla* and *M. javanica* and their signs, including buried scat, in Nepal and Vietnam (Anon, 2018). New field techniques and methods are also being generated. For example, ant-eating chats *Myrmecocichla formicivora* in South Africa may hover over *S. temminckii* when it is foraging diurnally which could have application for detecting this species (W. Panaino, *pers. comm.*). Similarly, marking *S. temminckii* individuals by drilling a hole in the non-vascular part of a dorsal scale is being trialled in order to employ mark-recapture methods (W. Panaino, *pers. comm.*). Research in Taiwan and Sabah, Malaysia on *M. pentadactyla* and *M. javanica* respectively, indicates that when flies are present at the entrance to burrows, there is a very high likelihood that the burrow is occupied by a pangolin (N. Sun and E. Panjang, *pers. comm.*). Additionally, identification of individual *S. gigantea* on camera trap images using scale pattern and disposition is being trialled in Uganda (S. Nixon, *pers. comm.*).

There are also potential statistical and modelling solutions to the current challenge of sparse pangolin data, caused by low detectability. Estimation of population parameters is central to monitoring for conservation and management decisions. However, monitoring pangolins is generally difficult, and is compounded where populations have been reduced by overexploitation and where detection rates are low. There is a rich and on-going history of statistical methodological developments to improve estimation of population parameters. Critical to this process has been the acknowledgement that individuals and species are not detected perfectly, and that imperfect detection can bias population estimates, while unmodeled heterogeneity in detection can compromise inference and mask or mislead important effects on populations. The use of model selection practices (i.e., multimodel inference based on information criteria) in the estimation of population parameters has resulted in prolific research on the factors that affect those parameters, substantially improving our ability to make informed management decisions. Bayesian estimation can allow for more precise estimates, even when density, occupancy, or detection is low, and hierarchical models improve inference by directly linking hypotheses about the underlying state space (what determines the distribution of individuals across space) to observational models of how we detect those patterns imperfectly. Models are available to estimate occupancy, abundance, and density from numerous field study methods and can often be tailored to the study system at hand. There are also an increasing number of options for estimating density for species without natural marks or with partial marks that could prove applicable for pangolin monitoring. Thus, by simultaneously considering the parameters of interest, the field methods and statistical models available, it is possible to provide more rigorous estimates and robust inferences about pangolin status and trends over time than has been possible to date.

Opportunities might also exist in technology in the future. For example, the advent of 'Narrowband IoT' (Internet of Things) and 5G will likely mean it will become standard for camera traps to transmit high resolution photographs to researchers in real time, perhaps having used built in machine learning to filter the images down to only those containing pangolins (A. Davies, *pers. comm.*), which would improve the efficiency of monitoring. The introduction of thermopiles and bolometers (which detect species based on a low-resolution thermal image of a species) in the next few years might also offer a low-cost alternative to camera traps for detecting particular species, including pangolins. Advances are also being made in other areas including acoustic-based monitoring devices (e.g., AudioMoth) and open source bio-logging equipment, the group aggregated purchase of which (e.g., through GroupGets) means such technology is becoming much more affordable. Challenges, remain, however in processing large volumes of audio data. The use of gNIS (non-invasive genetic sampling including eDNA and faecal DNA) or iDNA (e.g., from leeches or other invertebrates in the environment; Schnell, 2015; Drinkwater *et al.*, 2018) could have application to detect and monitor pangolin populations. The use of RFID tags with Bluetooth or other technologies could also have application to signal when pangolins have entered or exited burrows, providing a 'doorbell' technique, which could aid in understanding when burrows are occupied. Finally, the use of drones could make getting fixes on radio-tracked pangolins much more efficient than at present, particularly in areas that are hard to access or traverse (e.g., limestone forests).

5. Key research needs to inform pangolin monitoring

There is limited knowledge of pangolins and their ecology and biology which prevents effective application of a number of monitoring methods and hinders the generation of knowledge with which to manage populations. Research is needed to fill these knowledge gaps which should enable pangolin monitoring to be more targeted as opposed to opportunistic in the future. Researchers and conservation practitioners are encouraged to synthesise and publish incidental pangolin records that they possess to help fill these knowledge gaps. However, there are a number of specific research needs that were identified during the development of this guidance. They include the following:

- Knowledge of home range size for the different species and how it changes across habitats and by season, including distances travelled per unit of time (e.g., day).
- The factors determining the distribution of pangolins at the macro- and micro-scale.
- Potential habitat preferences, understanding of habitat use and if and how this changes by season, including natural habitat *versus* artificial and degraded landscapes, and the ability of pangolin species to persist in isolated blocks of monoculture habitat (e.g., oil palm plantations).
- Burrow occupancy and use and how this changes by species, sex, lunar phase and season, and factors determining the use of burrows *versus* other resting structures.
- The structure and demography of pangolin populations.
- Population recruitment and growth rates for the different species, and typical dispersal behaviour.
- Accurate circadian patterns and if and how they change by season.
- Prey preferences and if and how this changes by season.
- How pangolins adapt to anthropogenic disturbance.

6. Monitoring methods and approach for pangolins

There remains a long way to go in order to comprehensively understand pangolins and their ecology in order to effectively monitor and manage populations in order to achieve conservation objectives. However, existing successes and failures and increasing interest, funding and research for pangolins, augurs well that knowledge gaps can be filled in order to inform monitoring and conservation management. The aim of this guidance is to equip pangolin range states and conservation practitioners with methods that can be used to detect and monitor pangolin populations, including estimating occupancy, abundance and/or other parameters of interest. In interpreting this guidance it is important to distinguish between methods that have proven and immediate application to pangolins, and those that have not been applied to pangolins, or specific species to date, and therefore require piloting and/or field testing and evaluation to determine their feasibility and suitability. In many instances method application is dependent on the generation of basic ecological knowledge (e.g., home range size estimates to determine appropriate sampling units) to inform the feasibility of methods discussed in this guidance document.

The approach taken in developing this guidance was to address key considerations in the design of long-term ecological monitoring programmes adapted from Gitzen *et al.* (2012). This included consideration of the following key components of monitoring programmes:

- **Parameter of interest:** primarily presence, occupancy, or density, but also relative abundance, survival, resource selection and other information about space use. When parameters of interest are discussed below, they are done so with the understanding that confirming presence is the minimum standard for population monitoring over time, followed by occupancy rates, and that density estimates (or abundance/area) provide the greatest information for understanding ecology and for conservation, but are also the most difficult to estimate and often require more extensive methods. Relative abundance is an index that has at times been used as a surrogate for population parameters. However, inference is questionable because it is very difficult to meet the assumptions needed to account for underlying heterogeneity of observations and counts. Direct estimation of the parameters (i.e. occupancy, abundance, density) is preferred.

- **Statistical analyses:** possible statistical analyses to be conducted to estimate parameters of interest.
- **Sampling design:** how the sample units will be selected, consideration of which should include stratification across spatial variables that may influence patterns in detection and occupancy or density, and inclusion of factors with conservation implications (addressing status+ questions – see below).
- **Response design (sampling protocol):** how the data will be collected in the selected sample units, what information should be recorded, and what information will be critical to unbiased estimates of parameters of interest.
- **Effort and allocation planning:** the level of effort required to attain adequate quality information.

As a result, there are a number of methods and approaches proposed (see Section 6.1–6.14). In some instances, methods have been combined (for example the use of burrow counts and camera trapping to determine occupancy) and readers are strongly advised to read through this guidance in its entirety before selecting methods for implementation. Local context and available resources also need to be considered when deciding on the most appropriate methods. There are likely to be sites and circumstances where much more frequent repeat monitoring is needed (e.g., where poaching levels are high) compared to others, while habitat heterogeneity, topography and other circumstances may preclude transplanting one approach to other sites. Consideration should also be given to local context and existing knowledge of pangolin populations at sites and whether more active monitoring methods may be appropriate (e.g., burrow counts, detection dogs) where densities and detection rates will be very low, compared to passive ('wait and see') methods (e.g., camera trapping). In almost all cases it will be important to collect data and information on hunting/poaching pressure at sites as a key determinant of pangolin presence, occupancy, abundance or other parameter of interest. Another key consideration is whether application of a specific method could result in adverse consequences for the target species. For example, if the use of artificial nest boxes would make it easier for poachers to harvest pangolins, the method should be avoided. Importantly, it is advisable when designing monitoring programmes based on this guidance to seek appropriate expertise at the design stage. This will mean involving statisticians, ecological monitoring experts and social scientists to ensure that the design of monitoring programmes is robust and that they have sufficient statistical power to detect changes in the parameter(s) of interest (Gitzen *et al.*, 2012). Every effort has been made to consider the variability of sites, habitats, species and local contexts when developing this guidance but there are likely circumstances not covered by this guidance. In such circumstances, method selection should be based on the monitoring or research question being asked, the local context and expert advice.

The approach taken here was also to incorporate principles of targeted and adaptive monitoring, and it is recommended that future pangolin monitoring efforts embrace these principles. This approach was taken in an effort to avoid future pangolin monitoring efforts suffering from the pitfalls of surveillance monitoring, including poorly designed and focused projects (e.g., collecting monitoring data for the sake of it), lack of management-orientated hypotheses guiding monitoring efforts, and the inefficient use of conservation resources (see Nichols and Williams, 2006). The intention is not to dismiss surveillance monitoring for pangolins entirely, especially because it can, and is, generating useful information for management, but to encourage future ecological monitoring efforts for pangolins to go beyond surveillance monitoring. Targeted monitoring is characterised by both monitoring design and implementation being based on hypotheses about the response of biological or ecological systems to management decisions (Nichols and Williams, 2006). It entails defining specific monitoring objectives based on conservation management information needs, and in particular, asking the right questions to inform management decision-making. This can be eloquently characterised as asking ‘status+’ questions, i.e. asking questions that will provide information on species status and information useful for conservation management, as opposed to asking questions about status alone. For example, an alternative question to, ‘what is the density of pangolins in a given area?’ could be ‘are pangolin densities higher in areas with ranger patrols?’ The latter question, assuming appropriate monitoring methods are used in order to test this hypothesis (e.g., by monitoring in comparable areas with and without ranger patrols), would enable management decisions to be informed. In this case it could entail increasing the coverage of ranger patrols if densities were found to be higher in areas with patrols. Although answering such questions will likely require more data compared to surveillance monitoring, the major benefit to this approach is the ability to inform conservation management and determine status (i.e. the approach is additive not alternative).

Adaptive monitoring is characterised by the incorporation of new questions into monitoring approaches but without affecting the integrity of key indicators being measured (see Lindenmayer and Likens, 2009). Monitoring programmes adopting this approach have a number of characteristics. They should i) address well-defined and tractable questions; (ii) be based on robust statistical design, iii) be based on a conceptual model of the system being studied and how components of the system, e.g., species populations, might function and respond, and iv) should answer questions of relevance to conservation management (Lindenmayer and Likens, 2009; Gitzen *et al.*, 2012). Critical to informing appropriate questions is the development of conceptual models of the species or ecosystem being studied. Although such models do not yet exist for pangolins, they are being developed and in the interim, existing exercises that have evaluated the viability of pangolin populations and the pressures on them may provide a useful substitute (e.g., Lee *et al.*, 2018). The use of such models allows specific questions to be framed, in order to collect data to answer questions about the system and the target of monitoring (Lindenmayer and Likens, 2009).

Incumbent to both targeted and adaptive monitoring is hypothesis testing about ecological systems and how the target of monitoring (e.g., pangolin occupancy, abundance) may respond to management decisions. This necessitates a need to comprehensively understand the underlying systems being studied. This is currently not the case for pangolins because they have received little research attention to date. However, key research needs have been identified (see Section 5), which if met, should allow a better understanding of pangolin species and their biology and ecology to inform future monitoring.

There are 14 methods presented in the remainder of this section that are applicable to one, multiple or all pangolin species (Table 2). A number of these methods have existing application to pangolins (e.g., burrow counts, social research), while a number have not been tested to date and require development, initial field testing and evaluation (e.g., arboreal camera traps, acoustic arrays) (see Table 2). It is important to distinguish between these methods when designing monitoring programmes based on this guidance. Additionally, combinations of several methods can improve the inference for parameters of interest, and in particular, population density, often the ultimate objective for population monitoring. In the remainder of this section each method is presented with details on the type of parameters they can provide information and data on, the species that they are applicable to, and information on the design of suitable monitoring programmes using these methods. Specifically, for each method the following components are discussed: 1) parameter of interest, 2) statistical analyses, 3) sampling design, 4) response design, 5) effort and allocation planning, 6) key assumptions, 7) revisitation design, 8) advantages and disadvantages, 9) cost, and 10) any important notes. Discussion of a method feasibility where populations are at low densities due to overexploitation for example, and where sympatric pangolin species are present is presented in the specific section for each method as appropriate.

Table 2. Methods for detecting and monitoring different pangolin species. Methods with demonstrated application are shaded dark green, methods with potential application to species are shaded light green, and methods with theoretical application but which require proof of concept or field testing and evaluation are shaded orange.

Guidance section	Method	Species							
		Fossorial				Semi-arboreal			Arboreal
		Manis pentadactyla	*Manis crassicaudata*	*Smutsia gigantea*	*Smutsia temminckii*	*Manis javanica*	*Manis culionensis*	*Phataginus tricuspis*	*Phataginus tetradactyla*
6.1	Burrow counts/detections								
6.2	Social research								
6.3	Camera trapping								
6.4	Non-invasive genetic sampling (gNIS)								
6.5	Telemetry								
6.6	Detection dogs								
6.7	Arboreal camera trapping								
6.8	Point count								
6.9	Artificial nest boxes								
6.10	Exhaustive plot surveys								
6.11	Prospection/reconnaissance surveys								
6.12	Acoustic monitoring								
6.13	iDNA								
6.14	Citizen science								

6.1 Burrow counts or detections

Burrows have been used to estimate ecological parameters for pangolins including *M. pentadactyla*, and *M. crassicaudata* populations in parts of Pakistan (e.g., Mahmood *et al.*, 2014). However, estimates in Pakistan have been based on a number of assumptions, including that one active burrow equates to the presence of one pangolin (see Willcox *et al.*, 2019). This requires further testing, however, because it is known that individuals of other pangolin species typically use a burrow for 2–3 nights before moving to another and have multiple 'active' burrows; conspecifics are also known to use unoccupied burrows of other pangolins (i.e. two different animals may use the same burrow in a short period of time).

Further research is needed on burrow architecture, occupancy and use by species that are principally fossorial, *M. pentadactyla*, *M. crassicaudata* and *S. temminckii.* Additionally, although *S. gigantea* is fossorial, it is also known to use other resting structures and further research is required to better understand its use of burrows *versus* other structures, in order to inform whether burrow-based monitoring methods could have application. Burrow searches may be used to confirm presence and estimate occupancy, although detection of burrows alone is not sufficient (there must be confirmation that at least one burrow at a site is presently occupied by a pangolin).

Detection of burrows can be difficult depending on habitat features and terrain resulting in missed detections (false negatives). However, recent statistical developments intended to estimate gopher tortoise populations in the U.S. combine distance sampling and estimation of burrow occupancy rates (Stober *et al.* 2017) and offer the opportunity to estimate pangolin density for suitable pangolin species with appropriate study design and sampling considerations. This will not be applicable in all situations, particularly in sites where access is difficult because of the terrain; a situation that is relevant for many of the extant *M. pentadactyla* populations. In these situations other methods including detection dogs (Section 6.6) and exhaustive plot surveys (Section 6.10) may need to be considered.

Species applicable to: *M. pentadactyla, M. crassicaudata, S. temminckii*

Parameter of interest	Presence, occupancy, abundance, density
Statistical analyses	**For confirming presence:** none required, although previous studies could be used to estimate the effort that would be required to likely detect an occupied burrow (e.g., power analysis) to ensure adequate effort is applied. **For occupancy estimation:** single-season single species occupancy models, or dynamic occupancy models. **For density estimation:** hybrid sampling design combining distance sampling and burrow occupancy estimation (see Strober *et al.* 2017). Abundance can be derived from density.
Sampling design	**For confirming presence:** systematic search by site or transects and examination of burrows found to confirm at least one individual. **For occupancy estimation:** sample the study site(s) by randomly or systematically selecting plots or transects separated at minimum by the approximate diameter of the home range size of the study species. **For density estimation:** place multiple radial points or transect lines or areas randomly or systemically, depending on research question and design (Buckland *et al.* 2001).
Response design	**For confirming presence:** on encountering burrows, confirm occupancy using endoscope/borescope, or by placing a camera trap, or sweeping burrow entrance and leaving overnight. **For occupancy estimation:** recording detection/non-detection data of both occupied and unoccupied burrows at sampling plots over repeated visits, or using multiple independent observers or multiple burrow searches to estimate detection rates. On encountering burrows, confirm occupancy using endoscope/borescope, or by placing a camera trap, or sweeping burrow entrance and leaving overnight. **For density estimation:** one or multiple independent observers walk or otherwise traverse each transect and identify pangolin burrows recording the distance each burrow is detected from the transect (use a laser range finder or transect tapes to estimate distance if needed). On encountering burrows, record detection or non-detection of pangolin using endoscope/borescope, or by placing a camera trap, or sweeping burrow entrance and leaving overnight.
Effort and allocation planning	Simulation or power analysis can allow for adequate sample sizes including number of sites (occupancy) or number and length of transects per area (occupancy or density) and number of repeat visits (if using temporal replicates for site occupancy). See appendix. While population density is the ideal parameter of interest for providing information on status and for management and conservation decisions,

	when population density is very low, it may be preferable to stratify effort over larger areas and collect less-intensive data for estimating site occupancy. A small-scale pilot study could assist in determining which approach will be the more informative given financial and logistic constraints.
Key assumptions	**For confirming presence:** a live pangolin must be confirmed in a burrow (i.e., using a scope or camera trap). **For occupancy estimation:** surveyors can accurately identify pangolin burrows and distinguish unoccupied burrows from those of other species (false positives). Heterogeneity in detection of burrows can be accounted for (particularly important as differences in habitat, vegetation cover, and seasonality can affect detection of burrows and should be recorded and utilized as covariates in occupancy models). **For density estimation with distance sampling and burrow occupancy approach:** surveyors can accurately identify pangolin burrows and distinguish them from burrows of other species. Heterogeneity in detection of burrows can be accounted for (particularly important as differences in habitat, vegetation cover, and seasonality can affect detection of burrows and should be recorded and utilized as covariates in distance sampling models).
Revisitation design	Repeat surveys could be completed annually, biennially or at other time intervals (e.g., summer and winter, every three years) and should be informed by the local context, monitoring needs and available resources.
Advantages and disadvantages	*Advantages*: relatively inexpensive and quick to implement; an active monitoring method that will likely improve detection rates compared to passive detector arrays. *Disadvantages*: may require large number of transects or sites if detection and/or occupancy are very low, including in potentially dangerous terrain. Experience required to locate and identify burrows – this may require additional surveyors including local community members or indigenous peoples.
Cost	Can be relatively inexpensive compared to some other methods, though is site dependent. Requires only a GPS, a transect tape, and a boroscope or equivalent, though training is required for survey teams on sampling protocols. Substantial resources will be required for distance sampling in various habitat types (e.g., flooded peat-swamp forests, evergreen limestone forests) where access and placement of transects is challenging.
Notes	Burrow occupancy can be determined quickly by confirming presence of the study species (e.g., by sweeping burrow aprons [not applicable in all habitats or seasons] and checking for tracks, with a camera trap outside burrows or by using an endoscope/borescope). This may require repeat visits to burrows. Information on burrow characteristics should be collected on encountering burrows (e.g., entrance diameter, depth (if feasible), habitat type, slope, aspect, surrounding vegetation). Ideally, surveyors would complete training prior to data collection.

6.2 Social research

Social research, which for the purpose of this guidance includes social science research methods and methods seeking to acquire traditional or local ecological knowledge and hunting data, has been used to generate information, data and knowledge of pangolin populations and to make inferences on the status of species (e.g., Newton *et al.*, 2008; Nash *et al.*, 2016). A range of different methods exist to collect relevant data from local communities and indigenous peoples, and other stakeholders, which include but are not limited to questionnaires, a range of interview methods (e.g., unstructured and semi-structured interviews), and participatory mapping, and a range of methods exist that can be used to ask sensitive questions (see Nuno and St John, 2015). These methods can be used to collect data on the presence on pangolins (e.g., at the site level), can be combined with other methods to estimate occupancy (Brittain *et al.*, 2018), which if combined with home range data can be used to estimate abundance, and can be used generate relative indices of abundance. However, caution must be used in areas where more than one pangolin species is present as respondents can describe multiple 'types' of pangolin (e.g., Newton *et al.* 2008), but which may not equate to species. Social research methods can be coupled with field methods by providing initial information about areas where more intensive surveys may be productive in an adaptive sampling framework. These methods have application to all species of pangolin, though caution must be used at sites where sympatric pangolin species occur.

Species applicable to: *M. pentadactyla, M. javanica, M. crassicaudata, M. culionensis, P. tricuspis, P. tetradactyla, S. gigantea, S. temminckii*

Parameters of interest	Presence, relative index of abundance, occupancy
Statistical analyses	**For indicating presence:** none required, although previous studies could be used to determine a minimum number of, and class of respondents across study sites that would likely return reliable information on species presence in an area. Indicated or confirmed presence could be used as a threshold to trigger ecological sampling as part of an adaptive sampling protocol to achieve estimation of occupancy, abundance, or density. **For relative index of abundance:** Generalised Linear Mixed Models (GLMMs), regression; inferential statistics.

	For occupancy estimation: single-season single species occupancy models, or dynamic occupancy models.
Sampling design	**For indicating presence:** systematic surveys stratified across region(s) of interest. **For relative index of abundance:** there are myriad ways to identify sites and the exact method will depend on the specific research questions (see Newing, 2011). As an example, the following steps could be used to randomly select sites in a given area (e.g., around a national park): use a grid and stratified sampling to randomly select grid cells, then randomly select villages within each stratified grid cell. **For occupancy estimation:** divide a study area into a grid with cell size equivalent to home range size of the study species to create sites about which respondents in a local area may have ecological knowledge about the species present. Number of and selection of villages to survey about detection of species for grid cells will depend on the geographical context of human population density and land use in the study area.
Response design	**For indicating presence:** diverse demographic representation of local residents and stakeholders across villages in the region will decrease potential biases in information gathered at this stage (e.g., women, hunters, plantation workers, etc.). **For relative index of abundance:** the response design will depend on the specific research questions being asked but may comprise questionnaires, interviews (including methods to ask sensitive questions) or participatory mapping. Data could be collected on socio-demographic characteristics (e.g., age, occupation), income (personal, household), gender, and poverty levels in addition to information on: pangolin distribution, hunting and hunting trends, and perceived abundance of study species. As relative abundance indices can be are highly susceptible to bias resulting from unaccounted for differences in detection, special consideration should be given to any factors that may affect detection and all effort should be made to account for this in the study design and subsequent statistical analyses and inference. **For occupancy estimation:** interviews with respondents within villages about detections of species within each sampling "site" serve as repeated surveys for compiling detection histories. Diverse demographic representation of local residents and stakeholders in the region can decrease potential biases but this information can also be used as covariates for detection (i.e., gender, age class, time spent in specific grid cells, purpose of visits to specific grid cells). Other considerations include the minimum required responses per site, selection from which respondents identify species detected in grid cells (e.g. including positive/negative species controls), and occupancy and detectability covariates (habitat should be included for both).

	For all methods: conducting participatory mapping to understand where peoples' knowledge is concentrated spatially can improve resulting accuracy. It is also be important to ensure standardisation of interview/survey technique if being delivered by multiple researchers. Asking about multiple species may disguise focus on pangolins (which could draw detrimental attention or bias). This can also be used as an opportunity to obtain ecological knowledge about pangolins and other species, and allow for formal investigation of those relationships (i.e., co-occurrence models). Care is needed at sites where sympatric species occur to ensure respondents are providing accurate responses.
Effort and allocation planning	Comprehensive planning for effective surveys is needed (see Newing, 2011), and ideally, social scientists would be consulted and included in the design phase to produce the best results. Simulation or power analysis can allow for adequate sample sizes including number of sites and number of respondents given an expected variation in responses (see appendix). In previous studies utilizing relative indices of abundance, conducting at least 10 interviews with residents of each village complied with predicated response saturation levels, i.e. was found to be sufficient to capture existing potential variation in responses (see Guest, 2006; Nash *et al.*, 2016).
Key assumptions	**For indicating presence:** respondents can identify and have knowledge of pangolins; respondents can accurately differentiate between species of pangolin where sympatric species occur; respondents will be willing to share information; respondents will be able to recall relevant information and provide honest responses; respondents understand the questions they are asked. **For relative index of abundance:** in addition to the above for indicating presence, there must be an assumption that there is no heterogeneity in detection. In other words, all respondents have equal probabilities of detecting the species of interest, or the cumulative respondent probability of detection for each sampling units (i.e., village) is equal. These assumptions are unlikely to be met and in most instances occupancy will likely be a more appropriate parameter of interest. **For occupancy estimation:** in addition to the above for indicating presence, assume that respondents' recollection of detecting species is spatially and temporally accurate within the scale of sampling units and the time frame of interest.
Revisitation design	Repeat surveys could be completed annually, biennially or at other time intervals to estimate changes in parameters of interest and should be informed by the local context, monitoring needs and available resources. Repeat surveys at the same sites would ideally use the same respondents.
Advantages and disadvantages	*Advantages*: can cover large areas at relatively low expense; can acquire historical information; a number of methods exist for asking sensitive questions; can promote cultural buy in to study and conservation actions; can provide immediate initial information on

	status changes that may be more difficult to detect with other approaches and requires further investigation. *Disadvantages*: there are potential cultural barriers that will may need to be overcome (see key assumptions); research using human respondents requires ethical considerations and clearance from institutional research authorization committees. Without appropriate research design considerations (e.g., specialist survey techniques where illegality may be apparent) there is a risk of alerting local people to the financial value of pangolins which could lead to inadvertent negative effects, or respondents may be unwilling to provide honest responses. Collaborating with social scientists and working with experienced surveyors could help to overcome this.
Cost	Low cost; relatively small team required.
Notes	Social research and applications can extend far beyond the population status parameters identified here. For example, occupancy and abundance trends can be predicted using social information collected about hunting efforts (real and perceived) or perceived population trends, and harvest rates derived from social research methods can be used as covariates on probability of local extinction in dynamic occupancy models. Additionally, this class of methods requires a select skill set apart from more common ecological monitoring methods and inherent differences and difficulties should be respected and considered before and during initiation of monitoring programmes. In particular, it is critical to follow appropriate ethics guidance, including obtaining free, prior and informed consent from participants. Collaboration with experienced social scientists is highly recommended to ensure all actions comply with ethical standards and that response design is adequate and results will be unbiased.

6.3 Camera trapping

Camera trapping has been used to determine the presence of all pangolin species and there has been success in estimating multi-year trends in occupancy and abundance, albeit imprecisely, using camera-trap data for *M. javanica* (O. Wearn, *pers. comm.*). Existing detection rates have been low in many places, which is due to a combination of a lack of knowledge to inform camera trap placement, traps not being targeted for pangolins, and populations having declined severely at some sites. Use of camera traps will be most effective at sites where populations of ground-dwelling pangolins exist at high densities (i.e., have not severely declined) or when sampling designs are stratified across areas of variable densities to ensure adequate encounter rates to estimate detection probabilities.

This method can be used confidently to confirm species presence, estimate occupancy, and potentially estimate density if specific assumptions are met. For example, applications exist to estimate density using spatial capture-recapture or spatial mark-resight if some or all of the individuals encountered are individually recognizable (Royle and Young 2008; Kane *et al.* 2015). While there are methods available to estimate density using encounter rates of unmarked individuals including the Royle-Nichols model relating occupancy to abundance (Royle and Nichols 2003), random encounter models (Rowcliffe *et al.*, 2008), or "unmarked" models (Chandler and Royle 2013), accuracy and precision of all these approaches can be strongly influenced when strict assumptions are not met (Cusack *et al.* 2015, Burgar *et al.* 2018), although supplemental information about animal movement can improve performance. Developing methods of estimating density of unmarked individuals using camera traps in a research area of continuing active investigation and the value of these models in this context is still hotly debated. Recently developed applications include distance sampling for camera-traps (Howe *et al.*, 2017) and other adaptations of point count methods (Moeller, 2017), but are still relatively untested. Some possible designs, models and considerations for attempting to estimate density of unmarked individuals are presented below. More information on sampling designs and assumptions is available in Wearn and Glober-Kapfer (2017). However, given the potential issues found to affect density estimation using unmarked individuals demonstrated in the extensive literature, it is strongly recommended that researchers seek out collaboration with experienced quantitative ecologists to ensure reliable results prior to initial investment of resources. It would also be wise to nest sampling designs so that if estimates of density are not obtainable or of sufficient precision, data collected can still be used to estimate occupancy rates.

This treatment is limited to terrestrial camera-trap applications and excludes the potential use or arboreal camera-traps (see Section 6.7).

Species applicable to: *M. pentadactyla, M. crassicaudata, M. javanica, M. culionensis, S. gigantea, S. temminckii, P. tricuspis*

Parameter of interest	Presence, occupancy, abundance, density
Statistical analyses	**For confirming presence:** none required, although previous studies could be used to determine a minimum effort in number of cameras and length of deployment to return reliable information on species presence in an area. Indicated or confirmed presence could be used as a threshold to trigger more intensive sampling as part of an adaptive sampling protocol to achieve estimation of occupancy, abundance, or density. **For occupancy estimation:** single-season single-species occupancy, dynamic occupancy models. **For density estimation:** possible methods could include distance sampling (Howe *et al.*, 2017), random encounter modelling (Rowcliffe *et al.*, 2008), unmarked models with informed priors on home range size (Burgar *et al.*, 2018), or spatial mark-resight models if a subset of the population is marked (such as with telemetry tags; Sollmann *et al.*, 2013a).
Sampling design	**For confirming presence:** camera-traps should be placed in areas with high likelihood of detection (i.e., suspected burrow entrances). Unfortunately, camera traps along trails have only rarely detected pangolins and this is likely due to limited use of trails for most species. It has been suggested that at least some pangolin species move along the edges of natural structures and that detection could be improved by placing cameras along downed tree branches or using drift fence-like structures to funnel pangolins in front of a camera field of view. Using multiple cameras across an area will increase the probability of detection and decrease the amount time of deployment before a species is confirmed when present. Other details of camera trap type and of use are documented at length in multiple books and review articles (O'Connell *et al.*, 2010, Sunarto *et al.*, 2013, Meek *et al.*, 2014; Wearn and Glober-Kapfer, 2017) and should be considered.

	For occupancy estimation: use a camera trap array across the study area, ideally using cell size (sampling unit) based on the species' home range size with at least one camera located towards the centre of each grid cell. Cameras should be placed to maximize detection (see above for confirming presence) and strive for equal representation across the study area. If optimal camera placement strategy is unknown, then cameras should be placed as close to cell centres as possible (i.e. randomly). In this way, microhabitat features used by pangolins can be discovered, which can inform future placement in an adaptive sampling framework. Cameras need to be spaced according to an animal's home range as described above, otherwise site use, rather than occupancy, will be investigated. If investigating factors that affect occupancy (e.g., of land-use or hunting/poaching pressure), camera placement should be stratified across treatment types or across gradients for equal representation. **For density estimation:** *Basic design considerations for several estimation approaches are provided here but details and limitations should be found in associated primary literature.* For random encounter models (REM) and distance sampling, placement of camera traps should be random (e.g. systematically random) across the study site (technically *random with respect to animal movement*; see Rowcliffe *et al.* 2013). This can be combined with stratified sampling by broad habitat type, and known 'non-habitat' can be excluded a priori. For REM and distance sampling, cameras should ideally be placed sufficiently far apart to ensure independence, i.e. by more than one home-range diameter. For spatial mark-resight (SMR), camera traps should be spaced at a distance approximately the diameter of a single home range (2σ) to maximize the number of individuals exposed to the trapping array for detection, but also allowing for recaptures of individuals at multiple "traps". Extent of trapping grid will increase inversely with population density (see Sun *et al.*, 2014 for guidance).
Response design	**For confirming presence:** detection of an individual of the target species is sufficient to confirm presence. Additional information about the areas where pangolin species are confirmed or not detected including local covariates (e.g., habitat, vegetation, local perceived hunting or poaching effort, etc.) or survey covariates (length of camera deployment, weather and climate conditions, details of specific camera trap set up, can all help to identify features associated with presence and guide more intensive sampling protocols. **For occupancy estimation:** detections of a species over time of camera deployment are used to comprise a capture history for each site. Length of repeated surveys (e.g., days, weeks, months) within a complete session (length of camera deployment) will vary depending on length of survey and scale of inference, but should consider geographical and temporal closure assumptions (when a species is detected at a site, the model assumes a species was always present at a site and available to be detected for all surveys in a session). If detection at different sites will likely differ, covariates or factors correlated to or directly related to these differences should be recorded (e.g., altitude, temperature, season, rainfall) to account for possible heterogeneity in detection.

	For density estimation: response design will depend on the modelling approach selected (recommendations in each case are given in Wearn and Glover-Kapfer, 2017). Considerations should include how camera traps are set-up to record detections, and length of deployment and secondary sessions to meet temporal and geographical closure assumptions.
Effort and allocation planning	**For confirming presence:** depending on design, approximately 6,000 camera/trap nights were required to detect a pangolin species in a previous study, but low effort (a single camera for a single night) may be required if combined with other techniques that identify potential burrows. **For occupancy estimation:** informed by simulation or power analysis, required number of cameras, time of deployment, and number of "occasions" (secondary sessions) will depend on occupancy and detection rates (see appendix). Given expected low occupancy and low detection probability for pangolins in some landscapes, intensive sampling is likely needed (e.g., 100+ points per grid, each sampled for 60+ days). **For density estimation:** dependent on selected method. Simulation exercises should be used to ensure greatest probability of success in achieving density estimates and identifying factors that can bias estimates (see appendix).
Key assumptions	**For confirming presence:** cameras are allowed to operate for sufficient time to reasonably detect a species, which could be relatively lengthy given low detection rates. Species can be accurately identified in photos produced by camera type utilized and will not be misidentified. **For occupancy estimation:** specific to camera trap applications, species can be accurately identified in photos produced by camera type utilized and will not be misidentified. **For density estimation:** *Below is specific to camera trap approaches highlighted in the sampling designs. Additional assumptions and limitations should be found in associated primary literature.* For REM and distance sampling, camera trap locations and orientations are selected so that animal encounters with traps are random and not influenced by camera placement. **For spatial-mark resight:** if marks are artificial, the tagging locations for the marking process must also be included in estimation or the resulting densities will skew positively with the increased spatial extent of the state space (violates assumptions that marked and unmarked individuals have equal probabilities of detection; see Whittington *et al.*, 2018 for solution).
Revisitation design	Repeat surveys could be completed annually, biennially or at other time intervals to estimate changes in occupancy, density and/or abundance as appropriate over time. This should be informed by local context, monitoring needs and available resources. Ideally, camera traps would be placed in the same fixed locations on repeat surveys. Subject to study

	design, revisitation may entail replication sampling across different sites.
Advantages and disadvantages	*Advantages:* highly standardised and replicable method; non-invasive; low maintenance; scalable; results can be fed into larger scale analyses; can borrow detection probabilities from other species to complete modelling and estimate abundance (e.g., using Bayesian hierarchical modelling); produces verifiable records. *Disadvantages:* very low detection rates for pangolin species given current methodologies means that extensive field effort (time and extent of camera arrays) is required to collect sufficient data (e.g., 30-60 days to confirm presence for a passive array); data management can be time consuming, though data management software now available (e.g., ZSL Camera Trap Analysis Package, camtrapR; reviewed in Scotson *et al.*, 2017; Young *et al.*, 2018); risk of theft or damage to cameras; optimal camera placement can be challenging; low detection rates dramatically reduces power to detect of trends over space and time.
Cost	High upfront equipment costs but they can be reduced by sharing of equipment. Camera traps can also be reused over multiple surveys, but life-time of camera traps in tropical humid habitats is limited (e.g., three years). Occupancy-based camera-trapping may be the most cost effective and informative method if camera-trap placement can be improved.
Notes	Camera trapping will likely be most effective where pangolin populations have not suffered severe declines or if used at high enough densities to enable realistic detection probabilities**. This application is very limited in areas with low density or occupancy as power and precision is directly related to status and detection rates, which are also low.** However, camera trapping can also be used to make inferences about habitat use and activity patterns, again given sufficient detections. It can also be combined with other methods (see burrow counts, detection dogs, artificial nest boxes). Further development of methodologies to substantially improve detection will enhance the value of this method for pangolin monitoring.

6.4 Non-invasive genetic sampling (gNIS)

The use of non-invasive genetic sampling (gNIS), refers to a broad suite of sampling and laboratory analyses describing the non-invasive collection of samples of scat, hair, water, soil or other naturally occurring materials in the environment (Taberlet et al,. 1996; Waits and Paetkau 2005; Bohmann *et al.*, 2014) and extracting and amplifying DNA (using PCR) to identify samples to the species or individual level. Amplification success depends on factors including the rate of DNA degradation which is species and sample type specific and dependent on time and environmental conditions (temperature, humidity, UV exposure, etc). Rigorous collection, laboratory, and statistical methodologies have been developed over the last two decades to reduce potential for misidentification and contamination (see Waits and Paetkau (2005) for an initial review). Collaboration with wildlife geneticists highly trained in working with low-quality low-quantity DNA is highly recommended to reduce very common errors and produce reliable results. Sampling using gNIS can be used to determine presence and estimate occupancy when samples are identified to the species level, and density when at least a subset of samples are identified to the individual level (Augustine *et al.*, 2018).

Species applicable to: *M. pentadactyla*, *M. javanica*, *M. crassicaudata*, *M. culionensis*, *P. tricuspis*, *P. tetradactyla*, *S. gigantea*, *S. temminckii*

Parameter of interest	Presence, occupancy, abundance, density
Statistical analyses	Occupancy modelling; hierarchical occupancy modelling to account for nested sub-samples.
Sampling design:	**For confirming presence:** there are many potential applications of gNIS to allow for confirming of presence including systematic sampling of water bodies or more target sampling of soil from potential burrows, or scat. This method may be particularly effective when combined with the use of detection dogs (see section 6.6). **For occupancy estimation:** single-species single-season occupancy or dynamic occupancy models. **For density estimation:** spatial capture-recapture, spatial mark-resight, and associated spatial partial identity models (SPIM) are possible when all or a subset of the samples are identified to the individual.

Response design.	**For confirming presence:** amplification rates can vary with species and conditions and therefore pilot studies are required to optimize sampling protocols (Taberlet *et al.*, 2012, Lonsinger *et al.*, 2015, Woodruff *et al.*, 2015). Previous studies on other taxa in water bodies in other regions suggest 1– 2 litres of water should be collected. Quantities and methods for sampling from other materials (e.g., soil from burrows, scat, etc.) should be initially based on guidance for similar circumstances, but optimized based on pilot degradation studies. Collection of both environmental covariate data including climate, recent weather, and condition of samples, and sampling location data including habitat, vegetation, poaching pressure and/or other threats would all help to identify features associated with presence and guide more intensive sampling protocols. **For occupancy estimation:** sampling for detections can be repeated over time at sites or among spatial replicates along transects (see Hines *et al.*, 2010). Similar considerations for confirming presence apply, and false positives can be accounted for in models with the inclusion of supplemental data (Chambert *et al.*, 2015). **For density estimation:** sampling can be repeated over time at sites or among spatial replicates along transects (see Fuller *et al.*, 2016, Sun *et al.*, 2017, Morin *et al.*, 2018). Pilot studies to assess degradation described above should be targeted at amplifying DNA to adequately achieve consensus individual identification from non-invasive samples (see Waits and Paetkau, 2005).
Effort and allocation planning	Effort and allocation of resources will vary widely depending on parameter of interest, local facilities, and state of current genetic knowledge for species. Collaboration with a wildlife geneticist with expertise in primer design and gNIS methodologies is highly encouraged and will inform thought towards requirements.
Key assumptions	**For confirming presence:** when metagenomic approaches are used, a DNA match does not categorically equate to the presence of the target species at the sampled site because eDNA can be dispersed and the potential for 'false positives' should be factored into study design. When nDNA or mtDNA primers are used, it is assumed that adequate primer development has excluded the possibility of cross amplification with other potential species (for example, see de Barba *et al.*. 2014, Wultsch *et al.*, 2015). **For occupancy estimation:** assume that potential false positives are handled upstream in the primer design phase or estimated from supplemental data (Chambert *et al.*, 2015). **For density estimation:** assume that individuals are not misidentified (ghosts and shadows; see Sethi *et al.*, 2014).
Revisitation design	Repeat surveys could be completed annually, biennially or at other time intervals to estimate changes in occupancy and should be informed by the local context, monitoring needs and available resources. Repeat surveys at the same sites would be ideal. Using individual identification

	could allow for estimation of changes in demographic rates including population growth with open population models.
Advantages and disadvantages	*Advantages*: non-invasive; collection of samples requires minimal training and single survey designs can allow for minimal field efforts (only have to visit sites once or twice); could be used to determine presence of sympatric species. *Disadvantages*: relatively untested on pangolins; laboratory work is expensive and requires high level of expertise; permitting process for international movement of specimens can be challenging and time consuming; DNA references are poor for many tropical mammals including pangolins.
Cost	Generally expensive but costs could be reduced by collaborating with local partners with labs. This would also negate the need for international movement of material and CITES permits. Additionally, upfront costs will be reduced with increased genetics work on pangolins (creating reference collections and designing primers).
Notes	High level of expertise required and laboratory training is required. Commercial companies and university research groups now exist that specialise in gNIS, and should be consulted. Initial investment in pangolin genetics may already be in progress for law enforcement activities. gNIS methods can substantially enhance the value of complimentary monitoring methods (e.g., detection dogs and burrow surveys).

6.5 Telemetry

Telemetry-based methods have had application to most pangolin species but predominantly to *M. pentadactyla* and *S. temminckii* (e.g., Pietersen *et al.*, 2014; Sun *et al.*, 2018; also see Pagès, 1975; Willcox *et al.*, 2019). Preliminary research using telemetry has been conducted on other species including *M. javanica* but has been hindered by high transmitter drop-off rates. The scales of *M. javanica* appear too thin and weak to bear the weight of transmitters attached to similar species, though tracking of *M. culionensis* has been possible (e.g., Schoppe and Alvarado, 2015). Either through the use of existing protocols for species where these methods have been successful or with technological solutions in the form of smaller, lighter and more energy efficient transmitters (e.g., with GPS capability), telemetry methods are an excellent tool for collecting information on species space use and survival rates. In particular, there is an urgent need to apply this to method to pangolin species for which home size is not known (see Table 1), in order to use it to inform many of the other methods discussed in this guidance.

Species applicable to: *M. pentadactyla*, *M. javanica*, *M. crassicaudata*, *M. culionensis*, *P. tricuspis*, *P. tetradactyla*, *S. gigantea*, *S. temminckii*

Parameter of interest	Space use (home range size and habitat selection), and survival rates
Statistical analyses	**For space use:** there is a multitude of methods to estimate home range size, habitat use, and resources selection. Appropriate estimators will depend on the exact study questions. **For survival rates:** known-fate survival models (White and Burnham, 1999) and Cox proportional hazard rates (Cox, 1992; Lin and Wei 1989).
Sampling design	**For space use:** repeated relocation of telemetered individuals. Timing of relocation and adequate number of individuals will depend on the population density, study questions, and location of individual animals of the study species by tracking animals to locate them in burrows, or through the use of prospection surveys or point counts. **For survival rates:** telemetered individuals are located at regular individuals to determine status (alive or dead). Tags must last a suitable amount of time such that a proportion of the population will be a risk of mortality during the time they are monitored.

Response design	**For space use:** telemetry studies will be most useful when relocations can be correlated with habitat and land cover covariates to explain and test hypotheses about space use. **For survival rates:** collection of variable that are hypothesized to affect survival (proximity to human settlements, diel activity, hunting pressure) will enhance the usefulness of estimated mortality rates, including when tag stops transmitting or falls off.
Effort and allocation planning	**For space use:** existing research indicates c.85+ days of tracking to accurately the home range of *S. temminckii* (see Heath and Coulson, 1997). Comparable research is needed for other species. **For survival rates:** has not been attempted with pangolins yet. Pilot studies will be needed to determine amount of time and size of telemetered population to make inference about survival rates.
Key Assumptions	Assumptions include that: equipment has been calibrated properly; each unit used has equal ability and accuracy; tagged individuals represent an adequate proportion of the population (no bias in capture of individuals to tag and track); telemetry tags do not alter behaviour or affect survival.
Revisitation design	Will depend on research question. May not be needed if this method was used just to estimate home range of selected individuals at a given site. The same methodology could be used across sites to test for variation in home range size (e.g., by site, age of animal, sex).
Advantages and disadvantages	*Advantages*: tracking of live animals presents the opportunity to collect other biological data and information (e.g., demographics, reproduction, and prey species). *Disadvantages*: tags are temporary and data limited; tags will be damaged and become detached; animals can't always be located; small numbers of animals can prevent robust statistical analyses; VHF based telemetry is resource intensive.
Cost	Is expensive, but economies of scales can be achieved by buying in bulk. Resource costs include time spent actively searching for tagged animals; veterinary and post-mortem costs should be factored into projects for deceased animals. Metal plates can be used to avoid breakages.
Notes	Many other methods depend on assumptions about home range size and habitat use, or may directly incorporate telemetered individuals into population models to improve inference about population dynamics (see Sollmann *et al.*, 2013a).

6.6 Detection dogs

Detection dogs have not been used at any scale to monitor pangolin population to date, but have been used successfully to detect buried *M. pentadactyla* scat in Nepal and live *M. javanica* in southern Vietnam (presence). Local hunting dogs have also been used to determine the presence of *M. culionensis* in the Philippines (Schoppe and Alvarado, 2015). Detection dog could be used to determine presence, estimate occupancy, and to estimate density and abundance when combined with other methods such as non-invasive genetic sampling (see Section 6.4). Detection dogs may comprise the best available method for determining the presence of species at sites that have undergone severe population declines (e.g., *M. pentadactyla* and *M. javanica* in Southeast Asia) and/or where species occur at very low densities, but it is an expensive method and still requires extensive survey efforts. Detection dogs have potential application to all but one pangolin species through detection of live animals, burrows, cavities (e.g., tree hollows) and faeces. The detection of *P. tetradactyla* faeces will likely not be possible assuming this species always defecates in tree hollows.

Species applicable to: *M. pentadactyla*, *M. javanica*, *M. crassicaudata*, *M. culionensis*, *P. tricuspis*, *P. tetradactyla*, *S. gigantea*, *S. temminckii*

Parameter of interest	Presence, occupancy, abundance, density
Statistical analyses	**For confirming presence:** none required, although previous studies could be used to determine a minimum effort in number of sampling sites, transects and visits to return reliable information on species presence in an area. Indicated or confirmed presence could be used as a threshold to trigger more intensive sampling as part of an adaptive sampling protocol to achieve estimation of occupancy, abundance, or density. **For occupancy estimation:** single-species single-season occupancy models, dynamic occupancy models. **For density estimation:** distance sampling of live detections from a searched transect or radial plot, or combined with burrow occupancy, or spatial capture-recapture when combined either with non-invasive genetic sampling (gNIS) for soil at burrows or scat detected, or when marking individuals detected.

Sampling design	**For confirming presence:** in consultation with dog handlers, determine the search strategy and appropriate effort depending on the terrain and the extent of the area of interest. Detection of live pangolins would confirm presence, whereas detection of signs such as burrows, cavities, or faeces would require further sampling including gNIS of samples, scoping of burrows or cavities, returning to the sign after sweeping entrance of burrows or set-up of a camera-trap to confirm the presence of a pangolin. **For occupancy estimation:** divide a study area into a grid with minimum grid cell size equivalent to home range size of the study species to create sites for localized searches. Sites can consist of transects or circular plots with the transect width or radius equivalent of the detection distance of a dog. Multiple transects or circular plots within a site could improve detection rates or allow for spatial replicates for estimating detection with single site visits (see Hines *et al.*, 2010). Sites should be stratified across variables of interest which could include covariates such as habitat type, level of exploitation (e.g., human disturbances, hunting/poaching pressure), and location of key features (environmental and human). **For density estimation:** either transects or circular plots can be used for distance sampling or SCR methods with detection dogs. Sites should be stratified across variables of interest which could include covariates such as habitat type, level of exploitation (e.g., human disturbances, hunting/poaching pressure), and location of key features (environmental and human). For distance sampling, place multiple radial points or transect lines or areas randomly or systemically at a spacing at least the distance of a species home range (Buckland *et al.*, 2001). For SCR, sampling sites should be spaced at a distance approximately the diameter of an individual's home range. Additionally, an SCR method using detection dogs was recently formalized in an adaptive sampling framework specifically for rate and patchily distributed species and this may substantially improve parameter estimation in low density populations (see Wong *et al.*, 2018).
Response design	**For confirming presence:** One handler per dog; handler allows the dog to lead the plot sample following established methods (Wasser *et al.*, 2004; 2014). Dog will find a live pangolin, a burrow or other sign(s). Depending on what is found, occupancy can be confirmed (e.g., live animal; fresh scat) or may require additional method as described above (e.g., camera trap outside a burrow to confirm pangolin present). This will require a return visit to the burrow. Where live animals are captured, morphometric data (e.g., size, weight, no. of scale rows etc) should also be collected where feasible. **For occupancy estimation:** Searches with dogs could be repeated over time, or replicated over transect segments or multiple circular plots within a site to estimate detection during a single survey (see Hines *et al.* 2010). Detections for occupancy include live pangolins or confirmed active sign as above (burrow occupancy or confirmation of species using metagenomics or mtDNA). Covariates that may affect both detection of animals or sign, and quality of DNA should be recorded for inclusion in models. Two-phase adaptive sampling for occupancy may be an efficient approach with more intensive sampling triggered by the

	initial detection of a pangolin or sign, allowing for focusing effort in areas with greater opportunities for detection (Conroy *et al.*, 2008). **For density estimation**: for distance sampling, dog and handler traverse each transect and identify pangolin detections or discovered sign, recording the distance each from transects or starting reference point (use a laser range finder or transect tapes to estimate distance if needed). On encountering burrows, record detection or non-detection of pangolin using endoscope/borescope, or by placing a camera trap, or sweeping burrow entrance and leaving overnight. On encountering scat, collection of a sample can allow for confirmation of species and identification of individual. Note, counting of only signs violates the assumption that individuals do not move during sampling (i.e., one individual may deposit multiple scats or use multiple burrows), and inference of density is only valid when individuals are detected, when the sign is identified to individual, or when burrow detections are combined with burrow occupancy estimation (Strober *et al.* 2017). For SCR, dog and handler again search along transects or from a reference point and should keep track of search paths to account for effort across space. Location of live encountered pangolins or sign should be recorded. Individual pangolins detected can be marked if there will be replicate surveys over time. Alternatively, sites may be searched once following a single survey SCR protocol (Morin *et al.*, 2016, Morin *et al.*, 2018). On encountering scat, collection of a sample is required for identification of individual. In the SCR context, multiple detections of the same individual from scat improves parameter estimation. Environmental covariate data that may affect detection and amplification of DNA when appropriate, should be recorded. If using an adaptive sampling approach, transects spaced at a coarser resolution may be initially used with more intensive sampling triggered by the detection of a pangolin or sign, allowing for focusing effort in areas with greater opportunities for detection (see Wong *et al.* 2018).
Effort and allocation planning	While population density is the ideal parameter of interest for providing information on status and for management and conservation decisions, when population density is very low, it may be preferable to stratify effort over larger areas and collect less-intensive data for estimating site occupancy or utilize an adaptive sampling approach for occupancy (Conroy *et al.*, 2008) or SCR (Wong *et al.*, 2018). A small-scale pilot study could assist in determining which approach will be the more informative given financial and logistic constraints. Simulation and power analyses are highly encouraged to make the most of resources given the limits in available dog-handler teams and the expense.
Key assumptions	Key assumptions include: dogs and handlers have had adequate training, and that dogs are consistently able to detect pangolins and/or their signs.
Revisitation design	Repeat surveys could be completed annually, biennially or at other time intervals to estimate changes in occupancy and should be informed by the local context, monitoring needs and available resources. Repeat surveys at the same sites would be ideal.
Advantages and disadvantages	*Advantages*: as an active monitoring method, the use of detection dogs should increase effectiveness of confirming species presence and

	estimating population parameters, even where populations have been severely reduced through by overexploitation; dogs can operate in complex habitats. *Disadvantage*: very expensive; high level of skill required by dog handlers; limited number of providers with trained dogs; and need to consider logistics and veterinary care into research plans; dogs currently prohibited from many protected areas; constraints on who is able to work with dogs in some countries (e.g., Indonesia, Malaysia).
Cost	An expensive method.
Notes	Use of detection dogs to locate live pangolins provide additional opportunities for research including marking of individuals and use of bio-loggers and other tracking tags. Genetic samples should be collected to provide reference samples for metagenomic libraries and potentially provide a link to studies on trafficking. Currently few options for trained detection dogs and securing and scheduling services can be difficult. Additionally, transport to range states and work conditions therein present risks to trained detection dogs and must be considered. Local hunting dogs have sometimes been used as substitutes for professionally trained dogs and have been known to injure live pangolins they find posing ethical considerations about the use of hunting dogs. The welfare of pangolins should be considered when determining the most appropriate methods to use.

6.7 Arboreal camera trapping

Arboreal camera trapping has not been tested to detect or monitor *P. tetradactyla* or the semi-arboreal pangolin species but has potential application (though no *M. javanica* have so far been detected in ~1,000 arboreal camera trap nights in one mammal study in Borneo (J. Haysom, *pers. comm.*). Like terrestrial camera-trapping, it could potentially be used to confirm species presence and to estimate occupancy (Bowler *et al.*, 2017). Theoretically, with sufficient detection it should also be possible to estimate species density, but this would depend up on the assumptions discussed in section 6.2. For the purposes of this guidance arboreal camera trapping also encompasses other optical and thermal sensors that could enable detection of *P. tetradactyla* and/or semi-arboreal pangolins.

Species applicable to: *P. tetradactyla*, *P. tricuspis*, *M. javanica*, *M. culionensis*

Parameter of interest	Presence, occupancy
Statistical analyses	**For confirming presence:** none required, although pilot studies focused on known individuals or in *ex-situ* settings could be used to determine a minimum effort in terms of number of cameras and length of deployment to return reliable information on species presence in an area. Pilots should be planned carefully and give consideration to important variables such as canopy cover. Indicated or confirmed presence could be used as a threshold to trigger more intensive sampling as part of an adaptive sampling protocol to achieve estimation of occupancy, abundance, or density. **For occupancy estimation:** single-species single-season occupancy models.
Sampling design	**For confirming presence:** camera-traps should be placed in areas with high likelihood of detection and oriented to maximize detection. Pilot studies or *ex-situ* trials could aid in determining ideal camera placement and orientation. Using multiple cameras across an area will increase the probability of detection and decrease the amount time of deployment before a species is confirmed when present. **For occupancy estimation:** As with terrestrial camera trapping, use a camera trap array across the study area, using cell size (sampling unit) based on species' home range size with at least one camera located towards the centre of each grid cell. Cameras should be placed to maximize detection (see camera trapping for confirming presence) and strive for equal representation across the study area. Cameras need to be spaced according to an animal's home range as described above, otherwise site use, rather than occupancy, will be

	investigated. If investigating factors that affect occupancy (e.g., of land-use or hunting/poaching pressure), camera placement should be stratified across treatment types or across gradients for equal representation. Additionally for arboreal camera trapping, tree species placement should be documented to identify preferences and inform future study designs.
Response design	**For confirming presence:** detection of an individual of the target species is sufficient to confirm presence. Additional information about the areas where pangolin species are confirmed or not detected including local covariates (e.g., tree species, habitat, vegetation, local perceived hunting or poaching effort, etc.) or survey covariates (length of camera deployment, weather and climate conditions, details of specific camera trap set up including location and orientation in a tree), can all help to identify features associated with presence and guide more intensive sampling protocols. Camera traps should be targeted at trees pangolins are known to prefer (where available information exists). Importantly, the field of view should be maximised when placing camera traps; this is usually considered when using non-arboreal camera traps but will require additional consideration when applied to arboreal camera traps. This could be achieved by placing cameras to look at neighbouring trees, to focus on tree trunks as opposed for branches, and/or on placing more than one camera on the circumference of the tree trunk. Consideration should also be given to decrease thermal glare or other false triggers (e.g., from vegetation). Environmental covariate data should also be collected including data such as habitat, vegetation, weather, poaching pressure and/or other threats. **For occupancy estimation:** detections of a species over time of camera deployment are used to comprise a capture history for each site. Length of repeated surveys (e.g., days, weeks, months) within a complete session (length of camera deployment) will vary depending on length of survey and scale of inference, but should consider geographical and temporal closure assumptions (when a species is detected at a site, the model assumes the species was always present at a site and available to be detected for all surveys in a session). If detection at different sites will likely differ, covariates or factor correlated to or directly related to these differences should be recorded (e.g., altitude, temperature, season, rainfall) to account for possible heterogeneity in detection. Detection rates will be low in low density populations and it is not yet known how effective arboreal camera traps will be at detecting pangolins. However, multiple cameras within a single grid cell could aid in improving detection rates.
Effort and allocation planning	This will ideally be informed by simulation or power analysis, but pilot studies will be required to inform detection rates as this method has never been implemented before. Other considerations include time to install, check, and/or remove camera traps on each tree, which could realistically comprise half a day or more per tree based on other monitoring methods that required climbing trees in tropical environments (see Whitworth *et al.*, 2016).

Key assumptions	Proof of concept is needed to determine if arboreal and semi-arboreal pangolins are detected with arboreal camera traps, including arboreal *versus* ground-level camera-traps.
Revisitation design	Repeat surveys could be completed annually, biennially or at other time intervals to estimate changes in occupancy over time and should be informed by the local context, monitoring needs and available resources. Ideally, camera traps would be placed in the same fixed locations on repeat surveys. Subject to study design, revisitation may entail replicating sampling across sites.
Advantages and disadvantages	*Advantages:* knowledge of prey and tree species used and/or preference, where known, could be used to target trap placement. *Disadvantages:* unproven method requires proof of concept and initial investment in pilot studies to generate useful data to inform future study designs. Field of view could be very limited if camera traps not placed to maximise it and ideal positioning is currently unknown; potentially many false triggers from vegetation or inclement weather; installation involves climbing trees and will likely be difficult (e.g., time, effort, safety); little known about use of trees by pangolins (e.g., height); additional information on species ecology, in particular *P. tetradactyla*, needed to inform application of this method.
Cost	High upfront equipment costs but which can be reduced by sharing of equipment. Placement of camera traps in trees will require additional time; potentially half a day per tree in order to set up cameras depending on the number being installed based on other studies of arboreal species. Other costs associated with this method include equipment (e.g., climbing rig) and training on tree climbing and rope access.
Notes	Local knowledge will be critical to identify trees for the placement of camera traps. Emerging technology such as drones could potentially be used to inform camera-trap placement - *P. tetradactyla* reportedly basks in the sun at the top of trees; R. Cassidy, *pers. comm.*). Rigid pulley systems could potentially be used to hold cameras in place rather than attaching then to branches or tree trunk but would require piloting.

6.8 Point count

Point counts are counts undertaken from a fixed location for a fixed period of time (Sutherland, 2006). They have not been purposefully applied to pangolins to date, but potentially have application to detecting the presence of *P. tetradactyla*, which is particularly elusive and seemingly highly sensitive to potential threats. However, this species is diurnal and positioning a surveyor at fixed points in suitable habitat at study sites where the species is known to exist could have potential for confirming the species' presence and occupancy, either through a visual sighting or through an auditory cue, such as hearing an individual breaking into and ant nest of termite mound. This method has not been tested and requires initial pilot studies for proof of concept and further developments of applications.

Species applicable to: *P. tetradactyla*

Parameter of interest	Presence, occupancy
Statistical analyses	**For confirmation of presence:** none required, although pilot studies focused on known individuals or in *ex-situ* facilities could be used to determine a minimum effort in number of points and length of surveys to return reliable information on species presence in an area. Indicated or confirmed presence could be used as a threshold to trigger more intensive sampling as part of an adaptive sampling protocol to achieve estimation of occupancy, abundance, or density. **For occupancy estimation:** single species single-season occupancy models and dynamic occupancy models.
Sampling design	Contingent on proof of concept (and conservative estimates of the species' home range size for occupancy), which are not currently available.
Response design	Surveyor(s) position themselves at point count stations for a given period of time. Time of day in which to conduct the surveys and duration of surveys should be based on local knowledge, i.e. with local community members and/or indigenous peoples familiar with *P. tetradactyla* if possible.
Effort and allocation planning	This will ideally be informed by simulation or power analysis, but pilot studies will be required for proof of concept and to inform detection rates as this method has never been implemented before.
Key assumptions	Assumptions include that the species doesn't detect surveyor presence and freeze or avoid the area being surveyed resulting in false absences.

Revisitation design	Subject to successful application, repeat surveys could be completed annually, biennially or at other time intervals to estimate changes in occupancy and should be informed by the local context, monitoring needs and available resources. Repeat surveys at the same sites would ideally using the same observers.
Advantages and disadvantages	*Advantages*: the species' sensitivity to potential threats means surveyors being stationed as a fixed point in suitable habitat may enable detection; detection may be auditory and/or visual. *Disadvantage*: unproven method that requires proof of concept and initial investment in pilot studies to generate useful data to inform future study designs. Spatial coverage of data collection is very limited; it is very time intensive; even though *P. tetradactyla* is diurnal individuals will be hard to detect.
Cost	Relatively low cost.
Notes	Working with local people or indigenous peoples will be critical to identifying potential survey locations and for acquiring local knowledge on what to look and listen for while surveying. Available information suggest this species is restricted to riverine or flooded forests but this may not be the case and should be explicitly considered in survey design. This method has potential to support implementation of other methods, for example, sighted individuals could be caught for use in radio-telemetry research.

6.9 Artificial nest boxes

Artificial nest boxes, although used for pangolins in captivity within artificial burrows, have not been tested for detecting and/or monitoring pangolins in the wild. It is proposed that they may have application for *P. tetradactyla* and the semi-arboreal pangolin species. Use of this method would entail the placement of a number of artificial nest boxes across a study site, which would be checked periodically to determine presence and occupancy. If individuals are marked on initial discovery, density can be estimated using SCR. However, as they have not been tested, they first require proof of concept, including whether pangolins would use them and determining baseline detection rates. If considering this method, consideration should be given to whether its application could result in adverse consequences for the target species. For example, if the use of artificial nest boxes would make it easier for poachers to harvest pangolins. If this is likely to be the case, this method should not be used.

Species applicable to: *P. tetradactyla*, *P. tricuspis*, *M. javanica*, *M. culionensis*

Parameter of interest	Presence, occupancy, abundance, density
Statistical analyses	**For confirming presence:** none required, although pilot studies focused on known individuals or in *ex-situ* settings could be used to determine a minimum effort in length of deployment to return reliable information on species presence in an area. **For occupancy estimation:** single species single-season occupancy models and dynamic occupancy models. **For density estimation:** SCR
Sampling design	Nest boxes could be installed on trees. Nest boxes could be placed randomly in sampling units (using a random stratified design) or in a targeted fashion at field signs (e.g., adjacent to arboreal ant nests). See Ford *et al.* (2015) for an example with southern flying squirrels, an endangered species in the U.S. Contingent on proof of concept (and conservative estimates of the species' home range size for occupancy and SCR, which are no currently available.
Response design	Once installed, nest boxes would be installed periodically checked to determine use and if possible, capture and mark pangolins. Survey effort

	and duration would be contingent on detection rates and parameters of interest.
Effort and allocation planning	This will ideally be informed by simulation or power analysis, but pilot studies will be required for proof of concept and to inform detection rates as this method has never been implemented before. Other considerations include time to install, check, and/or remove boxes on each tree, which could comprise half a day per tree (see Whitworth *et al.*, 2016).
Key assumptions	That pangolins will use artificial nest boxes; that appropriate tree species and location on tress can be identified for successful deployment.
Revisitation design	Repeat surveys could theoretically be completed annually, biennially or at other time intervals to estimate changes in occupancy over time. They should be informed by the local context, monitoring needs and available resources. Ideally, artificial nest boxes would be placed in the same locations on repeat surveys.
Advantages and disadvantages	*Advantages:* there is potential to integrate additional technological applications to enhance the data collected on life history of pangolins (i.e., nest box cameras, bio-loggers). *Disadvantages:* unproven method that requires proof of concept and initial investment in pilot studies to generate useful data to inform future study designs. Thermoregulation is important in pangolins so the correct materials will need to be identified.
Cost	Cost will be determined by, among other things, materials used. Placement of boxes will require additional time, potentially half a day or more per tree. Other costs associated with this method include equipment (e.g., climbing rig) and advised training on tree climbing and rope access (see Whitworth *et al.*, 2016).
Notes	Local knowledge will be critical to identifying trees for the placement of artificial nest boxes. Pangolins evidently use a variety of structures and microhabitats as dens, and not all are enclosed spaces; it is unknown how reliant a species is on dens similar in structure to nest boxes and what influence this will have on the number of missed/undetected individuals.

6.10 Exhaustive plot surveys

Plot surveys entail exhaustively searching a fixed area for the target species. These may be square quadrants, rectangular strips or belts or other shapes (Milner-Gulland and Rowcliffe, 2003). They have had success in detecting *M. culionensis* (see Schoppe and Alvarado, 2015) and may have application to other species, including *M. crassicaudata, S. temminckii*

Species applicable to: *M. crassicaudata*, *S. temminckii*

Parameter of interest	Presence, relative abundance
Statistical analyses	**For indicating presence:** none required, although previous studies could be used to determine a minimum search effort for detecting species in different habitat types and conditions. **For relative index of abundance:** Regression; inferential statistics.
Sampling design	**For indicating presence:** sampling plots need to be of adequate size to allow for detection of pangolins (will be relative to density), but small enough that surveyors can exhaustively search each plot without missing detections (will be habitat and terrain specific). **For relative abundance:** sampling plots need to be of adequate size to allow for detection of pangolins (will be relative to density), but small enough that surveyors can exhaustively search each plot without missing detections (will be habitat and terrain specific). Differences in variables of interest (habitat, vegetation, hunting pressure, etc.) should be collected.
Response design	**For confirmation of presence:** live detections, examination of burrows found for occupancy. Genetic species identification may be required to confirm at least one individual present (see gNIS, section 6.6). **For relative index of abundance:** the response design will depend on the specific research questions and the nature of the variables tested. As relative abundance indices are highly susceptible to bias resulting from differences in detection unaccounted for, special consideration should be given to any factors that may affect detection and all effort should be made to account for this in the study design and subsequent statistical analyses and inference.
Effort and allocation planning	Power analysis will allow for evaluation of sampling effort required to make inference based on regression or other frequentist statistics. Simulation studies should also be employed to fully understand the robustness of the method to violations in the assumptions below (especially the assumption of perfect detection, which is routinely problematic).

Assumptions	Key assumptions include: that all individuals within the plot are found; the population is static during sampling event; and, plots surveyed are representative of the population. Violation of the detection assumption negates any inference derived from relative abundance metrics (see Sollmann *et al.*, 2013b).
Revisitation design	Repeat surveys could be completed annually, biennially or at other time intervals to estimate changes in occupancy and should be informed by the local context, monitoring needs and available resources. Repeat surveys at the same sites would be ideal.
Advantages and disadvantages	*Advantages*: allows for capture and marking of individuals and collection of other material (e.g., scat). *Disadvantages*: high survey effort needed; large areas will need to be covered for species that occur at low densities.
Cost	Relatively low cost.
Notes	Use of a vehicle may be required. Complementary methods can be used to inform plot locations (e.g., social research methods).

6.11 Prospection/reconnaissance surveys

Prospection surveys comprise traversing predefined routes (e.g., roads, forest tracks) and visually searching for the target species and/or their signs. This method has been applied to confirm the presence of *M. crassicaudata* and field signs including burrows at survey sites in Khyber Pakhtunkhwa, Pakistan (Mahmood *et al.*, 2018) and for *S. gigantea* in Gabon and Uganda (S. Nixon and N. Matthews, unplub. data). Prospection surveys have potential application for confirming the presence of species of *M. crassicaudata* and *S. temminckii* given they occur in more open habitats where there is more favourable probability of detection.

Species applicable to: *M. crassicaudata*, *S. temminckii*

Parameter of interest	Presence
Statistical analyses	**For indicating presence:** none required, although previous studies could be used to determine a minimum search effort for detecting species in different habitat types and conditions.
Sampling design	None required.
Response design	Survey teams follow pre-determined routes on foot or by vehicle to observing for trail sign (e.g., burrows, tracks, feeding) and the target species. Survey routes should be recorded using GPS to account for coverage and effort.
Effort and allocation planning	Dependent on species and size of site.
Assumptions	Assumptions include: that pangolins do not move in response to early detection of vehicles; do not avoid using burrow near roads; are detectable from roads, forest trails or other survey routes; that it will be possible to detect the study species or sign, especially if travelling in a moving vehicle.
Revisitation design	Should be informed by the local context, monitoring needs and available resources. Can be incorporated into existing monitoring protocols such as ranger based monitoring, retrieving or used when moving between study sites.
Advantages and disadvantages	*Advantages:* could use satellite data to identify potential areas of habitat; can also record presence of non-target species; and, this method is scalable; initial detections could identify areas for more intensive sampling, or trigger adaptive sampling thresholds that would then allow for more successful use of methods for estimation of population parameter; can identify hunting pressures (e.g., snaring densities).

	Disadvantages: pangolins may avoid roads which will decrease detection; areas with low accessibility cannot be accessed
Cost	Prospection surveys can be cheap to conduct depending on scale.
Notes	This is a useful method for conducting a 'recce' following which other method would be implemented depending on specific research questions. Knowledge of pangolin field signs is a pre-requisite.

6.12 Acoustic monitoring

Acoustic monitoring entails installing an array of acoustic monitoring devices at study sites in order to detect specific sounds made by target species. Although pangolins do not vocalise, they make substantial noise when breaking apart ant nests and termite mounds, and when feeding, and acoustic monitoring could be used to detect these sounds. However, although theoretically applicable, it has not yet been attempted on pangolins and proof of concept is first required. This will necessitate generating acoustic signatures of pangolins in a range of behaviours (e.g., breaking into ant nests, breaking into termitaria, feeding and other behaviours) as well as other species that predate on ants and termites, and other species ecologically similar to pangolins, in order to determine acoustic signatures made by pangolins and distinguish them from signatures of other species. Assuming this is possible, this approach will estimate a density of pangolin sounds and will make the assumption that the frequency of sound generation is the same across different habitats. In order to use this to estimate pangolin densities, it will be critical to have estimates of how often pangolins make these sounds, and which requires further research.

Species applicable to: *M. pentadactyla, M. crassicaudata, M. javanica, M. culionensis, S. gigantea, S. temminckii, P. tricuspis, P. tetradactyla*

Parameter of interest	Presence, occupancy
Statistical analyses	**For confirmation of presence:** none required, although pilot studies focused on known individuals or in *ex-situ* settings could be used to determine a minimum effort in number of detectors, length of deployment, and placement and orientation to return reliable information on species presence in an area. **For occupancy estimation:** single species single-season occupancy models and dynamic occupancy models.
Sampling design	This is an untested method and pilot studies will be required to determine range of detection for accurate identification, appropriate positioning and orientation of acoustic detectors. Ultimately, sampling designs would be comprised of an array of detectors with spacing determined by species information and sound attenuation in different habitat and environmental contexts. Stratified random sampling could be used to investigate specific questions, for example occupancy within different habitat types of areas with and without ranger patrols.

Response design	For deployment of acoustic arrays for parameter estimation, site spacing will need to account for sound attenuation (ensuring sampling units are independent) but include sufficient replicates to allow triangulation between sampling stations. Survey effort per unit area including number of detectors and duration of deployment would be contingent on detection rates and parameters of interest. This is currently not known for pangolins and requires field testing and evaluation. Environmental covariate data that could alter detection and triangulation such as habitat, vegetation, and weather should be collected
Effort and allocation planning	This will ideally be informed by simulation or power analysis, but pilot studies will be required for proof of concept and to inform detection rates as this method has never been implemented before. Other considerations include time to install, check, and/or remove detector arrays and time in analysing audio files and extracting data.
Key assumptions	They include: the ability to identify unique acoustic signatures for pangolins (e.g., breaking apart nests, scratching, and feeding) and accurately identify location of identified sounds.
Revisitation design	Repeat surveys could theoretically be completed annually, biennially or at other time intervals to estimate changes in occupancy over time. They should be informed by the local context, monitoring needs and available resources. Ideally, arrays would be placed in the same locations on repeat surveys.
Advantages and disadvantages	*Advantages*: technology is affordable (e.g., AudioMoth); relatively easy to set up in the field; devices should detect other species, the presence of people and hunting/poaching activities; can also be used for anti-poaching and surveillance purposes; could also provide spatial information via triangulation with other devices; could be used to determine temporal movement patterns. Could be coupled with camera-trapping for occupancy modelling. *Disadvantages*: has not yet been tested (for pangolins or in many range state environments) and requires proof of concept that acoustic signatures can be identified and triangulated. Other methods of acoustic detection have found variable error rates in accurately identifying sounds and attributing to species.
Cost	Acoustic monitoring devices (e.g., AudioMoth) currently retail at about USD50 per sensor and are available via GroupGets. The largest resource investment is likely to be installation of acoustic monitoring grids and time in analysing audio files and extracting data.
Notes	There is potential to monitor other species and threats at the same time.

6.13 Invertebrate-derived DNA (iDNA)

Invertebrate-derived DNA (iDNA) is the identification of vertebrate DNA that has been ingested by invertebrates including leeches, mosquitos or other invertebrates (Calvignac-Spencer *et al.*, 2013; Schnell *et al.*, 2018). In this context, extracted vertebrate DNA is amplified using PCR and compared against metagenomic primers developed for target species in order to determine whether DNA from that species had been ingested, indicating that the target species was present at a site visited by the sampled invertebrate. Detection is affected by factors including the probability that the selected invertebrate fed on the target species, that the selected invertebrate species is collected during sampling, that the target species' DNA can be extracted and amplified and can be correctly identified (Schnell *et al.*, 2018). In theory, iDNA could have application for each species of pangolin, using for example, ticks and/or Tetse flies, to estimate occupancy (see Abrams *et al.*, 2018), but this method has not been tested.

Species applicable to: *M. pentadactyla*, *M. javanica*, *M. crassicaudata*, *M. culionensis*, *P. tricuspis*, *P. tetradactyla*, *S. gigantea*, *S. temminckii*

Parameter of interest	Presence, occupancy
Statistical analyses:	**For confirmation of presence:** none required, although pilot studies focused on known individuals or in *ex-situ* settings could be used to determine a minimum effort in capture of invertebrates and amplification rates to return reliable information on species presence in an area. **For occupancy estimation:** hierarchical occupancy models would need to be developed and tested to account for the dual latent states of invertebrate and target pangolin presence.
Sampling design	This is an untested method and pilot studies will be required. Sampling designs would be comprised of an array of sampling stations with spacing determined by species information and movement distances of invertebrates in different temporal and environmental contexts. Within available cells a nested design using stratified random sampling could be used based on the specific research question being asked. Within selected grid cells there should be sufficient sampling stations depending on the ecology of the target vector.

Response design	Sampling protocols would depend on invertebrates used as "detectors" (will be regionally and species-specific). It is not possible to determine appropriate general protocols until the method of invertebrate sampling and amplification rates of pangolin species' DNA within have been investigated.
Effort and allocation planning	Unknown as not yet attempted for pangolins and proof of concept needed.
Key assumptions	Key assumptions include: that the relevant invertebrate vector fed on the target species, that the invertebrate vector is collected during sampling, that the target species' DNA can be extracted and amplified and can be correctly identified.
Revisitation design	Contingent on proof of concept, revisitation could be conducted at the same sites on a temporal scale relevant to the study system and local context, including likely threats to the study species.
Advantages and disadvantages	*Advantages*: potential to capture large scale and spatial contexts; can replicate across landscapes; easy to standardised across replicate sites; field set up requires minimal expertise; if used with metabarcoding using universal primers, it can provide information on other species as well. *Disadvantages*: remains untested on pangolins; is expensive; permits to move samples internationally (CITES permits) can be challenging to obtain, and can be time consuming.
Cost	Application of this method would require large initial investment for the development of single mtDNA sequences and development and testing of primers, microsatellite arrays and metabarcoding.
Notes	This method will require access to laboratories with an ability to process samples. Private companies that offer these services but will be more expensive than university partners. Material to create reference libraries may require CITES permits, but insects should not.

6.14 Citizen science

Despite being characteristically elusive and shy, pangolins are observed (detected) by a range of different stakeholders in range countries, including local community members, indigenous peoples, as well as tourists and members of the public. Acquiring detailed information on perceived abundance or similar information from local community members will realistically require visiting sites with pangolins and conducting social research. However, members of the public, tourists and other interested individuals could assist in confirming the presence of pangolins at sites by providing evidence of their detection. This could be done by providing an account of their observations, and would ideally be verified by a geo-referenced photograph to confirm the location of the sighting. Although a mechanism exists for the African continent through MammalMAP, an initiative of the Animal Demography Unit at the University of Cape Town, South Africa, no such mechanism yet exists on a global scale. Platforms such as iNaturalist have potential for collating this data and information.

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